Jo Dale Carothers, SBN 228703
jcarothers@weintraub.com
Eric A. Caligiuri, SBN 260442
ecaligiuri@weintraub.com
WEINTRAUB TOBIN CHEDIAK COLEMAN GRODIN
LAW CORPORATION
475 Sansome Street, Suite 510
San Francisco, CA 94111
Telephone: 415.433.1400
Facsimile: 415.433.3883

Attorneys for Plaintiff
Applied Optoelectronics, Inc.

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

APPLIED OPTOELECTRONICS, INC., Plaintiff, vs. CAMBRIDGE INDUSTRIES USA, INC., Defendant.	**Case No.:** **COMPLAINT FOR PATENT INFRINGEMENT** **DEMAND FOR JURY TRIAL**

For its complaint against Defendant Cambridge Industries USA, Inc. ("CIG" or "Defendant"), Plaintiff Applied Optoelectronics, Inc. ("AOI" or "Plaintiff") alleges on personal knowledge as to its own activities and on information and belief as to the activities of others as follows:

THE PARTIES

1. Plaintiff AOI is a Delaware Corporation with its principal place of business located at 13139 Jess Pirtle Blvd., Sugar Land, Texas 77478.

2. On information and belief, Defendant Cambridge Industries USA, Inc. is a Delaware Corporation with its principal place of business located at 2445 Augustine Dr 6th Floor, Santa Clara, CA 95054.

3. On information and belief, CIG is registered to do business in the State of California, has designated an agent for service of process in the State of California, and has a physical office

located in the State of California and specifically in this district.

NATURE OF ACTION

4. This is an action alleging patent infringement by Defendant CIG of U.S. Patent No. 9,523,826 (the "'826 Patent"), entitled "Pluggable optical transceiver module," and issued on December 20, 2016; U.S. Patent No. 10,466,432 (the "'432 Patent"), entitled "High speed optical transceiver module" and issued on November 5, 2019; U.S. Patent No. 9,170,383 (the "'383 Patent"), entitled "Multi-channel optical transceiver module including dual fiber type direct link adapter for optically coupling optical subassemblies in the transceiver module," and issued on October 27, 2015; U.S. Patent No. 10,042,116 (the "'116 Patent"), entitled "Techniques for direct optical coupling of photodetectors to optical demultiplexer outputs and an optical transceiver using the same," and issued on August 7, 2018; U.S. Patent No. 10,175,431 (the "'431 Patent"), entitled "Optical transceiver with a multiplexing device positioned off-center within a transceiver housing to reduce fiber bending loss," and issued on January 8, 2019; and U.S. Patent No. 10,379,301 (the "'301 Patent"), entitled "Multi-channel parallel optical receiving device," and issued on August 13, 2019; U.S. Patent No. 10,313,024 (the "'024 Patent"), entitled "Transmitter Optical Subassembly With Trace Routing To Provide Electrical Isolation Between Power And RF Traces," and issued on June 4, 2019; and U.S. Patent No. 10,788,690 (the "'690 Patent"), entitled "Optical Isolator Array For Use In An Optical Subassembly Module," and issued on September 29, 2020 (collectively, the "Asserted Patents"). A true and correct copy of each of the Asserted Patents is attached hereto as Exhibits A–H.

5. Plaintiff AOI is the assignee and owner of record of the '826 Patent, and all rights, title, and interest in and to the '826 Patent.

6. Plaintiff AOI is the assignee and owner of record of the '432 Patent, and all rights, title, and interest in and to the '432 Patent.

7. Plaintiff AOI is the assignee and owner of record of the '383 Patent, and all rights, title, and interest in and to the '383 Patent.

8. Plaintiff AOI is the assignee and owner of record of the '116 Patent, and all rights, title, and interest in and to the '116 Patent.

9. Plaintiff AOI is the assignee and owner of record of the ’431 Patent, and all rights, title, and interest in and to the ’431 Patent.

10. Plaintiff AOI is the assignee and owner of record of the ’301 Patent, and all rights, title, and interest in and to the ’301 Patent.

11. Plaintiff AOI is the assignee and owner of record of the ’024 Patent, and all rights, title, and interest in and to the ’024 Patent.

12. Plaintiff AOI is the assignee and owner of record of the ’690 Patent, and all rights, title, and interest in and to the ’690 Patent.

JURISDICTION AND VENUE

13. This is an action for patent infringement arising under the patent laws of the United States, Title 35 of the United States Code, including without limitation 35 U.S.C. §§ 271 *et seq.* This Court has subject matter jurisdiction over this case pursuant to 28 U.S.C. §§ 1331 and 1338(a), because this action arises under the patent laws of the United States, Title 35 of the United States Code, including but not limited to 35 U.S.C. §§ 271, 281, 284 and 285.

14. This Court has personal jurisdiction over CIG. On information and belief, CIG has a major R&D, Sales, Marketing and Customer Support presence in USA in Santa Clara, California. CIG's product domain expertise includes optical modules (transceivers).

15. On information and belief, CIG designs products in this state and district and sells and offers for sale goods to customers in this state and district via its sales people and through its distributers. On information and belief, CIG is registered to do business in the State of California and has designated Iris Wong, located at 2445 Augustine Drive, 6TH Floor Santa Clara, CA 95054 as an agent for service of process in the State of California. On information and belief, CIG has at least one physical office located in the State of California and specifically in this district at 2445 Augustine Dr 6th Floor, Santa Clara, CA 95054 as shown below in the image from Google Earth.

///

///

///

2/20/24, 7:36 AM Santa Clara, California - Google Maps

Google Maps Santa Clara, California

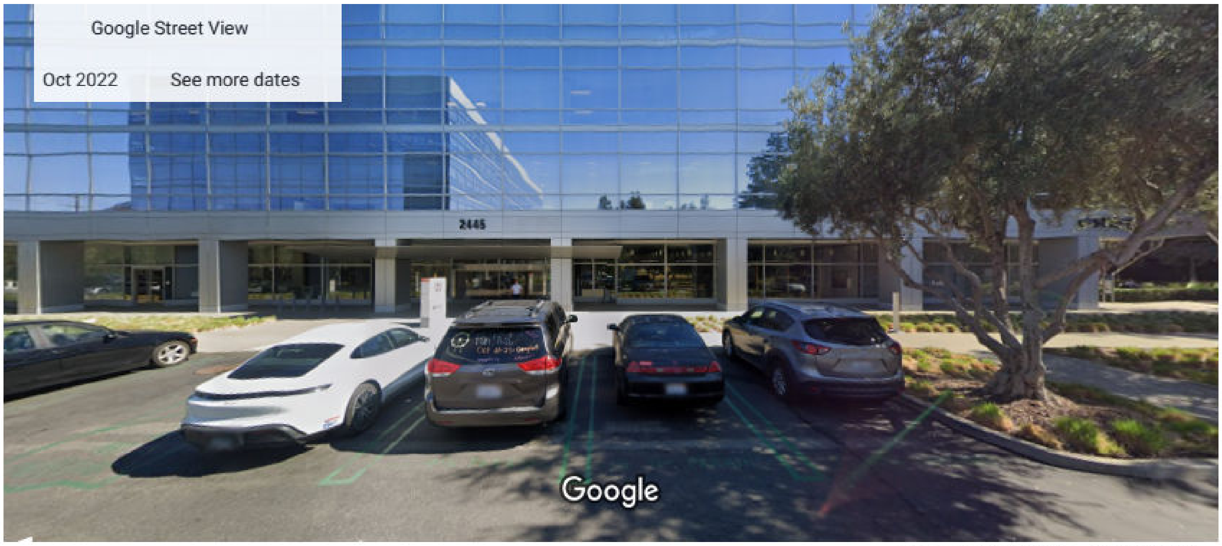
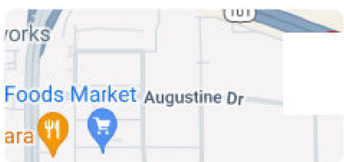


Image capture: Oct 2022 © 2024 Google



16. Further, CIG's website at https://cig-usa.business.site/ includes a photo indicating its address in Santa, Clara, California.

17. Venue is proper in the United States District Court for the Northern District of California under 28 U.S.C. §§ 1391(b)-(d) and/or 1400(b) because, on information and belief, CIG has committed acts of infringement in this district and has a regular and established place of business

in this district. On information and belief, CIG designs products in this state and district at its physical office located in this district at 2445 Augustine Dr 6th Floor, Santa Clara, CA 95054, and sells and offers for sale infringing goods to customers in this state and district via its sales people and through its distributers. On information and belief, CIG also imports infringing products into this district.

INTRADISTRICT ASSIGNMENT

18. This case is a patent infringement dispute that is appropriate for district-wide assignment.

AOI'S BUSINESS

19. AOI is a leading provider of fiber-optic networking products. It serves four growing end-markets: internet data centers (Data Center), Cable Television Broadband (CATV), fiber-to-the-home (FTTH), and telecommunications. AOI designs and manufactures a range of optical communications products employing our vertical integration strategy from laser chips, components, subassemblies and modules to complete turn-key equipment. AOI designs, manufactures, and integrates its own analog and digital lasers using a proprietary Molecular Beam Epitaxy (MBE) fabrication process, which it believes is unique in its industry. The lasers are proven to be reliable over time and highly tolerant of changes in temperature and humidity (delivering millions of hours service), making them well-suited to the CATV and FTTH markets where networking equipment is often installed outdoors.

20. AOI has a state-of–the-art semiconductor component fab at its USA Headquarters near Houston, Texas.

DEFENDANT'S INFRINGING ACTIVITIES

21. On information and belief, CIG, either directly or through other entities under its control, imports, uses, offers for sale, and/or sells infringing products, including without limitation the CIG 100G QSFP CWDM4 module Version 1, CIG 100G QSFP CWDM4 Module Version 2, CIG 100G LR4 Module, CIG 400G QSFP-DD DR4 Module, CIG 400G QSFP-DD FR4 Module, and CIG 100G QSFP28 PSM4 (the "Accused Products"). *See, e.g.*, Exhibits I through T.

///

22. On information and belief, CIG infringes the Asserted Patents by engaging in acts constituting infringement under 35 U.S.C. § 271, including without limitation by making, using, selling and/or offering for sale in and/or importing into the United States without authority one or more Accused Products that infringe one or more claims of the Asserted Patents.

23. On information and belief, CIG promotes, sells and/or offers to sell its products throughout the United States, including without limitation by offering the Accused Products through its sales people.

FIRST CAUSE OF ACTION

(Infringement of the ’826 Patent)

24. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1-23 of this Complaint.

25. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’826 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’826 Patent.

26. Defendant has directly infringed at least, for example, claims 1 and 7 of the ’826 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

27. The claim chart attached hereto as Exhibit I identifies on a limitation-by-limitation basis where each limitation of claims 1 and 7 of the ’826 Patent is found within the exemplary Accused Product. Each limitation of claims 1 and 7 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claims 1 and 7 of the ’826 Patent.

28. GIG does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

///

29. GIG has knowledge and notice of the Asserted Patent and its infringement since at least, and through, the filing of this Complaint.

30. As a direct and proximate result of CIG's infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

31. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

32. On information and belief, unless enjoined by this Court, CIG will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI's irreparable damage. It would be difficult to ascertain the amount of compensation which would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by CIG.

SECOND CAUSE OF ACTION

(Infringement of the '432 Patent)

33. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–32 of this Complaint.

34. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the '432 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the '432 Patent.

35. Defendant has directly infringed at least, for example, claim 1 of the '432 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

36. The claim chart attached hereto as Exhibit J identifies on a limitation-by-limitation basis where each limitation of claim 1 of the '432 Patent is found within the exemplary Accused Product. Each limitation of claim 1 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the

exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claim 1 of the ’432 Patent.

37. CIG does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

38. CIG has knowledge and notice of the Asserted Patents and their infringement since at least, and through, the filing of this Complaint.

THIRD CAUSE OF ACTION

(Infringement of the ’383 Patent)

39. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–38 of this Complaint.

40. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’383 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’383 Patent.

41. Defendant has directly infringed at least, for example, claim 1 of the ‘383 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

42. The claim chart attached hereto as Exhibit K identifies on a limitation-by-limitation basis where each limitation of claim 1 of the ’383 Patent is found within the exemplary Accused Product. Each limitation of claim 1 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as Claim 1 of the ’383 Patent.

43. CIG does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

///

44. AOI is informed and believes, and on the basis of such information and belief, alleges that CIG's infringement of the '383 Patent is willful and deliberate, at least at all times after receiving AOI's letter and claim charts dated October 20, 2023, alleging that CIG infringes these patents. Accordingly, AOI is entitled to enhanced damages pursuant to 35 U.S.C. § 284 and to an award of attorney's fees and costs incurred in prosecuting this action pursuant to 35 U.S.C. § 285.

45. CIG has knowledge and notice of the Asserted Patents and their infringement since at least, and through, the filing of this Complaint.

FOURTH CAUSE OF ACTION

(Infringement of the '301 Patent)

46. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–45 of this Complaint.

47. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the '301 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the '301 Patent.

48. Defendant has directly infringed at least, for example, claims 1 and 7 of the '301 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

49. The claim charts attached hereto as Exhibit L through N identifies on a limitation-by-limitation basis where each limitation of claim 1 of the '301 Patent is found within the exemplary Accused Product. Each limitation of claims 1 and 7 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claims 1 and 7 of the '301 Patent.

50. CIG does not have a license to any of Plaintiff's patents or technology, including without limitation the Asserted Patents.

///

51. AOI is informed and believes, and on the basis of such information and belief, alleges that CIG's infringement of the '301 Patent is willful and deliberate, at least at all times after receiving AOI's letter and claim charts dated October 20, 2023, alleging that CIG infringes these patents. Accordingly, AOI is entitled to enhanced damages pursuant to 35 U.S.C. § 284 and to an award of attorney's fees and costs incurred in prosecuting this action pursuant to 35 U.S.C. § 285.

FIFTH CAUSE OF ACTION

(Infringement of the '690 Patent)

52. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–51 of this Complaint.

53. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the '690 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the '690 Patent.

54. Defendant has directly infringed at least, for example, claim 1 of the '690 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

55. The claim chart attached hereto as Exhibit O identifies on a limitation-by-limitation basis where each limitation of claim 1 of the '690 Patent is found within the exemplary Accused Product. Each limitation of claim 1 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as Claim 1 of the '690 Patent.

56. CIG does not have a license to any of Plaintiff's patents or technology, including without limitation the Asserted Patents.

57. AOI is informed and believes, and on the basis of such information and belief, alleges that CIG's infringement of the '690 Patent is willful and deliberate, at least at all times after receiving AOI's letter and claim charts dated October 20, 2023, alleging that CIG infringes

these patents. Accordingly, AOI is entitled to enhanced damages pursuant to 35 U.S.C. § 284 and to an award of attorney's fees and costs incurred in prosecuting this action pursuant to 35 U.S.C. § 285.

SIXTH CAUSE OF ACTION

(Infringement of the '024 Patent)

58. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–57 of this Complaint.

59. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the '024 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the '024 Patent.

60. Defendant has directly infringed at least, for example, claim 1 of the '024 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

61. The claim chart attached hereto as Exhibit P identifies on a limitation-by-limitation basis where each limitation of claim 1 of the '024 Patent is found within the exemplary Accused Product. Each limitation of claim 1 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as Claim 1 of the '024 Patent.

62. CIG does not have a license to any of Plaintiff's patents or technology, including without limitation the Asserted Patents.

63. AOI is informed and believes, and on the basis of such information and belief, alleges that CIG's infringement of the '024 Patent is willful and deliberate, at least at all times after receiving AOI's letter and claim charts dated October 20, 2023, alleging that CIG infringes these patents. Accordingly, AOI is entitled to enhanced damages pursuant to 35 U.S.C. § 284 and to an award of attorney's fees and costs incurred in prosecuting this action pursuant to 35 U.S.C. § 285.

SEVENTH CAUSE OF ACTION

(Infringement of the ’431 Patent)

64. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–63 of this Complaint.

65. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’431 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’431 Patent.

66. Defendant has directly infringed at least, for example, claims 1 and 16 of the ‘431 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

67. The claim chart attached hereto as Exhibit Q identifies on a limitation-by-limitation basis where each limitation of claims 1 and 16 of the ’431 Patent is found within the exemplary Accused Product. Each limitation of claims 1 and 16 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claims 1 and 16 of the ’431 Patent.

68. CIG does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

69. AOI is informed and believes, and on the basis of such information and belief, alleges that CIG’s infringement of the ’431 Patent is willful and deliberate, at least at all times after receiving AOI’s letter and claim charts dated October 20, 2023, alleging that CIG infringes these patents. Accordingly, AOI is entitled to enhanced damages pursuant to 35 U.S.C. § 284 and to an award of attorney’s fees and costs incurred in prosecuting this action pursuant to 35 U.S.C. § 285.

///

///

///

EIGHTH CAUSE OF ACTION

(Infringement of the ’116 Patent)

70. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–69 of this Complaint.

71. On information and belief, CIG infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’116 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’116 Patent.

72. Defendant has directly infringed at least, for example, claim 1 of the ‘116 patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

73. The claim charts attached hereto as Exhibit R though T identifies on a limitation-by-limitation basis where each limitation of claim 1 of the ’116 Patent is found within the exemplary Accused Product. Each limitation of claim 1 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as Claim 1 of the ’116 Patent.

74. CIG does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

75. AOI is informed and believes, and on the basis of such information and belief, alleges that CIG’s infringement of the ’116 Patent is willful and deliberate, at least at all times after receiving AOI’s letter and claim charts dated October 20, 2023, alleging that CIG infringes these patents. Accordingly, AOI is entitled to enhanced damages pursuant to 35 U.S.C. § 284 and to an award of attorney’s fees and costs incurred in prosecuting this action pursuant to 35 U.S.C. § 285.

76. As a direct and proximate result of CIG’s infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

77. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

78. AOI is informed and believes, and on the basis of such information and belief, alleges that CIG's infringement of the '383 Patent, '301 Patent, '690 Patent, '024 Patent, '431Patent, and '116 Patent (collectively, "Previously Identified Patents") is willful and deliberate, at least at all times after receiving AOI's letter and claim charts dated October 20, 2023, alleging that CIG infringes these patents.

79. Accordingly, AOI is entitled to enhanced damages pursuant to 35 U.S.C. § 284 and to an award of attorney's fees and costs incurred in prosecuting this action as to the Previously Identified Patents pursuant to 35 U.S.C. § 285.

80. On information and believe, unless enjoined by this Court, CIG will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI's irreparable damage. It would be difficult to ascertain the amount of compensation which would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by CIG.

PRAYER FOR RELIEF

WHEREFORE, Plaintiffs respectfully pray that the Court grant the following relief:

A. For judgment that CIG has infringed and continues to infringe the '826 Patent;

B. For judgment that the '826 Patent is valid and enforceable;

C. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the '826 Patent;

D. For judgment that CIG has infringed and continues to infringe the '432 Patent;

E. For judgment that the '432 Patent is valid and enforceable;

F. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the '432 Patent;

G. For judgment that CIG has infringed and continues to infringe the '383 Patent;

H. For judgment that the ‘383 Patent is valid and enforceable;

I. For judgment that CIG has willfully infringed the ’383 Patent;

J. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the ’383 Patent;

K. For judgment that CIG has infringed and continues to infringe the ’301 Patent;

L. For judgment that the ‘301 Patent is valid and enforceable;

M. For judgment that CIG has willfully infringed the ’301 Patent;

N. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the ’301 Patent;

O. For judgment that CIG has infringed and continues to infringe the ’690 Patent;

P. For judgment that the ‘690 Patent is valid and enforceable;

Q. For judgment that CIG has willfully infringed the ’690 Patent;

R. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the ’690 Patent;

S. For judgment that CIG has infringed and continues to infringe the ’024 Patent;

T. For judgment that the ‘024 Patent is valid and enforceable;

U. For judgment that CIG has willfully infringed the ’024 Patent;

V. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the ’024 Patent;

W. For judgment that CIG has infringed and continues to infringe the ’431 Patent;

X. For judgment that the ‘431 Patent is valid and enforceable;

Y. For judgment that CIG has willfully infringed the ’431 Patent;

Z. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the ’431 Patent;

AA. For judgment that CIG has infringed and continues to infringe the ’116 Patent;

BB. For judgment that the ‘116 Patent is valid and enforceable;

CC. For judgment that CIG has willfully infringed the ’116 Patent;

DD. For a preliminary and permanent injunction prohibiting, CIG and all persons or entities acting in concert with CIG, from infringing the '116 Patent;

EE. An award of damages adequate to compensate Plaintiffs for the infringement, as well as prejudgment and post-judgment interest from the date the infringement began, but in no event less than a reasonable royalty as permitted by 35 U.S.C. § 284;

FF. An award of treble damages and/or exemplary damages due to CIG's willful misconduct under 35 U.S.C. § 284;

GG. A finding that this case is exceptional and an award of interest, costs, expenses, and attorneys' fees incurred by Plaintiffs in prosecuting this action as provided by 35 U.S.C. § 285;

HH. For any other orders necessary to accomplish complete justice between the parties; and

II. For such other and further relief as this Court or a jury may deem just and proper.

JURY DEMAND

Pursuant to Rule 38 of the Federal Rules of Civil Procedure, Plaintiffs demand a trial by jury on all cause of actions and issues so triable.

Dated: February 20, 2024 WEINTRAUB TOBIN CHEDIAK COLEMAN GRODIN

By: *\/s/ Jo Dale Carothers*
Jo Dale Carothers

Attorneys for Plaintiff
Applied Optoelectronics, Inc.

EXHIBIT A

US009523826B2

(12) **United States Patent**
Tsai et al.

(10) **Patent No.: US 9,523,826 B2**
(45) **Date of Patent: Dec. 20, 2016**

(54) **PLUGGABLE OPTICAL TRANSCEIVER MODULE**

(71) Applicant: **Applied Optoelectronics, Inc.**, New Taipei (TW)

(72) Inventors: **Chao-Hung Tsai**, New Taipei (TW); **Chien-Te Lin**, New Taipei (TW); **Che-Shou Yeh**, New Taipei (TW)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 88 days.

(21) Appl. No.: **14/504,500**

(22) Filed: **Oct. 2, 2014**

(65) **Prior Publication Data**

US 2015/0093083 A1 Apr. 2, 2015

(30) **Foreign Application Priority Data**

Oct. 2, 2013 (TW) .... 102135723 A

(51) **Int. Cl.**
G02B 6/42 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/423*** (2013.01); ***G02B 6/4246*** (2013.01); ***G02B 6/4261*** (2013.01); ***G02B 6/4284*** (2013.01); ***G02B 6/4292*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,201,520 B2 *	4/2007	Mizue	....	G02B 6/4292 385/92
2011/0081114 A1 *	4/2011	Togami	....	G02B 6/4246 385/76

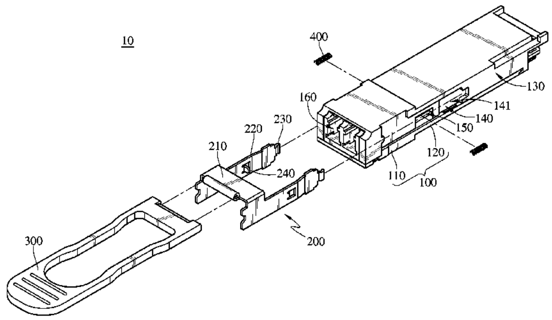
* cited by examiner

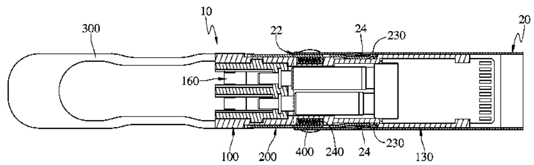
Primary Examiner — Michelle R Connelly
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

A pluggable optical transceiver module for inserted into plugging slot includes main body and sliding component. The main body has opposite two side surfaces and two sliding slots. The two sliding slots are located at the two side surfaces. The sliding component includes linkage arm and two extending arms. The two extending arms are connected to the linkage arm. Each extending arm has a second fastening part. The main body is between the two extending arms. The two extending arms are disposed on the two sliding slots to have fastening position and releasing position. Two first fastening parts are fastened to the two second fastening parts when the two extending arms are located at fastening position. The two second fastening parts press the two first fastening parts, respectively, for the two first fastening parts being farther from each other when the two extending arms are located at releasing position.

7 Claims, 8 Drawing Sheets





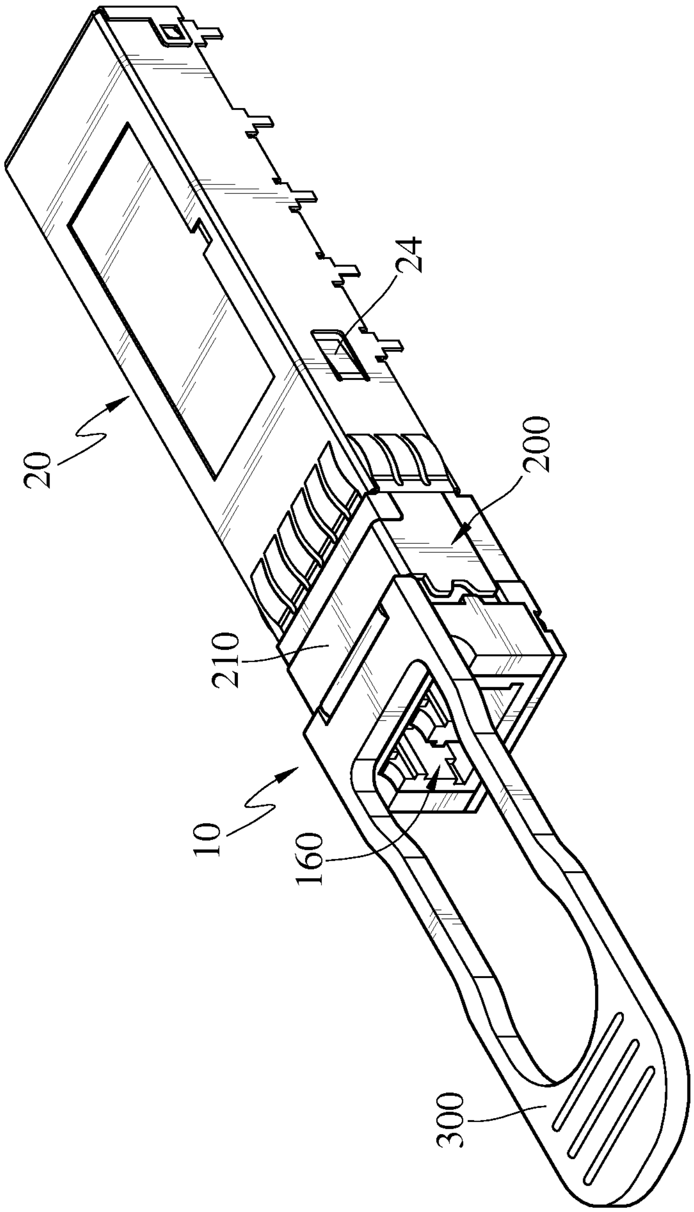


FIG. 1

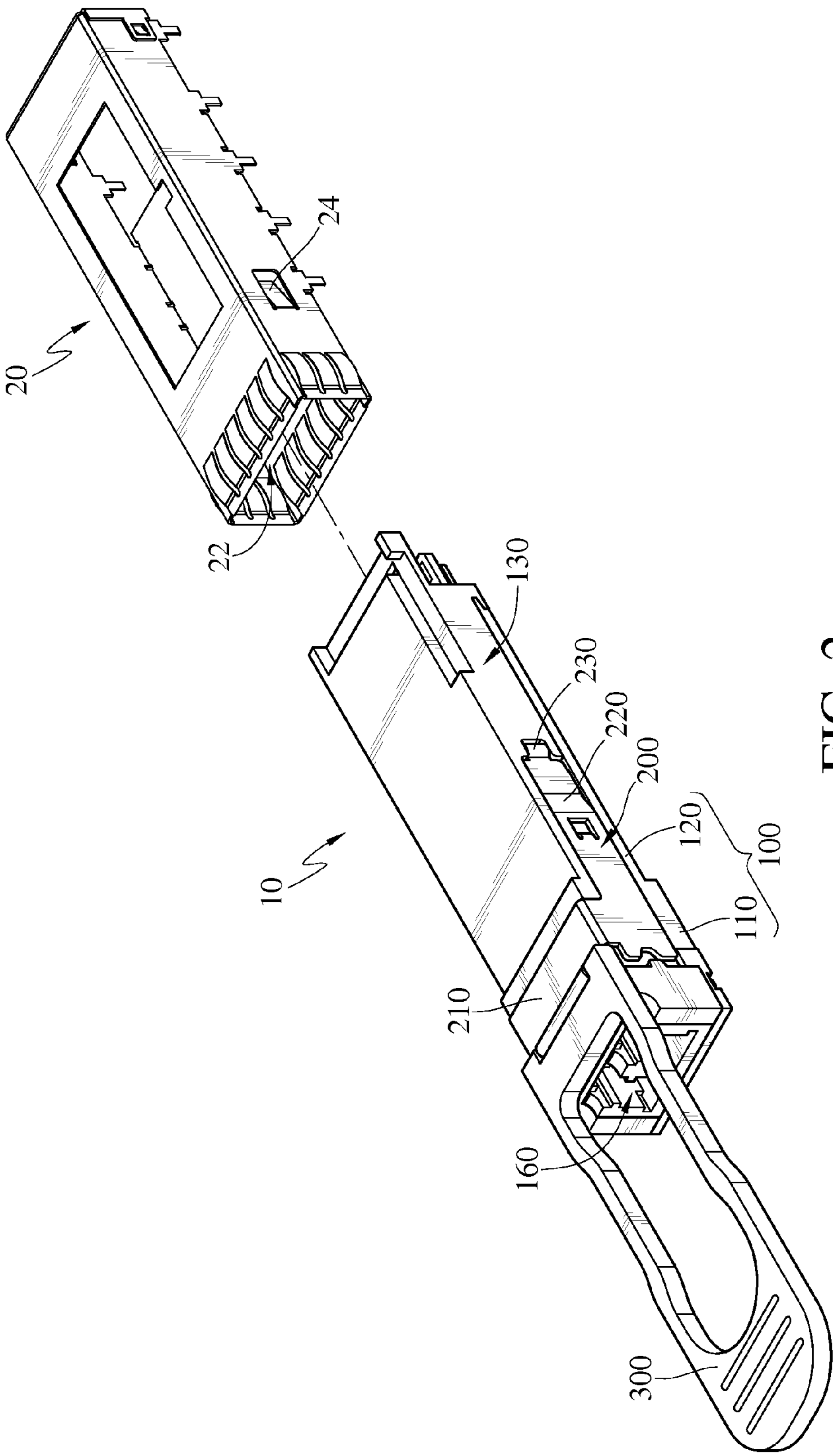


FIG. 2

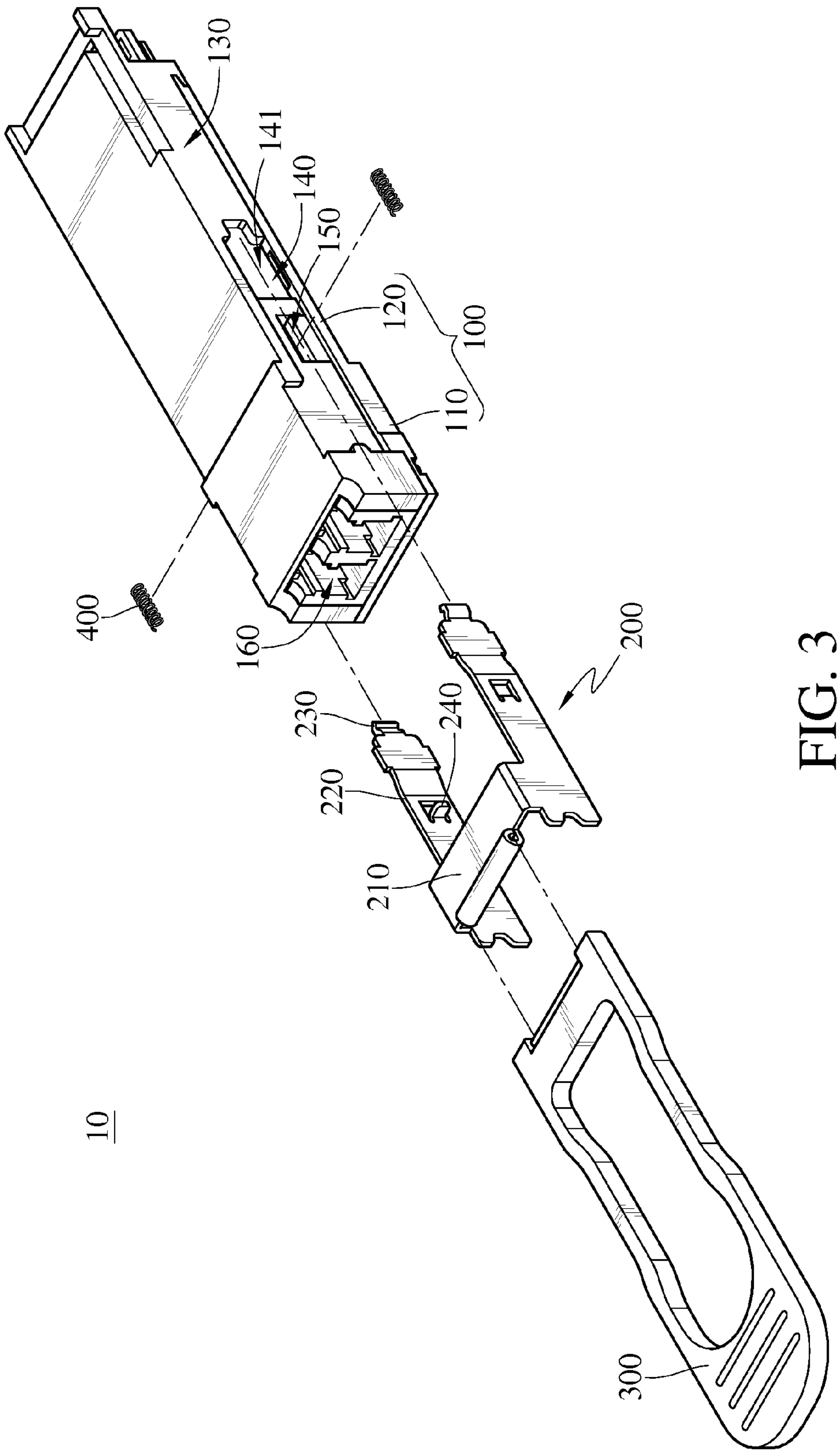


FIG. 3

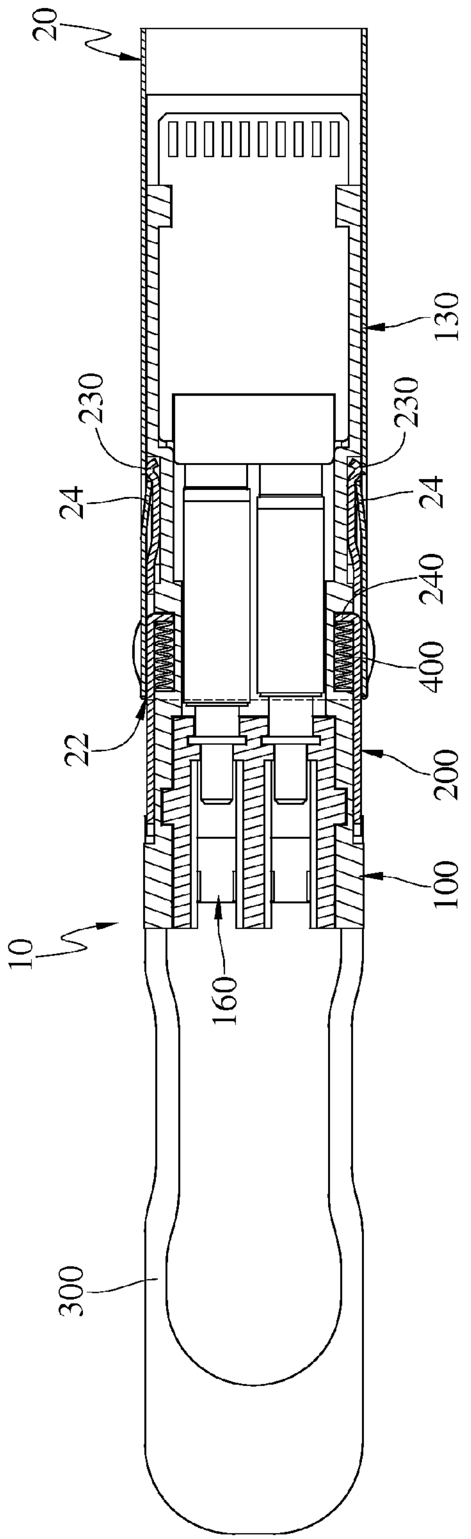


FIG. 4A

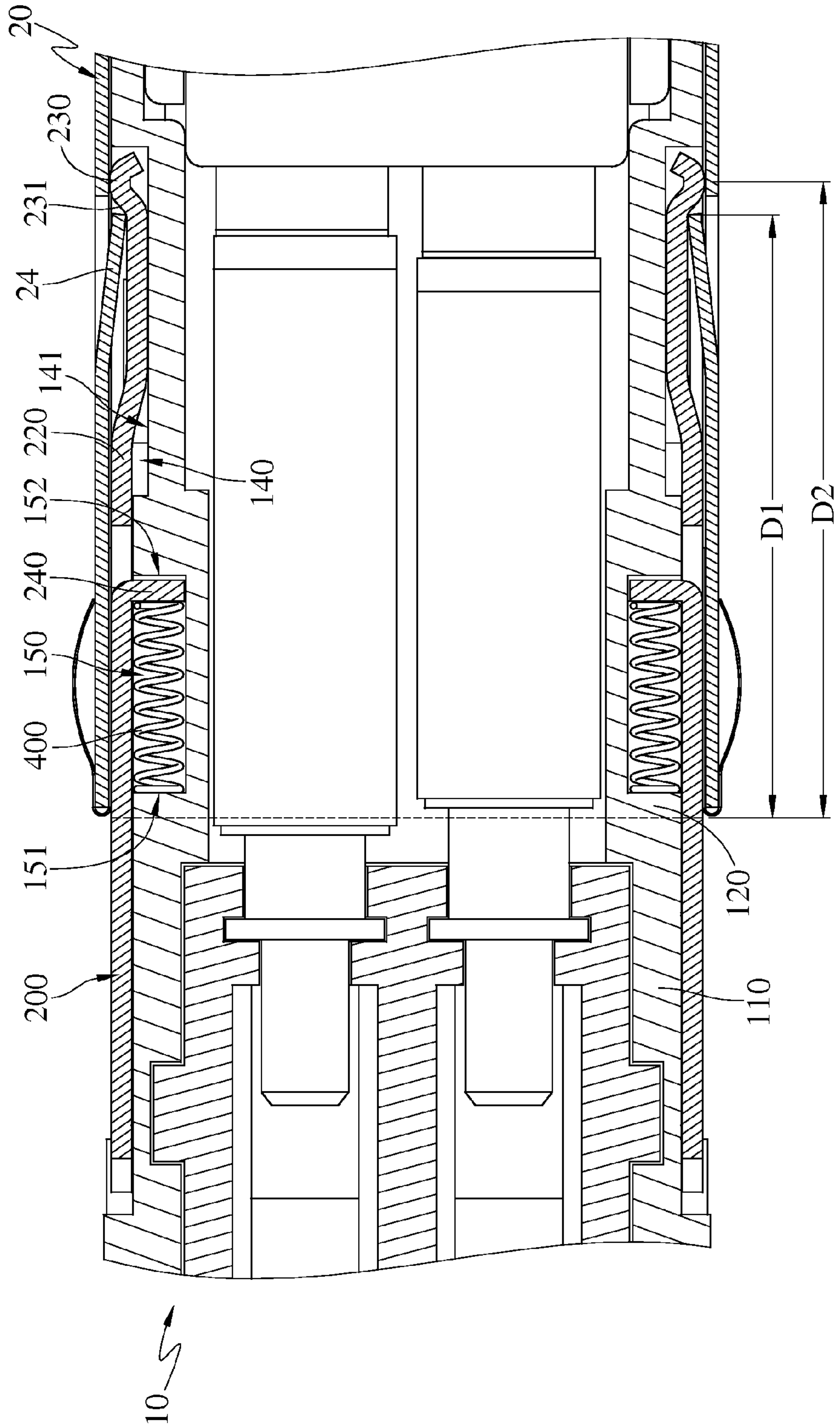


FIG. 4B

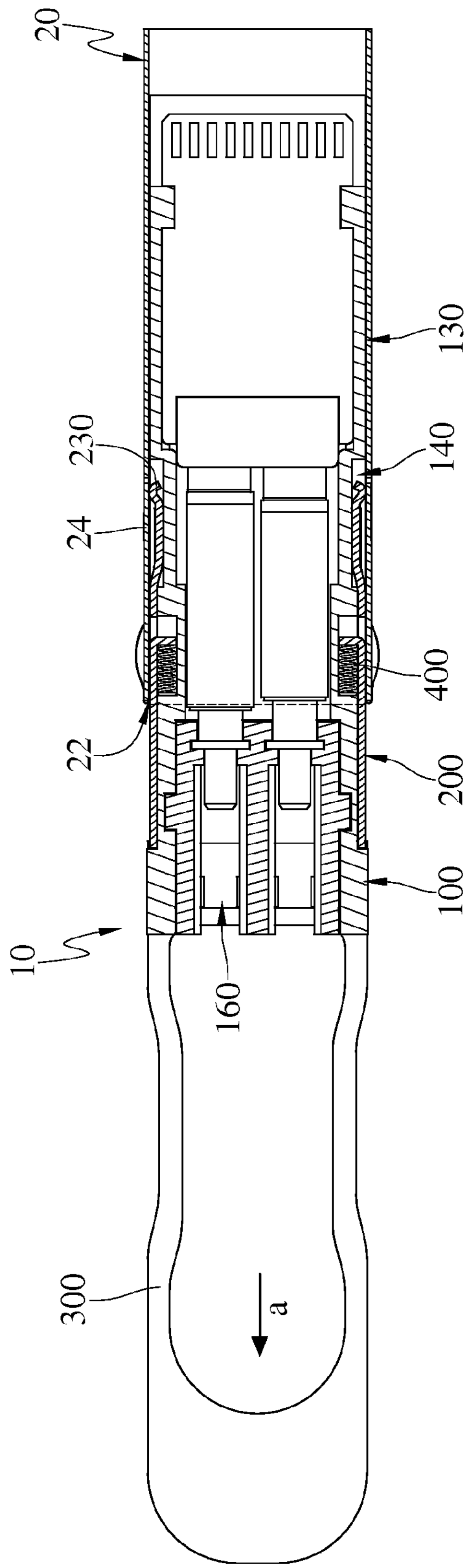


FIG. 5A

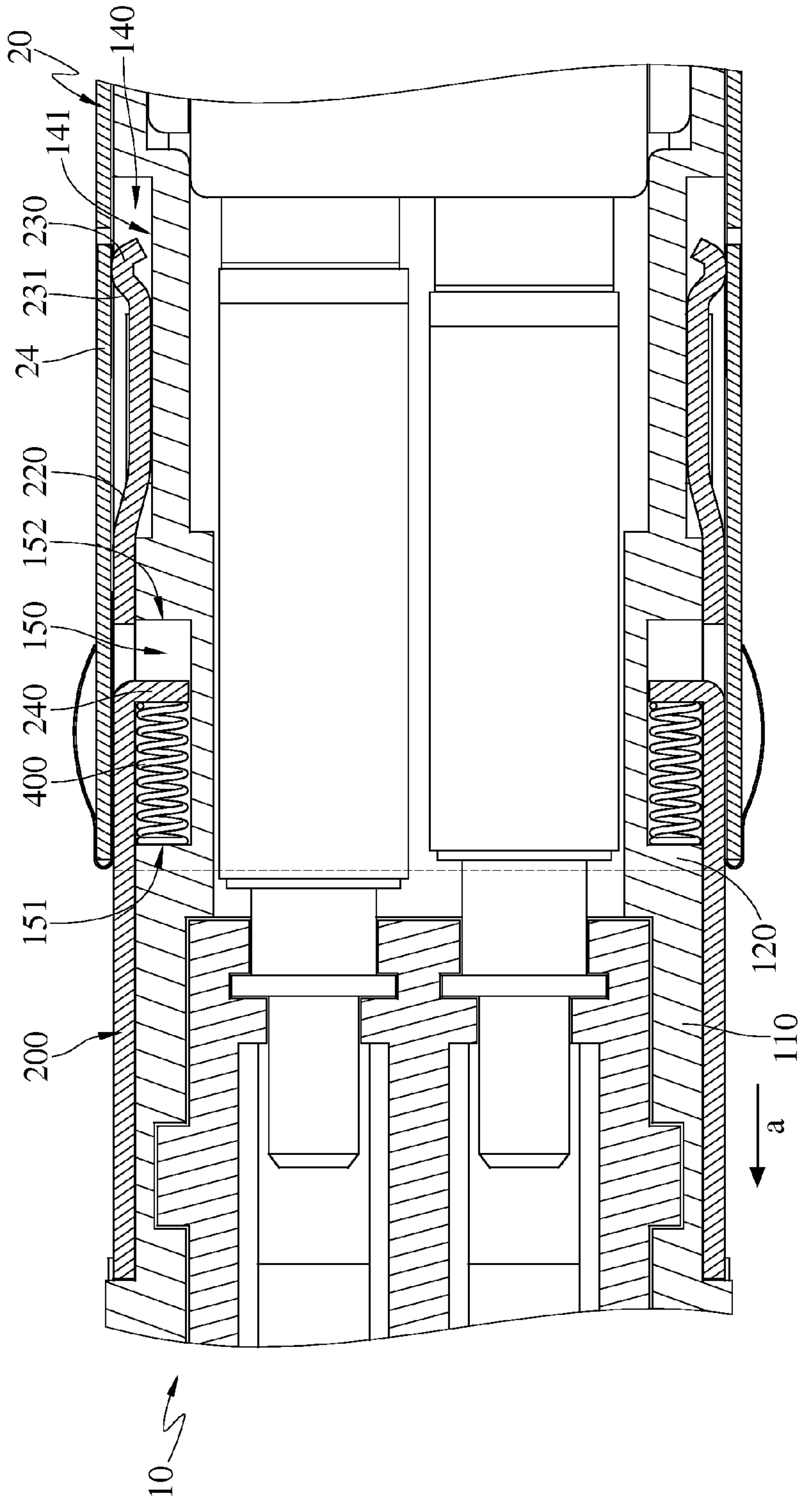


FIG. 5B

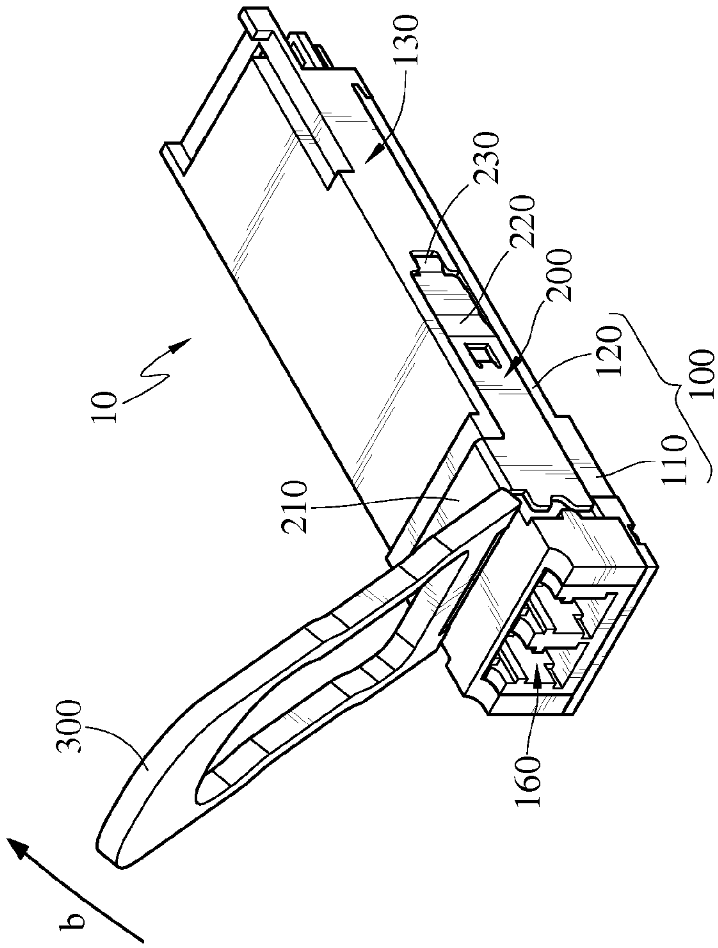


FIG. 6

PLUGGABLE OPTICAL TRANSCEIVER MODULE

CROSS-REFERENCE TO RELATED APPLICATIONS

This non-provisional application claims priority under 35 U.S.C. §119(a) on Patent Application No(s) 102135723. filed in Taiwan, R.O.C. on Oct. 2, 2013, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

The disclosure relates to an optical communication component, more particularly to a pluggable optical transceiver module.

BACKGROUND

An optical transceiver module is generally installed in an electronic communication facility in the modern high speed communication networks. In order to make the electronic communication facility flexible and easy to repair, the optical transceiver module is inserted into a corresponding socket disposed in the communication facility in a pluggable manner. In general, the socket is disposed on a circuit board. In order to define the electrical-to-mechanical interface of the optical transceiver module and the corresponding socket, different specifications have been provided such as XFP (10 Gigabit Small Form Factor Pluggable) used in 10 GB/s communication rate and QSFP (Quad Small Form-factor Pluggable).

A fastening mechanism is disposed in the socket corresponding to the optical transceiver module so that the optical transceiver module is securely fixed to the socket by the fastening mechanism. Therefore, it is indispensable that the optical transceiver module must have a releasing mechanism. This makes the optical transceiver module slip out from the socket by easily removing the lock.

On the other hand, a common communication facility, such as a hub, usually comprises at least one optical transceiver module for converting optical signals into electronic signals. When the common communication facility is used for a long time, dusts may drop on the surface of common communication facility. Thus, dusts may also drop on the optical transceiver module without any appropriate protection when the optical fiber cable is connected or removed from the optical transceiver module. Consequently, the dusts may damage the optical transceiver module and affect the transmission of the signals.

In view of this, it is important to improve the convenient connection and disconnection between the optical transceiver module and the socket and its dust-proof function.

SUMMARY

The disclosure provides a pluggable optical transceiver module configured to be inserted into a plugging slot. The pluggable optical transceiver module comprises a main body and a sliding component. The main body has two side surfaces opposite to each other and two sliding slots. The two sliding slots are located at the two side surfaces. The main body is configured to be inserted into the plugging slot. The sliding component comprises a linkage arm and two extending arms. The two extending arms are connected to two ends of the linkage arm, respectively. Each extending arm has a second fastening part. The main body is between the two extending arms. The two extending arms are slidably disposed on the two sliding slots to have a fastening position and a releasing position. Two first fastening parts are fastened to the two second fastening parts when the two extending arms are located at the fastening position. The two second fastening parts press the two first fastening parts, respectively, to make the two first fastening parts be farther away from each other when the two extending arms are located at the releasing position.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the drawings given herein below for illustration only, thus does not limit the present disclosure, wherein:

FIG. **1** is a perspective view of a pluggable optical transceiver module according to a first embodiment;

FIG. **2** is an exploded view of the pluggable optical transceiver module in FIG. **1**;

FIG. **3** is another exploded view of the pluggable optical transceiver module in FIG. **1**;

FIG. **4**A is a cross-sectional view of the pluggable optical transceiver module in FIG. **1** when a sliding component is located at a fastening position;

FIG. **4**B is a partial enlarged view of the pluggable optical transceiver module in FIG. **4**A;

FIG. **5**A is a cross-sectional view of the pluggable optical transceiver module in FIG. **1** when the sliding component is located at a releasing position;

FIG. **5**B is a partial enlarged view of the pluggable optical transceiver module in FIG. **5**A; and

FIG. **6** is a perspective view of the pluggable optical transceiver module in FIG. **2** when a pull handle pivots on a main body.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details. In other instances, well-known structures and devices are schematically shown in order to simplify the drawings.

FIG. **1** is a perspective view of a pluggable optical transceiver module according to a first embodiment. FIG. **2** is an exploded view of the pluggable optical transceiver module in FIG. **1**. In the first embodiment, a pluggable optical transceiver module **10** is configured to be inserted into a socket **20** to convert optical signals into electronic signals. The socket **20** has a plugging slot **22** and two first fastening parts **24**. Each first fastening part **24** is elastic. One end of the first fastening part **24** is connected to a case of the socket **20** and the other end of the first fastening part **24** is located in the plugging slot **22**. In this embodiment, the first fastening part **24** is an elastic slice.

FIG. **3** is another exploded view of FIG. **1**. FIG. **4**A is a cross-sectional view of FIG. **1** when a sliding component is located at a fastening position. FIG. **4**B is a partial enlarged view of FIG. **4**A. The pluggable optical transceiver module **10** comprises a main body **100**, a sliding component **200**, a pull handle **300** and two elastic components **400**. The main body **100** comprises a head part **110** and an inserted part **120** that are connected to each other. The inserted part **120** is configured to be inserted into the plugging slot **22** of the socket **20**. The main body **100** has two side surfaces **130**, two sliding slots **140** and two limiting spaces **150**. The two side surfaces **130** are located at opposite two sides of the head part **110** and the inserted part **120**, respectively. The two sliding slots **140** are located at the two side surfaces **130**, respectively, and extend from the head part **110** to the inserted part **120**. Each sliding slot **140** has a bottom surface **141** which is, but not limited to, parallel to the side surface **130**. In other embodiments, the slot bottom surface **141** encloses an acute angle with the side surface **130**.

The two limiting spaces **150** are located at the bottom surfaces **141** of the two sliding slots **140**, respectively. Each limiting space **150** has a first limiting surface **151** and a second limiting surface **152**. Both of the first limiting surface **151** and the second limiting surface **152** are connected to the bottom surface **141**. The first limiting surface **151** is closer to the head part **110** than the second limiting surface **152**.

Moreover, the main body **100** is configured to accommodate a photoelectric conversion circuit (not shown in the figures). Both of the two sliding slots **140** and the two limiting spaces **150** do not penetrate through the inner surface of the main body **100**. Therefore, the main body **100** protects the photoelectric conversion circuit from being contaminated by atmospheric dust.

The head part **110** has at least one optical fiber terminal **160**. An optical fiber plug may plug into the photoelectric conversion circuit in the main body **100** through the optical fiber terminal **160**.

The sliding component **200** comprises a linkage arm **210** and two extending arms **220**. The two extending arms **220** are connected to two ends of the linkage arm **210**, respectively. The main body **100** is between the two extending arms **220**. The two extending arms **220** are slidably disposed on the two sliding slots **140**, respectively. Each extending arm **220** has a second fastening part **230** and a limited part **240**. The second fastening part **230** extends along a direction far away from the side surface **130**. Each second fastening part **230** has a fastening surface **231** located at one side of the second fastening part **230** facing the head part **110**. A distance D1 between one side of the fastening surface **231** which is close to the side surface **130** and the head part **110** is less than a distance D2 from another side of the fastening surface **231** which is far away from the side surface **130** from and the head part **110**. That is, the fastening surface **231** is an inclined surface enclosing an acute angle with the side surface **130**. The limited part **240** extends toward the side surface **130** and is located in the limiting space **150**. The limited part **240** is able to slide between the first limiting surface **151** and the second limiting surface **152** relative to the main body **100**. The sliding component is able to slide relative to the main body **100** to have a fastening position and a releasing position. The two first fastening parts **230** are farther from the head part **110** when the two extending arms **220** are located at the fastening position. The two first fastening parts **230** are closer to the head part **110** when the two extending arms **220** are located at the releasing position.

The pull handle **300** is pivoted on the linkage arm **210** of the sliding component **200** and extends outside from the main body **100**. The pull handle **300** is able to pivot about the sliding component **200** to be in front of the head part **110** or on the top of the head part **110**. In this embodiment, the pull handle **300** is configured to slide the sliding component **200** but the disclosure is not limited thereto. In other embodiments, the pluggable optical transceiver module **10** does not comprise the pull handle **300** and is able to be unplugged from the socket **20** by unplugging the linkage arm **210** directly. Furthermore, in this embodiment, the pull handle **300** is pivoted on the linkage arm **210** but the disclosure is not limited thereto. In other embodiments, the pull handle **300** is welded to the linkage arm **210** or screwed to the linkage arm **210**.

Moreover, the pull handle **300** is a band extending outside from the main body **100** in other embodiments. In detail, the band is made of soft rubber materials and rigid materials, which makes the band be highly tough and highly strengthened so that the band is difficult to be ruptured. Meanwhile, because the end of the band is soft rubber, the band has greater deformation so that the band may be temporarily deformed to be in accordance with the operation of the users.

Two elastic components **400** are located at the two limiting spaces **150**, respectively. Each elastic component **400** is sandwiched between the first limiting surface **151** disposed on the limiting space **150** and the limited part **240** of the extending arm **220**. The elastic component **400** normally presses the limited part **240** so that the second fastening part **230** is located at the fastening position. In this embodiment, both of the number of the limiting spaces **150** and that of the elastic components **400** are, for example, two. In other embodiments, both of the number of the limiting space **150** and that of the elastic component **400** are one.

FIG. **4**A is a cross-sectional view of the pluggable optical transceiver module in FIG. **1** when a sliding component is located at a fastening position. FIG. **4**B is a partial enlarged view of the pluggable optical transceiver module in FIG. **4**A. FIG. **5**A is a cross-sectional view of the pluggable optical transceiver module in FIG. **1** when the sliding component is located at a releasing position. FIG. **5**B is a partial enlarged view of the pluggable optical transceiver module in FIG. **5**A. As seen in FIG. **4**A and FIG. **4**B, the pluggable optical transceiver module **10** is inserted into the plugging slot **22** of the socket **20**. The two first fastening parts **24** are fastened to the two second fastening parts **230** when the two elastic components **400** respectively press the two limited parts **240** to locate the two second fastening parts **230** at the fastening position. Therefore, the pluggable optical transceiver module **10** is stably inserted into the plugging lot **22** and electrically connected to the socket **20**.

As seen in FIG. **5**A and FIG. **5**B, users is able to pull the pull handle **300** along the direction indicated by an arrow a when removing the pluggable optical transceiver module **10** from the socket **20**. The sliding component **200** is slid by the pull handle **300** relative to the main body **200** to be located at the releasing position. Since the fastening surface **231** is an inclined surface, the two first fastening parts **24** pressed by the fastening surface **231** are far away from each other when the sliding component **200** slides along the direction indicated by the arrow a. That is, the two second fastening parts **230** open the two first fastening parts **24** to release the two first fastening parts **24** from the two second fastening parts **230**. Therefore, it is more convenient to plug the pluggable optical transceiver module **10** into the socket **20** and unplug the pluggable optical transceiver module **10** from the socket **20**.

FIG. **6** is a perspective view of the pluggable optical transceiver module in FIG. **2** when a pull handle pivots on the top of the main body **200**. Users are able to apply a force to pull out the pluggable optical transceiver module **10** when the pull handle **300** is located in front of the head part **110**. The pull handle **300** is pivoted about the sliding component **200** along the direction indicated by an arrow b to be located above the head part **110** when users insert an optical fiber plug (not shown in the figure) into the optical fiber terminal **160**. Since the pull handle **300** does not interfere with the optical fiber plug, it is more convenient for the users to insert the optical fiber plug into the optical fiber terminal **160**.

According to the pluggable optical transceiver module of the disclosure, by sliding the sliding component within the two sliding slots, a user is able to easily fasten or release the combination of the two first fastening parts and the two second fastening parts.

Moreover, the pull handle is pivoted about the sliding component so that the pull handle is located in front of the main body or on the top of the main body. Users are able to pull out the pluggable optical transceiver module when the pull handle is located in front of the main body. The pull handle does not interfere with the optical fiber plug when located on the main body. Therefore, it is more convenient for users to insert the optical fiber plug into the optical fiber terminal.

What is claimed is:

1. A pluggable optical transceiver module, for being inserted into a plugging slot of a socket, the socket comprising two first fastening parts located in the plugging slot, the pluggable optical transceiver module comprising:

a main body having two side surfaces that are opposite to each other and two sliding slots located at the two side surfaces, respectively, wherein the main body is configured to be inserted into the plugging slot, wherein the main body has at least one limiting space and two bottom surfaces forming the two sliding slots, respectively, the two bottom surfaces are parallel to the two side surfaces, the at least one limiting space is located at one of the two side surfaces;

a sliding component comprising a linkage arm and two extending arms, wherein the two extending arms are connected to two ends of the linkage arm, respectively, each extending arm has a second fastening part, the main body is between the two extending arms, the two extending arms are slidably disposed on the two sliding slots to have a fastening position and a releasing position, the two first fastening parts are fastened to the two second fastening parts when the two extending arms are located at the fastening position, and the two second fastening parts press the two first fastening parts, respectively, to make the two first fastening parts be farther away from each other when the two extending arms are located at the releasing position, wherein each extending arm has a limited part configured to move in the at least one limiting space; and

an elastic component, wherein the main body has a first limiting surface and a second limiting surface forming the limiting space, the first limiting surface is closer to the head part than the second limiting surface, and the elastic component is located in the limiting space and between the first limiting surface and the limited part and is covered by the extending arm such that the elastic component is confined by the main body and the sliding component.

2. The pluggable optical transceiver module according to claim **1**, wherein the main body comprises a head part and an inserted part connected to each other, the inserted part is configured to be inserted into the socket, the two side surfaces are located at two sides of the head part and the inserted part opposite to each other, respectively, wherein both the two sliding slots extend from the head part towards the inserted part, and the two extending arms are able to slide relative to the two sliding slots to have the fastening position which is farther away from the head part and the releasing position which is closer to the head part.

3. The pluggable optical transceiver module according to claim **2**, wherein each second fastening part has a fastening surface, and a distance between one side of the fastening surface which is close to the side surface and the head part is less than a distance between another side of the fastening surface which is far away from the side surface and the head part.

4. The pluggable optical transceiver module according to claim **2**, wherein the head part has at least one optical fiber terminal.

5. The pluggable optical transceiver module according to claim **1**, further comprising two elastic components, wherein the number of the at least one limiting surface is two, the main body has two first limiting surfaces and two second limiting surfaces forming the two limiting spaces together, respectively, the two first limiting surfaces are closer to the head part than the two second limiting surfaces, the two elastic components are located in the two limiting spaces, respectively, and each elastic component is between the first limiting surface and the limited part.

6. The pluggable optical transceiver module according to claim **1**, wherein the pluggable optical transceiver module further comprises a pull handle pivoted on the linkage arm of the sliding component.

7. A pluggable optical transceiver module, comprising:

a main body having a head part and an inserted part that are connected to each other, wherein the main body further comprises opposite two side surfaces and two sliding slots which are located at two sides of the head part and the inserted part opposite to each other, respectively, the two sliding slots are located at the two side surfaces, and the two sliding slots extend from the head part to the inserted part, respectively, wherein the main body has at least one limiting space and two bottom surfaces forming the two sliding slots, respectively, the two bottom surfaces are parallel to the two side surfaces, the at least one limiting space is located at one of the two side surfaces;

a sliding component comprising a linkage arm and two extending arms, wherein the linkage arm is connected between the two extending arms, each extending arm has a second fastening part, the main body is between the two extending arms, the two extending arms are able to slide relative to the two sliding slots to have a fastening position which is farther away from the head part and a releasing position which is closer to the head part, wherein each extending arm has a limited part configured to move in the at least one limiting space; and

an elastic component, wherein the main body has a first limiting surface and a second limiting surface forming the limiting space, the first limiting surface is closer to the head part than the second limiting surface, and the elastic component is located in the limiting space and between the first limiting surface and the limited part and is covered by the extending arm such that the elastic component is confined by the main body and the sliding component.

* * * * *

EXHIBIT B

US010466432B2

(12) **United States Patent**
Luo et al.

(10) **Patent No.: US 10,466,432 B2**
(45) **Date of Patent: Nov. 5, 2019**

(54) **HIGH SPEED OPTICAL TRANSCEIVER MODULE**

(71) Applicant: **Global Technology Inc.**, Ningbo, Zhejiang Province (CN)

(72) Inventors: **Jian-Hong Luo**, Ningbo (CN); **Chao-Hung Tsai**, Ningbo (CN); **Che-Shou Yeh**, Ningbo (CN); **Jang-Hung Tian**, Ningbo (CN)

(73) Assignee: **Global Technology Inc.**, Ningbo (CN)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/971,621**

(22) Filed: **May 4, 2018**

(65) **Prior Publication Data**

US 2019/0018206 A1 Jan. 17, 2019

(30) **Foreign Application Priority Data**

Jul. 13, 2017 (CN) .... 2017 2 0846636 U

(51) **Int. Cl.**
G02B 6/42 (2006.01)
H04B 10/40 (2013.01)
G02B 6/43 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/425*** (2013.01); ***G02B 6/43*** (2013.01); ***H04B 10/40*** (2013.01); *G02B 6/428* (2013.01)

(58) **Field of Classification Search**
CPC G02B 6/425; G02B 6/428; G02B 6/43; H04B 10/40
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,617,234 A 4/1997 Koga et al.
6,305,848 B1 * 10/2001 Gregory G02B 6/4246 385/134
7,058,263 B2 6/2006 Welch et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 203414640 U * 1/2014 .... G02B 6/42

OTHER PUBLICATIONS

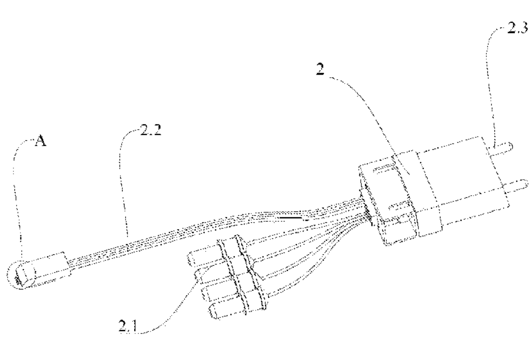
PCT Search Report and Written Opinion dated Jul. 6, 2017, received in corresponding PCT Application No. PCT/US17/29350, 9 pgs.
(Continued)

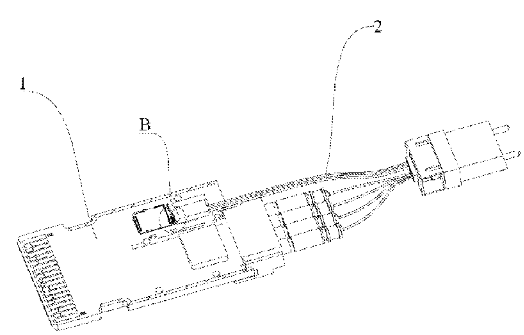
Primary Examiner — Daniel Petkovsek
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC

(57) **ABSTRACT**

The present disclosure discloses a high speed optical module having a PCBA component and a passive optical element. The PCBA component includes a receiver and a transmitter. The transmitter includes an amplifier chip and a photodiode array connected to pins of the amplifier chip. The transmitter includes a laser driving chip and a base. Multiple lasers are arranged side by side in the base. The lasers are connected to the laser driving chip. A plurality of fiber interfaces are arranged on output light paths corresponding to the plurality of lasers. The passive optical element includes ferrules corresponding to the plurality of fiber interfaces, and the ferrules are correspondingly inserted into the plurality of fiber interfaces in a one-to-one relationship. The passive optical element is inserted into the PCBA component by fiber interfaces arranged on the PCBA component.

7 Claims, 6 Drawing Sheets





(56) **References Cited**

U.S. PATENT DOCUMENTS

7,162,124	B1	1/2007	Gunn, III et al.	
7,329,054	B1 *	2/2008	Epitaux	G02B 6/4249 385/89
7,376,308	B2	5/2008	Cheben et al.	
7,532,783	B2	5/2009	Bai	
7,941,053	B2	5/2011	Dallesasse	
8,831,433	B2	9/2014	Ho et al.	
9,341,786	B1	5/2016	Gamache	
9,419,717	B2 *	8/2016	Huang	G01J 1/0271
9,476,763	B2	10/2016	Kachru et al.	
9,482,819	B2 *	11/2016	Li	G02B 6/29365
9,553,671	B1 *	1/2017	Nagarajan	H04B 10/40
9,557,500	B1	1/2017	Luo et al.	
9,614,620	B2 *	4/2017	Ho	G02B 6/43
10,088,639	B2 *	10/2018	Mentovich	G02B 6/4243
2003/0174964	A1	9/2003	Gao et al.	
2004/0161186	A1	8/2004	Crafts et al.	
2012/0301152	A1 *	11/2012	Edwards	G02B 6/4201 398/135
2015/0249501	A1	9/2015	Nagarajan	
2015/0256259	A1	9/2015	Huang	
2015/0316732	A1 *	11/2015	Schamuhn	G02B 6/4284 398/139
2016/0131854	A1 *	5/2016	de Jong	G02B 6/3879 385/59
2016/0149662	A1	5/2016	Soldano et al.	
2016/0349451	A1	12/2016	Shen et al.	
2017/0168252	A1	6/2017	Pezeshki et al.	
2017/0187462	A1 *	6/2017	Luo	G02B 6/4206
2017/0248763	A1 *	8/2017	Kawamura	G02B 6/421
2017/0307819	A1	10/2017	Ho et al.	
2017/0336582	A1	11/2017	Luo et al.	
2019/0018206	A1	1/2019	Luo	

OTHER PUBLICATIONS

U.S. Office Action dated Aug. 21, 2017, received in U.S. Appl. No. 15/137,823, 13 pgs.

U.S. Office Action dated Aug. 29, 2017, received in U.S. Appl. No. 15/432,242, 15 pgs.

U.S. Office Action dated Apr. 13, 2018, received in U.S. Appl. No. 15/432,242, 28 pgs.

U.S. Office Action dated Jan. 28, 2019, received in related U.S. Appl. No. 15/432,242, 10 pgs.

U.S. Office Action dated Apr. 16, 2019, received in related U.S. Appl. No. 16/142,466, 23 pgs.

* cited by examiner

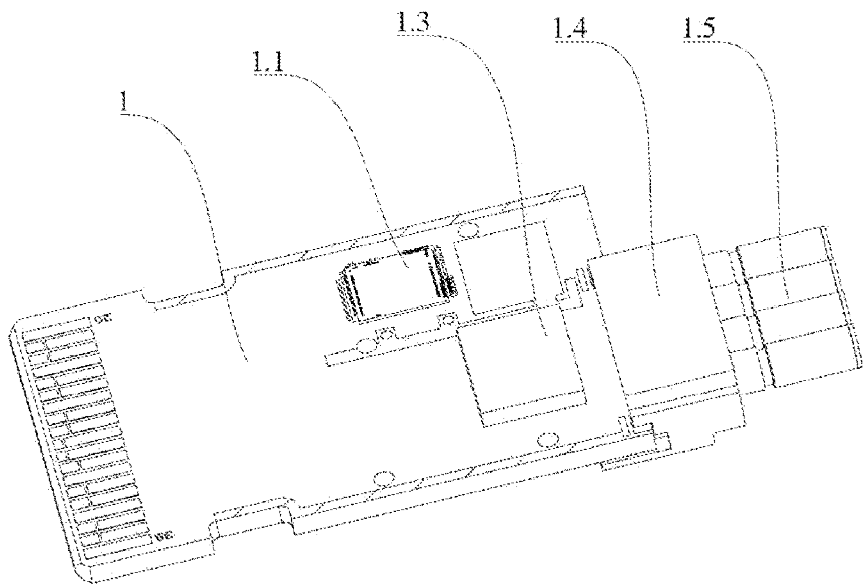


Figure 1

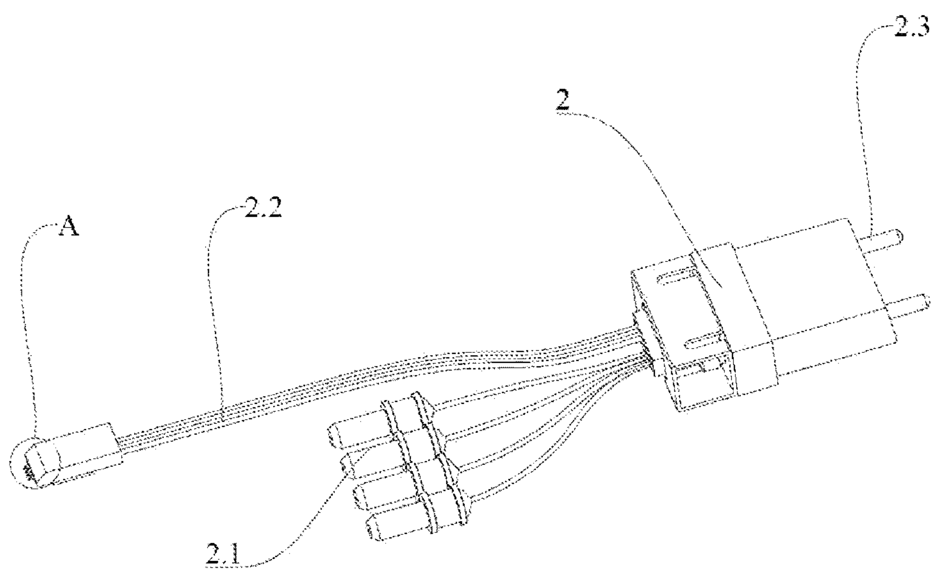


Figure 2

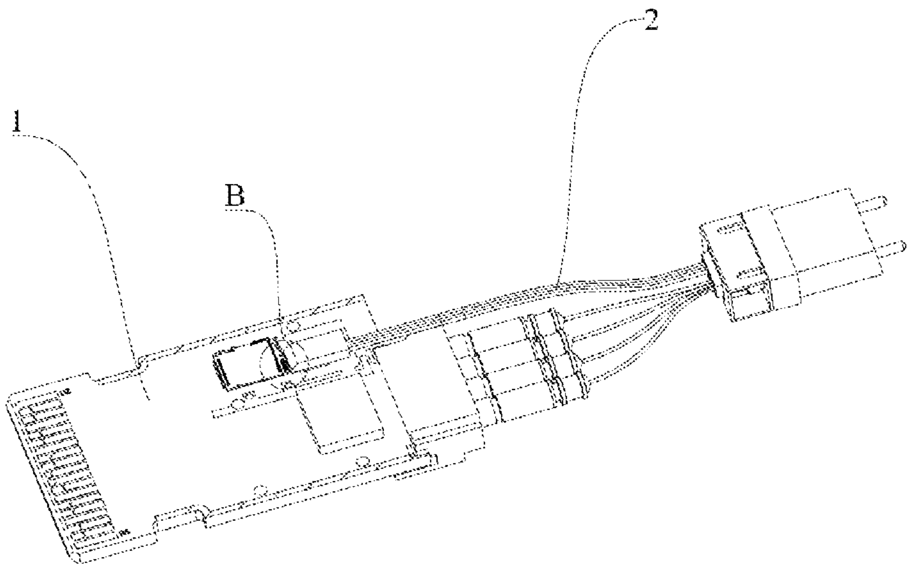


Figure 3

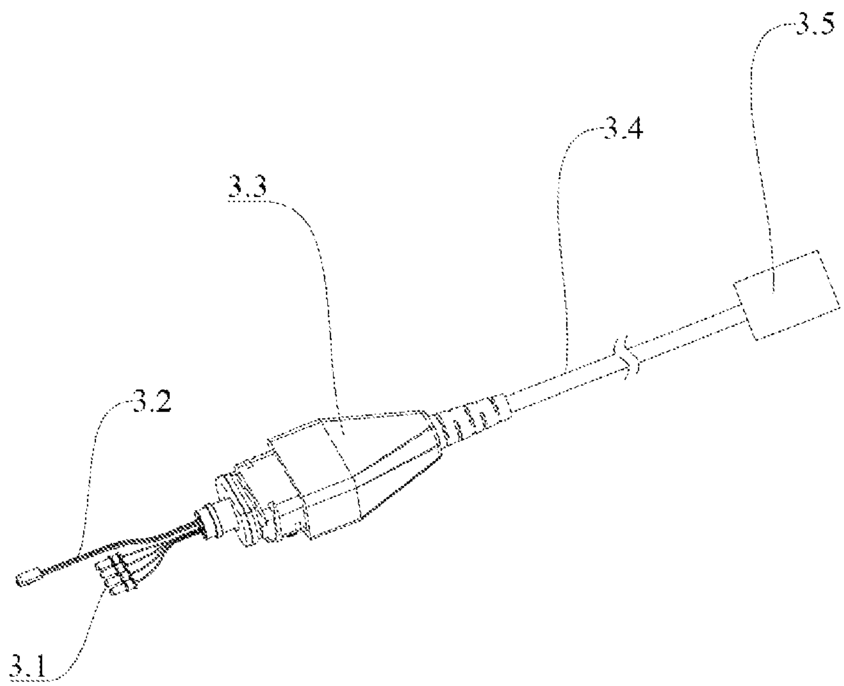


Figure 4

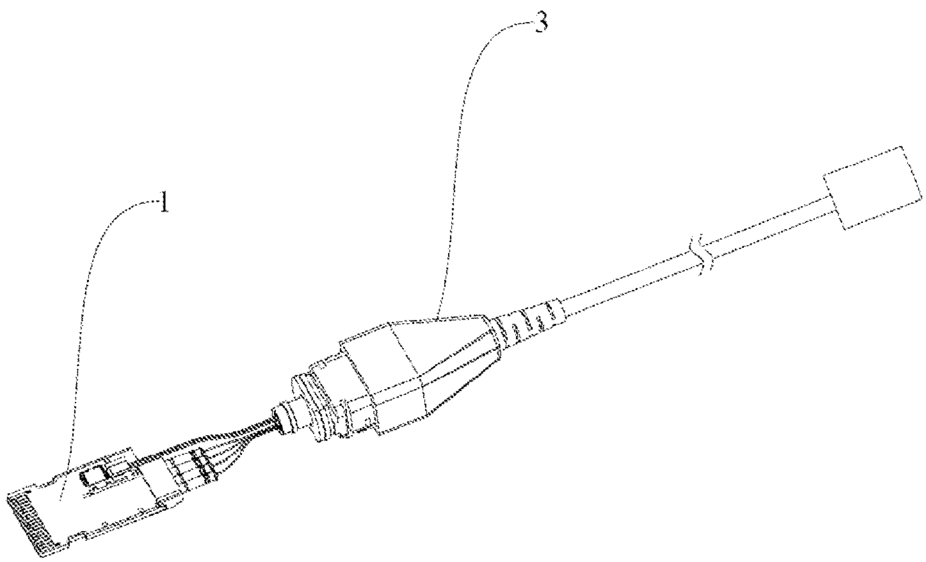


Figure 5

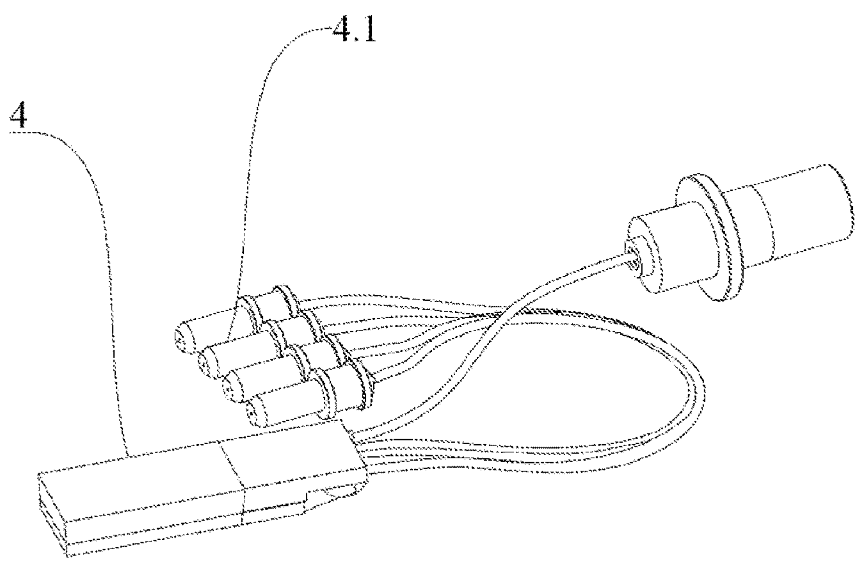


Figure 6

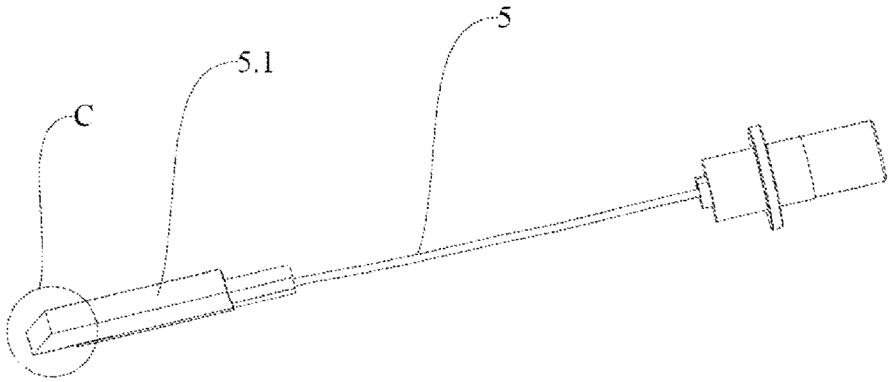


Figure 7

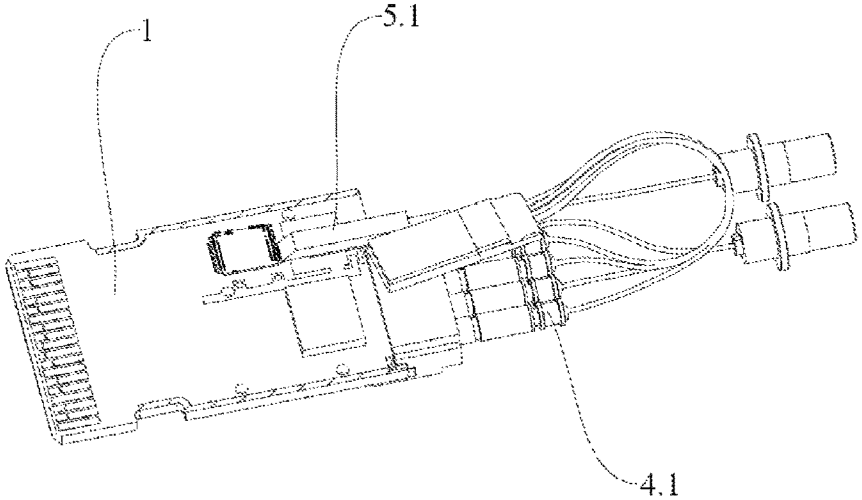


Figure 8

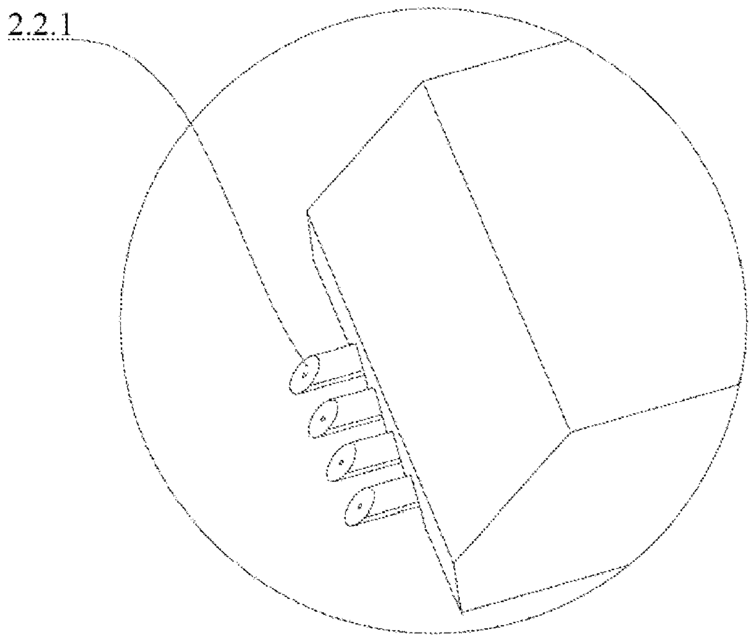


Figure 9

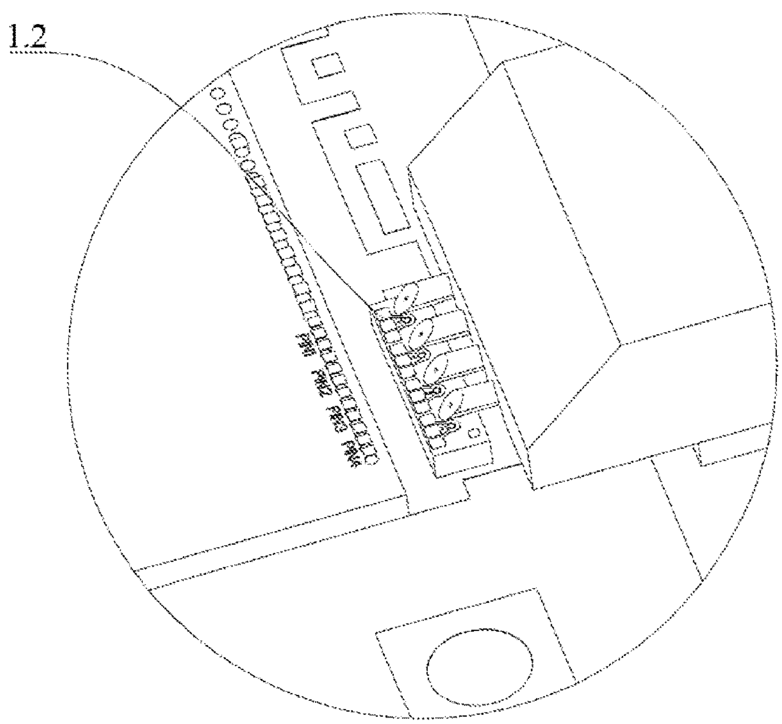


Figure 10

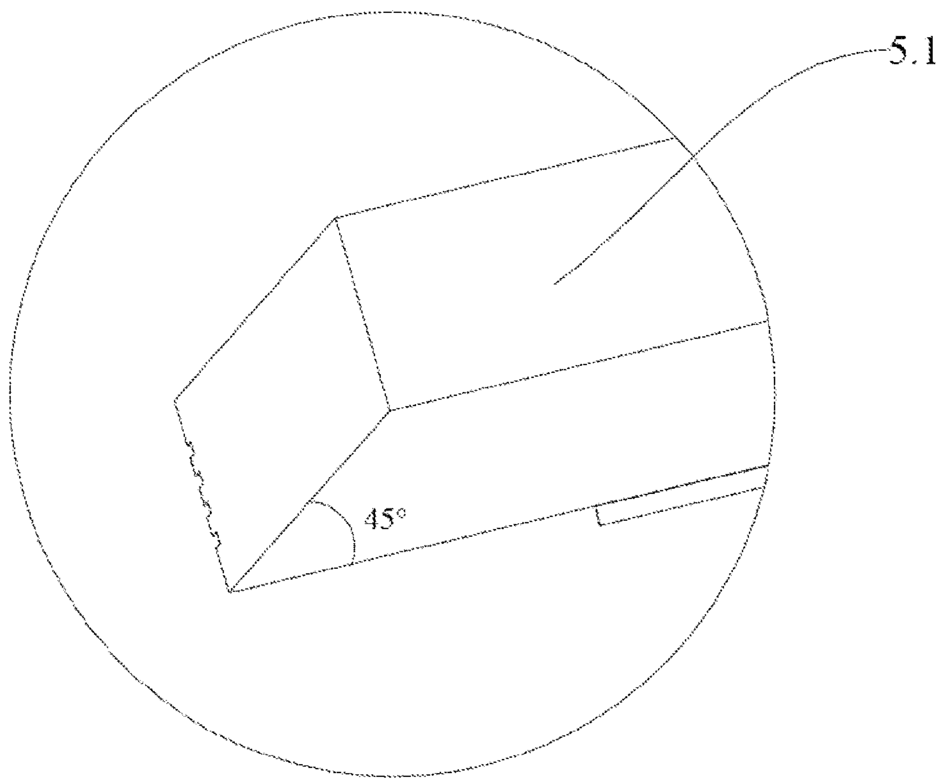


Figure 11

HIGH SPEED OPTICAL TRANSCEIVER MODULE

TECHNICAL FIELD

The present disclosure relates to the field of optical communication, and more particularly, to a high speed optical transceiver module.

BACKGROUND

High speed optical transceiver modules are primarily used in fields of optical communication such as data centers and Fiber to the Home (FTTH), and they are core communication modules in optical communication. Due to growing demands on transmission bandwidth and speed by upgraded communication systems, the configurations of optical transceiver modules are being developed to be with advantages of smaller in volume, better in integration and operating with multiple channels. The demands are also growing on cost-control and process-control. An existing high speed optical transceiver includes a printed circuit board assembly (PCBA) component and an optical engine which is usually directly soldered to the PCBA component. This design is not reliable when there is something wrong with soldered connection, which may result in inferiority of signal transmission in the high speed optical transceiver. Further, since such a design requires soldering the PCBA component to the optical engine, which just complicates the manufacture process, the yield rate remains a lot to be desired. Meanwhile, the corresponding complicated manufacturing process therefore includes handling the PCBA component first before soldering the optical engine to the PCBA component and mounting a protecting lid above the soldered position using screws.

SUMMARY

The present disclosure provides a high speed optical transceiver module including a PCBA component and a passive optical element.

The PCBA component includes a receiver and a transmitter. The receiver may include an amplifier chip and a photodiode array connected to pins of the amplifier chip. The transmitter may include a laser driving chip and a base. The base may include a plurality of lasers arranged side by side therein. The lasers are connected to the laser driving chip. A plurality of fiber interfaces are arranged on output light paths corresponding to the lasers. The passive optical element may include ferrules corresponding to the fiber interfaces, and the ferrules are correspondingly inserted into the fiber interfaces in a one-to-one relationship.

The present disclosure has the following advantages compared to prior arts.

The passive optical element is inserted into the PCBA component by the fiber interfaces arranged on the PCBA component. The connection approach is convenient, effective, and stable without resorting to soldering. Also, the PCBA component and the passive optical element can be manufactured separately, and assembled later. Modular production of the PCBA component and the passive optical element therefore can be achieved for the production of the disclosed optical transceiver module. Various types of products can be manufactured according to the type of the passive optical element. Therefore, the PCBA component can be used for general purposes. The functionalities of the high speed optical transceiver module could be more flexible

to satisfy numerous needs. The production efficiency and the product yield are also enhanced consequently. In some embodiments, 4 lasers and 4 fiber interfaces could be found in the transceiver module. In some embodiments, the passive optical element is a multi push on (MPO) connector. The MPO connector may include a first plurality of ferrules and a first fiber array on one end and a mechanical transfer (MT) pin on the other end. The first ferrules are correspondingly connected to the fiber interfaces in a one-to-one relationship. An end of the first fiber array is mounted over or in the proximity of the photodiode array. The MT pin is used to connect other photoelectric devices. In some embodiments, the passive optical element is a MPO connector having a tail fiber. The MPO connector with the tail fiber may include a tail sleeve. The tail sleeve may include a second plurality of ferrules and a second fiber array on one end and the tail fiber on the other end. The second ferrules are correspondingly connected to the fiber interfaces in a one-to-one relationship. An end of the second fiber array is mounted over or in proximity of the photodiode array, and the tail fiber may include an optical connector on an end. The optical connector can be configured to allow for general-purpose usage of the MPO connector with the tail fiber.

In some embodiments, the optical connector is one of an arrayed connector, a lucent connector (LC), and a subscriber connector (SC).

In some embodiments, each of the first and second fiber arrays is a fiber array having an angle of 41 to 45 degrees. The light emitted from the fiber array would be incident on the photodiode array vertically to provide the shortest light path.

In some embodiments, the passive optical element is a wavelength division multiplexer including a multiplexing component and a de-multiplexing component. The multiplexing component comprises a third plurality of ferrules connected to the plurality of fiber interfaces in one-to-one correspondence. The demultiplexing component comprises an arrayed waveguide grating (AWG) chip, and an end of the AWG chip is mounted on the photodiode array. Wavelength division multiplexing can be achieved by the multiplexing component and the demultiplexing component. In some embodiments, an end face of the AWG chip is a slope having a slope angle of 41 to 45 degrees so that light may enter the photodiode array vertically.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a structural schematic of a PCBA component.

FIG. **2** is a structural schematic of a MPO connector.

FIG. **3** is a structural schematic of a PSM**4** module.

FIG. **4** is a MPO connector with a tail fiber.

FIG. **5** is a structural schematic of a PSM**4** module with a tail fiber.

FIG. **6** is a structural schematic of a multiplexing component.

FIG. **7** is a structural schematic of a demultiplexing component.

FIG. **8** is a structural schematic of a CWDM**4** module.

FIG. **9** is an enlarged view of the part A.

FIG. **10** is an enlarged view of the part B.

FIG. **11** is an enlarged view of the part C.

REFERENCE NUMBERS

1 PCBA component, **1.1** amplifier chip, **1.2** photodiode array, **1.3** laser driving chip, **1.4** base, **1.5** fiber interface, **2** MPO connector, **2.1** first plurality of ferrules, **2.2** first fiber array, **2.2.1** end face of first fiber array, **2.3** MT pin, **3** MPO connector with a tail fiber, **3.1** second plurality of ferrules, **3.2** second fiber array, **3.3** tail sleeve, **3.4** tail fiber, **3.5** optical connector, **4** multiplexing component, **4.1** third plurality of ferrules, **5** de-multiplexing component, **5.1** AWG chip.

DETAILED DESCRIPTION

A high speed optical transceiver module may include a PCBA component **1** and a passive optical element. The PCBA component **1** may include a receiver and a transmitter. The receiver comprises an amplifier chip **1.1** and a photodiode array **1.2**. The photodiode array **1.2** is connected to pins of the amplifier chip **1.1**. The transmitter may include a laser driving chip **1.3** and a base **1.4**. The base **1.4** may include a plurality of lasers arranged side by side. The lasers are connected to the laser driving chip **1.3**. A plurality of fiber interfaces **1.5** are arranged on output light paths corresponding to the lasers. The passive optical element may include ferrules corresponding to the fiber interfaces **1.5**. The ferrules are correspondingly inserted into the fiber interfaces in another one-to-one relationship. Light emitted by the lasers is transmitted into the passive optical element through the ferrules of the passive optical element.

As shown in FIG. **1** to FIG. **5** and FIG. **9** to FIG. **10**, a parallel single-mode four-channel module, i.e., the PSM**4** module has two types of structures. A PSM**4** module of the first type may include a PCBA component **1** and a MPO connector **2**. The PCBA component **1** may include four lasers and four fiber interfaces. The MPO connector **2** may include a first plurality of ferrules **2.1** and a first fiber array **2.2** on one of its ends and a mechanical transfer (MT) pin **2.3** on the other end thereof. The first plurality of ferrules **2.1** are correspondingly connected to the fiber interfaces **1.5** in a one-to-one relationship. An end of the first fiber array **2.2** is disposed over the photodiode array **1.2**. The MT pin is a plug-in interface used to connect other photoelectric devices. Light emitted by the lasers enters the MPO connector **2** through the first plurality of ferrules **2.1**. After conversion, the light is transmitted from the end of the first fiber array **2.2** to the photodiode array **1.2**. The second type is a PSM**4** module with a tail fiber. The PSM**4** module in this embodiment may include a PCBA component **1** and a MPO connector with a tail fiber **3.4**. The MPO connector with the tail fiber **3.4** may include a tail sleeve **3.3**. The tail sleeve **3.3** may include a second plurality of ferrules **3.1** and a second fiber array **3.2** on one end with the tail fiber **3.4** on the other end. The second ferrules **3.1** are correspondingly connected to the fiber interfaces **1.5** in another one-to-one relationship. An end of the second fiber array **3.2** is mounted over or in proximity of the photodiode array **1.2**. A protecting lid is arranged at a predetermined position where the second fiber array **3.2** is disposed over or in proximity of the photodiode array **1.2**. The protecting lid is used to limit the end part of the second fiber array **3.2**. An optical connector **3.5** is arranged on an end part of the tail fiber **3.4**. The optical connector **3.5** could be chosen to meet different needs. For example, the optical connectors **3.5** could be MPO connectors, lucent connectors (LC), or subscriber connectors (SC). Both the first fiber array **2.2** and the second fiber array **3.2** are arrayed fibers having angles of 41 to 45 degrees. The light emitted from the first fiber array **2.2** or the second fiber array **3.2** would be incident on the photodiode array **1.2** vertically to provide the shortest light path, which might maintain the quality of the transmission signal.

As shown in FIGS. **6**-**8** and **11**, an optical transceiver module enabling wavelength multiplexing such as a CWDM**4** module including a PCBA component **1** and a wavelength division multiplexer is disclosed. The wavelength division multiplexer may include a MUX component **4** and a DEMUX component **5**. Four lasers and four fiber interfaces are arranged on the PCBA component **1**. The multiplexing component **4** may include a third plurality of ferrules **4.1**. The third plurality of ferrules **4.1** are connected to the fiber interfaces **1.5** on a one-to-one basis. The demultiplexing component **5** may include an arrayed waveguide grating (AWG) chip **5.1**. An end of the AWG chip **5.1** is mounted on the light receiving surface of the photodiode array **1.2**. The end face of the AWG chip **5.1** is oriented between 41 to 45 degrees so that the light path would be rotated by 90° before it is incident on the receiving surface of the photodiode array **1.2**. The angle of the end face of the AWG chip **5.1** can be adjusted according to different reflected volumes and required receiving responsiveness.

The PCBA component and the passive optical element of the present disclosure may be manufactured in modules separately before they are assembled together. High speed optical transceivers with various functionalities can be manufactured by combining various passive optical elements with the PCBA component. More functions may become available in the high speed optical transceiver. Modular production would also increase production efficiency and product yield.

What is claimed is:

1. A high-speed optical transceiver module, comprising:
a printed circuit board assembly (PCBA) component having a receiver and a transmitter; and
a passive optical element, wherein
the receiver comprises an amplifier chip and a photodiode array connected to pins of the amplifier chip;
the transmitter comprises a laser driving chip and a base;
the base comprises a plurality of lasers arranged side by side;
the plurality of lasers are connected to the laser driving chip;
a plurality of fiber interfaces are arranged on output light paths corresponding to the lasers;
the passive optical element comprises ferrules corresponding to the fiber interfaces and a fiber array for emitting light on the photodiode array of the receiver; and
the ferrules are inserted into the plurality of fiber interfaces in one-to-one correspondence.

2. The high-speed optical transceiver module of claim **1**, wherein the plurality of lasers comprise 4 lasers, and the plurality of fiber interfaces comprise 4 fiber interfaces.

3. The high-speed optical transceiver module of claim **2**, wherein the passive optical element is a multi push on (MPO) connector, the MPO connector having the ferrules and the fiber array at a first end and a mechanical transfer (MT) pin at a second end opposite the first end.

4. The high-speed optical transceiver module of claim **2**, wherein the passive optical element is a MPO connector having a tail fiber with an optical connector, the MPO connector comprises a tail sleeve, the tail sleeve comprises the ferrules and the fiber array on a first end and the tail fiber on a second end.

5. The high-speed optical transceiver module of claim **4**, wherein the optical connector is one of an arrayed connector, a lucent connector (LC), and a subscriber connector (SC).

6. The high-speed optical transceiver module of claim **2**, wherein the passive optical element is a wavelength division multiplexer comprising a multiplexing component and a demultiplexing component, the de-multiplexing component comprises an arrayed waveguide grating (AWG) chip, and an end of the AWG chip is mounted on the photodiode array.

7. The high-speed optical transceiver module of claim **6**, wherein an end face of the AWG chip is a slope having a slope angle of 41 to 45 degrees.

* * * * *

EXHIBIT C

US009170383B2

(12) **United States Patent**
Ho et al.

(10) **Patent No.: US 9,170,383 B2**
(45) **Date of Patent: Oct. 27, 2015**

(54) **MULTI-CHANNEL OPTICAL TRANSCEIVER MODULE INCLUDING DUAL FIBER TYPE DIRECT LINK ADAPTER FOR OPTICALLY COUPLING OPTICAL SUBASSEMBLIES IN THE TRANSCEIVER MODULE**

(71) Applicant: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(72) Inventors: **I-Lung Ho**, Sugar Land, TX (US); **Stefan J. Murry**, Houston, TX (US); **Richard Yeh**, New Taipei (TW)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 224 days.

(21) Appl. No.: **13/709,195**

(22) Filed: **Dec. 10, 2012**

(65) **Prior Publication Data**

US 2014/0161394 A1 Jun. 12, 2014

(51) **Int. Cl.**
G02B 6/42 (2006.01)
G02B 6/38 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/421*** (2013.01); ***G02B 6/4246*** (2013.01); ***G02B 6/4293*** (2013.01); *G02B 6/38* (2013.01); *G02B 6/3807* (2013.01); *G02B 6/3869* (2013.01); *G02B 6/3874* (2013.01); *G02B 6/3877* (2013.01); *G02B 6/42* (2013.01); *G02B 6/4201* (2013.01)

(58) **Field of Classification Search**
CPC G02B 6/42; G02B 6/4201; G02B 6/4246; G02B 6/4292; G02B 6/38; G02B 6/3807; G02B 6/3869; G02B 6/3877
USPC 385/53, 55, 84, 88, 89, 92, 94, 134, 139
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,350,063	B1	2/2002	Gilliland et al.	
7,090,509	B1	8/2006	Gilliland et al.	
2006/0215970	A1 *	9/2006	Mizue et al.	385/92
2010/0232757	A1	9/2010	Shiroshita	
2011/0103797	A1 *	5/2011	Oki et al.	398/79
2011/0225792	A1 *	9/2011	Oki et al.	29/428
2011/0229095	A1 *	9/2011	Oki	385/92
2011/0229096	A1 *	9/2011	Oki	385/92
2011/0255831	A1 *	10/2011	Oki et al.	385/78
2011/0262078	A1 *	10/2011	Oki et al.	385/78
2012/0275784	A1 *	11/2012	Soto et al.	398/38
2013/0156418	A1 *	6/2013	Stapleton et al.	398/25

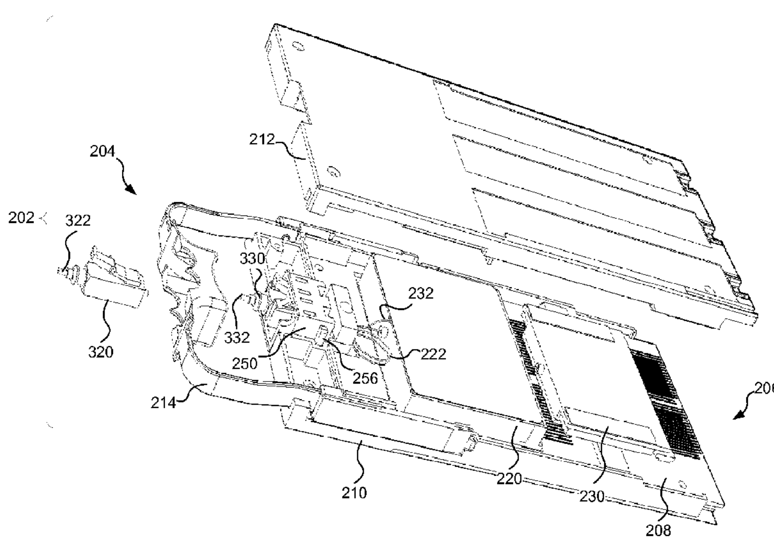
* cited by examiner

Primary Examiner — Ryan Lepisto
Assistant Examiner — Guy Anderson
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

A multi-channel optical transceiver includes a multi-channel transmitter optical subassembly (TOSA), a multi-channel receiver optical subassembly (ROSA), and a dual fiber type direct link adapter directly linked to the multi-channel TOSA and the multi-channel ROSA with optical fibers. The dual fiber type direct link adapter is also configured to receive pluggable optical connectors, such as LC connectors, mounted at the end of fiber-optic cables including optical fibers for carrying optical signals to and from the transceiver. The dual fiber type direct link adapter thus provides the optical input and output to the transceiver for the optical signals received by the ROSA and transmitted by the TOSA. The multi-channel optical transceiver may be used in a wavelength division multiplexed (WDM) optical system, for example, in an optical line terminal (OLT) in a WDM passive optical network (PON).

12 Claims, 6 Drawing Sheets



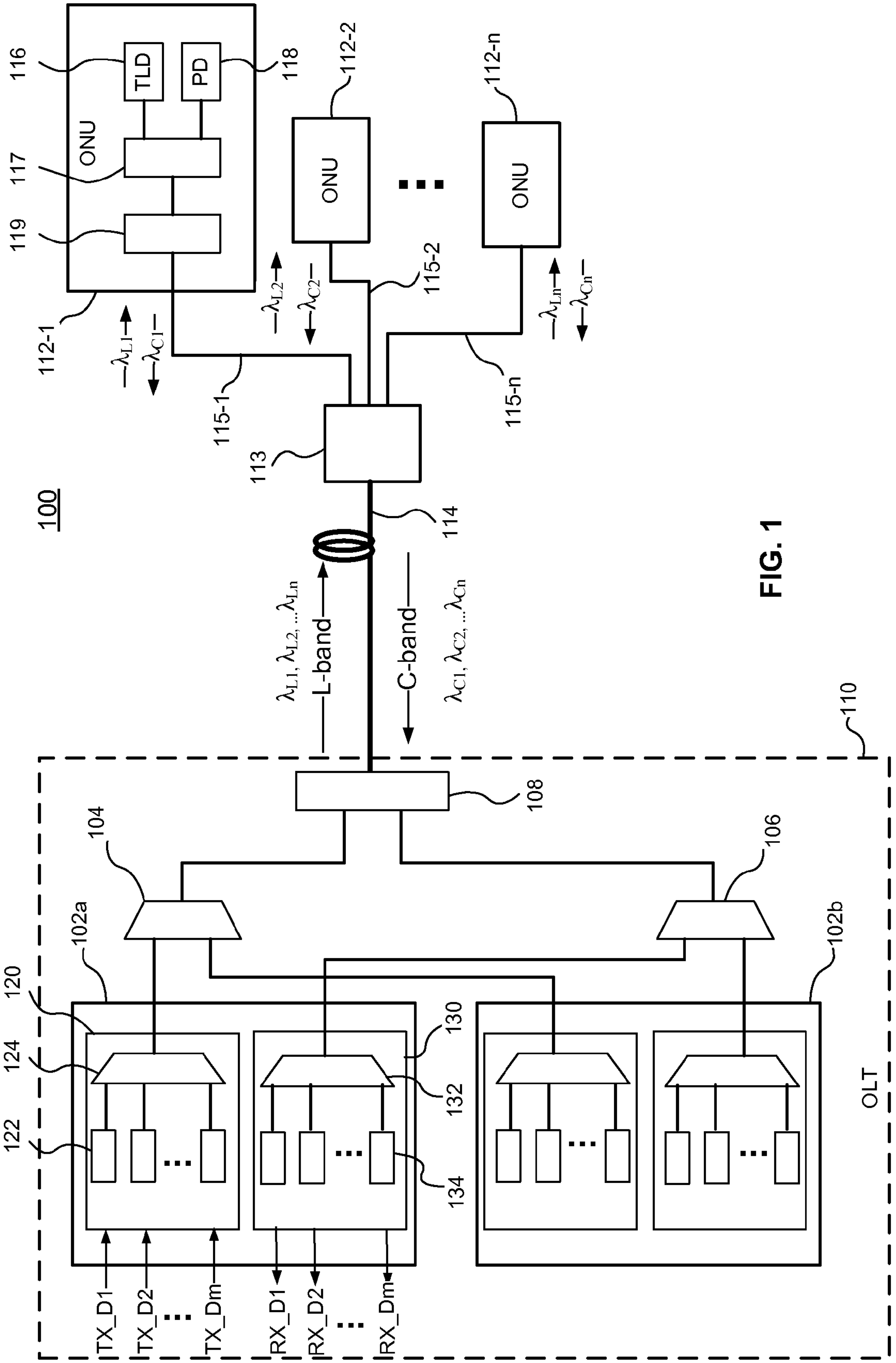
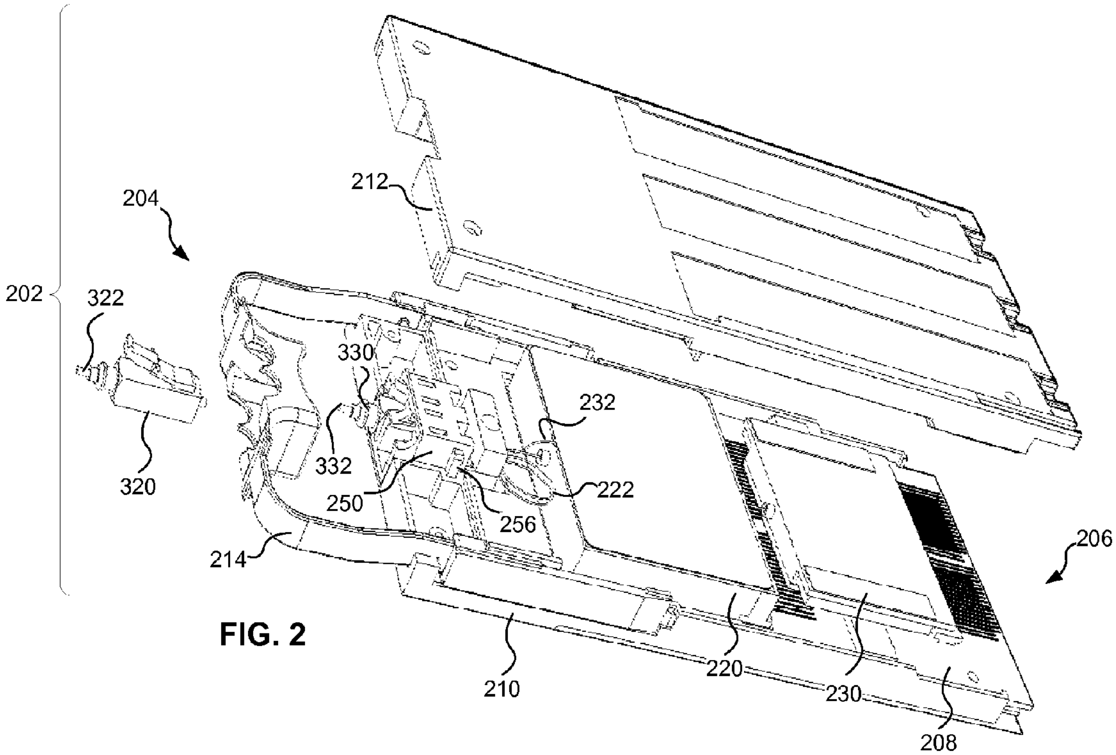
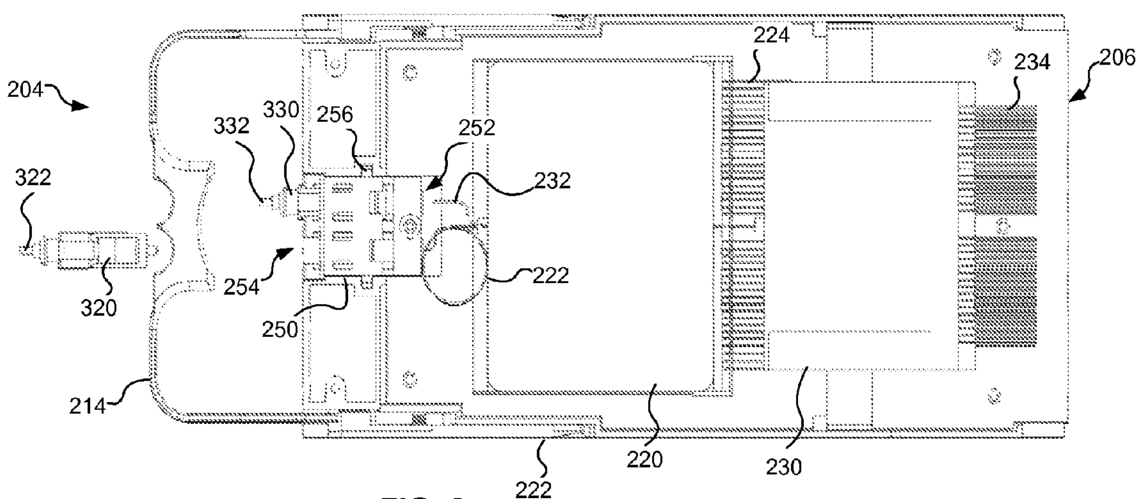

100
ONU
TLD
PD
116
117
118
119
112-1
112-2
112-n
ONU
ONU
λL1
λC1
λL2
λC2
λLn
λCn
115-1
115-2
115-n
113
114
λL1, λL2, ...λLn
L-band
C-band
λC1, λC2, ...λCn
108
110
104
106
102a
102b
120
124
122
130
132
134
OLT
TX_D1
TX_D2
TX_Dm
RX_D1
RX_D2
RX_Dm

FIG. 1



202
204
212
322
330
332
320
232
250
222
256
214
206
210
220
230
208

FIG. 2



224
234
206
204
332
330
256
252
322
232
254
222
320
250
214
220
230
222

FIG. 3

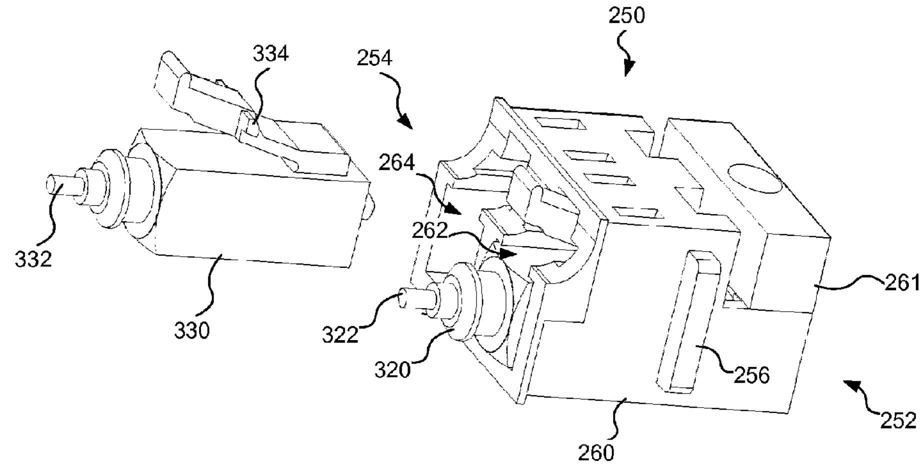


FIG. 4

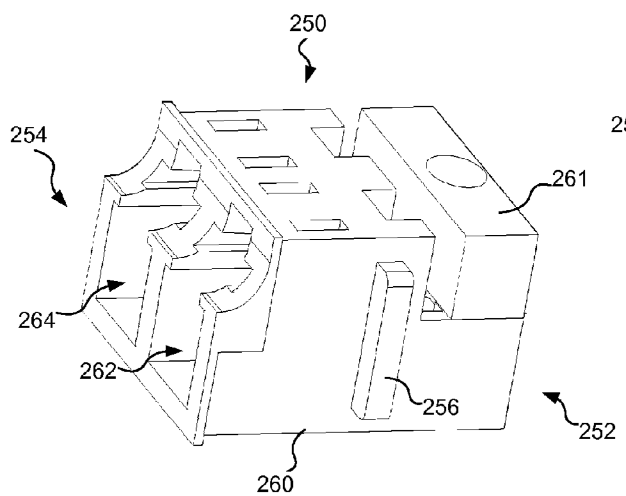


FIG. 5

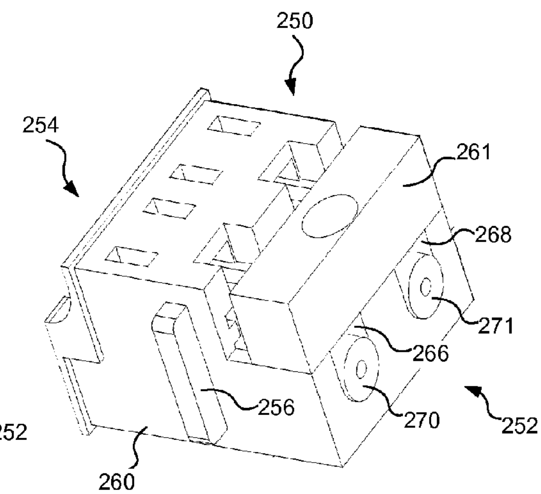


FIG. 6

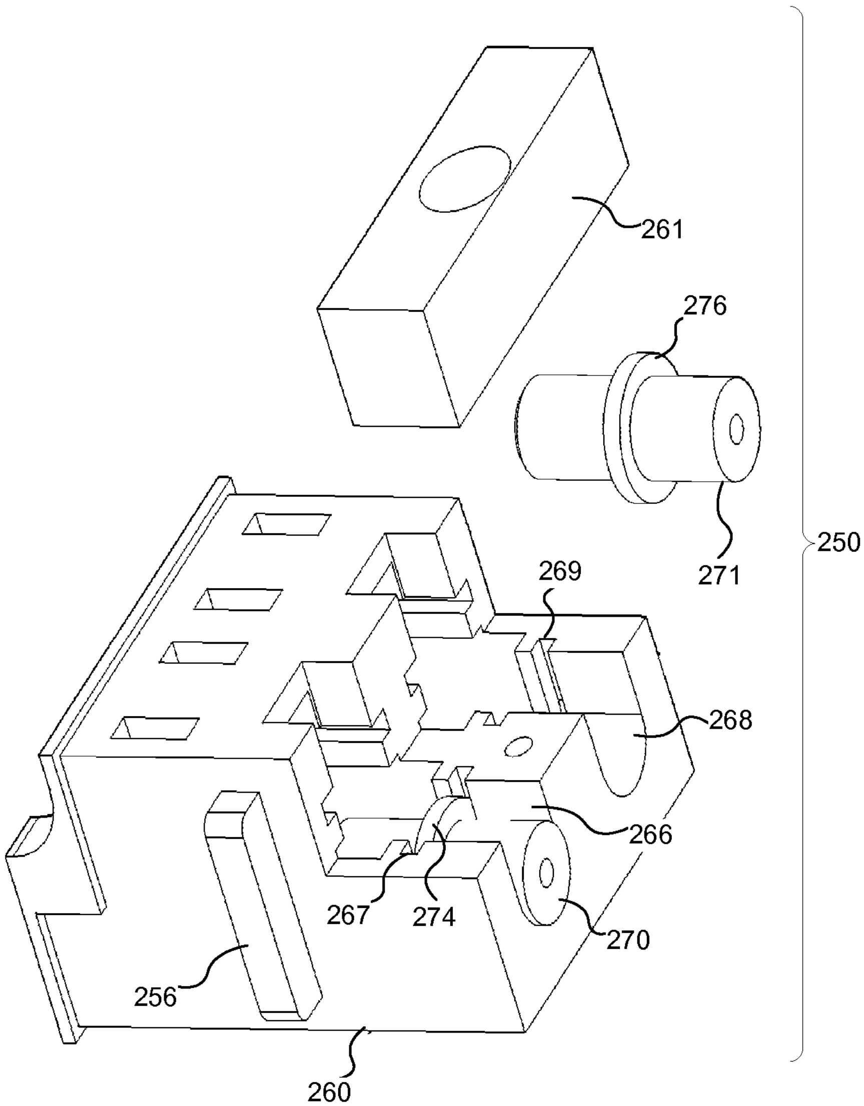


FIG. 7

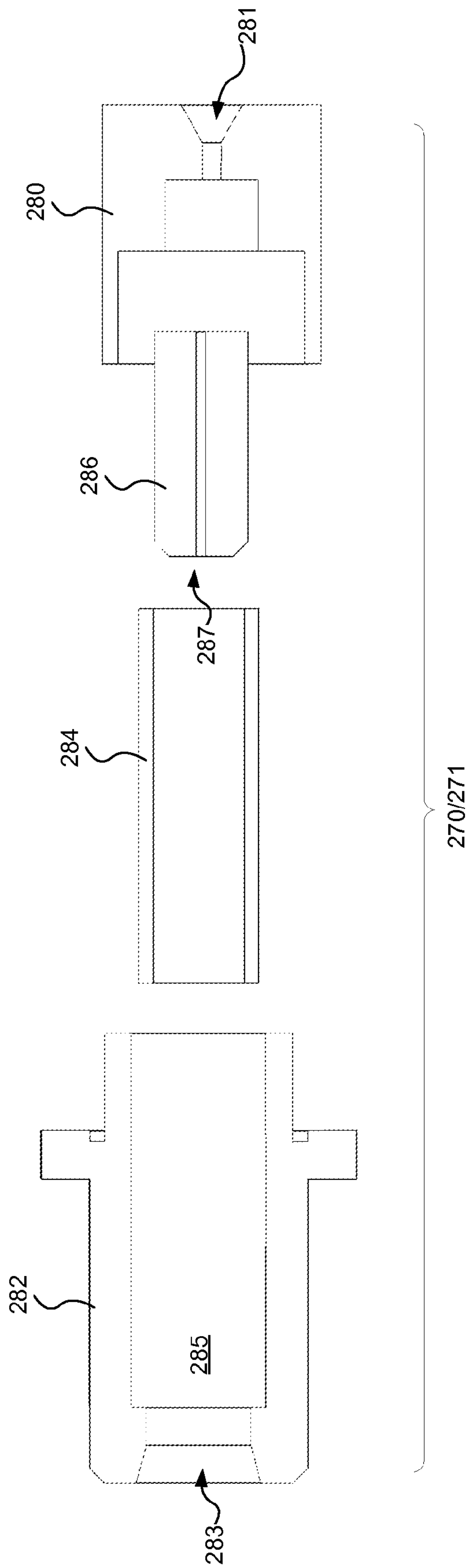


FIG. 8

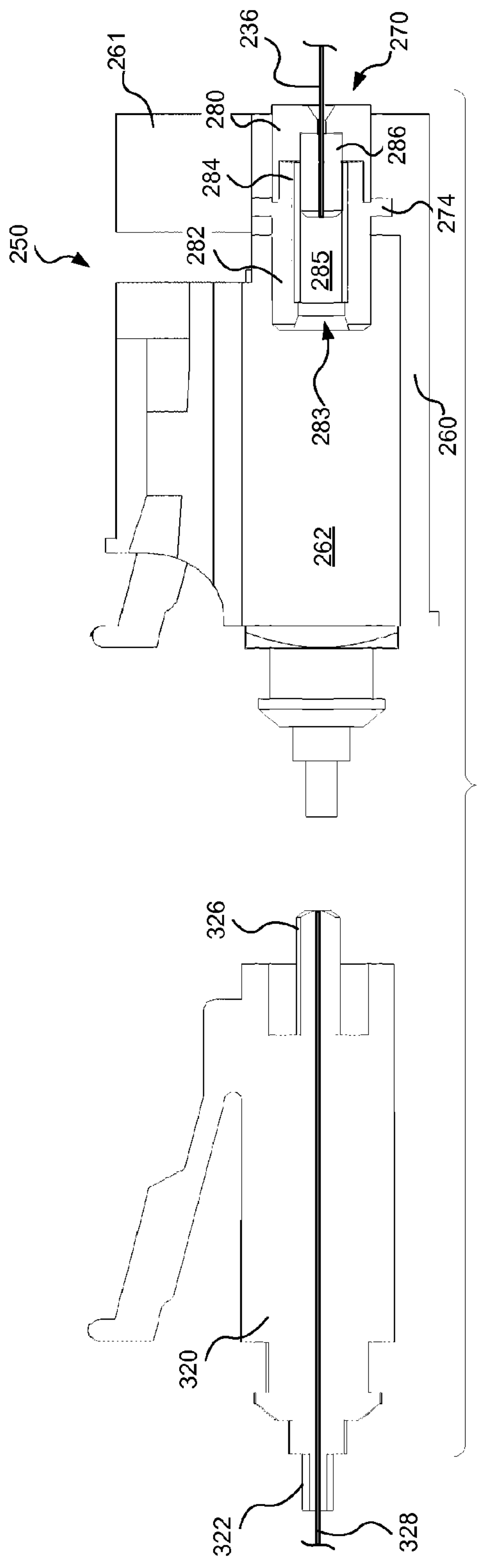

236
270
261
280
286
284
274
250
282
285
283
260
262
326
320
322
328

FIG. 9

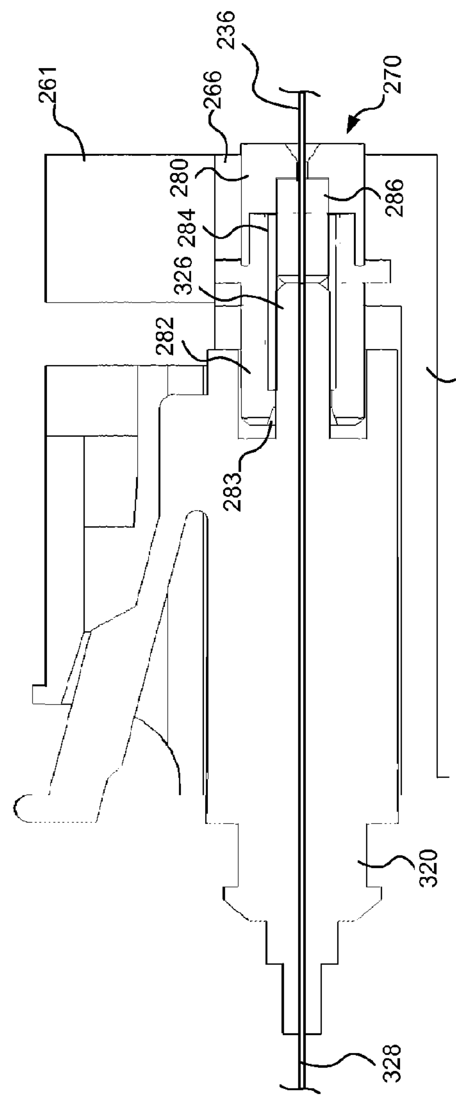

236
270
261
266
280
286
284
326
250
282
260
283
320
328

FIG. 10

MULTI-CHANNEL OPTICAL TRANSCEIVER MODULE INCLUDING DUAL FIBER TYPE DIRECT LINK ADAPTER FOR OPTICALLY COUPLING OPTICAL SUBASSEMBLIES IN THE TRANSCEIVER MODULE

TECHNICAL FIELD

The present disclosure relates to multi-channel optical transceiver modules and more particularly, to a multi-channel transceiver module including a dual fiber type direct link adapter for optically coupling optical subassemblies in the transceiver module.

BACKGROUND INFORMATION

Optical communications networks, at one time, were generally "point to point" type networks including a transmitter and a receiver connected by an optical fiber. Such networks are relatively easy to construct but deploy many fibers to connect multiple users. As the number of subscribers connected to the network increases and the fiber count increases rapidly, deploying and managing many fibers becomes complex and expensive.

A passive optical network (PON) addresses this problem by using a single "trunk" fiber from a transmitting end of the network, such as an optical line terminal (OLT), to a remote branching point, which may be up to 20 km or more. One challenge in developing such a PON is utilizing the capacity in the trunk fiber efficiently in order to transmit the maximum possible amount of information on the trunk fiber. Fiber optic communications networks may increase the amount of information carried on a single optical fiber by multiplexing different optical signals on different wavelengths using wavelength division multiplexing (WDM). In a WDM-PON, for example, the single trunk fiber carries optical signals at multiple channel wavelengths to and from the optical branching point and the branching point provides a simple routing function by directing signals of different wavelengths to and from individual subscribers. In this case, each subscriber may be assigned one or more of the channel wavelengths on which to send and/or receive data.

To transmit and receive optical signals over multiple channel wavelengths, the OLT in a WDM-PON may include a multi-channel transmitter optical subassembly (TOSA) and a multi-channel receiver optical subassembly (ROSA). The multi-channel TOSA and the multi-channel ROSA may be connected to external optical fibers that carry the transmitted and received optical signals. Optical connectors, such as LC connectors, may be provided at the ends of the optical fibers for connecting the optical fibers to the respective multi-channel TOSA and multi-channel ROSA. OLT transceiver modules often are designed to fit a relatively small form factor. One challenge with such OLT transceiver modules is accommodating the multi-channel TOSA and ROSA in the relatively small space available in an OLT module. In particular, certain components that may be used to provide optical connections to the TOSA and ROSA, such as conventional LC adapters, may not fit within the limited space.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** is a functional block diagram of a wavelength division multiplexed (WDM) passive optical network (PON) including at least one multi-channel optical transceiver, consistent with embodiments of the present disclosure.

FIG. **2** is an exploded view of a multi-channel optical transceiver including a dual fiber type direct link adapter for optically coupling directly to a TOSA and a ROSA, consistent with an embodiment of the present disclosure.

FIG. **3** is a top view inside the multi-channel optical transceiver shown in FIG. **2**.

FIG. **4** is a perspective view of one embodiment of the dual fiber type direct link adapter for coupling to first and second LC connectors.

FIGS. **5** and **6** are perspective views of the dual fiber type direct link adapter shown in FIG. **4** without the first and second LC connectors.

FIG. **7** is an exploded view of the dual fiber type direct link adapter shown in FIG. **4** illustrating the LC optical connecting portion.

FIG. **8** is a cross-sectional exploded view of the LC optical connecting portion of the dual fiber type direct link adapter shown in FIG. **4**.

FIGS. **9** and **10** are cross-sectional views of the dual fiber type direct link adapter shown in FIG. **4** with the LC connector disconnected and connected.

DETAILED DESCRIPTION

A multi-channel optical transceiver, consistent with embodiments described herein, generally includes a multi-channel transmitter optical subassembly (TOSA), a multi-channel receiver optical subassembly (ROSA), and a dual fiber type direct link adapter directly linked to the multi-channel TOSA and the multi-channel ROSA with optical fibers. The dual fiber type direct link adapter is also configured to receive pluggable optical connectors, such as LC connectors, mounted at the end of fiber-optic cables including optical fibers for carrying optical signals to and from the transceiver. The dual fiber type direct link adapter thus provides the optical input and output to the transceiver for the optical signals received by the ROSA and transmitted by the TOSA. The multi-channel optical transceiver may be used in a wavelength division multiplexed (WDM) optical system, for example, in an optical line terminal (OLT) in a WDM passive optical network (PON).

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid. The term "coupled" as used herein refers to any connection, coupling, link or the like by which signals carried by one system element are imparted to the "coupled" element and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals. As used herein, "direct link" refers to optically coupling with a single optical fiber mechanically coupled between two components without using pluggable connectors at the ends of the fiber link.

Referring to FIG. **1**, a WDM-PON **100** including one or more multi-channel optical transceivers **102***a*, **102***b*, consistent with embodiments of the present disclosure, is shown and described. The WDM-PON **100** provides a point-to-multi-point optical network architecture using a WDM system. According to one embodiment of the WDM-PON **100**, at least one optical line terminal (OLT) **110** may be coupled to a plurality of optical networking terminals (ONTs) or optical networking units (ONUs) **112-1** to **112-*n*** via optical fibers, waveguides, and/or paths **114**, **115-1** to **115-*n***. Although the OLT **110** includes two multi-channel optical transceivers **102*a***, **102*b*** in the illustrated embodiment, the OLT **110** may include one or more multi-channel optical transceivers.

The OLT **110** may be located at a central office of the WDM-PON **100**, and the ONUs **112-1** to **112-*n*** may be located in homes, businesses or other types of subscriber location or premises. A branching point **113** (e.g., a remote node) couples a trunk optical path **114** to the separate optical paths **115-1** to **115-*n*** to the ONUs **112-1** to **112-*n*** at the respective subscriber locations. The branching point **113** may include one or more passive coupling devices such as a splitter or optical multiplexer/demultiplexer. In one example, the ONUs **112-1** to **112-*n*** may be located about 20 km or less from the OLT **110**.

The WDM-PON **100** may also include additional nodes or network devices, such as Ethernet PON (EPON) or Gigabit PON (GPON) nodes or devices, coupled between the branching point **113** and ONUs **112-1** to **112-*n*** at different locations or premises. One application of the WDM-PON **100** is to provide fiber-to-the-home (FTTH) or fiber-to-the-premises (FTTP) capable of delivering voice, data, and/or video services across a common platform. In this application, the central office may be coupled to one or more sources or networks providing the voice, data and/or video.

In the WDM-PON **100**, different ONUs **112-1** to **112-*n*** may be assigned different channel wavelengths for transmitting and receiving optical signals. In one embodiment, the WDM-PON **100** may use different wavelength bands for transmission of downstream and upstream optical signals relative to the OLT **110** to avoid interference between the received signal and back reflected transmission signal on the same fiber. For example, the L-band (e.g., about 1565 to 1625 nm) may be used for downstream transmissions from the OLT **110** and the C-band (e.g., about 1530 to 1565 nm) may be used for upstream transmissions to the OLT **110**. The upstream and/or downstream channel wavelengths may generally correspond to the ITU grid. In one example, the upstream wavelengths may be aligned with the 100 GHz ITU grid and the downstream wavelengths may be slightly offset from the 100 GHz ITU grid.

The ONUs **112-1** to **112-*n*** may thus be assigned different channel wavelengths within the L-band and within the C-band. Transceivers or receivers located within the ONUs **112-1** to **112-*n*** may be configured to receive an optical signal on at least one channel wavelength in the L-band (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}). Transceivers or transmitters located within the ONUs **112-1** to **112-*n*** may be configured to transmit an optical signal on at least one channel wavelength in the C-band (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}). Other wavelengths and wavelength bands are also within the scope of the system and method described herein.

The branching point **113** may demultiplex a downstream WDM optical signal (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}) from the OLT **110** for transmission of the separate channel wavelengths to the respective ONUs **112-1** to **112-*n***. Alternatively, the branching point **113** may provide the downstream WDM optical signal to each of the ONUs **112-1** to **112-*n*** and each of the ONUs **112-1** to **112-*n*** separates and processes the assigned optical channel wavelength. The individual optical signals may be encrypted to prevent eavesdropping on optical channels not assigned to a particular ONU. The branching point **113** also combines or multiplexes the upstream optical signals from the respective ONUs **112-1** to **112-*n*** for transmission as an upstream WDM optical signal (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}) over the trunk optical path **114** to the OLT **110**.

One embodiment of the ONU **112-1** includes a laser **116**, such as a laser diode, for transmitting an optical signal at the assigned upstream channel wavelength (λ_{C1}) and a photodetector **118**, such as a photodiode, for receiving an optical signal at the assigned downstream channel wavelength (λ_{L1}). The laser **116** may include a tunable laser configured to be tuned to the assigned channel wavelength. This embodiment of the ONU **112-1** may also include a diplexer **117** coupled to the laser **116** and the photodetector **118** and a C+L band filter **119** coupled to the diplexer **117**, which allow the L-band channel wavelength (λ_{L1}) to be received by the ONU **112-1** and the C-band channel wavelength (λ_{C1}) to be transmitted by the ONU **112-1**.

The OLT **110** may be configured to generate multiple optical signals at different channel wavelengths (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}) and to combine the optical signals into the downstream WDM optical signal carried on the trunk optical fiber or path **114**. Each of the OLT multi-channel optical transceivers **102*a***, **102*b*** may include a multi-channel transmitter optical sub-assembly (TOSA) **120** for generating and combining the optical signals at the multiple channel wavelengths. The OLT **110** may also be configured to separate optical signals at different channel wavelengths (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}) from an upstream WDM optical signal carried on the trunk path **114** and to receive the separated optical signals. Each of the OLT multi-channel optical transceivers **102*a***, **102*b*** may thus include a multi-channel receiver optical sub-assembly (ROSA) **130** for separating and receiving the optical signals at multiple channel wavelengths.

One embodiment of the multi-channel TOSA **120** includes an array of lasers **122**, such as laser diodes, which may be modulated by respective RF data signals (TX_D**1** to TX_Dm) to generate the respective optical signals. The lasers **122** may be modulated using various modulation techniques including external modulation and direct modulation. An optical multiplexer **124**, such as an arrayed waveguide grating (AWG), combines the optical signals at the different respective downstream channel wavelengths (e.g., λ_{L1}, λ_{L2}, . . . λ_{Lm}). In some embodiments, the lasers **122** may be tunable lasers that generate the optical signals at the respective channel wavelengths. In other embodiments, the lasers **122** may generate optical signals over a band of channel wavelengths and filtering and/or multiplexing techniques may be used to produce the assigned channel wavelengths. In the illustrated embodiment, the OLT **110** further includes a multiplexer **104** for multiplexing the multiplexed optical signal from the multi-channel TOSA **120** in the multi-channel transceiver **102*a*** with a multiplexed optical signal from a multi-channel TOSA in the other multi-channel transceiver **102*b*** to produce the downstream aggregate WDM optical signal.

One embodiment of the multi-channel ROSA **130** includes a demultiplexer **132** for separating the respective upstream channel wavelengths (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}). An array of photodetectors **134**, such as photodiodes, detects the optical signals at the respective separated upstream channel wavelengths and provides the received data signals (RX_D**1** to RX_Dm). In the illustrated embodiment, the OLT **110** further includes a demultiplexer **106** for demultiplexing the upstream WDM optical signal into first and second WDM optical signals provided to the respective multi-channel ROSA in each of the transceivers **102*a***, **102*b***. The OLT also includes a diplexer **108** between the trunk path **114** and the multiplexer **104** and the demultiplexer **106** such that the trunk path **114** carries both the upstream and the downstream channel wavelengths. The transceivers **102*a***, **102*b*** may also include other components such as laser drivers, transimpedance amplifiers (TIAs), and control interfaces used for transmitting and receiving optical signals.

In one example, each of the multi-channel optical transceivers **102***a*, **102***b* may be configured to transmit and receive 16 channels such that the WDM-PON **100** supports **32** downstream L-band channel wavelengths and 32 upstream C-band channel wavelengths. In one example, the downstream L-band link between the OLT transceivers **102***a*, **102***b* and the ONUs **112-1** to **112-***n* may support a power budget of at least about 26 dB and the upstream C-band link between the ONUs **112-1** to **112-***n* and the OLT transceivers **102***a*, **102***b* may support a power budget of at least about 23 dB. One example of the WDM-PON **100** may operate at 1.25 Gbaud using 8B/10B encoded on-off keying as the modulation scheme. Other data rates and modulation schemes may also be used.

As mentioned above, the upstream and downstream channel wavelengths may span a range of channel wavelengths on the 100 GHz ITU grid. Each of the transceivers **102***a*, **102***b*, for example, may cover 16 channel wavelengths in the L-band for the TOSA and 16 channel wavelengths in the C-band for the ROSA such that the transceivers **102***a*, **102***b* together cover 32 channels. Thus, the multiplexer **104** may combine 16 channels from one transceiver **102***a* with 16 channels from the other transceiver **102***b*, and the demultiplexer **106** may separate a 32 channel WDM optical signal into two 16 channel WDM optical signals. To facilitate use of the multiplexer **104** and the demultiplexer **106**, the range of channel wavelengths may skip channels (e.g., 2 channels) in the middle of the range.

Referring to FIGS. **2** and **3**, one embodiment of a multi-channel optical transceiver module **202** is shown and described in greater detail. As discussed above, multiple multi-channel transceiver modules may be used in an OLT of a WDM-PON to cover a desired channel range. The transceiver module **202** may thus be designed to have a relatively small form factor with minimal space within the transceiver module **202**. The multi-channel optical transceiver module **202** generally provides an optical input and output at one end **204** and electrical input and output at another end **206**. The transceiver module **202** includes a transceiver housing **210** containing a multi-channel TOSA **220**, a multi-channel ROSA **230**, and a dual fiber type direct link adapter **250** directly linked to the TOSA **220** and the ROSA **230** for providing the optical input and output.

The dual fiber type direct link adapter **250** is coupled to the TOSA **220** and to the ROSA **230** with respective optical fibers **222**, **232** to provide the direct link between the adapter **250** and both the TOSA **220** and the ROSA **230**. The dual fiber type direct link adapter **250** is also configured to receive pluggable optical connectors **320**, **330**, such as LC connectors, which terminate fiber optic cables **322**, **332**. When the optical connectors **320**, **330** are plugged into the dual fiber type direct link adapter **250**, the adapter **250** establishes an optical coupling between the TOSA **220** and the ROSA **230** and the respective optical fibers in the fiber-optic cables **322**, **332**, which carry the optical signals to and from the transceiver.

The dual fiber type direct link adapter **250** has a direct link end **252** mechanically coupled to the optical fibers **222**, **232** and a pluggable connector end **254** configured to receive the pluggable optical connectors **320**, **330**. The direct link end **252** of the dual fiber type direct link adapter **250** is located inside the transceiver housing **210** and the pluggable connector end **254** faces outside of the transceiver housing **210**. The illustrated embodiment of the dual fiber type direct link adapter **250** also includes one or more flanges **256** or other structures that engage the transceiver housing **210** and secure the adapter **250** within the housing **210**.

The transceiver module **202** may also include one or more printed circuit boards **208** coupled to the TOSA **220** and/or ROSA **230**. The printed circuit board(s) **208** may include electronic components such as laser drivers, transimpedance amplifiers (TIAs), and control interfaces. The TOSA **220** is coupled to conductive leads **224** for carrying the electronic signals including the data to be transmitted by the TOSA **220**. The ROSA **230** is coupled to the conductive leads **234** for carrying the electronic signals including the data received by the ROSA **230**.

A top housing portion **212** encloses the TOSA **220**, the ROSA **230**, the adapter **250**, the optical fibers **222**, **232**, and other components within the housing **210**. The transceiver housing **210** may have a width of less than about 55 mm, a length of less than about 130 mm, and a height of less than about 10 mm. To fit within this transceiver housing **210**, the dual fiber type direct link adapter **250** may have a length from the direct link end **252** to the pluggable connector end **254** of less than about 30 mm. More specifically, one example of a transceiver housing **210** may have a width of 54.6 mm, a length of 110 mm, and a height of about 9.8 mm, and the direct link adapter **250** has a length of about 28 mm. A pull tab **214** may be coupled to the transceiver housing **210** to facilitate handling of the transceiver **202**.

Referring to FIGS. **4-7**, the dual fiber type direct link adapter **250** is described in greater detail. In the illustrated embodiment, the dual fiber type direct link adapter **250** includes an adapter body portion **260** defining first and second connector receiving regions **262**, **264** at the pluggable connector end **254** and defining first and second slots **266**, **268** at the direct link end **252**. The first and second connector receiving regions **262**, **264** are configured to receive the respective pluggable optical connectors **320**, **330**, such as LC connectors. The first and second slots **266**, **268** are configured to receive respective direct link connector assemblies **270**, **272**, which are mechanically coupled to optical fibers (not shown) directly linking the TOSA and ROSA (not shown). An adapter cover portion **261** covers the slots **266**, **268** and retains the direct link connector assemblies **266**, **268**. The direct link connector assemblies **270**, **272** also include flange portions **274**, **276** (shown in FIG. **7**) that extend into receiving grooves **267**, **269** in the respective slots **266**, **268** to prevent axial movement and hold the direct link connector assemblies in the slots.

In one embodiment, the dual fiber type direct link adapter **250** is configured to mechanically and optically connect to an LC type optical connector. In other embodiments, the dual fiber type direct link adapter **250** may be configured to connect with other types of pluggable optical connectors. The optical connectors **320**, **330** may be mechanically engaged with the dual fiber type direct link adapter **250** when plugged to maintain the optical coupling. The connector **330** includes, for example, a latch **334** that engages a corresponding portion within the adapter body portion **260**.

One end of each of the direct link connector assemblies **270**, **272** is mechanically coupled to the optical fibers to provide the direct link to the TOSA and ROSA, as described above. The other end of each of the direct link connector assemblies **270**, **272** defines a connector receptacle that extends into the respective connector receiving region **262**, **264** defined by the adapter body portion **260**, as described in greater detail below.

FIG. **8** shows the direct link connector assembly **270/271** in greater detail. In this illustrated embodiment, the direct link connector assembly **270** includes an outer housing formed by first and second outer housing portions **280**, **282** around a sleeve **284**, which receives a fiber ferrule **286**. A respective one of the optical fibers (not shown) may pass through an opening **281** in the first housing portion **280** and into the fiber ferrule **286**. The optical fiber may be secured to the fiber ferrule **286** such that an end face of the optical fiber is located at an optical coupling end **287** of the fiber ferrule **286**. The second housing portion **282** and the sleeve **284** define a connector receptacle **285** at the connector coupling end, which receives a fiber ferrule of a pluggable optical connector (not shown) through an opening **283**.

FIGS. **9** and **10** illustrate the connection of a pluggable optical connector **320** (e.g., an LC connector) to the dual fiber type direct link adapter **250**. As shown in FIG. **9** and described above, the direct link connector assembly **270** defines a connector receptacle **285** that extends into the connector receiving region **262**. The direct link optical fiber **236** extends into the connector assembly **270** and is secured to the fiber ferrule **286** with an end face of the optical fiber **236** exposed for optical coupling. The pluggable optical connector **320** includes a fiber ferrule **326** extending from one end. The optical fiber **328** in the fiber-optic cable **322** coupled to the optical connector **320** extends into the connector **320** and is secured to the fiber ferrule **286** with an end face of the optical fiber **328** exposed for optical coupling.

As shown in FIG. **10**, when the optical connector **320** is plugged into the dual fiber type direct link adapter **250**, the connector fiber ferrule **326** extends into the connector receptacle **285** and contacts the adapter fiber ferrule **286** such that optical coupling is established between the optical fibers **328**, **236**. In the illustrated embodiment, the pluggable optical connector **320** is an LC type optical connector and the connector assembly **270** (and connector receptacle **285**) is configured to mate with an LC type optical connector.

Accordingly, a dual fiber type direct link adapter, consistent with embodiments described herein, allows connection to a pluggable optical connector, such as an LC connector, while providing a direct optical link to both the TOSA and ROSA in a multi-channel optical transceiver. The direct link connection reduces the size of the adapter and allows a smaller transceiver module with a pluggable optical input and output.

Consistent with an embodiment, a multi-channel transceiver module includes a transceiver housing, a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths, and a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. A dual fiber type direct link adapter is located inside the transceiver housing and at one side of the transceiver housing. The dual fiber type direct link adapter has a direct link end located in the transceiver housing and a pluggable connector end facing outside of the transceiver housing. The direct link end of the dual fiber type direct link adapter is coupled to the TOSA with a first optical fiber and coupled to the ROSA with a second optical fiber to provide a direct link between the dual fiber type direct link adapter and the TOSA and the ROSA. The pluggable connector end is configured to receive first and second pluggable optical connectors for optically coupling the TOSA and the ROSA to external optical fibers.

Consistent with another embodiment, a dual fiber type direct link LC adapter includes an adapter body portion defining first and second LC connector receiving regions at an pluggable connector end and defining first and second slots at a direct link end. The dual fiber type direct link LC adapter includes also includes first and second direct link connector assemblies configured to be received in the first and second slots, respectively. Each of the direct link connector assemblies defines an LC connector receptacle at one end. The LC connector receptacle extends into a respective one of the LC connector receiving regions and is configured to receive a portion of an LC connector for optical coupling. Each of the direct link connector assemblies is configured to be mechanically coupled to an optical fiber at another end. The dual fiber type direct link LC adapter further includes an adapter cover portion configured to cover the first and second slots for retaining the direct link connector assemblies in the respective slots.

Consistent with a further embodiment, an optical line terminal comprises at least first and second multi-channel transceivers. Each of the multi-channel transceivers includes a transceiver housing, a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths, and a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. A dual fiber type direct link adapter is located inside the transceiver housing and at one side of the transceiver housing. The dual fiber type direct link adapter has a direct link end located in the transceiver housing and a pluggable connector end facing outside of the transceiver housing. The direct link end of the dual fiber type direct link adapter is coupled to the TOSA with a first optical fiber and coupled to the ROSA with a second optical fiber to provide a direct link between the dual fiber type direct link adapter and the TOSA and the ROSA. The pluggable connector end is configured to receive first and second pluggable optical connectors for optically coupling the TOSA and the ROSA to external optical fibers.

While the principles of the invention have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the invention. Other embodiments are contemplated within the scope of the present invention in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present invention, which is not to be limited except by the following claims.

What is claimed is:

1. A multi-channel transceiver module comprising:

a transceiver housing;

a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing, the TOSA being configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths;

a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing, the ROSA being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths; and

a dual fiber type direct link adapter located inside the transceiver housing and at one side of the transceiver housing, the dual fiber type direct link adapter having a direct link end located in the transceiver housing and a pluggable connector end facing outside of the transceiver housing, the direct link end of the dual fiber type direct link adapter being coupled to the TOSA with a first optical fiber and coupled to the ROSA with a second optical fiber to provide a direct link between the dual fiber type direct link adapter and the TOSA and the ROSA, the pluggable connector end being configured to receive first and second pluggable optical connectors for optically coupling the TOSA and the ROSA to external optical fibers, wherein the dual fiber type direct link adapter comprises:

an adapter body portion defining first and second slots, each of the first and second slots including at least one groove;

first and second direct link connector assemblies received in the first and second slots, respectively, of the adapter body portion, each of the first and second direct link connector assemblies including at least one flange extending into the groove in the first and second slots, respectively, to prevent axial movement of the first and second direct link connector assemblies, wherein one end of each of the direct link connector assemblies defines a connector receptacle configured to receive a portion of the optical connector for optical coupling, and wherein another end of each of the connector assemblies is directly linked to a respective optical fiber; and

an adapter cover portion covering the first and second slots and retaining the first and second direct link connector assemblies in the first and second slots, respectively.

2. The multi-channel transceiver module of claim **1** wherein the dual fiber type direct link adapter is a dual fiber type direct link LC adapter including an LC connector end configured to receive first and second LC connectors.

3. The multi-channel transceiver module of claim **1** wherein a length of the dual fiber type direct link adapter from the direct link end to the pluggable connector end is less than 30 mm.

4. The multi-channel transceiver module of claim **1** wherein a length of the transceiver housing is less than 130 mm, and a width of the transceiver housing is less than 55 mm.

5. The multi-channel transceiver module of claim **1** wherein each of the direct link connector assemblies comprises a fiber ferrule receiving a respective one of the optical fibers and a sleeve around the fiber ferrule, and wherein the sleeve defines at least a portion of the connector receptacle.

6. The multi-channel transceiver module of claim **1** wherein each of the direct link connector assemblies further comprises an outer housing around the fiber ferrule and sleeve, the outer housing defining at least a portion of the connector receptacle and including the flange portion for securing the direct link connector assembly.

7. The multi-channel transceiver module of claim **1** wherein the connector receptacle is configured to mate with an LC connector.

8. The multi-channel transceiver module of claim **1** wherein the dual fiber type direct link adapter defines first and second connector receiving regions configured to receive respective first and second pluggable optical connectors, and wherein the connector receptacles extend into the connector receiving regions.

9. An optical line terminal comprising:

at least first and second multi-channel transceivers, each of the multi-channel transceivers comprising:

a transceiver housing;

a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing, the TOSA being configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths;

a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing, the ROSA being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths; and

a dual fiber type direct link adapter located inside the transceiver housing and at one side of the transceiver housing, the dual fiber type direct link adapter having a direct link end located in the transceiver housing and a pluggable connector end facing outside of the transceiver housing, the direct link end of the dual fiber type direct link adapter being coupled to the TOSA with a first optical fiber and coupled to the ROSA with a second optical fiber to provide a direct link between the dual fiber type direct link adapter and the TOSA and the ROSA, the pluggable connector end being configured to receive first and second pluggable optical connectors for optically coupling the TOSA and the ROSA to external optical fibers, wherein the dual fiber type direct link adapter comprises:

an adapter body portion defining first and second slots, each of the first and second slots including at least one groove;

first and second direct link connector assemblies received in the first and second slots, respectively, of the adapter body portion, each of the first and second direct link connector assemblies including at least one flange extending into the groove in the first and second slots, respectively, to prevent axial movement of the first and second direct link connector assemblies, wherein one end of each of the direct link connector assemblies defines a connector receptacle configured to receive a portion of the optical connector for optical coupling, and wherein another end of each of the connector assemblies is directly linked to a respective optical fiber; and

an adapter cover portion covering the first and second slots and retaining the first and second direct link connector assemblies in the first and second slots, respectively.

10. The optical line terminal of claim **9** wherein the dual fiber type direct link adapter is a dual fiber type direct link LC adapter including an LC connector end configured to receive first and second LC connectors.

11. The optical line terminal of claim **9** wherein the wherein a length of the dual fiber type direct link adapter from the direct link end to the pluggable connector end is less than 30 mm.

12. The optical line terminal of claim **9** wherein each of the direct link connector assemblies comprises a fiber ferrule receiving a respective one of the optical fibers and a sleeve around the fiber ferrule, and wherein the sleeve defines at least a portion of the connector receptacle.

* * * * *

EXHIBIT D

US010042116B2

(12) **United States Patent**
Ho et al.

(10) **Patent No.: US 10,042,116 B2**
(45) **Date of Patent: Aug. 7, 2018**

(54) **TECHNIQUES FOR DIRECT OPTICAL COUPLING OF PHOTODETECTORS TO OPTICAL DEMULTIPLEXER OUTPUTS AND AN OPTICAL TRANSCEIVER USING THE SAME**

(71) Applicant: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(72) Inventors: **I-Lung Ho**, Sugar Land, TX (US); **Zhengyu Miao**, Sugar Land, TX (US); **Qin Li**, Houston, TX (US)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/137,823**

(22) Filed: **Apr. 25, 2016**

(65) **Prior Publication Data**

US 2017/0307819 A1 Oct. 26, 2017

(51) **Int. Cl.**
H04J 14/02 (2006.01)
G02B 6/12 (2006.01)
G02B 6/42 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/12016*** (2013.01); ***G02B 6/12011*** (2013.01); ***G02B 6/12019*** (2013.01); ***G02B 6/4246*** (2013.01); ***G02B 6/4292*** (2013.01); ***H04J 14/02*** (2013.01)

(58) **Field of Classification Search**
CPC H04J 14/02; H04J 14/0282; H04J 14/0221; H04J 14/0202; H04B 10/40; H04B 10/506; H04B 10/503; H04B 10/504; G02B 6/4246; G02B 6/4293; G02B 6/4249
USPC 398/135, 136, 137, 138, 139, 79, 82, 398/158.159, 85, 87, 84, 202, 208, 213, 398/214; 385/24, 37, 14, 43
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,617,234 A	4/1997	Koga et al.	
7,058,263 B2 *	6/2006	Welch	B82Y 20/00 385/24
7,162,124 B1	1/2007	Gunn, III et al.	

(Continued)

OTHER PUBLICATIONS

U.S. Office Action dated Apr. 13, 2018, received in U.S. Appl. No. 15/432,242, 28 pgs.

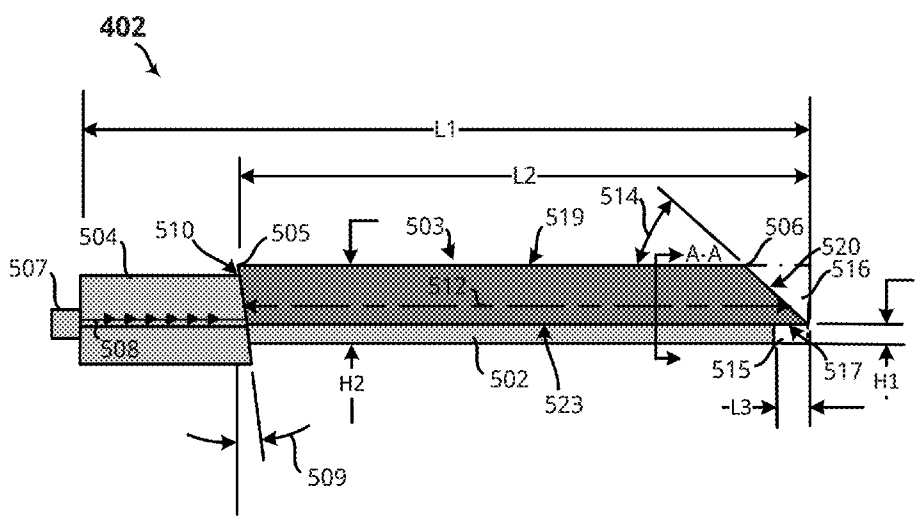
(Continued)

Primary Examiner — Hanh Phan
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

An arrayed waveguide grating (AWG) device for use in an optical transceiver is disclosed, and can de-multiplex an optical signal into N number of channel wavelengths. The AWG device can include an AWG chip, with the AWG chip providing a planar lightwave (PLC) circuit configured to de-multiplex channel wavelengths and launch the same into output waveguides. A region of the AWG chip may be tapered such that light traveling via the output waveguides encounters an angled surface of the tapered region and reflects towards an output interface region of the AWG chip. Thus detector devices may optically couple to the output interface region of the AWG chip directly, and can avoid losses introduced by other approaches which couple an output of an AWG to detectors by way of a fiber array or other intermediate device.

19 Claims, 7 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

7,376,308	B2	5/2008	Cheben et al.	
7,532,783	B2 *	5/2009	Bai	G02B 6/12019 385/14
7,941,053	B2 *	5/2011	Dallesasse	H04B 10/40 398/135
8,831,433	B2	9/2014	Ho et al.	
9,341,786	B1	5/2016	Gamache et al.	
2003/0174964	A1	9/2003	Gao et al.	
2004/0161186	A1	8/2004	Crafts et al.	
2015/0249501	A1 *	9/2015	Nagarajan	H04B 10/40 398/79
2016/0149662	A1	5/2016	Soldano et al.	
2016/0349451	A1	12/2016	Shen et al.	
2017/0168252	A1	6/2017	Pezeshki et al.	

OTHER PUBLICATIONS

PCT Search Report and Written Opinion dated Jul. 6, 2017, received in corresponding PCT Application No. PCT/US17/29350, 9 pgs.
U.S. Office Action dated Aug. 29, 2017, received in U.S. Appl. No. 15/432,242, 15 pgs.

* cited by examiner

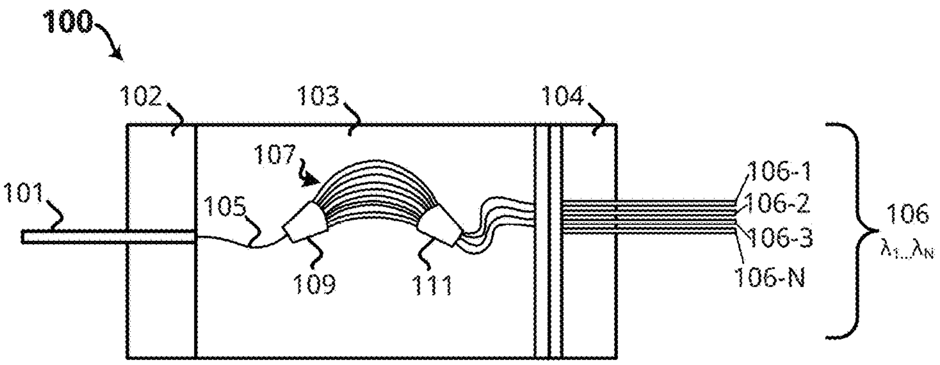

100
102
103
104
107
101
105
106-1
106-2
106-3
106-N
106
λ1...λN
109
111

FIG. 1

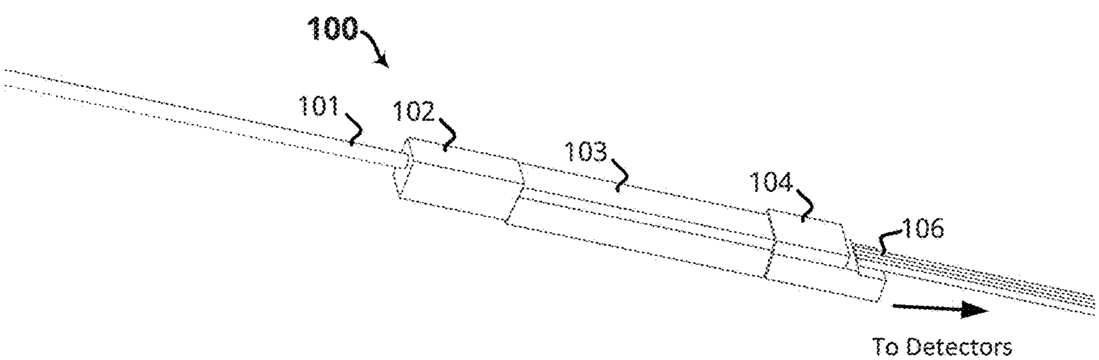

100
101
102
103
104
106
To Detectors

FIG. 2

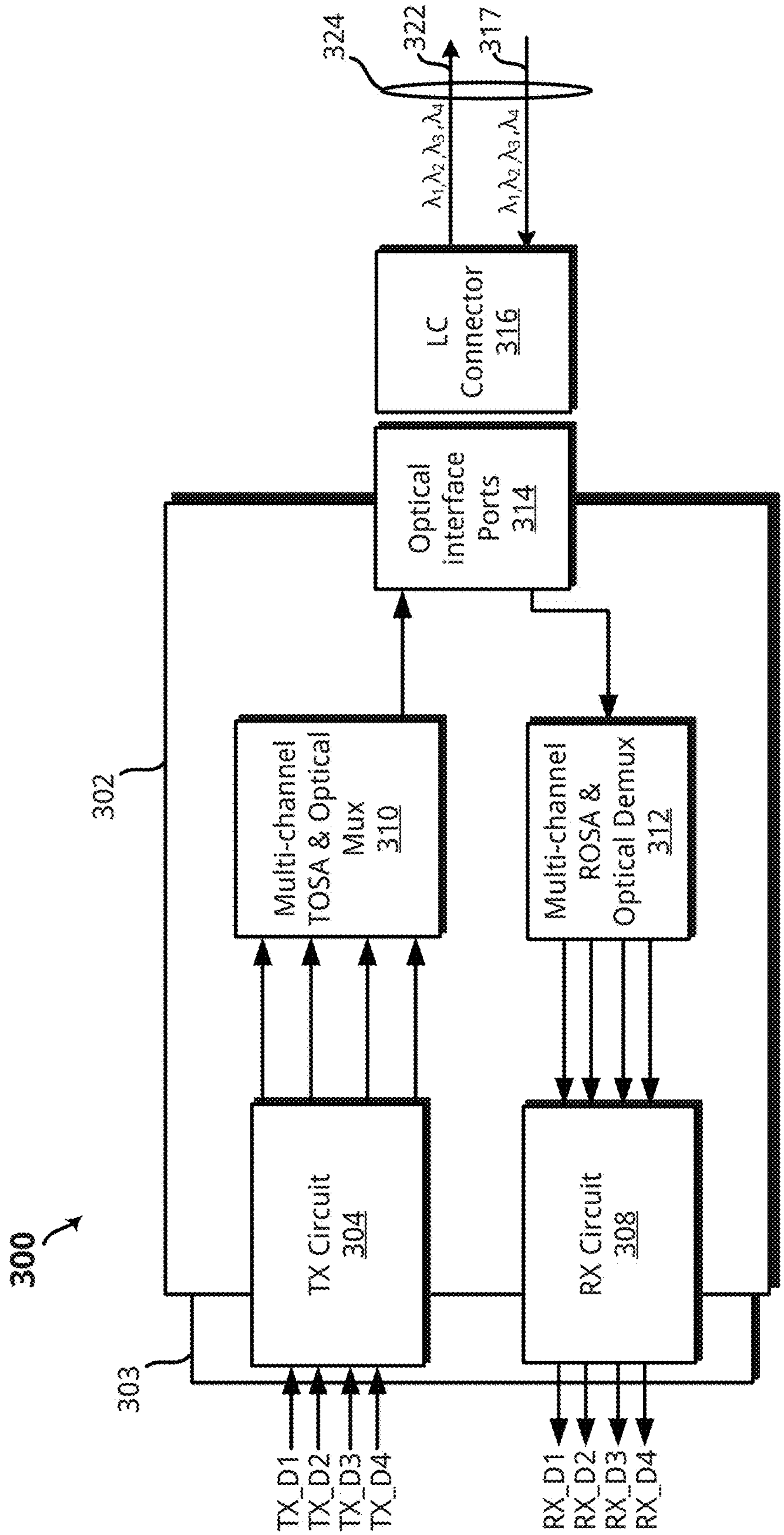

300
302
303
324
322
317
$\lambda_1,\lambda_2,\lambda_3,\lambda_4$
$\lambda_1,\lambda_2,\lambda_3,\lambda_4$
LC Connector 316
Optical interface Ports 314
Multi-channel TOSA & Optical Mux 310
Multi-channel ROSA & Optical Demux 312
TX Circuit 304
RX Circuit 308
TX_D1
TX_D2
TX_D3
TX_D4
RX_D1
RX_D2
RX_D3
RX_D4

FIG. 3

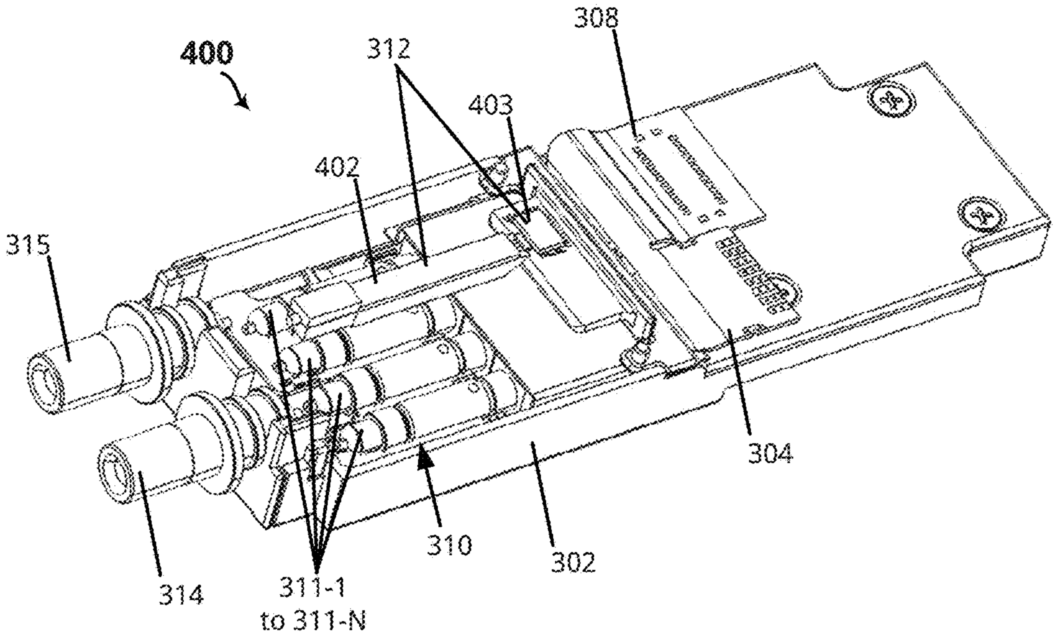


FIG. 4

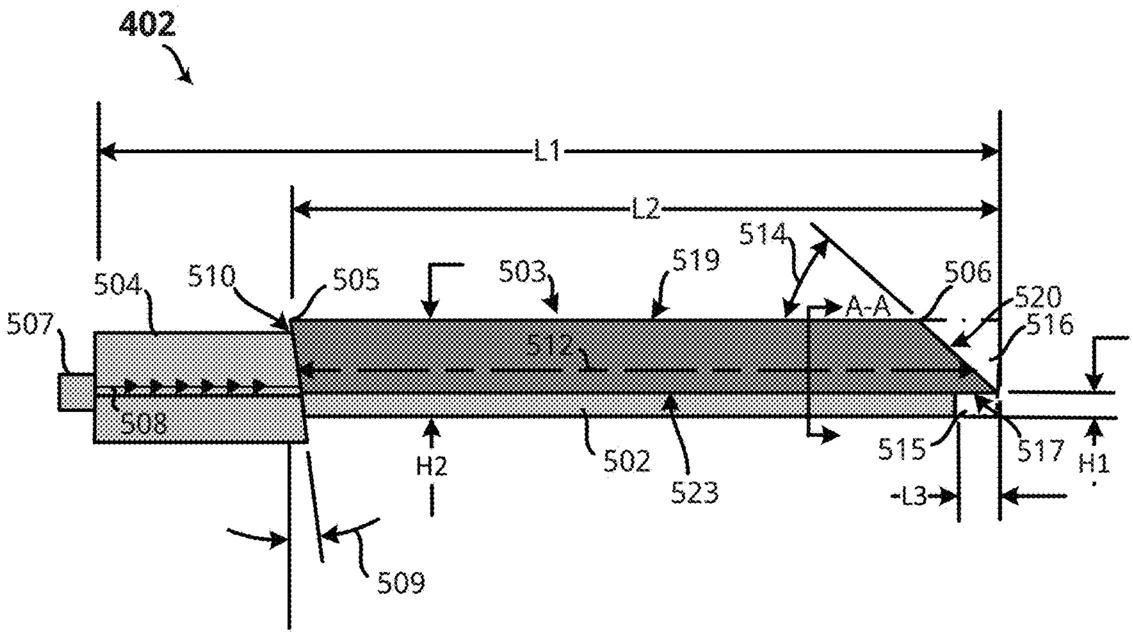

402
L1
L2
514
519
503
506
504
510
505
520
507
A-A
516
512
508
H2
502
523
515
517
H1
L3
509

FIG. 5A

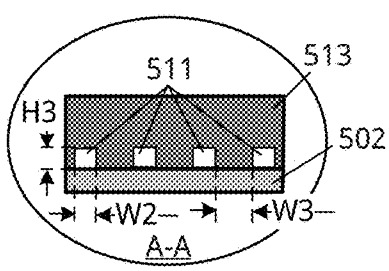

511
513
H3
502
W2
W3
A-A

FIG. 5B

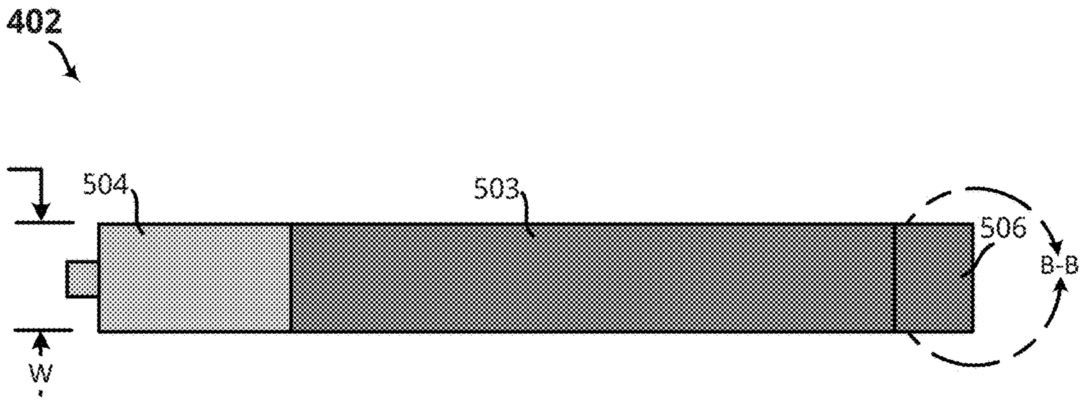


FIG. 6

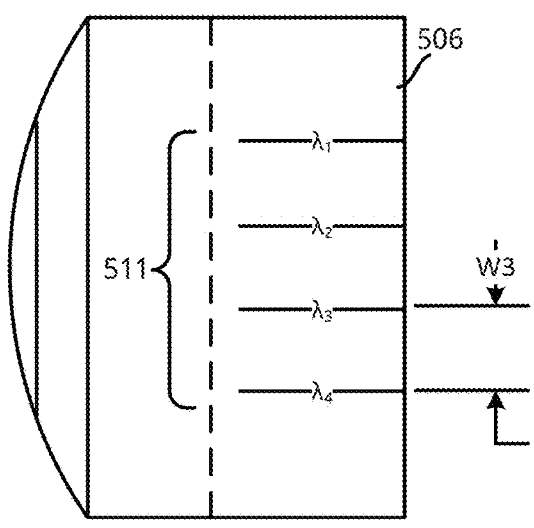


FIG. 7

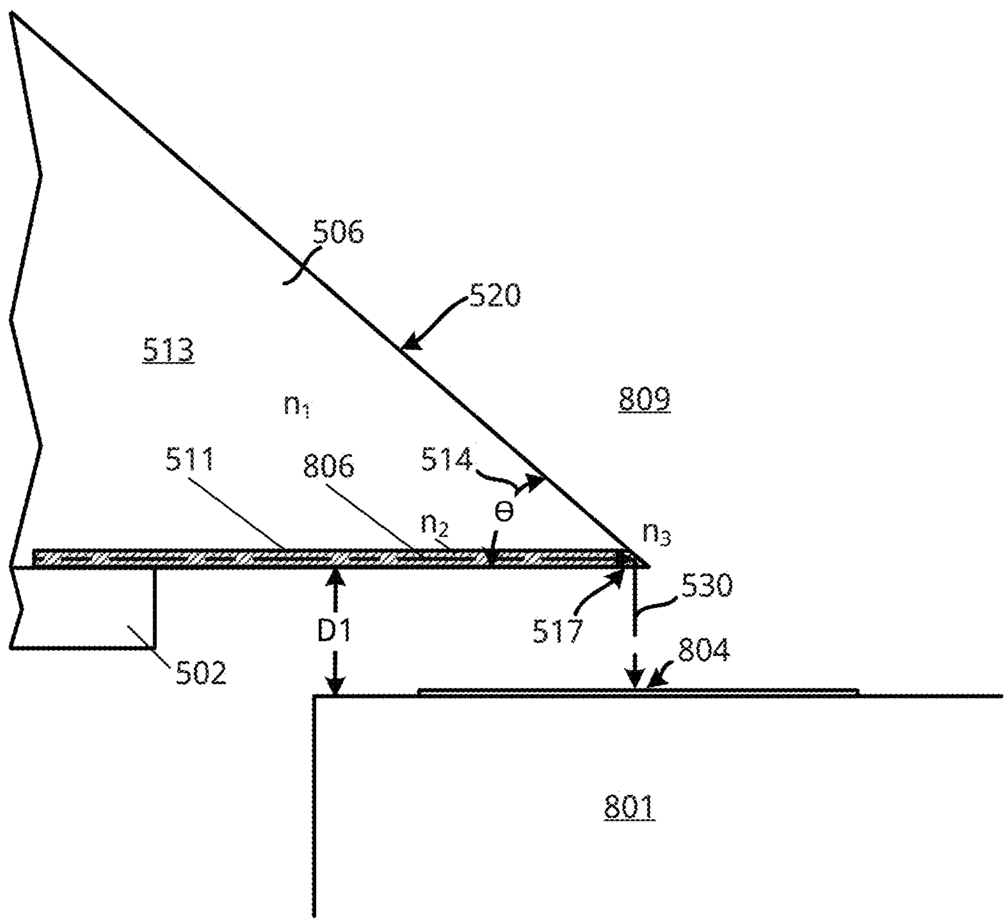


FIG. 8

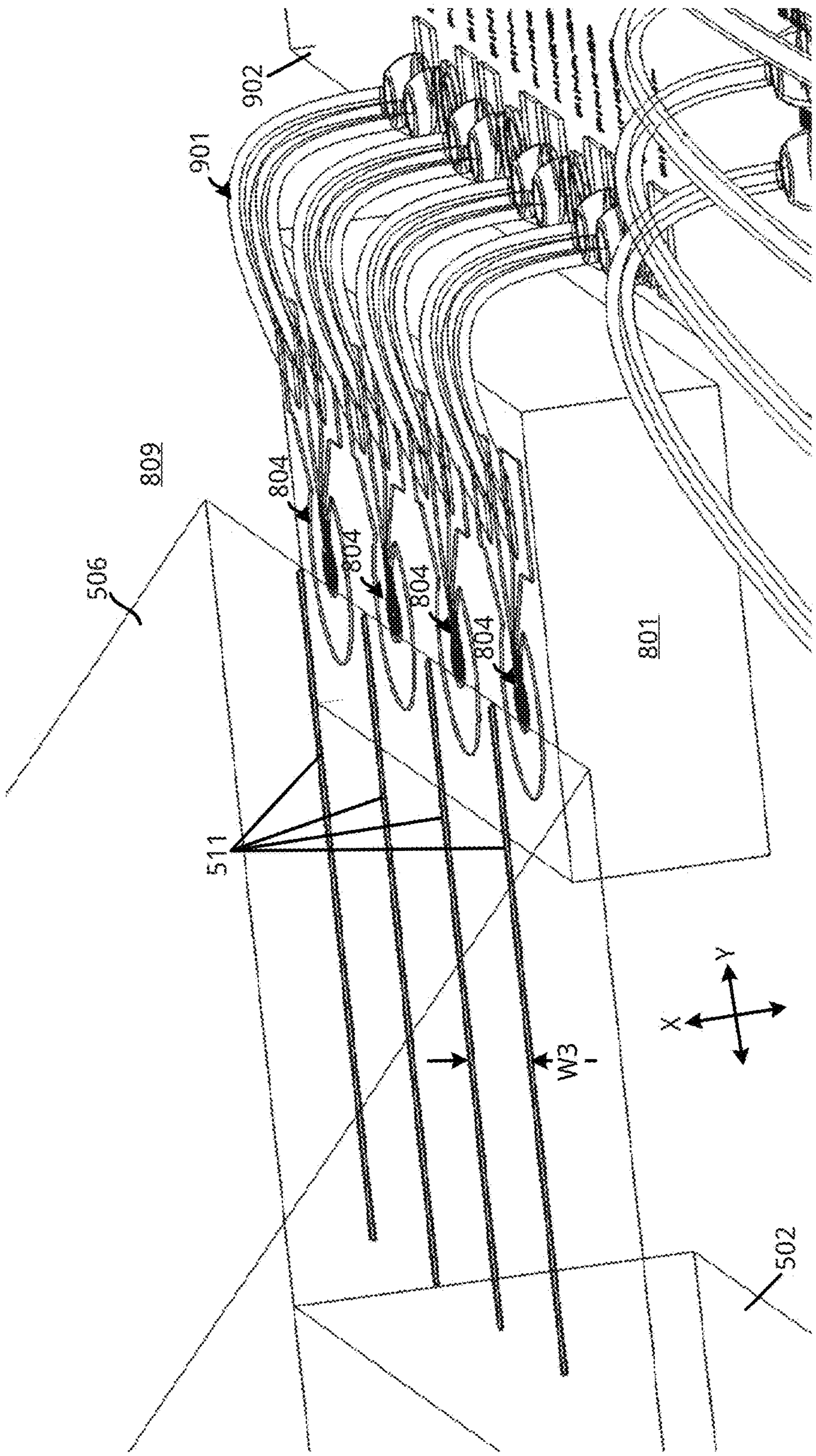


FIG. 9

TECHNIQUES FOR DIRECT OPTICAL COUPLING OF PHOTODETECTORS TO OPTICAL DEMULTIPLEXER OUTPUTS AND AN OPTICAL TRANSCEIVER USING THE SAME

TECHNICAL FIELD

The present disclosure relates to optical transceiver modules, and more particularly, to direct optical coupling of photodetectors to optical demultiplexer outputs to reduce fiber use and insertion loss.

BACKGROUND INFORMATION

Optical transceivers are used to transmit and receive optical signals for various applications including, without limitation, internet data centers, cable TV broadband, and fiber to the home (FTTH) applications. Optical transceivers provide higher speeds and bandwidth over longer distances, for example, as compared to transmission over copper cables. The desire to provide higher speeds in smaller optical transceiver modules for a lower cost has presented challenges, for example, with respect to maintaining optical efficiency (power), thermal management, insertion loss, and manufacturing yield. Optical transceivers can include one or more transmitter optical subassemblies (TOSAs) and receiver optical subassemblies (ROSAs) for the purpose of transmitting and receiving optical signals. As channel density becomes an increasingly important aspect of optical transceivers, the ability scale-down while maintaining nominal transceiver performance raises numerous non-trivial challenges.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** is a schematic diagram of an example arrayed waveguide grating (AWG) device.

FIG. **2** is a perspective view of the AWG device of FIG. **1** with an output coupled to a fiber array.

FIG. **3** schematically illustrates an embodiment of an optical transceiver module including a multi-channel transmitter optical sub-assembly (TOSA) and multi-channel receiver optical sub-assembly (ROSA).

FIG. **4** is a perspective view of an example small form-factor (SFF) pluggable transceiver with a multi-channel TOSA configuration and a multi-channel ROSA having a direct-coupling arrayed waveguide grating (AWG) device, in accordance with an embodiment of the present disclosure.

FIG. **5**A shows a side plan view of the AWG device of FIG. **4**, in accordance with an embodiment of the present disclosure.

FIG. **5**B shows a cross-sectional view of the AWG device of FIG. **5**A taken along the line A-A, in accordance with an embodiment of the present disclosure.

FIG. **6** shows an top plan view of the AWG device of FIG. **4**, in accordance with an embodiment of the present disclosure.

FIG. **7** shows an enlarged detail view of the AWG device of FIG. **6** taken along the line B-B, in accordance with an embodiment of the present disclosure.

FIG. **8** shows an enlarged view of a direct coupling end of the AWG device of FIG. **4**, in accordance with an embodiment of the present disclosure.

FIG. **9** shows a perspective view of the direct coupling end of the AWG device of FIG. **4**, in accordance with an embodiment of the present disclosure.

These and other features of the present embodiments will be understood better by reading the following detailed description, taken together with the figures herein described. The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing.

DETAILED DESCRIPTION

As discussed above, optical transceivers can include receiver optical subassemblies (ROSAs) that are configured to receive multiple channel wavelengths via a common fiber and de-multiplex the same for detection, amplification and conversion purposes. Some approaches to ROSAs include the use of an arrayed waveguide grating (AWG), which operate based on some underlying principles of optics that recognize light waves of different wavelengths interfere linearly with each other. This fundamental principle manifests itself in WDM signaling, which allows a plurality of channel wavelengths to be carried by a single optical fiber with negligible crosstalk between channels. AWGs can both multiplex and de-multiplex a WDM signal.

A schematic of one example AWG device **100** configured to multiplex/de-multiplex WDM signals is shown in FIG. **1**. The AWG device **100** may be a silica-based AWG device fabricated using planar lightwave circuit (PLC) techniques, which are similar to semiconductor processes used to produce ICs and can include depositing doped and un-doped layers of silica on a substrate, such as silicon. The AWG device **100** includes an input coupling region **102** to couple to the fiber **101**, an AWG chip region **103** or circuit for de-multiplexing channel wavelengths, and an output coupling region **104** for coupling to a fiber array **106**, with each fiber **106-1** to **106-4** being configured to receive different channel wavelengths. The AWG chip region **103** includes of an array of waveguides **107** (also called a phased array) and two couplers **109** and **111**. An input waveguide, e.g., waveguide **105**, carries an optical signal consisting of multiple wavelengths λ_1-λ_n into the first input coupler **109**, which then distributes the light amongst an array of waveguides. The light subsequently propagates through the array of waveguides **107** to the second output coupler **111**. The length of each of the waveguides **107** is chosen so that the optical path length difference between adjacent waveguides (dL) equals an integer multiple of the central wavelength λ_c of the demultiplexer. Linearly increasing length of the array waveguides **107** will cause interference and diffraction when light mixes in the output coupler **111**. As a result, each wavelength is focused into only one of the N output waveguides **106-1** to **106**-N, which may also be called output channels.

The particular configuration illustrated in FIG. **1** is a 1×4 PLC demultiplexer (or demux), but other channel configurations, e.g., 1×8, 1×16, 2×8, 2×16, etc., should be apparent in light of this disclosure. PLC-type demuxes can provide relatively low insertion loss, low polarization dependent loss (PDL) and function within a range of operating temperatures. FIG. **2** shows one example packaging of the AWG device **100**. As shown, the AWG device **100** includes the output coupling region **104** coupled to the fiber array **106**, with the fiber array **106** being coupled to detector devices such as photodiodes (not shown).

In use, a multiplexed optical signal (e.g., a WDM) may be received via the input fiber **101** and split into separate channel wavelengths via, for example, waveguides **107** of the AWG circuit **103**. The AWG device **100** may then launch the separated channel wavelengths into respective fibers **106-1** to **106**-N of the fiber array **106**. The AWG device **100** can introduce an insertion loss of about 3 to 7 db based on, for example, the optical coupling between the optical fiber **101** and the input coupling region **102**, and by virtue of the AWG circuit **103** itself. At an output end, additional loss can be introduced based on the optical coupling between the output coupling region **104** and the fiber array **106**. While the fiber array **106** can include a 45 degree cut to reduce back-reflection and insertion loss, the overall insertion loss introduced can be about 0.5 to 1.0 db, if not greater. Likewise, the optical coupling between the fiber array **106** and detector devices (not shown) can further introduce insertion loss of about 0.5 to 1.0 db. Thus the overall insertion loss introduced by use of the fiber array **106** can total about 1.0 to 2.0 db, which can significantly reduce sensitivity of the ROSA device and consequently reduce overall transceiver performance.

Thus, in accordance with an embodiment, a direct-coupling AWG device is disclosed that provides direct coupling between output channels of the AWG device and detector devices without the necessity of an intermediate fiber or other physical device. The direct-coupling AWG device may be used in combination with detectors and associated circuitry and can comprise a receiver optical subassembly (ROSA) for use in an optical transceiver device, or other optical device that seeks to de-multiplex optical WDM signals.

In more detail, the direct-coupling AWG device may be formed using, for example, PLC techniques or other suitable formation processes. In an embodiment, the AWG device is formed on a substrate such as a silicon wafer or any other suitable substrate, and may include depositing sequential layers of cladding and core material thereon. In an embodiment, the cladding layer may comprise silicon (Si) and the core material may comprise silicon dioxide (SiO_2), also known as Silica. However, other cladding and core materials may be used and are also within the scope of this disclosure. The formed AWG device may then form essentially a monolithic structure and provide a PLC configured to de-multiplex a WDM signal into multiple different channel wavelengths for output to associated detectors. The formed AWG device can include a plurality of sidewalls that extend longitudinally from a first end to a second end, with the plurality of sidewalls being formed at least in part by the cladding material. The first end of the AWG device may be configured to optically couple with an input fiber, and a portion proximal to the second end of the AWG device may be configured to optically couple with a plurality of detector devices. Thus, and for the purpose of reference, the first end may be generally understood to be an input coupling end and the second end may be generally understood as providing an output coupling region.

The input coupling end of the AWG device may be coupled to, for example, an LC connector receptacle or other suitable connector receptacle. The connector receptacle may be coupled to the AWG device by, for example, an adhesive or other suitable approach. The input end may be configured with a surface that is angled at about 8 degrees for the purposes of reducing back reflection of an optical signal launched into the AWG device by an associated input fiber.

The output coupling region of the AWG device can include output waveguides or output channels comprising core materials that are configured to substantially confine light, e.g., at least 80 percent of incident light, along a first light path that extends longitudinally towards a substantially reflective surface. The substantially reflective surface may be provided by a portion of the output coupling end that includes a tapered region. As generally referred to herein, the term substantially reflective refers to a surface capable of reflecting at least 80 percent of incident light. The tapered region may be formed by cutting away and polishing a portion of the AWG chip such that an angled surface is formed, although other approaches to providing the tapered region will be apparent. The core material may have an index of refraction different from that of the medium adjacent to the AWG chip, such as air. Thus, and in accordance with Snell's law, light traveling via the longitudinal path provided by the output waveguides can encounter the angled surface and substantially reflect along a second light path, with the second light path being generally orthogonal to the first light path. The particular amount of light reflected by the angled surface can be about 80% or more. Light along the second light path can encounter a sidewall of the AWG chip and be emitted therefrom towards detector devices. The surface of the sidewall region that emits the light away from the AWG device may be accurately described as an output interface or a direct coupling interface.

Detector devices such as a photodiode may be disposed in a manner that aligns light-sensitive regions of the same with the direct coupling interface of the AWG device. A detector device may be provided for each channel output such that each channel wavelength is received and detected by an associated detector. Each detector device may be configured to detect channel wavelengths and provide the same to associated circuitry for amplification and conversion to electrical signaling. The detector devices may be disposed a distance D from the direct coupling interface of the AWG device in order to reduce the potential of damage to the detector devices and/or the AWG device when, for example, shifting/moving the ROSA components during active alignment procedures. Active alignment procedures can be conducted during manufacturing by providing a test WDM signal into the AWG device and monitoring the optical power of the signals received by the detectors, moving components (e.g., the AWG device and/or the detectors) and retesting. Thus the potential for damage may be reduced by providing a small gap between the AWG device and detector devices. In some cases, a material such as a gel may be inserted between the AWG device and detector devices. The index of refraction for the material may be about 1.0 or other suitable index that allows light to pass into the detector devices. In other cases, the detector devices may be disposed directly on the surface of the AWG chip forming the direct coupling interface.

Thus, numerous advantages to the direct-coupling AWG device will be apparent in light of this disclosure. For example, the insertion losses associated with coupling a fiber array to an output end of the AWG device can be eliminated. Consequently, the insertion loss associated with coupling the fiber array to associated detectors devices may also be eliminated. Thus, overall insertion loss may be reduced by at least 1 db to 2 db. To this end, the overall performance of the ROSA improves as the sensitivity of the ROSA is increased by the same amount, e.g., 1 db to 2 db. In addition, the overall length of the AWG device can be reduced as the direct coupling interface of the AWG allows detector devices to be positioned beside the AWG device versus a fiber array such as a pigtail that extends from an end of the AWG device. This reduction in length is particularly important when designing AWG devices for highly-constrained housings, e.g., small form-factor configurations.

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid or course wavelength division multiplexing (CWDM).

The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals. Likewise, the term "directly coupled" or "directly optically coupled" as used herein refers any optical connection that allows light to be imparted from one element to another without the use of an intermediate device such as a fiber.

Example Optical Transceiver System

Now turning to FIG. **3**, there is an optical transceiver **300** consistent with embodiments of the present disclosure. In more detail, the optical transceiver **300** transmits and receives four (4) channels using four different channel wavelengths (λ_1, λ_2, λ_3, λ_4) and may be capable of transmission rates of at least about 25 gigabits (Gbs) per channel or more. In one example, the channel wavelengths λ_1, λ_2, λ_3, λ_4 may be 1270 nm, 1290 nm, 1310 nm, and 1330 nm, respectively. The optical transceiver **300** may also be capable of both short transmission distances of tens of meters, for example, to distances of 2 kilometers or more. The optical transceiver **300** may be used, for example, in internet data center applications or fiber to the home (FTTH) applications. In an embodiment, the optical transceiver **300** implements a Quad Small Form-Factor Plugging (QSFP) transceiver. For example, the optical transceiver **300** may be implemented within a QSFP receiver that comports with the "SFF Committee Specification SFF-8665 for QSFP+28 Gb/s 4× Pluggable Transceiver Solution (QSFP28)" published on May 10, 2013. The aspects and embodiments disclosed herein may be used within other transceiver types and is not necessarily limited to QSFP or QFSP+ transceivers. The optical transceiver **300** may be configured for dense wavelength division multiplexing (DWDM) or course wavelength division multiplexing (CWDM), depending on a desired configuration. Although aspects and scenarios disclosed herein discuss a four (4) channel configuration, other channel configurations, e.g., 2, 4, 16, 32, and so on, are within the scope of this disclosure.

As shown, the optical transceiver **300** includes a housing **302** that includes a multi-channel TOSA arrangement **310** for transmitting optical signals on different channel wavelengths, and a multi-channel ROSA **312** for receiving optical signals on different channel wavelengths. A transmit connecting circuit **304** and a receive connecting circuit **308** provide electrical connections to the multi-channel TOSA **310** and the multi-channel ROSA **312**, respectively, within the transceiver housing **302**. The transmit connecting circuit **304** and the receive connecting circuit **308** may communicate with external systems via data bus **303**. In some cases, data bus **303** is a 38-pin connector that comports with physical connector QSFP standards and data communication protocols.

In any event, the transmit connecting circuit **304** electrically couples to the electronic components in the multi-channel TOSA arrangement **310**, e.g., laser assemblies, and the receive connecting circuit **308** electrically couples to the electronic components in the multi-channel ROSA **312**, e.g., an array waveguide grating (AWG), detectors, amplification circuitry and so on. The transmit connecting circuit **304** and the receive connecting circuit **308** include at least conductive paths to provide electrical connections, and may also include additional circuitry. The multi-channel TOSA **310** transmits and multiplexes multiple different channel wavelengths, and is coupled to an optical interface port **314**. The optical interface port **314** may include an LC connector port, although other connector types are also within the scope of this disclosure.

In cases where the optical interface port **314** comprises a duplex, or bi-directional, LC receptacle, the LC connector receptacle provides optical connections to the multi-channel TOSA **310**, and provides optical connections to the multi-channel ROSA **312**. The LC connector receptacle may be configured to receive and be coupled to a mating LC connector **316** such that transmit optical fiber **322** of the external fibers **324** optically couples to the multi-channel TOSA **310** arrangement, and the receive optical fiber **317** of the external fibers **324** optically couples to the multi-channel ROSA **312**.

The multi-channel TOSA arrangement **310** can include multiple laser packages **311-1** to **311**-N (FIG. **4**) and optics for producing associated channel wavelengths, and can couple the same into the transmit optical fiber **322**. In particular, the lasers **311-1** to **311**-N in the multi-channel TOSA arrangement **310** can convert electrical data signals (TX_D**1** to TX_D**4**) received via the transmit connecting circuit **304** into modulated optical signals transmitted over transmit optical fiber **322**. The lasers may include, for example, distributed feedback (DFB) lasers with diffraction gratings. In other cases, the lasers may comprise electro-absorption modulated laser (EML) laser diode packages. The multi-channel TOSA **310** may also include monitor photodiodes for monitoring the light emitted by the lasers. The multi-channel TOSA **310** may further include one or more temperature control devices, such as a resistive heater and/or a thermoelectric cooler (TEC), for controlling a temperature of the lasers, for example, to control or stabilize the laser wavelengths.

The multi-channel ROSA **312** can include demultiplexing optics such as an AWG device **402**, as discussed further below, and a plurality of detectors such as photodiode packages configured to receive de-multiplexed channel wavelengths. The ROSA **312** can use the detectors and associated circuitry (e.g., a TIA) to detect, amplify and convert de-multiplexed channel wavelengths and can provide the same as electrical data signals, e.g., RX_D**1** to RX_D**4**.

Referring to FIG. **4**, an example small form-factor (SFF) pluggable optical transceiver **400** with a multi-channel TOSA arrangement and multi-channel ROSA is shown in greater detail. The embodiment shown in FIG. **4** is one example of the optical transceiver **300** of FIG. **3** implemented in a small-form factor. In some cases, the optical transceiver **400** may implement the QSFP+ specification, or other applicable pluggable small-form factor specification. To this end, and in an embodiment, the optical transceiver **400** may be compliant with the QSFP28 MSA standard, and may include physical dimensions that conform to the SFF-8661 specification. In other cases, the optical transceiver **400** may implement the C form-factor pluggable (CFP) standard. In any such cases, the optical transceiver **400** may be configured to transmit and receive at a line rate of at least 100 Gb/s, respectively. This may be particularly advantageous when using the optical transceiver in, for example, a 100GBASE-LR4 application, per the IEEE 802.3ba standard. As shown, the optical transceiver **400** includes a transceiver housing **302**, a multi-channel TOSA arrangement **310** including a plurality of laser assemblies to generate associated channel wavelengths and associated circuitry. The multi-channel TOSA arrangement **310** electrically couples to transmit flexible printed circuits (FPCs) **304** and couples to the optical interface port **314** at an end of the housing **302**. The multi-channel ROSA arrangement **312** electrically couples to a receive FPC **308**, and couples to the optical interface port **315** at an end of the housing **302**. In an embodiment, the transceiver **400** can be configured to operate in a WDM passive optical network (PON), and to this end, the AWG **402** may be configured as a passive optical device. However, in some cases the AWG **402** can include active components and is not necessarily limited in this regard.

The multi-channel TOSA arrangement **310** can include a plurality of laser packages **311-1** to **311**-N with each comprising, for example, an EML laser diode package. Each EML laser may include an integrated electro-absorption modulator (EAM) on a single chip, for example. Other laser types are also within the scope of this disclosure such as, for example, directly modulated laser (DML) diodes and TO can-type laser diodes. The particular laser type chosen may be based on a desired application. For instance, applications that require long-distance, e.g., about 10 km or greater, may favor EML lasers. Conversely, applications requiring shorter distances may use DMLs. In any event, and in accordance with an embodiment, each laser diode device of the multi-channel TOSA arrangement can be configured to transmit at about 25 Gb/s, or greater. Each laser package of the multi-channel TOSA arrangement **310** may provide a relatively narrow spectrum of channel wavelengths such as a single channel wavelength, or may be configured to provide a broad spectrum of channel wavelengths based on associated optics. In an embodiment, the lasers can provide center wavelengths 375 nm to 1650 nm, for example.

The multi-channel ROSA arrangement **312** can include a demux device, such as the direct-coupling arrayed waveguide grating (AWG) device **402**. The direct-coupling AWG **402** may be configured to demultiplex a signal, e.g., a WDM signal, received via the optical interface port **315** into individual channel wavelengths. A fiber or other waveguide (not shown) can extend from the optical interface port **315** to an input of the AWG device **402**. An output of the AWG **402** device can be coupled to, for example, an array of quad p-intrinsic-n (PIN) diodes and associated TIAs **403** for the purposes of detecting, amplifying and converting each of the channel wavelengths into an electrical signal. The AWG device **402** can be compatible with channel spacing configurations that comport with, for example, 25 nm IEEE LX-4 grids, 20-nm ITU G.694.2 CWDM grids, and a range of ITU G.694.1 DWDM grids in the range of 400 Ghz to 800 Ghz (e.g., 2 nm to 4 nm). The AWG device **402** may be directly coupled to detector devices, e.g., the array of photodetectors **801** (FIG. **8**), as discussed in greater detail below.

Referring to FIG. **5**A, one example of the direct-coupling AWG device **402** is shown in further detail, in accordance with an embodiment of the present disclosure. As shown, the AWG device **402** includes an AWG chip **503** having a first end **505** coupled to an input coupling region **504** and having a second end **506**, with the second end **506** being proximal to a direct coupling interface **517** or region. The input coupling region **504** can include an optical coupling port

507, with the optical coupling port **507** being configured to receive and optically couple to a fiber of the optical coupling receptacle **215**. In general, AWG devices can support both multiplexing and de-multiplexing of optical signals, and thus, the first end **505** is not necessarily an “input” in all applications. However, for the purposes of the aspects and scenarios disclosed herein, the first end **505** is configured to receive an optical signal via fiber **508** and generally launch the same along a longitudinal path indicated by arrows appearing along fiber **508** to launch a WDM optical signal into the AWG chip **503**. In some cases, the optical coupling port **507** is an LC receptacle. The input coupling region **504** may not necessarily contain a length of fiber and instead comprise, for instance, a cavity or other waveguide structure. Moreover, the length of fiber **508** depicted in FIG. **5**A can be provided by an optical cable mated with optical coupling port **507** and is not necessarily a separate length of fiber.

The input coupling region **504** may be coupled to the AWG chip **503** using, for example, an adhesive, although other methods of fixation should be apparent in light of this disclosure. The input coupling region **504** can include an end with a mounting surface **510** having an angle **509**, with angle **509** being about 8 degrees. The angle **509** can reduce back reflection when launching light into the AWG chip **503**. To this end, the first end **505** of the AWG chip may also include a mounting surface with an angle of about 8 degrees, thus allowing for proper alignment between a core of the fiber **508** and an input of the AWG chip **503**.

The AWG chip **503** can comprise, for example, a planar lightwave circuit (PLC) such as a silica-based planar lightwave PLC device. PLC devices can be fabricated using a wafer process similar to those used for integration of silicon microchips and ICs. Processes for AWG chips can include, for example, forming a circuit pattern using photolithography, etching and deposition and/or epitaxial growth on a substrate, e.g., a silicon or silicon-based substrate. The formed AWG chip **503** can include a cladding material of, for example, silica (SiO_2), and a core material of doped silica, or other suitable composition that can provide a contrasting index of refraction for light confinement purposes. The contours of the AWG chip **503** may be defined by the shaping/etching of the silica during formation processes, or by post-processes such as cutting and polishing. Thus the AWG chip **503** can comprise a plurality of sidewalls that are formed from a cladding material layer. However, the AWG chip **503** can include additional protective layers/coatings, such as a metal housing, and is not necessarily limited to the embodiment shown.

Turning to FIG. **5**B, an enlarged cross-section taken along the line A-A of FIG. **5**A shows additional aspects of the AWG chip **503** in greater detail. As shown, the AWG chip **503** can include a plurality of optical paths **511** or output waveguides formed via deposited/grown core layers, with the output waveguides **511** extending longitudinally along the AWG chip **503**. The output waveguides **511** may be formed using, for example, sequentially deposited/grown layers of doped silica or suitable core material. The output waveguides **511** form at least a portion of the waveguide circuit of the AWG chip **503** and operate similar to that of conductive leads/traces on a printed circuit board. Each of the output waveguides **511** may have a width W**2** of about 6 microns and a height H**3** of about 3 microns, although other core configurations are also within the scope of this disclosure. Channel spacing, e.g., width W**3**, between each waveguide is discussed below with regard to FIG. **7**. Likewise, the cladding layer **513** can be formed from sequentially deposited/grown layers of silica or other suitable cladding material.

In an embodiment, the output waveguides **511** of the AWG chip **503** can enable confinement of light within the waveguides defined by the circuit patterned on the AWG chip **503**. This functionality is based at least in part on the relative index of refraction between the compositions of the core versus the cladding. For example, a silica-based cladding material can include an index of refraction N_1 of about 1.45. In contrast, the output waveguides **511** can be formed from a core material having an index of refraction N_2, with index of refraction N_2 being within about 0.7% of N_1. The particular material composition of the core and cladding may be selected to reduce insertion loss with the fiber **508**, which is also known as index-matching. In any event, aspects and embodiments disclosed herein are not necessarily limited to silicon or silicon-based compositions and are equally applicable to other materials used to form an AWG device.

Turning back to FIG. **5**A, the AWG chip **503** can include an output interface **517** (also called a direct coupling interface), which is discussed in greater detail below. As shown, the second end **506** of the AWG chip **503** includes an angled surface **520** that extends from a first sidewall **519** to a second sidewall **523**, with the angled surface **520** defining a tapered region of the AWG chip **503**. The angled surface **520** can include an angle **514** relative to longitudinal axis **521**, with angle **514** being selected to cause incident light to reflect downwardly at about a 90-degree angle towards the region indicated at **515**, which is shown and discussed in further detail with reference to FIG. **8**. Depending on the particular materials used to form the AWG chip **503**, and more particularly, their respective index of refraction, the angle **514** can vary. Likewise, the angle **514** may vary within nominal manufacturing tolerances of, for instance, ±2%. In an embodiment, the angle **514** is a range between about 40 degrees to 45 degrees. In some cases, the angled surface **520** is provided by cutting, buffing, etching, or otherwise removing a portion of the AWG chip **503**. This removed region is generally indicated at **516** for purposes of illustration. The surface of the second end **506** may be polished to ensure surface-level defects caused by the removal process are removed or otherwise reduced such that a substantial portion, e.g., at least 80%, of light is reflected downwards towards to the region indicated at **515**. Formation of the AWG chip **503** can include removing a portion of the substrate generally indicated at **515** to expose the output interface region **517**. The exposed output interface region **517** may be polished to ensure a suitable optical coupling.

In an embodiment, the AWG device **402** can include an overall length L**1** of about 13 mm. The overall length L**1** can be less than a similarly configured AWG chip that uses a fiber array coupling scheme, such as the one discussed above with regard to FIGS. **1** and **2**. The AWG chip **503** can include a length L**2** of about 10 mm, and a height H**2** of about 1.30 mm including the substrate **502**, and about 1 mm without. To this end, the substrate can include a height H1 of about 0.3 mm. The region generally indicated at **515**, and more particularly the output interface region **517**, can include a length L**3** of about 0.60 mm.

Turning to FIG. **6**, a top plan view of the AWG **402** is shown, in accordance with an embodiment. As shown, the AWG **402** can include a width W of about 1.5 mm. Other configurations are within the scope of this disclosure and the specific examples provided herein should not be construed as limiting. FIG. **7** shows a detail view of a portion of the

AWG **402** taken along the line B-B, in accordance with an embodiment of the present disclosure. As shown, the output waveguides **511** include a channel spacing W**3** of about 0.25 mm, although other channel spacing arrangements will be apparent in light of this disclosure.

Turning to FIG. **8**, an enlarged perspective view of the second end **506** of the AWG chip **503** is shown, in accordance with an embodiment of the present disclosure. The embodiment of FIG. **8** is illustrated in a highly simplified and exaggerated manner for the purposes of clarity and practicality. As shown, the output waveguides **511** can each provide a first light path generally indicated at **806**, with the first light path **806** extending longitudinally towards the direct coupling end **506**. A detector array **801** such as a photodiode (PD) array or bar can be positioned at a distance D1 from the direct coupling interface **517**, with D**1** being about 50 microns. As previously discussed, the second end **506** can include the surface **520** which has an angle **514** of about 40 degrees to 45 degrees relative to the light path **806**, depending on the composition of the AWG chip. For example, the angle **514** may be about 41 degrees in instances where the output waveguides **511** and the cladding layer **513** are silicon-based or otherwise have an index of refraction of about 1.45 to 1.5. Each of the output waveguides **511** form at least a portion of the angled surface **520**, and thus also include a tapered region having the angle **514**. Note that the tapered regions of the output waveguides **511** may be introduced when, for instance, a portion of the AWG chip **503** is cut or otherwise removed.

In any event, the angle **514** can provide an angle of incidence that can allow a substantial amount of light, e.g., at least 80 percent, to reflect towards the detectors **801**. For example, as shown, light incident to the angled surface **520** or tapered region can reflect downwards along a second light path **530** and pass through the direct coupling interface **517**, with the second light path **530** being generally orthogonal to the first light path **806**. As previously discussed, the difference in the index of refraction between the cladding layer **513** (denoted as n_1) and the output waveguides **511** allow light signals to be substantially confined within the output waveguides **511**. Furthermore, the external regions **809** adjacent to the AWG **402**, and more particularly the angled surface **520**, can include an index of refraction of n_3, with the index of refraction N_3 being less than that of n_1 and n_2. For example, the external regions **809** may comprise air which has an index of refraction of about 1.00. Thus the separated channel wavelengths that launch along associated ones of the output waveguides **511** along light path **806** can be reflected towards the detectors **804** as a result of the contrast between index of refraction n2 and n3. The resulting angle of reflection may be calculated based on Snell's Law:

$$n1 \sin \theta_1 = n2 \sin \theta_2 \quad \text{Equation (1)}$$

Where n1 is the refractive index of a first medium, n2 is a refractive index of a second medium, sin θ_1 is the angle of incidence and sin θ_2 is the angle of reflection, thus:

$$\sin\theta_2 = \frac{n1 \sin\theta_1}{n2} \quad \text{Equation (2)}$$

In use, each of the output waveguides **511** can provide associated channel wavelengths along a first light path generally indicated at **806**. The light along light path **806** may then encounter the angled surface **520** and reflect therefrom along the second light path **530**, with the second light path **530** being generally orthogonal to the first light path **806**. Then, light traveling along the second light path **530** can encounter the photo-sensitive regions of the detectors **804**. FIG. **9** shows the orientation of the detectors **804** relative to each of the waveguides **511** in greater detail.

Turning to FIG. **9**, and with additional reference to FIG. **8**, another perspective view shows the second end **506** of the AWG chip **503** adjacent to the array of detectors **801**, in accordance with an embodiment of the present disclosure. The second end **506** is illustrated in a fully-transparent and simplified manner for practicality and clarity. As shown, each of the output waveguides **511** extends longitudinally to the second end **506** such that each of the output waveguides **511** provides a first respective light path, e.g., the first light path **806**. As previously discussed with reference to FIG. **7**, the output waveguides **511** can be spaced at a nominal distance W**3**, with the nominal distance W**3** being about 0.25 mm or a different distance depending on a desired channel spacing configuration. As further shown, each of the detector devices **804** are aligned beneath the output interface region **517**, and more particularly, beneath respective ones of the output waveguides **511**. Thus the AWG **402** may be understood to directly couple to the detectors **804**, without the necessity of an additional waveguide or fiber device there between. The detectors **804** may be electrically coupled to associated circuitry of the receive connecting circuit **108** such as a TIA via, for example, wire bonding **901** or other suitable electrical interconnection.

Further Example Embodiments

In one aspect an arrayed waveguide grating (AWG) chip is disclosed. The AWG chip comprising a first end for coupling to an optical coupling receptacle to receive an optical signal comprising a plurality of channel wavelengths, a planar lightwave circuit (PLC) coupled to the first end configured to de-multiplex each channel wavelength of the plurality of channel wavelengths, a plurality of output waveguides coupled to the PLC, each of the output waveguides configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC and provide the light along a light path that extends towards a second end of the AWG chip, and a tapered region disposed at the second end of the AWG chip configured to receive light via the plurality of output waveguides and reflect the same towards an output interface region of the AWG chip.

In another aspect, an optical transceiver module is disclosed. The optical transceiver module comprising a transceiver housing, a multi-channel receiver optical sub-assembly (ROSA) located in the transceiver housing and including an arrayed waveguide grating (AWG) chip, the AWG chip comprising a first end for coupling to an optical coupling receptacle to receive an optical signal comprising a plurality of channel wavelengths, a planar lightwave circuit (PLC) coupled to the first end configured to de-multiplex each channel wavelength of the plurality of channel wavelengths, a plurality of output waveguides coupled to the PLC, each of the output waveguides configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC and provide the light along a light path that extends towards a second end of the AWG chip, and a tapered region disposed at the second end of the AWG chip configured to receive light via the plurality of output waveguides and reflect the same towards an output interface region of the AWG chip, an array of detector devices disposed adjacent to the output interface region of the AWG chip, and a multi-channel transmitter optical assembly (TOSA) including at least one laser package located in the transceiver housing for transmitting optical signals at different channel wavelengths.

In yet another aspect, a method of forming an arrayed waveguide grating (AWG) is disclosed. The method comprising depositing sequential layers of cladding and core material onto a substrate to form a planar lightwave circuit (PLC), removing a portion of the substrate to expose an output interface region of the PLC, and removing a portion of the PLC to provide a tapered region proximal to the output interface region of the PLC.

While the principles of the disclosure have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the disclosure. Other embodiments are contemplated within the scope of the present disclosure in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present disclosure, which is not to be limited except by the following claims.

What is claimed is:

1. An arrayed waveguide grating (AWG) chip comprising:

a first end for coupling to an optical coupling receptacle to receive an optical signal comprising a plurality of channel wavelengths;

a substrate;

a planar lightwave circuit (PLC) disposed on the substrate, the PLC coupled to the first end and configured to de-multiplex each channel wavelength of the plurality of channel wavelengths;

a plurality of output waveguides coupled to the PLC, each of the output waveguides configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC and provide the light along a first light path that extends towards a second end of the AWG chip; and

a tapered region disposed at the second end of the AWG chip configured to receive light via the plurality of output waveguides and reflect the same towards an exposed output interface region of the AWG chip, wherein the exposed output interface region emits the received light from the AWG chip on the same side as the substrate without passing the received light through the substrate.

2. The AWG chip of claim **1**, wherein the exposed output interface region is configured to pass the reflected light received via the plurality of output waveguides out of the AWG chip along a second light path that is substantially orthogonal to the first light path.

3. The AWG chip of claim **1**, wherein the AWG chip defines a plurality of sidewalls extending longitudinally from the first end to the second end, and wherein the tapered region of the second end defines an angled surface that extends from a first sidewall of the plurality of sidewalls to a second sidewall of the plurality of sidewalls.

4. The AWG chip of claim **3**, wherein the angled surface has an interior angle of about 41 to 45 degrees relative to the exposed output interface region.

5. The AWG chip of claim **3**, wherein each of the output waveguides comprise a core material, and wherein a cladding material is disposed on the core material, the core material defining at least a portion of the plurality of sidewalls of the AWG chip.

6. The AWG chip of claim **5**, wherein the core material of each of the plurality of output waveguides has a first index of refraction, and a medium external to and adjacent the tapered region has a second index of refraction, the first index of refraction being greater than the second index of refraction.

7. The AWG chip of claim **6**, wherein the external medium comprises a material having an index of refraction of about 1.0.

8. The AWG chip of claim **5**, wherein the core material of each of the plurality of output waveguides provide a portion of the angled surface, and wherein the angled surface is configured to reflect incident light based on at least an interior angle of the angled surface.

9. The AWG chip of claim **5**, wherein the core material comprises doped silica (SiO_2) having an index of refraction of about 1.45 to 1.50.

10. The AWG chip of claim **1**, wherein the AWG chip is configured as a 1×N demultiplexer device whereby a single optical input signal is de-multiplexed into N different channel wavelengths.

11. The AWG chip of claim **1**, wherein the AWG chip is implemented in an AWG device package.

12. An optical transceiver module comprising:

a transceiver housing;

a multi-channel receiver optical sub-assembly (ROSA) located in the transceiver housing and including an arrayed waveguide grating (AWG) chip, the AWG chip comprising:

a first end for coupling to an optical coupling receptacle to receive an optical signal comprising a plurality of channel wavelengths, wherein the first end for coupling to the optical coupling receptacle includes an angled surface to reduce back reflections of an optical signal launched into the AWG chip;

a planar lightwave circuit (PLC) coupled to the first end configured to de-multiplex each channel wavelength of the plurality of channel wavelengths;

a plurality of output waveguides coupled to the PLC, each of the output waveguides configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC and provide the light along a first light path that extends towards a second end of the AWG chip; and

a tapered region disposed at the second end of the AWG chip configured to receive light via the plurality of output waveguides and reflect the same towards an output interface region of the AWG chip;

an array of detector devices disposed adjacent to the output interface region of the AWG chip; and

a multi-channel transmitter optical assembly (TOSA) including at least one laser package located in the transceiver housing for transmitting optical signals at different channel wavelengths.

13. The optical transceiver module of claim **12**, wherein the output interface region of the AWG chip is an exposed region adjacent an air gap, and wherein the air gap separates the output interface region of the AWG chip and the array of detector devices.

14. The optical transceiver module of claim **12**, wherein the output interface region of the AWG chip is separated from the array of detector devices by about 50 microns.

15. The optical transceiver module of claim **12**, wherein the AWG chip defines a plurality of sidewalls extending longitudinally from the first end to the second end, and wherein the tapered region of the second end defines an angled surface that extends from a first sidewall of the plurality of sidewalls to a second sidewall of the plurality of sidewalls.

16. The optical transceiver module of claim **15**, wherein the angled surface has an interior angle of about 41 to 45 degrees relative to the output interface region.

17. The optical transceiver module of claim **15**, wherein each of the output waveguides comprise a core material, and wherein a cladding material is disposed on the core material, the core material defining at least a portion of the plurality of sidewalls of the AWG chip.

18. The optical transceiver module of claim **17**, wherein the core material of each of the plurality of output waveguides provide a portion of the angled surface, and wherein the angled surface is configured to reflect incident light based on at least an interior angle of the angled surface relative to the output interface of the AWG chip.

19. The optical transceiver of claim **12**, wherein the transceiver is a Small Form-factor Pluggable (SFP) transceiver module and the ROSA is configured to receive at least four different channel wavelengths at transmission rates of at least about 25 Gbps per channel.

* * * * *

EXHIBIT E

US010175431B2

(12) **United States Patent**
Lin et al.

(10) **Patent No.: US 10,175,431 B2**
(45) **Date of Patent: Jan. 8, 2019**

(54) **OPTICAL TRANSCEIVER WITH A MULTIPLEXING DEVICE POSITIONED OFF-CENTER WITHIN A TRANSCEIVER HOUSING TO REDUCE FIBER BENDING LOSS**

(71) Applicant: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(72) Inventors: **Kai-Sheng Lin**, Sugar Land, TX (US); **Ziliang Cai**, Richmond, TX (US); **Stella Liang Chen**, Richmond, TX (US)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/242,005**

(22) Filed: **Aug. 19, 2016**

(65) **Prior Publication Data**

US 2018/0052289 A1 Feb. 22, 2018

(51) **Int. Cl.**
G02B 6/12 (2006.01)
G02B 6/42 (2006.01)
G02B 6/293 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/421*** (2013.01); ***G02B 6/12019*** (2013.01); ***G02B 6/2938*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G02B 6/421; G02B 6/12019; G02B 6/29329; G02B 6/2938; G02B 6/4246; G02B 6/4281; G02B 6/4292
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,341,786 B1 * 5/2016 Gamache G02B 6/30
9,419,717 B2 8/2016 Huang et al.
(Continued)

OTHER PUBLICATIONS

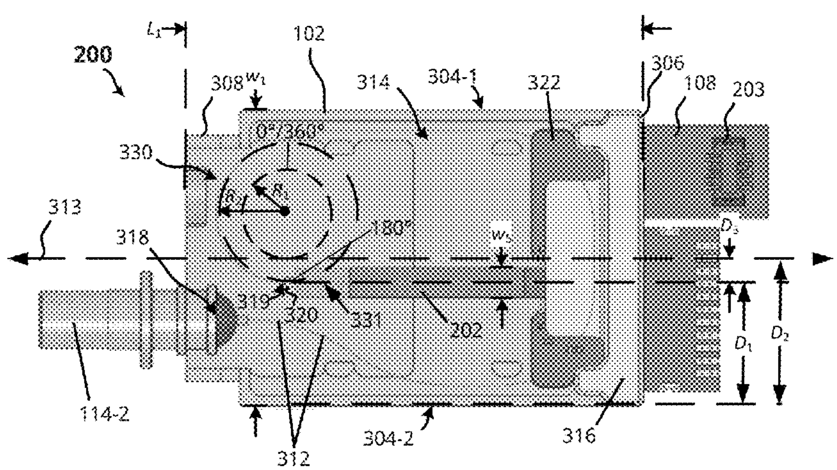
PCT Search Report-Written Opinion dated Sep. 22, 2017, received in corresponding PCT Application No. PCT/US17/47569, 9 pgs.
(Continued)

Primary Examiner — Jerry Blevins
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

Techniques for reducing optical fiber bending loss in an optical transceiver are disclosed. In an embodiment, a small form-factor (SFF) optical transceiver housing includes a demultiplexer device, such as an arrayed waveguide grating (AWG) device, having a longitudinal center line that is offset laterally by a distance D_{offset} from the longitudinal center line of the SFF optical transceiver housing. The lateral offset distance D_{offset} may advantageously enable an intermediate optical fiber coupling the demultiplexer with an optical coupling receptacle, such as an LC connector, to be routed within the SFF optical transceiver housing in a manner that avoids introducing bends that are less than a minimum bending radius associated with the intermediate optical fiber cable. Thus some embodiments of the present disclosure enable greater tolerance when routing an intermediate optical fiber within housings that would otherwise introduce bending loss by virtue of their constrained dimensions.

18 Claims, 4 Drawing Sheets



(52) **U.S. Cl.**
CPC ***G02B 6/29329*** (2013.01); ***G02B 6/4246*** (2013.01); ***G02B 6/4281*** (2013.01); ***G02B 6/4292*** (2013.01)

(58) **Field of Classification Search**
USPC 385/14
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,455,782 B2	9/2016	Zheng et al.	
9,553,671 B1	1/2017	Nagarajan et al.	
2008/0056644 A1*	3/2008	Naka	B29C 45/0013 385/55
2011/0058771 A1	3/2011	Lee et al.	
2012/0092756 A1	4/2012	Yoshida et al.	
2014/0241726 A1	8/2014	Ho et al.	

OTHER PUBLICATIONS

U.S. Office Action dated Dec. 15, 2017, received in U.S. Appl. No. 15/613,655, 13 pgs.
U.S. Office Action dated May 9, 2018, received in U.S. Appl. No. 15/613,655, 15 pgs.
PCT International Search Report and Written Opinion dated Jul. 10, 2018, received in PCT Application No. PCT/US18/36057, 12 pgs.

* cited by examiner

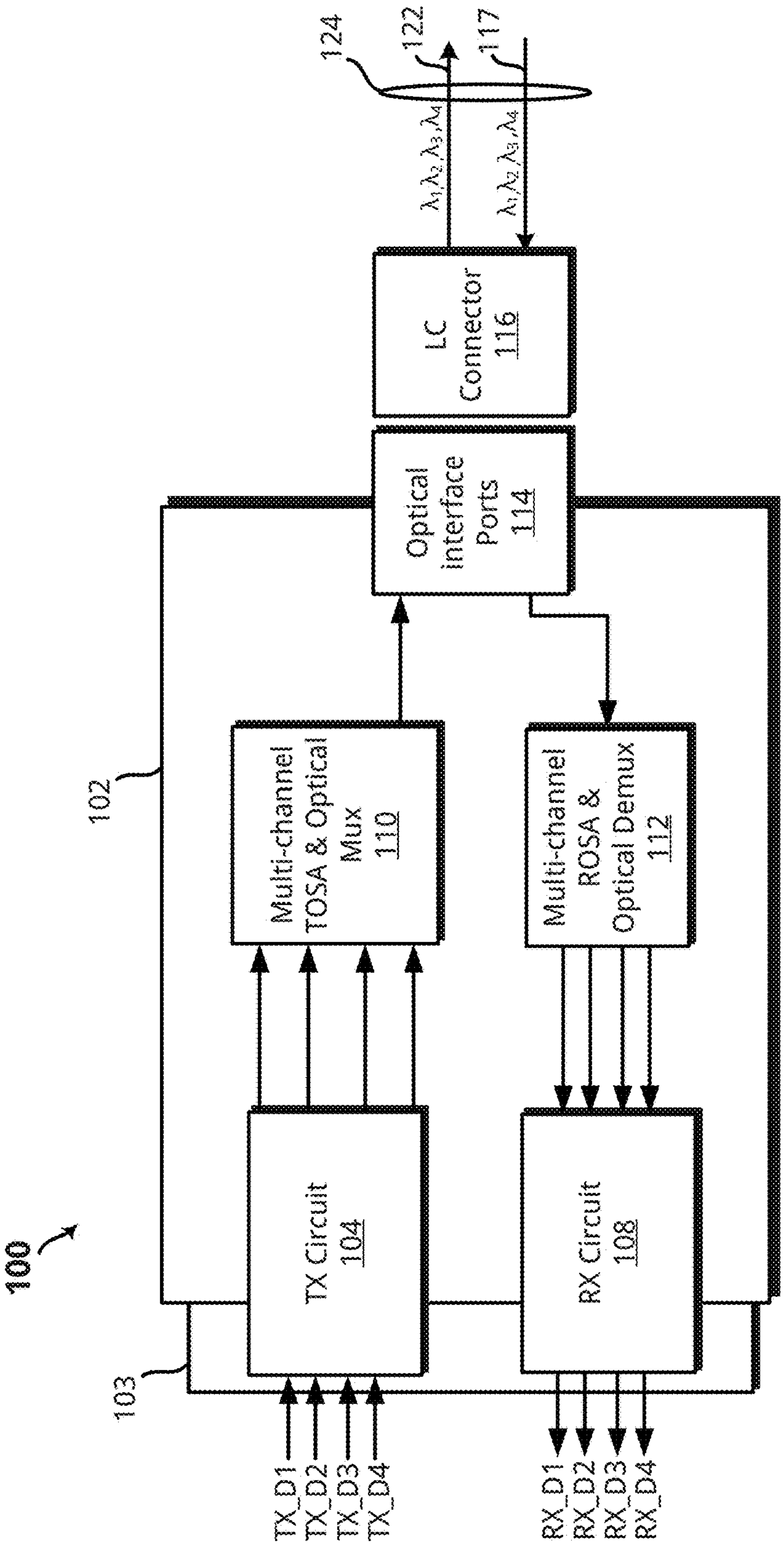

100
102
103
TX Circuit
104
RX Circuit
108
Multi-channel TOSA & Optical Mux
110
Multi-channel ROSA & Optical Demux
112
Optical interface Ports
114
LC Connector
116
117
122
124
$\lambda_1,\lambda_2,\lambda_3,\lambda_4$
$\lambda_1,\lambda_2,\lambda_3,\lambda_4$
TX_D1
TX_D2
TX_D3
TX_D4
RX_D1
RX_D2
RX_D3
RX_D4

FIG. 1

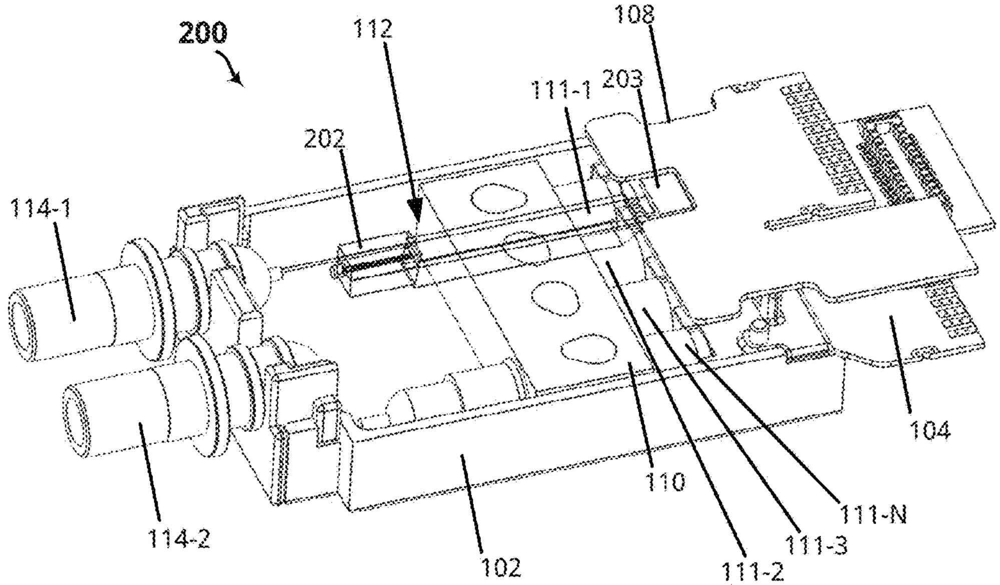


FIG. 2

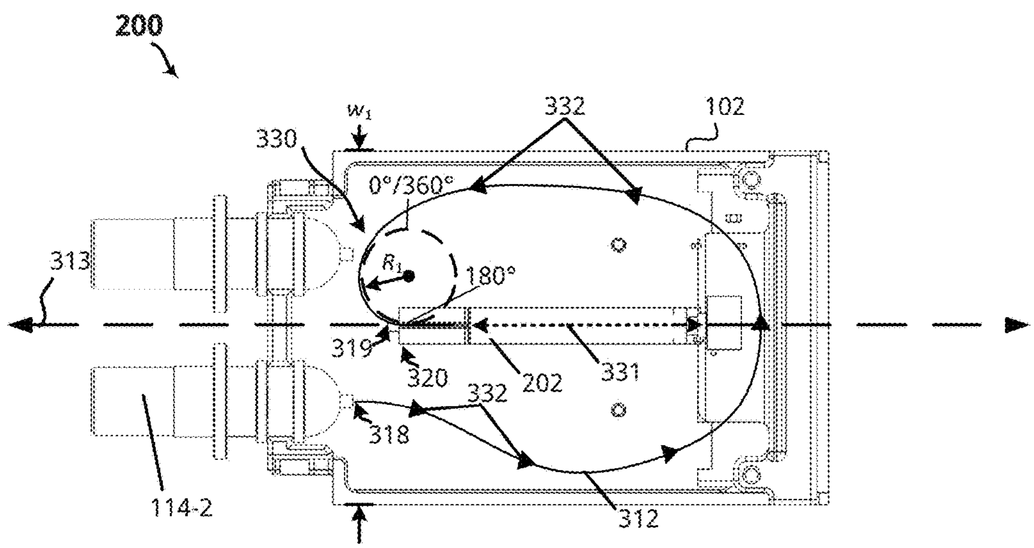
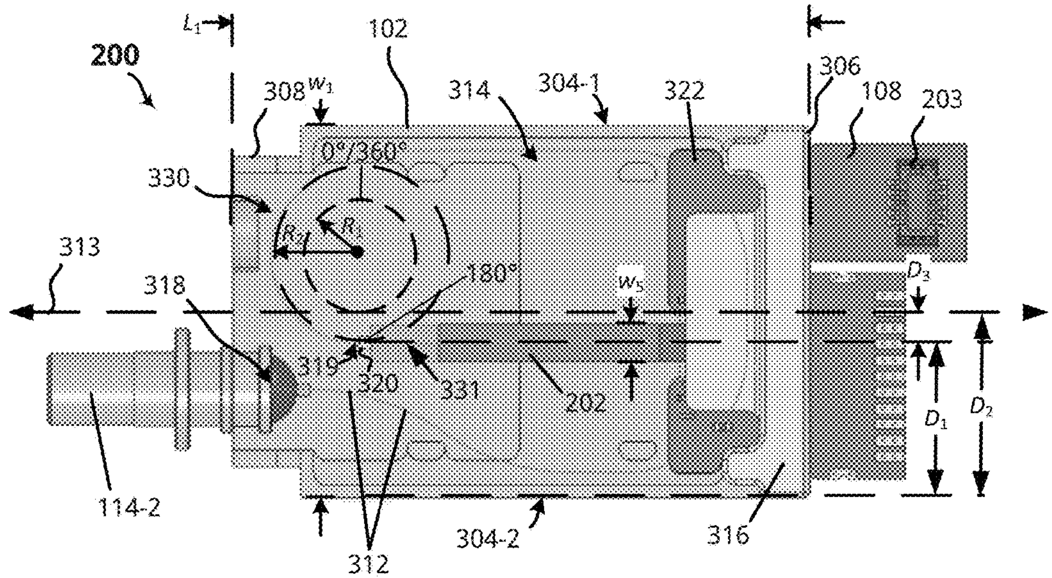
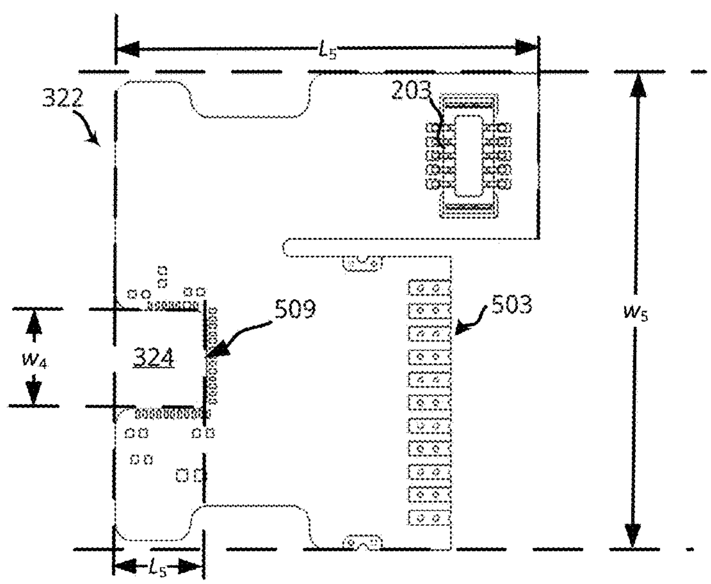

200
w_1
332
102
330
0°/360°
313
R_1
180°
319
320
202
331
332
318
114-2
312

FIG. 3



200
L_1
102
308
W_1
314
304-1
322
306
108
203
330
0°/360°
R_2
R_1
313
318
180°
W_5
D_3
319
320
331
202
D_1
D_2
114-2
304-2
316
312

FIG. 4



L_5
322
203
509
503
W_4
324
W_5
L_5

FIG. 5

OPTICAL TRANSCEIVER WITH A MULTIPLEXING DEVICE POSITIONED OFF-CENTER WITHIN A TRANSCEIVER HOUSING TO REDUCE FIBER BENDING LOSS

TECHNICAL FIELD

The present disclosure generally relates to optical transceiver modules, and more particularly, to an optical transceiver housing with a multiplexer device, such as an arrayed waveguide grating (AWG) device, at an off-center position to reduce fiber bending losses introduced by an optical fiber that optically couples an optical signal into the AWG device.

BACKGROUND INFORMATION

Optical transceivers are used to transmit and receive optical signals for various applications including, without limitation, internet data centers, cable TV broadband, and fiber to the home (FTTH) applications. Optical transceivers provide higher speeds and bandwidth over longer distances, for example, as compared to transmission over copper cables. The desire to provide higher speeds in smaller optical transceiver modules for a lower cost has presented challenges, for example, with respect to maintaining optical efficiency (power), thermal management, insertion loss, and manufacturing yield.

Optical transceivers can include one or more transmitter optical subassemblies (TOSAs) and receiver optical subassemblies (ROSAs) for the purpose of transmitting and receiving optical signals. As channel density becomes an increasingly important aspect of optical transceivers, the ability scale-down while maintaining nominal transceiver performance raises numerous non-trivial challenges.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** schematically illustrates an embodiment of an optical transceiver module including a multi-channel transmitter optical sub-assembly (TOSA) and multi-channel receiver optical sub-assembly (ROSA).

FIG. **2** is a perspective view of an example small form-factor (SFF) pluggable transceiver with a multi-channel TOSA configuration and a multi-channel ROSA, in accordance with an embodiment of the present disclosure.

FIG. **3** shows a top plan view of the example SFF pluggable transceiver of FIG. **2**, in accordance with an embodiment of the present disclosure.

FIG. **4** shows another top plan view of the example SFF pluggable transceiver of FIG. **2** having an off-center arrayed waveguide grating (AWG) device, in accordance with an embodiment of the present disclosure.

FIG. **5** shows an example flexible printed circuit for use in the optical transceiver of FIG. **4**, in accordance with an embodiment of the present disclosure.

These and other features of the present embodiments will be understood better by reading the following detailed description, taken together with the figures herein described. The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing.

DETAILED DESCRIPTION

Optical transceivers can include receiver optical subassemblies (ROSAs) that are configured to receive multiple channel wavelengths via a common fiber and de-multiplex the same for detection, amplification and conversion purposes. To de-multiplex a received signal, such as a wavelength division multiplexed (WDM) signal, a ROSA may use an arrayed waveguide grating (AWG) device to separate channel wavelengths and to provide the separated channel wavelengths to associated detector devices such as photodiodes. To couple the received optical signal into an AWG device, transceivers can include a length of intermediate fiber that extends from, for example, an LC connector receptacle to a coupling port of the AWG device. In some cases, the intermediate fiber is communications grade optical fiber, e.g., compliant with IEC 60793-2-10 and 60793-50, which is based on a glass or "cladding" having a diameter of about 125 microns (μm) or less. The region at the center of the fiber that carries the optical signal is generally referred to as the "core" and may measure from a few microns to 62.5 μm in diameter, for example. The optical fiber properties, e.g., the core, refractive index profile and so on, that define optical performance are generally referred to as the "waveguide" although the term may also apply to the entire optical fiber as well.

The optical fiber properties of an optical fiber also govern the extent of bending prior to the introduction of loss due to macro and micro bending. Macro-bending of an optical fiber, for example, references bends generally visible to the human eye and can introduce signal attenuation. Such bends can cause light to "leak out" an increasing amount as the bend becomes more acute and alters the refractive index profile of the optical fiber. On the other hand, micro-bending generally refers to small, potentially imperceptible, radius bends of the fiber core caused by, for example, lateral contact with surfaces in the transceiver housing and twists in the fiber optic cable. Manufacturers generally suggest that the minimum (R_{min}) bending radius for an optical fiber be about no less than 15-20× the diameter of the optical fiber to avoid introducing macro and/or micro bending and maintain nominal performance. Stated differently, an acute bending radius that is less than 15× the diameter of the optical fiber may introduce unacceptable power loss. For instance, a fiber diameter of 0.25 mm may include a minimum bending radius of 4 mm.

However, routing of optical fiber within a SFF housing often requires some amount of bending to couple the same into multiplexing and/or other processing components of TOSAs and ROSAs. For example, FIG. **3** shows a top plan view of an example optical transceiver **200**, and shows an intermediate optical fiber **312** routed in a bent/looped fashion to couple with an AWG device **202**. The optical transceiver **200** is shown in a highly simplified form for purpose of practicality and clarity. As shown, the intermediate optical fiber **312** is disposed within a transceiver housing **102** and includes a first end **318** coupled to an optical coupling receptacle **114-2**, e.g., an LC connector receptacle, and a second end **319** coupled to a coupling region **320** of the AWG device **202**. The intermediate optical fiber **312** may include a path or route, collectively depicted by arrows **332**, that necessitates one or more bends including the bend **330** that is adjacent to the second end **319** of the intermediate optical fiber **312**. As further shown, the longitudinal center line **331** of the AWG **202** is coaxial with the longitudinal center line **313** of the transceiver housing **102**, which results in bend radius R_1. As discussed above, the more acute the bend in the intermediate optical fiber **312** the more significant the change to the refractive index profile associated with the same. For the sake of illustration, consider an example scenario wherein the transceiver housing **102** includes a cross-wise width W_1 of about 8 mm. In this scenario, the bend radius R_1 may equal substantially equal to or less than 4 mm, which is about half the cross-wise width W_1 of the transceiver housing **102**. This unfortunately leaves little tolerance to route the intermediate optical fiber **312** as the extent of bend radius R_1, even in a best-case scenario, may already be at or below the minimum bending radius (R_{min}) associated with the intermediate optical fiber **312** by virtue of the constrained dimensions within the transceiver housing **102**.

Thus, the present disclosure has identified that placement of an optical demultiplexer device, such as an arrayed waveguide grating (AWG) device, laterally offset from the longitudinal center line of an optical transceiver housing may introduce additional tolerance for routing of an intermediate optical fiber. The laterally-offset position of the optical demultiplexer device may also be accurately referred to as an off-center housing position. In an embodiment, a length of the intermediate optical fiber adjacent to an input region of the optical demultiplexer device has a corresponding bend radius that is proportionally increased relative to the lateral offset. For instance, the AWG device **202** with a lateral offset of 1 millimeter (mm) relative to the longitudinal center **313** of the optical transceiver housing **102** may increase the bend radius of the bend **330** by an equal amount. The lateral offset may vary depending on a desired implementation. For example, the lateral offset may range between 0.05 mm to 5 mm, depending on the dimensions of the particular optical transceiver housing. By way of contrast to the embodiment shown in FIG. **3**, FIG. **4** shows one such example lateral offset D_{offset} for the AWG device **202** which results in radius R_2, which is discussed in greater detail further below. Thus the present disclosure provides techniques for selectively positioning an optical multiplexer/de-multiplexer within a transceiver housing to reduce the severity of the bends necessary to route an intermediate optical fiber, and by extension, maintain nominal performance of an optical transceiver. While specific examples and scenarios disclosed herein reference a ROSA arrangement having a AWG de-multiplexer device, other optical subassemblies such as TOSAs are within the scope of this disclosure. Moreover, other multiplexing/demultiplexing devices are within the scope of this disclosure and this disclosure is not necessarily limited to AWGs.

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid or course wavelength division multiplexing (CWDM).

The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals. Likewise, the term "directly coupled" or "directly optically coupled" as used herein refers any optical connection that allows light to be imparted from one element to another without the use of an intermediate device such as a fiber.

As used herein singular expressions such as "a," "an," and "the" are not limited to their singular form, and are intended to cover the plural forms as well unless the context clearly indicates otherwise.

From time to time one or more aspects of the present disclosure may be described using ranges. In such instances it should be understood that the indicated ranges are exemplary only unless expressly indicated otherwise. Moreover, the indicated ranges should be understood to include all of the individual values of falling within the indicated range, as though such values were expressly recited. Moreover, the ranges should be understood to encompass sub ranges within the indicated range, as though such sub ranges were expressly recited. By way of example, a range of 1 to 10 should be understood to include 2, 3, 4 . . . etc., as well as the range of 2 to 10, 3 to 10, 2 to 8, etc., as though such values and ranges were expressly recited.

Example Optical Transceiver System

Now turning to FIG. **1**, there is an optical transceiver **100** consistent with embodiments of the present disclosure. In more detail, the optical transceiver **100** transmits and receives four (4) channels using four different channel wavelengths (λ_1, λ_2, λ_3, λ_4) and may be capable of transmission rates of at least about 25 gigabits (Gbs) per channel or more. In one example, the channel wavelengths λ_1, λ_2, λ_3, λ_4 may be 1270 nm, 1290 nm, 1310 nm, and 1330 nm, respectively. The optical transceiver **100** may also be capable of both short transmission distances of tens of meters, for example, to distances of 2 kilometers or more. The optical transceiver **100** may be used, for example, in internet data center applications or fiber to the home (FTTH) applications. In an embodiment, the optical transceiver **100** implements a Quad Small Form-Factor Plugging (QSFP) transceiver. For example, the optical transceiver **100** may be implemented within a QSFP receiver that comports with the "SFF Committee Specification SFF-8665 for QSFP+28 Gb/s 4× Pluggable Transceiver Solution (QSFP28)" published on May 10, 2013. The aspects and embodiments disclosed herein may be used within other transceiver types and is not necessarily limited to QSFP or QFSP+ transceivers. The optical transceiver **100** may be configured for dense wavelength division multiplexing (DWDM) or course wavelength division multiplexing (CWDM), depending on a desired configuration. Although aspects and scenarios disclosed herein discuss a four (4) channel configuration, other channel configurations, e.g., 2, 4, 16, 32, and so on, are within the scope of this disclosure.

As shown, the optical transceiver **100** includes a transceiver housing **102** that includes a multi-channel TOSA arrangement **110** for transmitting optical signals on different channel wavelengths, and a multi-channel ROSA **112** for receiving optical signals on different channel wavelengths. A transmit connecting circuit **104** and a receive connecting circuit **108** provide electrical connections to the multi-channel TOSA **110** and the multi-channel ROSA **112**, respectively, within the transceiver housing **102**. The transmit connecting circuit **104** and the receive connecting circuit **108** may communicate with external systems via data bus **103**. In some cases, data bus **103** is a 38-pin connector that comports with physical connector QSFP standards and data communication protocols.

In any event, the transmit connecting circuit **104** electrically couples to the electronic components in the multi-channel TOSA arrangement **110**, e.g., laser assemblies, and the receive connecting circuit **108** electrically couples to the electronic components in the multi-channel ROSA **112**, e.g., an array waveguide grating (AWG), detectors, amplification circuitry and so on. The transmit connecting circuit **104** and the receive connecting circuit **108** include at least conductive paths to provide electrical connections, and may also include additional circuitry. The multi-channel TOSA **110** transmits and multiplexes multiple different channel wavelengths, and is coupled to an optical interface port **114**. The optical interface port **114** may include an LC connector port, although other connector types are also within the scope of this disclosure.

In cases where the optical interface port **114** comprises a duplex, or bi-directional, LC receptacle, the LC connector receptacle provides optical connections to the multi-channel TOSA **110**, and provides optical connections to the multi-channel ROSA **112**. The LC connector receptacle may be configured to receive and be coupled to a mating LC connector **116** such that transmit optical fiber **122** of the external fibers **124** optically couples to the multi-channel TOSA **110** arrangement, and the receive optical fiber **117** of the external fibers **124** optically couples to the multi-channel ROSA **112**.

The multi-channel TOSA arrangement **110** can include multiple laser packages and optics for producing associated channel wavelengths, and can couple the same into the transmit optical fiber **122**. In particular, the lasers in the multi-channel TOSA arrangement **110** can convert electrical data signals (TX_D1 to TX_D**4**) received via the transmit connecting circuit **104** into modulated optical signals transmitted over transmit optical fiber **122**. The lasers may include, for example, distributed feedback (DFB) lasers with diffraction gratings. In other cases, the lasers may comprise electro-absorption modulated laser (EML) laser diode packages. The multi-channel TOSA **110** may also include monitor photodiodes for monitoring the light emitted by the lasers. The multi-channel TOSA **110** may further include one or more temperature control devices, such as a resistive heater and/or a thermoelectric cooler (TEC), for controlling a temperature of the lasers, for example, to control or stabilize the laser wavelengths.

The multi-channel ROSA **112** can include demultiplexing optics such as an AWG device **402**, as discussed further below, and a plurality of detectors such as photodiode packages configured to receive de-multiplexed channel wavelengths. The ROSA **112** can use the detectors and associated circuitry (e.g., a TIA) to detect, amplify and convert de-multiplexed channel wavelengths and can provide the same as electrical data signals, e.g., RX_D1 to RX_D**4**.

Referring to FIG. **2**, an example small form-factor (SFF) pluggable optical transceiver **200** with a multi-channel TOSA arrangement **110** and multi-channel ROSA **112** is shown in accordance with an embodiment of the present disclosure. The embodiment shown in FIG. **2** is one example of the optical transceiver **100** of FIG. **1** implemented in a small-form factor (SFF) configuration. In some cases, the optical transceiver **200** may implement the QSFP+ specification, or other applicable pluggable small-form factor specification. To this end, and in an embodiment, the optical transceiver **200** may be compliant with the QSFP28 MSA standard, and may include physical dimensions that conform to the SFF-8661 specification. In other cases, the optical transceiver **200** may implement the C form-factor pluggable (CFP) standard. In any such cases, the optical transceiver **200** may be configured to transmit and receive at a line rate of at least 100 Gb/s, respectively. This may be particularly advantageous when using the optical transceiver in, for example, a 100GBASE-LR4 application, per the IEEE 802.3ba standard.

As shown, the optical transceiver **200** includes a transceiver housing **102**, a multi-channel TOSA arrangement **110** including a plurality of laser packages **111-1** to **111**-N to generate associated channel wavelengths and associated circuitry. The multi-channel TOSA arrangement **110** electrically couples to transmit flexible printed circuit (FPC) **104** and couples to the optical interface port **114-1** at an end of the transceiver housing **102**. The multi-channel ROSA arrangement **112** electrically couples to a receive FPC **108**, and couples to the optical interface receptacle **114-2** at an end of the transceiver housing **102**. In an embodiment, the optical transceiver **200** can be configured to operate in a WDM passive optical network (PON), and to this end, the AWG **202** may be configured as a passive optical device. However, in some cases the AWG **202** can include active components and is not necessarily limited in this regard.

The multi-channel TOSA arrangement **110** can include a plurality of laser packages **111-1** to **111**-N with each comprising, for example, an EML laser diode package. Each EML laser may include an integrated electro-absorption modulator (EAM) on a single chip, for example. Other laser types are also within the scope of this disclosure such as, for example, directly modulated laser (DML) diodes and TO can-type laser diodes. The particular laser type chosen may be based on a desired application. For instance, applications that require long-distance, e.g., about 10 km or greater, may favor EML lasers. Conversely, applications requiring shorter distances may use DMLs. In any event, and in accordance with an embodiment, each laser package **111-1** to **111**-N of the multi-channel TOSA arrangement **110** can be configured to transmit at about 25 Gb/s, or greater. Each laser package **111-1** to **111**-N of the multi-channel TOSA arrangement **110** may provide a relatively narrow spectrum of channel wavelengths such as a single channel wavelength, or may be configured to provide a broad spectrum of channel wavelengths based on associated optics. In an embodiment, the lasers can provide center wavelengths 375 nm to 1650 nm, for example.

The multi-channel ROSA arrangement **112** can include a demux device, such as the arrayed waveguide grating (AWG) device **202**. The AWG **202** may be configured to demultiplex a signal, e.g., a WDM signal, received via the optical interface port **115** into individual channel wavelengths. One example AWG device particularly well suited for the techniques disclosed herein is disclosed in U.S. patent application Ser. No. 15/137,823 entitled "Techniques for Direct Coupling of Photodetectors to Optical Demultiplexer Outputs and an Optical Transceiver using the Same" filed on Apr. 25, 2016, which is incorporated herein by reference in its entirety. An intermediate fiber **312** (FIGS. **3** and **4**) may extend from the optical interface port **114-2** to an input of the AWG device **202**. As discussed further below, the position of the AWG device **202** within the transceiver housing may provide a route for the intermediate optical fiber that reduces the severity of the bends necessary to route the same between an optical coupling receptacle and a de-multiplexing device.

An output of the AWG **202** device can be coupled to, for example, an array of quad p-intrinsic-n (PIN) diodes and associated TIAs **203** for the purposes of detecting, amplifying and converting each of the channel wavelengths into an electrical signal. The AWG device **202** can be compatible with channel spacing configurations that comport with, for example, 25 nm IEEE LX-4 grids, 20-nm ITU G.694.2

CWDM grids, and a range of ITU G.694.1 DWDM grids in the range of 400 Ghz to 800 Ghz (e.g., 2 nm to 4 nm).

Although specific examples and scenarios disclosed herein are directed to an AWG device within a ROSA arrangement, this disclosure should not be construed as limiting in this regard. The techniques disclosed herein may be equally applicable with minor modifications to other subassemblies, such as TOSAs, that seek to route an intermediate optical fiber within a transceiver housing.

Turning to FIG. **4**, another example of the optical transceiver **200** is shown in accordance with an embodiment of the present disclosure. The optical transceiver **200** is shown in a simplified manner. For example, the optical coupling receptacle **114-1**, TOSA arrangement **110**, and top cover portion are omitted merely for the purpose of clarity and practicality. As shown, the transceiver housing **301** includes a plurality of sidewalls, e.g., sidewalls **304-1** to **304-2**, that extend from a first end **306** to a second end **308** along a longitudinal axis **313**. The longitudinal axis **313** also generally denotes a center longitudinal line of the transceiver housing **102**. An inner surface of the plurality of sidewalls **304-1** and **304-2** may define at least a portion of the cavity **314**. As further shown, an AWG device **202** is at least partially disposed within the cavity **314**. The AWG device **202** may extend length-wise in parallel with the longitudinal center line **313**. A flexible printed circuit board (FPC) **322** having the receive connecting circuit **108** may also at least partially be disposed within the cavity **314**.

The receive connecting circuit **108** of the FPC **322** may comprise, for example, a TIA **203** or other suitable circuitry configured to receive data from, for example, photodetectors (not shown) associated with the AWG device **202** in order to amplify and convert the same into electrical signals, e.g., RX_D**1** to RX_D**4**. The receive FPC **322** is discussed in greater detail below with regard to FIG. **5**. A bracket **316** may form an interference or press-fit with the transceiver housing **301** and may assist in holding the FPC **322** in position.

Continuing with FIG. **4**, the AWG device **202** may be disposed within the cavity **314** and positioned to at least partially extend into a slot **324** (FIG. **5**) of the FPC **322**. Thus the AWG device **202** may be disposed in a rearward position that is adjacent to the first end **306** of the transceiver housing **102** in order to provide sufficient clearance for the intermediate optical fiber **312** to couple into the AWG **202** without exceeding a minimum bending radius, which is discussed further below in greater detail.

In an embodiment, the optical transceiver **200** may include relatively constrained dimensions, e.g., a SFF configuration. For example, the transceiver housing **102** may include an overall length L_1 of about 20 mm and a cross-wise width W_1 of about 10 mm, although other overall lengths L_1 and widths W_1 are within the scope of this disclosure depending on the dimensions particular optical transceiver housing. As discussed above with regard to FIG. **3**, such constrained dimensions may thus cause a route taken by the intermediate optical fiber **312** to introduce bends that are less than a minimum bending radius (R_{min}) associated with the intermediate optical fiber **312**. For example, the constraints of the transceiver housing **102**, e.g., a 10 mm width W_1, the resulting bend radius R_1 for the intermediate optical fiber **312** may be about equal to or less than a minimum bending radius (R_{min}) for the intermediate optical fiber **312**, which is to say about 4 mm for the sake of providing one specific non-limiting example. As previously discussed, the R_{min} may vary depending on the particular properties of the intermediate fiber cable **312**, and the particular specific example radiuses and measurements discussed herein are not intended to limit the present disclosure.

On the other hand, in accordance with an embodiment, when the AWG device **202** is disposed at distance D_1 relative to sidewall **304-2**, with distance D_1 being laterally offset from the longitudinal center line **313** of the transceiver housing **102** by lateral offset D_{offset}, the bend radius R_2 results. As shown, the lateral offset of D_{offset} displaces the AWG device **202** generally towards the optical coupling receptacle **114-2**. The resulting bend radius R**2** thus provides a larger bend radius relative to bend radius R_1, and accordingly, more tolerance for a route taken by the intermediate optical fiber **312** in the region of the cavity **314** adjacent to the sidewall **304-1**.

In one specific example embodiment, the lateral offset D_{offset} is at least about 1 mm, although other offsets are also applicable depending on the dimensions of the particular transceiver housing. In some cases, the lateral offset D_{offset} is between about 0.5 and 10 mm, for example. Thus a proportional increase in bend radius is observed relative to bend radius R_1 as the intermediate optical fiber **312** includes a resulting bend radius of R_2 (e.g., $R_1+D_{offset}=R_2$). As shown, the intermediate optical fiber **312** includes a continuous curvilinear portion, e.g., the bend **330**, adjacent the AWG **202**, with the continuous curve linear portion having an arc length of at least 90 degrees. Accordingly, the bend radius R_2 may significantly reduce loss relative to bend radius R_1, and moreover, provide a relatively larger degree of tolerance as the intermediate fiber **312** is routed and attached during manufacturing. Accordingly, and depending on the particular D_{offset} chosen, the bend radius R_2 may be at least about 1.5× greater than the bend radius R_1 and/or the minimum bend radius R_{min} associated with the intermediate optical fiber **312**. Thus fiber losses may advantageously be minimized or otherwise reduced.

FIG. **5** shows the FPC **322** in isolation in accordance with an embodiment. As shown, the FPC **322** includes leads **503** for connecting with external mating circuitry and controllers (not shown), a TIA **203**, and a slot **324**. The FPC **322** includes an overall length L_5 and an overall width W_5. The overall length L_5 may measure about 10 mm and width W_5 may measure about 9 mm, although other lengths and widths are within the scope of this disclosure. In some cases, the overall width W_5 allows the FPC **322** to reside within the footprint of the transceiver housing **102**, and more particularly, is less than or about equal to the width W_1 of the transceiver housing **102**.

In an embodiment, the slot **324** is configured to surround at least a portion of the AWG **202**, and allows the AWG device **202** to occupy a rearward position of the housing **501** by allowing an end of the AWG **202** to abut the edge **509** of the slot **324**. The slot **324** may also be accurately referred to as a notch, opening, or cutout. The slot **324** of the FPC **322** can include a width W_4 substantially equal to or slightly greater (e.g., +5%) than a corresponding cross-wise width W_5 of the AWG device **202**. Likewise, the slot **324** of the FPC **322** can include a length L_5 configured to allow at least a portion of the AWG device **202** to extend into the slot **324**. In one specific example embodiment, the slot **324** includes a width W_4 of about 2 mm and a length L_5 of about 2 mm, although other lengths and widths may be used depending on the particular dimensions chosen for the AWG device **202**.

Further Example Embodiments

In accordance with an aspect of the present disclosure an optical transceiver is disclosed. The optical transceiver including a housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis, wherein the plurality of sidewalls define a cavity having a first longitudinal center line, an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity, the second longitudinal center line being disposed at a lateral offset D_{offset} relative to the first longitudinal center line, an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber, and an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device, the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius equal to or greater than a minimum bend radius R_{min} associated with the intermediate optical fiber to reduce fiber bending losses.

In accordance with another aspect of the present disclosure an optical transceiver module is disclosed. The optical transceiver module including a transceiver housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis, wherein the plurality of sidewalls define a cavity having a first longitudinal center line, a multi-channel receiver optical sub-assembly (ROSA) arrangement located in a cavity of the transceiver housing, the ROSA arrangement comprising an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity, the second longitudinal center line being disposed at a lateral offset D_{offset} relative to the first longitudinal center line, an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber, and an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device, the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius equal to or greater than a minimum bend radius R_{min} associated with the intermediate optical fiber to reduce fiber bending losses, a multi-channel transmitter optical assembly (TOSA) including at least one laser package located in the transceiver housing for transmitting optical signals at different channel wavelengths.

In accordance with another aspect of the present disclosure an optical transceiver is disclosed. The optical transceiver including a housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis, wherein the plurality of sidewalls define a cavity having a first longitudinal center line, an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity, the second longitudinal center line being disposed at a lateral offset D_{offset} relative to the first longitudinal center line, an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber, and an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device, the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius greater than or equal to a minimum bend radius R_{min} associated with the intermediate optical fiber, the minimum bend radius R_{min} being 4 millimeters.

While the principles of the disclosure have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the disclosure. Other embodiments are contemplated within the scope of the present disclosure in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present disclosure, which is not to be limited except by the following claims.

What is claimed is:

1. An optical transceiver comprising:

a housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis, wherein the plurality of sidewalls define a cavity having a first longitudinal center line;

an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity, the second longitudinal center line being disposed at a lateral offset D_{offset} that measures at least 1 millimeter relative to the first longitudinal center line;

an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber; and

an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device, the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius equal to or greater than a minimum bend radius R_{min} associated with the intermediate optical fiber to reduce fiber bending losses.

2. The optical transceiver of claim **1**, wherein the bend radius is least 1.5× greater than the minimum bend radius R_{min}.

3. The optical transceiver of claim **1**, wherein a diameter of the intermediate optical fiber is about 0.20 to 0.25 millimeters and the bend radius is equal to or greater than 4 mm.

4. The optical transceiver of claim **1**, wherein lateral offset D_{offset} displaces the AWG device towards the optical coupling receptacle relative to the second longitudinal center line of the cavity.

5. The optical transceiver of claim **1**, wherein the housing has a length L_1 of about 20 mm and a width W_1 of about 10 mm.

6. The optical transceiver of claim **1**, wherein the optical receptacle is an LC-type receptacle.

7. The optical transceiver of claim **1**, further comprising:

a flexible printed circuit (FPC) disposed at least partially within the cavity and electrically coupled to the AWG device, wherein the FPC includes a slot having a width W_4 and a length L_5, the width W_4 and the length L_5 being configured to receive and surround at least a portion of the AWG device.

8. The optical transceiver of claim **1**, wherein the AWG device forms at least a portion of a receiver optical subassembly (ROSA) arrangement.

9. The optical transceiver of claim **1**, wherein the AWG device comprises a planar lightwave circuit chip configured to de-multiplex N number of channel wavelengths.

10. An optical transceiver module comprising:

a transceiver housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis, wherein the plurality of sidewalls define a cavity having a first longitudinal center line;

a multi-channel receiver optical sub-assembly (ROSA) arrangement located in a cavity of the transceiver housing, the ROSA arrangement comprising:

an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity, the second longitudinal center line being disposed at a lateral offset D_{offset} relative to the first longitudinal center line, wherein lateral offset D_{offset} displaces the AWG device towards the optical coupling receptacle relative to the second longitudinal center line of the cavity;

an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber; and

an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device, the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius equal to or greater than a minimum bend radius R_{min} associated with the intermediate optical fiber to reduce fiber bending losses;

a multi-channel transmitter optical assembly (TOSA) including at least one laser package located in the transceiver housing for transmitting optical signals at different channel wavelengths.

11. The optical transceiver module of claim **10**, wherein the bend radius is least 1.5× greater than the minimum bend radius R_{min}.

12. The optical transceiver module of claim **10**, wherein a diameter of the intermediate optical fiber is about 0.20 to 0.25 millimeters and the bend radius is equal to or greater than 4 mm.

13. The optical transceiver module of claim **10**, wherein the lateral offset D_{offset} measures at least 1 millimeter relative to the first longitudinal center line of the cavity.

14. The optical transceiver module of claim **10**, wherein the transceiver housing has a length L_1 of about 20 mm and a width W_1 of about 10 mm.

15. The optical transceiver module of claim **10**, wherein the optical receptacle is an LC-type receptacle.

16. An optical transceiver comprising:

a housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis, wherein the plurality of sidewalls define a cavity having a first longitudinal center line;

an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity, the second longitudinal center line being disposed at a lateral offset D_{offset} that measures at least 1 millimeter relative to the first longitudinal center line;

an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber; and

an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device, the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius greater than or equal to a minimum bend radius R_{min} associated with the intermediate optical fiber, the minimum bend radius R_{min} being 4 millimeters.

17. The optical transceiver of claim **16**, wherein the optical transceiver is implemented in a small form-factor (SFF) housing.

18. The optical transceiver of claim **17**, wherein lateral offset D_{offset} displaces the AWG device towards the optical coupling receptacle relative to the second longitudinal center line of the cavity.

* * * * *

EXHIBIT F

US010379301B2

(12) **United States Patent**
Luo et al.

(10) **Patent No.: US 10,379,301 B2**
(45) **Date of Patent: Aug. 13, 2019**

(54) **MULTI-CHANNEL PARALLEL OPTICAL RECEIVING DEVICE**

(71) Applicant: **Global Technology Inc.**, Ningbo (CN)

(72) Inventors: **Jian-Hong Luo**, Ningbo (CN); **Dong-Biao Jiang**, Ningbo (CN); **Peng Nie**, Ningbo (CN); **Xiao-Liang Ding**, Ningbo (CN)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/432,242**

(22) Filed: **Feb. 14, 2017**

(65) **Prior Publication Data**

US 2017/0336582 A1 Nov. 23, 2017

(30) **Foreign Application Priority Data**

May 23, 2016 (CN) 2016 1 03460078

(51) **Int. Cl.**
G02B 6/42 (2006.01)
G02B 6/12 (2006.01)
G02B 6/32 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/4249*** (2013.01); ***G02B 6/12019*** (2013.01); ***G02B 6/32*** (2013.01); ***G02B 6/4214*** (2013.01); ***G02B 6/4281*** (2013.01)

(58) **Field of Classification Search**
CPC G02B 6/12019; G02B 6/32; G02B 6/4214; G02B 6/4249
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,617,234	A	4/1997	Koga et al.
6,305,848	B1	10/2001	Gregory
7,058,263	B2	6/2006	Welch et al.

(Continued)

OTHER PUBLICATIONS

PCT Search Report and Written Opinion dated Jul. 6, 2017, received in corresponding PCT Application No. PCT/US17/29350, 9 pgs.

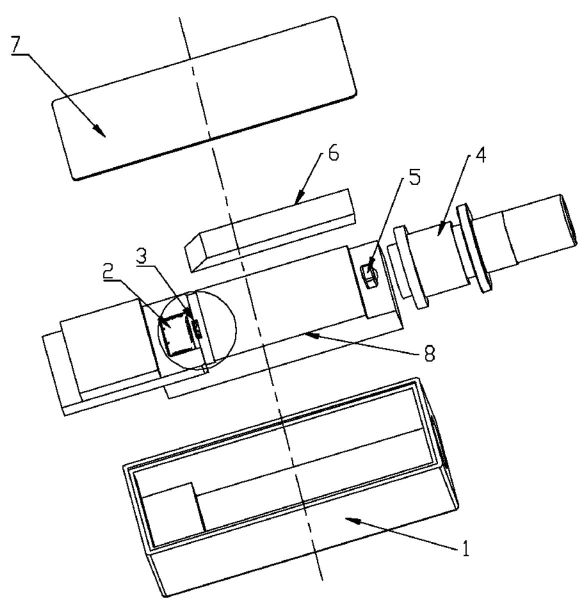
(Continued)

Primary Examiner — Daniel Petkovsek
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC

(57) **ABSTRACT**

The present disclosure provides a multi-channel parallel optical receiving device, including a carrier, a light receiving chip, a plurality of optoelectronic diodes disposed on a top surface of an end of the carrier, an optical fiber connector disposed in another end of the carrier, and an arrayed waveguide grating disposed on the top surface of the carrier. The plurality of optoelectronic diodes is electrically connected to the light receiving chip, and an input end of the arrayed waveguide grating is connected to the optical fiber connector for receiving an optical signal from the optical fiber. The optical signals are divided into multi-channel optical signals in parallel. The top surface of an output end of the arrayed waveguide grating is at a predetermined angle, causing the multi-channel optical signals to be reflected by the top surface and to photosensitive surfaces of the optoelectronic diodes arranged in parallel.

7 Claims, 6 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

7,162,124	B1 *	1/2007	Gunn, III	G02B 6/30 385/27
7,329,054	B1	2/2008	Epitaux et al.	
7,376,308	B2	5/2008	Cheben et al.	
7,532,783	B2	5/2009	Bai	
7,941,053	B2	5/2011	Dallesasse	
8,831,433	B2	9/2014	Ho et al.	
9,341,786	B1 *	5/2016	Gamache	G02B 6/30
9,476,763	B2	10/2016	Kachru et al.	
9,482,819	B2	11/2016	Li et al.	
9,553,671	B1	1/2017	Nagarajan et al.	
9,557,500	B1	1/2017	Luo et al.	
10,088,639	B2	10/2018	Mentovich et al.	
2003/0174964	A1 *	9/2003	Gao	G02B 6/1221 385/49
2004/0161186	A1 *	8/2004	Crafts	G02B 6/12004 385/14
2012/0301152	A1	11/2012	Edwards et al.	
2015/0249501	A1	9/2015	Nagarajan	
2015/0256259	A1	9/2015	Huang et al.	
2015/0316732	A1	11/2015	Schamuhn et al.	
2016/0131854	A1	5/2016	De Jong	
2016/0149662	A1 *	5/2016	Soldano	G02B 6/30 398/51
2016/0349451	A1 *	12/2016	Shen	G02B 6/12019
2017/0168252	A1 *	6/2017	Pezeshki	G02B 6/4246
2017/0187462	A1	6/2017	Luo et al.	
2017/0248763	A1	8/2017	Kawamura et al.	
2017/0307819	A1	10/2017	Ho et al.	
2019/0018206	A1	1/2019	Luo et al.	

OTHER PUBLICATIONS

U.S. Office Action dated Aug. 21, 2017, received in U.S. Appl. No. 15/137,823, 13 pgs.

U.S. Office Action dated Mar. 18, 2019, received in related U.S. Appl. No. 15/971,621, 17 pgs.

U.S. Office Action dated Apr. 16, 2019, received in related U.S. Appl. No. 16/142,466, 23 pgs.

* cited by examiner

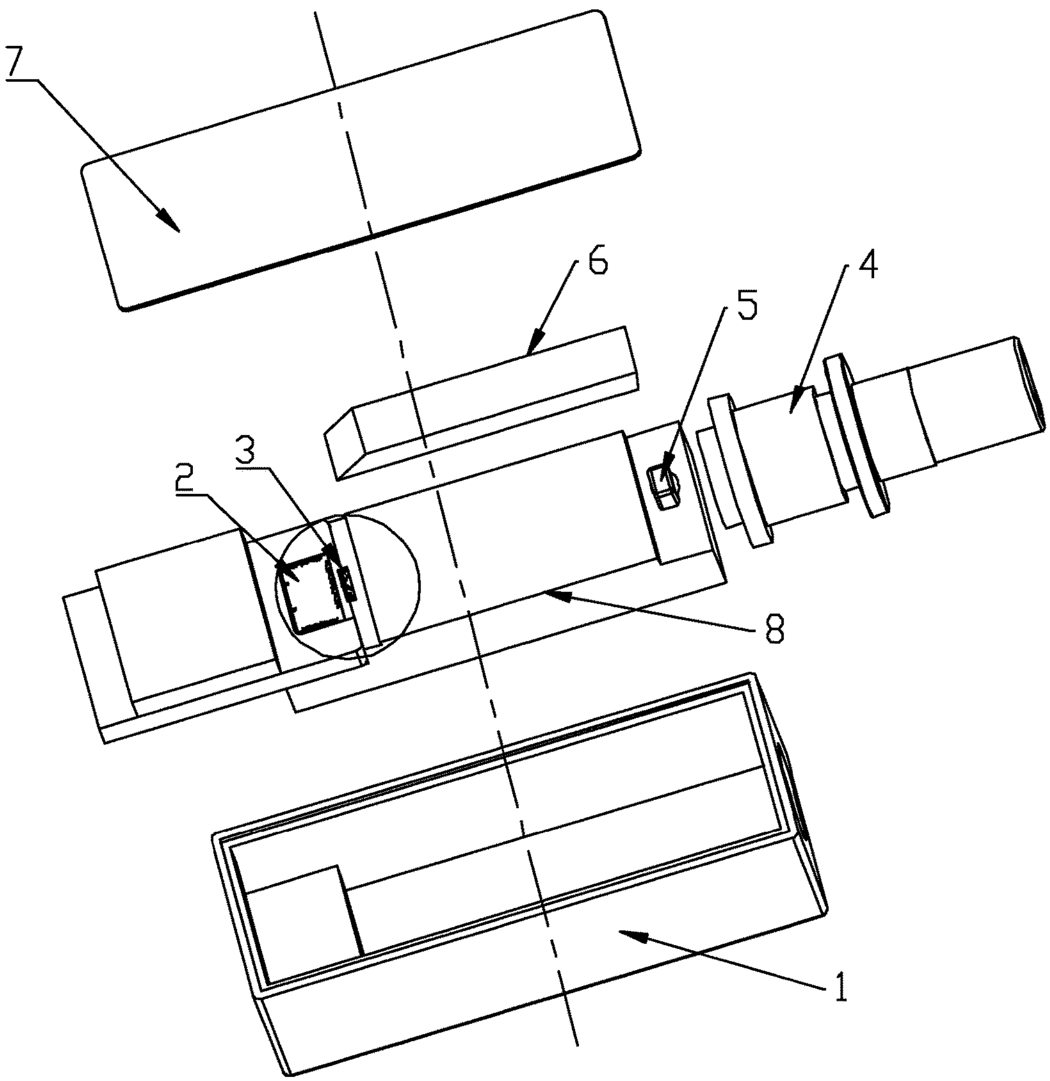


FIG. 1

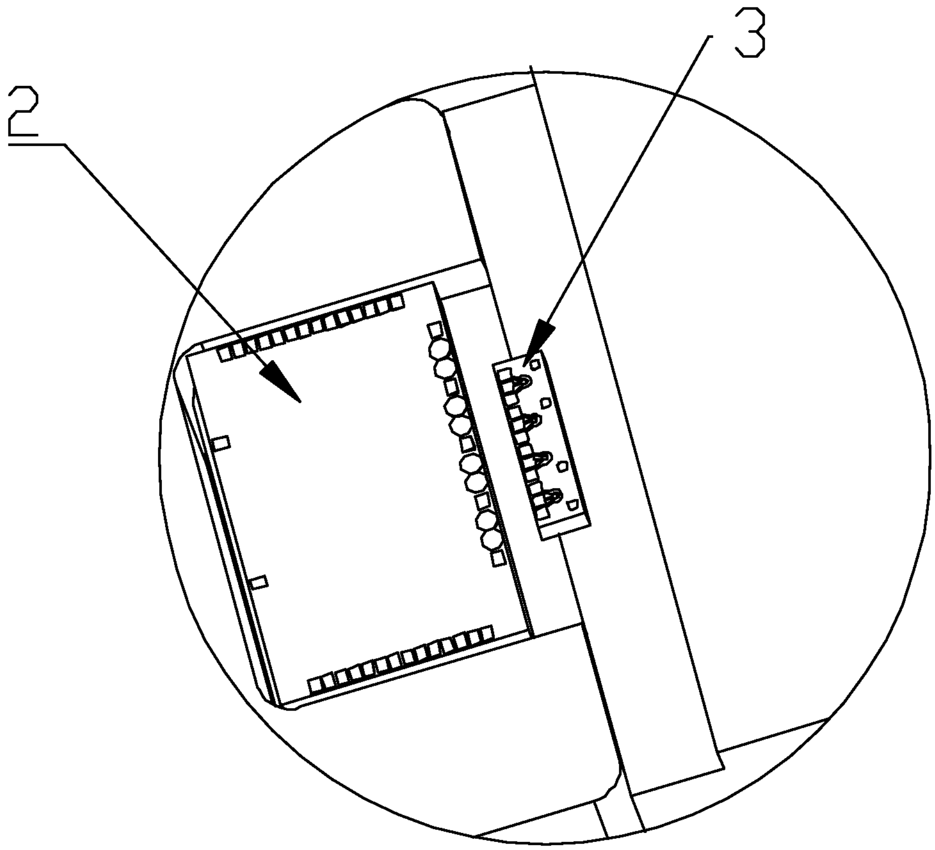


FIG. 2

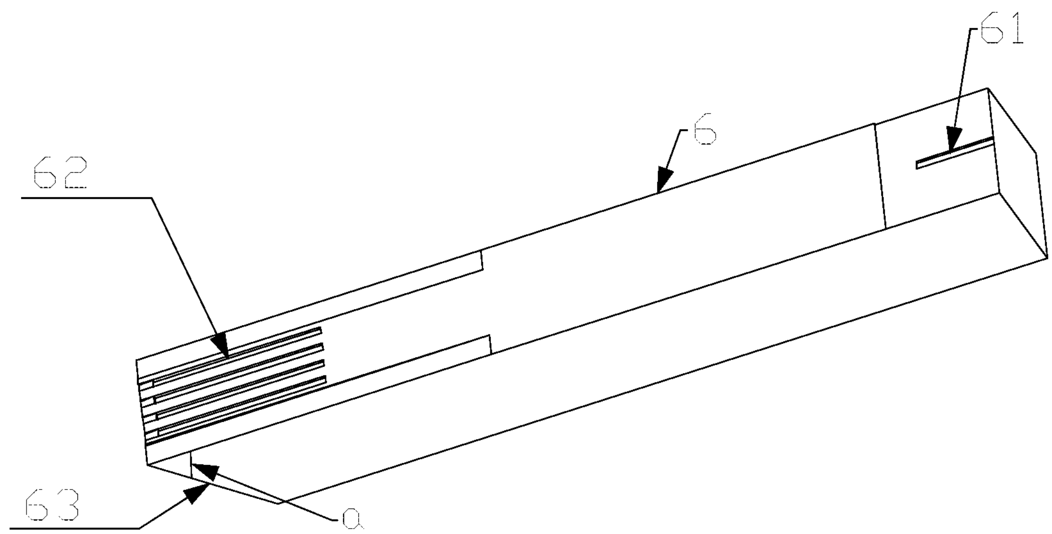


FIG. 3

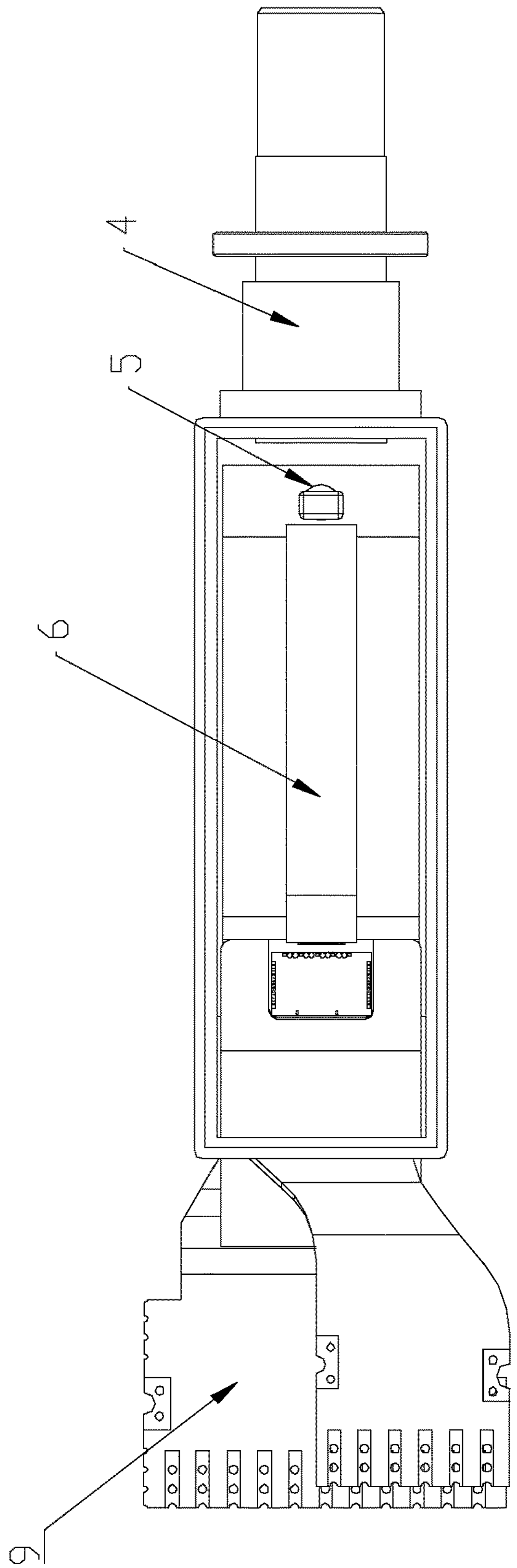


FIG. 4

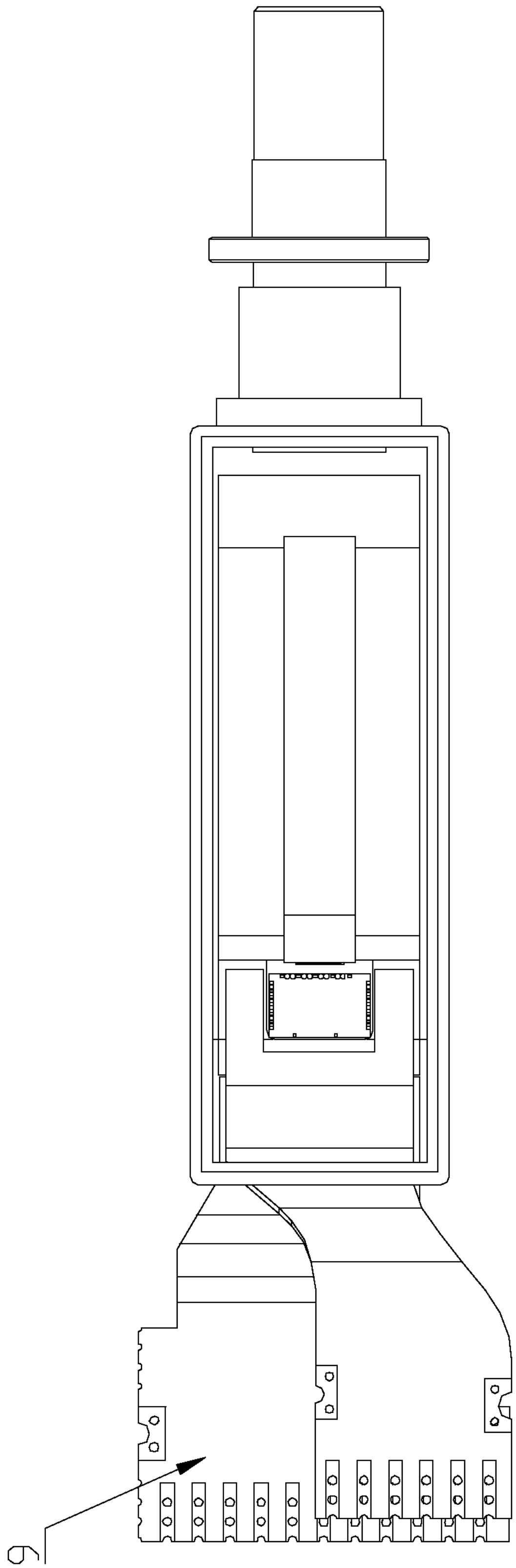


FIG. 5

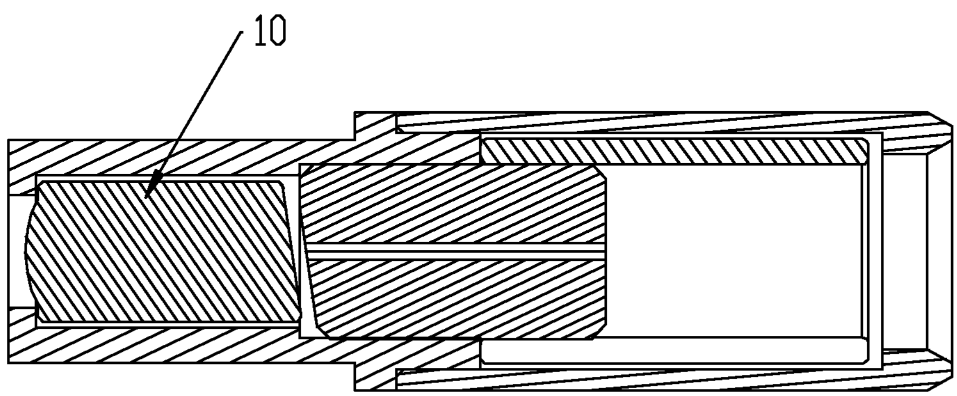


FIG. 6

MULTI-CHANNEL PARALLEL OPTICAL RECEIVING DEVICE

TECHNICAL FIELD

The present disclosure relates to fiber optical communications, and, more particularly, to multi-channel parallel optical receiving modules.

BACKGROUND

The optical receiving module refers to a device used in the field of the fiber optical communication for receiving an optical signal from an optical fiber and converting the received optical signal into an electrical signal. With the corresponding market continuing to grow, the demands of product cost and performance become stricter and stricter. In the current optical communication of the dada center, transmitting speed of a single channel of product and the number of the channels must increase in order to improve the overall performance of the datacenter whose limited physical space puts restraint on density of the products. Hence, in many circumstances, multi-channel paralleling lights need to be enabled in the optical module. The data transmission of the optical modules needs to be implemented by connecting the optical modules, and the optical modules are connected by a jumper, resulting in higher cost.

SUMMARY

The present disclosure overcomes the currently existing technical drawback. The present disclosure provides a multi-channel parallel optical receiving module capable of achieving multi-channel receiving and transmitting. Further, the disclosed module is reliable and could be manufactured with reduced cost.

The present disclosure provides a multi-channel parallel optical receiving module including a carrier and a light receiving chip. A plurality of optoelectronic diodes may be disposed in array on a top surface of an end of the carrier, and the optoelectronic diodes may be electrically connected to the light receiving chip. An optical fiber connector may be disposed in another end of the carrier. An arrayed waveguide grating may be further disposed on the top surface of the carrier, and an input end of the arrayed waveguide grating may be connected to the optical fiber connector for receiving an optical signal from the optical fiber. The optical signals may be divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths. The top surface of an output end of the arrayed waveguide grating may be at a predetermined angle so that the multi-channel optical signals may be reflected by the top surface to photosensitive surfaces of the plurality of optoelectronic diodes arranged in array.

With the aforementioned structure, the present disclosure has following features. In the present disclosure, the top surface of the arrayed waveguide grating may be designed to allow for the optical signals emitting from the arrayed waveguide grating to be reflected by the top surface to the photosensitive surfaces of the optoelectronic diodes. Based on such design, after the position of the optoelectronic diodes is determined, only a placement groove or a guiding structure for the arrayed waveguide grating is needed on the carrier to guide the arrayed waveguide grating to be in the position aligning with the optoelectronic diodes. Accordingly, the arrayed waveguide grating may be installed without too much difficulty, and the coupling between the arrayed waveguide grating and the optoelectronic diodes may be no longer necessary. Further, the optoelectronic diodes and the light receiving chip may be disposed on the same surface, simplifying the design of the structure and reducing the length of the bonding wire to enhance the integrity of the entire structure and lower the manufacturing cost of the same.

In some embodiments, the plurality of optoelectronic diodes may be disposed on the same circuit board. With this structure, the position of the optoelectronic diodes may become definitive to simplify and streamline the manufacturing process.

In some embodiments, the amount of the optoelectronic diodes may be equal to the amount of the optical paths divided by the arrayed waveguide grating.

In some embodiments, the predetermined angle of the top surface of an output end of the arrayed waveguide grating may be 41 to 46 degrees.

In some embodiments, the predetermined angle of the top surface of the output end of the arrayed waveguide grating may be 42 degrees.

In some embodiments, a first lens, for coupling the optical fiber, may be disposed between the input end of the arrayed waveguide grating and the optical fiber connector. With this structure, the first lens may be disposed between the optical fiber connector and the arrayed waveguide grating for a coupling process to be finalized.

In some embodiments, the input end of the arrayed waveguide grating may be inserted directly into the optical fiber connector, and a graded index lens may be disposed in an end where the optical fiber connector and the arrayed waveguide grating may connect. With this structure, the number of the coupling is reduced, which in turn may improve the integrity of the product.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more understood from the detailed description given herein below and the accompanying drawings which are given by way of illustration only and thus are not limitative of the present disclosure and wherein:

FIG. **1** shows a an exploded view of a structure of the present disclosure;

FIG. **2** shows an enlarged view of a structure in FIG. **1**;

FIG. **3** shows perspective view of a structure of an arrayed waveguide grating;

FIG. **4** shows a perspective view of a structure according to a first embodiment of the present disclosure;

FIG. **5** shows a perspective view of a structure according to a second embodiment of the present disclosure; and

FIG. **6** shows a sectional view of an optical fiber connector according to a second embodiment of the present disclosure.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details. In other instances, well-known structures and devices are schematically shown in order to simplify the drawings.

As shown in FIG. **1** to FIG. **6**, the present disclosure provides a multi-channel parallel optical receiving device which includes a carrier **8** and a light receiving chip **2**. A plurality of optoelectronic diodes **3** may be disposed on a top surface of an end of the carrier **8**, and the plurality of optoelectronic diodes **3** may be electrically connected to the light receiving chip **2**. The light receiving chip **2** of this embodiment may be a trans-impedance amplifier (TIA) chip, and the optoelectronic diodes **3** and the trans-impedance amplifier (TIA) chip may be connected by bonding wires. An optical fiber connector **4** may be disposed at another end of the carrier **8**, and an arrayed waveguide grating **6** may be further disposed on the top surface of the carrier **8**. An input end **61** of the arrayed waveguide grating **6** may be connected to the optical fiber connector **4** for receiving an optical signal from the optical fiber. The optical signals may be divided into multi-channel optical signals in parallel by the arrayed waveguide grating **6** based on their wavelengths. The top surface **63** of an output end **62** of the arrayed waveguide grating **6** may be designed to be at a predetermined angle, allowing for the multi-channel optical signals to be reflected by the top surface **63** to the photosensitive surfaces of the plurality of optoelectronic diodes **3** arranged in array.

The optical receiving module of this embodiment may further include a bottom shell **1** and top cap **7**, defining a space in which the aforementioned structure may be placed so that the aforementioned structure may be protected. Some other shell bodies may be used in the present disclosure to serve the protection purpose. The light receiving chip **2** may be connected to a flexible circuit board **9** by the bonding wires, and the flexible circuit board **9** may be used to connect to other devices of the optical device. The arrayed waveguide grating **6** may include an input end **61** and an output end **62**, and the optical signal may be input from the input end. Since a wavelength division multiplexing technology may be used in the optical fiber of the present disclosure, the signals with different wavelengths may be divided into the multi-channel optical signals and output from the output end. The arrayed waveguide grating is a well-known technology, in which the plurality of optical filters capable of filtering the optical signals in different wavelengths is used, so that each of the channels may transmit the optical signal having the specific wavelength range, and the optical signals from the optical fiber may be divided before being outputted. The top surface **63** may be an inclined plane, enabling the reflection of the optical signal upon the top surface **63**. The reflected optical signal may be transmitted to the photosensitive surface of the plurality of optoelectronic diodes **3** on the carrier **8** since the top surface **63** may tilt at a predetermined angle. Generally speaking, the optical paths from the output end **62** of the arrayed waveguide grating **6** may correspond to the optoelectronic diodes **3**. This embodiment here shows four channels as an example, as the amount of the channels could be based on the actual demand.

With the aforementioned structure, the present disclosure has following features. In the present disclosure, the top surface **63** of the arrayed waveguide grating **6** may be designed to be with a predetermined angle. Therefore, the optical signals emitting from the arrayed waveguide grating **6** may be reflected by the top surface **63** to the photosensitive surfaces of the plurality of optoelectronic diodes. Based on such design, after the position of the optoelectronic diodes is determined, only a placement groove or a guiding structure for the arrayed waveguide grating **6** may be needed on the carrier **8** to guide the arrayed waveguide grating **6** to be in the position aligning with the optoelectronic diodes. Accordingly, the arrayed waveguide grating may be installed without much difficulty, and the coupling between the arrayed waveguide grating **6** and the optoelectronic diodes may be no longer necessary. Further, the optoelectronic diodes and the light receiving chip **2** may be disposed on the same surface, reducing length of the bonding wire to improve the integrity and lower the manufacturing cost.

The plurality of optoelectronic diodes may be disposed on the same circuit board. The position of the optoelectronic diodes may become definitive so as to simplify and streamline the manufacturing process. The optoelectronic diodes may be disposed onto the carrier **8** simultaneously, minimizing the iteration of disposing the optoelectronic diodes.

The amount of the optoelectronic diodes may be equal to the amount of the optical paths divided by the arrayed waveguide grating **6**.

The predetermined angle of the top surface **63** of an output end **62** of the arrayed waveguide grating **6** may be 41 to 46 degrees.

The predetermined angle of the top surface **63** of the output end **62** of the arrayed waveguide grating **6** may be 42 degrees.

FIG. **4** is an embodiment of the present disclosure in which first lens **5**, for coupling the optical fiber, may be disposed between the input end **61** of the arrayed waveguide grating **6** and the optical fiber connector **4**. In this embodiment, the first lens **5** disposed on the carrier **8** may be located on the optical path of the optical fiber connector **4** and the arrayed waveguide grating **6**, for the optical coupling to be realized.

FIG. **5** to FIG. **6** show a second embodiment of the present disclosure in which the input end **61** of the arrayed waveguide grating **6** may be inserted directly into the optical fiber connector **4**, and a graded index lens **10** may be disposed on a end where the optical fiber connector **4** and the arrayed waveguide grating **6** may connect. With this structure, the lens does not need to be coupled on the carrier **8**, reducing the number of the optical coupling and increasing the integrity of the entire product.

The foregoing description, for the purpose of explanation, has been described with reference to specific embodiments; however. The embodiments were chosen and described in order to best explain the principles of the disclosure and its practical applications, to thereby enable others skilled in the art to best utilize the disclosure and various embodiments with various modifications as are suited to the particular use contemplated. The embodiments depicted above and the appended drawings are exemplary and are not intended to be exhaustive or to limit the scope of the disclosure to the precise forms disclosed. Modifications and variations are possible in view of the above teachings.

What is claimed is:

1. A multi-channel parallel optical receiving device, comprising:

a carrier;

a light receiving chip disposed on a top surface of an end of the carrier;

a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and the plurality of optoelectronic diodes electrically connected to the light receiving chip via bonding wire, wherein the optoelectronic diodes and the light receiving chip are disposed directly on the same top surface of the end of the carrier;

an optical fiber connector disposed in an end of the carrier;

an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier, the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end, and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber, wherein the top surface of the carrier underlies the middle of the arrayed waveguide grating; and

wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths, a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel, wherein the predetermined angle of the top surface defined by the output end of the arrayed waveguide grating is in a range of 41 to 46 degrees such that the top surface provides the reflection.

2. The multi-channel parallel optical receiving device according to claim **1**, wherein the top surface of the end of the carrier is defined at least in part by a circuit board, and wherein the plurality of optoelectronic diodes and the light receiving chip are directly disposed on the circuit board.

3. The multi-channel parallel optical receiving device according to claim **1**, wherein the amount of the optoelectronic diodes is equal to the amount of optical paths divided by the arrayed waveguide grating.

4. The multi-channel parallel optical receiving device according to claim **1**, wherein the predetermined angle of the top surface of the output end of the arrayed waveguide grating is 42 degrees.

5. The multi-channel parallel optical receiving device according to claim **1**, wherein a first lens, for coupling the optical fiber, is disposed between the input end of the arrayed waveguide grating and the optical fiber connector.

6. The multi-channel parallel optical receiving device according to claim **1**, wherein the input end of the arrayed waveguide grating is inserted directly into the optical fiber connector and a graded index lens is disposed in an end where the optical fiber connector and the arrayed waveguide grating connect.

7. A multi-channel parallel optical receiving device, comprising:

a carrier;

a light receiving chip disposed on a top surface of an end of the carrier;

a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and the plurality of optoelectronic diodes electrically connected to the light receiving chip via wire bonding, wherein the plurality of optoelectronic diodes and the light receiving chip are directly disposed on the same top surface of the end of the carrier;

an optical fiber connector disposed in an end of the carrier;

an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier, the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end, and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber;

wherein the top surface of the carrier that defines the midpoint of the carrier underlies the middle of the arrayed waveguide grating; and

wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths, a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle of 42 degrees, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel.

* * * * *

EXHIBIT G

US010313024B1

(12) **United States Patent**
Ho et al.

(10) **Patent No.: US 10,313,024 B1**
(45) **Date of Patent: Jun. 4, 2019**

(54) **TRANSMITTER OPTICAL SUBASSEMBLY WITH TRACE ROUTING TO PROVIDE ELECTRICAL ISOLATION BETWEEN POWER AND RF TRACES**

(71) Applicant: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(72) Inventors: **I-Lung Ho**, Sugar Land, TX (US); **Kevin Liu**, Houston, TX (US); **YongXuan Liang**, Stafford, TX (US)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/963,246**

(22) Filed: **Apr. 26, 2018**

(51) **Int. Cl.**

H04J 14/02	(2006.01)
H04B 10/00	(2013.01)
H04B 10/80	(2013.01)
H01S 5/022	(2006.01)
H01S 5/024	(2006.01)
H01S 5/40	(2006.01)
H04B 10/50	(2013.01)
H01S 5/042	(2006.01)

(52) **U.S. Cl.**
CPC ***H04B 10/80*** (2013.01); ***H01S 5/0222*** (2013.01); ***H01S 5/02284*** (2013.01); ***H01S 5/02415*** (2013.01); ***H01S 5/042*** (2013.01); ***H01S 5/4087*** (2013.01); ***H04B 10/50*** (2013.01); ***H04J 14/02*** (2013.01)

(58) **Field of Classification Search**
USPC 398/135, 164, 79
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,798,820 B2 *	9/2010	Hong	H05K 1/117 385/92
9,614,620 B2 *	4/2017	Ho	G02B 6/43
2004/0163836 A1 *	8/2004	Kumar	H01S 5/02212 174/50
2005/0105915 A1 *	5/2005	Light	G02B 6/4292 398/164
2005/0175350 A1 *	8/2005	Hartzell	G02B 6/4246 398/135

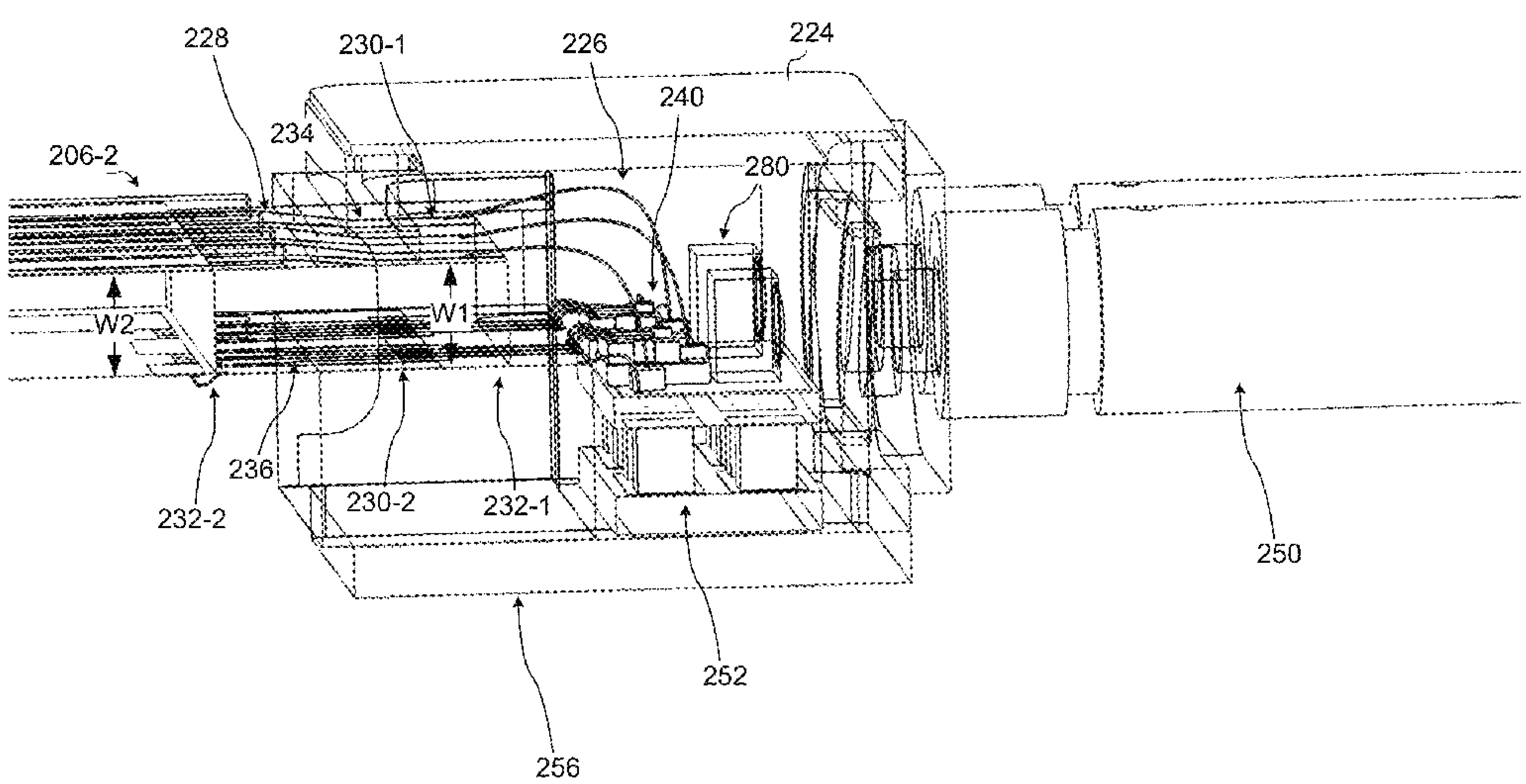
(Continued)

Primary Examiner — David C Payne
Assistant Examiner — Pranesh K Barua
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

The present disclosure is generally directed to a transmitter optical subassembly (TOSA) having a hermetically-sealed housing with a feedthrough device that electrically isolates RF and power traces. In more detail, a TOSA consistent with the present disclosure includes a substrate with driving circuitry disposed thereon. A first end of the substrate may electrically couple to transmit connecting circuitry and a second end may couple to a hermetically-sealed housing. The hermetically-sealed housing can include one or more laser packages for emitting associated channel wavelengths in addition to monitor photodiodes (PDs), and temperature control devices such as TECs. The hermetic-sealed housing includes a first end with a feedthrough device that provides traces to electrically couple to the circuitry of the substrate. The hermetic-sealed housing further includes an optical coupling port, e.g., a LC connector, for coupling to an external fiber, for example.

17 Claims, 4 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0225955	A1*	10/2005	Grebenkemper	H05K 1/0218 361/780
2005/0286906	A1*	12/2005	Togami	G02B 6/4277 398/164
2007/0237472	A1*	10/2007	Aronson	G02B 6/4292 385/101
2011/0188863	A1*	8/2011	Mason	H04B 10/40 398/137
2012/0301152	A1*	11/2012	Edwards	G02B 6/4201 398/135
2013/0114629	A1*	5/2013	Firth	G02B 6/4201 372/20
2014/0152373	A1*	6/2014	Romas, Jr.	H01L 25/18 327/374
2015/0162989	A1*	6/2015	Oomori	H04B 10/50 398/201
2015/0162990	A1*	6/2015	Daiber	H04B 10/503 398/183
2016/0139477	A1*	5/2016	Jack	G09G 3/19 359/275
2017/0272169	A1*	9/2017	Ho	H04B 10/40

* cited by examiner

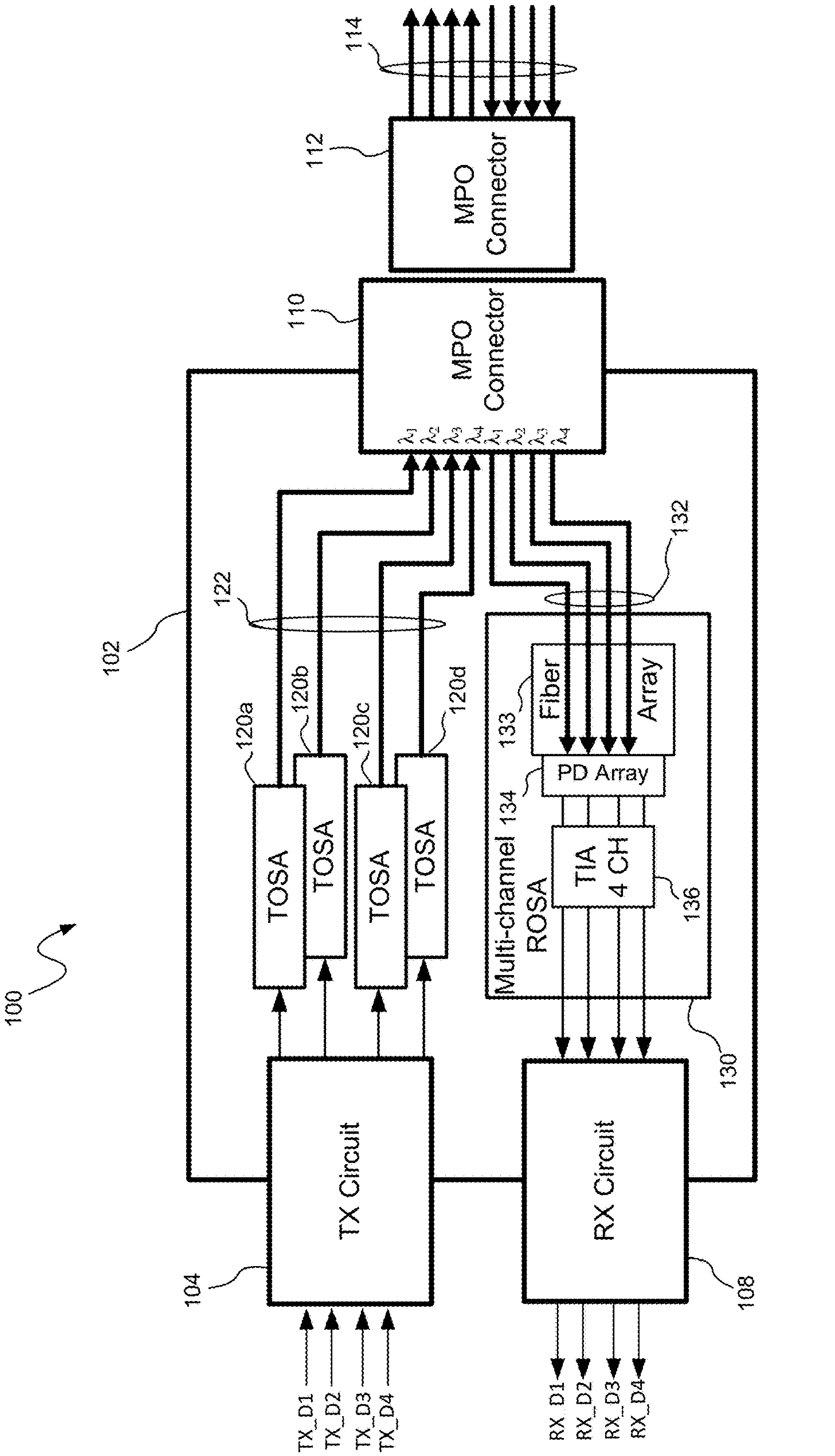

100
102
104
108
110
112
114
122
130
132
133
134
136
120a
120b
120c
120d
MPO Connector
MPO Connector
TOSA
TOSA
TOSA
TOSA
Fiber Array
PD Array
TIA 4 CH
Multi-channel ROSA
TX Circuit
RX Circuit
λ1 λ2 λ3 λ4 λ1 λ2 λ3 λ4
TX_D1
TX_D2
TX_D3
TX_D4
RX_D1
RX_D2
RX_D3
RX_D4

FIG. 1A

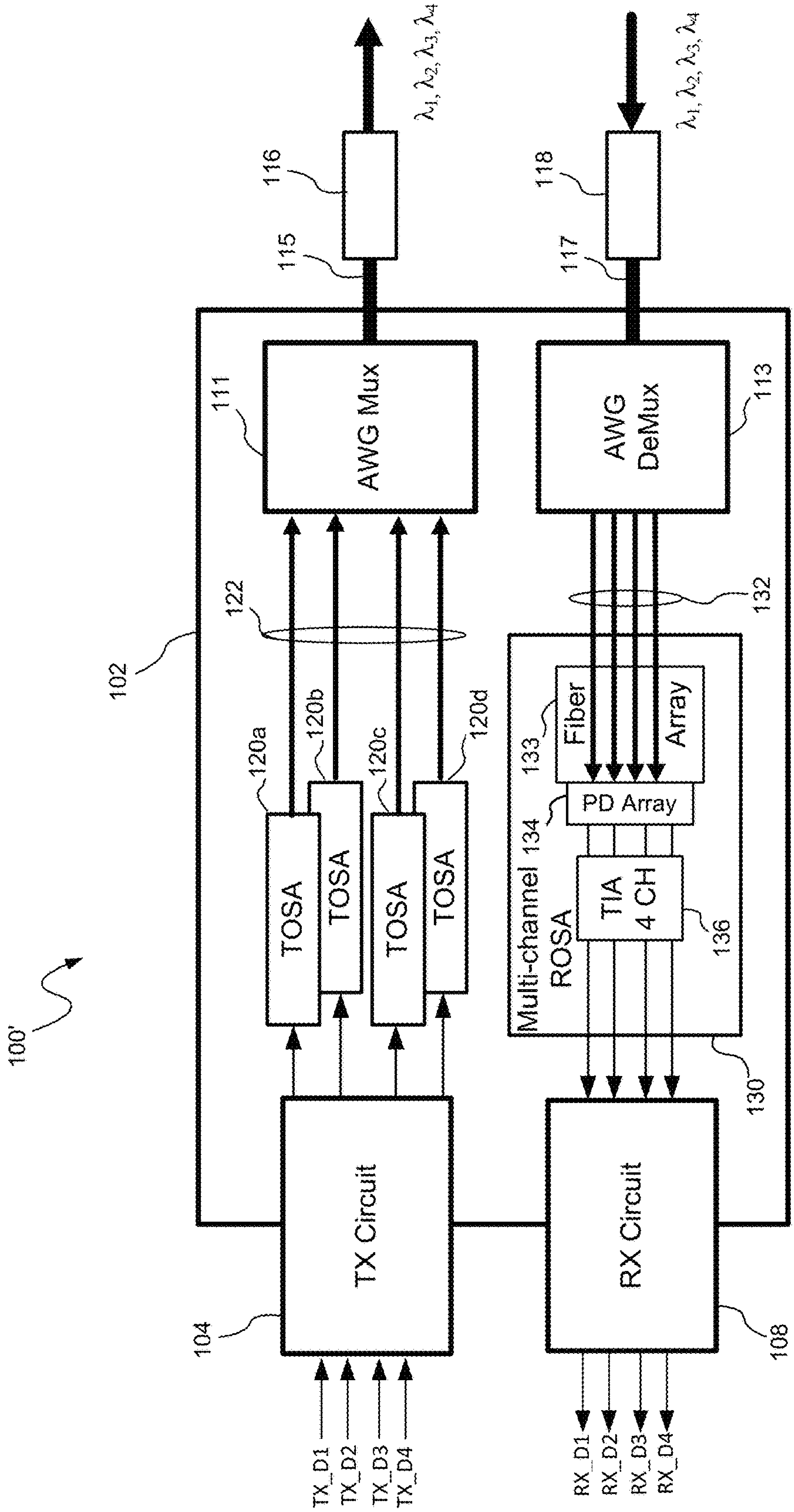

100'
102
104
108
111
113
115
116
117
118
120a
120b
120c
120d
122
130
132
133
134
136
$\lambda_1, \lambda_2, \lambda_3, \lambda_4$
$\lambda_1, \lambda_2, \lambda_3, \lambda_4$
AWG Mux
AWG DeMux
TOSA
TOSA
TOSA
TOSA
Fiber Array
PD Array
TIA 4 CH
Multi-channel ROSA
TX Circuit
RX Circuit
TX_D1
TX_D2
TX_D3
TX_D4
RX_D1
RX_D2
RX_D3
RX_D4

FIG. 1B

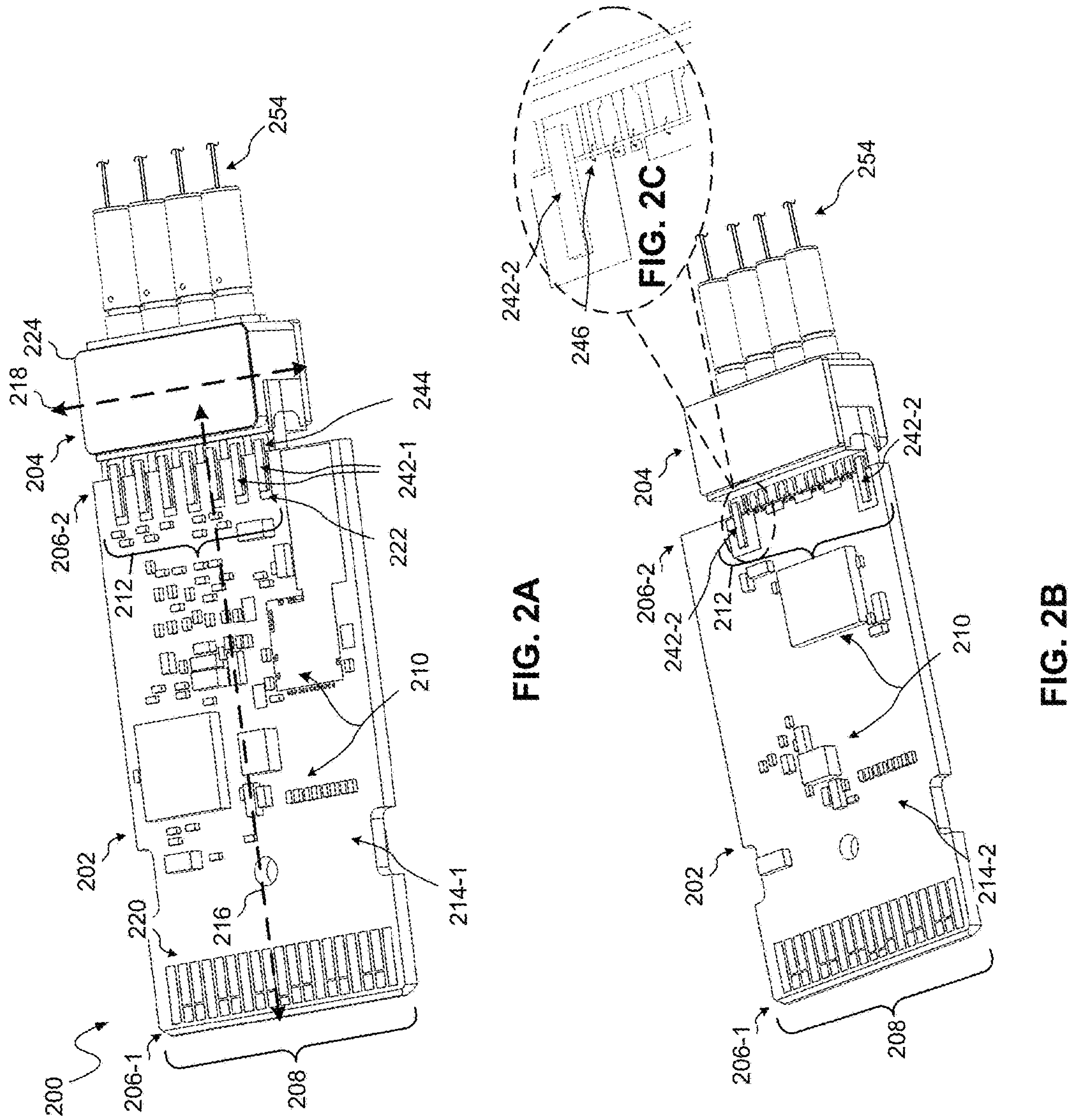

200
202
204
206-1
206-2
208
210
212
214-1
216
218
220
222
224
242-1
244
254
242-2
246
214-2
FIG. 2C

FIG. 2A

FIG. 2B

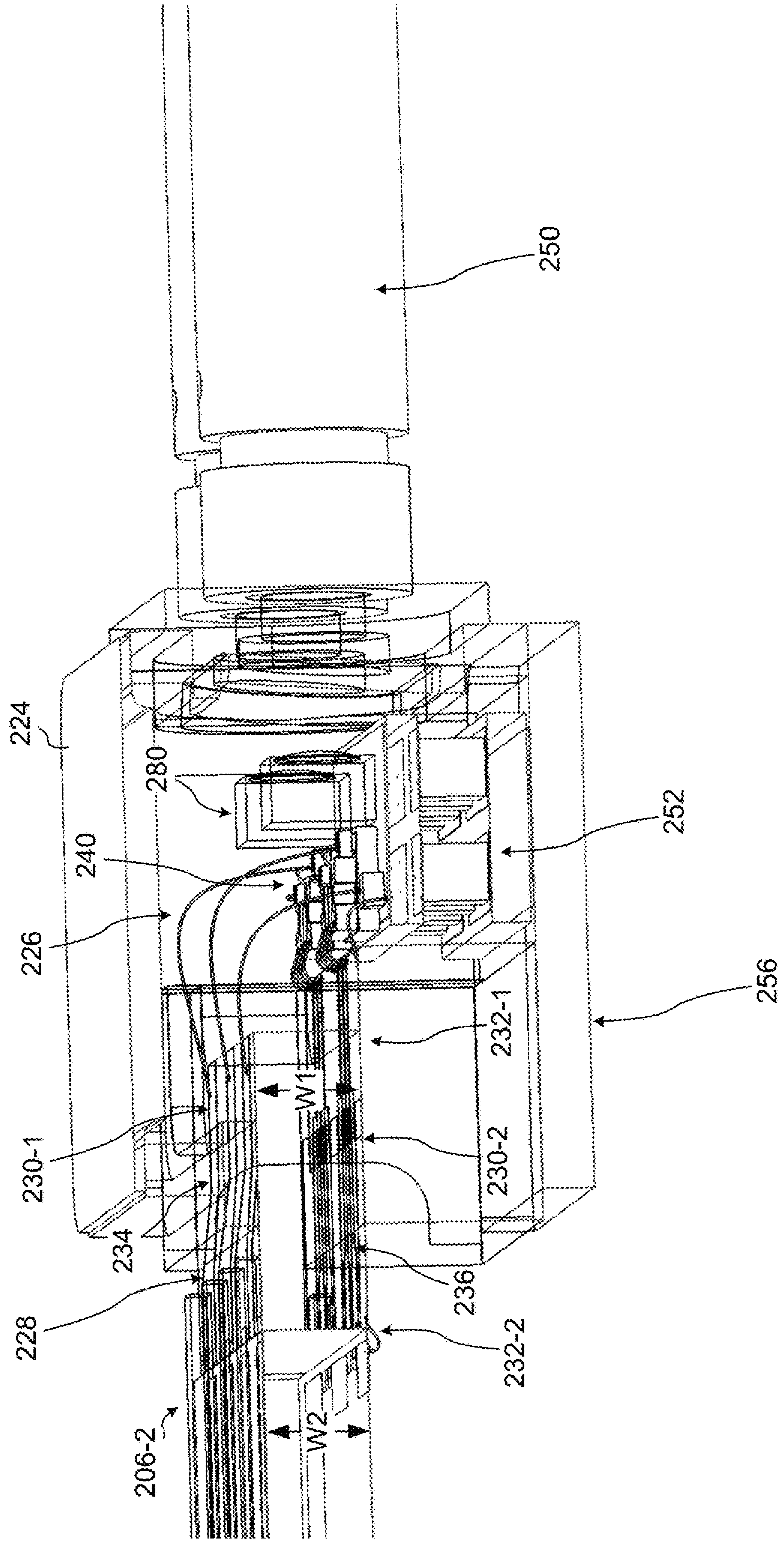

250
224
280
252
240
226
256
232-1
W1
230-1
230-2
234
236
228
232-2
206-2
W2

FIG. 3

TRANSMITTER OPTICAL SUBASSEMBLY WITH TRACE ROUTING TO PROVIDE ELECTRICAL ISOLATION BETWEEN POWER AND RF TRACES

TECHNICAL FIELD

The present disclosure relates to optical communications and more particularly, to a transmitter optical subassembly (TOSA) with a hermetically-sealed light engine housing that electrically isolates DC and RF traces to ensure nominal performance.

BACKGROUND INFORMATION

Optical transceivers are used to transmit and receive optical signals for various applications including, without limitation, internet data center, cable TV broadband, and fiber to the home (FTTH) applications. Optical transceivers provide higher speeds and bandwidth over longer distances, for example, as compared to transmission over copper cables. The desire to provide higher speeds in smaller optical transceiver modules for a lower cost has presented challenges, for example, with respect to thermal management, insertion loss, and manufacturing yield.

Optical transceiver modules generally include one or more transmitter optical subassemblies (TOSAs) for transmitting optical signals. In general, TOSAs include one or more lasers to emit one or more channel wavelengths and associated circuitry for driving the lasers. Some optical applications, such as long-distance communication, may require TOSAs to include hermetically-sealed housings with arrayed waveguide gratings, laser packages and associated circuitry disposed therein to reduce loss and ensure optical performance. However, the inclusion of hermetically-sealed components increases manufacturing complexity, cost, and raises non-trivial challenges.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIGS. **1**A and **1**B are block diagrams of multi-channel optical transceivers, consistent with embodiments of the present disclosure.

FIG. **2**A is a perspective view of a first side of an transmitter optical subassembly (TOSA) module consistent with embodiments of the present disclosure.

FIG. **2**B is a perspective view of a second side of the TOSA module of FIG. **2**A consistent with embodiments of the present disclosure.

FIG. **2**C shows an enlarged region of the second side of the TOSA module shown in FIG. **2**B in accordance with an embodiment of the present disclosure.

FIG. **3** shows a cross-sectional view of a hermetically-sealed housing consistent with an embodiment of the present disclosure.

DETAILED DESCRIPTION

As discussed above, some TOSAs can reach optical transmission distances of up to 10 km or more. Such TOSAs may be suitable for use in C form-factor pluggable (CFP), CFP2, CFP4 and quad small form-factor pluggable (QSFP) applications. In general, such TOSAs include a hermetic-sealed package (or housing) with an LC receptacle (or other

suitable port) for optical coupling. The hermetic-sealed package can house laser packages, e.g., electro-absorption modulator integrated lasers (EMLs), power monitors photodiodes (PDs), an optical multiplexer such as an arrayed waveguide grating for multiplexing multiple channel wavelengths, and electrical interconnects such as flexible printed circuit boards. To supply power such as direct current (DC) and RF signaling to drive the lasers, feedthrough devices may be utilized. The feedthrough device may include patterns/traces disposed thereon to propagate signals from external circuitry to components within the hermetic-sealed package. Multiple feedthrough devices may be utilized in some instances to provide both RF and DC signals. However, the available space to route traces shrinks as TOSA packages continue to scale, which can lead to electrical interference between DC and RF signals that may degrade performance.

Thus, the present disclosure is generally directed to a TOSA having a hermetically-sealed housing with a feedthrough device that electrically isolates RF traces from power-related traces (e.g., DC traces, ground traces) by disposing power and RF traces on opposite sides. This configuration of power and RF traces may also be referred to as an opposing arrangement. In more detail, a TOSA consistent with the present disclosure includes a substrate with driving circuitry disposed thereon. A first end of the substrate may electrically couple to transmit connecting circuitry and a second end may couple to a hermetically-sealed housing. Thus, the first end may be referred to as an electrical coupling end and the second end may be referred to as a light engine interface end. The hermetically-sealed housing can include one or more laser packages for emitting channel wavelengths in addition to monitor photodiodes (PDs), and temperature control devices such as TECs. The hermetically-sealed housing includes a first end with a feedthrough device that provides traces to electrically couple to the circuitry of the substrate. The hermetically-sealed housing further includes an optical coupling port, e.g., a LC connector, for coupling to an external fiber, for example. A first side of the feedthrough device may include traces configured to propagate power signals, e.g., DC signals, from circuitry of the substrate to components within the hermetically-sealed housing. On the other hand, a second side of the feedthrough device, opposite the first side, may include traces configured to propagate RF signals from circuitry of the substrate to components within the hermetically-sealed housing.

Therefore, the RF and power signal traces of the feedthrough device may be electrically isolated from each other based on the distance therebetween, e.g., provided by the width of the feedthrough device, and/or the material properties of the feedthrough device. For example, the feedthrough device may comprise ceramic or other suitable material that may provide electrical shielding. Likewise, the power and RF traces may be similarly disposed and routed on either side of the substrate to minimize or otherwise reduce electrical interference. In addition, a first type of interconnect device such as DC bus bars or other similarly rigid device may be utilized to electrically couple traces of the substrate to the corresponding power traces (including ground traces) of the feedthrough substrate. A plurality of the first type of interconnect devices may be both used to provide power and to brace the hermetically-sealed housing to the substrate. A second type of interconnect device, different from the first type, such as wire bonding may be utilized to electrically couple the substrate to the RF traces of the feedthrough device. Wire bonding, although particularly well suited for high-speed RF transmission, can be relatively fragile and the increased rigidity of the interface between the substrate and the hermetic-sealed housing provided by the first type of interconnect device may advantageously provide bracing to limit stress that could break or otherwise compromise the wire bonds.

As used herein, the terms hermetic-sealed and hermetically-sealed may be used interchangeably and refer to a housing that releases a maximum of about $5*10^{-8}$ cc/sec of filler gas. The filler gas may comprise an inert gas such as nitrogen, helium, argon, krypton, xenon, or various mixtures thereof, including a nitrogen-helium mix, a neon-helium mix, a krypton-helium mix, or a xenon-helium mix.

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid. This disclosure is equally applicable to coarse wavelength division multiplexing (CWDM). In one specific example embodiment, the channel wavelengths are implemented in accordance with local area network (LAN) wavelength division multiplexing (WDM), which may also be referred to as LWDM. The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals.

The term substantially, as generally referred to herein, refers to a degree of precision within acceptable tolerance that accounts for and reflects minor real-world variation due to material composition, material defects, and/or limitations/peculiarities in manufacturing processes. Such variation may therefore be said to achieve largely, but not necessarily wholly, the stated characteristic. To provide one non-limiting numerical example to quantify "substantially," minor variation may cause a deviation of up to and including ±5% from a particular stated quality/characteristic unless otherwise provided by the present disclosure.

Referring to the Figures, FIG. **1**A, an optical transceiver **100**, consistent with embodiments of the present disclosure, is shown and described. In this embodiment, the optical transceiver **100** transmits and receives four (4) channels using four different channel wavelengths (λ1, λ2, λ3, λ4) and may be capable of transmission rates of at least about 25 Gbps per channel. In one example, the channel wavelengths λ1, λ2, λ3, λ4 may be 1270 nm, 1290 nm, 1310 nm, and 1330 nm, respectively. Other channel wavelengths are within the scope of this disclosure including those associated with local area network (LAN) wavelength division multiplexing (WDM). The optical transceiver **100** may also be capable of transmission distances of 2 km to at least about 10 km. The optical transceiver **100** may be used, for example, in internet data center applications or fiber to the home (FTTH) applications.

This embodiment of the optical transceiver **100** includes multiple transmitter optical subassemblies (TOSAs) **120***a-d* for transmitting optical signals on different channel wavelengths and a multi-channel receiver optical subassembly (ROSA) **130** for receiving optical signals on different channel wavelengths. The TOSAs **120***a-d* and the multi-channel ROSA **130** are located in a transceiver housing **102**.

A transmit connecting circuit **104** and a receive connecting circuit **108** provide electrical connections to the TOSAs **120***a-d* and the multi-channel ROSA **130**, respectively, within the housing **102**. The transmit connecting circuit **104** is electrically connected to the electronic components (e.g., the laser, monitor photodiode, etc.) in each of the TOSAs **120***a-d* and the receive connecting circuit **108** is electrically connected to the electronic components (e.g., the photodiodes, the TIA, etc.) in the multi-channel ROSA **130**. The transmit connecting circuit **104** and the receive connecting circuit **108** may be flexible printed circuits (FPCs) including at least conductive paths to provide electrical connections and may also include additional circuitry.

Each of the TOSAs **120***a-d* may be implemented as the TOSA **200** as discussed in greater detail below. Each TOSA may be electrically coupled to conductive paths on the transmit connecting circuit **104** and be configured to receive driving signals (e.g., TX_D**1** to TX_D**4**) and launch channel wavelengths on to fibers of the transmit optical fibers **122**.

A multi-fiber push on (MPO) connector **110** provides optical connections to the TOSAs **120***a-d* and the multi-channel ROSA **130** within the housing **102**. The MPO connector **110** is optically coupled to the TOSAs **120***a-d* and the multi-channel ROSA **130** via transmit optical fibers **122** and receive optical fibers **132**, respectively. The MPO connector **110** is configured to be coupled to a mating MPO connector **112** such that the optical fibers **122**, **132** in the optical transceiver **100** are optically coupled to external optical fibers **114**.

Continuing on, this embodiment of the multi-channel ROSA **130** shown in FIG. **1**A includes a photodetector array **134** including, for example, photodiodes optically coupled to a fiber array **133** formed by the ends of the receive optical fibers **132**. The multi-channel ROSA **130** also includes a multi-channel transimpedance amplifier **136** electrically connected to the photodetector array **134**. The photodetector array **134** and the transimpedance amplifier **136** detect and convert optical signals received from the fiber array **133** into electrical data signals (RX_D**1** to RX_D**4**) that are output via the receive connecting circuit **108**. Other embodiments of a ROSA may also be used in the transceiver **100** for receiving and detecting one or more optical signals.

This embodiment of the optical transceiver **100** does not include an optical multiplexer or demultiplexer. The optical signals may be multiplexed and demultiplexed external to the optical transceiver **100**.

Referring to FIG. **1**B, another embodiment of an optical transceiver **100'** includes the same light engine (e.g., TOSAs **120***a-d* and ROSA **130**) described above together with an optical multiplexer **111** and an optical demultiplexer **113**. The optical multiplexer **111** and the optical demultiplexer **113** both may include arrayed waveguide gratings (AWGs). The optical multiplexer **111** is optically coupled to the transmit optical fibers **122** and the optical demultiplexer **113** is optically coupled to the receive optical fibers **132**. The optical multiplexer **111** multiplexes the optical signals being transmitted over transmit optical fibers **122** to provide a multiplexed optical signal on an output optical fiber **115**. The optical demultiplexer **113** demultiplexes a multiplexed optical signal received on an input optical fiber **117** to provide received optical signals on receive optical fibers **132**. The output optical fiber **115** and the input optical fiber **117** are coupled to an output optical connector **116** and an input optical connector **118**, respectively.

This embodiment of the optical transceiver **100'** includes 4 channels and may be configured for coarse wavelength division multiplexing (CWDM), although other numbers of channels are possible. This embodiment of the optical transceiver **100'** may also be capable of transmission rates of at least about 25 Gbps per channel and transmission distances of 2 km to at least about 10 km and may be used in internet data center applications or fiber to the home (FTTH) applications.

Referring now to FIGS. **2**A-**2**B, an example transmitter optical subassembly (TOSA) module **200** is shown consistent with an embodiment of the present disclosure. As shown, the TOSA **200** includes a substrate **202** and a hermetically-sealed light engine **204** coupled to an end of the substrate **202**. In more detail, the substrate **202** includes a first end **206-1** that extends to a second end **206-2** along a longitudinal axis **216**. The substrate may comprise a printed circuit board (PCB) formed of silicon or any other material capable of coupling/mounting to electrical components. The substrate **202** includes at least two mounting surfaces for mounting of components, such as mounting surfaces **214-1** and **214-2**, which are disposed opposite each other in an opposing arrangement/configuration.

The substrate **202** includes a transmit circuit (TX) interface region **208** proximate the first end **206-1**, a light engine interface region **212** proximate the second end **206-2** of the substrate, and a light engine driving circuit **210** disposed therebetween. The TX interface region **208** may include a plurality of terminals/pads **220** for electrically coupling to a transmit connecting circuit, e.g., transmit connecting circuit **104**. The TX interface region **208** may therefore receive signals, e.g., power and other signals such as RF, from an associated transmit connecting circuit when coupled thereto. The light engine interface region **212** also includes terminals/pads **222** for electrically coupling to the hermetically-sealed light engine **204**.

The light engine driving circuit **210** may include power conversion circuitry and other chips/devices suitable for driving a light engine such as the hermetically-sealed light engine **204**. The light engine driving circuit **210** may be disposed on one or more of the mounting surfaces of the substrate **202**. For instance, as shown in FIGS. **2**A and **2**B, the light driving circuit is disposed on both the first and second mounting surfaces **214-1**, **214-2**. This dual-sided arrangement allows for separation of RF and DC traces which may advantageously minimize or otherwise reduce electrical interference with each other. However, this disclosure is not necessarily limited in this regard and the light driving circuit may be disposed on only one side of the substrate **202** depending on a desired configuration. The light engine driving circuit **210** may electrically couple to the TX interface region **208**, and more specifically to the plurality of terminals/pads, via traces. Likewise, the light engine driving circuit **210** may electrically couple to the pads/terminals of the light engine interface region **212** via traces, which are described in greater detail below.

The hermetically-sealed light engine **204** includes a hermetically-sealed housing **224** or housing **224** defined by a plurality of sidewalls. The housing **224** may include a longitudinal axis **218** that extends substantially transverse relative to the longitudinal axis **216** of the substrate **202**. The housing **224** may comprise, for example, metal, plastic, ceramic, or any other suitable material. The housing **224** may be formed from multiple pieces, or a single piece, of material.

The housing **224** may further define a laser cavity **226** (FIG. **3**) which may be filled with an inert gas to form an inert atmosphere. In one embodiment, the inert atmosphere sealed within the hermetically-sealed container comprises nitrogen, and preferably, 1 atmosphere (ATM) of nitrogen. The inert atmosphere may also be formed from nitrogen, helium, argon, krypton, xenon, or various mixtures thereof, including a nitrogen-helium mix, a neon-helium mix, a krypton-helium mix, or a xenon-helium mix. The inert gas or gas mix included within the hermetically-sealed container may be selected for a particular refractive index or other optical property. Gases may also be selected based on their ability to promote thermal insulation. For instance, Helium is known to promote heat transfer may be utilized alone or in addition to others of the aforementioned gases. In any event, the terms hermetic-sealed and hermetically-sealed may be used interchangeably and refers to a housing that releases a maximum of about $5*10^{-8}$ cc/sec of filler gas.

As shown, the housing **224** may abut (e.g., directly couple to) the second end **206-2** of the substrate **202** and extend therefrom. This may also be referred to as an end-to-end connection between the housing **224** and the substrate **202**. The housing **224** may be securely attached to the substrate via an adhesive or other suitable device such as screws, rivets, friction-fit, tongue-and-groove or any combination thereof. However, the housing **224** may not necessarily directly couple to the second end **206-2** of the substrate **202** and the housing **224** may indirectly couple to the second end **206-2** of the substrate **202** via an intermediate device/structure.

Alternatively, or in addition to adhesive or other attachment devices, the housing **224** may be securely attached to the substrate **202** based on electrical interconnect devices (or simply interconnects) soldered or otherwise coupled between the substrate **202** and the housing **224** such as shown in FIGS. **2**A and **2**B. For example, a first type of interconnects referred to collectively as **242** and individually as **242-1** and **242-2** may be coupled to the substrate **202** by way of respective pads **222**. The first type of interconnect devices **242** may be substantially similar in dimension and type, although other embodiments are within the scope of this disclosure. For instance, each of the interconnect devices **242** may have substantially similar dimensions and may each comprise copper, aluminum, steel or any other suitably conductive metal or metal alloy. In other cases, the interconnect devices **242-1** may comprise a different metal material than that of the interconnect devices **242-2** and have different dimensions. In one specific example embodiment, the interconnect devices **242** comprise DC bus bar interconnects.

As shown, the interconnects **242-1** may be coupled to the first surface **214-1** of the substrate **202** and the interconnects **242-2** may be disposed opposite the interconnects **242-1** on the second surface **214-2** of the substrate **202**. This opposing configuration/arrangement of interconnects may increase structural stability of the interface between the housing **224** and the substrate **202** versus only coupling interconnects on only one side of the substrate **202**. In this embodiment, each of the first interconnect devices **242-1** may be disposed in a coextensive manner with corresponding ones of the second interconnect devices **242-2**, although in other cases the interconnect devices may be disposed in a staggered manner and may not necessarily be coextensive. In some cases the interconnects **242** may only be coupled on one side to provide electrical communication between the substrate **202** and the housing **224** and this disclosure should not be construed as limiting in this regard.

In any event, the interconnect devices **242** may be suitably rigid, and thus prevent or otherwise mitigate rotational movement of the housing **224** relative to the substrate **202**. A substantial portion, e.g., greater than 50%, of the bottom surface of each of the interconnect devices **242** may couple to the pads **222** of the substrate **202**. This may allow the interconnect devices **242** to have a relatively large amount of surface area in contact with the substrate **202** to allow for additional soldering. The additional soldering may further increase structural support and securely hold the housing **224** in position relative to the substrate **202**. Thus, in some cases, the ratio of surface area of each of the interconnects **242** coupled to the substrate **202** relative to the housing **224** may be 2:1, 3:1, 4:1, 6:1, or any ratio therebetween.

In an embodiment, each of the interconnect devices **242** may form a substantially continuous electrical conductor when electrically coupled, e.g., when soldered or otherwise electrically coupled, to associated pads **222** of the substrate **202** and the pads **244** of the housing **224**. The continuous electrical conductor may be straight, e.g., without bends. Although the interconnects **242-2** may be configured to carry a DC signal, the associated pads of the substrate **202** and the housing **224** may not necessarily be electrically coupled to the light engine driving circuit **210** and the laser packages **240**, which may also be referred to as laser transmitter arrangements or simply laser arrangements (See FIG. **3**). Instead, the interconnects **242-2** may be electrically isolated and may simply be present to provide structural support (e.g., to prevent rotational movement) between the substrate **202** and the housing **224** and/or a ground connection. Alternatively, one or more of the interconnects **242-2** may be electrically isolated while others may be utilized to provide a DC signal between the substrate **202** and the hermetically-sealed light engine **204**.

Continuing on, a second type of interconnect **246** may electrically couple the substrate **202** to the hermetically-sealed light engine **204** to provide RF signaling. The second type of interconnect **246** may comprise wire bonding, as shown, although other types of interconnect devices may be utilized. As shown, the embodiment of FIGS. **2**B and **2**C include a plurality of the second type of interconnect **246**. Wire bonding may be particularly well suited for transmission of high-frequency RF signals. However, wire bonding can be easily damaged based on, for instance, movement between the substrate **202** and the housing **224**. In an embodiment, the first interconnect devices **242** may introduce rigidity and a secure connection between the substrate **202** and the housing **224** to prevent or otherwise mitigate the potential for such damage.

FIG. **3** shows a cross-sectional view of the housing **224** consistent with an embodiment of the present disclosure. The housing **224** depicted in FIG. **3** includes transparent sections for clarity and for ease of explanation. As shown, the housing **224** includes a plurality of sidewalls that define cavity **226**. The cavity **226** includes laser packages **240** disposed therein. The laser packages **240** may be configured to launch associated channel wavelengths into a fiber, e.g., one of fibers **254** (See FIG. **2**B), or other waveguide disposed in connector/receptacle **250**. Note, the fibers **254** may be implemented as the transmit optical fiber **122** of FIGS. **1**A and **1**B. Focusing lenses, e.g., focus lens **280**, may be disposed within the cavity **226** and aligned with associated laser packages to launch light emitted from the same into a fiber or waveguide of receptacle **250**. The cavity **226** may also include temperature control devices **252** in thermal communication with the laser packages **240**. The temperature control devices **252** may comprise TECs or other suitable devices. The temperature control devices **252** may also be in thermal communication with the bottom sidewall **256** to allow for transfer of heat. Therefore, the temperature control devices **252** may advantageously disperse heat through a metal housing (or other housing) that the housing **224** may be disposed in.

The cavity **226** may be at least partially formed by a feedthrough device **228**, which may also be referred to as a passthrough device **228**. The feedthrough device **228** may comprise, for example, a suitably rigid non-metal material such as inorganic material such as a crystalline oxide, nitride or carbide material, which may be commonly referred to as ceramic. Some elements, such as carbon or silicon, may also be considered ceramics, and are also within the scope of this disclosure. A first portion **232-1** of the feedthrough device **228** may at least partially extend into the cavity and a second portion **232-2** may extend from the cavity **226**.

The feedthrough device **228** may be defined by at least a first mounting surface **230-1** and a second mounting surface **230-2** disposed opposite the first surface **230-1** in an opposing arrangement/configuration. Each of the first and second mounting surfaces **230-1** and **230-2** may include traces disposed/patterned thereon, and may also be referred to herein as simply first and second surfaces **230-1**, **230-2**. For example, the first surface **203-1** may include power traces **234** (or DC traces **234**) disposed thereon that are configured for transmission of DC signals. On the other hand, the second surface **230-2** may include traces **236** (or RF traces **236**) disposed thereon that are configured for transmission of RF signals. The feedthrough device **228** may include a width (or thickness) of W**1**, with W**1** being between 0.1 mm to 2 mm, although other dimensions are within the scope of this disclosure. The width W**1** may be configured to allow the feedthrough device **228** to prevent or otherwise reduce electrical interference between the DC and RF signals carried by the traces **234** and **236**, respectively. The width W**1** of the feedthrough device **228** may be equal to the width W**2** of the substrate **202**. However, the widths W**1** and W**2** may not necessarily be equal and width W**2** may be greater or less than the width W**1**. As further shown, the first and second mounting surfaces **214-1**, **214-2** of the substrate **202** may extend in parallel, and may be substantially coplanar, with the first and second surfaces **230-1**, **230-2** of the feedthrough device **228** when the substrate **202** and the feedthrough device **228**, are coupled together.

Continuing on, a first end of the DC traces **234** may be electrically coupled to the substrate **202**, and more particularly, the light engine driving circuit **210** via respective interconnect devices, such as the first type of interconnect devices **242-1**. The second end of the DC traces **234** on the first surface **230-1** of the feedthrough device **228** may then be wire bonded, such as shown, or otherwise electrically coupled to the laser transmitter arrangements **240** via a suitable approach. Each laser transmitter arrangement **240** may comprise, for instance, a laser diode and a monitor photodiode and may be configured to emit an associated channel wavelength. Likewise, a first end of the RF traces **234** electrically couple to the light engine driving circuit **210** via respective interconnect devices, e.g., the second type of interconnect devices **242-2**, and a second end electrically couples to the laser transmitter arrangements **240** via wire bonding or other suitable approach.

In an accordance with an aspect of the present disclosure a transmitter optical subassembly (TOSA) module is disclosed. The TOSA module comprising a hermetically-sealed light engine with a housing that defines a hermetic-sealed cavity and at least one laser package for emitting an associated channel wavelength disposed within the hermetic-sealed cavity, a substrate defined by first and second surfaces disposed opposite each other, the substrate including an electrical coupling region for electrically coupling with a transmit connecting circuit and a light engine interface region for electrically coupling with the hermetically-sealed light engine, a light engine driving circuit disposed on the substrate to provide a radio frequency (RF) signal and a power signal to drive the hermetically-sealed light engine to output one or more channel wavelengths, and wherein the substrate includes at least a first trace disposed on the first surface to provide the power signal and at least a second trace disposed on the second surface to provide the RF signal, the first and second traces being disposed in an opposing arrangement to provide electrical isolation to reduce electrical interference between the power signal and the RF signal.

In accordance with another aspect of the present disclosure an optical transceiver. The optical transceiver comprising a housing, a transmitter optical subassembly (TOSA) module disposed in the housing, the TOSA module comprising a hermetically-sealed light engine with a housing that defines a hermetic-sealed cavity and at least one laser package disposed within the hermetic-sealed cavity, a substrate defined by first and second surfaces disposed opposite each other, the substrate including an electrical coupling region for electrically coupling with a transmit connecting circuit and a light engine interface region for electrically coupling with the hermetically-sealed light engine, a light engine driving circuit disposed on the substrate to provide a radio frequency (RF) signal and a power signal to drive the hermetically-sealed light engine to output one or more channel wavelengths, and wherein the substrate includes at least a first trace disposed on the first surface to provide the power signal, and at least a second trace disposed on the second surface to provide the RF signal, the first and second traces being disposed in an opposing arrangement to provide electrical isolation to reduce electrical interference between the power signal and the RF signal, a receive optical subassembly (ROSA) module disposed in the housing.

While the principles of the invention have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the disclosure. Other embodiments are contemplated within the scope of the present disclosure in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present disclosure, which is not to be limited except by the following claims.

What is claimed is:

1. A transmitter optical subassembly (TOSA) module comprising:

a hermetically-sealed light engine with a housing that defines a hermetic-sealed cavity and at least one laser package for emitting an associated channel wavelength disposed within the hermetic-sealed cavity;

a substrate defined by first and second surfaces disposed opposite each other, the substrate including an electrical coupling region for electrically coupling with a transmit connecting circuit and a light engine interface region for electrically coupling with the hermetically-sealed light engine;

a light engine driving circuit disposed on the substrate to provide a radio frequency (RF) signal and a power signal to drive the hermetically-sealed light engine to output one or more channel wavelengths;

wherein the substrate includes at least a first trace disposed on the first surface to provide the power signal and at least a second trace disposed on the second surface to provide the RF signal, the first and second traces being disposed in an opposing arrangement to provide electrical isolation to reduce electrical interference between the power signal and the RF signal

a feedthrough device to electrically couple the at least one laser package to the light engine driving circuit; and

wherein the feedthrough device is defined by at least a first surface disposed opposite a second surface, and wherein the first and second surfaces extend substantially parallel with the first and second surfaces of the substrate.

2. The TOSA module of claim **1**, further comprising at least a first interconnect device of a first type electrically coupled to the first trace and a corresponding trace of the hermetically-sealed light engine housing to provide the power signal, and at least a second interconnect device of a second type electrically coupled to the second trace and a corresponding trace of the hermetically-sealed light engine housing to provide the RF signal, the first and second types of interconnect devices being different.

3. The TOSA module of claim **2**, wherein the first type of interconnect device is a DC bus bar interconnect.

4. The TOSA module of claim **2**, wherein the second type of interconnect device is a wire bond.

5. The TOSA module of claim **1**, further comprising at least one ground trace disposed on the second surface adjacent the second trace.

6. The TOSA module of claim **5**, further comprising a DC bus bar interconnect device electrically coupled to the at least one ground trace and a wire bond electrically coupled to the second trace.

7. The TOSA module of claim **1**, wherein the electrical isolation is provided at least in part by a width of the substrate and/or material properties of a material that forms the substrate.

8. The TOSA module of claim **1**, further comprising a plurality of electrical interconnects that brace the substrate to the housing of the hermetically-sealed light engine.

9. The TOSA module of claim **1**, wherein the feedthrough device is configured to directly couple to the substrate with an end-to-end connection.

10. The TOSA module of claim **1**, wherein the first and second surfaces of the feedthrough device are substantially coplanar with the first and second surfaces of the substrate when the feedthrough device and substrate are coupled together.

11. The TOSA module of claim **1**, further comprising at least one trace for receiving the power signal from the light engine driving circuit disposed on the first surface of the feedthrough and at least one trace for receiving the RF signal from the light engine driving circuit disposed on the second surface.

12. An optical transceiver comprising:

a housing;

a transmitter optical subassembly (TOSA) module disposed in the housing, the TOSA module comprising:

a hermetically-sealed light engine with a housing that defines a hermetic-sealed cavity and at least one laser package disposed within the hermetic-sealed cavity;

a substrate defined by first and second surfaces disposed opposite each other, the substrate including an electrical coupling region for electrically coupling with a transmit connecting circuit and a light engine interface region for electrically coupling with the hermetically-sealed light engine;

a light engine driving circuit disposed on the substrate to provide a radio frequency (RF) signal and a power signal to drive the hermetically-sealed light engine to output one or more channel wavelengths; and wherein the substrate includes at least a first trace disposed on the first surface to provide the power signal, and at least a second trace disposed on the second surface to provide the RF signal, the first and second traces being disposed in an opposing arrangement to provide electrical isolation to reduce electrical interference between the power signal and the RF signal;

at least a first interconnect device of a first type electrically coupled to the first trace and a corresponding trace of the hermetically-sealed light engine to provide the power signal, and at least a second interconnect device of a second type electrically coupled to the second trace and a corresponding trace of the hermetically-sealed light engine to provide the RF signal, the first and second types of interconnect devices being different;

a receive optical subassembly (ROSA) module disposed in the housing.

13. The optical transceiver of claim **12**, wherein the first type of interconnect device comprises a DC bus bar disposed on the first and second surfaces of the substrate.

14. The optical transceiver of claim **12**, wherein the second type of interconnect device is a wire bonds.

15. A transmitter optical subassembly (TOSA) module comprising:

a hermetically-sealed light engine with a housing that defines a hermetic-sealed cavity and at least one laser package for emitting an associated channel wavelength disposed within the hermetic-sealed cavity;

a substrate defined by first and second surfaces disposed opposite each other, the substrate including an electrical coupling region for electrically coupling with a transmit connecting circuit and a light engine interface region for electrically coupling with the hermetically-sealed light engine;

a light engine driving circuit disposed on the substrate to provide a radio frequency (RF) signal and a power signal to drive the hermetically-sealed light engine to output one or more channel wavelengths;

wherein the substrate includes at least a first trace disposed on the first surface to provide the power signal and at least a second trace disposed on the second surface to provide the RF signal, the first and second traces being disposed in an opposing arrangement to provide electrical isolation to reduce electrical interference between the power signal and the RF signal; and

at least a first interconnect device of a first type electrically coupled to the first trace and a corresponding trace of the hermetically-sealed light engine housing to provide the power signal, and at least a second interconnect device of a second type electrically coupled to the second trace and a corresponding trace of the hermetically-sealed light engine housing to provide the RF signal, the first and second types of interconnect devices being different.

16. The TOSA module of claim **15**, wherein the first type of interconnect device is a DC bus bar interconnect.

17. The TOSA module of claim **15**, wherein the second type of interconnect device is a wire bond.

* * * * *

EXHIBIT H

US010788690B2

(12) **United States Patent**
Lin et al.

(10) **Patent No.: US 10,788,690 B2**
(45) **Date of Patent: Sep. 29, 2020**

(54) **OPTICAL ISOLATOR ARRAY FOR USE IN AN OPTICAL SUBASSEMBLY MODULE**

(71) Applicant: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(72) Inventors: **Kai-Sheng Lin**, Sugar Land, TX (US); **Kevin Liu**, Houston, TX (US); **Ziliang Cai**, Richmond, TX (US)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 105 days.

(21) Appl. No.: **16/257,635**

(22) Filed: **Jan. 25, 2019**

(65) **Prior Publication Data**

US 2020/0241334 A1 Jul. 30, 2020

(51) **Int. Cl.**
G02F 1/01 (2006.01)
G02F 1/09 (2006.01)

(52) **U.S. Cl.**
CPC ***G02F 1/093*** (2013.01)

(58) **Field of Classification Search**
CPC G02F 1/093; G02F 1/0136; G02B 5/3083; G02B 6/2746; G02B 27/283
USPC 359/484.03
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2010/0002988 A1* 1/2010 Yoshie G02B 6/122 385/14
2014/0146389 A1* 5/2014 Ye G02F 1/093 359/484.03

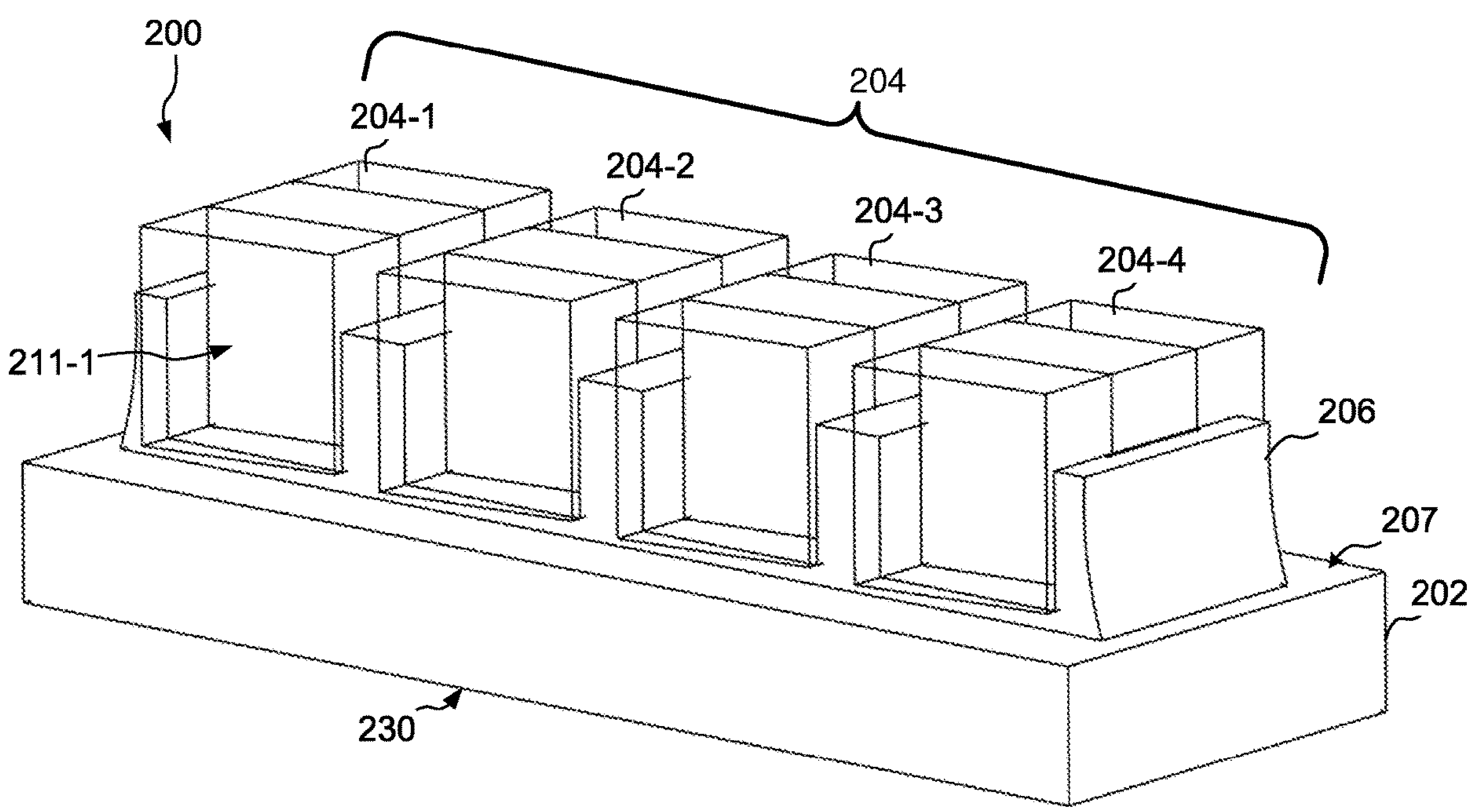
* cited by examiner

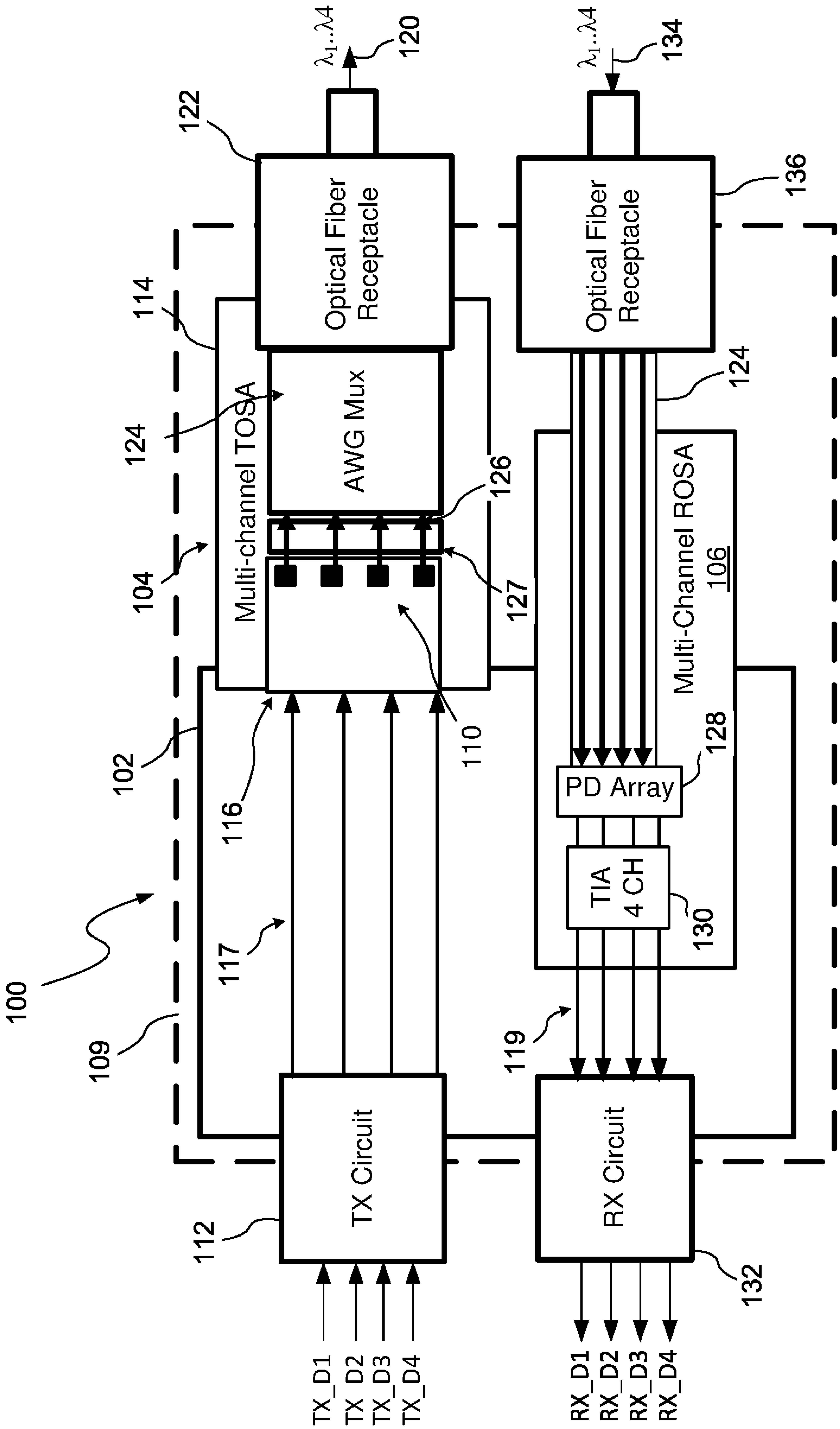
Primary Examiner — William R Alexander
Assistant Examiner — Henry A Duong
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perrault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

This present disclosure is generally directed to an optical isolator array with a magnetic base that allows for mounting and alignment of N number of optical isolators modules within an optical subassembly module. In an embodiment, the magnetic base provides at least one mounting surface for coupling to N number of optical isolators, with N being equal to an optical channel count for the optical subassembly (e.g., 4-channels, 8-channels, and so on). The magnetic base includes an overall width that allows for a desired number of optical isolators to get mounted thereon. Each optical isolator can be uniformly disposed along the same axis on the magnetic base and at a distance D from adjacent optical isolators. An adhesive such as ultraviolet-curing (UV-curing) optical adhesives may be used to secure each optical isolator at a predefined position and increase overall structural integrity.

19 Claims, 6 Drawing Sheets





$\lambda_1..\lambda_4$
120
$\lambda_1..\lambda_4$
134
122
Optical Fiber Receptacle
Optical Fiber Receptacle
136
114
124
AWG Mux
124
Multi-channel TOSA
126
104
127
Multi-Channel ROSA
106
110
102
128
PD Array
116
TIA 4 CH
130
117
100
109
119
TX Circuit
RX Circuit
112
132
TX_D1
TX_D2
TX_D3
TX_D4
RX_D1
RX_D2
RX_D3
RX_D4

FIG. 1

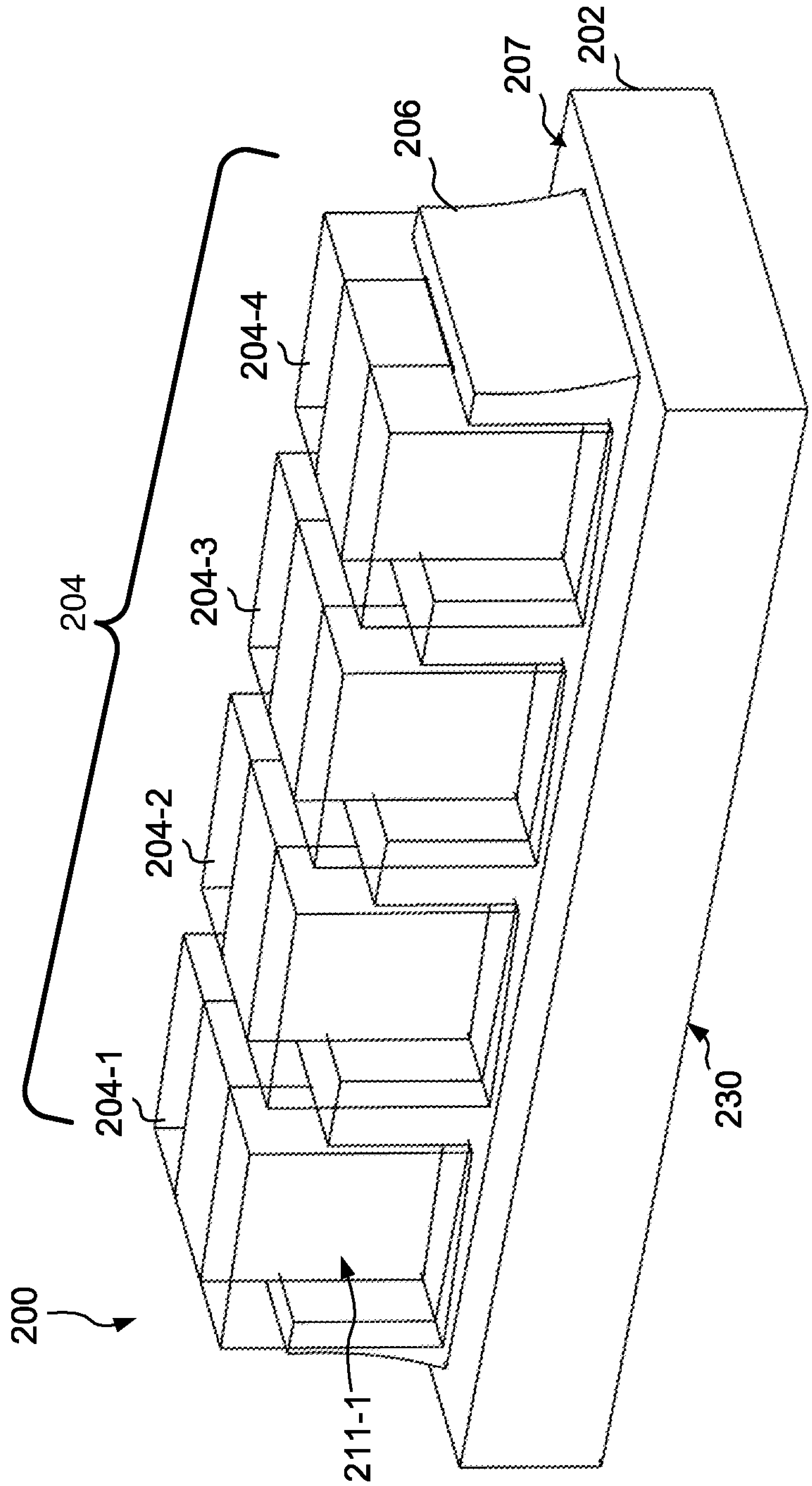


FIG. 2

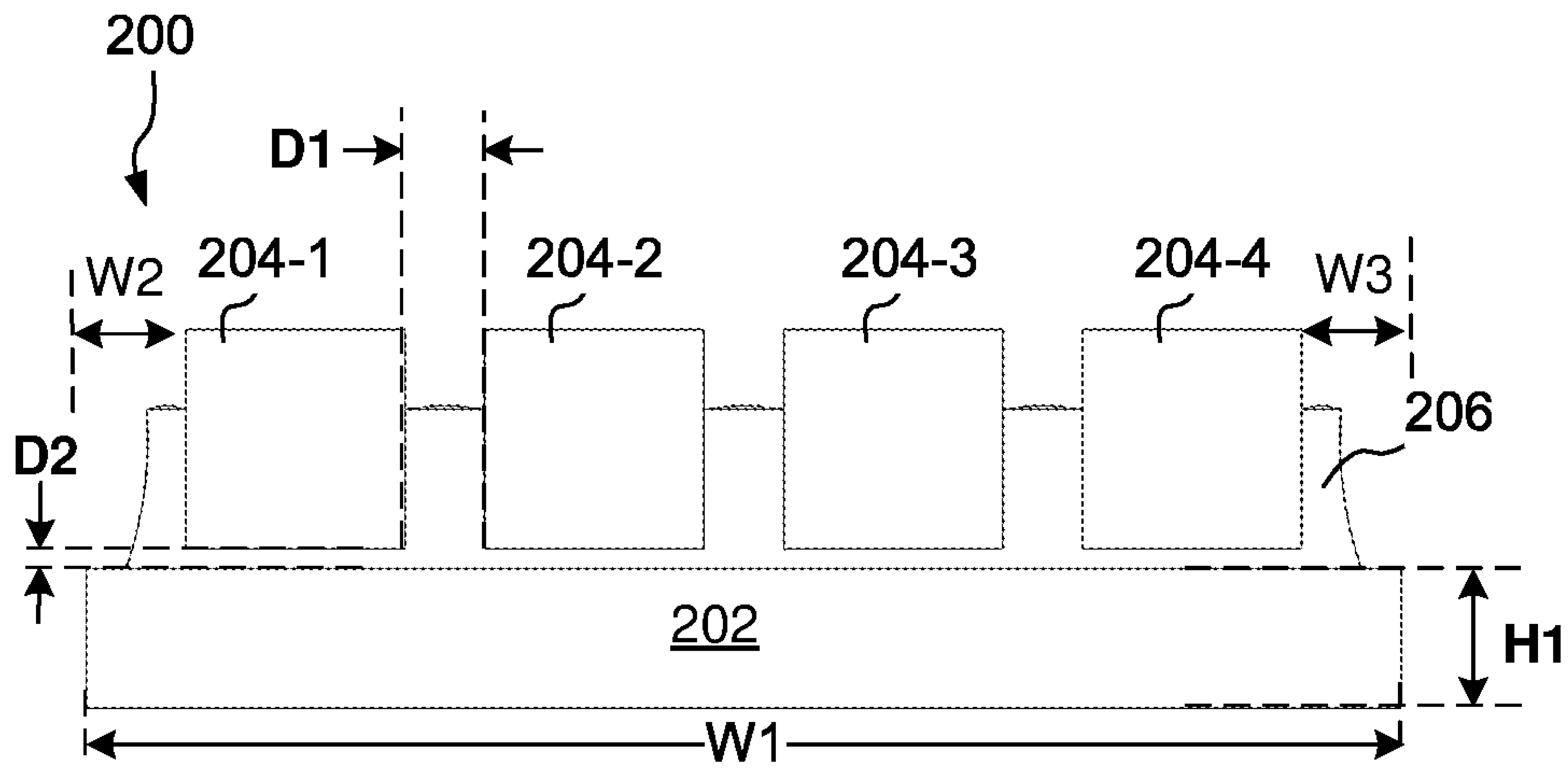

200
D1
204-1
204-2
204-3
204-4
W2
W3
206
D2
202
H1
W1

FIG. 3

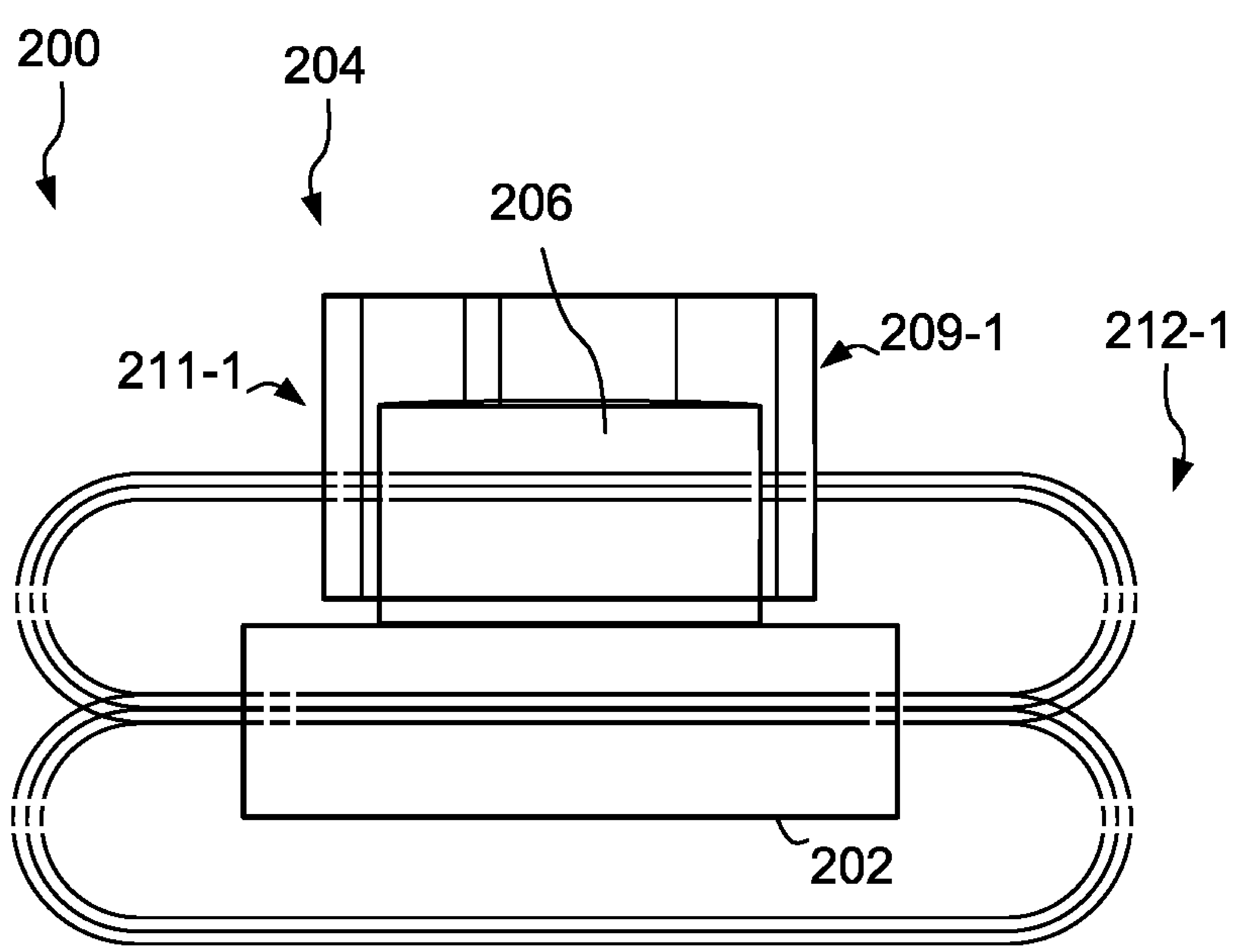

200
204
206
211-1
209-1
212-1
202

FIG. 4

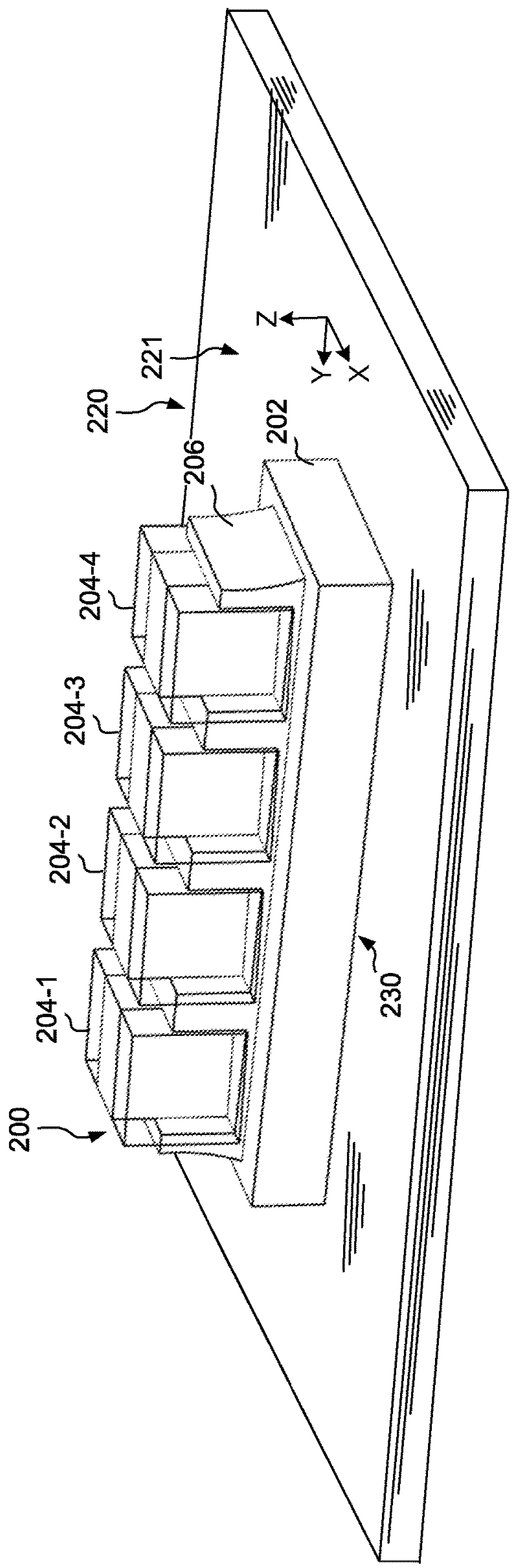

200
204-1
204-2
204-3
204-4
206
220
221
202
230
Z
Y
X

FIG. 5

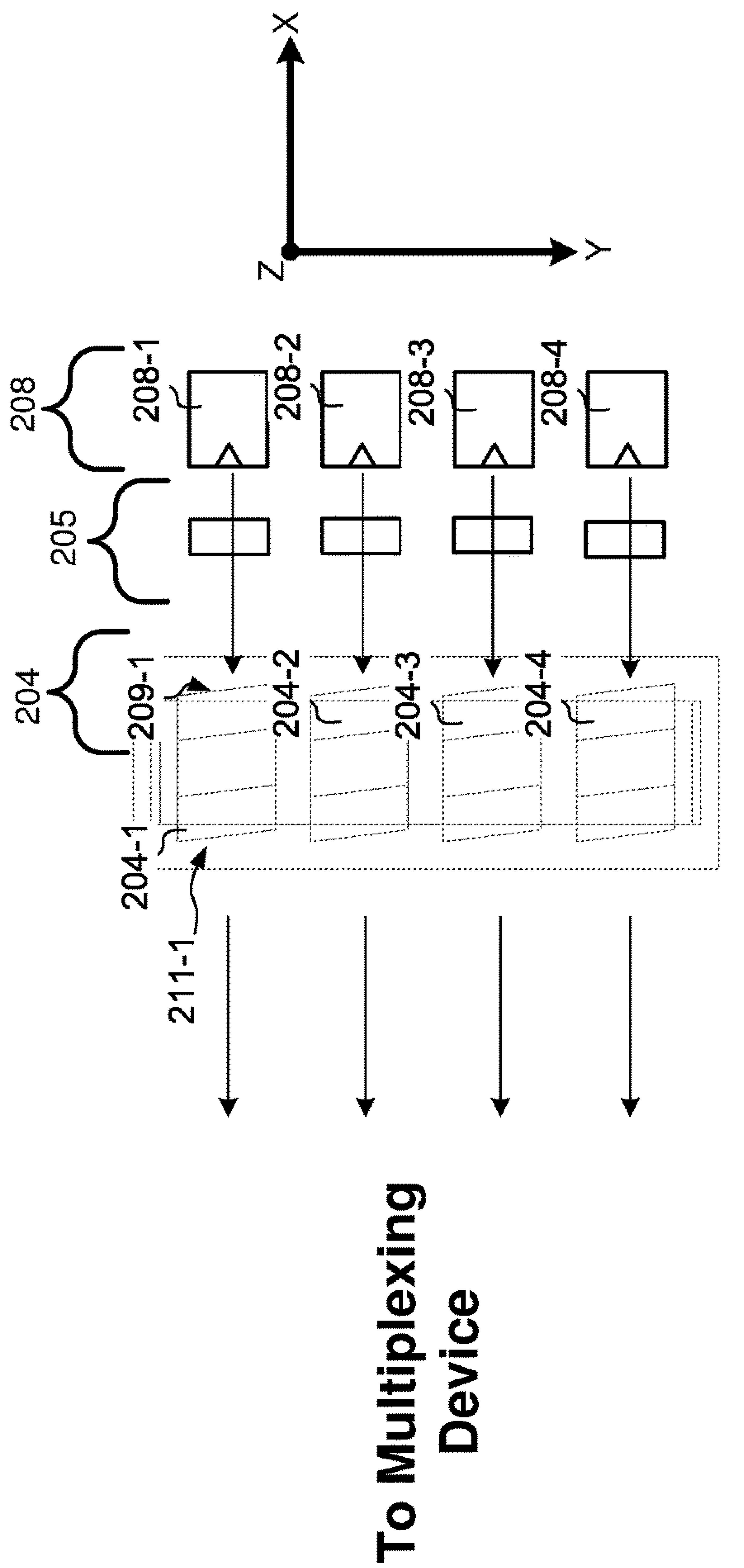

X
Y
Z
208
208-1
208-2
208-3
208-4
205
204
209-1
204-1
204-2
204-3
204-4
211-1
To Multiplexing Device

FIG. 6

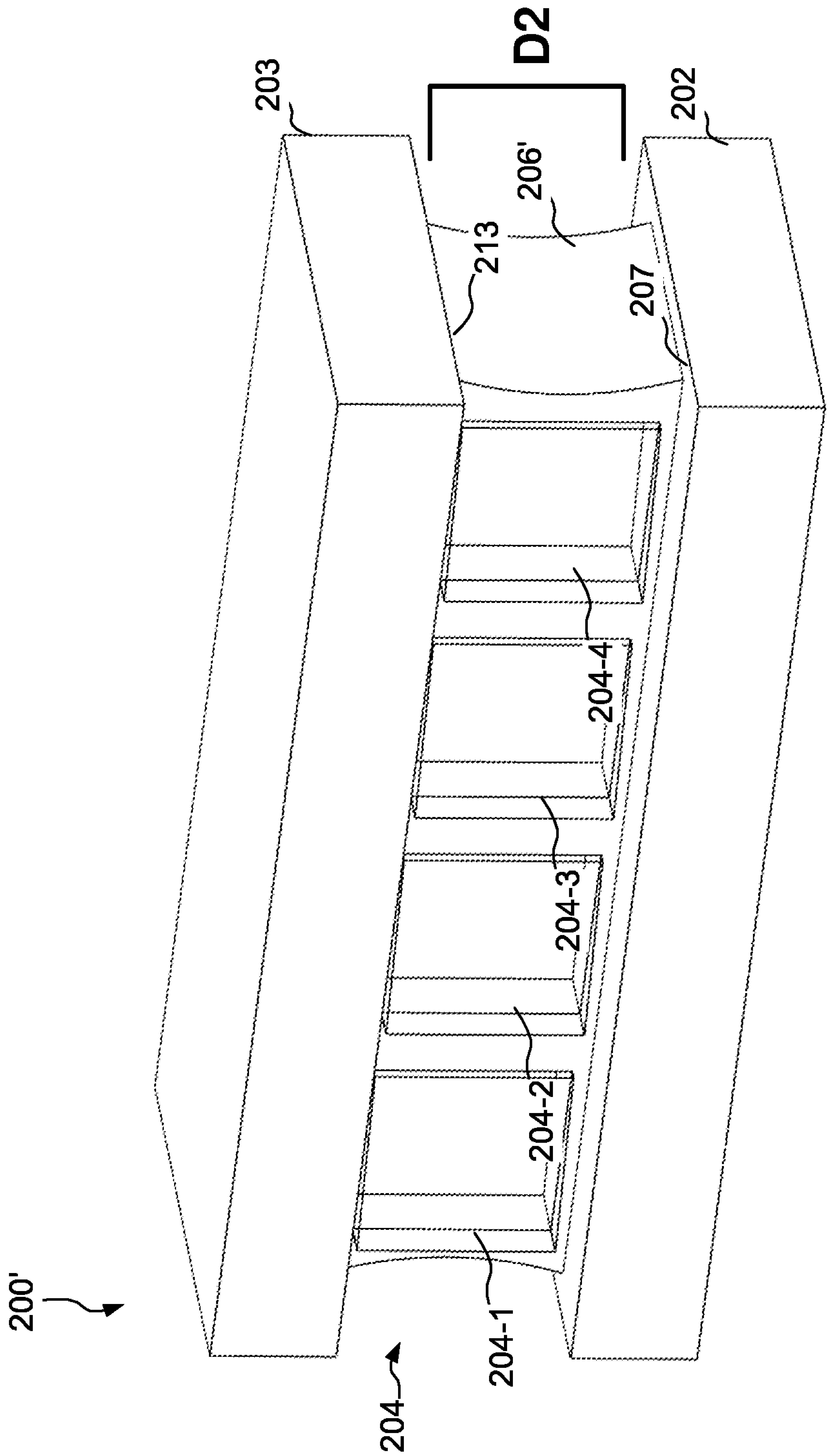


FIG. 7

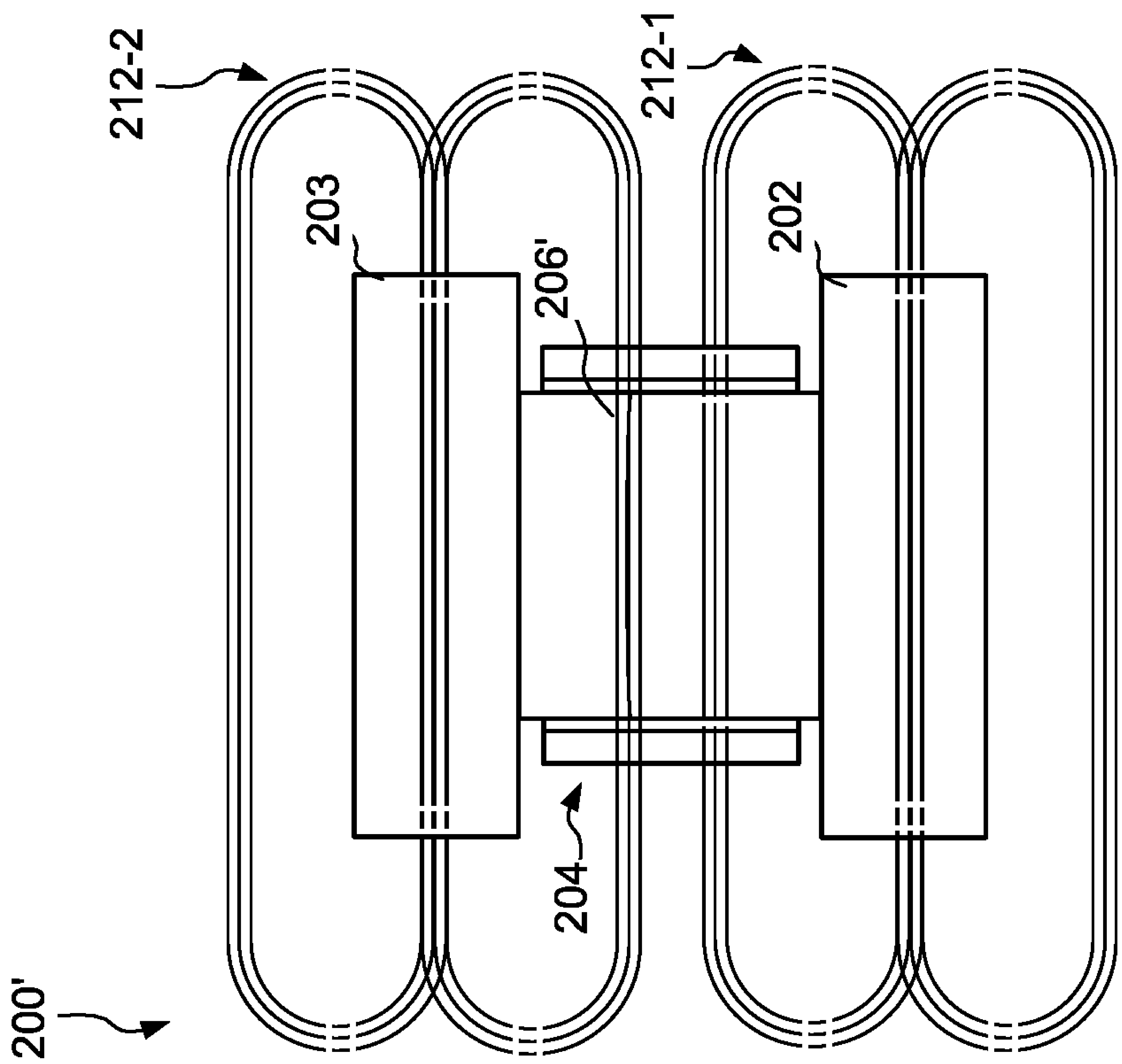


FIG. 8

OPTICAL ISOLATOR ARRAY FOR USE IN AN OPTICAL SUBASSEMBLY MODULE

TECHNICAL FIELD

The present disclosure relates to optical communications, and more particularly, to an optical isolator array for use in a multi-channel optical subassembly module, the optical isolator array having a magnetic base with a relatively compact and modular profile that supports N number of optical isolators for use in an optical subassembly module.

BACKGROUND INFORMATION

Optical transceivers are used to transmit and receive optical signals for various applications including, without limitation, internet data center, cable TV broadband, and fiber to the home (FTTH) applications. Optical transceivers provide higher speeds and bandwidth over longer distances, for example, as compared to transmission over copper cables. The desire to provide higher transmit/receive speeds in increasingly space-constrained optical transceiver modules has presented significant challenges. Moreover, optical transceiver modules include a wide-range of package profiles with large variations in channel density and housing dimensions, for instance, that can make reusability of components difficult across multiple types of profiles, if not impossible.

For example, some approaches to transmitter optical subassemblies (TOSAs) include having a plurality of laser arrangements including, for example, a laser diode driver (LDD), laser diode, focus lens and multiplexer device, and a multiplexing device for combining channel wavelengths from each of the plurality of laser arrangements in a single housing. Each component of the TOSA must be securely attached and optically aligned with other associated optical components, which presents significant challenges for part designs (e.g., sub-mounts, lenses, mirror holders, and so on) that can be reused between package types, particularly as TOSAs continue to scale. In addition, manufacture of such TOSAs routinely require multiple test, correction, and re-test stages, which can ultimately increase per-unit manufacture time, complexity, and reduce yield.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** shows a block diagram of a multi-channel optical transceiver in accordance with an embodiment of the present disclosure.

FIG. **2** shows a perspective view of an optical isolator array for use in the optical transceiver of FIG. **1**, in accordance with an embodiment of the present disclosure.

FIG. **3** shows a front view of the optical isolator array of FIG. **2**, in accordance with an embodiment of the present disclosure.

FIG. **4** shows a side view of the optical isolator array of FIG. **2**, in accordance with an embodiment of the present disclosure.

FIG. **5** shows a perspective view of the optical isolator array of FIG. **2** coupled to an optical subassembly substrate, in accordance with an embodiment of the present disclosure.

FIG. **6** shows a top-down view of the optical isolator array of FIG. **2** and associated optical components, in accordance with an embodiment of the present disclosure.

FIG. **7** shows another example optical isolator array suitable for use in the optical transceiver of FIG. **1**, in accordance with an embodiment of the present disclosure.

FIG. **8** shows a side view of the example optical isolator array of FIG. **7**, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

This present disclosure is generally directed to an optical isolator array with a magnetic base (or plate) that allows for mounting and alignment of N number of optical isolator chips, referred to herein as simply optical isolators, within an optical subassembly module. In an embodiment, the magnetic base provides at least one mounting surface for supporting and coupling to N number of optical isolators, with N being equal to an optical channel count for the optical subassembly (e.g., 4-channels, 8-channels, and so on). The magnetic base includes an overall width that allows for a desired number of optical isolators to get mounted thereon. Each optical isolator can be disposed along the same axis on the magnetic base and at a uniform distance from adjacent optical isolators. The optical isolators can extend substantially parallel relative to each other when coupled to the magnetic base. Further, each optical isolator provides a light-receiving surface at a first end to receive channel wavelengths from a corresponding laser diode, and a light-emitting surface at a second end, opposite the first end, to pass the received channel wavelengths along a direction of propagation. The polarity and orientation of the magnetic base within the optical subassembly module establishes the direction of propagation through each optical isolator. The magnetic base introduces a magnetic field with a magnetic field strength sufficient to ensure nominal power along the desired direction of propagation. Accordingly, each optical isolator coupled to the magnetic base can pass channel wavelengths along the same direction. In an embodiment, this includes optical isolators passing channel wavelengths along a corresponding light path that extends parallel relative to each other. An adhesive such as ultraviolet-curing (UV-curing) optical adhesives may be used to secure each optical isolator at a predefined position on the magnetic base and provide additional structural support. Other types of adhesives and fixation approaches may be utilized and are within the scope of this disclosure.

In another embodiment of the present disclosure, an optical isolator array is disclosed that includes first and second magnetic bases or plates disposed opposite each other and a plurality of optical isolators sandwiched/disposed therebetween. The optical isolators may be coupled via, for instance, adhesive or other suitable approach to the first and second magnetic bases. The first and second magnetic bases introduce a first and second magnetic field, respectively, and can determine a direction of propagation for the optical isolators based on the same. The magnetic field strength of the first and second magnetic bases may be substantially equal, or different depending on a desired configuration. The addition of a second magnet, and by extension, a second magnetic field, results in greater isolation performance relative to that of a single magnetic field.

Continuing on, each of the first and second magnetic bases may be configured identically, and thus, either magnetic base can be utilized to couple the optical isolator array to the surface of a substrate, e.g., the sidewall of a transmitter optical subassembly (TOSA). In this embodiment, at least one layer of adhesive may extend between the first and second magnetic bases to securely hold the optical isolators in a predetermined position between the first and second magnetic bases and can increase the overall structural integrity of the optical isolator array.

Numerous advantages will be apparent over other approaches that utilize discrete/separate optical isolators coupled to a substrate. For example, an optical isolator array consistent with the present disclosure can be easily be shortened or lengthened to accommodate different optical subassembly housing/packaging requirements and/or when less or more optical channels are desired. The total number of optical isolators may vary according to desired channel counts, and such modifications are achievable without substantial redesign of the optical isolator array. Alternatively, or in addition, the distance/pitch between adjacent optical isolator chips may be varied to accommodate a wide-range of package designs.

In addition, an optical isolator array consistent with the present disclosure may be separately manufactured and optionally tested apart from other optical subassembly components, and then subsequently coupled into an associated housing, e.g., a TOSA housing, as a single unit. This advantageously ensures that each of the optical isolators are optically aligned with associated active and/or passive optical components, e.g., multiplexers, laser diodes, and so on, by virtue of the optical isolator array being coupled to the optical subassembly at a predefined position. The orientation of each optical isolator can be uniformly adjusted in tandem at a fine-grain level (e.g., by less than 10 microns) by simply shifting the physical position of the magnetic base relative to associated optical components, thus minimizing or otherwise reducing the overall number adjustments to achieve nominal power. This can significantly reduce manufacturing complexity, error, and the number of fix-and-repeat testing iterations that normally characterizes optical subassembly manufacturing.

While the present disclosure includes examples and scenarios directed specifically to optical isolator arrays being used in a transmitter optical subassembly (TOSA) arrangement, this disclosure is not limited in this regard. For example, an optical isolator consistent with the present disclosure may be utilized to align and mount optical isolators in receiver optical subassembly (ROSA) arrangements.

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid. This disclosure is equally applicable to coarse wavelength division multiplexing (CWDM). In one specific example embodiment, the channel wavelengths are implemented in accordance with local area network (LAN) wavelength division multiplexing (WDM), which may also be referred to as LWDM.

The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals. On the other hand, the term "direct optical coupling" refers to an optical coupling via an optical path between two elements that does not include such intermediate components or devices, e.g., a mirror, waveguide, and so on, or bends/turns along the optical path between two elements.

The term substantially, as generally referred to herein, refers to a degree of precision within acceptable tolerance that accounts for and reflects minor real-world variation due to material composition, material defects, and/or limitations/peculiarities in manufacturing processes. Such variation may therefore be said to achieve largely, but not necessarily wholly, the stated/nominal characteristic. To provide one non-limiting numerical example to quantify "substantially," such a modifier is intended to include minor variation that can cause a deviation of up to and including ±5% from a particular stated quality/characteristic unless otherwise provided by the present disclosure.

Referring to the Figures, FIG. **1**, an optical transceiver **100**, consistent with embodiments of the present disclosure, is shown and described. In this embodiment, the optical transceiver **100** includes a multi-channel transmitter optical subassembly (TOSA) arrangement **104** and a multi-channel receiver optical subassembly (ROSA) arrangement **106** coupled to a substrate **102**, which may also be referred to as an optical module substrate. The substrate **102** may comprise, for example, a printed circuit board (PCB) or PCB assembly (PCBA). The substrate **102** may be configured to be "pluggable" for insertion into an optical transceiver cage **109**.

In the embodiment shown, the optical transceiver **100** transmits and receives four (4) channels using four different channel wavelengths (λ**1**, λ**2**, λ**3**, λ**4**) via the multi-channel TOSA arrangement **104** and the multi-channel ROSA arrangement **106**, respectively, and may be capable of transmission rates of at least about 25 Gbps per channel. In one example, the channel wavelengths λ**1**, λ**2**, λ**3**, λ**4** may be 1270 nm, 1290 nm, 1310 nm, and 1330 nm, respectively. Other channel wavelengths are within the scope of this disclosure including those associated with local area network (LAN) wavelength division multiplexing (WDM). The optical transceiver **100** may also be capable of transmission distances of 2 km to at least about 10 km. The optical transceiver **100** may be used, for example, in Internet data center applications or fiber to the home (FTTH) applications. Although the following examples and embodiments show and describe a 4-channel optical transceiver, this disclosure is not limited in this regard. For example, the present disclosure is equally applicable to 2, 6, or 8-channel configurations.

In more detail, the multi-channel TOSA arrangement **104** includes a TOSA housing **114** with a plurality of sidewalls that define a cavity (not shown). The cavity includes a plurality of laser arrangements **110**, an optical isolator array **127**, and a multiplexing device **124** disposed therein. The optical isolator array **127** may be implemented as the optical isolator array **200** of FIGS. **2**-**6** or the optical isolator array **200'** of FIGS. **7**-**8**, which will be discussed in greater detail below. In an any event, each laser arrangement of the plurality of laser arrangements **110** can be configured to transmit optical signals having different associated channel wavelengths. Each laser arrangement may include passive and/or active optical components such as a laser diode (LD), monitor photodiode (MPD), laser diode driver (LDD), and so on. Additional components comprising each laser arrangement include filters, optical isolators, filtering capacitors, and so on.

To drive the plurality of laser arrangements **110**, the optical transceiver **100** includes a transmit connecting circuit **112** to provide electrical connections to the plurality of laser arrangements **110** within the housing **114**. The transmit connecting circuit **112** may be configured to receive driving signals (e.g., TX_D**1** to TX_D**4**) from, for example, circuitry within the optical transceiver cage **109**. The housing **114** may be optionally hermetically sealed to prevent ingress of foreign material, e.g., dust and debris. Therefore, a plurality of transit (TX) traces **117** (or electrically conductive paths) may be patterned on at least one surface of the substrate **102** and are electrically coupled with a feedthrough device **116** of the TOSA housing **114** to bring the transmit connecting circuit **112** into electrical communication with the plurality of laser arrangements **110**, and thus, electrically interconnect the transmit connecting circuit **112** with the multi-channel TOSA arrangement **104**. The feedthrough device **116** may comprise, for instance, ceramic, metal, or any other suitable material.

In operation, the multi-channel TOSA arrangement **104** may then receive driving signals (e.g., TX_D**1** to TX_D**4**), and in response thereto, generates and launches multiplexed channel wavelengths on to an output waveguide **120** such as a transmit optical fiber. The generated multiplexed channel wavelengths may be combined based on a demultiplexing device **124** such as an arrayed waveguide grating (AWG) that is configured to receive emitted channel wavelengths **126** from the plurality of laser assemblies **110** and output a signal carrying the multiplexed channel wavelengths on to the output waveguide **120** by way of optical fiber receptacle **122**.

Continuing on, the multi-channel ROSA arrangement **106** includes a demultiplexing device **124**, e.g., an arrayed waveguide grating (AWG), a photodiode (PD) array **128**, and an amplification circuitry **130**, e.g., a transimpedance amplifier (TIA). An input port of the demultiplexing device **124** may be optically coupled with a receive waveguide **134**, e.g., an optical fiber, by way of an optical fiber receptacle **136**. An output port of the demultiplexing device **124** may be configured to output separated channel wavelengths on to the PD array **128**. The PD array **128** may then output proportional electrical signals to the TIA **130**, which then may be amplified and otherwise conditioned. The PD array **128** and the transimpedance amplifier **130** detect and convert optical signals received from the fiber array **133** into electrical data signals (RX_D**1** to RX_D**4**) that are output via the receive connecting circuit **132**. In operation, the PD array **128** may then output electrical signals carrying a representation of the received channel wavelengths to a receive connecting circuit **132** by way of conductive traces **119** (which may be referred to as conductive paths).

Referring to FIGS. **2-6**, an example optical isolator array **200** is shown consistent with an embodiment of the present disclosure. As shown, the optical isolator array **200** includes a magnetic base **202** (or magnetic plate) and a plurality of optical isolators shown collectively as **204** and individually as **204-1** to **204-4**. The magnetic base **202** may be formed from a metal or metal alloy such as iron, nickel, cobalt, or any combination thereof. In an embodiment the magnetic base **202** may be configured as a permanent magnet device, although other types of magnets are within the scope of this disclosure as such electromagnet devices.

A plurality of sidewalls define the magnetic base **202** and provide at least a first mounting surface **207**. The first mounting surface **207** can be substantially planar, as shown, although in other embodiments the first mounting surface **207** may not necessarily be flat. The first mounting surface **207** supports the plurality of optical isolators **204**. The overall width W**1** (See FIG. **3**) of the magnetic base **202** may be a function of the desired number of optical isolators. For instance, in the embodiment shown in FIG. **3** the overall width W**1** may measure about 100 microns with each of the plurality of optical isolators **204** having a corresponding with of about 20 microns. In this example, 100 microns may be chosen for the overall width W**1** to allow for a portion of the overall width W**1**, namely widths W**2** and W**3**, to provide adhesive overflow regions, with W**2** and W**3** each measuring equally at about 10 microns. This advantageously provides sufficient mounting space for the four optical isolators as well as surface area to allow each end of the at least one layer of adhesive **206** to flow and cure without overflowing beyond the sides of the magnetic base **202**. Thus, the following equation may be used to determine the overall width W**1** of the magnetic base **202**:

$$W1=N*Wn+Wn \qquad \text{Equation (1)}$$

with W**1** being the overall length, N being the desired number of optical isolators, and Wn being the width of an optical isolator.

On the other hand, the overall height H**1** of the magnetic base **202** may be chosen to ensure, for instance, that each optical isolator of the plurality of optical isolators **204** is aligned vertically with an associated laser arrangement along a Z axis, which will be discussed in greater detail below with regard to FIG. **7**.

Each of the plurality of optical isolators **204** can comprise polarization-insensitive Faraday Isolators that include multiple segments/portions including a rotator portion sandwiched/disposed between first and second polarization sections. The first and second polarization sections polarizers can comprise birefringent wedges, e.g. made of rutile (TiO_2). This configuration is particularly well suited for space constrained housing. Each of the plurality of optical isolators **204** may include segments formed from different materials to target desired channel wavelengths.

The plurality of optical isolators may be secured at a predefined position on the first mounting surface **207** via at least one layer of adhesive **206**. As shown, the at least one layer of adhesive **206** may be disposed in a manner that at least partially surrounds each optical isolator of the plurality of optical isolators **204**. The at least one layer of adhesive **206** may flow during a depositing process along a direction that is substantially transverse relative to the first mounting surface **207** based on capillary action caused by proximity of each of the plurality of optical isolators **204**, or may simply cure as shown based on being disposed between each optical isolator of the plurality of optical isolators **204**. In either case, the at least one layer of adhesive **206** can be used as, in a general sense, a submount to hold and/or support each of the plurality of optical isolators at a predefined position relative to the magnetic base **202**.

To this end, a method for forming the optical isolator array **200** may include first disposing the at least one layer of adhesive **206** on to the mounting surface **207** of the base followed by disposing each of the plurality of optical isolators **204** at their predefined positions. Notably, the use of adhesives to hold each optical isolator **204-1** to **204-4** in place advantageously allows for relatively simple, fine-grain adjustments to the pitch/distance between optical isolators. As further shown in FIG. **3**, each of the plurality of optical isolators **204** may be disposed at predefined positions that include a uniform distance of D**1** between adjacent optical isolators. The at least one layer of adhesive **206** may vertically displace each of the plurality of optical isolators **204** by a distance D**2**. Distance D**2** may be uniform across the plurality of optical isolators **204**, although variations may be introduced by design and/or by function of how the at least one layer of adhesive **206** cures. Each of the optical isolators may be further disposed parallel with each other in a linear array.

With specific reference to FIG. **4**, the magnetic base **202** introduces a first magnetic field **212-1**. As shown, the flux lines of the first magnetic field **212-1** intersect with each of the optical isolators in the plurality of optical isolators **204** mounted to the magnetic base **202**. In operation, the polarity of the first magnetic field **212-2** therefore determines the direction of propagation for light which is incident to the plurality of optical isolators **204**.

Turning to FIG. **5**, the optical isolator array **200** is shown mounted to a substrate **220**. In particular, the magnetic base **202** of the optical isolator array **200** is coupled to the mounting surface **221** provided by the substrate **220** by way of a substrate mating surface **230**. The substrate mating surface **230** may be substantially planar and correspond with the mounting surface **221** of a substrate **220**.

The substrate **220** may comprise, for example, a printed circuit board (PCB), a sidewall of a housing (e.g., made of metal or other suitably rigid material) or any other suitable material. The optical isolator array **200** may be at least partially assembled separately from other components in an optical subassembly and later coupled during manufacturing processes as effectively, a single piece. Accordingly, each of the plurality of optical isolators **204** may be disposed at a predetermined orientation and position on the magnetic base **202** to ensure that each will be aligned within nominal tolerances along and X and Y axis. Optical alignment of the optical isolator array **200**, and more particularly each of the optical isolators mounted thereon, with associated passive and/or active optical components, e.g., a laser diode, may therefore be achieved by simply coupling the optical isolator **200** at a predefined location on the mounting surface **221** of the substrate **220**. The overall height H**1** (See FIG. **3**) may then displace the plurality of optical isolators **200** along the Z axis such that each optical isolator is optically aligned within nominal tolerances of associated active and/or passive components.

For example, and as shown in the highly simplified embodiment of FIG. **6**, each of the optical isolators **204-1** to **204-4** may be optically aligned with a corresponding collimating lens of a plurality of collimating lenses **205** and corresponding laser diode **208-1** to **208-4** of the plurality of laser diodes **208** based at least in part on the dimensions of the magnetic base **202**. This advantageously allows for the mounting surface **221** of the substrate **220** to act as a stop for the substrate mating surface **230** and provide a positive indication that each of the optical isolators is at a desired position along the Z axis simply by having the substrate mating surface **230** of the magnetic base **202** flush with the mounting surface **221** of the substrate **220**. Likewise, alignment for each of the plurality of optical isolators **204** along the X and Y axis requires simply ensuring the magnetic base **202** is positioned at a predetermined X and Y position relative to the associated optical components.

Each of the laser diodes **208-1** to **208-4** may be configured to emit a different channel wavelength. Following the laser diodes **208**, each of the optical isolators **204-1** to **204-4** include a light-receiving surface (e.g., light-receiving surface **209-1**) for receiving channel wavelengths from a corresponding laser diode of the laser diodes **208-1** to **208-4**, and a light-emitting surface (e.g., light-emitting surface **211-1**) disposed opposite the light-receiving surface for passing the received channel wavelengths to the multiplexing device, e.g., the multiplexing device **124** (FIG. **1**). Each light-receiving and light-emitting surface may be angled, e.g., at about 8 degrees, relative to a corresponding light path, such as shown.

Thus, after coupling of the optical isolator array **200** on the substrate **220**, an optical path may then extend from each an emission surface of each of the laser diodes **208-1** to **208-4**, through an associated collimating lens of the plurality of collimating lenses **205** and then through the an associated optical isolator of the plurality of optical isolators **204**. Each of the light paths may extend substantially parallel to each other, although other embodiments are within the scope of this disclosure.

FIG. **7** shows another example optical isolator array **200'** in accordance with an embodiment of the present disclosure. As shown, the optical isolator array **200'** is substantially similar to the optical isolator array **200** discussed above with regard to FIGS. **2-6**, the description of which is equally applicable to the embodiment of FIG. **7** but will not be repeated for brevity. However, the example optical isolator array **200'** includes a second magnetic base **203**. The second magnetic base **203** may be disposed on an upper surface of the optical isolators **204-1** to **204-4**, or alternatively supported by the at least one layer of adhesive **206'** disposed between the optical isolators **204** and the second magnetic base **203**.

Therefore, the plurality optical isolators **204** and the at least one layer of adhesive **206'** can be sandwiched/disposed between the first and second magnetic bases **202**, **203**. The first and second magnetic bases may extend substantially parallel relative to each other and may have identical dimensions, although other embodiments are within the scope of this disclosure. As shown, the at least one layer of adhesive **206'** may extend a distance D**2** from the mounting surface **207** of the first magnetic base **202** up to a mounting surface **213** of the second magnetic base **203**. To this end, the at least one layer of adhesive **206'** securely attaches the first and second magnetic bases **202**, **203** to each other, and more importantly, securely fixes the optical isolators **204-1** to **204-4** therebetween.

As shown in FIG. **8**, the first and second magnetic base **202**, **203** introduce first and second magnetic fields **212-1**, **212-2**, respectively. The first and second magnetic fields **212-1**, **212-2** may at least partially overlap, or not, depending on a desired configuration. In either case, the polarity of the first and second magnetic fields **212-1**, **212-2** may be utilized to establish a direction of propagation for wavelengths incident to the plurality of optical isolators **204**.

In accordance with an aspect of the present disclosure an optical isolator array for use in an optical subassembly module is disclosed. The optical isolator array comprising a first magnetic base defining at least one mounting surface, a plurality of optical isolators mounted to the at least one mounting surface, each of the plurality of optical isolators disposed substantially in parallel relative to each other, and at least one layer of adhesive disposed on the at least one mounting surface to couple the plurality of optical isolators to the first magnetic base and to hold each optical isolator of the plurality of optical isolators at a predefined position relative to each other.

In accordance with another aspect of the present disclosure an optical transceiver is disclosed. The optical transceiver comprising a transceiver housing, at least one optical transmitter subassembly (TOSA) arrangement disposed in the transceiver housing, the at least one TOSA arrangement comprising a substrate defined by at least one mounting surface, a plurality of laser diodes mounted to the at least one mounting surface of the substrate, each laser diode of the plurality of laser diodes to emit a different associated channel wavelength along a corresponding light path of a plurality of light paths, and an optical isolator array mounted to the at least one mounting surface adjacent the plurality of laser diodes such that the plurality of light paths intersect with the optical isolator array, the optical isolator array comprising a at least a first magnetic base and a plurality of optical isolators coupled thereto, and wherein each optical isolator is optically aligned with a corresponding laser diode of the plurality of laser diodes via a corresponding light path, an optical receiver subassembly (ROSA) disposed in the transceiver housing.

While the principles of the disclosure have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the disclosure. Other embodiments are contemplated within the scope of the present disclosure in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present disclosure, which is not to be limited except by the following claims.

What is claimed is:

1. An optical isolator array for use in an optical subassembly module, the optical isolator array comprising:

a first magnetic base defining at least one mounting surface;

a plurality of optical isolators mounted to the at least one mounting surface, each of the plurality of optical isolators disposed substantially in parallel relative to each other; and

at least one layer of adhesive disposed on the at least one mounting surface to couple the plurality of optical isolators to the first magnetic base and to hold each optical isolator of the plurality of optical isolators at a predefined position relative to each other.

2. The optical isolator array of claim **1**, wherein the magnetic base is formed from a permanent magnet.

3. The optical isolator array of claim **1**, wherein the magnetic base introduces a first magnetic field that intersects with the plurality of optical isolators to establish a direction of propagation.

4. The optical isolator array of claim **1**, wherein each optical isolator of the plurality of optical isolators comprises a Faraday Isolator.

5. The optical isolator array of claim **1**, wherein each optical isolator of the plurality of optical isolators includes an angled light-receiving surface to receive channel wavelengths from an associated laser diode.

6. The optical isolator array of claim **1**, wherein the plurality of optical isolators is disposed uniformly across the at least one mounting surface.

7. The optical isolator array of claim **1**, wherein the at least one layer of adhesive is disposed between adjacent optical isolators of the plurality of optical isolators.

8. The optical isolator array of claim **1**, wherein the magnetic base includes a substrate mating surface, and whereby the substrate mating surface is substantially flat to correspond with a mounting surface of a substrate and to mount thereto.

9. The optical isolator array of claim **1**, further comprising a second magnetic base, the second magnetic base being coupled to the plurality of optical isolators via the at least one layer of adhesive.

10. The optical isolator array of claim **9**, wherein the second magnetic base introduces a second magnetic field, the second magnetic field intersecting with the plurality of optical isolators.

11. An optical transceiver, the optical transceiver comprising:

a transceiver housing;

at least one optical transmitter subassembly (TOSA) arrangement disposed in the transceiver housing, the at least one TOSA arrangement comprising:

a substrate defined by at least one mounting surface;

a plurality of laser diodes mounted to the at least one mounting surface of the substrate, each laser diode of the plurality of laser diodes to emit a different associated channel wavelength along a corresponding light path of a plurality of light paths; and

an optical isolator array mounted to the at least one mounting surface adjacent the plurality of laser diodes such that the plurality of light paths intersect with the optical isolator array, the optical isolator array comprising a at least a first magnetic base and a plurality of optical isolators coupled thereto, and wherein each optical isolator is optically aligned with a corresponding laser diode of the plurality of laser diodes via a corresponding light path;

an optical receiver subassembly (ROSA) disposed in the transceiver housing.

12. The optical transceiver of claim **11**, wherein the first magnetic base of the optical isolator array is formed from a permanent magnet.

13. The optical transceiver of claim **11**, wherein the first magnetic base introduces a first magnetic field that intersects with the plurality of optical isolators to establish a direction of propagation.

14. The optical transceiver of claim **11**, wherein each optical isolator of the plurality of optical isolators includes an angled light-receiving surface to receive channel wavelengths from a corresponding laser diode of the plurality of laser diodes.

15. The optical transceiver of claim **11**, wherein the plurality of optical isolators is disposed uniformly across the at least one mounting surface.

16. The optical transceiver of claim **11**, wherein at least one layer of adhesive is disposed between adjacent optical isolators of the plurality of optical isolators.

17. The optical transceiver of claim **11**, wherein the first magnetic base includes a substrate mating surface, and whereby the substrate mating surface is substantially flat to correspond with the mounting surface of a substrate to mount thereto.

18. The optical transceiver of claim **11**, further comprising a second magnetic base, the second magnetic base being coupled to the plurality of optical isolators and the first magnetic base via at least one layer of adhesive.

19. The optical transceiver of claim **18**, wherein the second magnetic base introduces a second magnetic field, the second magnetic field intersecting with the plurality of optical isolators.

* * * * *

EXHIBIT I

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

<u>CIG 100G QSFP28 PSM4</u>

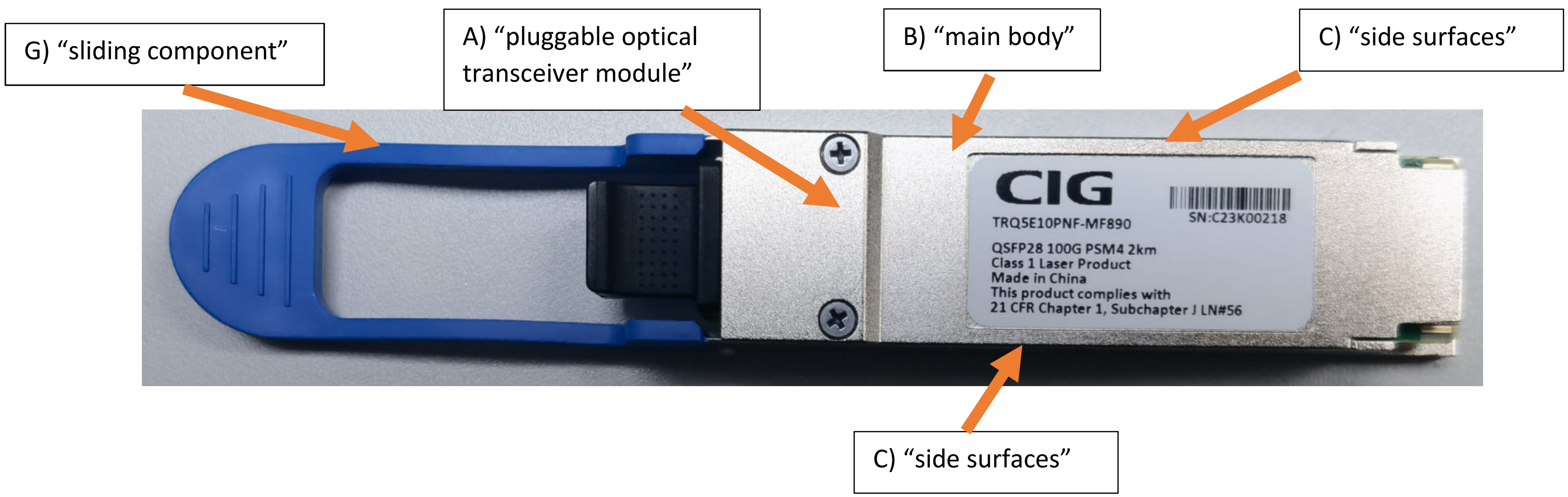


Figure 1

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

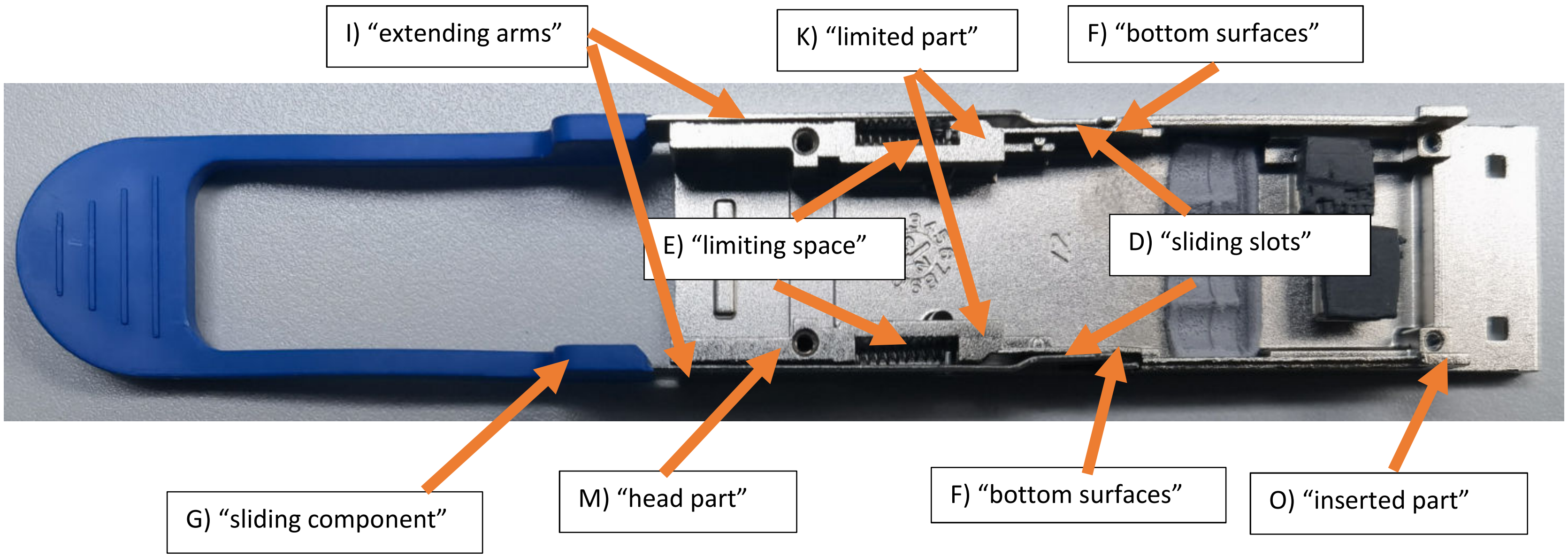


Figure 2

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

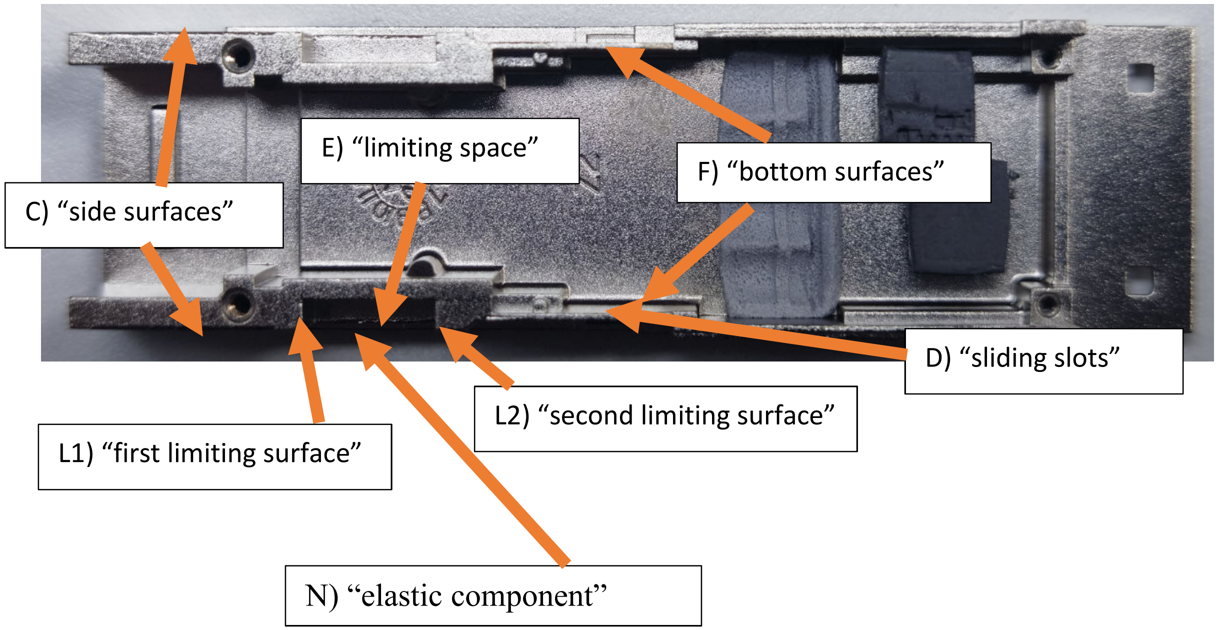


Figure 3

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

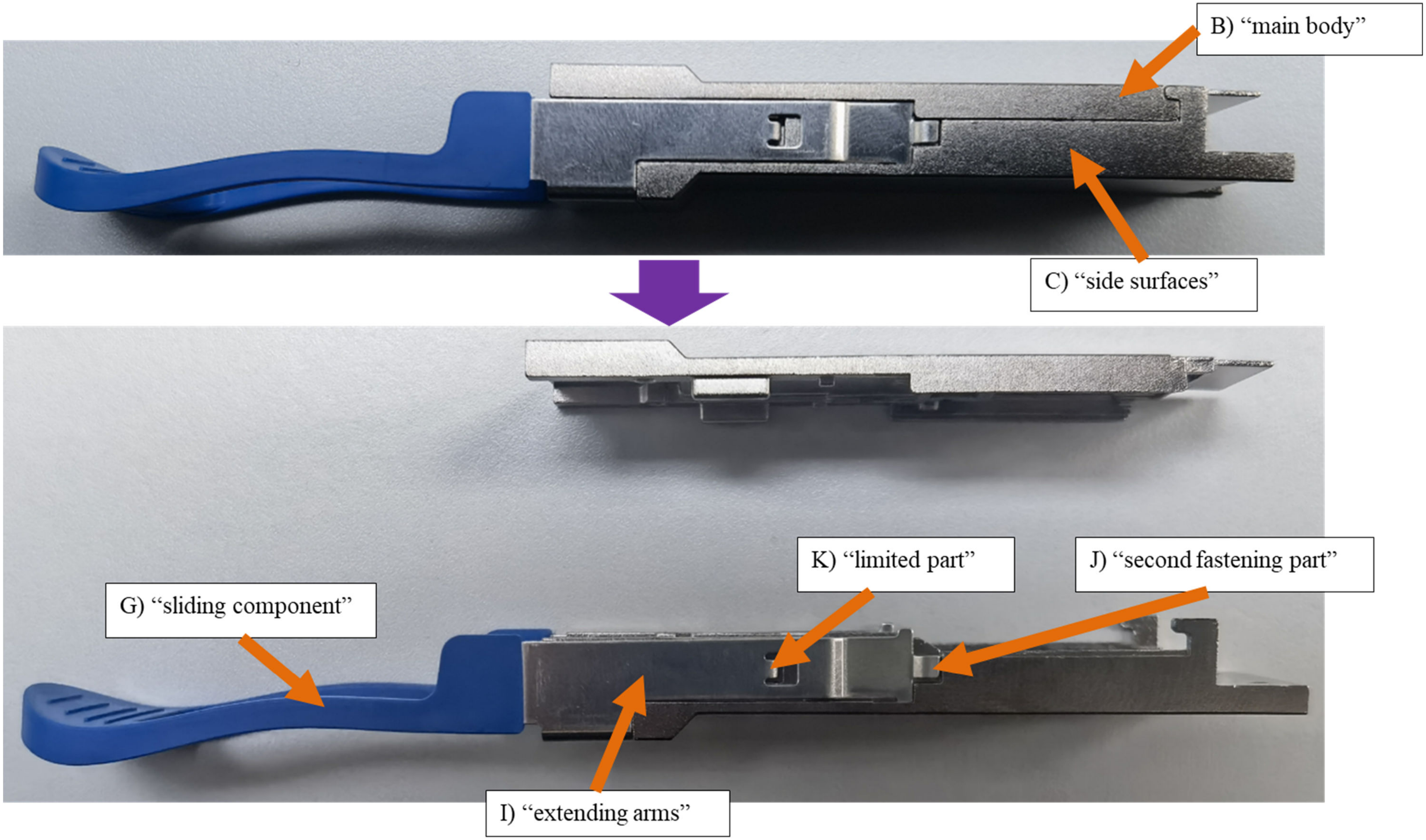


Figure 4

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

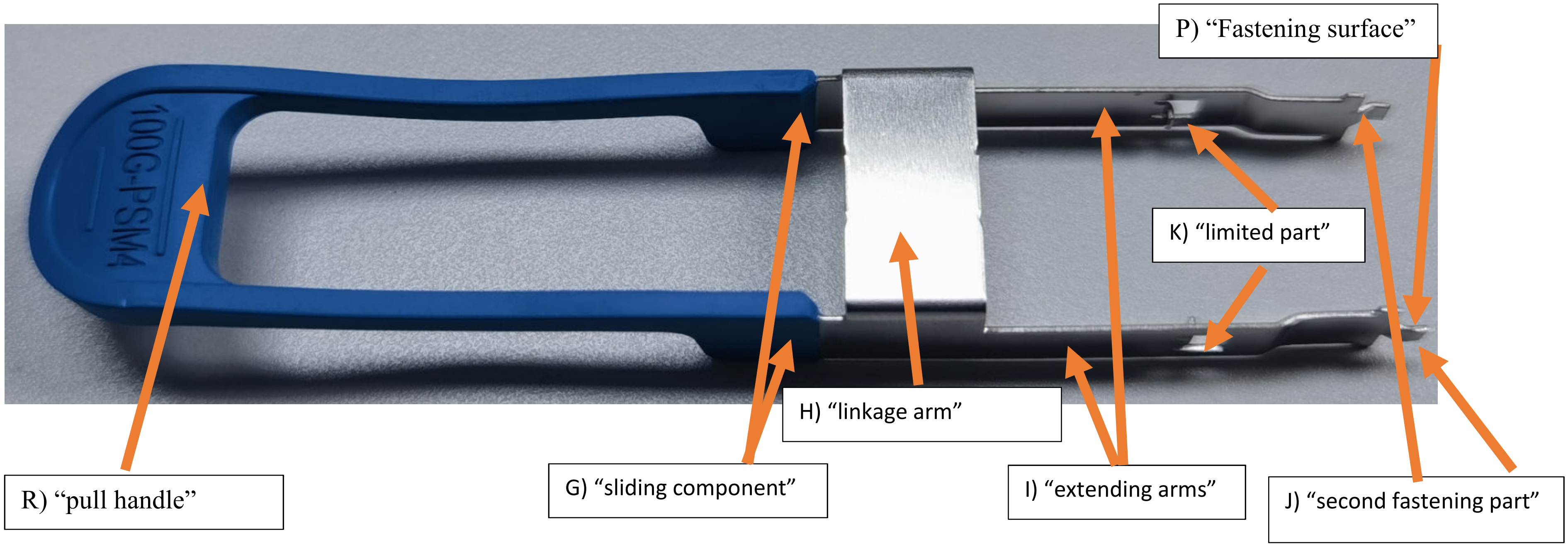


Figure 5

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

Independent Claim 1

U.S. Patent No. 9,523,826 Claim 1	CIG 100G QSFP28 PSM4
1. A pluggable optical transceiver module, for being inserted into a plugging slot of a socket, the socket comprising two first fastening parts located in the plugging slot, the pluggable optical transceiver module comprising:	Pluggable optical transceiver module **(A)** (100G QSFP28 PSM4) is shown in FIGs. 1–5.
a main body having two side surfaces that are opposite to each other and	Main body **(B)** has two side surfaces **(C)** that are opposite to each other. See FIGs. 1–5.
two sliding slots located at the two side surfaces, respectively,	Two sliding slots **(D)** are located at the two side surfaces **(C)**, respectively. See FIGs. 1 and 2.
wherein the main body is configured to be inserted into the plugging slot,	Main body **(B)** is configured to be inserted into a plugging slot. See FIGs. 1–5.
wherein the main body has at least one limiting space and two bottom surfaces forming the two sliding slots, respectively,	Main body **(B)** has at least one limiting space **(E)** and two bottom surfaces **(F)** forming the two sliding slots **(D)**. See FIGs. 1–3.
the two bottom surfaces are parallel to the two side surfaces,	Two bottom surfaces **(F)** are parallel to the two side surfaces **(C)**. See FIGs. 2 and 3.
the at least one limiting space is located at one of the two side surfaces;	The at least one limiting space **(E)** is located at one of the two side surfaces **(C)**. See FIGs. 2–3.
a sliding component comprising a linkage arm and two extending arms,	Sliding component **(G)** comprises a linkage arm **(H)** and two extending arms **(I)**. See FIGs. 2 and 5.
wherein the two extending arms are connected to two ends of the linkage arm, respectively,	The two extending arms **(I)** are connected to two ends of the linkage arm **(H)**. See FIGs. 2, 4, and 5.
each extending arm has a second fastening part,	Each extending arm **(I)** has a second fastening part **(J).** See FIG. 5.
the main body is between the two extending arms,	The main body **(B)** is between the two extending arms **(I)**. See FIGs. 1, 2, and 4.
the two extending arms are slidably disposed on the two sliding slots to have a fastening position and a releasing position,	Two extending arms **(I)** are slidably disposed on the two sliding slots **(D)** to have a fastening position and releasing position. See FIGs. 2–4.

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

U.S. Patent No. 9,523,826 Claim 1	CIG 100G QSFP28 PSM4
the two first fastening parts are fastened to the two second fastening parts when the two extending arms are located at the fastening position,	The two first fastening parts are configured to be fastened to the two second fastening parts **(J)** when the two extending arms **(I)** are located at the fastening position. See FIGs. 2–4.
and the two second fastening parts press the two first fastening parts, respectively, to make the two first fastening parts be farther away from each other when the two extending arms are located at the releasing position,	The two second fastening parts **(J)** on information and belief press the two fastening parts (of the socket) to make the two first fastening parts (of the socket) to be farther away from each other when the two extending arms **(I)** are located at the releasing position. See FIGs. 2–4.
wherein each extending arm has a limited part configured to move in the at least one limiting space;	Each extending arm **(I)** has a limited part **(K)** configured to move in the at least one limiting space **(E)**. See FIG. 2.
and an elastic component,	An elastic component **(N).** See FIG. 3.
wherein the main body has a first limiting surface and a second limiting surface forming the limiting space,	The main body **(B)** has a first limiting **(L1)** surface and a second limiting surface **(L2)** forming the limiting space**.** See FIGs. 1 and 3.
the first limiting surface is closer to the head part than the second limiting surface,	The first limiting surface **(L1)** is closer to the head part **(M)**. See FIGs. 2–3.
and the elastic component is located in the limiting space and between the first limiting surface and the limited part and is covered by the extending arm such that the elastic component is confined by the main body and the sliding component.	The elastic component **(N)** is located in the limiting space **(E)** and between the first limiting surface **(L1)** and the second limiting surface **(L2)** such that the elastic component **(N)** is confined by the main body **(B)** and the sliding component **(G)**. See FIGs. 1–3.

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

Independent Claim 7

U.S. Patent No. 9,523,826 Claim 7	**Molex 100G QSFP28 PSM4**
7. A pluggable optical transceiver module, comprising:	Pluggable optical transceiver module (**A**) (100G QSFP28 PSM4) is shown in FIGs. 1–5.
a main body having a head part and an inserted part that are connected to each other,	Main body (**B**) having a head part (**M**) and an inserted part (**O**) that are connected to each other. See FIG. 1–2.
wherein the main body further comprises opposite two side surfaces and	Main body (**B**) having two opposite side surfaces (**C**). See FIGs. 1 and 3–4.
two sliding slots which are located at two sides of the head part and the inserted part opposite to each other, respectively,	Two sliding slots (**D**) which are located at two sides of the head part (**M**) and the inserted part (**O**) opposite each other, respectively. See FIG. 2.
the two sliding slots are located at the two side surfaces, and the two sliding slots extend from the head part to the inserted part, respectively,	Two sliding slots (**D**) shown located at the two side surfaces (**C**), and the two sliding slots (**D**) extend from the head part (**M**) to the inserted part (**O**). See FIG. 2.
wherein the main body has at least one limiting space and two bottom surfaces forming the two sliding slots, respectively,	Main body (**B**) has at least one limiting space (**E**), and two bottom surfaces (**F**) forming the two sliding slots (**D**). See FIGs. 1–3.
the two bottom surfaces are parallel to the two side surfaces,	Two bottom surfaces (**F**) are parallel to the two side surfaces (**C**). See FIGs. 2–3.
the at least one limiting space is located at one of the two side surfaces;	The at least one limiting space (**E**) is located at one of the two side surfaces (**C**). See FIGs. 2–3.

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

U.S. Patent No. 9,523,826 **Claim 7**	**Molex 100G QSFP28 PSM4**
a sliding component comprising a linkage arm and two extending arms,	Sliding component (**G**) having a linkage arm (**H**) and two extending arms (**I**). See FIGs. 2 and 5.
wherein the linkage arm is connected between the two extending arms,	Linkage arm (**H**) is connected between the two extending arms (**I**). See FIGs. 2 and 5.
each extending arm has a second fastening part,	Each extending arm (**I**) has a second fastening part (**J**). See FIG. 5.
the main body is between the two extending arms,	The main body (**B**) is between the two extending arms (**I**). See FIGs. 1-2 and 4.
the two extending arms are able to slide relative to the two sliding slots to have a fastening position which is farther away from the head part and a releasing position which is closer to the head part,	Two extending arms (**I**) are able to slide relative to the two sliding slots (**D**) to have a fastening position which on information and belief are further away from the head part (**M**), and releasing position which is closer to the head part (**M**). See FIGs. 2-4.
wherein each extending arm has a limited part configured to move in the at least one limiting space;	Each extending arm (**I**) has a limited part (**K**) configured to move in the at least one limiting space (**E**). See FIGs. 2-4.
and an elastic component,	An elastic component (**N**). See FIG. 3.
wherein the main body has a first limiting surface and a second limiting surface forming the limiting space,	The main body (**B**) has a first limiting surface (**L1**) and a second limiting surface (**L2**). See FIG. 1 and 3.
the first limiting surface is closer to the head part than the second limiting surface,	The first limiting surface (**L1**) is closer to the head part (**M**). See FIGs. 2–3.
and the elastic component is located in the limiting space and between the first limiting surface and the limited part and is	The elastic component (**N**) is located in the limiting space (**E**) and between the first limiting surface (**L1**) and the first limited part (**K**) such that the elastic component (**N**) is covered by the

EXHIBIT I - Representative Claim Chart for U.S. Patent No. 9,523,826

U.S. Patent No. 9,523,826 Claim 7	**Molex 100G QSFP28 PSM4**
covered by the extending arm such that the elastic component is confined by the main body and the sliding component.	extending arm (**I**) and is confined by the main body (**B**) and the sliding component (**G**). See FIGs. 2-4.

EXHIBIT J

EXHIBIT J - Representative Claim Chart for U.S. Patent No. 10,466,432

CIG 100G QSFP28 PSM4

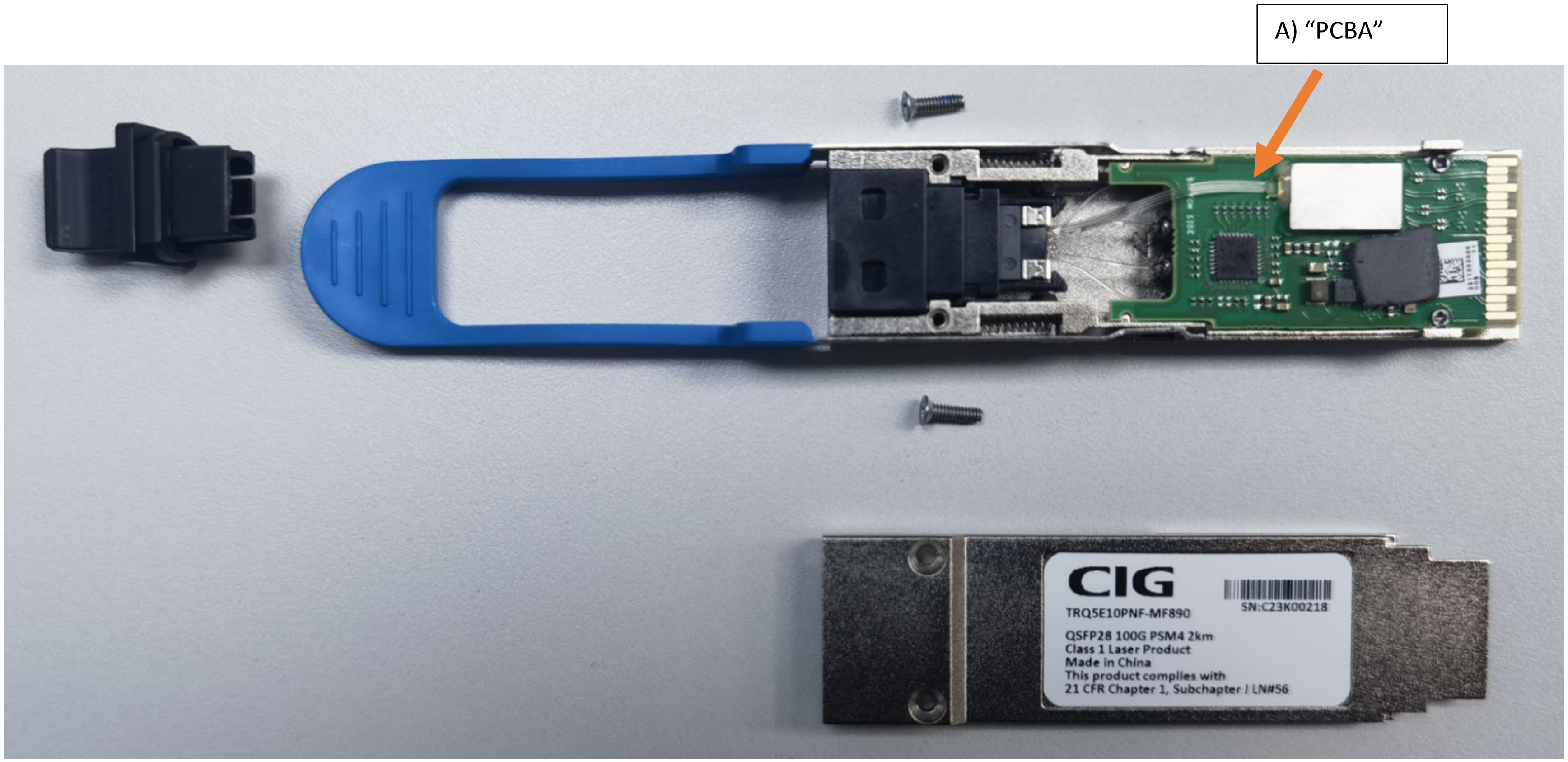


Figure 1

EXHIBIT J - Representative Claim Chart for U.S. Patent No. 10,466,432

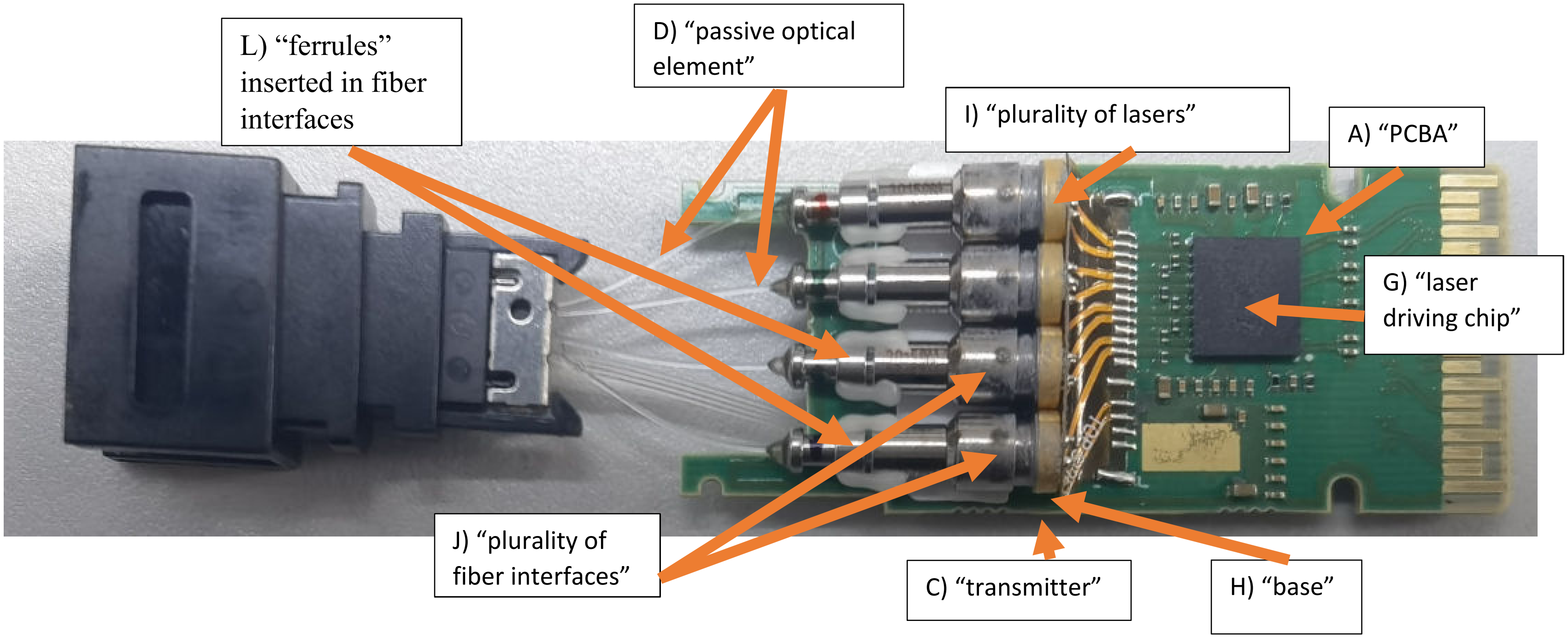


Figure 2

EXHIBIT J - Representative Claim Chart for U.S. Patent No. 10,466,432

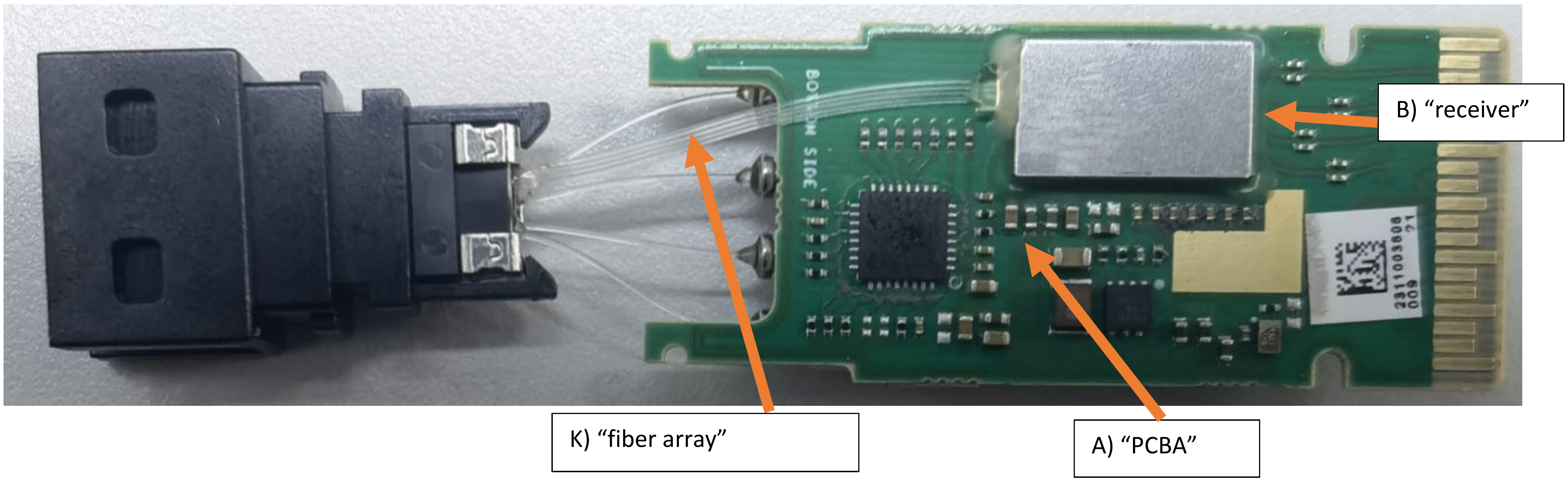


Figure 3

EXHIBIT J - Representative Claim Chart for U.S. Patent No. 10,466,432

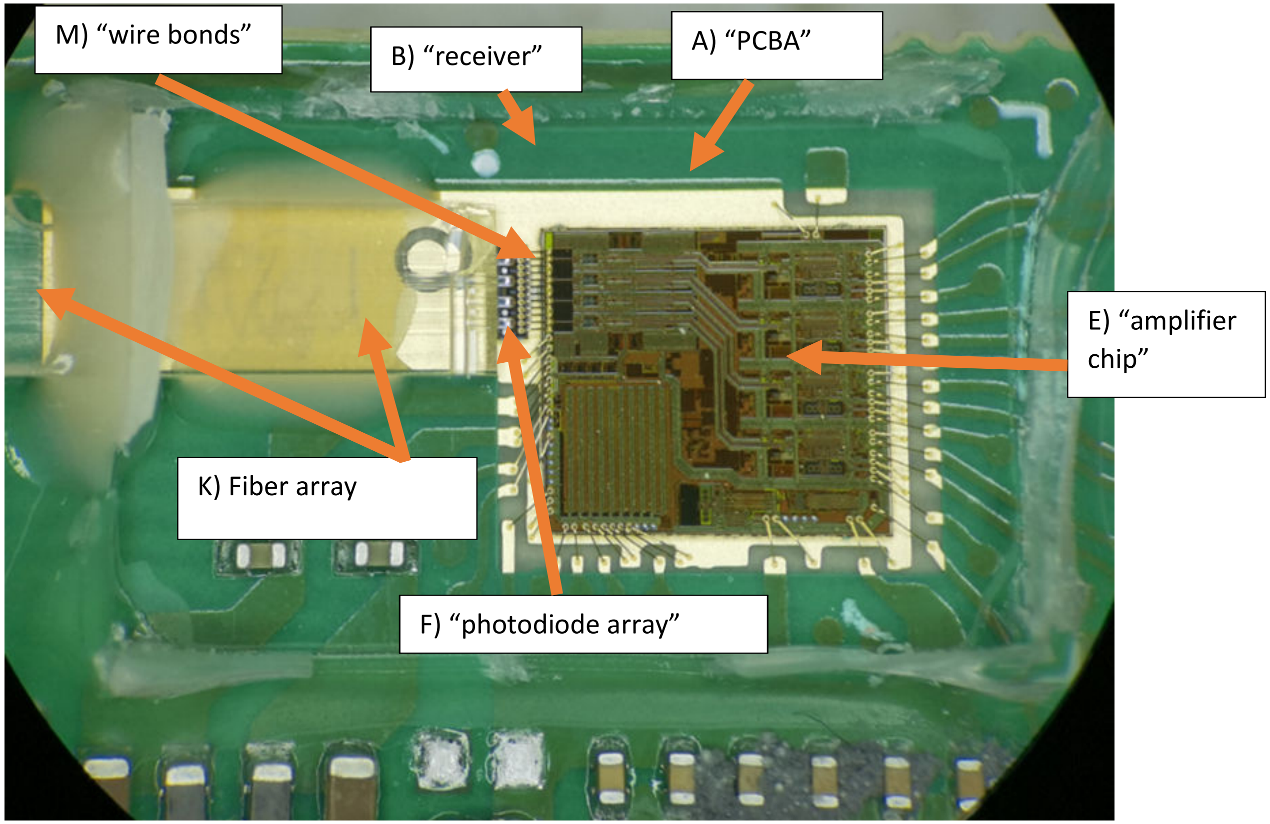


Figure 4

EXHIBIT J - Representative Claim Chart for U.S. Patent No. 10,466,432

Independent Claim 1

U.S. Patent No. 10,466,432 Claim 1	**CIG 100G QSFP28 PSM4**
1. A high-speed optical transceiver module, comprising:	FIGs. 1–4 show a 4-channel, 100G transceiver, which is a high-speed optical transceiver module.
a printed circuit board assembly (PCBA) component having a receiver and a transmitter; and	A printed circuit board assembly (PCBA) **(A)** is shown in FIGs. 1–4. PCBA **(A)** includes receiver **(B)** as shown in FIG. 3, and PCBA **(A)** includes transmitter **(C)** as shown in FIG. 2.
a passive optical element,	a passive optical element **(D)** is shown in FIG. 2.
wherein the receiver comprises an amplifier chip and a photodiode array connected to pins of the amplifier chip;	Receiver **(B)** includes an amplifier chip **(E)** and a photodiode array **(F)**, photodiode array **(F)** is connected to pins of amplifier chip **(E)** via wire bonds **(M)** as shown in FIG. 3–4.
the transmitter comprises a laser driving chip and a base;	Transmitter **(C)** includes a laser driving chip **(G)** and base **(H)** as shown in FIG. 2.
the base comprises a plurality of lasers arranged side by side;	Base **(H)** comprises a plurality of lasers **(I)** arranged side by side as shown in FIGs. 2.
the plurality of lasers are connected to the laser driving chip;	The plurality of lasers **(I)** are connected to the laser driving chip **(G)**. See FIG. 2.
a plurality of fiber interfaces are arranged on output light paths corresponding to the lasers;	A plurality of fiber interfaces **(J)** are arranged on output light paths corresponding to the lasers **(I)** as shown in FIG. 2.
the passive optical element comprises ferrules corresponding to the fiber interfaces	The passive optical element **(D)** comprises ferrules (**L**) corresponding to the fiber interfaces **(J)** as shown in FIG. 2.
and a fiber array for emitting light on the photodiode array of the receiver; and	Fiber array **(K)** is for emitting light on the photodiode array **(F)** of the receiver **(B)** as shown in FIGs. 3–4.
the ferrules are inserted into the plurality of fiber interfaces in one-to-one correspondence.	The ferrules (**L**) are shown inserted into the plurality of fiber interfaces **(J)** in one-to-one correspondence as shown in FIG. 2.

EXHIBIT K

EXHIBIT K - Representative Claim Chart for U.S. Patent No. 9,170,383

<u>CIG 100G QSFP CWDM4 Module Version 1</u>

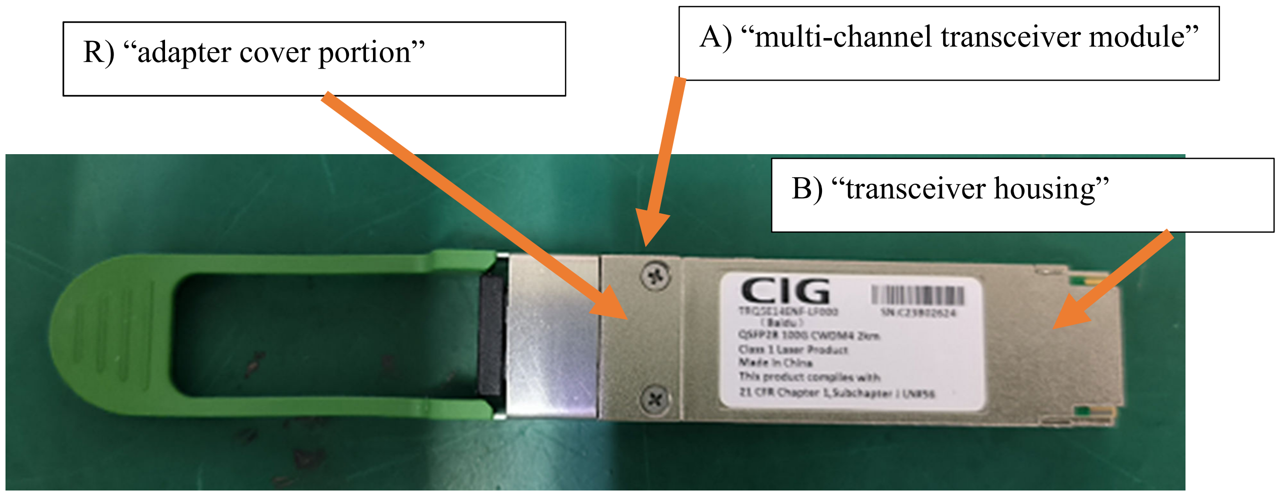


Figure 1

EXHIBIT K - Representative Claim Chart for U.S. Patent No. 9,170,383

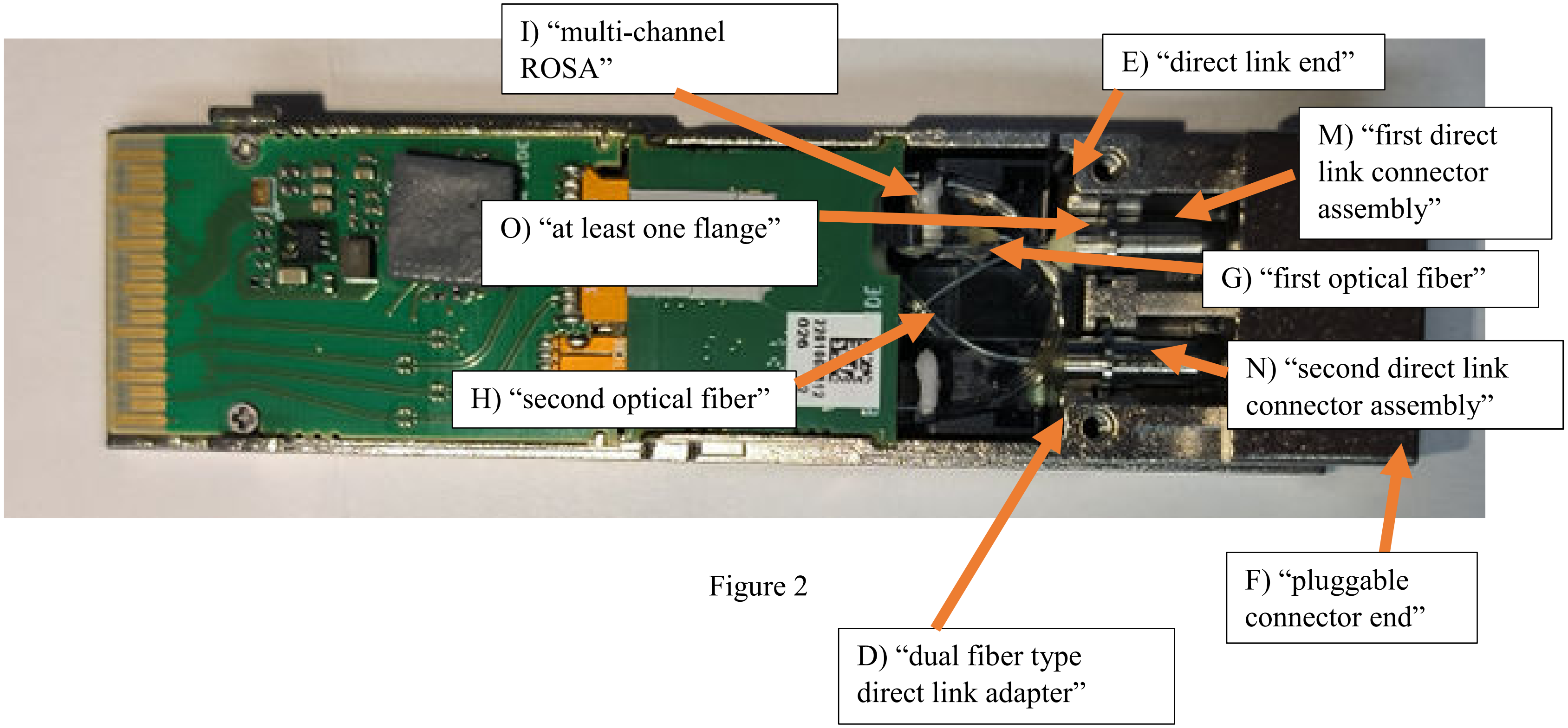


Figure 2

EXHIBIT K - Representative Claim Chart for U.S. Patent No. 9,170,383

Figure 3

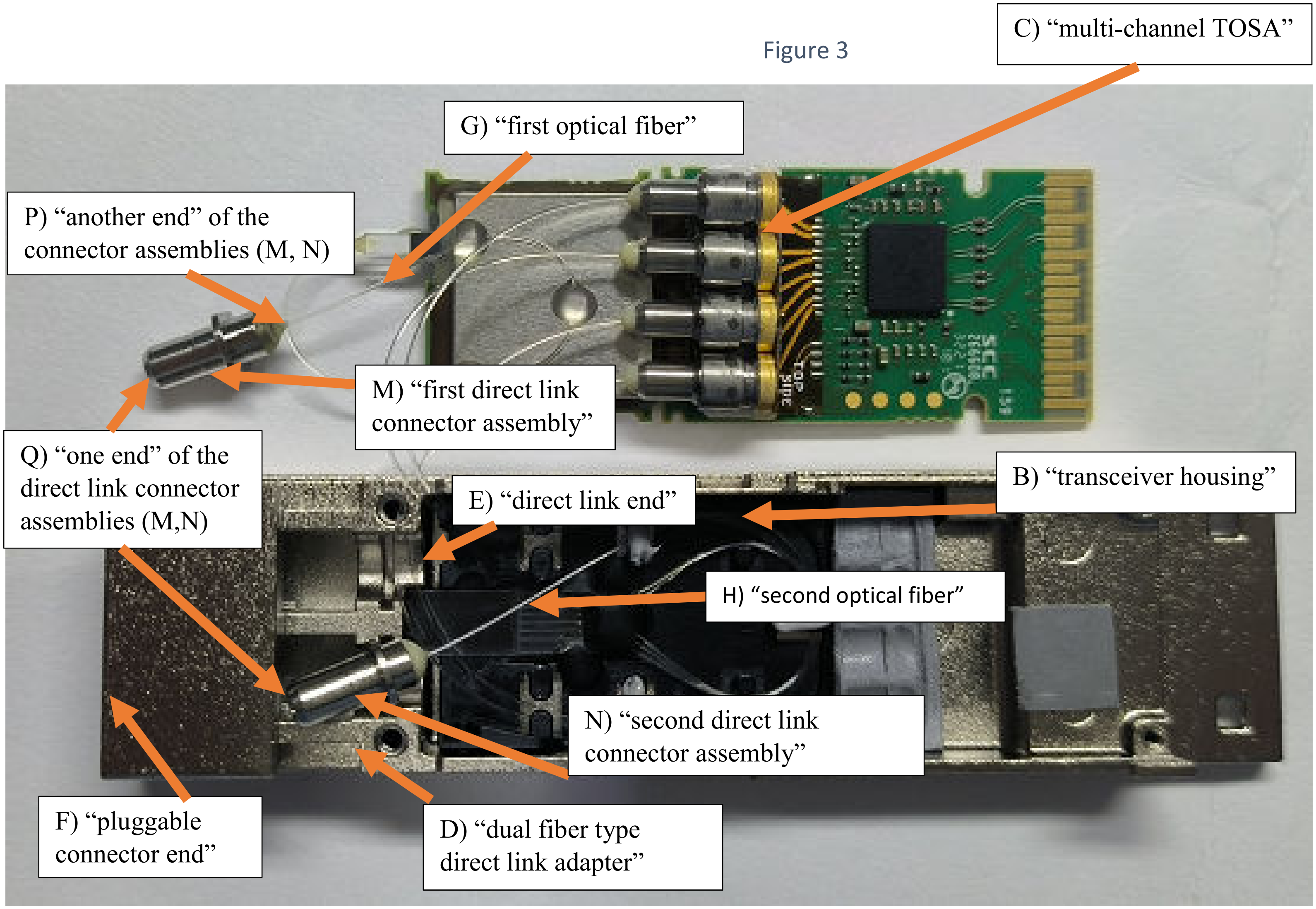


EXHIBIT K - Representative Claim Chart for U.S. Patent No. 9,170,383

Figure 4

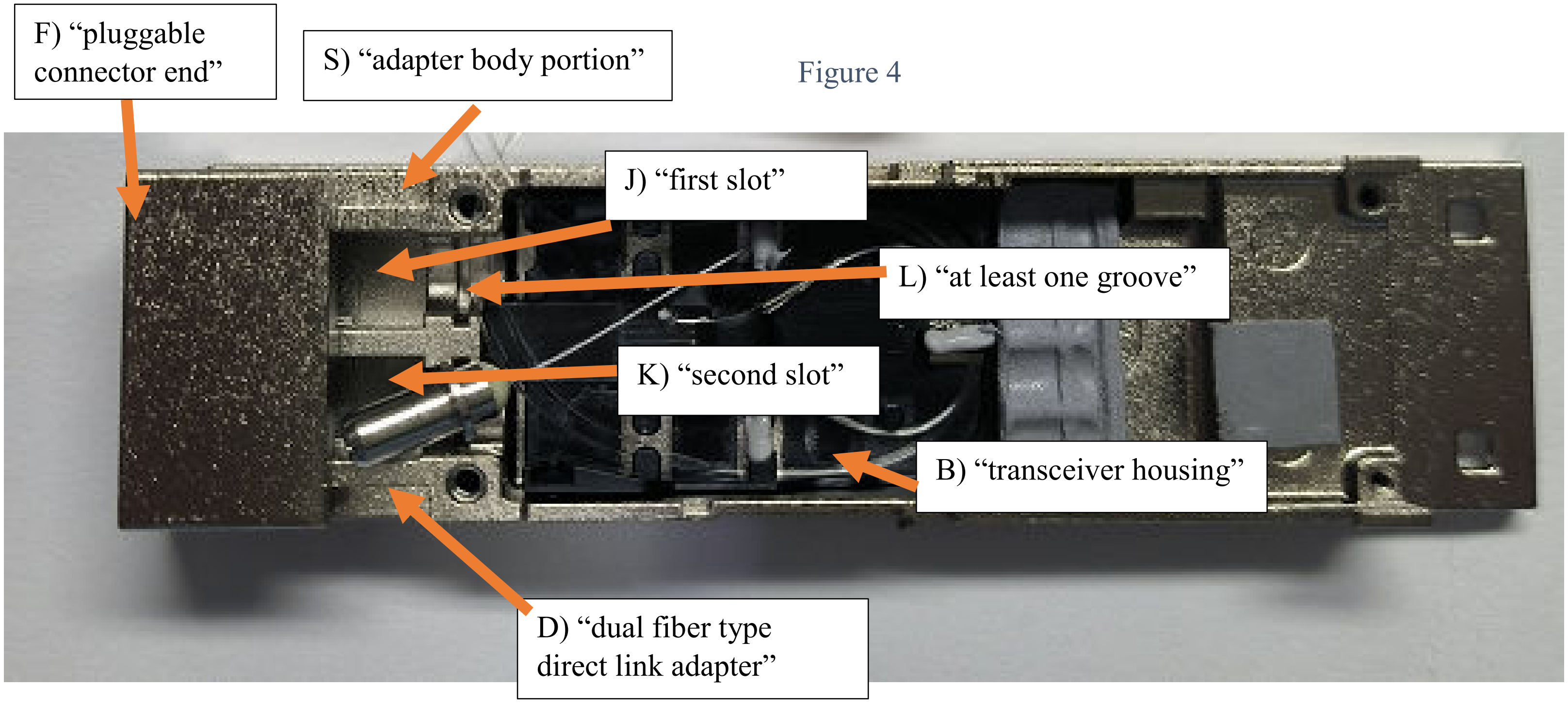


EXHIBIT K - Representative Claim Chart for U.S. Patent No. 9,170,383

I) "multi-channel ROSA"

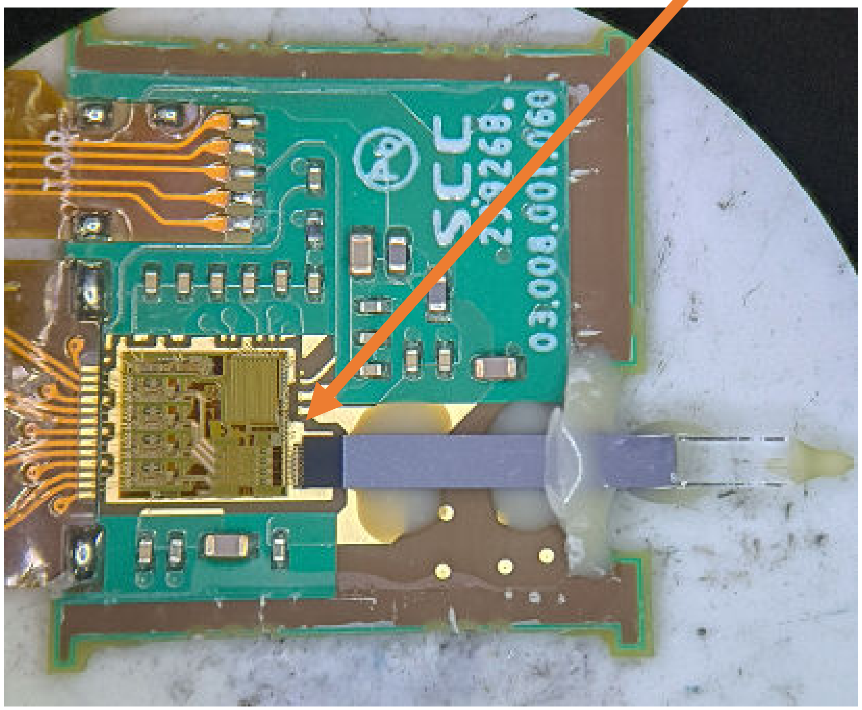


Figure 2

EXHIBIT K - Representative Claim Chart for U.S. Patent No. 9,170,383

Independent Claim 1

U.S. Patent No. 9,170,383 Claim 1	100G QSFP CWMD4 - Version 1
1. A multi-channel transceiver module comprising:	Multi-channel transceiver module **(A)** (100G QSFP CWMD4). See FIGs. 1-5.
a transceiver housing;	Transceiver housing **(B)**. See FIGs. 1-5.
a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing,	Multi-channel transmitter optical subassembly (TOSA) **(C)** is located in the transceiver housing **(B)**. See FIG. 3.
the TOSA being configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths;	The TOSA **(C)** is configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. See FIG. 3.
a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing,	A multi-channel receiver optical subassembly (ROSA) **(I)** is located in the transceiver housing **(B)**. See FIGs. 2 and 5.
the ROSA being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths; and	The ROSA **(I)** is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. See FIG. 5.
a dual fiber type direct link adapter located inside the transceiver housing and at one side of the transceiver housing,	A dual fiber type direct link adapter **(D)** is located inside the transceiver housing **(B)**. The dual fiber type direct link adapter **(D)** is located at one side of the transceiver housing **(B)**. See FIGs. 2-4.
the dual fiber type direct link adapter having a direct link end located in the transceiver housing and a pluggable connector end facing outside of the transceiver housing,	The dual fiber type direct link adapter **(D)** has a direct link end **(E)** located in the transceiver housing **(B)** and a pluggable connector end **(F)** facing outside of the transceiver housing **(B)**. See FIG. 3.
the direct link end of the dual fiber type direct link adapter being coupled to the TOSA with a first optical fiber and coupled to the ROSA with a second optical fiber to provide a direct link between the dual fiber type direct link adapter and the TOSA and the ROSA,	Direct link end **(E)** of the dual fiber type direct link adapter **(D)** is coupled to the TOSA **(C)** with a first optical fiber **(G)** and coupled to the ROSA **(I)** with a second optical fiber **(H)** providing a direct link between the dual fiber type direct link adapter **(D)** and the TOSA **(C)** and the ROSA **(I)**. See FIGs. 2-5.
the pluggable connector end being configured to receive first and second pluggable optical connectors for optically coupling the TOSA and the ROSA to external optical fibers,	The pluggable connector end **(F)** is configured to receive first and second optical pluggable optical connectors for optically

EXHIBIT K - Representative Claim Chart for U.S. Patent No. 9,170,383

U.S. Patent No. 9,170,383 Claim 1	**100G QSFP CWMD4 - Version 1**
	coupling the TOSA **(C)** and ROSA **(I)** to external optical fibers**.** See FIGs. 2-4.
wherein the dual fiber type direct link adapter comprises: an adapter body portion defining first and second slots,	The dual fiber direct link adapter **(D)** includes an adapter body portion **(S)** defining first and second slots **(J, K)**. See FIG. 4.
each of the first and second slots including at least one groove;	Each of the first and second slots **(J, K)** include at least one groove **(L)**. See FIG. 4.
first and second direct link connector assemblies received in the first and second slots, respectively, of the adapter body portion,	First and second direct link connector assemblies **(M, N)** are received in the first and second slots **(J,K)**, respectively, of the adapter body portion **(S)**. See FIGs. 2 and 4.
each of the first and second direct link connector assemblies including at least one flange extending into the groove in the first and second slots, respectively, to prevent axial movement of the first and second direct link connector assemblies,	Each of the first and second direct link connector assemblies **(M, N)** include at least one flange **(O)** extending into the groove **(L)** in the first and second slots **(J, K)**, respectively, to prevent axial movement of the first and second direct link connector assemblies **(M, N)**. See FIGs. 2 and 4.
wherein one end of each of the direct link connector assemblies defines a connector receptacle configured to receive a portion of the optical connector for optical coupling,	One end (**Q**) of each of the direct link connector assemblies **(M, N)** defines a connector receptacle configured to receive a portion of the optical connector for optical coupling. See FIGs. 2-4.
and wherein another end of each of the connector assemblies is directly linked to a respective optical fiber; and	Another end (**P**) of each of the connector assemblies **(M, N)** is directly linked to a respective optical fiber **(G, H)**. See FIGs. 2 and 3.
an adapter cover portion covering the first and second slots and retaining the first and second direct link connector assemblies in the first and second slots, respectively.	An adapter cover portion **(R)** covers the first and second slots **(J, K)** to retain the first and second direct link connector assemblies **(M, N)** in the first and second slots **(J, K)**, respectively. See FIGs. 1 and 2.

EXHIBIT L

EXHBIT L - Representative Claim Charts for U.S. Patent No. 10,379,301

<u>CIG 100G LR4 Module</u>

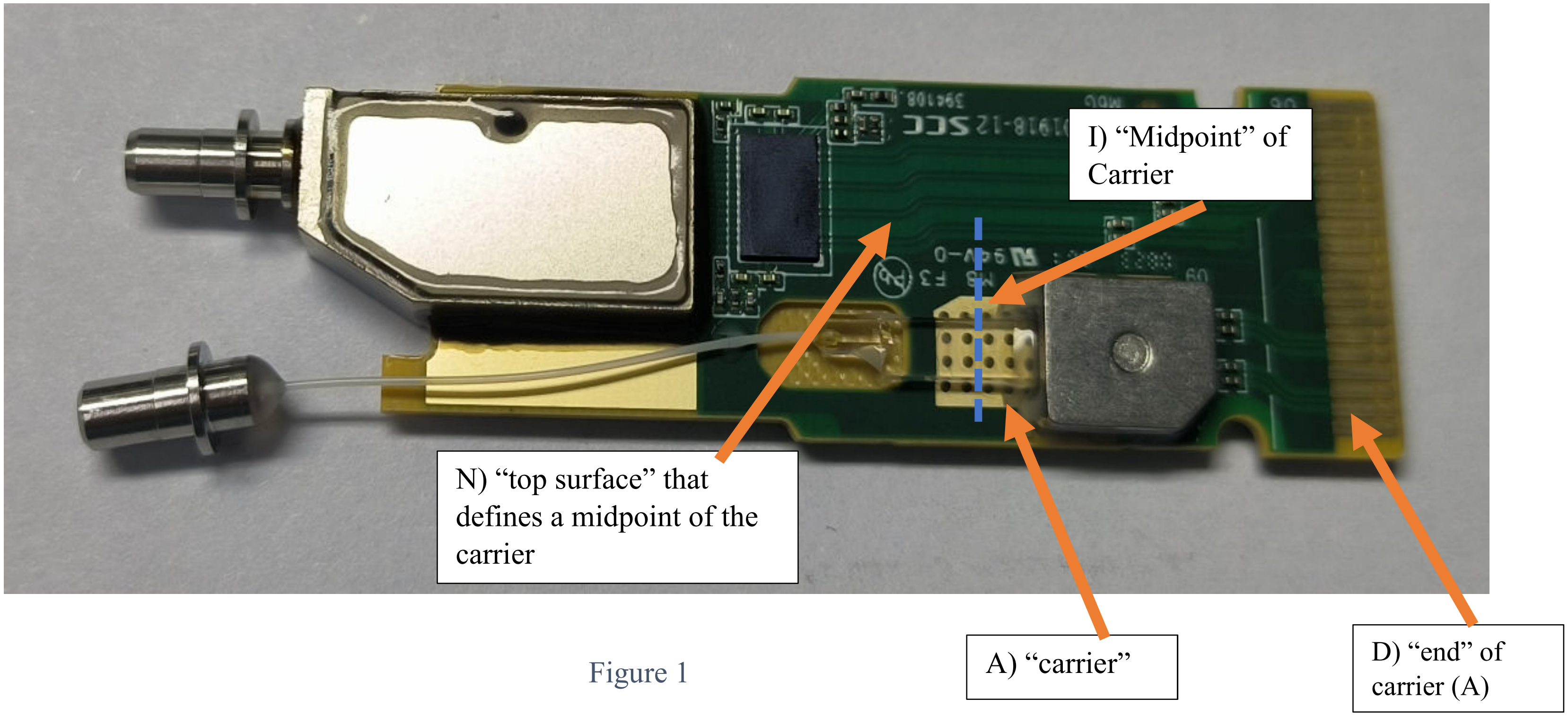


Figure 1

EXHBIT L - Representative Claim Charts for U.S. Patent No. 10,379,301

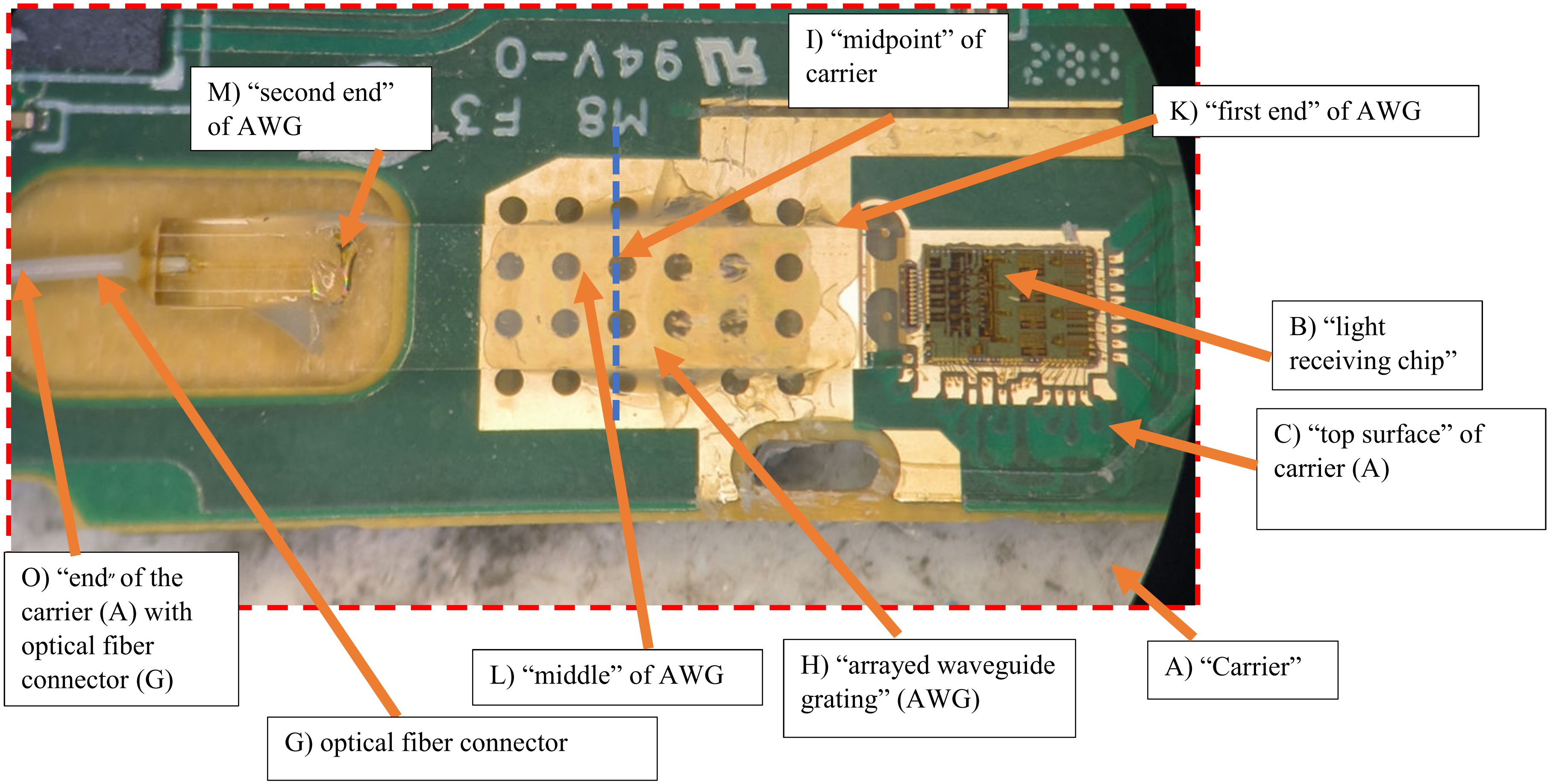


Figure 2

EXHBIT L - Representative Claim Charts for U.S. Patent No. 10,379,301

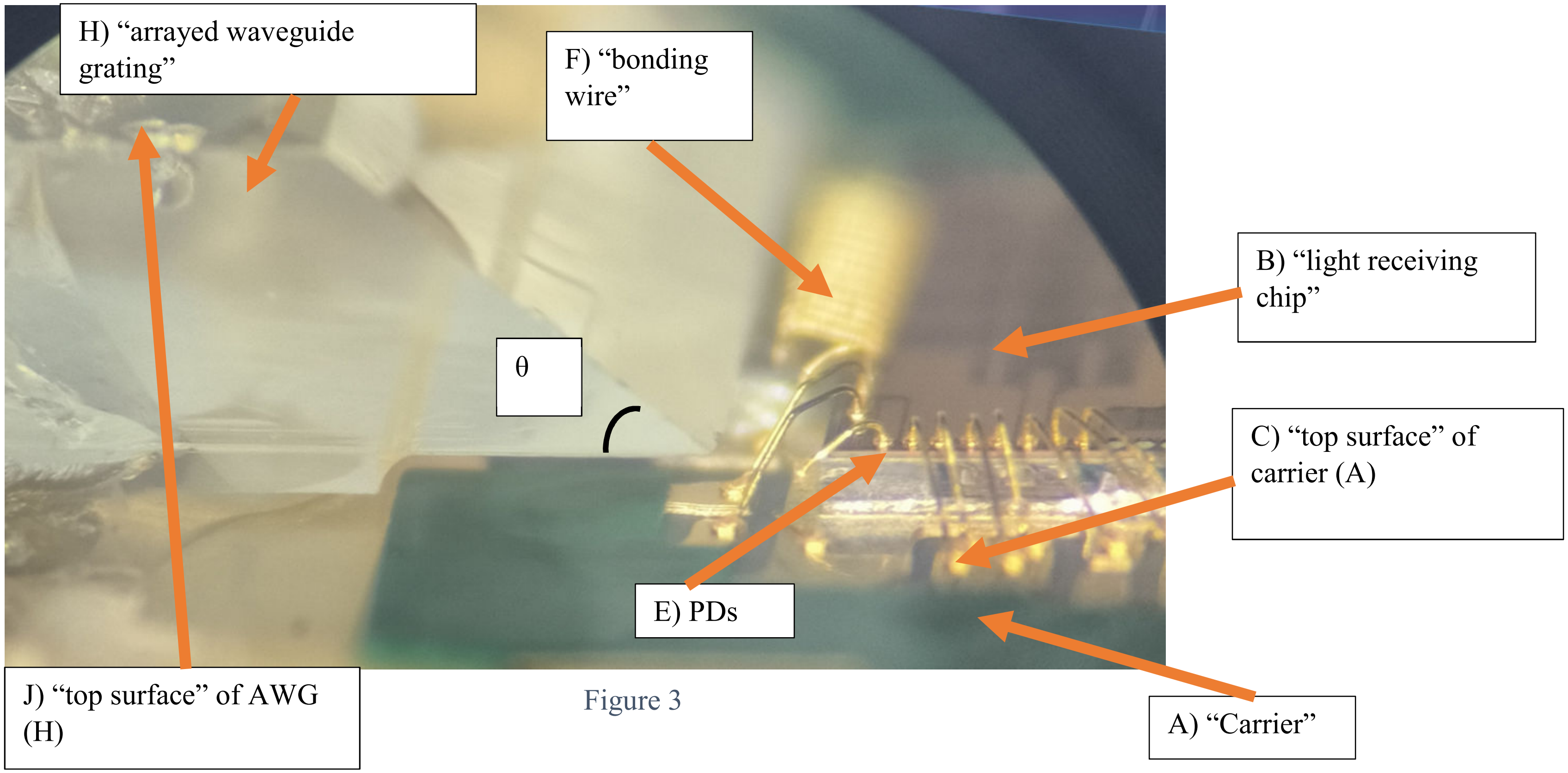


Figure 3

EXHIBIT L - Representative Claim Charts for U.S. Patent No. 10,379,301

Independent Claim 1

U.S. Patent No. 10,379,301 Claim 1	100G LR4
A multi-channel parallel optical receiving device, comprising:	A 4-channel, 100G transceiver (100G QSFP CWDM4). See FIGs. 1–3.
a carrier;	Carrier (**A**). See FIGs. 1–3.
a light receiving chip disposed on a top surface of an end of the carrier;	Light receiving chip **(B)** is disposed on top surface **(C)** of an end **(D)** of the carrier **(A)**. See FIGs. 1–3.
a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and	A plurality of optoelectronic diodes "PDs" **(E)** are disposed on the top surface **(C)** of an end (**D**) of the carrier (**A**); see FIGs. 1–3.
the plurality of optoelectronic diodes electrically connected to the light receiving chip via bonding wire,	The plurality of optoelectronic diodes (PDs) **(E)** are electrically connected to the light receiving chip **(B)** via bonding wire **(F)**. See FIG. 3.
wherein the optoelectronic diodes and the light receiving chip are disposed directly on the same top surface of the end of the carrier;	The optoelectronic diodes (PDs) **(E)** and the light receiving chip **(B)** are disposed directly on the same top surface **(C)** of the end **(D)** of the carrier **(A)**. See FIGs. 1 and 3.
an optical fiber connector disposed in an end of the carrier;	Optical fiber connector (**G**) is disposed in an end (**O**) of the carrier **(A).** See FIG. 2.
an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier,	Arrayed waveguide grating "AWG" **(H)** is disposed on top surface **(N)** that defines a midpoint **(I)** of the carrier **(A)**. See FIGs. 1–3.
the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end,	Arrayed waveguide grating (AWG) **(H)** includes a first end (**K**), a middle (**L**)**,** and a second end (**M**) disposed opposite the first end (**K**). See FIG. 2.
and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber,	An input end (second end (**M**)) of the arrayed waveguide grating (AWG) **(H)** is connected to the optical fiber connector

EXHBIT L - Representative Claim Charts for U.S. Patent No. 10,379,301

U.S. Patent No. 10,379,301 Claim 1	100G LR4
	(G) for receiving an optical signal from the optical fiber**.** See FIG. 2.
wherein the top surface of the carrier underlies the middle of the arrayed waveguide grating; and	Top surface **(N)** of the carrier **(A)** underlies the middle (**L**) of the arrayed waveguide grating (AWG) **(H)**. See FIGs. 1–2.
wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths,	The optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating (AWG) **(H)** based on their wavelengths. See FIG. 2–3.
a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel,	Top surface **(J)** defined by an output end of the arrayed waveguide grating (AWG) **(H)** is at a predetermined angle **(θ)**, causing the multi-channel optical signals reflected by top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** to be reflected to a photosensitive surface of the plurality of optoelectronic diodes (PDs) **(E),** which are arranged in parallel. See FIGs. 3.
wherein the predetermined angle of the top surface defined by the output end of the arrayed waveguide grating is in a range of 41 to 46 degrees such that the top surface provides the reflection.	The predetermined angle **(θ)** of the top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** is in a range of 41 to 46 degrees such that the top surface **(J)** provides the reflection. See FIG. 3.

EXHBIT L - Representative Claim Charts for U.S. Patent No. 10,379,301

Independent Claim 7

U.S. Patent No. 10,379,301 Claim 7	**100G LR4**
A multi-channel parallel optical receiving device, comprising:	A 4-channel, 100G transceiver (100G QSFP CWDM4). See FIGs. 1–3.
a carrier;	Carrier (**A**). See FIGs. 1–3.
a light receiving chip disposed on a top surface of an end of the carrier;	Light receiving chip **(B)** is disposed on top surface **(C)** of an end **(D)** of the carrier **(A)**. See FIGs. 1–3.
a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and	A plurality of optoelectronic diodes "PDs" **(E)** are disposed on the top surface **(C)** of an end (**D**) of the carrier (**A**); see FIGs. 1–3.
the plurality of optoelectronic diodes electrically connected to the light receiving chip via wire bonding,	The plurality of optoelectronic diodes (PDs) **(E)** are electrically connected to the light receiving chip **(B)** via bonding wire **(F)**. See FIG. 3.
wherein the plurality of optoelectronic diodes and the light receiving chip are directly disposed on the same top surface of the end of the carrier;	The plurality of optoelectronic diodes (PDs) **(E)** and the light receiving chip **(B)** are directly disposed on the same top surface **(C)** of the end **(D)** of carrier **(A)**. See FIGs. 1 and 3.
an optical fiber connector disposed in an end of the carrier;	Optical fiber connector (**G**) is disposed in an end (**O**) of the carrier **(A).** See FIG. 2.
an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier,	Arrayed waveguide grating "AWG" **(H)** is disposed on top surface **(N)** that defines a midpoint **(I)** of the carrier **(A)**. See FIGs. 1–3.
the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end,	Arrayed waveguide grating (AWG) **(H)** includes a first end (**K**), a middle (**L**)**,** and a second end (**M**) disposed opposite the first end (**K**). See FIG. 2.
and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber;	An input end (second end (**M**)) of the arrayed waveguide grating (AWG) **(H)** is connected to the optical fiber connector **(G)** for receiving an optical signal from the optical fiber. See FIG. 2.

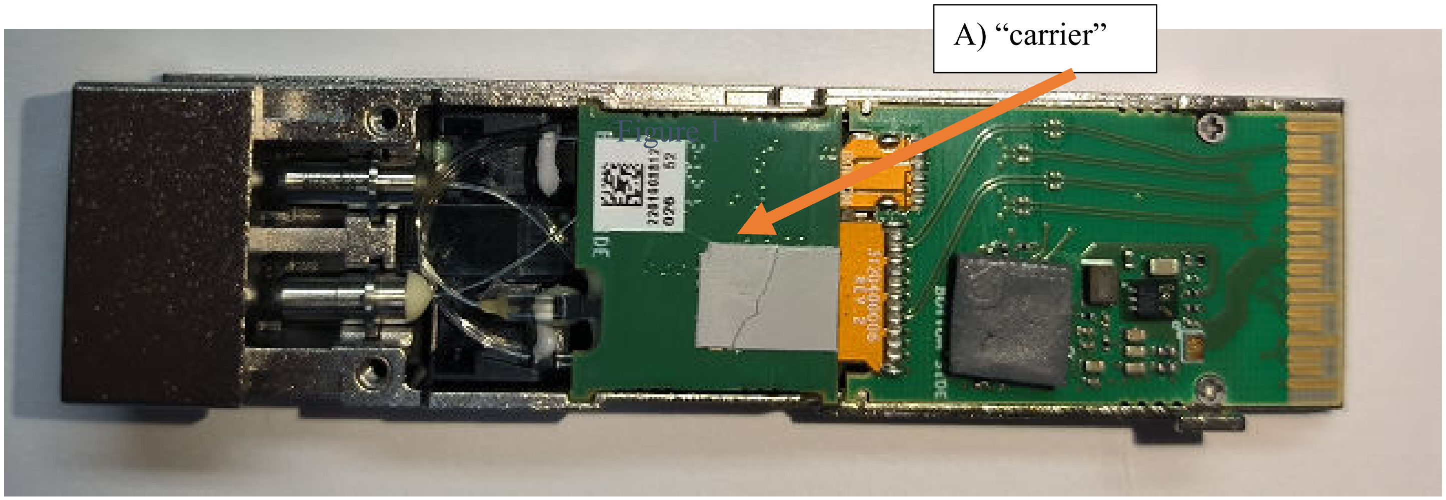
EXHBIT L - Representative Claim Charts for U.S. Patent No. 10,379,301

U.S. Patent No. 10,379,301 **Claim 7**	**100G LR4**
wherein the top surface of the carrier that defines the midpoint of the carrier underlies the middle of the arrayed waveguide grating; and	The top surface (**N**) of the carrier **(A)** that defines the midpoint of the carrier underlies the middle (**L**) of the arrayed waveguide grating (AWG) (**H**). See FIGs. 1–2.
wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths,	The optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating (AWG) **(H)** based on their wavelengths. See FIGs. 2–3.
a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle of 42 degrees, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel.	On information and belief, top surface **(J)** at an output end of the arrayed waveguide grating (AWG) **(H)** is at a predetermined angle of approximately 42 degrees **(θ)**, causing the multi-channel optical signals reflected by top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** to be reflected to a photosensitive surface of the plurality of optoelectronic diodes (PDs) **(E),** which are arranged in parallel. See FIG. 3.

EXHIBIT M

EXHBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

<u>CIG 100G QSFP CWDM4 Module – VERSION 1</u>



EXHBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

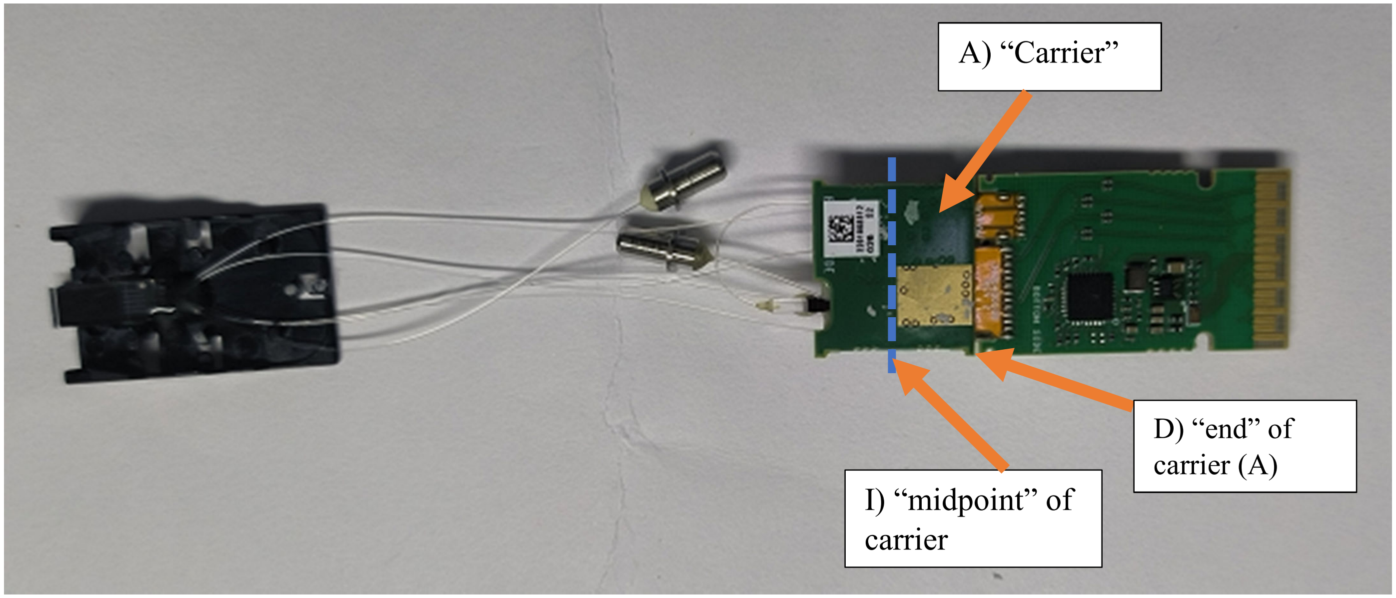


Figure 2

EXHIBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

Figure 3

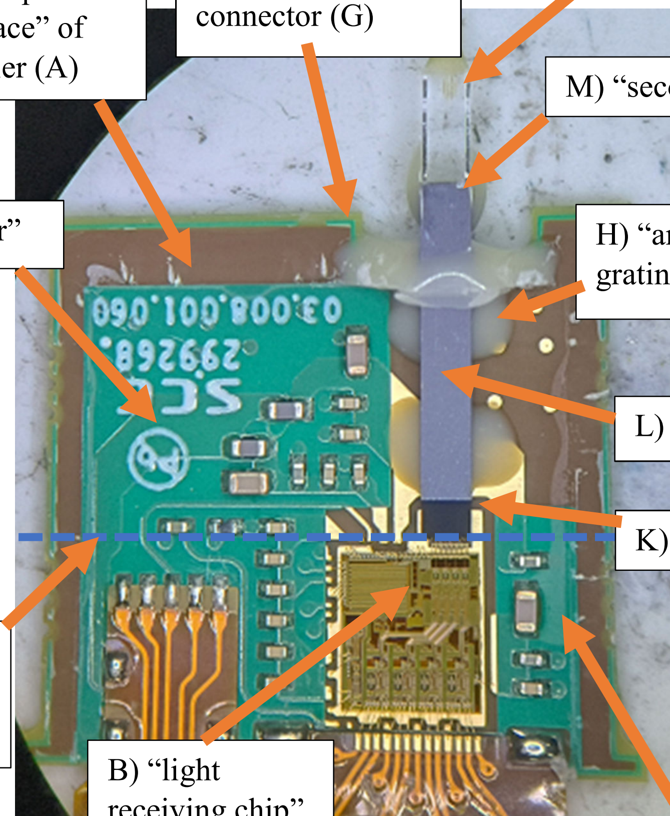


Figure 4

EXHIBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

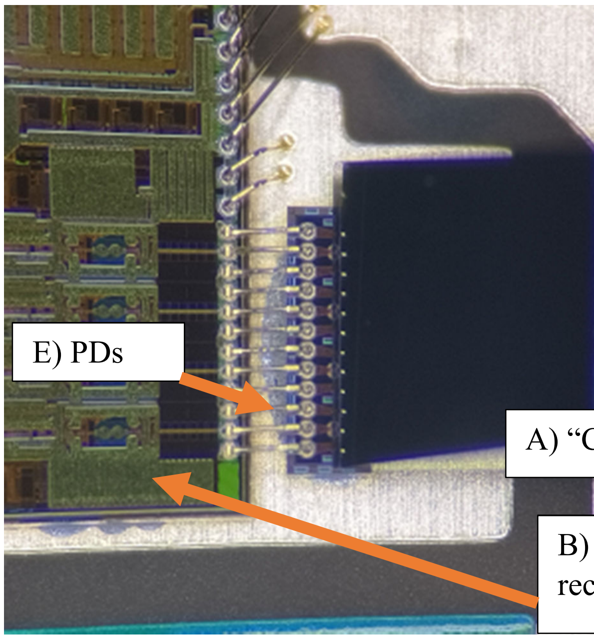


Figure 5

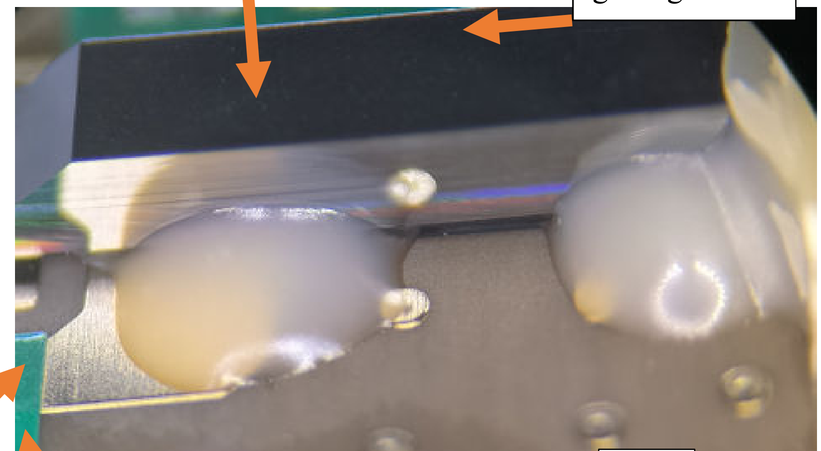


Figure 6

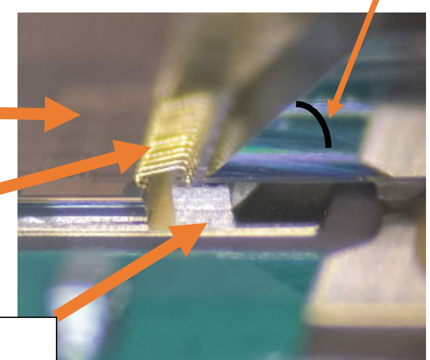


Figure 7

EXHIBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

Independent Claim 1

U.S. Patent No. 10,379,301 Claim 1	100G QSFP CWDM4 - Version 1
A multi-channel parallel optical receiving device, comprising:	A 4-channel, 100G transceiver (100G QSFP CWDM4). See FIGs. 1–7.
a carrier;	Carrier (**A**). See FIGs. 1–7.
a light receiving chip disposed on a top surface of an end of the carrier;	Light receiving chip **(B)** is disposed on top surface **(C)** of an end **(D)** of the carrier **(A)**. See FIG. 4.
a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and	A plurality of optoelectronic diodes "PDs" **(E)** are disposed on the top surface **(C)** of an end (**D**) of the carrier (**A**); see FIGs. 4-7.
the plurality of optoelectronic diodes electrically connected to the light receiving chip via bonding wire,	The plurality of optoelectronic diodes (PDs) **(E)** are electrically connected to the light receiving chip **(B)** via bonding wire **(F)**. See FIGs. 5–7.
wherein the optoelectronic diodes and the light receiving chip are disposed directly on the same top surface of the end of the carrier;	The optoelectronic diodes (PDs) **(E)** and the light receiving chip **(B)** are disposed directly on the same top surface **(C)** of the end **(D)** of the carrier **(A)**. See FIGs. 4–7.
an optical fiber connector disposed in an end of the carrier;	Optical fiber connector (**G**) is disposed in an end (**O**) of the carrier **(A).** See FIG. 4.
an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier,	Arrayed waveguide grating "AWG" **(H)** is disposed on top surface **(N)** that defines a midpoint **(I)** of the carrier **(A)**. See FIGs. 2–4.
the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end,	Arrayed waveguide grating (AWG) **(H)** includes a first end (**K**), a middle (**L**), and a second end (**M**) disposed opposite the first end (**K**). See FIG. 4.

EXHIBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

U.S. Patent No. 10,379,301 Claim 1	100G QSFP CWDM4 - Version 1
and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber,	An input end (second end (**M**)) of the arrayed waveguide grating (AWG) **(H)** is connected to the optical fiber connector **(G)** for receiving an optical signal from the optical fiber**.** See FIG. 4
wherein the top surface of the carrier underlies the middle of the arrayed waveguide grating; and	Top surface **(N)** of the carrier **(A)** underlies the middle (**L**) of the arrayed waveguide grating (AWG) **(H)**. See FIGs. 2-4.
wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths,	The optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating (AWG) **(H)** based on their wavelengths. See FIG. 4.
a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel,	Top surface **(J)** defined by an output end of the arrayed waveguide grating (AWG) **(H)** is at a predetermined angle **(θ)**, causing the multi-channel optical signals reflected by top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** to be reflected to a photosensitive surface of the plurality of optoelectronic diodes (PDs) **(E),** which are arranged in parallel. See FIGs. 4-7.
wherein the predetermined angle of the top surface defined by the output end of the arrayed waveguide grating is in a range of 41 to 46 degrees such that the top surface provides the reflection.	The predetermined angle **(θ)** of the top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** is in a range of 41 to 46 degrees such that the top surface **(J)** provides the reflection. See FIGs. 6-7.

EXHIBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

Independent Claim 7

U.S. Patent No. 10,379,301 Claim 7	100G QSFP CWDM4 Version 1
A multi-channel parallel optical receiving device, comprising:	A 4-channel, 100G transceiver (100G QSFP CWDM4). See FIGs. 1–7.
a carrier;	Carrier (**A**). See FIGs. 1–7.
a light receiving chip disposed on a top surface of an end of the carrier;	Light receiving chip **(B)** is disposed on top surface **(C)** of an end **(D)** of the carrier **(A)**. See FIG. 4.
a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and	A plurality of optoelectronic diodes "PDs" **(E)** are disposed on the top surface **(C)** of an end (**D**) of the carrier (**A**); see FIGs. 4–7.
the plurality of optoelectronic diodes electrically connected to the light receiving chip via wire bonding,	The plurality of optoelectronic diodes (PDs) **(E)** are electrically connected to the light receiving chip **(B)** via bonding wire **(F)**. See FIGs. 5–7.
wherein the plurality of optoelectronic diodes and the light receiving chip are directly disposed on the same top surface of the end of the carrier;	The plurality of optoelectronic diodes (PDs) **(E)** and the light receiving chip **(B)** are directly disposed on the same top surface **(C)** of the end **(D)** of carrier **(A)**. See FIGs. 4-7.
an optical fiber connector disposed in an end of the carrier;	Optical fiber connector (**G)** is disposed in an end (**O**) of the carrier **(A).** See FIG. 4.
an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier,	Arrayed waveguide grating "AWG" **(H)** is disposed on top surface **(N)** that defines a midpoint **(I)** of the carrier **(A)**. See FIGs. 2-4.
the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end,	Arrayed waveguide grating (AWG) **(H)** includes a first end (**K**), a middle **(L),** and a second end (**M**) disposed opposite the first end (**K**). See FIG. 4
and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber;	An input end (second end (**M**)) of the arrayed waveguide grating (AWG) **(H)** is connected to the optical fiber connector **(G)** for receiving an optical signal from the optical fiber. See FIG. 4

EXHIBIT M - Representative Claim Charts for U.S. Patent No. 10,379,301

U.S. Patent No. 10,379,301 Claim 7	100G QSFP CWDM4 Version 1
wherein the top surface of the carrier that defines the midpoint of the carrier underlies the middle of the arrayed waveguide grating; and	The top surface (**N**) of the carrier **(A)** that defines the midpoint of the carrier underlies the middle (**L**) of the arrayed waveguide grating (AWG) (**H**). See FIGs. 2–4.
wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths,	The optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating (AWG) **(H)** based on their wavelengths. See FIG. 4.
a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle of 42 degrees, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel.	On information and belief, top surface **(J)** at an output end of the arrayed waveguide grating (AWG) **(H)** is at a predetermined angle of approximately 42 degrees **(θ)**, causing the multi-channel optical signals reflected by top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** to be reflected to a photosensitive surface of the plurality of optoelectronic diodes (PDs) **(E),** which are arranged in parallel. See FIGs. 4–7.

EXHIBIT N

EXHBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

CIG 100G QSFP CWDM4 Module - Version 2

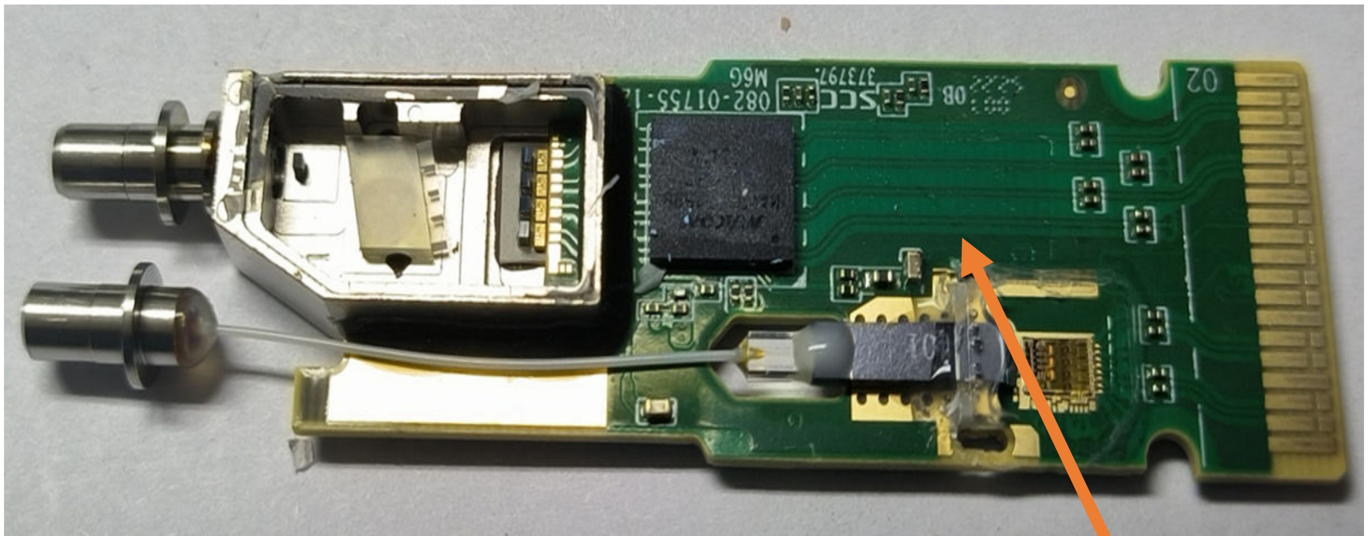


Figure 1

EXHBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

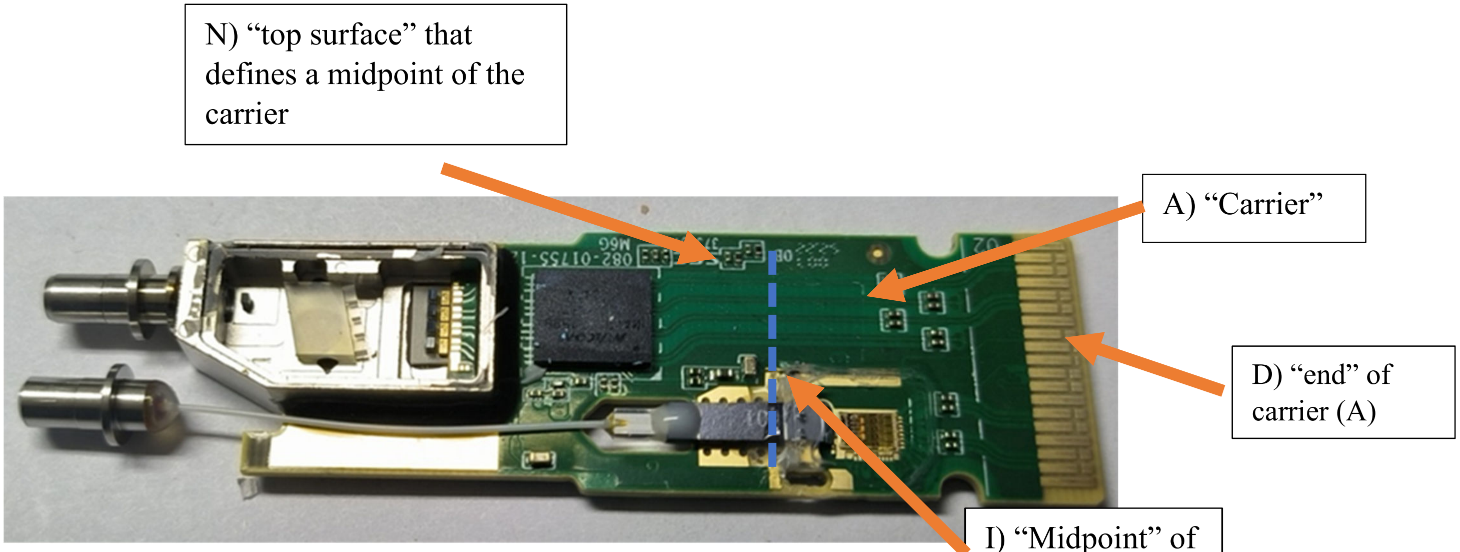


Figure 2

EXHBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

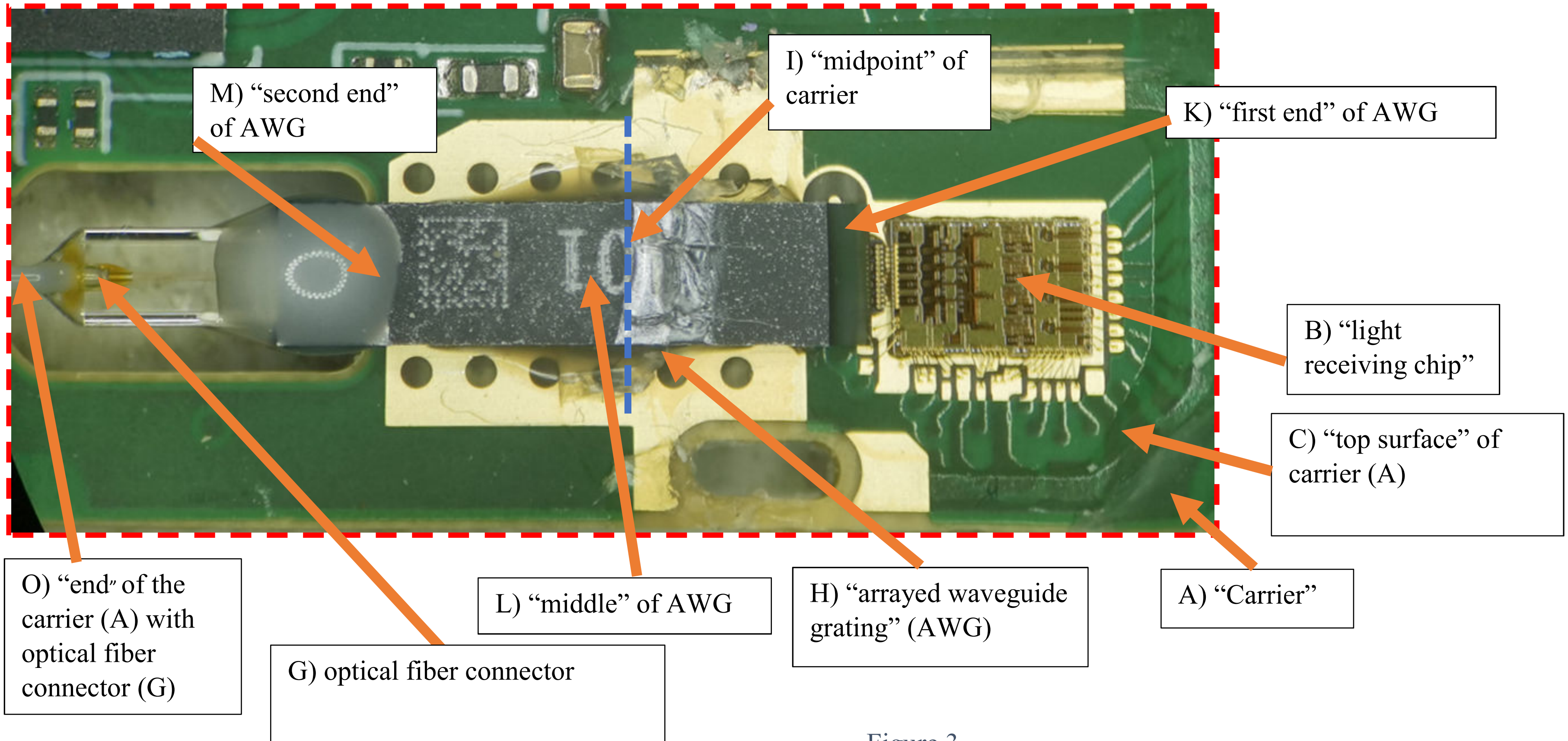


Figure 3

EXHBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

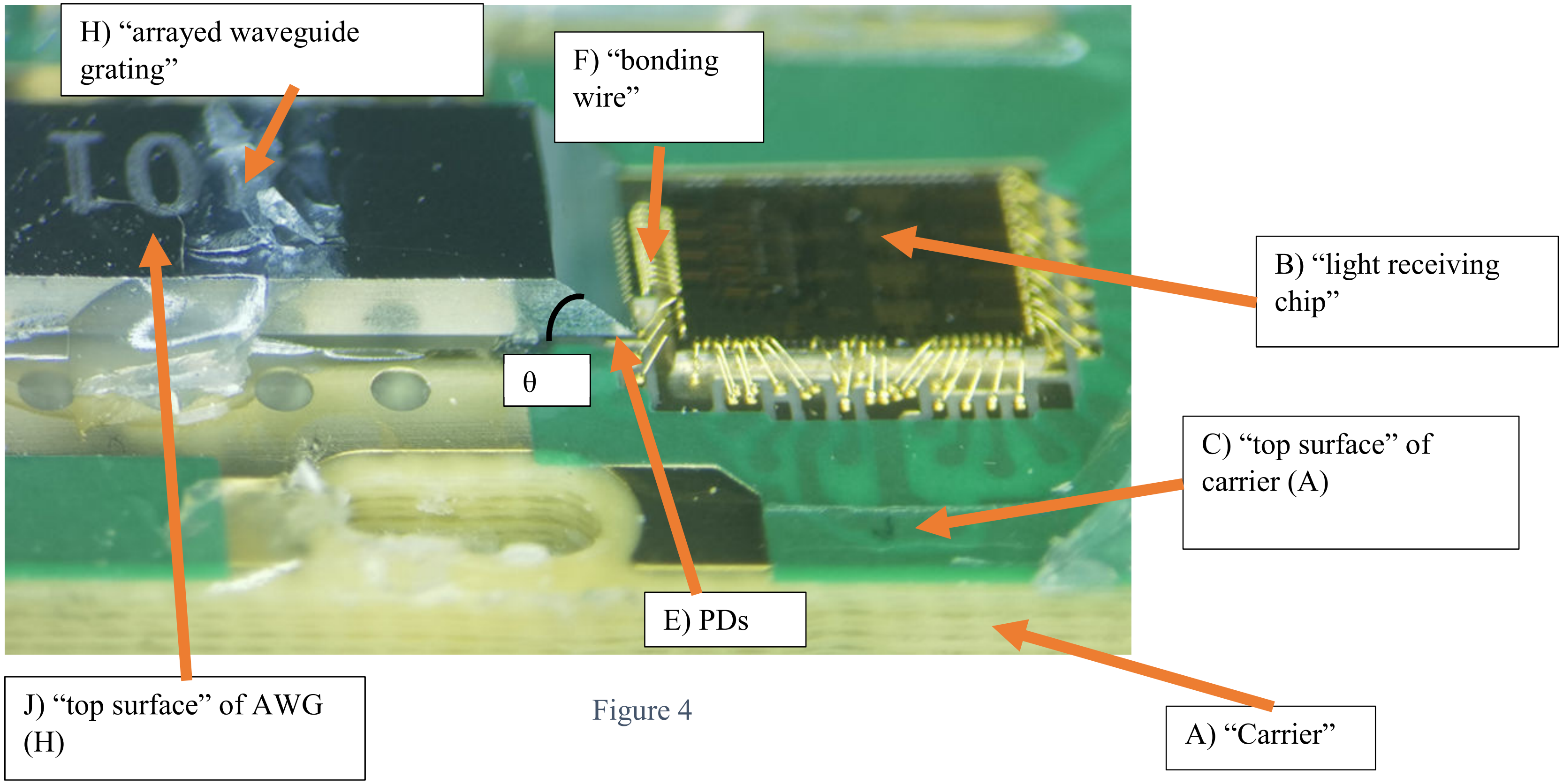


Figure 4

EXHIBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

Independent Claim 1

U.S. Patent No. 10,379,301 Claim 1	100G QSFP CWDM4 - Version 2
A multi-channel parallel optical receiving device, comprising:	A 4-channel, 100G transceiver (100G QSFP CWDM4). See FIGs. 1–4.
a carrier;	Carrier (**A**). See FIGs. 1–4.
a light receiving chip disposed on a top surface of an end of the carrier;	Light receiving chip **(B)** is disposed on top surface **(C)** of an end **(D)** of the carrier **(A)**. See FIG. 2–3.
a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and	A plurality of optoelectronic diodes "PDs" **(E)** are disposed on the top surface **(C)** of an end (**D**) of the carrier (**A**); see FIGs. 2 and 4.
the plurality of optoelectronic diodes electrically connected to the light receiving chip via bonding wire,	The plurality of optoelectronic diodes (PDs) **(E)** are electrically connected to the light receiving chip **(B)** via bonding wire **(F)**. See FIG. 4.
wherein the optoelectronic diodes and the light receiving chip are disposed directly on the same top surface of the end of the carrier;	The optoelectronic diodes (PDs) **(E)** and the light receiving chip **(B)** are disposed directly on the same top surface **(C)** of the end **(D)** of the carrier **(A)**. See FIGs. 2 and 4.
an optical fiber connector disposed in an end of the carrier;	Optical fiber connector (**G**) is disposed in an end (**O**) of the carrier **(A).** See FIG. 3.
an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier,	Arrayed waveguide grating "AWG" **(H)** is disposed on top surface **(N)** that defines a midpoint **(I)** of the carrier **(A)**. See FIGs. 2–3
the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end,	Arrayed waveguide grating (AWG) **(H)** includes a first end (**K**), a middle (**L**)**,** and a second end (**M**) disposed opposite the first end (**K**). See FIG. 3.
and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber,	An input end (second end (**M**)) of the arrayed waveguide grating (AWG) **(H)** is connected to the optical fiber connector

EXHBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

U.S. Patent No. 10,379,301 Claim 1	100G QSFP CWDM4 - Version 2
	(G) for receiving an optical signal from the optical fiber**.** See FIG. 3.
wherein the top surface of the carrier underlies the middle of the arrayed waveguide grating; and	Top surface **(N)** of the carrier **(A)** underlies the middle (**L**) of the arrayed waveguide grating (AWG) **(H)**. See FIGs. 2-3.
wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths,	The optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating (AWG) **(H)** based on their wavelengths. See FIG. 3.
a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel,	Top surface **(J)** defined by an output end of the arrayed waveguide grating (AWG) **(H)** is at a predetermined angle **(θ)**, causing the multi-channel optical signals reflected by top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** to be reflected to a photosensitive surface of the plurality of optoelectronic diodes (PDs) **(E),** which are arranged in parallel. See FIG. 4.
wherein the predetermined angle of the top surface defined by the output end of the arrayed waveguide grating is in a range of 41 to 46 degrees such that the top surface provides the reflection.	The predetermined angle **(θ)** of the top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** is in a range of 41 to 46 degrees such that the top surface **(J)** provides the reflection. See FIG. 4.

EXHIBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

Independent Claim 7

U.S. Patent No. 10,379,301 Claim 7	**100G QSFP CWDM4 Version 2**
A multi-channel parallel optical receiving device, comprising:	A 4-channel, 100G transceiver (100G QSFP CWDM4). See FIGs. 1–4.
a carrier;	Carrier (**A**). See FIGs. 1–4.
a light receiving chip disposed on a top surface of an end of the carrier;	Light receiving chip **(B)** is disposed on top surface **(C)** of an end **(D)** of the carrier **(A)**. See FIGs. 2–3.
a plurality of optoelectronic diodes disposed on the top surface of the end of the carrier, and	A plurality of optoelectronic diodes "PDs" **(E)** are disposed on the top surface **(C)** of an end (**D**) of the carrier (**A**); see FIGs. 2 and 4.
the plurality of optoelectronic diodes electrically connected to the light receiving chip via wire bonding,	The plurality of optoelectronic diodes (PDs) **(E)** are electrically connected to the light receiving chip **(B)** via bonding wire **(F)**. See FIG. 4.
wherein the plurality of optoelectronic diodes and the light receiving chip are directly disposed on the same top surface of the end of the carrier;	The plurality of optoelectronic diodes (PDs) **(E)** and the light receiving chip **(B)** are directly disposed on the same top surface **(C)** of the end **(D)** of carrier **(A)**. See FIGs. 2 and 4.
an optical fiber connector disposed in an end of the carrier;	Optical fiber connector (**G**) is disposed in an end (**O**) of the carrier **(A).** See FIG. 3.
an arrayed waveguide grating further disposed on a top surface of the carrier that defines a midpoint of the carrier,	Arrayed waveguide grating "AWG" **(H)** is disposed on top surface **(N)** that defines a midpoint **(I)** of the carrier **(A)**. See FIGs. 2-3.
the arrayed waveguide grating having a first end, a middle, and a second end disposed opposite the first end,	Arrayed waveguide grating (AWG) **(H)** includes a first end (**K**), a middle **(L),** and a second end (**M**) disposed opposite the first end (**K**). See FIG. 3.
and an input end of the arrayed waveguide grating connected to the optical fiber connector for receiving an optical signal from the optical fiber;	An input end (second end (**M**)) of the arrayed waveguide grating (AWG) **(H)** is connected to the optical fiber connector **(G)** for receiving an optical signal from the optical fiber. See FIG. 3.

EXHIBIT N - Representative Claim Charts for U.S. Patent No. 10,379,301

U.S. Patent No. 10,379,301 Claim 7	**100G QSFP CWDM4 Version 2**
wherein the top surface of the carrier that defines the midpoint of the carrier underlies the middle of the arrayed waveguide grating; and	The top surface (**N**) of the carrier **(A)** that defines the midpoint of the carrier underlies the middle (**L**) of the arrayed waveguide grating (AWG) (**H**). See FIGs. 2–3.
wherein the optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating based on their wavelengths,	The optical signal is divided into multi-channel optical signals in parallel by the arrayed waveguide grating (AWG) **(H)** based on their wavelengths. See FIG. 3.
a top surface defined by an output end of the arrayed waveguide grating is at a predetermined angle of 42 degrees, causing the multi-channel optical signals reflected by the top surface defined by the output end of the arrayed waveguide grating to be reflected to a photosensitive surface of the plurality of optoelectronic diodes arranged in parallel.	On information and belief, top surface **(J)** at an output end of the arrayed waveguide grating (AWG) **(H)** is at a predetermined angle of approximately 42 degrees **(θ)**, causing the multi-channel optical signals reflected by top surface **(J)** defined by the output end of the arrayed waveguide grating (AWG) **(H)** to be reflected to a photosensitive surface of the plurality of optoelectronic diodes (PDs) **(E),** which are arranged in parallel. See FIGs. 4.

EXHIBIT O

EXHIBIT O - Representative Claim Chart for U.S. Patent No. 10,788,690

CIG 400G QSFP-DD DR4 Module

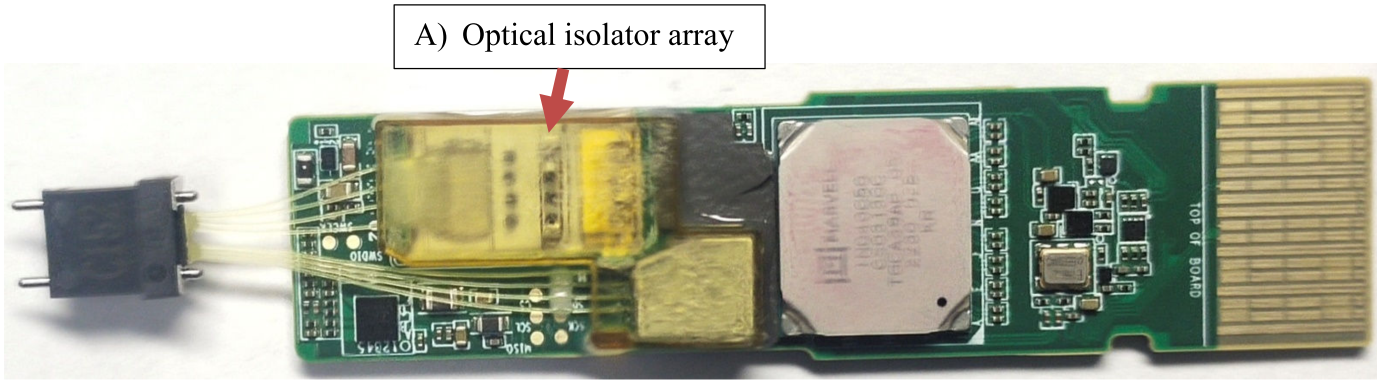


Figure 1

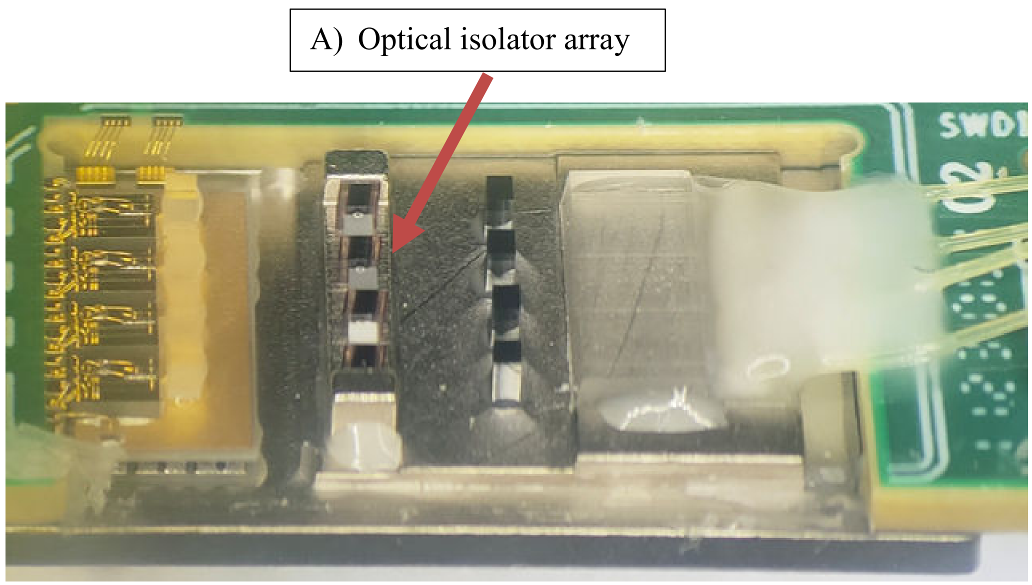


Figure 2

EXHIBIT O - Representative Claim Chart for U.S. Patent No. 10,788,690

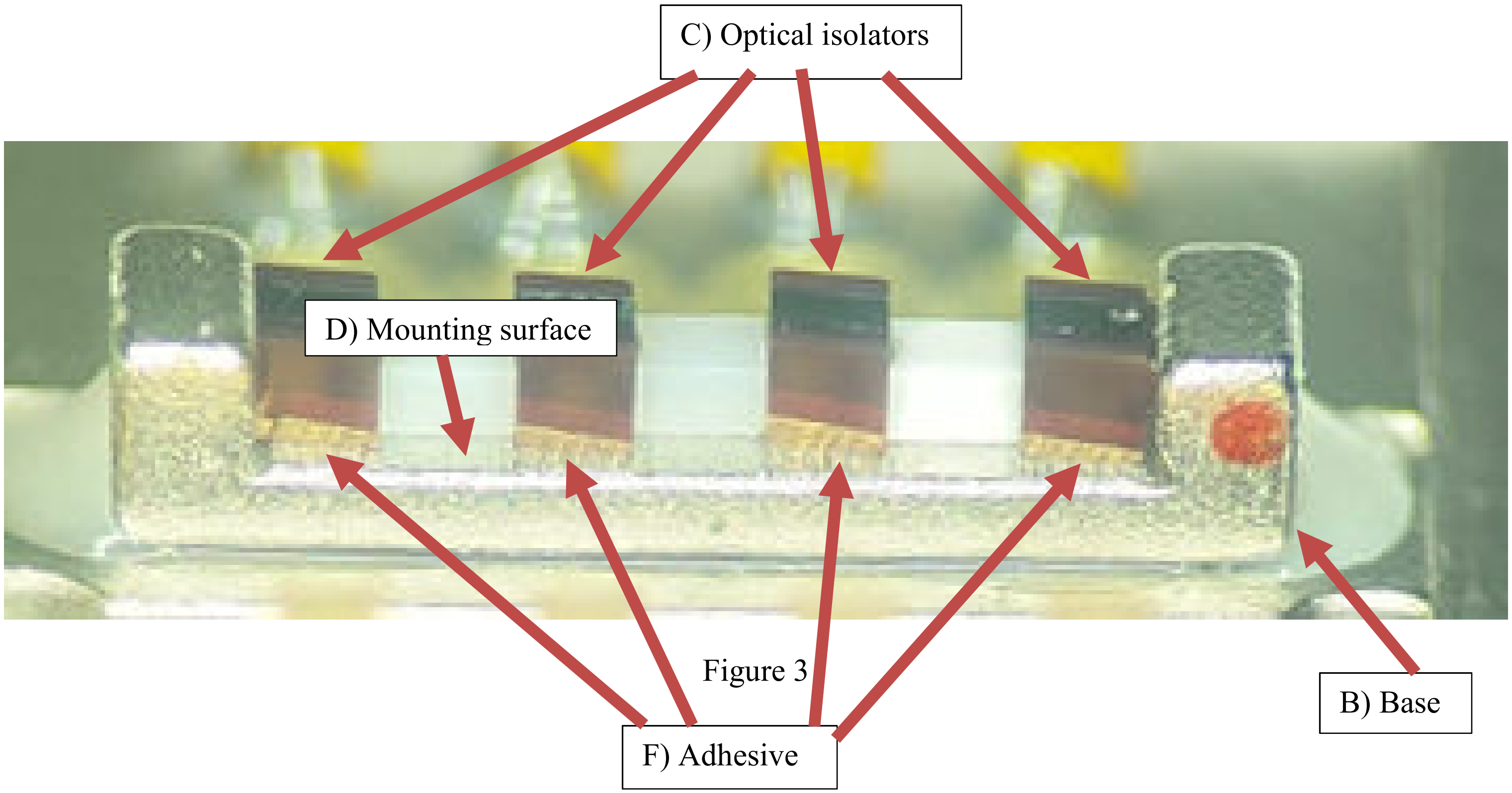


Figure 3

EXHIBIT O - Representative Claim Chart for U.S. Patent No. 10,788,690

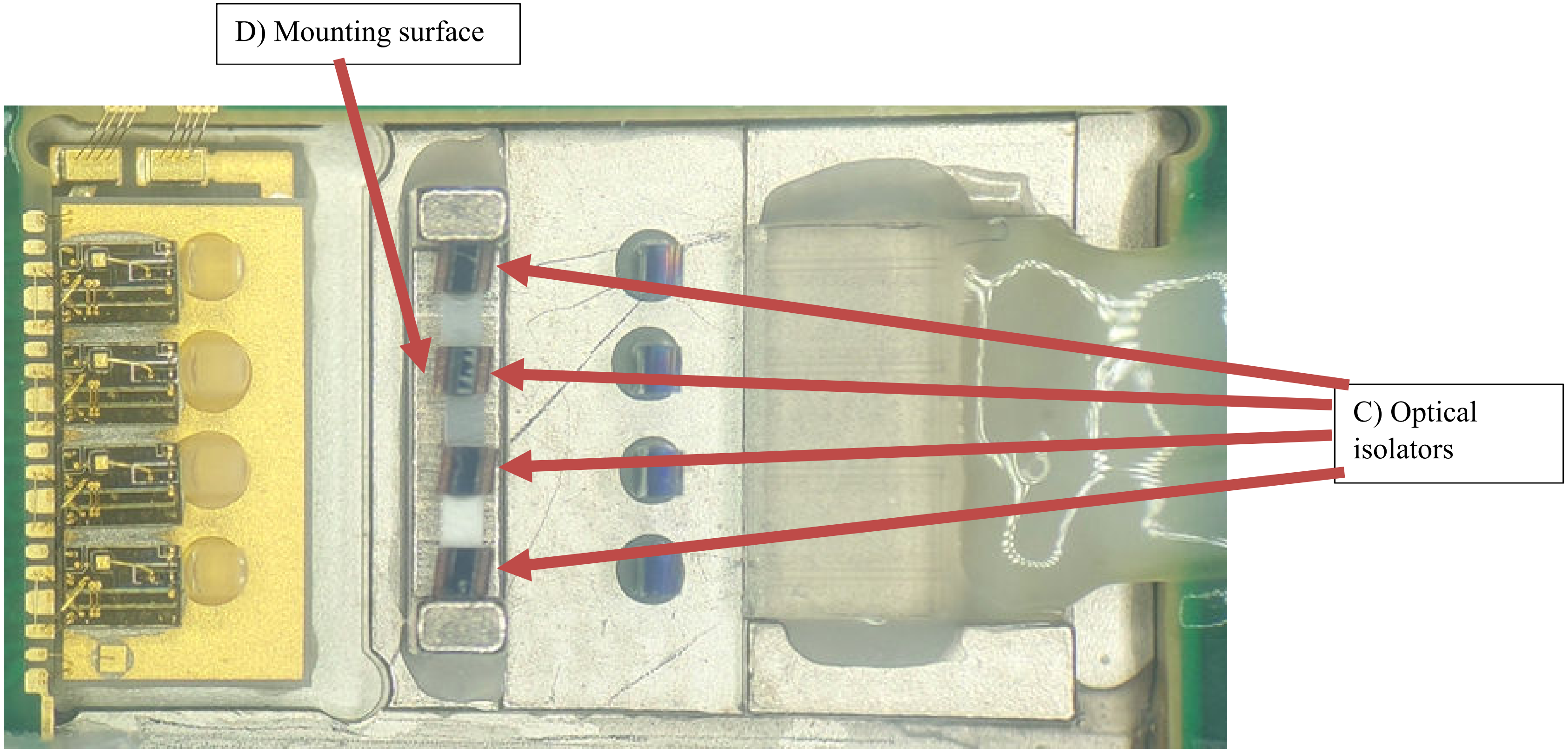


Figure 4

EXHIBIT O - Representative Claim Chart for U.S. Patent No. 10,788,690

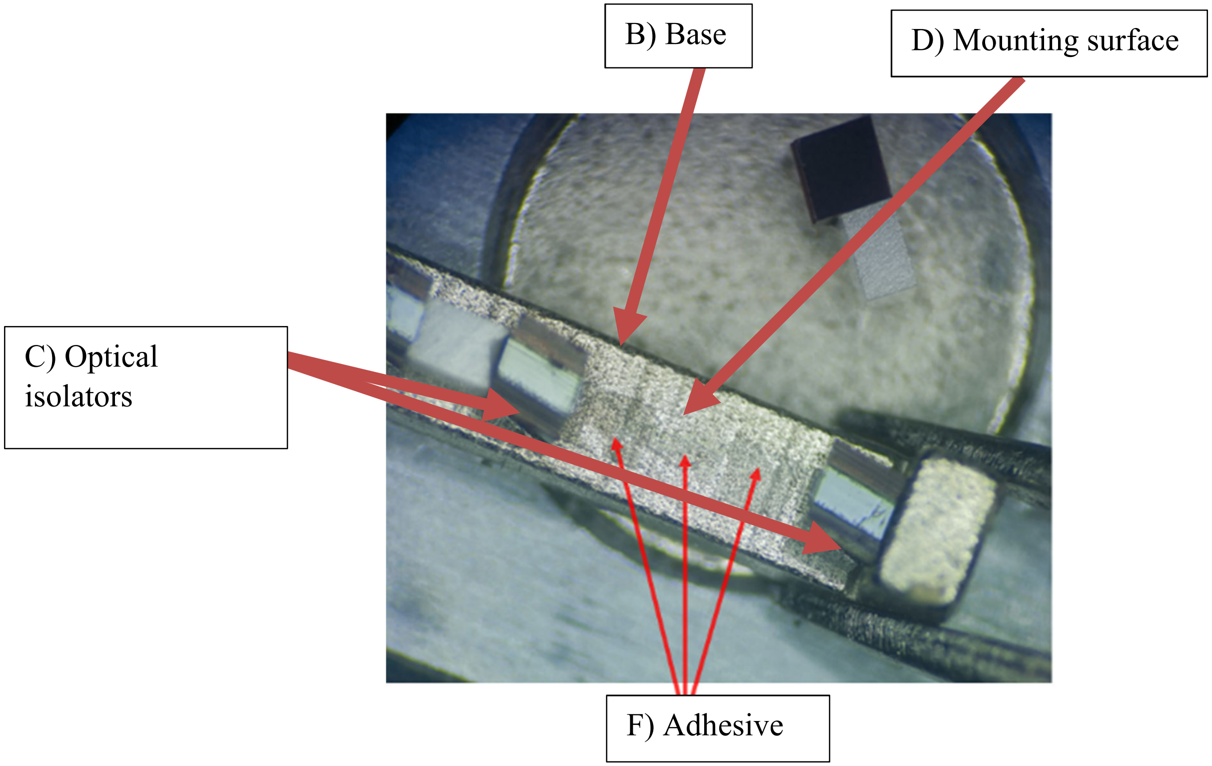


Figure 5

EXHIBIT O - Representative Claim Chart for U.S. Patent No. 10,788,690

Independent Claim 1

U.S. Patent No. 10,788,690 **Claim 1**	**CIG 400G QSFP-DD DR4 Module**
1. An optical isolator array for use in an optical subassembly module, the optical isolator array comprising:	Optical isolator array **(A)** is used in a transmitter optical subassembly (TOSA), which is an optical subassembly module. See FIGs. 1 and 2.
a first magnetic base defining at least one mounting surface;	A first magnetic base **(B)** defines a mounting surface. See FIG. 3.
a plurality of optical isolators mounted to the at least one mounting surface, each of the plurality of optical isolators disposed substantially in parallel relative to each other; and	A plurality of optical isolators **(C)** are mounted to the mounting surface **(D)** and the optical isolators **(C)** are disposed in parallel. See FIG. 4.
at least one layer of adhesive disposed on the at least one mounting surface to couple the plurality of optical isolators to the first magnetic base and to hold each optical isolator of the plurality of optical isolators at a predefined position relative to each other.	Adhesive **(F)** disposed on the mounting surface **(D)** holds each optical isolator **(C)** at a predefined position on the base **(B)**. See FIGs. 3 and 5. In FIG. 5, remnants of the adhesive **(F)** is shown in the area on the mounting surface **(D)** where the optical isolator **(C)** was removed. See FIGs. 3 and 5.

EXHIBIT P

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

CIG 400G QSFP-DD FR4 Module

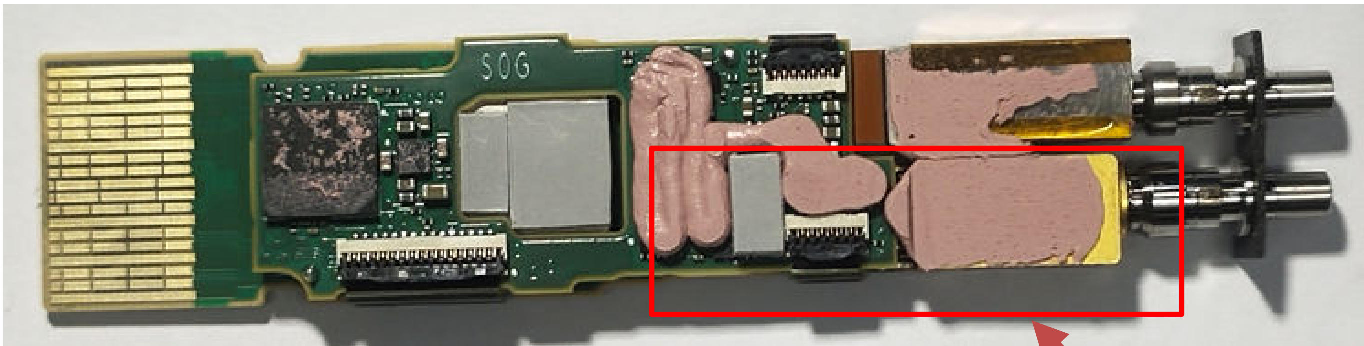


Figure 1

A) Transmitter optical

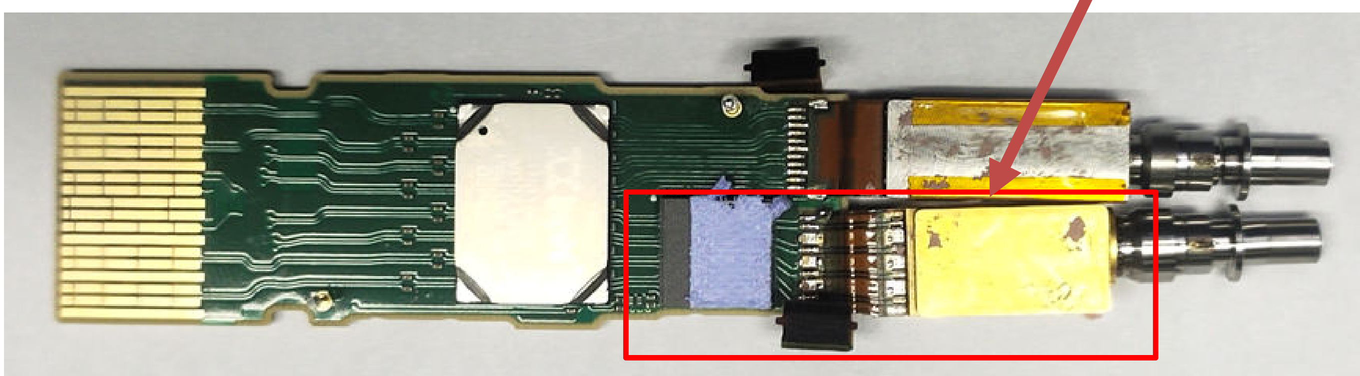


Figure 2

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

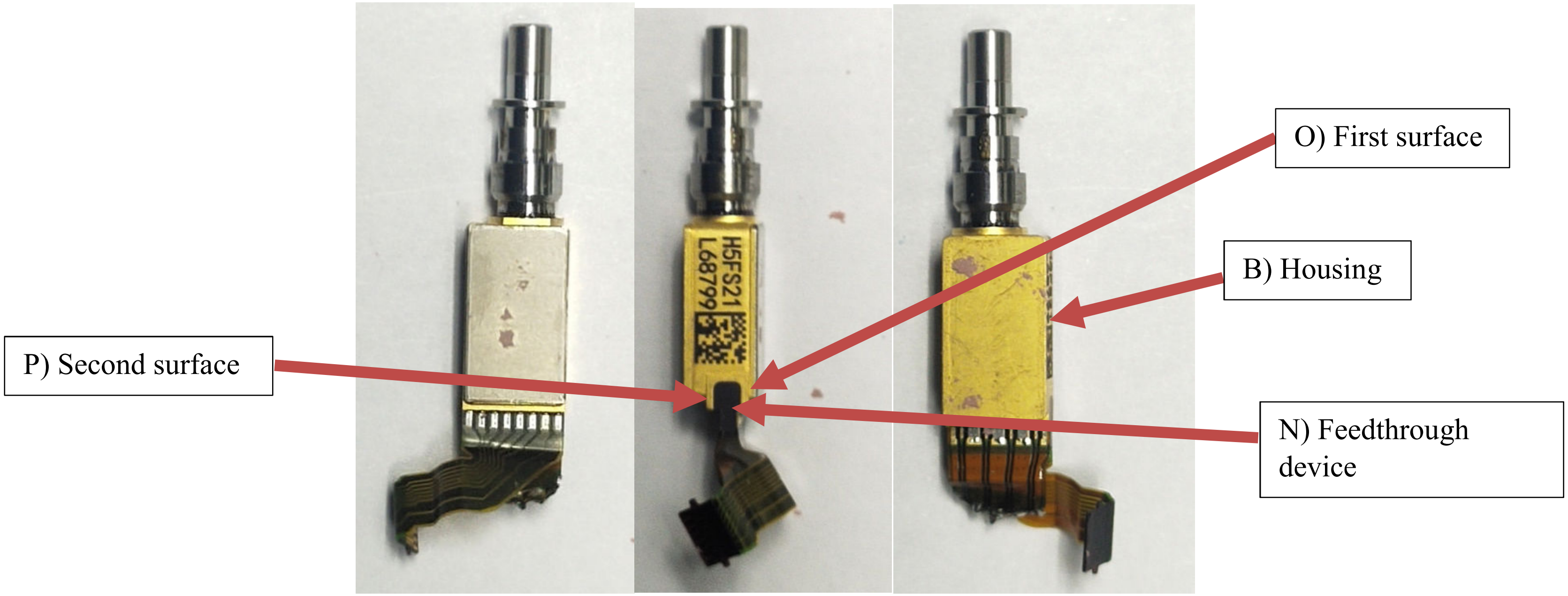


Figure 3

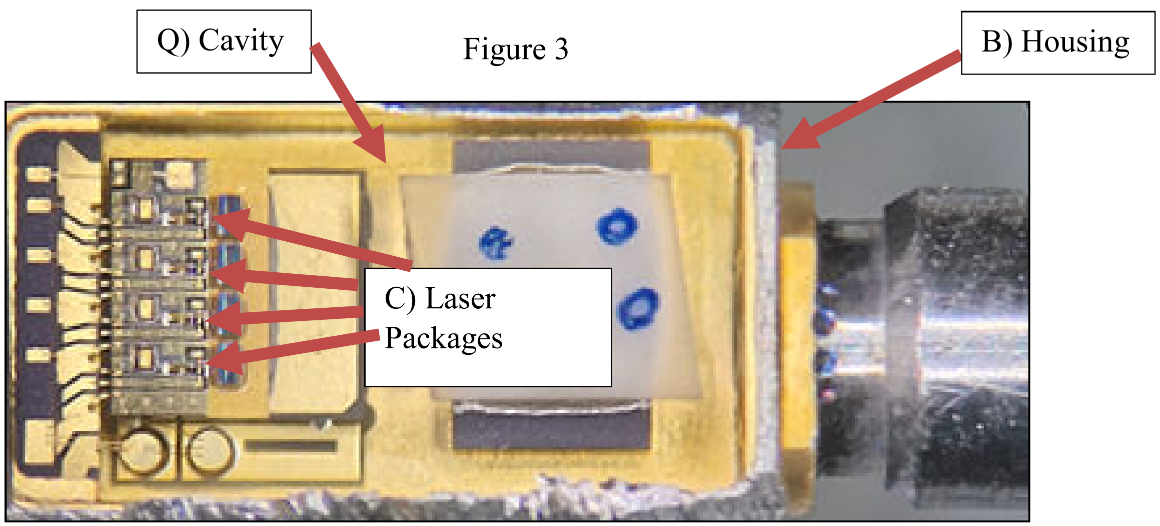


Figure 4

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

F) Electrical Coupling Region

G) Light engine interface region

Figure 5

D) Printed Circuit Board

E) Daughter Board

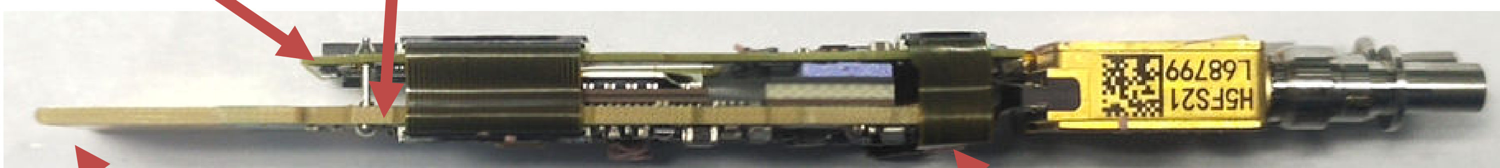


Figure 6

F) Electrical Coupling Region

G Light engine interface region

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

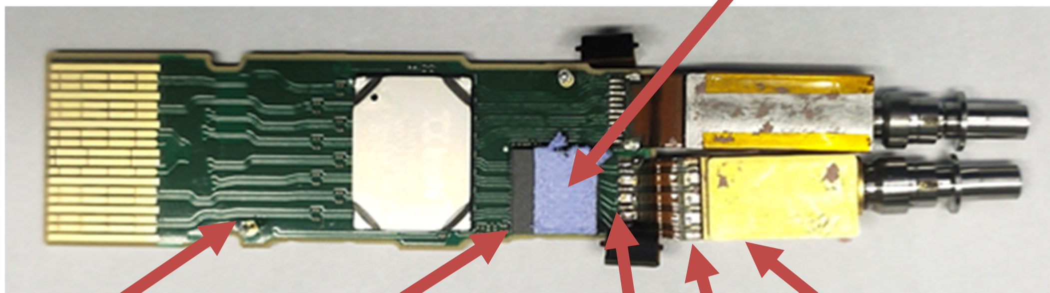


Figure 7

Figure 8

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

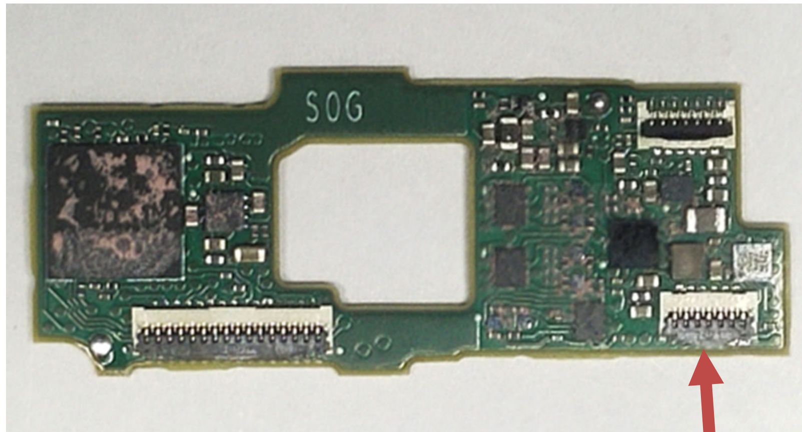


Figure 9

M) Power signal traces

C) Laser packages

N) Feedthrough device

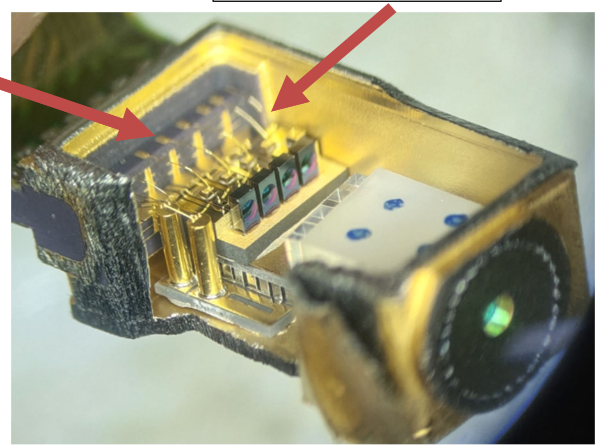


Figure 10

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

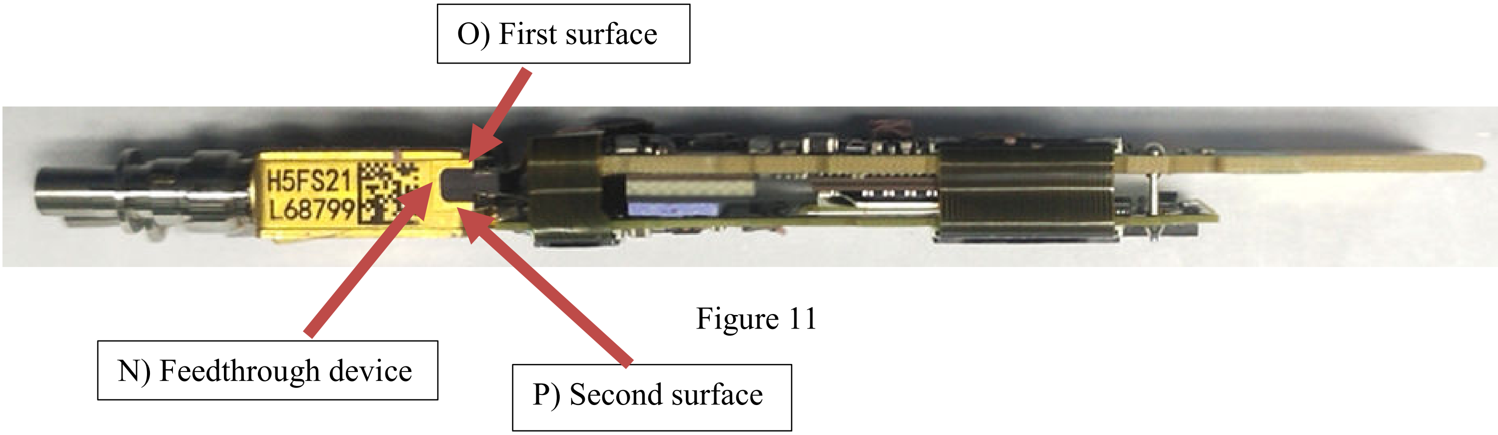


Figure 11

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

Independent Claim 1

<u>U.S. Patent No. 10,313,024</u> Claim 1	CIG 400G QSFP-DD FR4 Module
1. A transmitter optical subassembly (TOSA) module comprising:	The CIG FR4 Module includes a transmitter optical subassembly (TOSA) **(A)**. See FIGs. 1 and 2.
a hermetically-sealed light engine with a housing that defines a hermetic-sealed cavity and at least one laser package for emitting an associated channel wavelength disposed within the hermetic-sealed cavity;	As shown in FIGS. 3 and 4, the module is a hermetically-sealed light engine with a housing **(B)** that defines a hermetically-sealed cavity (**Q**), and four laser packages **(C)** are located within the cavity **(Q)** where each laser package (**C**) emits light having an associated channel wavelength.
a substrate defined by first and second surfaces disposed opposite each other, the substrate including an electrical coupling region for electrically coupling with a transmit connecting circuit and a light engine interface region for electrically coupling with the hermetically-sealed light engine;	A printed circuit board (PCB) **(D)** and a daughter board **(E)** attached to the PCB together form an underlying substrate for circuitry. The substrate formed by the PCB (**D**) and the daughter board (**E**) is defined by the surfaces of the PCB **(D)** and the surfaces of the daughter board **(E)**, which are disposed opposite from each other. The substrate formed by the PCB **(D)** and the daughter board **(E)** includes an electrical coupling region **(F)** and a light engine interface region **(G)**. See FIGs. 5 and 6.
a light engine driving circuit disposed on the substrate to provide a radio frequency (RF) signal and a power signal to drive the hermetically-sealed light engine to output one or more channel wavelengths;	A light engine driving circuit **(H)** includes at least an EML driver **(I)**, which is is disposed on the PCB substrate **(J)** and provides the signals to drive the light engine **(K)**. See FIGs. 7 and 8.
wherein the substrate includes at least a first trace disposed on the first surface to provide the power signal and at least a second trace disposed on the second surface to provide the RF signal, the first	The PCB **(D)** includes traces **(L)** on a top surface, which provide RF signals. See FIG. 7.

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

U.S. Patent No. 10,313,024 **Claim 1**	**CIG 400G QSFP-DD FR4 Module**
and second traces being disposed in an opposing arrangement to provide electrical isolation to reduce electrical interference between the power signal and the RF signal	The daughter board **(E)** includes power surface traces **(M)** on a top surface, which provide power signals. The power signal traces **(M)** provided on the top surface of the daughter board **(E)** are electrically isolated from the RF signal traces provided on the PCB **(D)**. See FIGs 5-6 and 9. The RF signal traces **(L)** on the top surface of the PCB **(D)** and the power signal traces **(M)** on the top surface of the daughter board **(E)** are disposed in an opposing arrangement because the respective top surfaces of the PCB **(D)** and daughter board **(E)** are disposed across from each other when the daughter board **(E)** is attached to the PCB **(D)** to form the substrate. See FIGs. 7 and 9.
a feedthrough device to electrically couple the at least one laser package to the light engine driving circuit; and	Feedthrough device **(N)** couples the laser packages **(C)** to the light engine driving circuit **(H)**. See FIGs. 3, 7, and 10.
wherein the feedthrough device is defined by at least a first surface disposed opposite a second surface, and wherein the first and second surfaces extend substantially parallel with the first and second surfaces of the substrate.	The feedthrough device **(N)** is defined by a first surface **(O)** and a second surface **(P)** and these surfaces are parallel with the first surface and the second surface of the substrate when attached. See FIGs. 3 and 11.

EXHIBIT P - Representative Claim Chart for U.S. Patent No. 10,313,024

EXHIBIT Q

Exhibit Q - Representative Claim Charts for U.S. Patent No. 10,175,431

1. **<u>CIG 100G QSFP CWDM4 Module Version 1</u>**

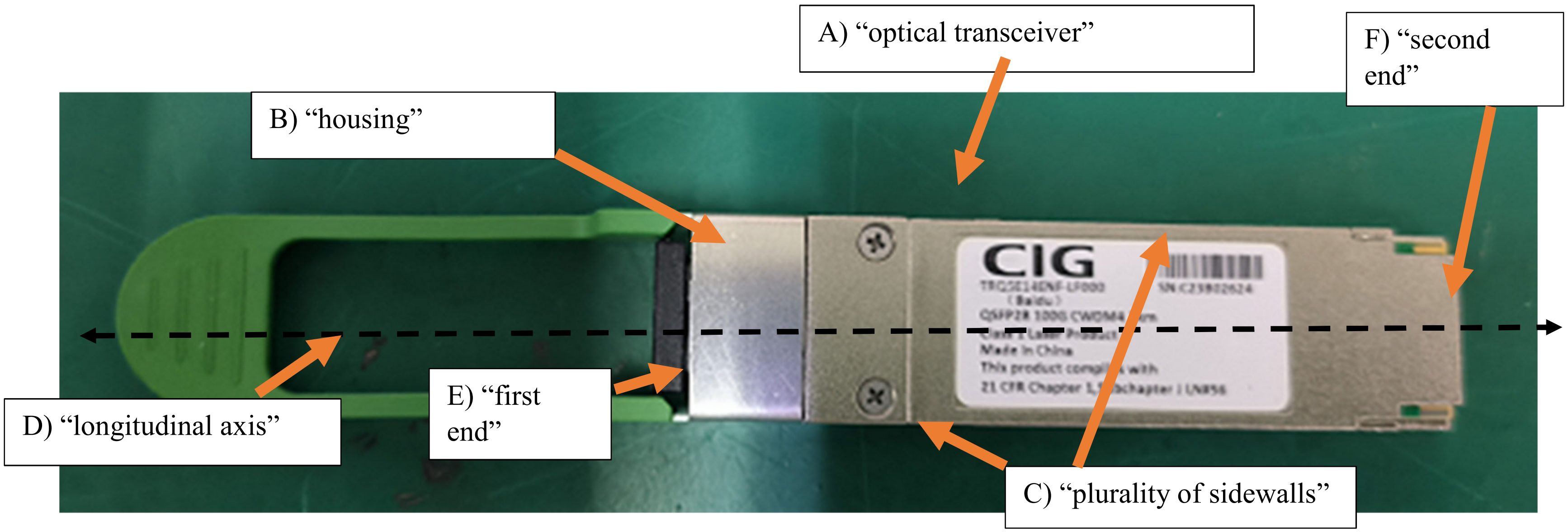


Figure 1

Exhibit Q - Representative Claim Charts for U.S. Patent No. 10,175,431

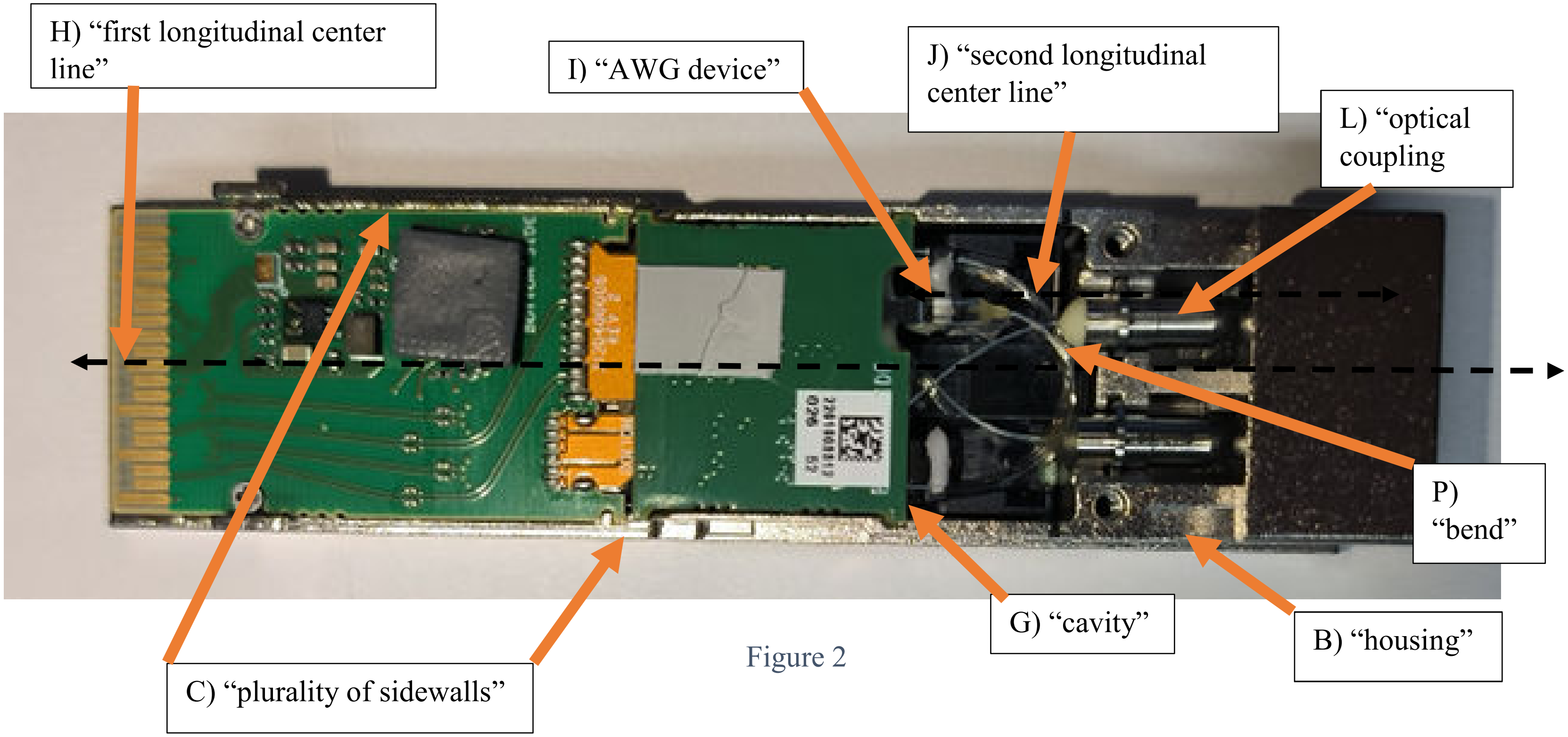


Figure 2

Exhibit Q - Representative Claim Charts for U.S. Patent No. 10,175,431

Figure 3

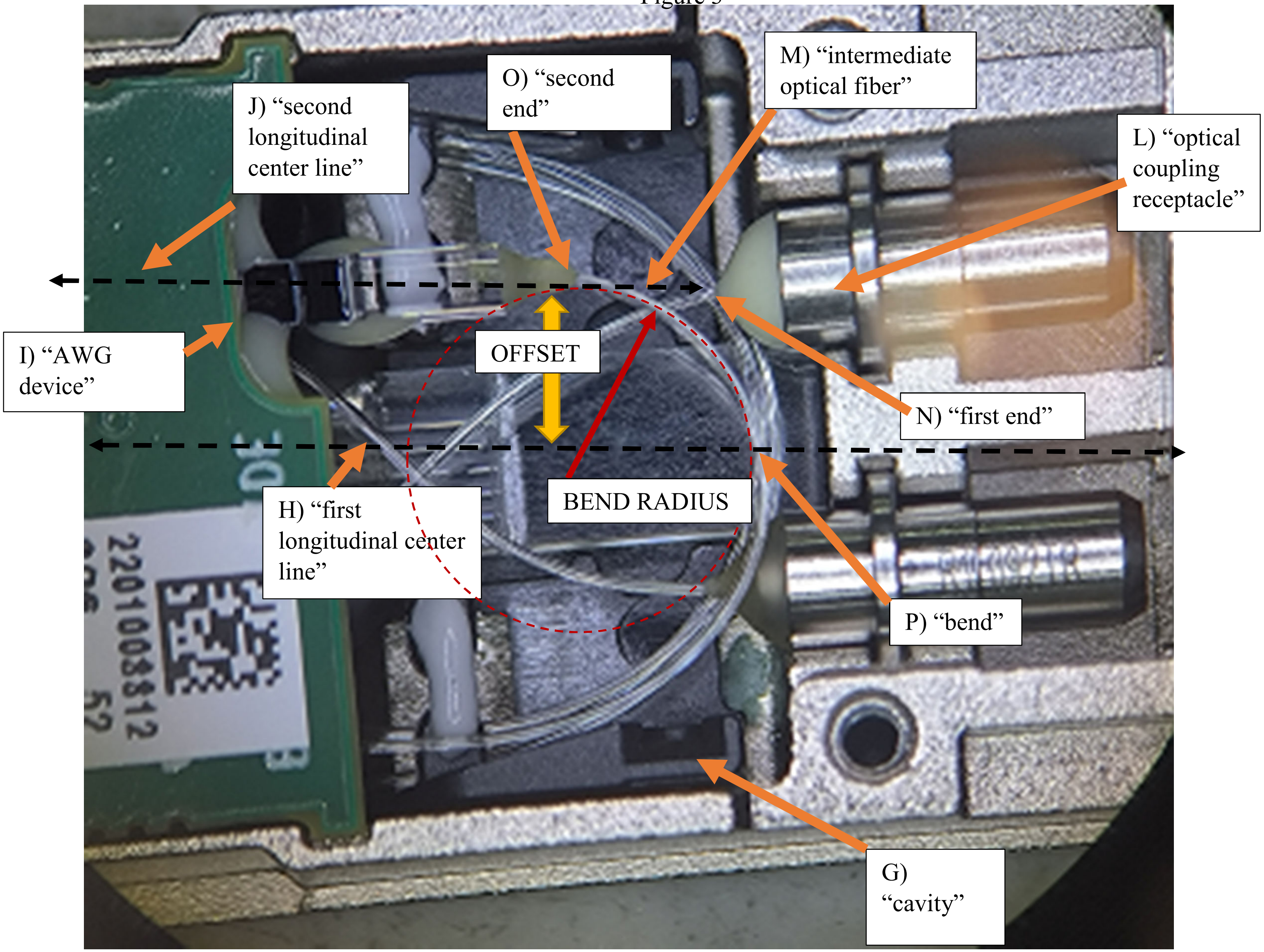


Exhibit Q - Representative Claim Charts for U.S. Patent No. 10,175,431

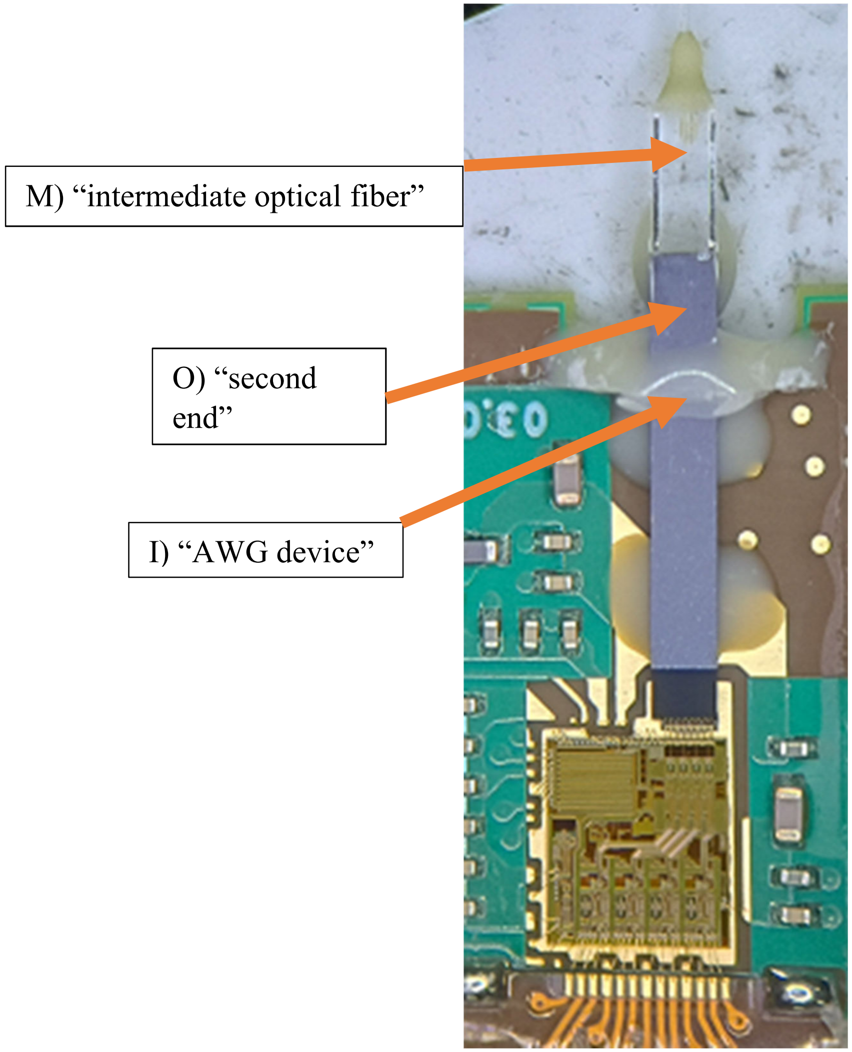


Figure 4

Exhibit Q - Representative Claim Charts for U.S. Patent No. 10,175,431

Independent Claim 1

U.S. Patent No. 10,175,431 Claim 1	100G QSFP CWMD4 – Version 1
1. An optical transceiver comprising:	Optical transceiver (**A**) (100G QSFP CWDM4) is shown in FIGs. 1-4
a housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis,	A housing **(B)** has a plurality of sidewalls **(C)** extending from a first end **(E)** to a second end **(F)** along a longitudinal axis **(D).** See FIGs. 1 and 2.
wherein the plurality of sidewalls define a cavity having a first longitudinal center line;	The plurality of sidewalls **(C)** define a cavity **(G)** having a first longitudinal center line **(H)**. See FIGs. 2-3.
an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity,	An arrayed waveguide grating (AWG) device **(I)** is disposed at least partially within the cavity **(G)** and has a second longitudinal center line **(J)** that extends substantially parallel with the first longitudinal center line **(H)** of the cavity **(G)**. See FIGs. 2-4.
the second longitudinal center line being disposed at a lateral offset D_{offset} that measures at least 1 millimeter relative to the first longitudinal center line;	The second longitudinal center line **(J)** is disposed at a lateral offset that on information and belief measures at least 1 millimeter relative to the first longitudinal center line **(H)**. See FIGs. 2 and 3.
an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber; and	An optical coupling receptacle **(L)** is at least partially disposed within the cavity **(G)** for optically coupling to a receive optical fiber.
an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device,	An intermediate optical fiber **(M)** is disposed within the cavity **(G)**. The intermediate optical fiber **(M)** has a first end **(N)** optically coupled to the optical coupling receptacle **(L)** and a second end **(O)** optically coupled to the AWG device **(I)**. See FIGs. 2-4.
the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius equal to or greater than a minimum bend radius R_{min} associated with the intermediate optical fiber to reduce fiber bending losses.	The intermediate fiber **(M)** includes a bend **(P)** adjacent to the second end **(O)** of the intermediate optical fiber **(M)** with a bend radius that on information and belief is equal to or greater than a minimum bend radius associated with the intermediate optical fiber **(M)** to reduce fiber bending losses. See FIGs. 2 and 3.

Exhibit Q - Representative Claim Charts for U.S. Patent No. 10,175,431

Independent Claim 16

U.S. Patent No. 10,175,431 Claim 16	100G QSFP CWMD4
An optical transceiver comprising:	Optical transceiver (**A**) (100G QSFP CWDM4) is shown in FIGs. 1-4.
a housing comprising a plurality of sidewalls extending from a first end to a second end along a longitudinal axis,	A housing **(B)** having a plurality of sidewalls **(C)** extending from a first end **(E)** to a second end **(F)** along a longitudinal axis **(D).** See FIGs. 1 and 2.
wherein the plurality of sidewalls define a cavity having a first longitudinal center line;	The plurality of sidewalls **(C)** define a cavity **(G)** having a first longitudinal center line **(H)**. See FIG. 2.
an arrayed waveguide grating (AWG) device at least partially disposed within the cavity and having a second longitudinal center line that extends substantially in parallel with the first longitudinal center line of the cavity,	An arrayed waveguide grating (AWG) device **(I)** is disposed at least partially within the cavity **(G)** and has a second longitudinal center line **(J)** that extends substantially parallel with the first longitudinal center line **(H)** of the cavity **(G)**. See FIGs. 2-4.
the second longitudinal center line being disposed at a lateral offset D_{offset} that measures at least 1 millimeter relative to the first longitudinal center line;	The second longitudinal center line **(J)** is disposed at a lateral offset that on information and belief measures at least 1 millimeter relative to the first longitudinal center line **(H)**. See FIGs. 2 and 3.
an optical coupling receptacle at least partially disposed within the cavity for optically coupling to a receive optical fiber;	An optical coupling receptacle **(L)** is at least partially disposed within the cavity **(G)** for optically coupling to a receive optical fiber.
and an intermediate optical fiber disposed within the cavity and having a first end optically coupled to the optical coupling receptacle and a second end optically coupled to the AWG device,	An intermediate optical fiber **(M)** is disposed within the cavity **(G)**. The intermediate optical fiber **(M)** has a first end **(N)** optically coupled to the optical coupling receptacle **(L)** and a second end **(O)** optically coupled to the AWG device **(I)**. See FIGs. 2-4.
the intermediate fiber having a bend adjacent to the second end of the intermediate optical fiber with a bend radius greater than or equal to a minimum bend radius R_{min} associated with the	The intermediate fiber **(M)** includes a bend **(P)** adjacent to the second end **(O)** of the intermediate optical fiber **(M)** with a bend radius that on information and belief is equal to or greater than a

Exhibit Q - Representative Claim Charts for U.S. Patent No. 10,175,431

U.S. Patent No. 10,175,431 Claim 16	100G QSFP CWMD4
intermediate optical fiber, the minimum bend radius R_{min} being 4 millimeters.	minimum bend radius of 4 millimeters associated with the intermediate optical fiber **(M)** to reduce fiber bending losses. See FIGs. 2 and 3.

EXHIBIT R

EXHIBIT R - Representative Claim Chart for U.S. Patent No. 10,042,116

<u>CIG 100G LR4 Module</u>

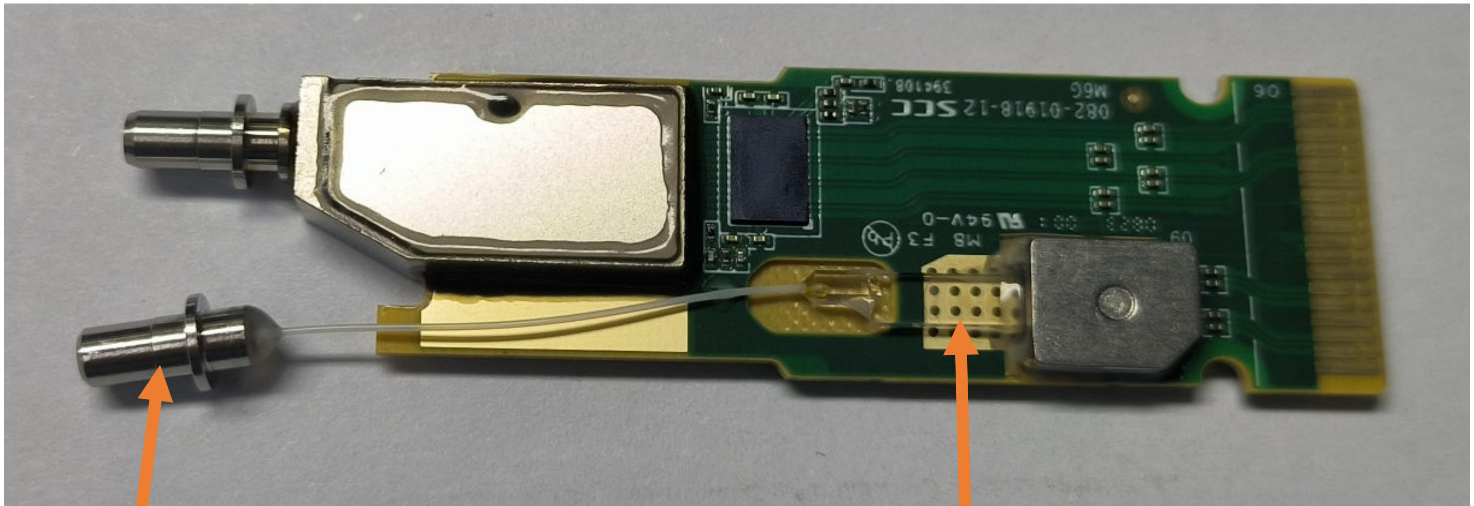


Figure 1

C) optical coupling receptacle

A) “AWG Chip”

EXHIBIT R - Representative Claim Chart for U.S. Patent No. 10,042,116

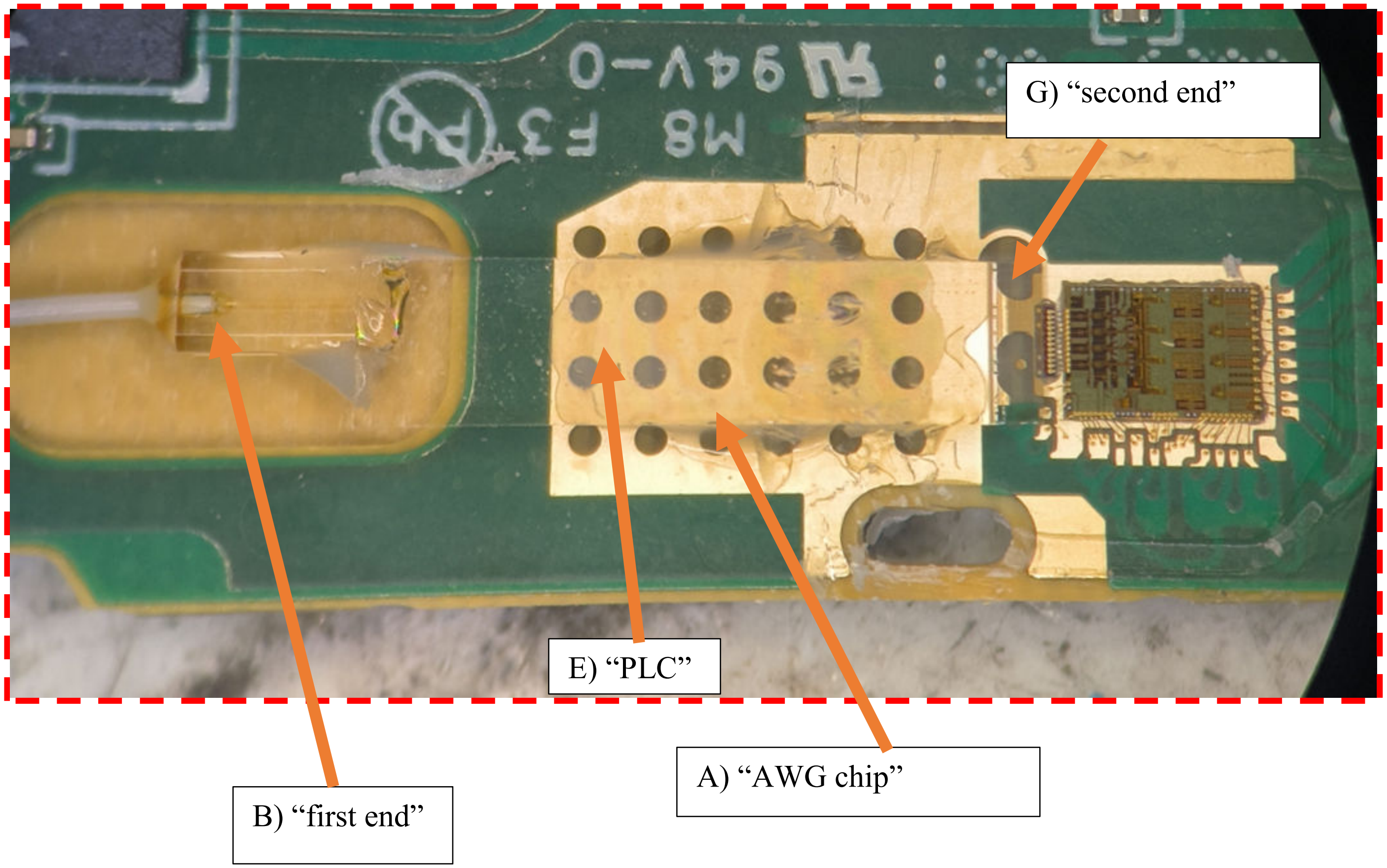


Figure 2

EXHIBIT R - Representative Claim Chart for U.S. Patent No. 10,042,116

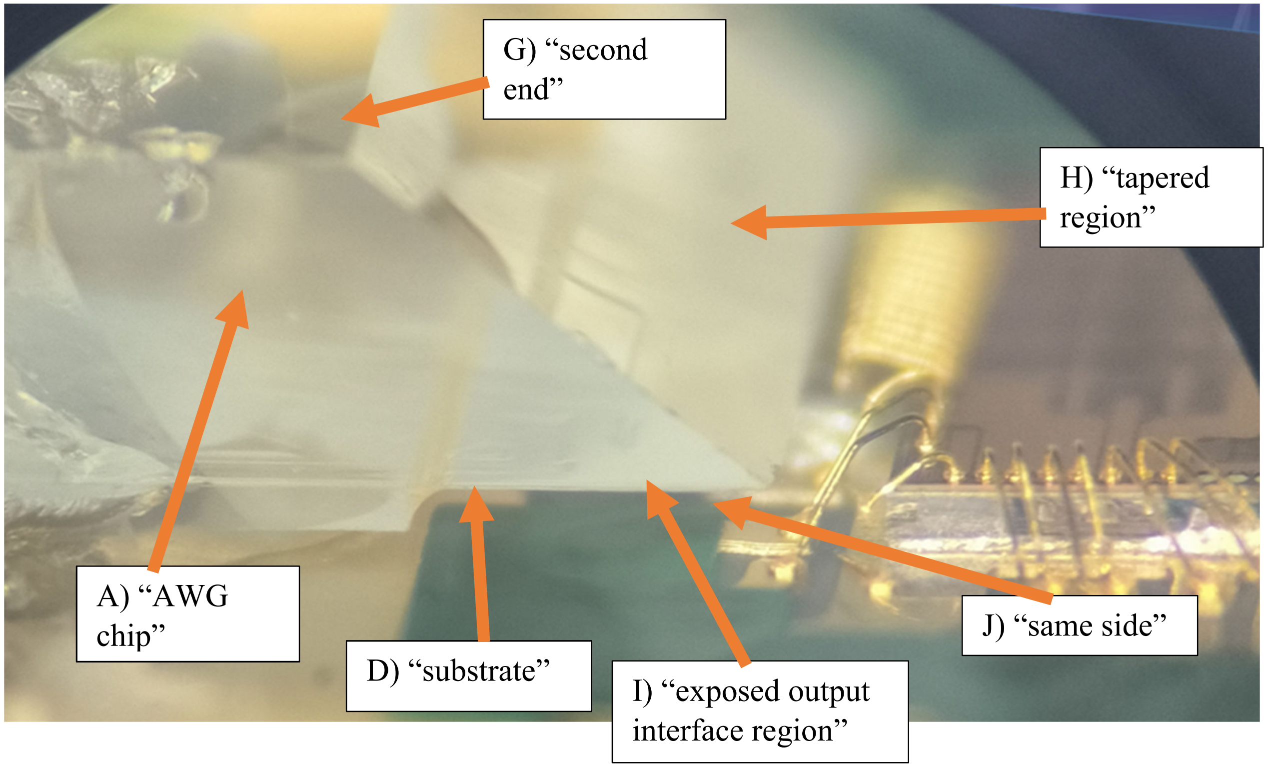


Figure 3

EXHIBIT R - Representative Claim Chart for U.S. Patent No. 10,042,116

2. U.S. Patent No. 10,042,116

a. Independent Claim 1

U.S. Patent No. 10,042,116 Claim 1	100G QSFP CWDM4
An arrayed waveguide grating (AWG) chip comprising:	Arrayed waveguide grating (AWG) chip **(A)** (100G QSFP CWDM4). See FIGs. 1-3.
a first end for coupling to an optical coupling receptacle to receive an optical signal comprising a plurality of channel wavelengths;	First end **(B)** of arrayed waveguide grating (AWG) chip **(A)** is for coupling to optical coupling receptacle **(C)** shown as an LC connector coupled to arrayed waveguide grating (AWG) chip **(A)** via optical fiber to receive an optical signal comprising a plurality of channel wavelengths. See FIGs. 2.
a substrate;	Substrate **(D)** See FIGs. 2.
a planar lightwave circuit (PLC) disposed on the substrate,	Planar lightwave circuit (PLC) **(E)** is disposed on substrate **(D)**. See FIGs. 2-3.
the PLC coupled to the first end and configured to de-multiplex each channel wavelength of the plurality of channel wavelengths;	PLC **(E)** is coupled to the first end **(B)** and PLC **(E)** is configured to de-multiplex each channel wavelength of the plurality of channel wavelengths. See FIG. 2.
a plurality of output waveguides coupled to the PLC, each of the output waveguides configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC and provide the light along a first light path that extends towards a second end of the AWG chip; and	The AWG chip **(A)** includes a plurality of output waveguides which are coupled to the planer lightwave circuit (PLC) **(E)**, each of the output waveguides is configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC **(E)** and to provide the light along a first light path that extends towards a second end **(G)** of the AWG chip **(A)**. See FIGs. 2-3.
a tapered region disposed at the second end of the AWG chip configured to receive light via the plurality of output waveguides and reflect the same towards an exposed output interface region of the AWG chip,	A tapered region **(H)** disposed at the second end **(G)** of the AWG chip **(A)** is configured to receive light via the plurality of output waveguides and reflect the same towards an exposed output interface region **(I)** of the AWG chip **(A)**. See Figs. 2-3.

EXHIBIT R - Representative Claim Chart for U.S. Patent No. 10,042,116

U.S. Patent No. 10,042,116 Claim 1	100G QSFP CWDM4
wherein the exposed output interface region emits the received light from the AWG chip on the same side as the substrate without passing the received light through the substrate.	The exposed output interface region (**I**) emits received light from the AWG chip **(A)** on the same side **(J)** as the substrate **(D)** without passing the received light through the substrate **(D).** See FIG. 3.

EXHIBIT S

EXHIBIT S - Representative Claim Chart for U.S. Patent No. 10,042,116

CIG 100G QSFP CWDM4 Module – VERSION 1

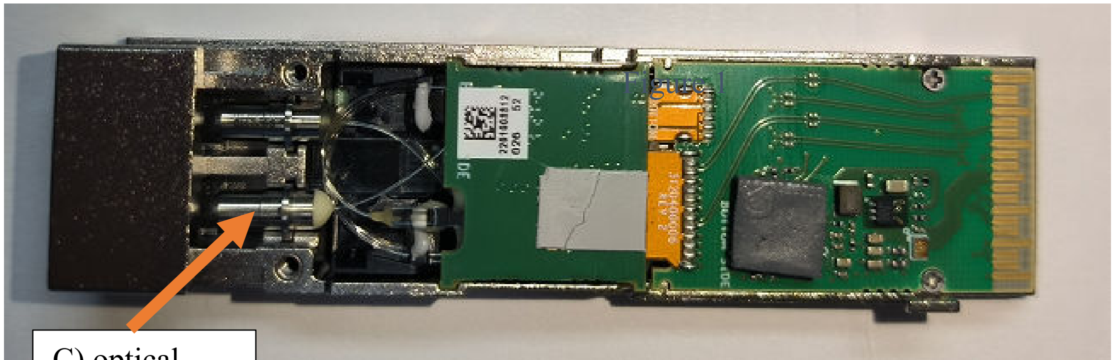


Figure 1

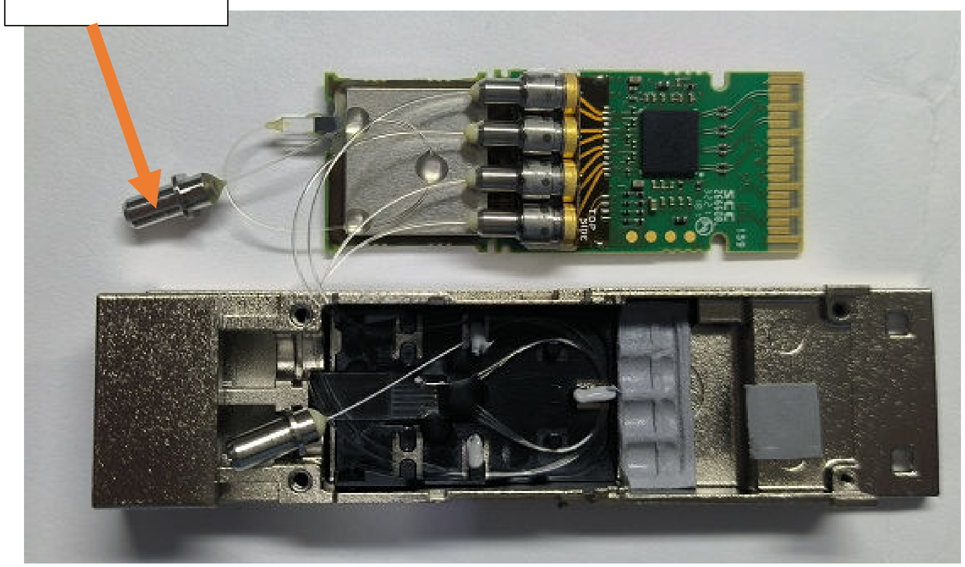


Figure 2

EXHIBIT S - Representative Claim Chart for U.S. Patent No. 10,042,116

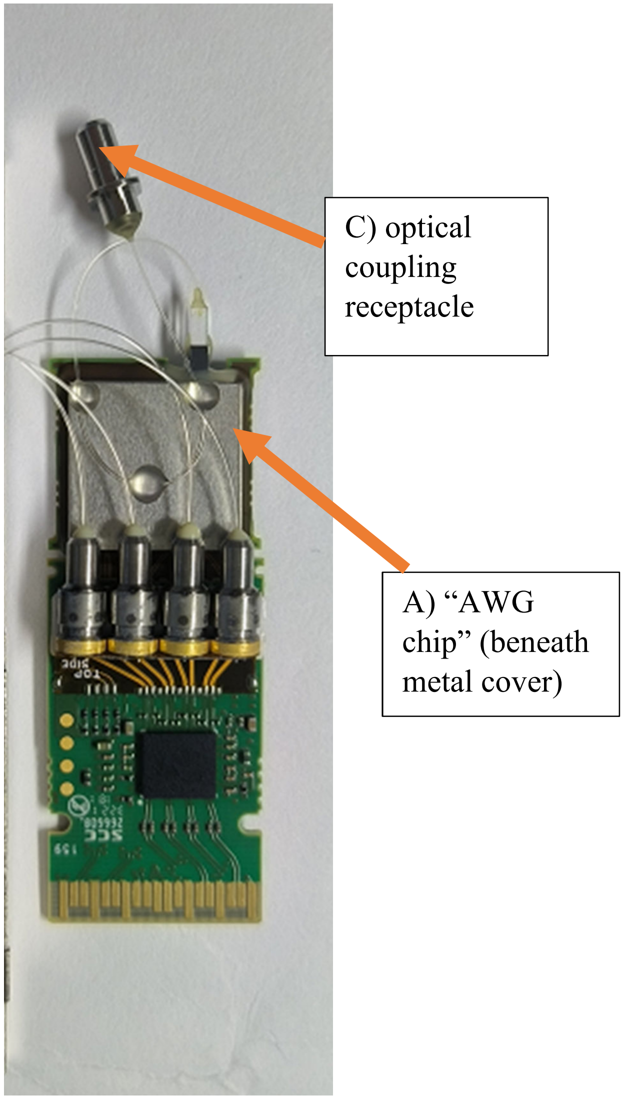


Figure 3

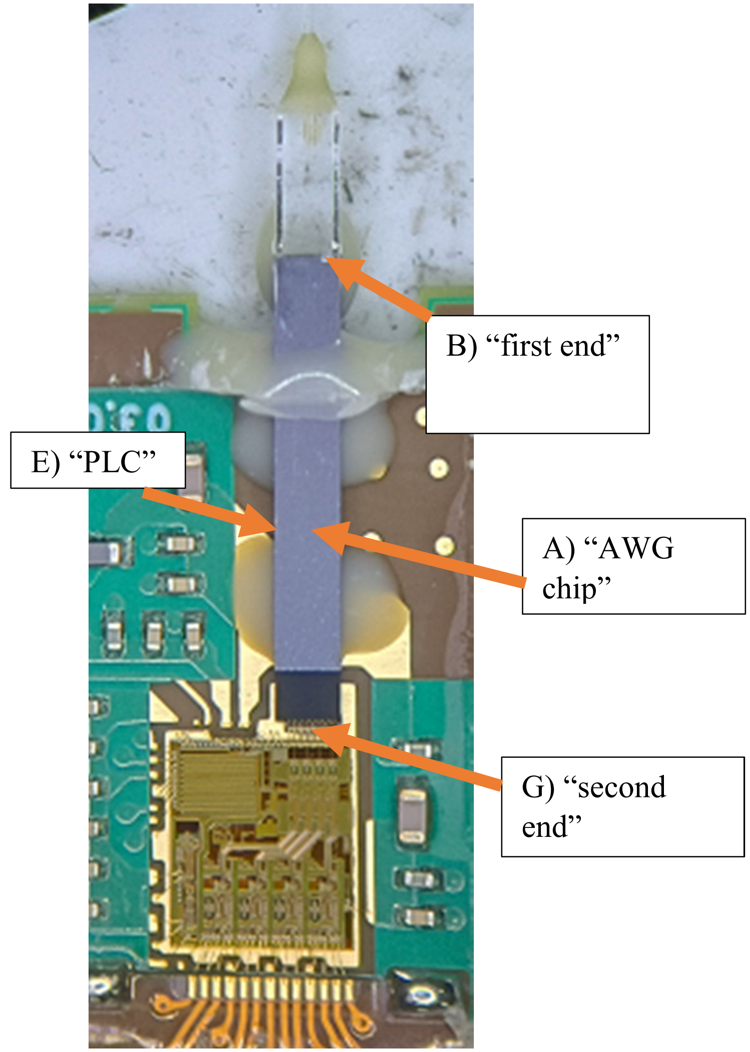


Figure 4

EXHIBIT S - Representative Claim Chart for U.S. Patent No. 10,042,116

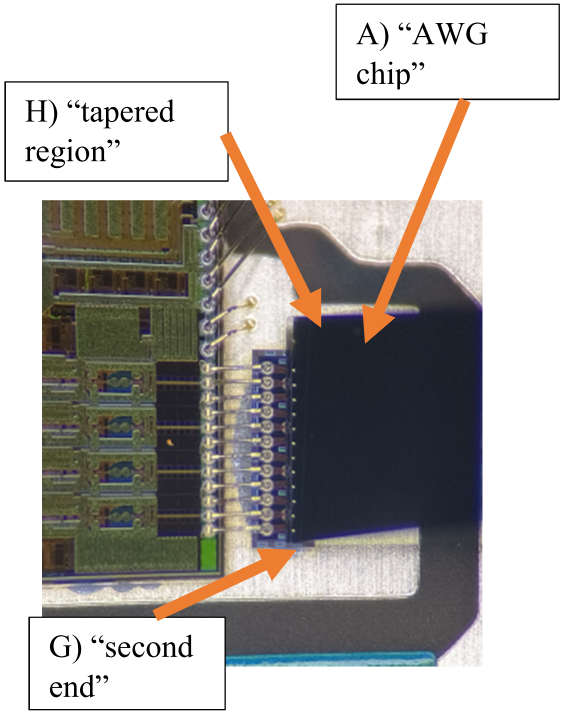


Figure 5

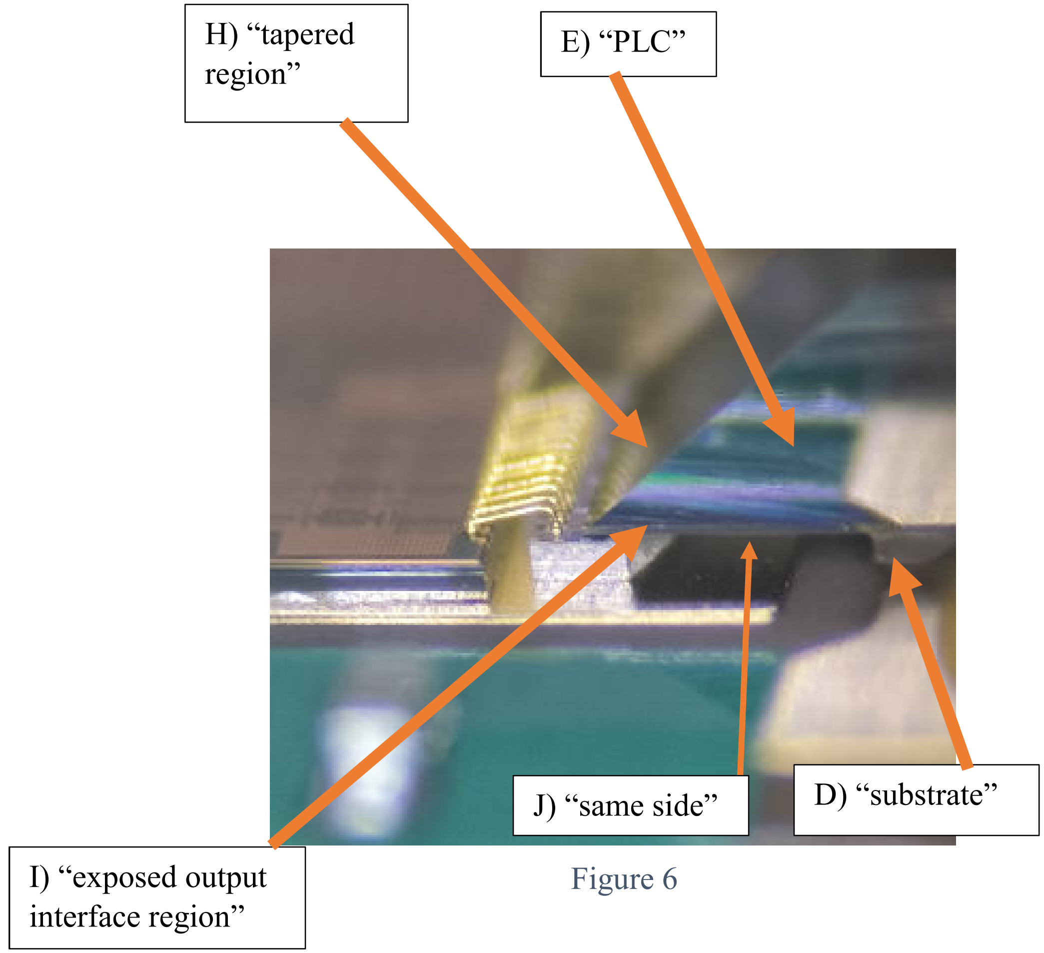


Figure 6

EXHIBIT S - Representative Claim Chart for U.S. Patent No. 10,042,116

Independent Claim 1

U.S. Patent No. 10,042,116 **Claim 1**	**100G QSFP CWDM4 – VERSION 1**
An arrayed waveguide grating (AWG) chip comprising:	Arrayed waveguide grating (AWG) chip **(A)** (100G QSFP CWDM4). See FIGs. 1-6.
a first end for coupling to an optical coupling receptacle to receive an optical signal comprising a plurality of channel wavelengths;	First end **(B)** of arrayed waveguide grating (AWG) chip **(A)** is for coupling to optical coupling receptacle **(C)** shown as an LC connector coupled to arrayed waveguide grating (AWG) chip **(A)** via optical fiber to receive an optical signal comprising a plurality of channel wavelengths. See FIGs. 3-4.
a substrate;	Substrate **(D)** See FIGs. 3-4.
a planar lightwave circuit (PLC) disposed on the substrate,	Planar lightwave circuit (PLC) **(E)** is disposed on substrate **(D)**. See FIG. 6.
the PLC coupled to the first end and configured to de-multiplex each channel wavelength of the plurality of channel wavelengths;	PLC **(E)** is coupled to the first end **(B)** and PLC **(E)** is configured to de-multiplex each channel wavelength of the plurality of channel wavelengths. See FIG. 4.
a plurality of output waveguides coupled to the PLC, each of the output waveguides configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC and provide the light along a first light path that extends towards a second end of the AWG chip; and	The AWG chip **(A)** includes a plurality of output waveguides which are coupled to the planer lightwave circuit (PLC) **(E)**, each of the output waveguides is configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC **(E)** and to provide the light along a first light path that extends towards a second end **(G)** of the AWG chip **(A)**. See FIGs. 4-6.
a tapered region disposed at the second end of the AWG chip configured to receive light via the plurality of output waveguides and reflect the same towards an exposed output interface region of the AWG chip,	A tapered region **(H)** disposed at the second end **(G)** of the AWG chip **(A)** is configured to receive light via the plurality of output waveguides and reflect the same towards an exposed output interface region **(I)** of the AWG chip **(A)**. See Figs. 5 and 6.

EXHIBIT S - Representative Claim Chart for U.S. Patent No. 10,042,116

U.S. Patent No. 10,042,116 Claim 1	**100G QSFP CWDM4 – VERSION 1**
wherein the exposed output interface region emits the received light from the AWG chip on the same side as the substrate without passing the received light through the substrate.	The exposed output interface region (**I**) emits received light from the AWG chip **(A)** on the same side **(J)** as the substrate **(D)** without passing the received light through the substrate **(D).** See FIG. 6.

EXHIBIT T

EXHIBIT T - Representative Claim Chart for U.S. Patent No. 10,042,116

CIG 100G QSFP CWDM4 Module – VERSION 2

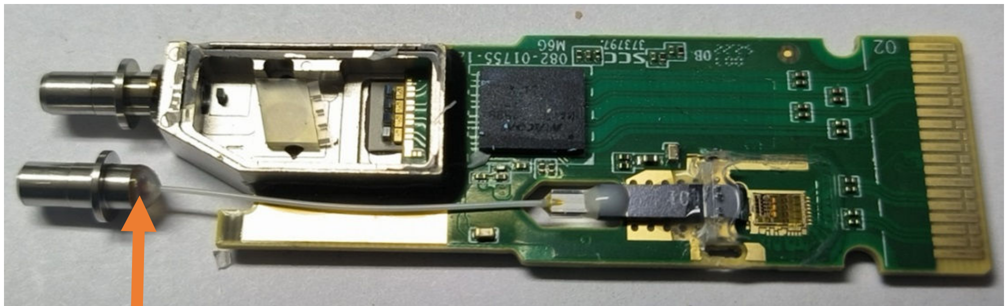


Figure 1

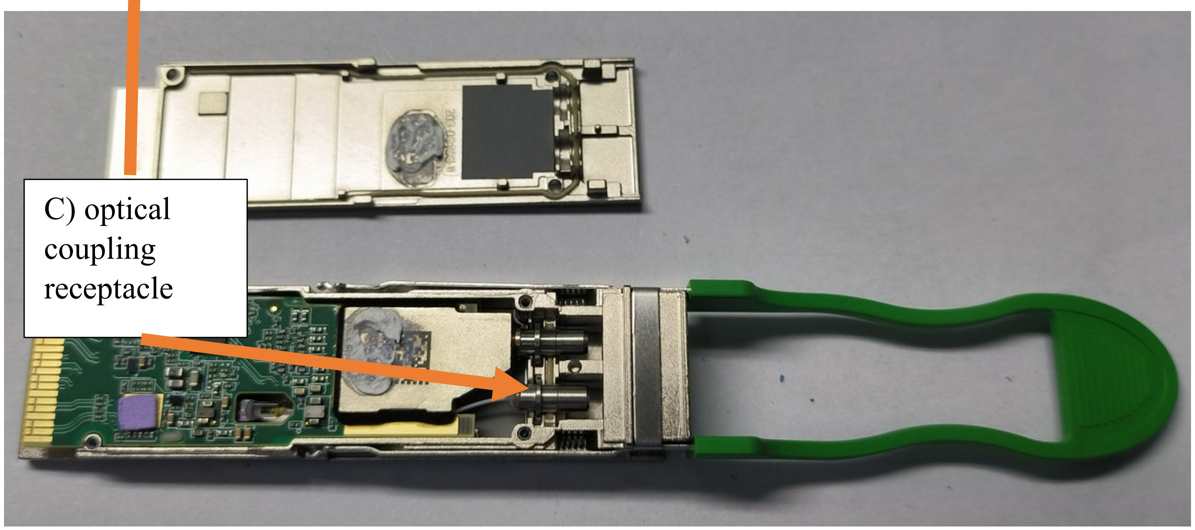


Figure 2

EXHIBIT T - Representative Claim Chart for U.S. Patent No. 10,042,116

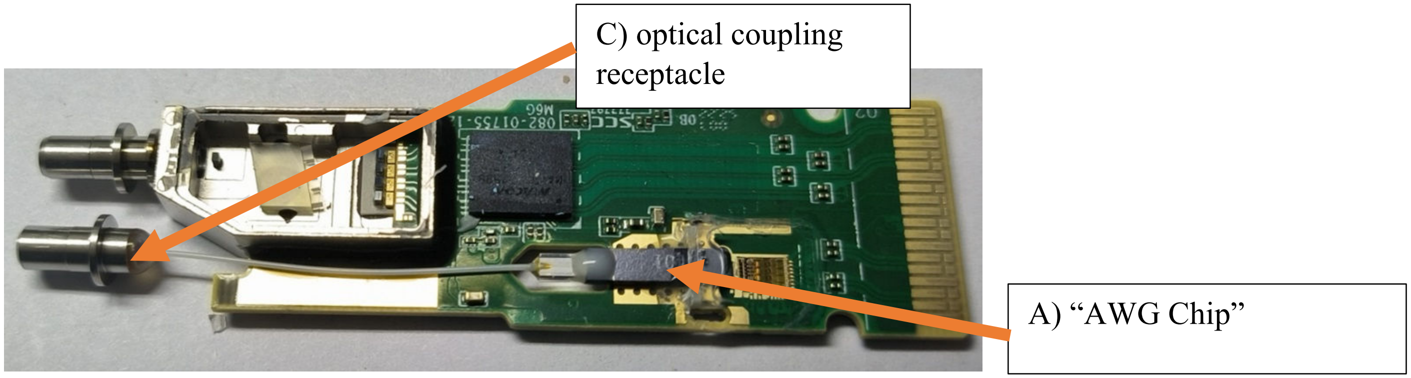


Figure 3

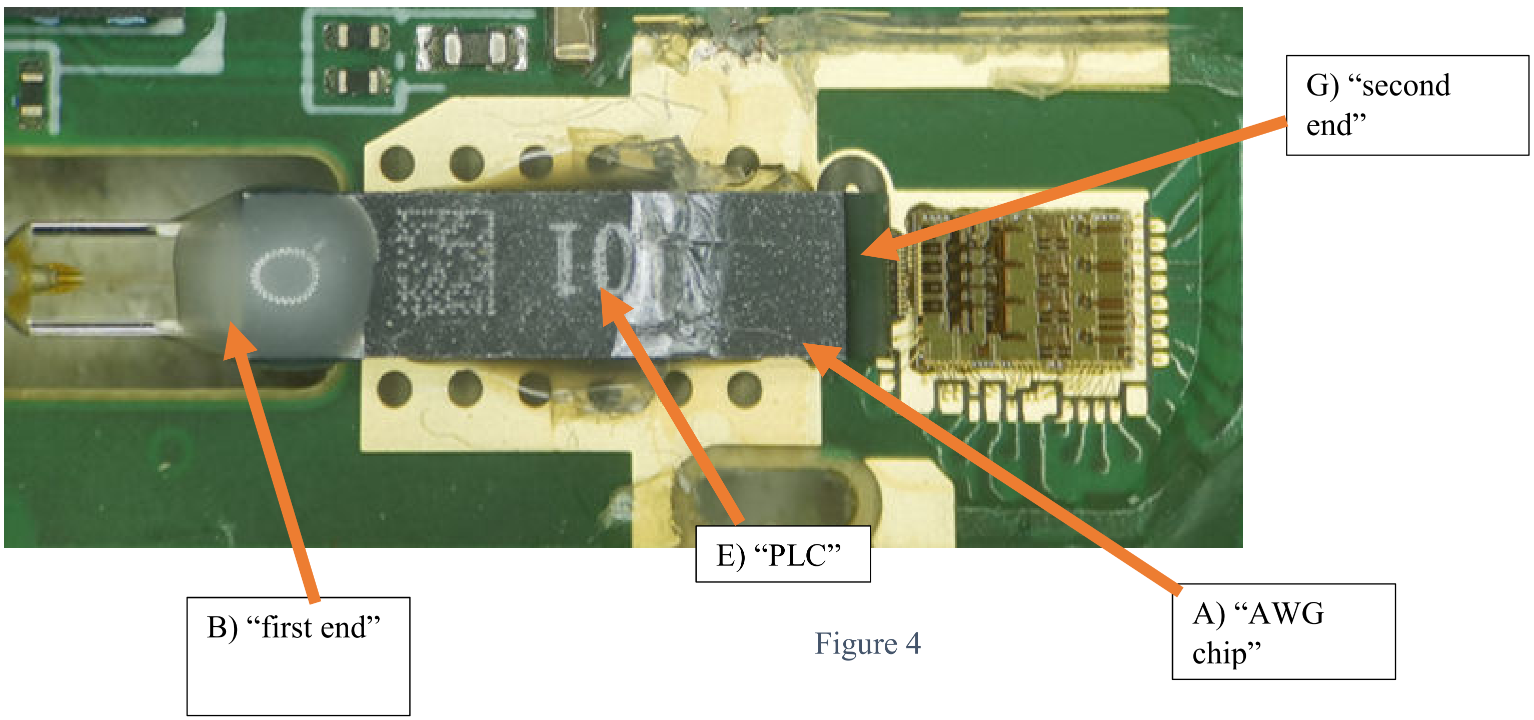


Figure 4

EXHIBIT T - Representative Claim Chart for U.S. Patent No. 10,042,116

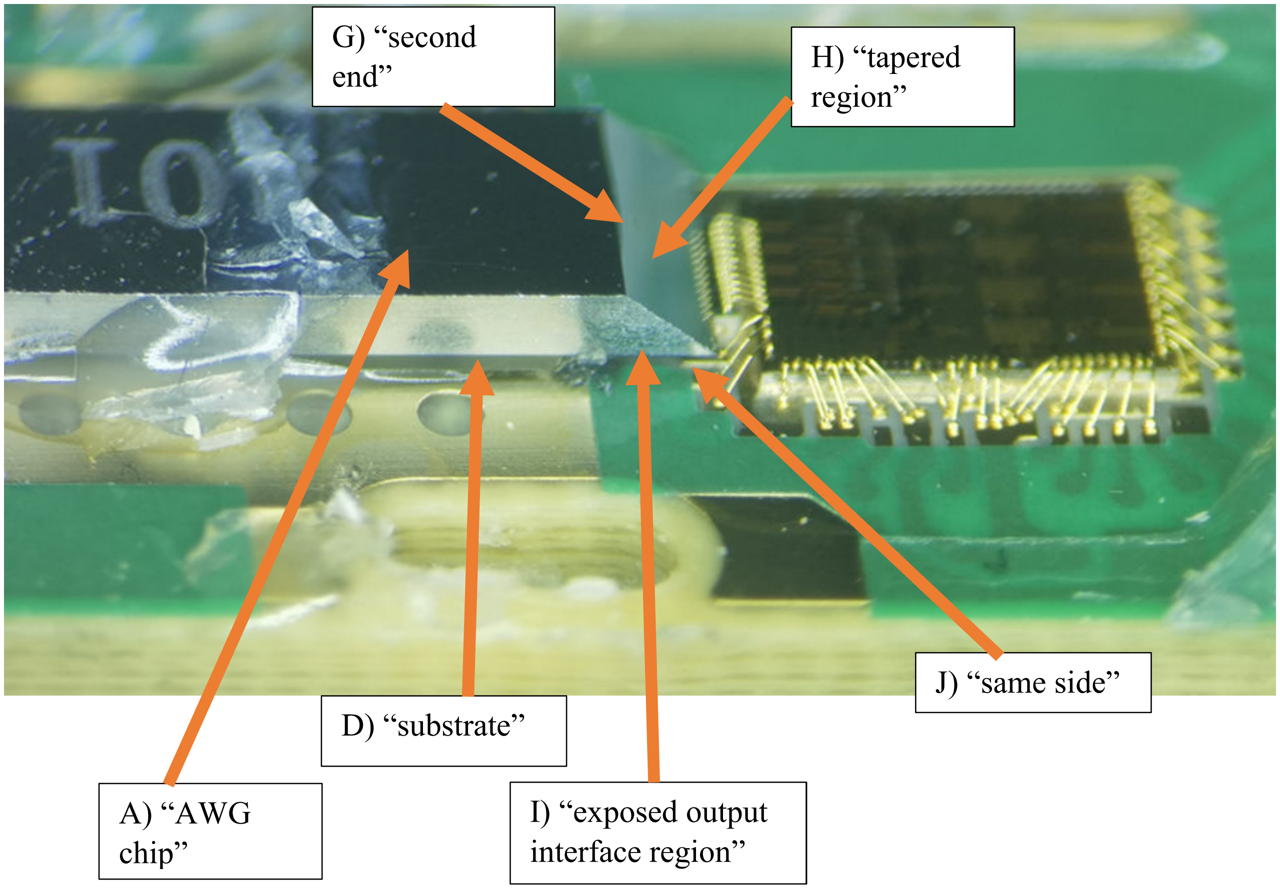


Figure 5

EXHIBIT T - Representative Claim Chart for U.S. Patent No. 10,042,116

Independent Claim 1

U.S. Patent No. 10,042,116 Claim 1	**100G QSFP CWDM4 – VERSION 2**
An arrayed waveguide grating (AWG) chip comprising:	Arrayed waveguide grating (AWG) chip **(A)** (100G QSFP CWDM4). See FIGs. 1-5.
a first end for coupling to an optical coupling receptacle to receive an optical signal comprising a plurality of channel wavelengths;	First end **(B)** of arrayed waveguide grating (AWG) chip **(A)** is for coupling to optical coupling receptacle **(C)** shown as an LC connector coupled to arrayed waveguide grating (AWG) chip **(A)** via optical fiber to receive an optical signal comprising a plurality of channel wavelengths. See FIGs. 3-4.
a substrate;	Substrate **(D)** See FIGs. 3-4.
a planar lightwave circuit (PLC) disposed on the substrate,	Planar lightwave circuit (PLC) **(E)** is disposed on substrate **(D)**. See FIG. 4-5.
the PLC coupled to the first end and configured to de-multiplex each channel wavelength of the plurality of channel wavelengths;	PLC **(E)** is coupled to the first end **(B)** and PLC **(E)** is configured to de-multiplex each channel wavelength of the plurality of channel wavelengths. See FIG. 4.
a plurality of output waveguides coupled to the PLC, each of the output waveguides configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC and provide the light along a first light path that extends towards a second end of the AWG chip; and	The AWG chip **(A)** includes a plurality of output waveguides which are coupled to the planer lightwave circuit (PLC) **(E)**, each of the output waveguides is configured to receive light corresponding to an associated de-multiplexed channel wavelength launched from the PLC **(E)** and to provide the light along a first light path that extends towards a second end **(G)** of the AWG chip **(A)**. See FIGs. 4-5.
a tapered region disposed at the second end of the AWG chip configured to receive light via the plurality of output waveguides and reflect the same towards an exposed output interface region of the AWG chip,	A tapered region **(H)** disposed at the second end **(G)** of the AWG chip **(A)** is configured to receive light via the plurality of output waveguides and reflect the same towards an exposed output interface region **(I)** of the AWG chip **(A)**. See Figs. 4-5.

EXHIBIT T - Representative Claim Chart for U.S. Patent No. 10,042,116

U.S. Patent No. 10,042,116 **Claim 1**	**100G QSFP CWDM4 – VERSION 2**
wherein the exposed output interface region emits the received light from the AWG chip on the same side as the substrate without passing the received light through the substrate.	The exposed output interface region (**I**) emits received light from the AWG chip **(A)** on the same side **(J)** as the substrate **(D)** without passing the received light through the substrate **(D).** See FIG. 5.