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(54) **MULTIPLE WAVELENGTH OPTICAL SOURCE**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,995,937 A 12/1976 Baues et al.
4,006,967 A 2/1977 Kenan et al.
4,140,362 A 2/1979 Tien

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0310438 A1 4/1989
GB 2168215 A 6/1986

(Continued)

OTHER PUBLICATIONS

Backlund et al, Multifunctional grating couplers for bidirectional incoupling into planar waveguides., IEEE Photonics Tech. Lett., vol. 12 No. 3 pp. 315–316 (Mar. 2000).

(Continued)

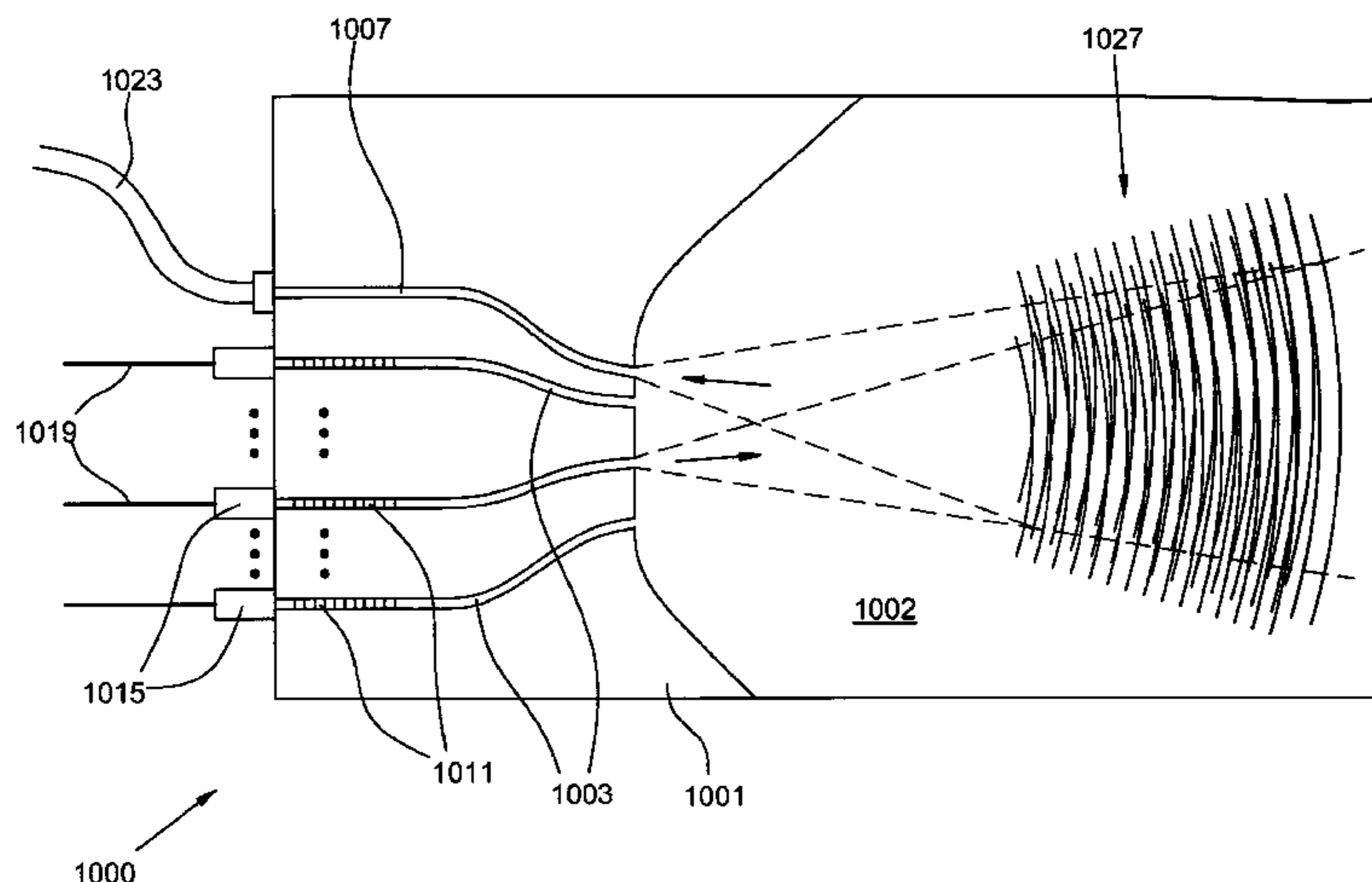
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(57) **ABSTRACT**

A planar optical waveguide is formed having sets of locking diffractive elements and means for routing optical signals. Lasers are positioned to launch signals into the planar waveguide that are successively incident on elements of the locking diffractive element sets, which route fractions of the signals back to the lasers as locking feedback signals. The routing means route between lasers and output port(s) portions of those fractions of signals transmitted by locking diffractive element sets. Locking diffractive element sets may be formed in channel waveguides formed in the planar waveguide, or in slab waveguide region(s) of the planar waveguide. Multiple routing means may comprise routing diffractive element sets formed in a slab waveguide region of the planar waveguide, or may comprise an arrayed waveguide grating formed in the planar waveguide. The apparatus may comprise a multiple-wavelength optical source.

51 Claims, 9 Drawing Sheets



U.S. PATENT DOCUMENTS

4,387,955 A 6/1983 Ludman et al.
 4,440,468 A 4/1984 Auracher et al.
 4,660,934 A 4/1987 Akiba et al.
 4,740,951 A 4/1988 Lizet et al.
 4,743,083 A 5/1988 Schimpe
 4,746,186 A 5/1988 Nicia
 4,773,063 A 9/1988 Hunsperger et al.
 4,786,133 A 11/1988 Gidon et al.
 4,803,696 A 2/1989 Pepper et al.
 4,824,193 A 4/1989 Maeda et al.
 4,834,474 A 5/1989 George et al.
 4,846,552 A 7/1989 Veldkamp et al.
 4,852,960 A 8/1989 Alferness et al.
 4,923,271 A 5/1990 Henry et al.
 4,938,553 A 7/1990 Maerz et al.
 5,040,864 A 8/1991 Hong
 5,042,898 A 8/1991 Morey et al.
 5,093,874 A 3/1992 Hawkins et al.
 5,107,359 A 4/1992 Ohuchida
 5,165,104 A 11/1992 Weverka
 5,195,161 A 3/1993 Adar et al.
 5,274,657 A 12/1993 Horii et al.
 5,357,591 A 10/1994 Jiang
 5,450,511 A 9/1995 Dragone
 5,453,871 A 9/1995 Kolner et al.
 5,668,900 A 9/1997 Little et al.
 5,768,450 A 6/1998 Bhagavatula
 5,812,318 A 9/1998 Babbitt et al.
 5,830,622 A 11/1998 Canning et al.
 5,887,094 A 3/1999 Bakhti et al.
 5,907,647 A 5/1999 Eggleton et al.
 5,995,691 A 11/1999 Arai et al.
 6,011,884 A 1/2000 Dueck et al.
 6,011,885 A 1/2000 Dempewolf et al.
 6,021,242 A 2/2000 Harumoto et al.
 6,137,933 A 10/2000 Hunter et al.
 6,144,480 A 11/2000 Li et al.
 6,169,613 B1 1/2001 Amitai et al.
 6,169,614 B1 1/2001 Whitcomb et al.
 6,243,514 B1 6/2001 Thompson
 6,266,463 B1 7/2001 Laming et al.
 6,285,813 B1 9/2001 Schultz et al.
 6,323,970 B1 11/2001 Popovich
 6,408,118 B1 6/2002 Ahuja et al.
 6,473,232 B2 10/2002 Ogawa
 6,553,162 B1 4/2003 Okayama
 6,603,901 B1 8/2003 Hale et al.
 6,678,429 B2 1/2004 Mossberg et al.
 6,702,897 B2 3/2004 Cullen et al.
 6,718,093 B2 4/2004 Zhou
 6,768,834 B1 7/2004 Gruhlke
 6,781,944 B1 8/2004 Tanaka
 6,813,048 B2 11/2004 Kitamura
 6,823,115 B2 11/2004 Greiner et al.
 6,829,417 B2 12/2004 Greiner et al.
 6,836,492 B2 12/2004 Ido
 6,850,670 B2 2/2005 Parhami et al.
 6,859,318 B1 2/2005 Mossberg
 6,876,791 B2 4/2005 Murashima et al.
 6,879,441 B1 4/2005 Mossberg
 6,928,223 B2 8/2005 Walpole et al.
 6,961,491 B2 11/2005 Greiner et al.
 6,965,464 B2 11/2005 Mossberg
 6,965,716 B2 11/2005 Greiner et al.
 6,985,656 B2 1/2006 Iazikov et al.
 6,987,911 B2 1/2006 Mossberg
 6,990,276 B2 1/2006 Brice et al.
 6,993,223 B2 1/2006 Greiner et al.
 7,003,187 B2 2/2006 Frick et al.
 7,009,743 B2 3/2006 Mossberg

7,016,569 B2 3/2006 Mule et al.
 7,049,704 B2 5/2006 Chakravorty et al.
 7,054,517 B2 5/2006 Mossberg et al.
 7,062,128 B2 6/2006 Mossberg
 7,116,453 B2 10/2006 Mossberg
 7,116,852 B2 10/2006 Tuda
 7,120,334 B1 10/2006 Greiner et al.
 7,123,794 B2 10/2006 Greiner et al.
 7,181,103 B1 2/2007 Greiner et al.
 7,190,859 B2 3/2007 Greiner et al.
 7,194,161 B1 3/2007 Deri et al.
 7,209,611 B2 4/2007 Joyner
 7,224,855 B2 5/2007 Iazikov et al.
 7,260,290 B1 8/2007 Greiner et al.
 7,286,732 B2 10/2007 Greiner et al.
 7,499,612 B2 3/2009 Mossberg et al.
 2002/0071646 A1 6/2002 Eggleton et al.
 2003/0011833 A1 1/2003 Yankov et al.
 2003/0039444 A1 2/2003 Mossberg et al.
 2003/0068113 A1 4/2003 Janz et al.
 2003/0117677 A1 6/2003 Mossberg
 2003/0185269 A1 10/2003 Gutin
 2004/0047561 A1 3/2004 Tuda
 2004/0076374 A1 4/2004 Greiner et al.
 2004/0131360 A1 7/2004 Iazikov et al.
 2004/0170356 A1 9/2004 Iazikov et al.
 2004/0173680 A1 9/2004 Mossberg et al.
 2004/0179779 A1 9/2004 Greiner et al.
 2004/0208466 A1 10/2004 Mossberg et al.
 2004/0258356 A1 12/2004 Brice et al.
 2005/0018951 A1 1/2005 Mossberg et al.
 2005/0063430 A1 3/2005 Doucet et al.
 2005/0078912 A1 4/2005 Iazikov et al.
 2005/0135744 A1 6/2005 Greiner et al.
 2005/0135745 A1 6/2005 Greiner et al.
 2005/0135747 A1 6/2005 Greiner et al.
 2005/0152011 A1 7/2005 Mossberg
 2005/0163425 A1 7/2005 Greiner et al.
 2005/0196114 A1 9/2005 Xu et al.
 2006/0023280 A1 2/2006 Mossberg
 2006/0139712 A1 6/2006 Mossberg
 2006/0177178 A1 8/2006 Greiner et al.
 2006/0193553 A1 8/2006 Mossberg et al.
 2006/0210214 A1 9/2006 Uhlhorn et al.
 2006/0233493 A1 10/2006 Mossberg
 2006/0256831 A1 11/2006 Voladin et al.

FOREIGN PATENT DOCUMENTS

JP 4368901 A 12/1992
 JP 5019726 A 5/1993
 JP 1031121 A 2/1998
 JP 2003033805 2/2003
 WO 9935523 A1 7/1999
 WO 9956159 A1 11/1999
 WO 2005054120 A1 7/2002
 WO 02075411 A1 9/2002

OTHER PUBLICATIONS

Bates et al, Gaussian beams from variable groove depth grat-
 ing couplers in planar waveguides, Appl. Opt., vol. 32 No.
 12 pp. 2112–2116 (Apr. 1993).
 Bedford et al, Bow–Tie Surface–Emitting Lasers, IEEE Pho-
 tonics Technology Letters, vol. 12 No. 8 p. 948 (Aug. 2000).
 Brady et al, Holographic Interconnections in Photorefractive
 Waveguides., Applied Optics, vol. 30 No. 17 p. 2324 (Jun.
 1991).
 Brazas et al, Analysis of input–grating couplers having finite
 lengths., Appl. Opt., vol. 34 No. 19 pp. 3786–3792 (Jul.
 1995).

- Brigham et al, Analysis of scattering from large planar gratings of compliant cylindrical shells, *J. Acoust. Soc. A.*, vol. 61 No. 1 pp. 48–59 (Jan. 1977).
- Canning et al, Grating structures with phase mask period in silica-on-silicon planar waveguides., *Opt. Commun.*, vol. 171 pp. 213–217 (1999).
- Capron et al, Design and Performance of a Multiple Element Slab Waveguide Spectrograph for Multimode Fiber-Optic WDM System., *J. Lightwave Tech.*, vol. 11 No. 12 pp. 2009–2014 (Dec. 1993).
- Chen et al, Guided-wave planar optical interconnects using highly multiplexed polymer waveguide holograms., *J. Lightwave Tech.*, vol. 10 No. 7 pp. 888–897 (Jul. 1992).
- Chen et al, Ten channel single-mode wavelength division demultiplexer in the near IR, *Integrated Optical Circuits*, vol. 1583 pp. 134–142 (Intl. Soc. Opt. Eng., Boston, MA, USA, Sep. 1991).
- Cowin et al., Compact polymeric wavelength division multiplexer., *Electron. Lett.*, vol. 35 No. 13 pp. 1074–1076 (Jun. 1999).
- Day et al, Filter-Response Line Shapes of Resonant Waveguide Grating., *J. Lightwave Tech.*, vol. 14 No. 8 pp. 1815–1824 (Aug. 1998).
- Deri et al, Quantitative Analysis of Integrated Optic Waveguide Spectrometers, *IEEE Photonics Tech. Lett.* vol. 6 No. 2 pp. 242–244 (Feb. 1994).
- Eldada et al, Dispersive properties of planar polymer bragg gratings., *IEEE Photonics Tech. Lett.*, vol. 12 No. 7 pp. 819–821 (Jul. 2000).
- Eriksson et al, Parabolic-Confocal Unstable-Resonator Semiconductor Lasers-Modeling and Experiments, *IEEE J. Quantum Electronics*, vol. 34 No. 5 p. 858 (May 1998).
- Eriksson et al, Surface-Emitting Unstable-Resonator Lasers with Integrated Diffractive Beam-Forming Elements, *IEEE Photonics Technology Letters*, vol. 9 No. 12 p. 1570 (Dec. 1997).
- Fu et al, 1×8 supergrating wavelength-division demultiplexer in a silica planar waveguide., *Opt. Lett.*, vol. 22 No. 21 pp. 1627–1629 (1997).
- Gini et al, Polarization Independent InP WDM Multiplexer/Demultiplexer Module, *J. Lightwave Tech.*, vol. 16 No. 4 pp. 625–630 (Apr. 1998).
- Grunnet-Jepsen et al, Fibre Bragg grating based spectral encoder/decoder for lightwave CDMA, *Electon. Lett.*, vol. 35 No. 13 pp. 1096–1097 (Jun. 1999).
- Grunnett-Jepsen et al, Demonstration of All-Fiber Sparse Lightwave CDMA Based on Temporal Phase Encoding, *Photonics Tech. Lett.*, vol. 11 No. 10 p. 1283 (Oct. 1999).
- Henry, Four-Channel Wavelength Division Multiplexers and Bandpass Filters Based on Elliptical Bragg Reflectors., *J. Lightwave Tech.*, vol. 8 No. 5 pp. 748–755 (May 1990).
- Hirayama et al., “Novel Surface Emitting Laser Diode Using Photonic Band-Gap Cavity,” *Appl. Phys. Lett* 69(6), Aug. 5, 1996.
- Kaneko et al, Design and Applications for silica-based planar lightwave circuits., *IEEE J. Sel. Top. Quant. Elec.*, vol. 5 No. 5 pp. 1227–1236 (Sep./Oct. 1999).
- Kazarinov et al, Narrow-Band Resonant Optical Reflectors and Resonant Optical Transformers for Laser Stabilization and Wavelength Division Multiplexing, *IEEE J. Quantum Electronics*, vol. QE-23 No. 9 p. 1419 (Sep. 1987).
- Koontz et al, Preservation of rectangular-patterned InP gratings overgrown by gas source molecular beam epitaxy., *Appl. Phys. Lett.*, vol. 71 No. 10 pp. 1400–1402 (Sep. 1997).
- Kristjansson et al, Surface-Emitting Tapered Unstable Resonator Laser with Integrated Focusing Grating Coupler, *IEEE Photonics Technology Letters*, vol. 12 No. 10 p. 1319 (Oct. 2000).
- Kurokawa et al, Time-space-conversion optical signal processing using arrayed-waveguide grating., *Electron. Lett.*, vol. 33 No. 22 pp. 1890–1891 (Oct. 1997).
- Li, Analysis of planar waveguide grating couplers with double surface corrugations of identical periods., *Opt. Commun.*, vol. 114 pp. 406–412 (1995).
- Lohmann, et al., “Graphic Codes for Computer Holography,” *Applied Optics*, vol. 34, No. 17, Jun. 10, 1995.
- Madsen et al, Planar Waveguide Optical Spectrum Analyzer Using a UV-Induced Grating, *IEEE J. Sel. Yop. Quant. Elec.*, vol. 4 No. 6 pp. 925–929 (Nov./Dec. 1998).
- Magnusson et al, New Principle for optical filters., *Appl. Phys. Lett.*, vol. 61 No. 9 pp. 1022–1024 (Aug. 1992).
- McGreer, Tunable Planar Concave Grating Demultiplexer, *IEEE Photonics Tech. Lett.*, vol. 8 No. 4 pp. 551–553 (Apr. 1996).
- McGreer, Diffraction from Concave Gratings in Planar Waveguides, *IEEE Photonics Tech. Lett.*, vol. 7 No. 3 pp. 324–326 (Mar. 1995).
- Minier et al, Diffraction characteristics of superimposed holographic gratings in planar optical waveguides, *IEEE Photonics Tech. Lett.*, vol. 4 No. 10 p. 115 (Oct. 1992).
- Miya, Silica-based planar lightwave circuits: passive thermally active devices., *IEEE J. Sel. Top. Quant. Elec.*, vol. 6 No. 1 pp. 38–45 (Jan./Feb. 2000).
- Modh et al, “Deep-Etched Distributed Bragg Reflector Lasers with Curved Mirrors-Experiments and Modeling” *IEEE J. Quantum Electronics*, vol. 37 No. 6 p. 752 (Jun. 2001).
- Ojha et al, Demonstration of low loss integrated InGaAsP/InP demultiplexer device with low polarization sensitivity, *Electron. Lett.*, vol. 29 No. 9 p. 805 (Apr. 1993).
- Paddon et al, Simple approach to Coupling in Textured Planar Waveguides, *Opt. Lett.*, vol. 23 No. 19 pp. 1529–1531 (1998).
- Preston, “Digital holographic logic”, *Pattern Recognition*, vol. 5, p. 37 (1973).
- Rantala et al, Sol-gel hybrid glass diffractive elements by direct electron-beam exposure., *Electron. Lett.* vol. 34 No. 5 pp. 455–456 (Mar. 1998).
- Song et al, Focusing-grating-coupler arrays for uniform and efficient signal distribution in a backboard optical interconnect., *Appl. Opt.*, vol. 34 No. 26 pp. 5913–5919 (Sep. 1995).
- Soole et al, High speed monolithic WDM detector for 1.5 μm fibre band., *Electron. Lett.*, vol. 31 No. 15 pp. 1276–1277 (Jul. 1995).
- Sudbo et al, Reflectivity of Integrated Optical filters Based on Elliptic Bragg Reflectors., *Lightwave Tech.*, vol. 8 No. 6 pp. 998–1006 (Jun. 1990).
- Sun et al, Demultiplexer with 120 channels and 0.29-nm channel spacing, *IEEE Photonics Tech. Lett.*, vol. 10 No. 1 pp. 90–92 (Jan. 1998).
- Taillaert, et al., Out-of-plane grating coupler for efficient butt-coupling between compact planar waveguides and single-mode fibers, *IEEE J. Quantum Electron.*, vol. 38, No. 7 (Jul. 2002).
- Takenouchi et al, Analysis of optical-signal processing using an arrayed-waveguide grating., *Optics Express*, vol. 6 No. 6 pp. 124–135 (Mar. 2000).

- Tang et al, A novel wavelength-division-demultiplexer with optical in-plane to surface-normal conversion, IEEE Photonics Tech. Lett., vol. 7 No. 8 p. 908 (Aug. 1995).
- Taylor, et al., Determination of diffraction efficiency for a second-order corrugated waveguide, IEEE J. Quantum Electron., vol. 33, No. 2 (Feb. 1997).
- International Preliminary Examination Report, mailed Feb. 23, 2004 for application PCT/US02/27288.
- International Preliminary Examination Report, mailed Jul. 26, 2004 for application PCT/US02/08199.
- International Preliminary Examination Report, mailed Oct. 6, 2006 for application PCT/US02/12869.
- International Search Report, mailed Aug. 22, 2002 for application PCT/US02/08199.
- International Search Report, mailed Jan. 2, 2003 for application PCT/US02/27288.
- International Search Report, mailed Feb. 26, 2003 for application PCT/US02/12869.
- International Search Report, mailed May 5, 2004 for application PCT/US03/27472.
- Reasons for Allowance, mailed Sep. 23, 2003 for U.S. Appl. No. 10/229,444.
- Reasons for Allowance, mailed Nov. 19, 2004 for U.S. Appl. No. 09/811,081
- Reasons for Allowance, mailed Nov. 19, 2004 for U.S. Appl. No. 10/602,327.
- Reasons for Allowance, mailed May 6, 2005 for U.S. Appl. No. 10/989,236.
- Reasons for Allowance, mailed May 19, 2005 for U.S. Appl. No. 09/843,597.
- Reasons for Allowance, mailed Jul. 22, 2005 for U.S. Appl. No. 10/923,455.
- Reasons for Allowance, mailed Aug. 5, 2005 for U.S. Appl. No. 10/794,634.
- Reasons for Allowance, mailed Sep. 15, 2005 for U.S. Appl. No. 10/998,185.
- Reasons for Allowance, mailed Sep. 15, 2005 for U.S. Appl. No. 10/857,987.
- Reasons for Allowance, mailed Sep. 16, 2005 for U.S. Appl. No. 10/842,790.
- Reasons for Allowance, mailed Dec. 5, 2005 for U.S. Appl. No. 11/239,540.
- Reasons for Allowance, mailed Jun. 12, 2006 for U.S. Appl. No. 11/055,559.
- Reasons for Allowance, mailed Aug. 3, 2006 for U.S. Appl. No. 11/361,407.
- Reasons for Allowance, mailed Oct. 13, 2006 for U.S. Appl. No. 11/062,109.
- Reasons for Allowance, mailed Dec. 19, 2006 for U.S. Appl. No. 11/532,532.
- Reasons for Allowance, mailed Jan. 24, 2007 for U.S. Appl. No. 10/898,527.
- Reasons for Allowance, mailed Jan. 25, 2007 for U.S. Appl. No. 11/383,494.
- Reasons for Allowance, mailed Mar. 20, 2007 for U.S. Appl. No. 11/423,856.
- Reasons for Allowance, mailed Aug. 20, 2007 for U.S. Appl. No. 11/685,212.
- Reasons for Allowance, mailed Oct. 22, 2008 for U.S. Appl. No. 11/334,039.
- Office Action, mailed Apr. 2, 2003 for U.S. Appl. No. 09/811,081.
- Office Action, mailed Aug. 5, 2003 for U.S. Appl. No. 09/811,081.
- Office Action, mailed Dec. 30, 2003 for U.S. Appl. No. 09/811,081.
- Office Action, mailed May 18, 2004 for U.S. Appl. No. 10/653,876.
- Office Action, mailed May 24, 2004 for U.S. Appl. No. 10/602,327.
- Office Action, mailed Jun. 15, 2004 for U.S. Appl. No. 09/811,081.
- Office Action, mailed Jun. 30, 2004 for U.S. Appl. No. 09/843,597.
- Office Action, mailed Jan. 12, 2005 for U.S. Appl. No. 09/843,597.
- Office Action, mailed Jul. 21, 2005 for U.S. Appl. No. 11/076,251.
- Office Action, mailed Mar. 10, 2006 for U.S. Appl. No. 11/055,559.
- Office Action, mailed Jun. 20, 2006 for U.S. Appl. No. 11/062,109.
- Office Action, mailed Aug. 11, 2006 for U.S. Appl. No. 10/898,527.
- Office Action, mailed Sep. 29, 2006 for U.S. Appl. No. 11/423,856.
- Office Action, mailed Jun. 27, 2007 for U.S. Appl. No. 11/676,273.
- Office Action, mailed Jan. 15, 2008 for U.S. Appl. No. 11/676,273.
- Office Action, mailed May 30, 2008 for U.S. Appl. No. 11/334,039.
- Office Action, mailed Aug. 8, 2008 for U.S. Appl. No. 11/676,273.
- JP Office Action, mailed Aug. 15, 2008 for application 2003-524057.
- Office Action, mailed Apr. 7, 2009 for U.S. Appl. No. 11/676,273.
- Alavie et al., "A Multiplexed Bragg Grating Fiber Laser Sensor System", IEEE Photonics Tech. Lett., vol. 5 No. 9 pp. 1112-1114 (Sep. 1993).
- Avrutsky et al., "Multiwavelength Diffraction and Apodization Using Binary Superimposed Gratings", IEEE Photonics Tech. Lett., vol. 10 No. 6 pp. 839-841 (Jun. 1998).
- Babbitt et al., "Optical Waveform Processing Routing with Structured Surface Gratings", Opt. Commun., vol. 148 pp. 23-26 (1998).
- Babbitt et al., "Spatial Routing of Optical Beams Through Time-Domain Spatial-Spectral Filtering", Opt. Lett., vol. 20 No. 8 pp. 910-912 (Apr. 1995).
- Office Action, issued in U.S. Appl. No. 12/408,039, mailed May 7, 2010.
- Office Action, issued in EP Patent Application No. 02 796 438.6, mailed Apr. 27, 2010.
- Tien et al., "Use of Concentric-Arc Grating as a Thin-Film Spectrographic for Guided Waves" Appl. Phys. Lett. vol. 37 No. 6 pp. 524-525 (Sep. 15, 1980).
- Ura et al., "Integrated Optic Wavelength Demultiplexer Using a Coplanar Grating Lens", Applied Optics, vol. 29 No. 9 pp. 1369-1373 (Mar. 20, 1990).
- Wang et al., "Theory and Applications of Guided-Mode Resonance Filters", Applied Optics, vol. 32 No. 14 pp. 2606-2613 (May 10, 1993).
- Wang et al., "Wavelength-Division Multiplexing and Demultiplexing on Locally Sensitized Single-Mode Polymer Microstructure Waveguides", Optics Letters, vol. 15, No. 7, pp. 363-365 (Apr. 1, 1990).

- Wang et al., "Five-Channel Polymer Waveguide Wavelength Division Demultiplexer for the Near Infrared", IEEE Photonics Technology Letters, vol. 3 No. 1 pp. 36-38 (Jan. 1991).
- Wiesman et al., "Apodized Surface-Corrugated Gratings with Varying Duty Cycles", IEEE Photonics Technology Letters, vol. 12 No. 6 pp. 639-641 (Jun. 2000).
- Wu et al., "Simplified Coupled-Wave Equations for Cylindrical Waves in Circular Grating Planar Waveguides", Journal of Lightwave Technology, vol. 10 No. 11 pp. 1575-1589 (Nov. 1992).
- Office Action mailed Oct. 9, 2007 for U.S. Appl. No. 11/280,876.
- Office Action mailed Jul. 1, 2008 for U.S. Appl. No. 11/280,876.
- Office Action mailed Mar. 5, 2009 for U.S. Appl. No. 11/280,876.
- Notice of Allowability mailed Jun. 25, 2009 for U.S. Appl. No. 11/280,876.
- Mossberg, "Planar Holographic Optical Processing Devices", Optics Letters, USA, Optical Society of America, vol. 26, No. 7, pp. 414-416 (Apr. 1, 2001).
- Mossberg, "Time-Domain Frequency-Selective Optical Data Storage", Optics Letters vol. 7 No. 2, pp. 77-79, 1982.
- Marhic, "Coherent Optical CDMA Networks", Journal of Lightwave Technology vol. 11 No. 5, pp. 854-864, 1993.
- Capmany, et al., "Autocorrelation Pulse Distortion in Optical Fiber CDMA Systems Employing Ladder Networks", Journal of Lightwave Technology vol. 17 No. 4, p. 570, 1999.
- Cornwell, et al., "Experimental Demonstration of Coherent Coding of Picosecond Pulses", Electronics Letters vol. 34 No. 2, pp. 204-2-5, 1998.
- Sampson, et al., "Photonic CDMA by Coherent Matched Filtering Using Time-Addressed Coding in Optical Ladder Networks", Journal of Lightwave Technology vol. 12 No. 11, pp. 2001-2010, Nov. 1994.
- Chang, et al., "Fiber-Optic Ladder Networks for Inverse Decoding Coherent CDMA", Journal of Lightwave Technology vol. 10 No. 12, pp. 1952-1962, Dec. 1992.
- Weiner, et al., "Femtosecond Spectral Holography" IEEE Journal of Quantum Electronics vol. 28 No. 10, pp. 2251-2261, 1992.
- Mazurenko, Y.T., "Time-Domain Fourier Transform Holography and Possible Applications in Signal Processing", Optical Engineering vol. 31 No. 4 pp. 739-749 Apr. 1992.
- Mazurenko, Y.T., "Holography of Wave Packets", Applied Physics B 50 pp. 101-114 (1990).
- Mazurenko, Yu T., "Reconstruction of a Time-Varying Wavefront by Multibeam Interference", Sov. Tech. Phys. Lett. 10, 228 (1984).
- Kato, et al., "PLC Hybrid Integration Technology and Its Application to Photonics Components", vol. 6 No. 1, pp. 4-13, Jan./Feb. 2000.
- Fathallah, et al., "Passive Optical Fast Frequency-Hop CDMA Communication System", Journal of Lightwave Technology, vol. 17 No. 3, pp. 397-405, Mar. 1999.
- Chen, et al., "Wavelength-Encoding/Temporal-Spreading Optical Code Division Multiple-Access System with In-Fiber Moiré Gratings", Applied Optics vol. 38 No. 21, pp. 4500-4508 (1999).
- Chen, et al., "Applications of Ultrashort Pulse Propagation in Bragg Gratings for Wavelength-Division Multiplexing and Code-Division Multiple Access", IEEE Journal of Quantum Electronics vol. 34 No. 11, pp. 2117-2129, Nov. 1998.
- Merkel, et al., "Optical Coherent Transient True-Time Delay Regenerator", Optics Letters vol. 21 No. 15, pp. 1102-1104, Aug. 1, 1996.
- Bai, et al., "Real-Time Optical Waveform Convolver/Cross Correlator", Applied Physics Letters vol. 45 No. 7, pp. 714-716 (1984).
- Mossberg, et al., "Lithographic Holography in Planar Waveguides", SPIE International Technical Group Newsletter vol. 12 No. 2 Nov. 2001.
- Salehi, et al., "Coherent Ultrashort Light Pulse Code-Division Multiple Access Communication Systems", Journal of Lightwave Technology vol. 8, pp. 479-491 Mar. 1990.
- Notice of Allowance mailed Oct. 30, 2009 for U.S. Appl. No. 12/403,281.
- Notice of Allowance mailed Feb. 10, 2010 for U.S. Appl. No. 12/367,159.
- Notice of Allowance mailed Jan. 28, 2010 for U.S. Appl. No. 11/280,876.
- Notice of Allowance mailed Jan. 8, 2010 for U.S. Appl. No. 11/676,273.
- Office Action mailed Dec. 10, 2009 for U.S. Appl. No. 12/408,039.
- Notice of Allowance mailed Mar. 2, 2010 for U.S. Appl. No. 12/403,281.
- Notice of Allowance mailed Feb. 5, 2010 for U.S. Appl. No. 11/676,273.
- Japanese Office Action mailed Mar. 18, 2010 for application 2003-524057.

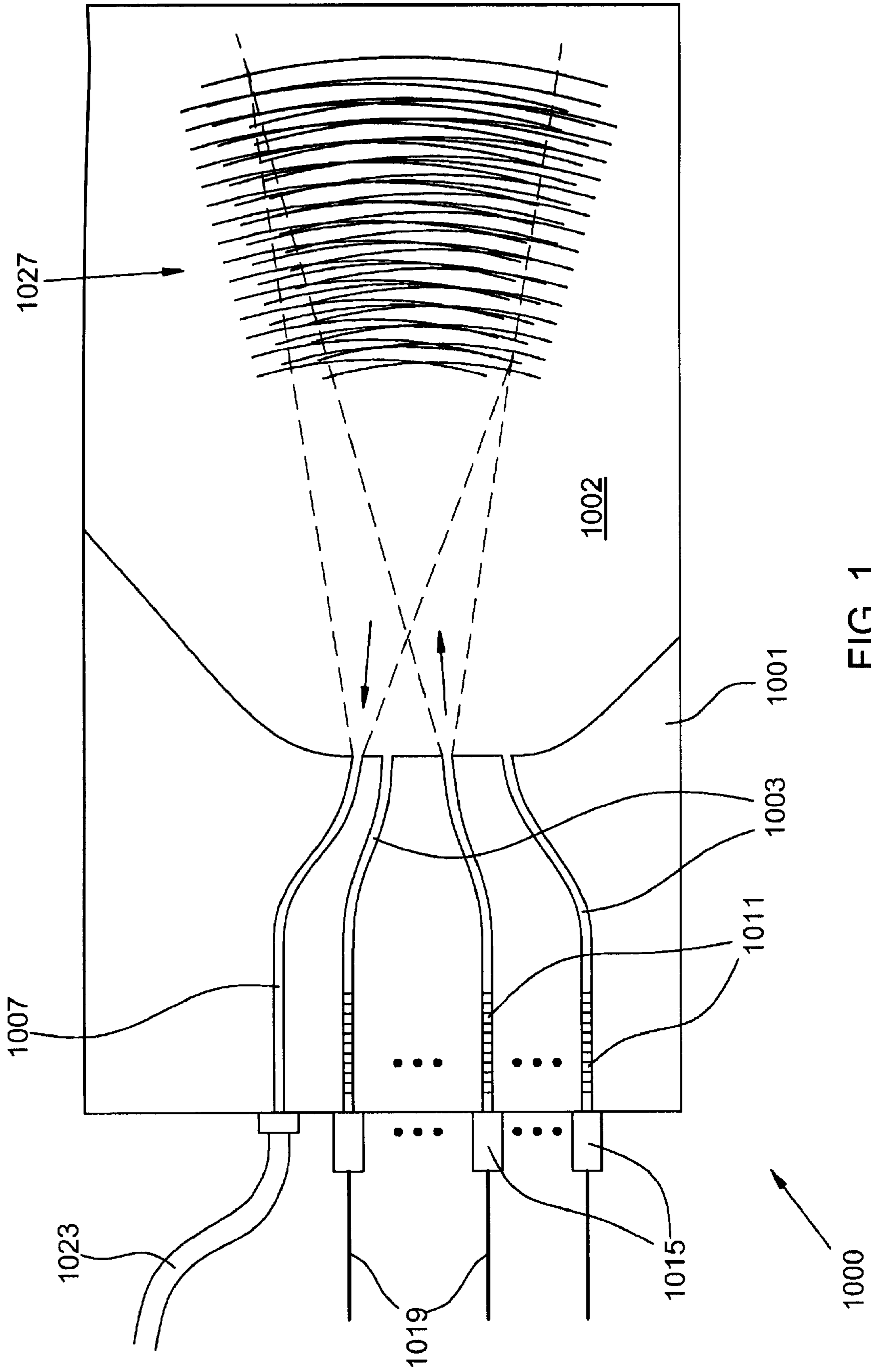


FIG. 1

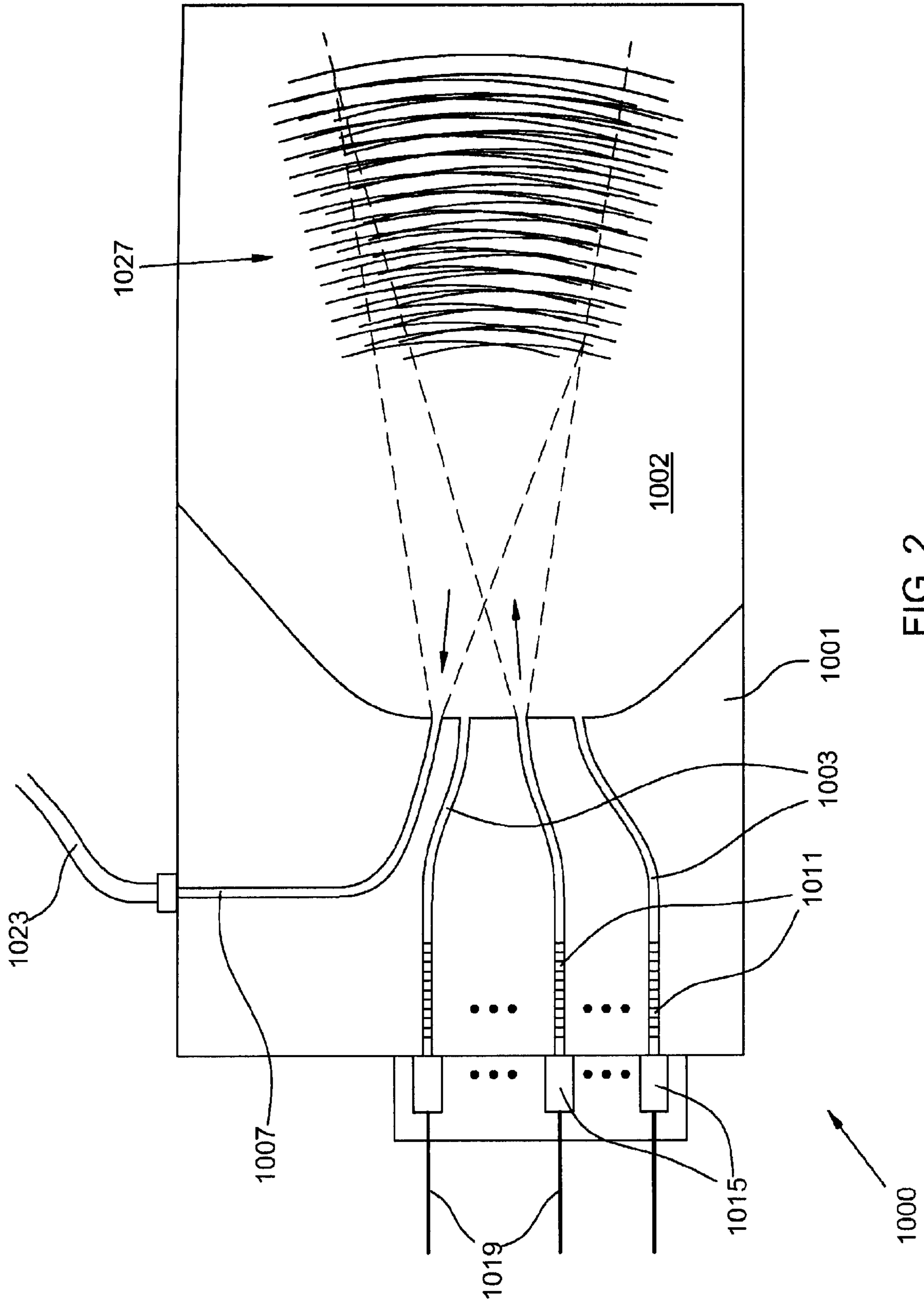


FIG. 2

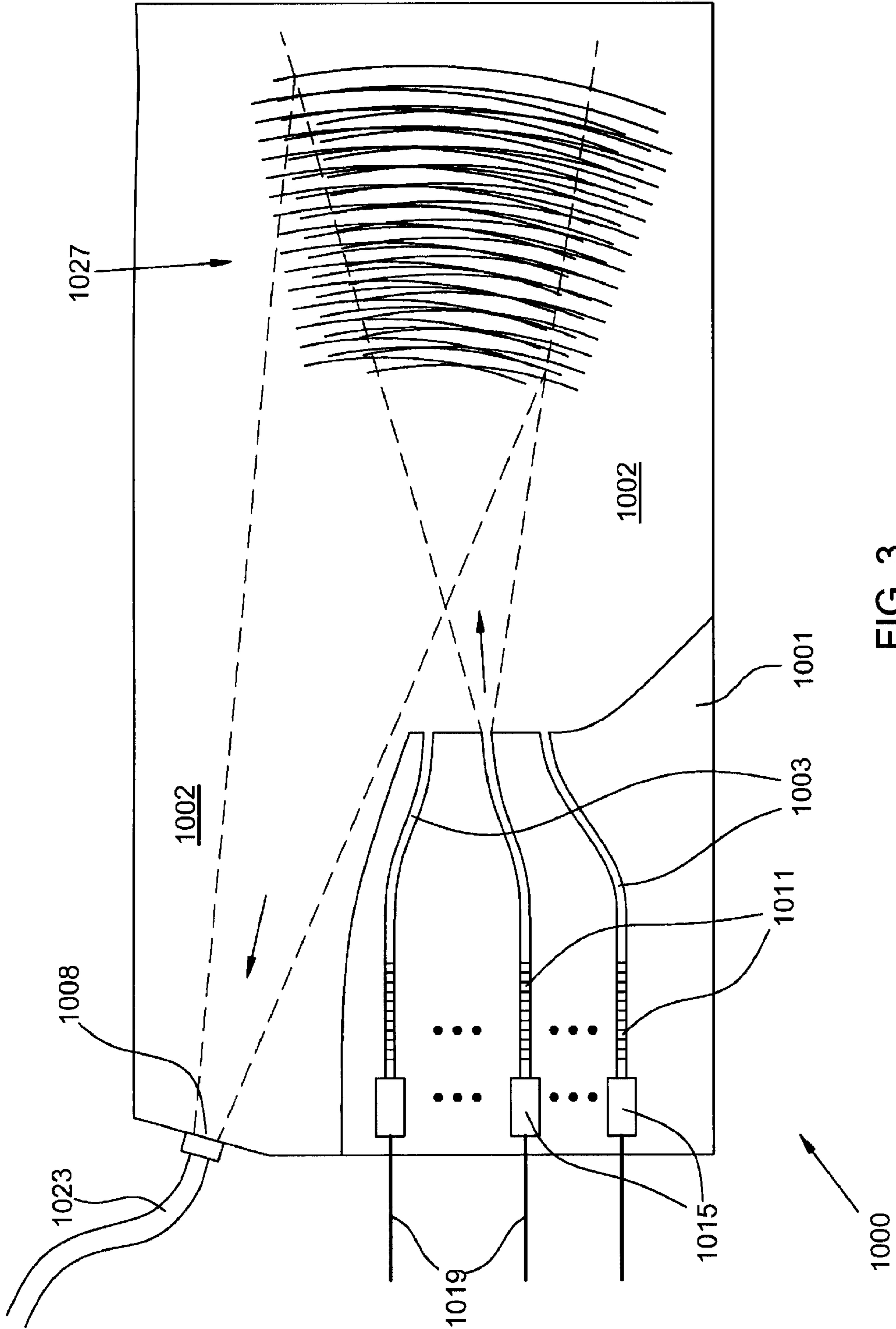


FIG. 3

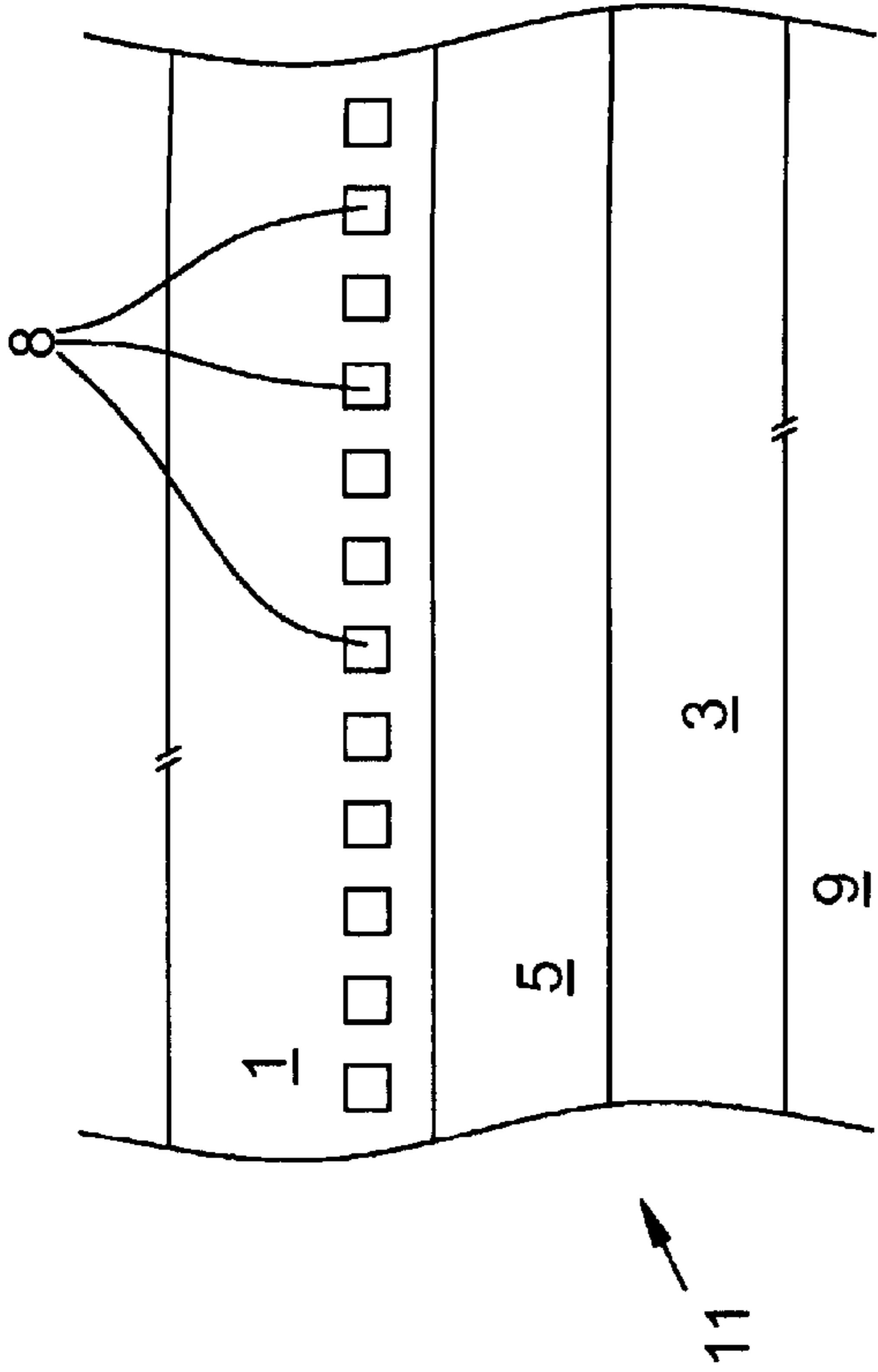


FIG. 4A

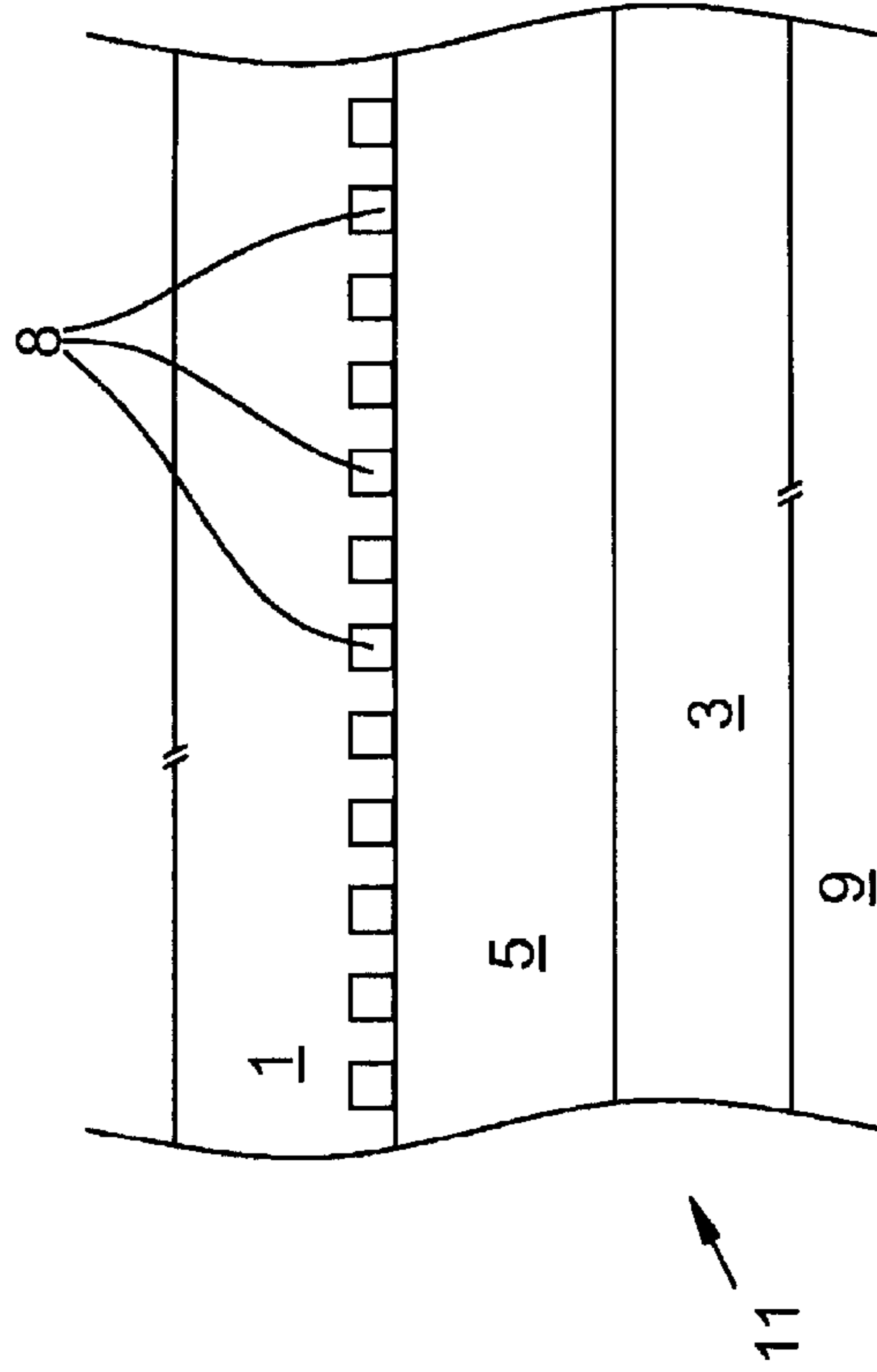


FIG. 4B

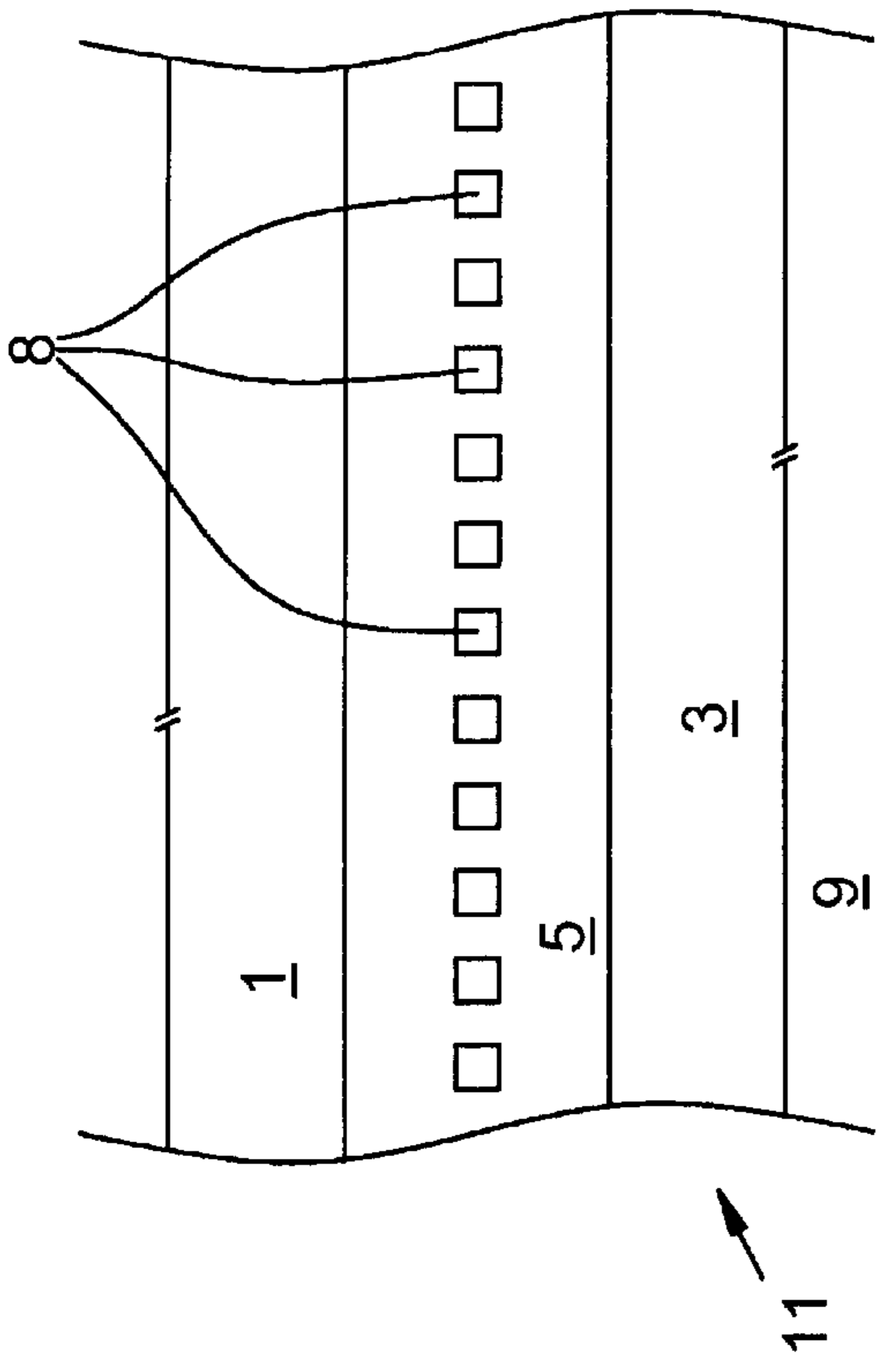


FIG. 4C

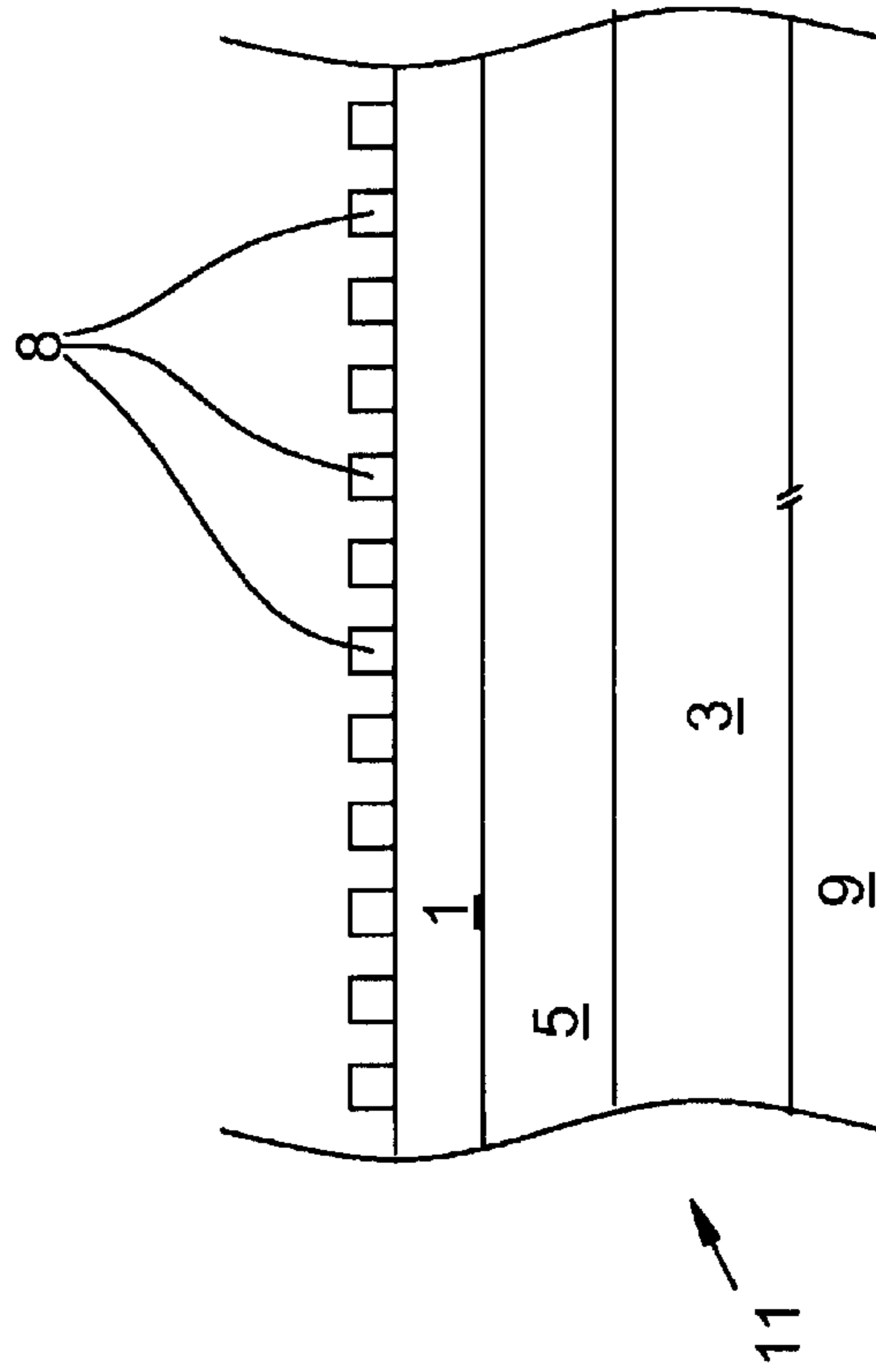


FIG. 4D

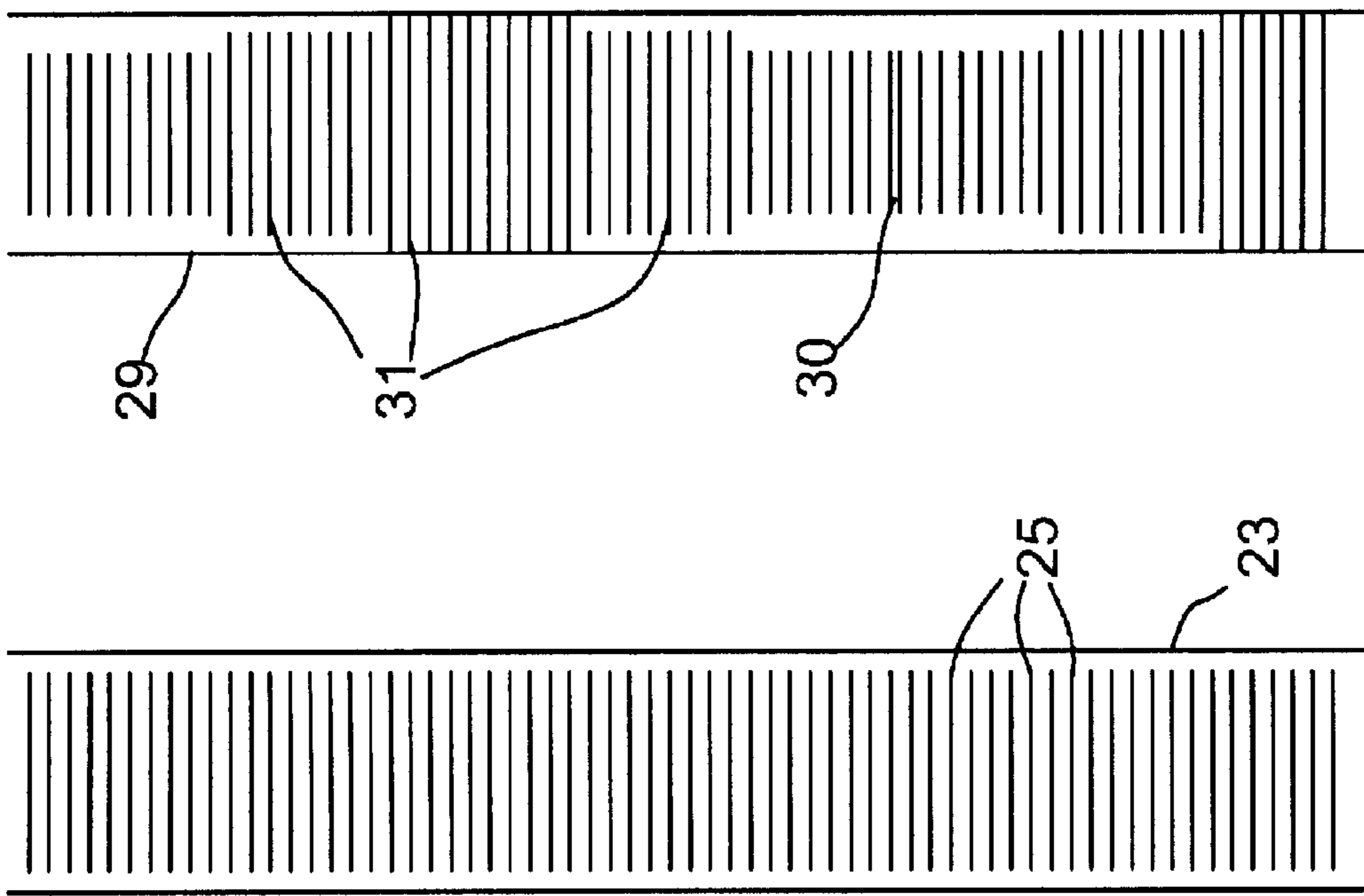


FIG. 5A

FIG. 5B

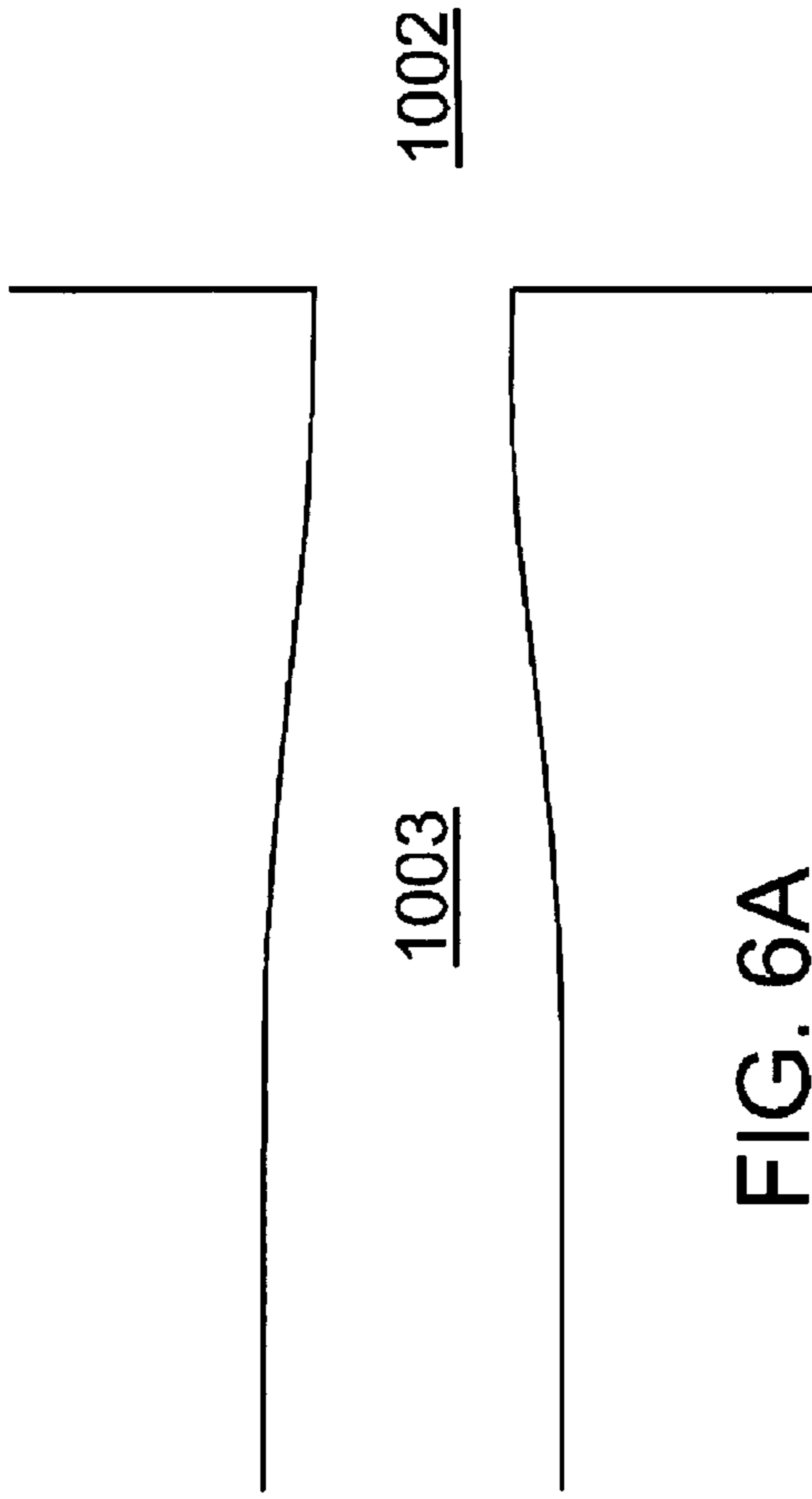


FIG. 6A

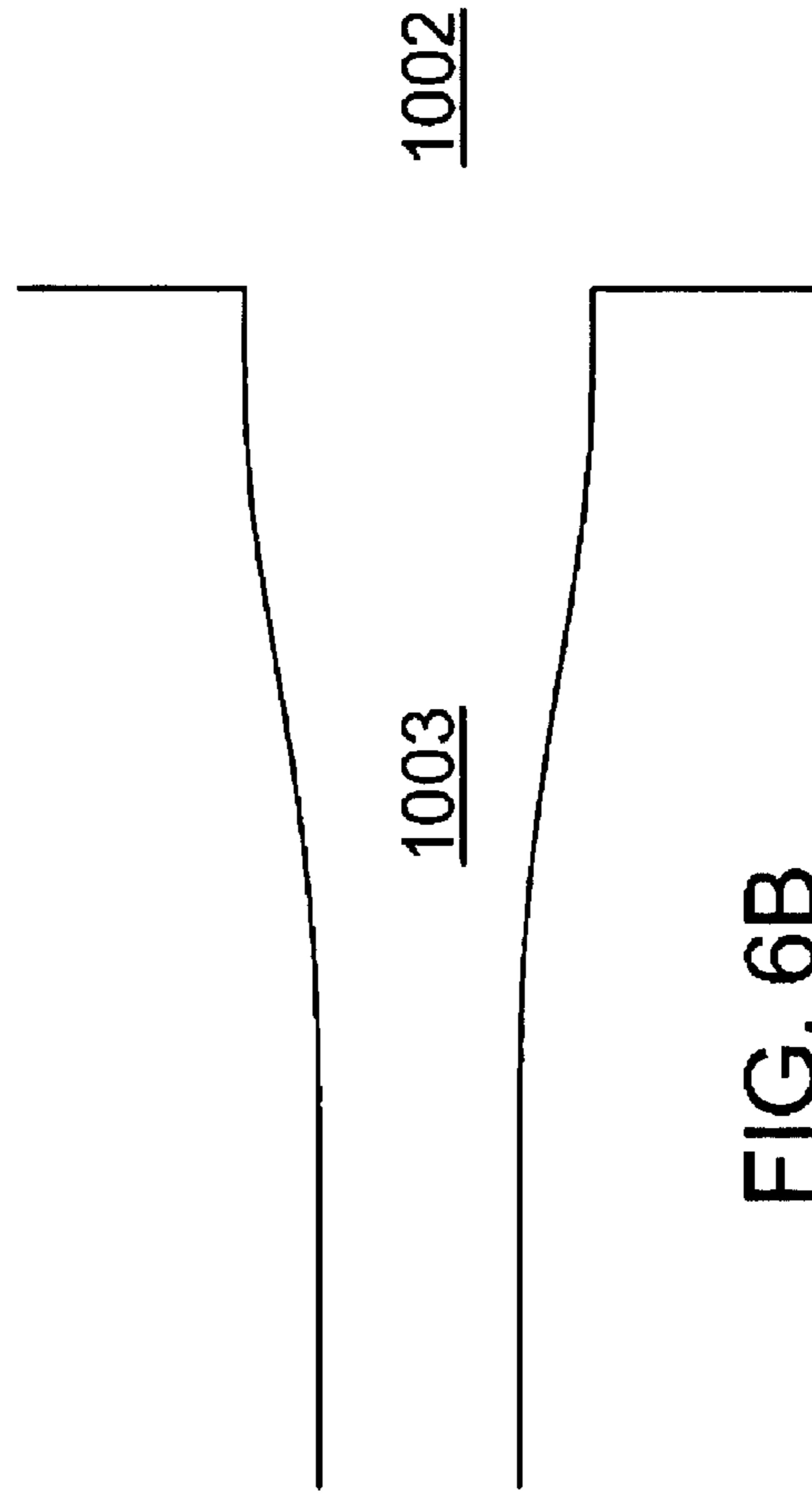


FIG. 6B

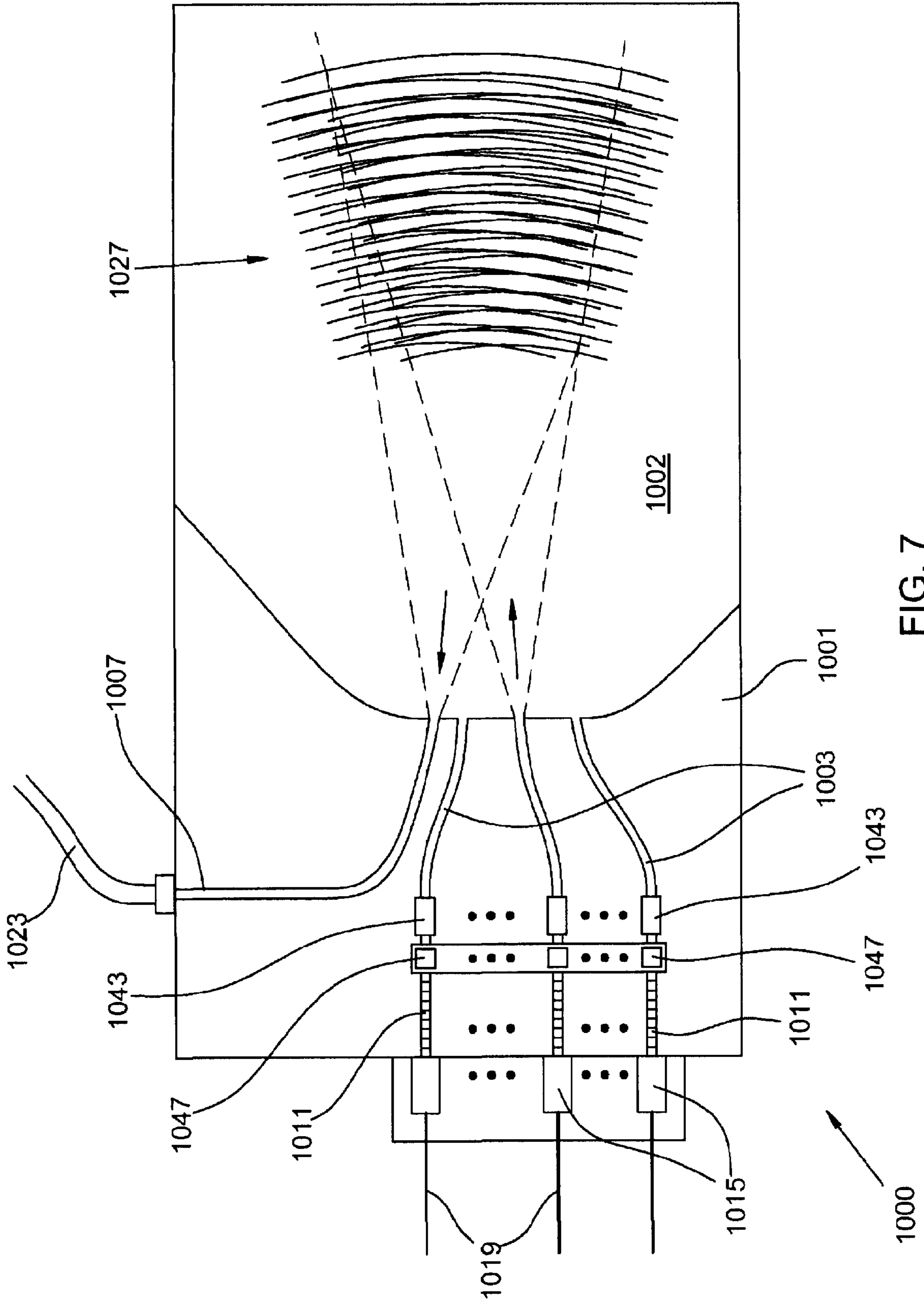


FIG. 7

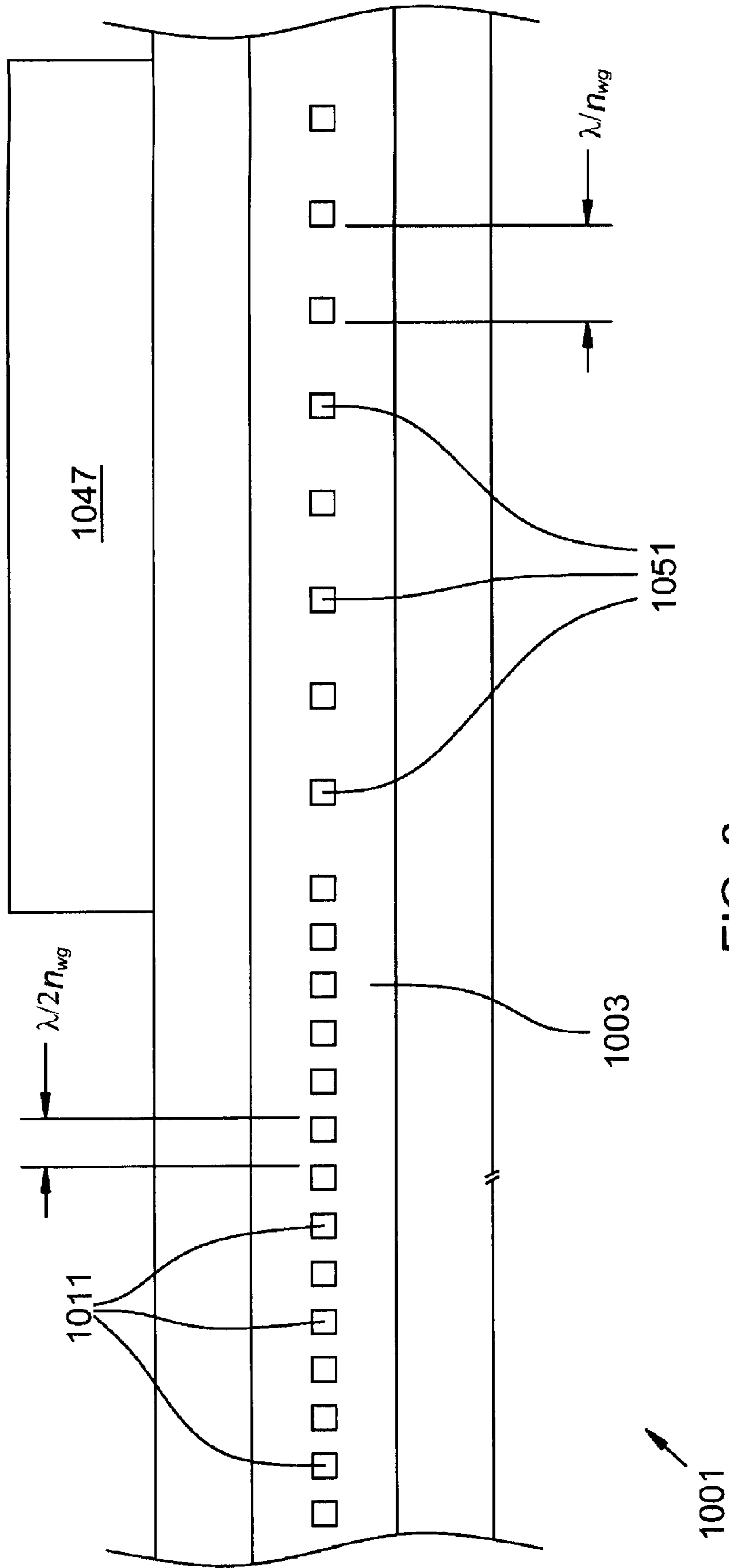


FIG. 8

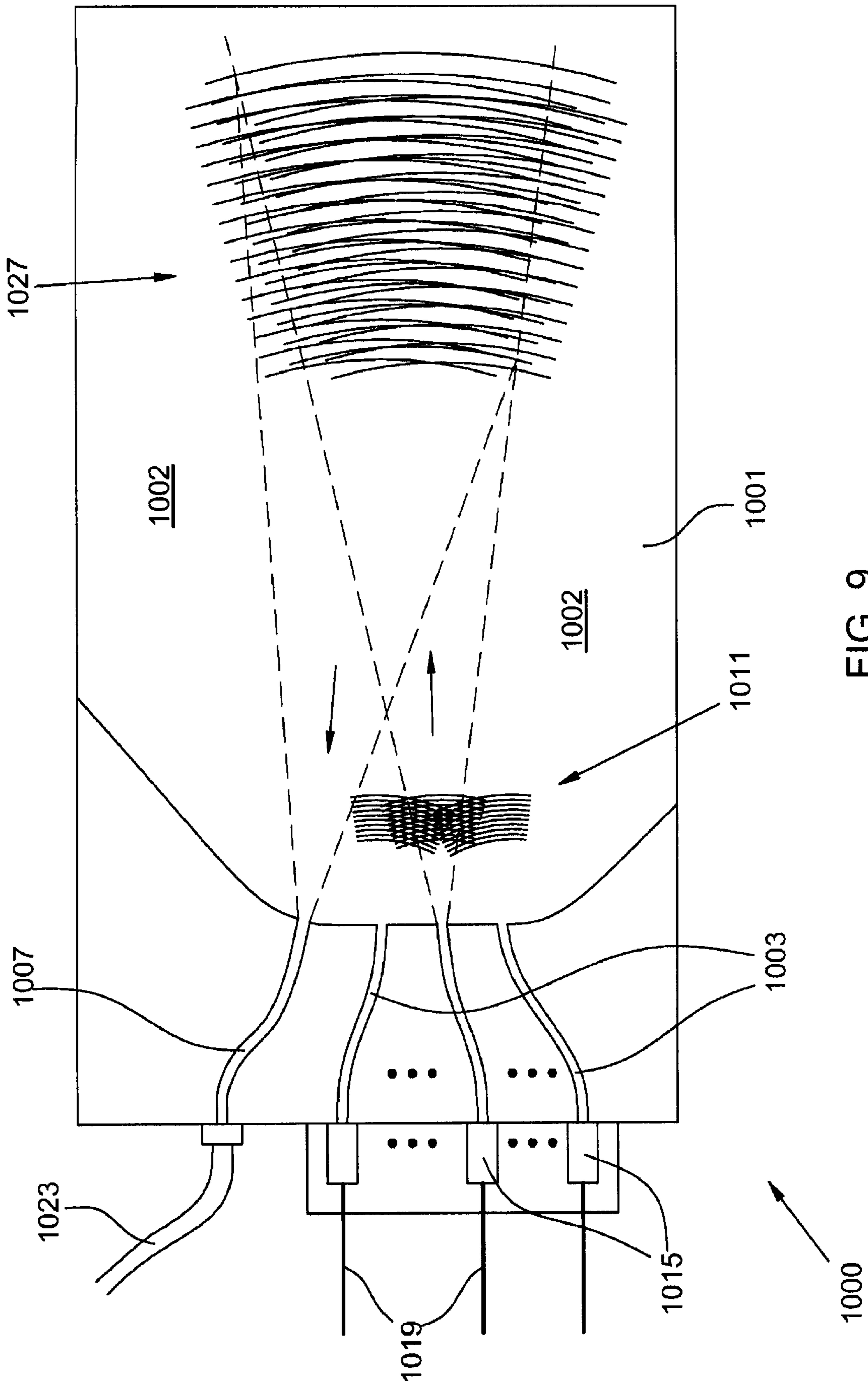


FIG. 9

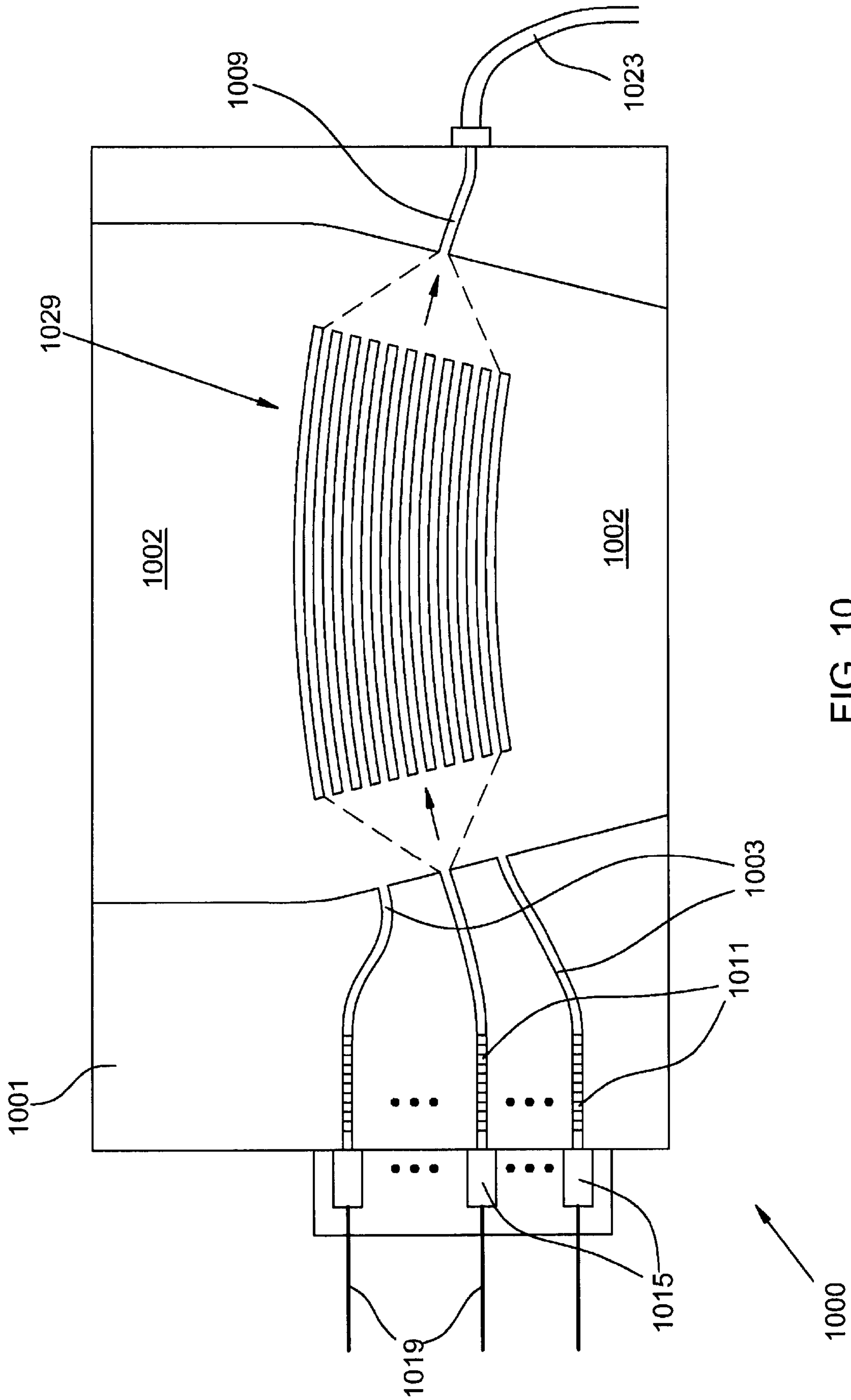


FIG. 10

MULTIPLE WAVELENGTH OPTICAL SOURCE

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

RELATED APPLICATIONS

This application is a continuation of U.S. non-provisional application Ser. No. 10/923,455 filed Aug. 21, 2004 (now U.S. Pat. No. 7,054,517), which in turn claims benefit of U.S. provisional App. No. 60/497,410 filed Aug. 21, 2003, each of said provisional and non-provisional applications being hereby incorporated by reference as if fully set forth herein.

U.S. application Ser. No. 10/923,455 is also a continuation-in-part of U.S. non-provisional application Ser. No. 10/653,876 filed Sep. 2, 2003 (now U.S. Pat. No. 6,829,417), which is in turn a continuation-in-part of U.S. non-provisional application Ser. No. 10/229,444 filed Aug. 27, 2002 (now U.S. Pat. No. 6,678,429), each of said non-provisional applications being hereby incorporated by reference as if fully set forth herein. U.S. application Ser. No. 10/229,444 in turn claims benefit of U.S. provisional App. No. 60/315,302 filed Aug. 27, 2001 and U.S. provisional App. No. 60/370,182 filed Apr. 4, 2002, each of said provisional applications being hereby incorporated by reference as if fully set forth herein.

U.S. application Ser. No. 10/923,455 is also a continuation-in-part of U.S. non-provisional application Ser. No. 09/811,081 filed Mar. 16, 2001 (now U.S. Pat. No. 6,879,441), and a continuation-in-part of U.S. non-provisional application Ser. No. 09/843,597 filed Apr. 26, 2001 (now U.S. Pat. No. 6,965,464), application Ser. No. 09/843,597 in turn being a continuation-in-part of said application Ser. No. 09/811,081. Said application Ser. No. 09/811,081 in turn claims benefit of: 1) U.S. provisional App. No. 60/190,126 filed Mar. 16, 2000; 2) U.S. provisional App. No. 60/199,790 filed Apr. 26, 2000; 3) U.S. provisional App. No. 60/235,330 filed Sep. 26, 2000; and 4) U.S. provisional App. No. 60/247,231 filed Nov. 10, 2000. Each of said provisional and non-provisional applications is hereby incorporated by reference as if fully set forth herein.

BACKGROUND

The field of the present invention relates to optical devices incorporating distributed optical structures. In particular, a multiple wavelength optical source incorporating at least one distributed optical structure is disclosed herein.

Distributed optical structures employed in the multiple wavelength optical sources disclosed or claims herein may be implemented with a variety of adaptations, such as those described in:

U.S. non-provisional application Ser. No. 09/811,081 entitled "Holographic spectral filter" filed Mar. 16, 2001 in the name of Thomas W. Mossberg (now U.S. Pat. No. 6,879,441);

U.S. non-provisional application Ser. No. 09/843,597 entitled "Optical processor" filed Apr. 26, 2001 (now U.S. Pat. No. 6,965,464);

U.S. non-provisional application Ser. No. 10/229,444 entitled "Amplitude and phase control in distributed optical structures" filed Aug. 27, 2002 in the names of Thomas W. Mossberg and Christoph M. Greiner (now U.S. Pat. No. 6,678,429);

U.S. non-provisional application Ser. No. 10/602,327 entitled "Holographic spectral filter" filed Jun. 23, 2003 in the name of Thomas W. Mossberg (now U.S. Pat. No. 6,859,318);

U.S. non-provisional application Ser. No. 10/653,876 entitled "Amplitude and phase control in distributed optical structures" filed Sep. 2, 2003 in the names of Thomas W. Mossberg and Christoph M. Greiner (now U.S. Pat. No. 6,829,417);

U.S. non-provisional application Ser. No. 10/740,194 entitled "Optical multiplexing device" filed Dec. 17, 2003 in the names of Dmitri Iazikov, Thomas W. Mossberg, and Christoph M. Greiner;

U.S. non-provisional application Ser. No. 10/794,634 entitled "Temperature-compensated planar waveguide optical apparatus" filed Mar. 5, 2004 in the names of Dmitri Iazikov, Thomas W. Mossberg, and Christoph M. Greiner (now U.S. Pat. No. 6,985,656);

U.S. non-provisional application Ser. No. 10/798,089 entitled "Optical structures distributed among multiple optical waveguides" filed Mar. 10, 2004 in the names of Christoph M. Greiner, Thomas W. Mossberg, and Dmitri Iazikov (now U.S. Pat. No. 6,823,115);

U.S. non-provisional application Ser. No. 10/842,790 entitled "Multimode planar waveguide spectral filter" filed May 11, 2004 in the names of Thomas W. Mossberg, Christoph M. Greiner, and Dmitri Iazikov (now U.S. Pat. No. 6,987,911);

U.S. non-provisional application Ser. No. 10/857,987 entitled "Optical waveform recognition and/or generation and optical switching" filed May 29, 2004 in the names of Lawrence D. Brice, Christoph M. Greiner, Thomas W. Mossberg, and Dmitri Iazikov (now U.S. Pat. No. 6,990,276); and

U.S. non-provisional application Ser. No. 10/898,527 entitled "Distributed optical structures with improved diffraction efficiency and/or improves optical coupling" filed Jul. 22, 2004 in the names of Dmitri Iazikov, Christoph M. Greiner, and Thomas W. Mossberg.

Each of these applications and patents is hereby incorporated by reference as if fully set forth herein.

SUMMARY

A method for forming an optical apparatus comprises: forming a planar optical waveguide; forming at least one set of locking diffractive elements in or on the planar optical waveguide; forming means for routing an optical signal corresponding to at least one said set of locking diffractive elements; and positioning a laser corresponding to at least one said set of locking diffractive elements. The planar optical waveguide substantially confines in at least one transverse spatial dimension optical signals propagating therein. Each laser is positioned so as to launch a corresponding laser optical signal into the planar optical waveguide so that the corresponding laser optical signal is successively incident on the diffractive elements of the corresponding locking diffractive element set. Each locking diffractive element set routes within the planar optical waveguide a fraction of the corresponding laser optical signal back to the corresponding laser, with a corresponding locking transfer function, as a corresponding locking optical feedback signal, thereby substantially restricting the corresponding laser optical signal to a corresponding laser operating wavelength range determined at least in part by the corresponding locking transfer function of the corresponding locking diffractive element set.

Each corresponding routing means routes within the planar optical waveguide, between the corresponding laser and a corresponding output optical port with a corresponding routing transfer function, at least a portion of that fraction of the corresponding laser optical signal that is transmitted by the corresponding locking diffractive element set. The optical apparatus may comprise multiple lasers, multiple corresponding locking diffractive element sets, and multiple corresponding routing means, thereby comprising a multiple-wavelength optical source.

The locking diffractive element sets may be formed in corresponding channel waveguides formed in the planar optical waveguide, or may be formed in one or more slab waveguide regions of the planar optical waveguide. The multiple corresponding routing means may comprise corresponding routing diffractive element sets formed in a slab waveguide region of the planar optical waveguide, or may comprise an arrayed waveguide grating formed in the planar optical waveguide. The multiple lasers may be individually assembled with the planar waveguide, may be assembled with the planar waveguide as an integrated laser array, or may be integrated directly into the planar waveguide. The corresponding laser output signals may be routed to a single output port or to multiple output ports.

Objects and advantages pertaining to diffractive element sets, planar optical waveguides, or multiple-wavelength optical sources may become apparent upon referring to the disclosed embodiments as illustrated in the drawings or disclosed in the following written description or appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates schematically a planar waveguide with multiple locking diffractive element sets and multiple routing diffractive element sets, and multiple lasers.

FIG. 2 illustrates schematically a planar waveguide with multiple locking diffractive element sets and multiple routing diffractive element sets, and multiple lasers.

FIG. 3 illustrates schematically a planar waveguide with multiple locking diffractive element sets and multiple routing diffractive element sets, and multiple lasers.

FIGS. 4A–4D are schematic cross-sections of diffractive elements in a planar waveguide.

FIGS. 5A–5B are schematic top views of diffractive elements in a planar waveguide.

FIGS. 6A–6B illustrate schematically termination of a channel waveguide core in a planar waveguide.

FIG. 7 illustrates schematically a planar waveguide with multiple locking diffractive element sets and multiple routing diffractive element sets, multiple photodetectors, multiple variable optical attenuators, and multiple lasers.

FIG. 8 is a schematic cross-section of diffractive elements in a planar waveguide.

FIG. 9 illustrates schematically a planar waveguide with multiple locking diffractive element sets and multiple routing diffractive element sets, and multiple lasers.

FIG. 10 illustrates schematically a planar waveguide with multiple locking diffractive element sets and an arrayed-waveguide grating, and multiple lasers.

The embodiments shown in the Figures are exemplary, and should not be construed as limiting the scope of the present disclosure and/or appended claims.

DETAILED DESCRIPTION OF EMBODIMENTS

An optical apparatus according to the present disclosure comprises a planar optical waveguide having at least one set

of diffractive elements. The planar optical waveguide substantially confines in at least one transverse dimension optical signals propagating therein, and is generally formed on or from a substantially planar substrate of some sort. The confined optical signals typically propagate as transverse optical modes supported or guided by the planar optical waveguide. These optical modes are particular solutions of the electromagnetic field equations in the space occupied by the waveguide. The planar optical waveguide may comprise a slab waveguide, substantially confining in one transverse dimension an optical signal propagating in two dimensions therein, or may comprise a channel waveguide, substantially confining in two transverse dimension an optical signal propagating therein. It should be noted that the term “planar waveguide” is not used consistently in the literature; for the purposes of the present disclosure and/or appended claims, the terms “planar optical waveguide” and “planar waveguide” are intended to encompass both slab and channel optical waveguides.

The planar waveguide typically comprises a core surrounded by lower-index cladding (often referred to as upper and lower cladding, or first and second cladding; these may or may not comprise the same materials). The core is fabricated using one or more dielectric, semiconductor, or other materials substantially transparent over a desired operating wavelength range. In some instances one or both claddings may be vacuum, air, or other ambient atmosphere. More typically, one or both claddings comprise material layers, with the cladding refractive indices n_1 and n_2 typically being smaller than the core refractive index n_{core} . (In some instances in which short optical paths are employed and some degree of optical loss can be tolerated, the cladding indices might be larger than the core index while still enabling the planar waveguide to support guided, albeit lossy, optical modes.) A planar waveguide may support one or more transverse modes, depending on the dimensions and refractive indices of the core and cladding. A wide range of material types may be employed for fabricating a planar waveguide, including but not limited to glasses, polymers, plastics, semiconductors, combinations thereof, or functional equivalents thereof. The planar waveguide may be secured to a substrate, for facilitating manufacture, for mechanical support, or for other reasons. A planar waveguide typically supports or guides one or more optical modes characterized by their respective amplitude variations along the confined dimension.

The set of diffractive elements of the planar optical waveguide may also be referred to as: a set of holographic elements; a volume hologram; a distributed reflective element, distributed reflector, or distributed Bragg reflector (DBR); a Bragg reflective grating (BRG); a holographic Bragg reflector (HBR); a directional photonic-bandgap structure; a mode-selective photonic crystal; or other equivalent terms of art. Each diffractive element of the set diffracts, reflects, scatters, or otherwise redirects a portion of an incident optical signal (said process hereinafter simply referred to as diffraction). Each diffractive element of the set typically comprises some suitable alteration of the planar waveguide (ridge, groove, index modulation, density modulation, and so on), and is spatially defined by a virtual one- or two-dimensional curvilinear diffractive element contour. The curvilinear shape of the contour may be configured to impart desired spatial characteristics onto the diffracted portion of the optical signal. The curvilinear contours may be smoothly curved, or may be approximated by multiple short, substantially linear contour segments (in some instances dictated by fabrication constraints). Implementa-

tion of a diffractive element with respect to its virtual contour may be achieved in a variety of ways, including those disclosed in the references cited hereinabove. Each curvilinear diffractive element is shaped to direct or route its diffracted portion of the optical signal between input and output optical ports. The relative spatial arrangement (e.g. longitudinal spacing) of the diffractive elements of the set, and the relative amplitude diffracted from each diffractive element of the set, yield desired spectral or temporal characteristics for the overall diffracted optical signal routed between the input and output optical ports. It should be noted that optical ports (input or output) may be defined structurally (for example, by an aperture, waveguide, fiber, lens, laser or other optical source, or other optical component) or functionally (i.e., by a spatial location, size, convergence, divergence, collimation, or propagation direction), or both structurally and functionally. In some instances a pair of corresponding input and output ports may comprise the same optical port (i.e., the diffracted portion of the optical signal is retro-reflected). In some instances the input and output ports may be interchanged (i.e., the action of the diffractive element set is symmetric). For a single-mode planar waveguide, such a set of diffractive elements may be arranged to yield an arbitrary spectral/temporal transfer function (i.e., diffracted amplitude and phase as functions of wavelength). In a multimode planar waveguide, modal dispersion or mode-to-mode coupling of diffracted portions of the optical signal may limit the range of spectral/temporal transfer functions that may be implemented.

The curvilinear diffractive elements of the set (or equivalently, their corresponding contours) are spatially arranged with respect to one another so that the corresponding portions of the optical signal diffracted by each element interfere with one another at the output optical port, so as to impart desired spectral or temporal characteristics onto the portion of the optical signal collectively diffracted from the set of diffractive elements and routed between the input and output optical ports. The diffractive elements in the set are arranged so that an input optical signal, entering the planar waveguide through an input optical port, is successively incident on diffractive elements of the set. For the purposes of the present disclosure or appended claims, "successively incident" shall denote a situation wherein a wavevector at a given point on the wavefront of an optical signal (i.e., a wavefront-normal vector) traces a path (i.e., a "ray path") through the diffractive element set that successively intersects the virtual contours of diffractive elements of the set. Such wavevectors at different points on the wavefront may intersect a given diffractive element virtual contour at the same time or at differing times; in either case the optical signal is considered "successively incident" on the diffractive elements. A fraction of the incident amplitude is diffracted by a diffractive element and the remainder is transmitted and incident on another diffractive element, and so on successively through the set of diffractive elements. The diffractive elements may therefore be regarded as spaced substantially longitudinally along the propagation direction of the incident optical signal, and a given spatial portion of the wavefront of such a successively incident optical signal therefore interacts with many diffractive elements of the set. (In contrast, the diffractive elements of a thin diffraction grating, e.g. the grating lines of a surface grating, may be regarded as spaced substantially transversely across the wavefront of a normally incident optical signal, and a given spatial portion of the wavefront of such a signal therefore interacts with only one or at most a few adjacent diffractive elements).

The set of diffractive elements provides dual functionality, spatially routing an optical signal between an input optical port and an output optical port, while at the same time acting to impart a spectral/temporal transfer function onto the input optical signal to yield an output optical signal. The curvilinear diffractive elements may be designed (by computer generation, for example) so as to provide optimal routing, imaging, or focusing of the optical signal between an input optical port and a desired output optical port, thus reducing or minimizing insertion loss. Simple curvilinear diffractive elements (segments of circles, ellipses, parabolas, hyperbolas, and so forth), if not optimal, may be employed as approximations of fully optimized contours. Numerous short, substantially linear segments may be employed to approximate a smoothly curved contour. A wide range of fabrication techniques may be employed for forming the diffractive element set, and any suitable technique(s) may be employed while remaining within the scope of the present disclosure and/or appended claims. Particular attention is called to design and fabrication techniques disclosed in the references cited hereinabove. The following are exemplary only, and are not intended to be exhaustive.

Diffractive elements may be formed lithographically on the surface of a planar optical waveguide, or at one or both interfaces between core and cladding of a planar optical waveguide. Diffractive contours may be formed lithographically in the interior of the core layer or a cladding layer of the planar optical waveguide using one or more spatial lithography steps performed after an initial deposition of layer material. Diffractive elements may be formed in the core or cladding layers by projecting ultraviolet light or other suitable radiation through an amplitude or phase mask so as to create an interference pattern within the planar waveguide (fabricated at least in part with suitably sensitive material) whose fringe contours match the desired diffractive element contours. Alteration of the refractive index by exposure to ultraviolet or other radiation results in index-modulated diffractive elements. The mask may be zeroth-order-suppressed according to methods known in the art, including the arts associated with fabrication of fiber Bragg gratings. The amplitude or phase mask may be produced lithographically via laser writer or e-beam, it may be interferometrically formed, or it may be formed by any other suitable technique. In instances where resolution is insufficient to produce a mask having required feature sizes, a larger scale mask may be produced and reduced to needed dimensions via photoreduction lithography, as in a stepper, to produce a mask at the needed scale. Diffractive elements may be formed by molding, stamping, impressing, embossing, or other mechanical processes. A phase mask may be stamped onto the core or cladding surface followed by optical exposure to create diffractive elements throughout the core and or cladding region. The optical or UV source used to write the diffractive elements in this case should have a coherence length comparable or longer than the distance from the stamped phase mask to the bottom of the core region. Stamping of the phase mask directly on the device may simplify alignment of diffractive elements with ports or other device components, especially when those components may be formed in the same or another stamping process. Many approaches to the creation of refractive index modulations or gratings are known in the art and may be employed in the fabrication of diffractive element sets.

Irradiation-produced refractive index modulations or variations for forming diffractive elements will optimally fall in a range between about 10^{-4} and about 10^{-1} ; however, refractive index modulations or variations outside this range

may be employed as well. Refractive index modulations or variations may be introduced by light of any wavelength (including ultraviolet light) that produces the desired refractive index changes, provided only that the photosensitive material employed is suitably stable in the presence of light in the desired operating wavelength range of the optical device. Exposure of a complete set of diffractive elements to substantially spatially uniform, refractive-index-changing light may be employed to tune the operative wavelength range of the diffractive element set. Exposure of the diffractive element set to spatially non-uniform refractive-index changing light may be employed to chirp or otherwise wavelength-modulate the diffractive element set (described further hereinbelow). The sensitivity of planar waveguide materials to irradiation produced refractive index modulations may be increased using hydrogen-loading, flame-brushing, boron or other chemical doping, or other method known in the art, for example in the context of making fiber Bragg gratings.

The curvilinear shape of the diffractive element contours may be determined by a variety of standard optical imaging system design tools. Essentially, each diffractive element contour may be optimized to image the input port onto the output port in a phase coherent manner. Inputs to the design are the detailed structure of the input and output optical ports and their locations. Standard ray tracing approaches to optical element design may provide a diffractive contour at each optical distance into the planar waveguide that will provide an optimal imaging of the input signal at the input port onto the optimal output signal at the output port. Simple curves may be employed as approximations of the fully optimized contours. Diffractive element virtual contours may be spaced by an optical path difference (as described above) that provides for the field image of successive diffractive contours to be substantially in phase at a desired wavelength. If the overall response of the diffractive element set is to be apodized with amplitude or phase modulation (to yield a desired spectral/temporal transfer function), the optical spacing of successive diffractive element contours may be varied in a controlled manner to provide required phase differences between diffracted components at the output port, or the diffractive strength of the elements may be individually controlled (as disclosed in the references cited hereinabove).

An alternative approach to designing the diffractive element contours for a diffractive element set is to calculate interference patterns between numerically simulated fields at a desired wavelength and with specified temporal waveforms entering the input port and exiting the output port. If a spectral transfer function is specified in a design, a corresponding temporal waveform may be obtained by Fourier transform. In forming or writing a summed pattern for the diffractive element set, suitable discretization is applied as needed for any lithographic or UV exposure approach that is utilized for fabrication. The holographic structure may be designed by interference of computer-generated beams having the desired computer-generated temporal waveforms, with the resulting calculated arrangement of diffractive elements implemented by lithography or other suitable spatially-selective fabrication techniques. For example, interference between a delta-function-like pulse and a desired reference optical waveform (or its time-reverse) may be calculated, and the resulting interference pattern used to fabricate a diffractive element set that acts to either recognize or generate the desired reference optical waveform.

In an alternative method for making the diffractive element structure, the core consists of a material of appropriate

index that is also photosensitive at the wavelength of the desired operational signal beams. As in traditional holography, the input and output recording beams (same wavelength as operational signal beams of the envisioned device) are overlapped in the core and the interference pattern between them is recorded. Subsequently the core material is developed and, if necessary, a cladding may be deposited or attached by other means. A specified spectral transfer function may be generated by imparting spectrally sweeping the desired amplitude and phase variations on the recording beams, or the recording beams may be pulsed with temporal waveforms having the desired Fourier spectrum.

The phrase “operationally acceptable” appears herein describing levels of various performance parameters of planar waveguides and diffractive element sets thereof. Such parameters may include optical coupling coefficient (equivalently, optical coupling efficiency), diffraction efficiency, undesirable optical mode coupling, optical loss, and so on. An operationally acceptable level may be determined by any relevant set or subset of applicable constraints or requirements arising from the performance, fabrication, device yield, assembly, testing, availability, cost, supply, demand, or other factors surrounding the manufacture, deployment, or use of a particular assembled optical device. Such “operationally acceptable” levels of such parameters may therefore vary within a given class of devices depending on such constraints or requirements. For example, a lower optical coupling efficiency may be an acceptable trade-off for achieving lower device fabrication costs in some instances, while higher optical coupling may be required in other instances in spite of higher fabrication costs. In another example, higher optical loss (due to scattering, absorption, undesirable optical coupling, and so on) may be an acceptable trade-off for achieving lower device fabrication cost or smaller device size in some instances, while lower optical loss may be required in other instances in spite of higher fabrication costs and/or larger device size. Many other examples of such trade-offs may be imagined. Optical devices and fabrication methods therefor as disclosed herein, and equivalents thereof, may therefore be implemented within tolerances of varying precision depending on such “operationally acceptable” constraints or requirements. Phrases such as “substantially adiabatic”, “substantially spatial-mode-matched”, “so as to substantially avoid undesirable optical coupling”, and so on as used herein shall be construed in light of this notion of “operationally acceptable” performance.

Schematic plan views of exemplary embodiments of multiple-wavelength optical sources **1000** are shown in FIGS. 1–3. Multiple channel optical waveguide cores **1003** are formed in a region of planar waveguide **1001**. Each channel waveguide core **1003** is positioned to receive a corresponding optical signal from a corresponding laser **1015**. In FIG. 1, lasers **1015** comprise a set of individual lasers each independently assembled with the planar waveguide **1001**. In FIG. 2, lasers **1015** comprise an integrated laser array that is assembled with the planar waveguide **1001**. In FIG. 3, lasers **1015** are integrally formed on the planar waveguide **1001**. Drive current or electronic control signals may be delivered to lasers **1015** via electrical conductors **1019**. Each corresponding channel waveguide includes a set of locking diffractive elements **1011**. Each laser optical signal launched along the corresponding channel waveguide core **1003** is successively incident on the diffractive elements of the corresponding locking diffractive element set **1011**. The locking diffractive element sets **1011** each route along the corresponding channel waveguide core **1003** a fraction of the

laser optical signal launched by the corresponding laser **1015** into the channel waveguide. The routed fraction of the optical signal is directed back to the laser to serve as a locking optical feedback signal. Each locking diffractive element set **1011** imparts onto the diffracted fraction of the optical signal a corresponding locking transfer function, which determines at least in part the operating wavelength range of the corresponding laser **1015**. The spectral characteristics of the locking transfer function are independent of the operating current or other operating parameters of the laser, and the resulting optical feedback tends to substantially restrict the laser optical signal to a selected operating wavelength range in spite of variations in drive current or other laser operating parameters.

The lasers **1015** may typically comprise semiconductor devices, wherein injection of drive current results in optical gain. The laser optical signals may be modulated by modulation of the laser drive currents. The laser may include two reflectors (e.g. opposing facets of a semiconductor laser chip) and thereby form a resonant optical cavity for supporting laser oscillation. In this instance the combination of the laser **1015** with the locking diffractive element set **1011** in the channel waveguide results in an external-cavity feedback laser, wherein a portion of the laser output from the laser oscillator is re-injected back through the output facet to stabilize the laser within the wavelength range determined by the locking diffractive element set. In this instance, compensation (active or passive) may be required so that longitudinal modes of the laser resonant cavity and the external cavity substantially coincide; otherwise, the laser output power or laser wavelength may fluctuate to an unacceptable degree as the respective longitudinal mode frequencies drift relative to one another. Alternatively, reflectivity of the front laser facet may be suppressed (by a suitable anti-reflection coating, for example, thereby diminishing or suppressing laser oscillation supported only within the laser chip), and the locking diffractive element set may serve as a laser resonator mirror. In this instance the laser **1015** and the channel waveguide with locking diffractive element sets **1011** together comprise a hybrid resonant optical cavity for supporting laser oscillation within the wavelength range determined by the locking diffractive element set. Both of these scenarios shall fall within the scope of the present disclosure or appended claims.

The diffractive elements may be formed in the channel waveguides in any suitable way, including but not limited to those listed hereinabove, and including but not limited to those disclosed in the incorporated references listed hereinabove. Examples are shown in FIGS. **4A–4D**, which are schematic side cross-sectional views of diffractive elements in a planar waveguide **11**. The planar waveguide in these embodiments is formed on a substrate **9** and comprises a core **5** surrounded by cladding **1** and **3**. Diffractive elements **8** may be formed within the core (FIG. **4A**), in the cladding (FIG. **4B**), on the cladding (FIG. **4C**), at the interface between core and cladding (FIG. **4D**), or any combination of these locations. The diffractive elements **8** may comprise core material (FIG. **4B**; FIG. **4D**, if the diffractive elements protrude into the cladding as shown), cladding material (FIGS. **4A** and **4C**; FIG. **4D**, if the diffractive elements extend into the core), or one or more materials differing from the core material and the cladding material (FIGS. **4A–4D**).

The locking transfer functions may be determined by the particular arrangement of the elements of the corresponding locking diffractive element sets in each channel waveguide. A particular transfer function is chosen to yield the desired spectral or temporal characteristics for the optical feedback

signal directed back to the laser, typically to restrict the laser optical signal to an operating wavelength range, or to otherwise optimize performance of the feedback-locked laser. For example, such a feedback-locked laser may exhibit reduced wavelength fluctuations (within operationally acceptable limits) despite modulation of its drive current. The spectral locations $\lambda_1, \lambda_2, \lambda_3, \dots, \lambda_N$ of these operating wavelength ranges may be chosen in any desired fashion. In one example, operating wavelength ranges may be selected to substantially correspond to operating wavelength channels of a wavelength-division-multiplexing (WDM) telecommunications system, such as the ITU telecommunications grid. If the set of operating wavelengths is spanned by the gain bandwidth of a single type of laser, then all of lasers **1015** may be substantially identical, with each operating wavelength determined by the corresponding locking diffractive element set.

To provide an optical feedback signal at a given vacuum wavelength λ , a periodic spacing between the diffractive elements of $m\lambda/2n_{wg}$ may be employed (where m is a non-negative integer diffractive order, and n_{wg} is the effective index of the channel waveguide). An example is shown schematically in FIG. **5A**, wherein substantially identical, substantially uniformly spaced diffractive elements **25** are provided along channel waveguide core **23**. Desired spectral profiles of the locking transfer functions differing from that produced by a simple periodic diffractive element set may be achieved by manipulation of relative amplitude or phase (i.e. apodization) of portions of the optical signal diffracted by each element of the locking diffractive element sets, in turn achieved by proper relative arrangement of the diffractive elements in the planar waveguide. An example is shown in FIG. **5B**, wherein the transverse extent of the diffractive elements **31** varies (introducing amplitude variation), and the spacing of the diffractive elements along channel waveguide core **29** varies as well (introducing phase variation, as at **30**). This is described in hereinabove or disclosed in the references incorporated hereinabove. While the strongest diffraction of the optical signal occurs for a first-order set of diffractive elements (i.e. $m=1$), any diffractive order may be employed for providing the locking feedback optical signal. The overall reflectivity of the locking diffractive element sets may be selected to yield desired laser performance (within operationally acceptable limits), and may typically range between about 1% and about 50%. The appropriate choice of locking reflectivity depends on several variables, including laser drive current, laser power, laser cavity round-trip optical gain or loss, optical losses or spurious reflectivity between the laser and the channel waveguide, and so on.

The locking diffractive element sets may be positioned in the planar waveguide **1001** so that the optical round trip time between the back reflector of the laser and the distal end of the corresponding locking diffractive element set is less than the bit modulation period to be employed when using the lasers as data transmitters. For example, if the maximum desired data transmission rate is 2.5 Gbit/sec and the average effective index within the combined laser and channel waveguide cavity is about 1.5, then the total length (from back laser reflector to distal end of locking diffractive element set) should be less than about 4 cm, typically between a few millimeters and about 2 cm. The reflective bandwidth of the locking diffractive element set may be chosen to be on the order of the longitudinal mode spacing of the combined laser and channel waveguide cavity; smaller reflective bandwidth may result in unacceptably large laser power fluctuations as the cavity modes shift relative to the reflective bandwidth. The reflective bandwidth should be sufficiently wide

to support a desired laser modulation rate or modulation bandwidth. Reflectivity of the interface between the lasers **1015** and the proximal ends of the channel waveguides may be chosen to yield desired laser performance. For example, it may be desirable to provide an anti-reflection coating (a single $\lambda/4$ layer, a $\lambda/4$ stack, or other) between the laser and the proximal end of the channel waveguide (on a laser facet, or on the proximal end face of the channel waveguide). Alternatively, it may be desirable to provide enhanced reflectivity between the laser and the channel waveguide. It may be desirable to manipulate the launch conditions between the lasers **1015** and the proximal ends of the corresponding channel waveguide cores **1003**. For example, spatial mode matching may result in less optical loss, a greater fraction of the laser power being launched into the channel waveguide, and a higher level of locking feedback optical signal getting back to the laser. This may be achieved (within operationally acceptable limits) by suitable configuration, adaptation, or arrangement of the laser or the proximal end of the channel waveguide core **1003**, or by additional optical components employed between the laser and channel waveguide, such as gradient or refractive lenses.

The fractions of the laser optical signals that are transmitted through the corresponding locking diffractive element sets constitute the outputs of the lasers. The transmitted fractions propagate along the corresponding channel waveguide cores **1003**, exit the corresponding distal ends thereof, and enter a slab optical waveguide region **1002** of the planar waveguide **1001** (FIGS. 1–3). In this region the transmitted fractions of the laser optical signals each propagate in two dimensions and impinge on routing diffractive element sets **1027**, which serve (along with distal portions of channel waveguide cores **1003**, and channel waveguide core **1007**) as means for routing the transmitted fractions of the laser optical signals between the corresponding laser and a corresponding output port. The transmitted fractions of the laser optical signals are successively incident on the diffractive elements of the routing diffractive element sets **1027**. The multiple routing sets of diffractive elements are each arranged to route at least a portion of the transmitted fraction of the corresponding laser optical signal to a corresponding output optical port. In the exemplary embodiments of FIGS. 1–3, the distal ends of the channel waveguide cores **1003** function as the corresponding input ports of the corresponding diffractive element sets **1027**. All of the routing diffractive element sets may route the corresponding optical signals to a single output port, or the routed optical signals may be routed among multiple output optical ports in any desired combination. An output optical port may comprise the end of a channel waveguide core **1007** formed on the planar waveguide **1001** (FIGS. 1 and 2), or may comprise a spatial beam size, beam shape, beam position, and beam propagation direction at an edge of the planar waveguide **1001** (designated **1008** in FIG. 3). The routed portions of the corresponding laser optical signals may enter an optical fiber **1023** positioned at the output port **1008** or at the end of channel waveguide core **1007**, as the case may be. The output port(s) may be located on the same edge of the planar waveguide **1001** as the lasers **1015** (FIG. 1), may be located on an adjacent edge of planar waveguide **1001** (FIGS. 2 and 3), or may be located in any other suitable location on an edge of planar waveguide **1001**. If multiple routed portions of the laser optical signals are routed to a common optical output port, then the corresponding routing diffractive element sets function as a multiplexer, and enable injection of multiple wavelength channels into a common optical fiber output.

The multiple routing diffractive element sets **1027** may comprise sets of curvilinear diffractive elements, with shapes chosen to route at least a portion of a diverging transmitted fraction of the corresponding laser optical signal to a corresponding output port, within operationally acceptable limits. The selection of suitable diffractive element shapes is described hereinabove or disclosed in the references incorporated hereinabove. The distal end of the channel waveguide cores **1003** may be tapered (FIG. 6A) or flared (FIG. 6B), as desired, to yield desired divergence of the laser optical signals in the slab waveguide region **1002**. The end of a channel waveguide core **1007**, if present, may be tapered or flared, as desired, to accommodate convergence of the routed laser optical signals in the slab waveguide region **1002**. Within each routing diffractive element set, the diffractive elements may be arranged to yield substantially uniform phase shifts and substantially similar diffracted amplitudes, or may be arranged to yield various phase shifts and amplitudes to in turn yield a desired routing transfer function (i.e. desired apodization). The routing transfer function will typically overlap spectrally the corresponding locking transfer function imparted by the corresponding locking diffractive element set. The spacings or other arrangements of the routing diffractive elements are analogous to those already described for the locking diffractive element sets, and are described hereinabove or disclosed in the references incorporated hereinabove. The multiple routing diffractive element sets may be longitudinally displaced relative to one another (i.e. “stacked”) and therefore occupy separate areal portions of the slab waveguide region **1002** of the planar waveguide **1001**. Or, the multiple routing diffractive element sets may occupy overlapping areal portions of the slab waveguide region **1002** of planar waveguide **1001**. Such overlapping sets of diffractive elements may be overlaid or interleaved as disclosed in the references incorporated hereinabove.

It is typically intended that the fraction of the laser optical signal transmitted by the corresponding locking diffractive element set is diffracted only by the corresponding routing diffractive element set (and a portion thereof thereby routed to the corresponding output port). In this way multiple laser optical signals at multiple corresponding, differing wavelengths from multiple corresponding lasers may be routed to the corresponding output ports, or to a single output port, by diffraction from the corresponding routing diffractive element sets, even if the optical signals must propagate through other routing diffractive element sets.

An exemplary use of a multiple-wavelength optical source, such as the exemplary embodiments of FIGS. 1–3, may be transmission of multiple wavelength-differentiated data channels into a single output port or into a single output optical fiber. Another exemplary use is switching of a single data channel among multiple carrier wavelengths, by electronic switching of an electronic modulation signal among the various lasers of the multiple-wavelength source. These uses or other uses of the multiple-wavelength optical sources shall fall within the scope of the present disclosure or appended claims.

Since the locking diffractive element sets and the corresponding routing diffractive element sets are all formed on the same planar optical waveguide, it may be possible to form them in a single lithographic step or sequence. For example, all of the locking and routing diffractive elements may be defined on a common mask used to form the diffractive elements on the planar waveguide. The spectral characteristics of each locking diffractive element set and its corresponding routing diffractive element set, as well as the

relative wavelength offsets of the various locking diffractive element sets (e.g. to match a corresponding wavelength channel spacing of a WDM system), may be very precisely set during the fabrication of such a mask. Once formed, any shifting of spectral characteristics of the various diffractive element sets due to environmental influences (such as temperature-induced wavelength shifts due to thermo-optic effects or thermal expansion of the planar waveguide) are well-correlated with one another, since all are formed on a common planar waveguide. If precise control of the absolute wavelengths is desired, a single temperature control mechanism may be employed for temperature stabilizing the planar waveguide, and all the diffractive element sets thereon. Such temperature control may be achieved by any suitable means, including any suitable temperature sensor, heat source, or feedback circuit, or other mechanism. The multiple-wavelength optical source may then be temperature-tuned to the desired wavelengths, or may be stabilized at a desired temperature or operating wavelengths.

In the exemplary embodiment of FIG. 7, each locking diffractive element set **1011** includes at least a section of higher-order diffractive elements **1051** (not visible in FIG. 7; shown in the schematic cross-section of FIG. 8), for redirecting a portion of the corresponding laser optical signal out of the planar waveguide. While the redirected portion of the optical signal represents optical loss during propagation along the channel waveguide, this redirected signal portion may be useful for monitoring the optical power level propagating along the channel waveguide. Photodetectors **1047** may be positioned above the higher-order section of diffractive elements **1051** for receiving the redirected portion of the optical signal. While any higher-order diffractive element set (i.e., higher than first order) will redirect a portion of the optical signal out of the planar waveguide, even-order diffractive element sets redirect at least one portion vertically from the planar waveguide, which may then be more efficiently collected by the photodetector. In the exemplary embodiment of FIG. 8, most of the locking diffractive element set **1011** is first-order (element spacing of $\lambda/2n_{wg}$), and the higher-order section **1051** is second-order (element spacing of λ/n_{wg}).

Photodetectors **1047** may be assembled individually onto the planar waveguide **1001** over the corresponding higher-order sections **1051** of the diffractive element sets **1011**, or the photodetectors may comprise an integrated photodetector array assembled onto the planar waveguide **1001**. Alternatively, photodetectors **1047** may be integrated directly into the planar waveguide **1001**, above or below the higher-order section of diffractive elements. The signals generated by the photodetectors **1047** may be used to measure the optical signal power propagating through the channel waveguides for monitoring, diagnostics, trimming, signal normalization, feedback control, or for other purposes. For example, the planar waveguide may further comprise multiple corresponding variable optical attenuators **1043** for controlling the optical power level propagating through the segments of the corresponding channel waveguides distal to the attenuators. The attenuators **1043** may be operatively coupled to the corresponding photodetectors **1047** through a feedback circuit for maintaining the laser optical signal level reaching the corresponding routing diffractive element sets **1027** within a selected operating range. Alternatively, the signals generated by the photodetectors **1047** may be used as a feedback signal for controlling the laser drive current to the corresponding lasers **1015**. These and any other suitable feedback mechanisms shall fall within the scope of the present disclosure or appended claims. Higher-order diffrac-

tive elements (for redirecting portions of the laser optical signals) or photodetectors may be positioned elsewhere besides the locking diffractive element sets. For example, the routing diffractive element sets may include higher-order sections, or other portions of channel waveguide cores **1003** or **1007** (instead of segments thereof having the locking diffractive element sets) may be provided with a higher-order set of diffractive elements for redirecting portions of the laser optical signals onto photodetectors. Any suitable location for positioning higher-order diffractive elements for redirecting portions of the laser optical signals to corresponding photodetectors shall fall within the scope of the present disclosure or appended claims.

In the exemplary embodiment illustrated schematically in FIG. 9, the locking diffractive element sets **1011** comprise curvilinear diffractive elements formed in the slab optical waveguide region **1002**. The laser optical signals emerge from the distal ends of channel waveguide cores **1003**, propagate in two dimensions through slab waveguide region **1002**, and are successively incident on the locking diffractive elements of the corresponding sets **1011**. The schematic cross-sectional views of FIGS. 4A–4D may represent curvilinear locking diffractive elements sets **1011**. The curvilinear diffractive elements are shaped to redirect a fraction of the laser optical signal back to the laser with a locking transfer function, in a manner analogous to that described hereinabove for locking diffractive element sets formed in channel waveguides. Suitable curvilinear shapes may be determined in a manner analogous to those used for determining the curvilinear shapes of the routing diffractive element sets, as described hereinabove or disclosed in the references incorporated hereinabove. The fractions of the corresponding laser optical signals transmitted by the corresponding locking diffractive element sets are successively incident on the elements of the corresponding routing diffractive element sets **1027**, which route portions of the corresponding laser optical signals to corresponding output port(s). The channel waveguide cores **1003** may be omitted completely, with the lasers **1015** launching the corresponding laser optical signals directly into slab waveguide region **1002**. The curvilinear locking diffractive elements sets may include higher-order sections thereof, for directing a portion of the corresponding laser optical signals out of the planar waveguide, and corresponding photodetectors may be positioned for receiving these corresponding redirected portions. The curvilinear locking diffractive element sets may be stacked, overlaid, or interleaved in a manner analogous to that described hereinabove for the routing diffractive element set, or disclosed in the references incorporated hereinabove.

In the exemplary embodiment of FIG. 10, the routing means for routing the laser optical signals from the corresponding lasers **1015** to the corresponding output port (channel waveguide **1009** in this example) comprises an arrayed-waveguide grating **1029** formed on planar waveguide **1001** (along with distal portions of channel waveguide cores **1003**, and channel waveguide core **1009**). Locking diffractive element sets **1011** formed along corresponding channel waveguide cores **1003** provide corresponding locking feedback signals to the corresponding lasers **1015**. The arrayed-waveguide grating (AWG; also referred to as a phased array or phased waveguide array) may be implemented in a variety of ways known in the art, so that the fractions of the corresponding laser optical signals transmitted by the corresponding locking diffractive element sets **1011** and propagating along corresponding channel waveguide cores **1003** are routed to corresponding output port(s). Various other aspects of the multiple-

wavelength optical source may be modified as already described herein: lasers **1015** may comprise individual lasers assembled with the planar waveguide, an integrated array of lasers assembled with the planar waveguide, or lasers integrated into the planar waveguide; locking diffractive element sets **1011** may include corresponding higher-order sections for redirecting portions of the corresponding laser optical signals out of the planar waveguide **1001**; other portions of channel waveguide cores **1003**, waveguide core **1009**, or the AWG **1029** may include corresponding higher-order sections for redirecting portions of the corresponding laser optical signals out of the planar waveguide **1001**; corresponding photodetectors may receive redirected portions of the corresponding optical signals; photodetectors may comprise individual photodetectors assembled with the planar waveguide, an integrated array of photodetectors assembled with the planar waveguide, or photodetectors integrated into the planar waveguide; photodetector signals may provide feedback control of laser optical signal power; the multiple laser optical signals may be directed to one or more output optical ports; or laser optical signals directed to output ports may enter corresponding optical fibers.

A wide variety of materials may be employed for forming the planar waveguide and the locking diffractive element sets, channel waveguides, slab waveguide, routing diffractive element sets, arrayed-waveguide gratings, or other elements of a multiple-wavelength optical source, and any suitable material or combination of materials shall fall within the scope of the present disclosure or appended claims. A common material combination is a silicon substrate with silica cladding (doped or undoped as appropriate) and with doped silica or silicon nitride or silicon oxynitride waveguide cores. If lasers or photodetectors are to be integrated into the planar waveguide, suitable materials must be chosen for the planar waveguide that are compatible with laser or photodetector materials at the operating wavelengths of the device. For typical telecommunications wavelengths, these will typically include III-V semiconductors or various alloys thereof.

Whether integrated into the planar waveguide, or assembled with the planar waveguide as an integrated array, lasers or photodetectors are subject to yield limitations in their manufacture. So that a single sub-standard laser or photodetector does not result in rejection of an entire array, arrays may be constructed with extra lasers or photodetectors. The planar waveguide may be fabricated with extra locking diffractive element sets and extra routing means to accommodate these extra lasers or photodetectors. In this way, if a laser or photodetector of an array is bad, the array may still be used. The corresponding electronic channels are simply switched on or off accordingly, to only use channels having a good laser or a good photodetector.

In the present disclosure or appended claims, the conjunction “or” is to be construed inclusively (e.g., “a dog or a cat” would be interpreted as “a dog, or a cat, or both”; Bryan A. Garner, *Elements of Legal Style* p. 103, 2nd ed. 2002), unless: i) it is explicitly stated otherwise, e.g., by use of “either-or”, “only one of”, or similar language; or ii) two or more of the listed alternatives are mutually exclusive within the specific context, in which case “or” would encompass only those combinations involving non-mutually-exclusive alternatives, if any.

It should be noted that many of the embodiments depicted in this disclosure are only shown schematically, and that not all the features may be shown in full detail or in proper proportion or location. Certain features or structures may be exaggerated relative to others for clarity. In particular, it

should be noted that the numbers of diffractive elements in an actual device may typically be larger than that shown in the Figures. The numbers of diffractive elements is reduced in the Figures for clarity. It should be further noted that the embodiments shown in the Figures are exemplary only, and should not be construed as specifically limiting the scope of the written description or the claims set forth herein. It is intended that equivalents of the disclosed exemplary embodiments or methods shall fall within the scope of the present disclosure. It is intended that the disclosed exemplary embodiments or methods, or equivalents thereof, may be modified while remaining within the scope of the present disclosure or appended claims.

What is claimed is:

1. A method for forming an optical apparatus, comprising: forming a planar optical waveguide substantially confining in at least one transverse spatial dimension optical signals propagating therein;

forming at least one set of locking diffractive elements in or on the planar optical waveguide;

forming means for routing an optical signal corresponding to at least one said set of locking diffractive elements; and

positioning a laser corresponding to at least one said set of locking diffractive elements so as to launch a corresponding laser optical signal into the planar optical waveguide so that the corresponding laser optical signal is successively incident on the diffractive elements of the corresponding locking diffractive element set,

wherein:

each locking diffractive element set routes within the planar optical waveguide a fraction of the corresponding laser optical signal back to the corresponding laser, with a corresponding locking transfer function, as a corresponding locking optical feedback signal, thereby substantially restricting the corresponding laser optical signal to a corresponding laser operating wavelength range determined at least in part by the corresponding locking transfer function of the corresponding locking diffractive element set; and

each corresponding routing means routes within the planar optical waveguide, between the corresponding laser and a corresponding output optical port with a corresponding routing transfer function, at least a portion of that fraction of the corresponding laser optical signal that is transmitted by the corresponding locking diffractive element set.

2. The method of claim 1, further comprising forming multiple sets of locking diffractive element sets and multiple corresponding routing means, and positioning multiple corresponding lasers so as to launch corresponding laser optical signals into the planar optical waveguide so that the corresponding laser optical signals are successively incident on the diffractive elements of the corresponding locking diffractive element sets.

3. The method of claim 2, wherein the multiple lasers comprise a set of individual lasers each assembled with the planar optical waveguide.

4. The method of claim 2, wherein the multiple lasers comprise an integrated laser array assembled with the planar optical waveguide.

5. The method of claim 2, wherein the multiple lasers are integrated into the planar optical waveguide.

6. The method of claim 5, wherein the planar optical waveguide and the multiple lasers integrated therein comprise semiconductor materials.

7. The method of claim 2, further comprising positioning multiple corresponding monitor photodetectors for receiving portions of the corresponding laser optical signals that propagate out of the planar optical waveguide.

8. The method of claim 7, wherein each locking diffractive element set comprises a corresponding higher-order set of diffractive elements for redirecting a portion of the corresponding laser optical signal to propagate out of the planar optical waveguide and impinge on the corresponding monitor photodetector.

9. The method of claim 7, wherein each routing means comprises a corresponding higher-order set of diffractive elements for redirecting a portion of the corresponding laser optical signal to propagate out of the planar optical waveguide and impinge on the corresponding monitor photodetector.

10. The method of claim 7, further comprising operatively coupling multiple corresponding feedback mechanisms to the corresponding monitor photodetectors for controlling power of the corresponding laser optical signals transmitted by the corresponding locking diffractive element sets.

11. The method of claim 2, further comprising forming multiple corresponding channel optical waveguides in the planar optical waveguide and positioning said corresponding channel waveguides for receiving the corresponding laser optical signals launched from the corresponding lasers into the planar optical waveguide, wherein the corresponding locking diffractive element sets route within the corresponding channel optical waveguides the corresponding fractions of the corresponding laser optical signals back to the corresponding lasers.

12. The method of claim 11, further comprising forming the corresponding channel optical waveguides with tapered or flared end segments for delivering to the corresponding routing means the portions of the corresponding laser optical signals transmitted by the corresponding locking diffractive element sets.

13. The method of claim 2, further comprising forming a slab waveguide region in the planar optical waveguide and positioning said slab waveguide region for receiving the corresponding laser optical signals launched from the corresponding lasers into the planar optical waveguide, wherein the corresponding locking diffractive element sets route within the slab waveguide region the corresponding fractions of the corresponding laser optical signals back to the corresponding lasers.

14. The method of claim 13, further comprising overlaying the corresponding locking diffractive element sets.

15. The method of claim 13, further comprising displacing longitudinally the corresponding locking diffractive element sets relative to one another.

16. The method of claim 13, further comprising interleaving the corresponding locking diffractive element sets.

17. The method of claim 13, further comprising forming the diffractive elements of the multiple locking diffractive sets so as to comprise curvilinear diffractive elements.

18. The method of claim 2, wherein the corresponding laser operating wavelength ranges substantially correspond to operating wavelength channels of a WDM telecommunications system.

19. The method of claim 2, further comprising forming the planar optical waveguide so as to comprise a core and cladding, and forming the diffractive elements of the multiple locking diffractive element sets in the core, in the cladding, on the cladding, or at an interface between the core and the cladding.

20. The method of claim 2, further comprising forming the multiple corresponding routing means:

so as to comprise multiple corresponding routing diffractive element sets formed in a slab optical waveguide region of the planar optical waveguide; and

so that the corresponding fractions of the corresponding laser optical signals transmitted by the corresponding locking diffractive element sets are successively incident on the diffractive elements of the corresponding routing diffractive element sets.

21. The method of claim 20, further comprising overlaying the corresponding routing diffractive element sets.

22. The method of claim 20, further comprising displacing longitudinally the corresponding routing diffractive element sets relative to one another.

23. The method of claim 20, further comprising interleaving the corresponding routing diffractive element sets.

24. The method of claim 20, further comprising forming the corresponding routing diffractive element sets so that the corresponding portions of the multiple corresponding laser optical signals transmitted by the corresponding locking diffractive element sets are routed by the corresponding routing diffractive element sets to a common output optical port.

25. The method of claim 20, further comprising positioning at least one optical fiber for receiving from the planar optical waveguide the corresponding portions of the multiple corresponding laser optical signals transmitted by the corresponding locking diffractive element sets and routed by the corresponding routing diffractive element sets to the corresponding output optical ports.

26. The method of claim 20, further comprising forming the diffractive elements of the multiple routing diffractive sets so as to comprise curvilinear diffractive elements.

27. The method of claim 20, further comprising forming the planar optical waveguide so as to comprise a core and cladding, and forming the diffractive elements of the multiple routing diffractive element sets in the core, in the cladding, on the cladding, or at an interface between the core and the cladding.

28. The method of claim 2, further comprising forming the multiple corresponding routing means so as to comprise an arrayed waveguide grating in the planar optical waveguide.

29. The method of claim 28, further comprising forming the arrayed waveguide grating so as to route the corresponding portions of the multiple corresponding laser optical signals transmitted by the corresponding locking diffractive element sets to a common output optical port.

30. The method of claim 28, further comprising positioning at least one optical fiber for receiving from the planar optical waveguide the corresponding portions of the multiple corresponding laser optical signals transmitted by the corresponding locking diffractive element sets and routed by the arrayed waveguide grating to the corresponding output optical ports.

31. The method of claim 2, further comprising operatively coupling a temperature controller to the planar optical waveguide for maintaining the planar optical waveguide substantially within an operating temperature range.

32. A method of forming an optical apparatus, the method comprising:

forming an optical waveguide;

forming at least a first set of diffractive elements in or on the optical waveguide, wherein each diffractive element of the at least the first set is formed to route, as a corresponding optical feedback signal and within the optical waveguide, a first fraction of a corresponding optical signal incident thereon, and wherein each diffractive element of the at least the first set is further formed to

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transmit a second fraction of the corresponding optical signal incident thereon; and

forming a second set of diffractive elements, wherein each diffractive element of the second set is formed to route, within the optical waveguide, the corresponding second fraction transmitted by each diffractive element of the at least the first set,

wherein each diffractive element of the at least the first set is further formed to impart a corresponding first transfer function onto the corresponding optical feedback signal to substantially restrict the corresponding optical signal to a corresponding wavelength range determined at least in part by the corresponding first transfer function.

33. *The method of claim 32, further comprising positioning an optical source corresponding to the at least the first set of diffractive elements so as to launch the corresponding optical signal into the optical waveguide.*

34. *The method of claim 33 wherein each diffractive element of the second set is formed to route the corresponding second fraction between the corresponding optical source and a corresponding output optical port, and wherein each diffractive element of the second set is further formed to impart a corresponding second transfer function onto the corresponding second fraction.*

35. *A method of operating an optical apparatus, the method comprising:*

receiving an input optical signal in an optical waveguide; routing as an optical feedback signal, within the optical waveguide and by at least a first set of diffractive elements formed in or on the optical waveguide, a first fraction of the received input optical signal;

imparting, by the at least the first set of diffractive elements, a first transfer function onto the optical feedback signal to substantially restrict the input optical signal to a wavelength range determined at least in part by the first transfer function;

transmitting, by the at least the first set of diffractive elements, a second fraction of the received optical input signal; and

routing, within the optical waveguide and by a second set of diffractive elements, the transmitted second fraction to an optical port.

36. *The method of claim 35, further comprising imparting, by the second set of diffractive elements, a second transfer function onto the second fraction routed to the optical port.*

37. *The method of claim 35 wherein said receiving the input optical signal includes receiving a plurality of input optical signals from a corresponding plurality of optical sources,*

wherein said routing as the optical feedback signal includes routing a plurality of optical feedback signals by a corresponding plurality of the at least the first set of diffractive elements,

wherein said imparting the first transfer function includes imparting, by the corresponding plurality of the at least the first set of diffractive elements, a corresponding plurality of first transfer functions onto the plurality of optical feedback signals to substantially restrict the plurality of input optical signals to corresponding wavelength ranges determined at least in part by the corresponding plurality of first transfer functions.

38. *The method of claim 35 wherein said routing the first fraction, by the at least the first set of diffractive elements, includes routing the first fraction within a channel waveguide formed within the optical waveguide, and*

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wherein the at least the first set of diffractive elements is formed within the channel waveguide.

39. *An optical apparatus, comprising:*

an optical waveguide;

at least a first set of diffractive elements formed in or on the optical waveguide, wherein each diffractive element of the at least the first set is configured to route, as a corresponding optical feedback signal and within the optical waveguide, a first fraction of a corresponding optical signal incident thereon, and wherein each diffractive element of the at least the first set is further configured to transmit a second fraction of the corresponding optical signal incident thereon; and

a second set of diffractive elements, wherein each diffractive element of the second set is configured to route, within the optical waveguide, the corresponding second fraction transmitted by each diffractive element of the at least the first set,

wherein each diffractive element of the at least the first set is further configured to impart a corresponding first transfer function onto the corresponding optical feedback signal to substantially restrict the corresponding optical signal to a corresponding wavelength range determined at least in part by the corresponding first transfer function.

40. *The apparatus of claim 39 wherein the diffractive elements of the at least the first set are formed in a channel waveguide located in a first region of the optical waveguide, and wherein the diffractive elements of the second set are formed in a slab waveguide located in a second region of the optical waveguide.*

41. *The apparatus of claim 39, further comprising at least one optical source configured to provide the corresponding optical signal to the at least the first set of diffractive elements formed in or on the optical waveguide.*

42. *The apparatus of claim 39, further comprising a plurality of photodetectors each configured to receive the corresponding second fraction routed by the second set of diffractive elements.*

43. *The apparatus of claim 39 wherein each diffractive element of the second set is further configured to impart a corresponding second transfer function onto the corresponding second fraction.*

44. *An apparatus, comprising:*

optical waveguide means for receiving an input optical signal;

at least a first set of diffractive element means for routing, as an optical feedback signal and within the optical waveguide means, a first fraction of the received input optical signal, for imparting a first transfer function onto the optical feedback signal to substantially restrict the input optical signal to a wavelength range determined at least in part by the first transfer function, and for transmitting a second fraction of the received optical input signal; and

a second set of diffractive element means for routing, within the optical waveguide means, the transmitted second fraction to an optical port.

45. *The apparatus of claim 44 wherein the at least the first set of diffractive element means is formed in a channel waveguide located in a first region of the optical waveguide means, and wherein the second set of diffractive element means is formed in a slab waveguide located in a second region of the optical waveguide means.*

46. *The apparatus of claim 44, further comprising at least one optical source means for launching at least a corre-*

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sponding portion of the input optical signal into the optical waveguide means.

47. The apparatus of claim 44, further comprising a plurality of detector means for receiving the second fraction transmitted to the optical port by the second set of diffractive element means.

48. A system, comprising:

a plurality of optical sources to respectively provide corresponding input optical signals; and
an optical waveguide that includes:

at least a first set of diffractive elements, wherein each diffractive element of the at least the first set is configured to route, as a corresponding optical feedback signal and within the optical waveguide, a first fraction of a corresponding input optical signal incident thereon, and wherein each diffractive element of the at least the first set is further configured to transmit a second fraction of the corresponding optical signal incident thereon; and

a second set of diffractive elements, wherein each diffractive element of the second set is configured to route, within the optical waveguide, the corresponding second fraction transmitted by each diffractive element of the at least the first set,

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wherein each diffractive element of the at least the first set is further configured to impart a corresponding first transfer function onto the corresponding optical feedback signal to substantially restrict the corresponding optical signal to a corresponding wavelength range determined at least in part by the corresponding first transfer function, and

wherein each corresponding wavelength range substantially corresponds to an operating wavelength channel.

49. The system of claim 48 wherein each said operating wavelength channel is a channel of a wavelength division multiplexing (WDM) system.

50. The system of claim 48 wherein the plurality of optical sources includes a plurality of lasers.

51. The system of claim 49, further comprising a plurality of detectors each configured to receive the corresponding second fraction routed by the second set of diffractive elements.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : RE42,206 E
APPLICATION NO. : 12/421971
DATED : March 8, 2011
INVENTOR(S) : Mossberg et al.

Page 1 of 3

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page, Item (60), under "Related U.S. Patent Documents", Lines 6-7, delete "and provisional application No. 60/199,790, filed on Apr. 26, 2000." and insert -- provisional application No. 60/199,790, filed on Apr. 26, 2000, and provisional application No. 60/190,126, filed on Mar. 16, 2000. --.

On the Title Page 2, Item (56), under "Other Publications", Line 19, below "2003/0039444 A1 2/2003 Mossberg et al." insert -- 2003/0067645 A1 4/2003 Ibsen et al. 359/124 --.

On the Title Page 2, Item (56), under "Other Publications", Line 22, below "2003/0185269 A1 10/2003 Gutin" insert -- 2003/0206694 A1 11/2003 Babin et al. 385/31 --.

On the Title Page 3, Item (56), under "Other Publications", Line 22, delete "Lighwave" and insert -- Lightwave --.

On the Title Page 3, Item (56), under "Other Publications", Line 25, delete "Spectrometers," and insert -- Spectrometers, --.

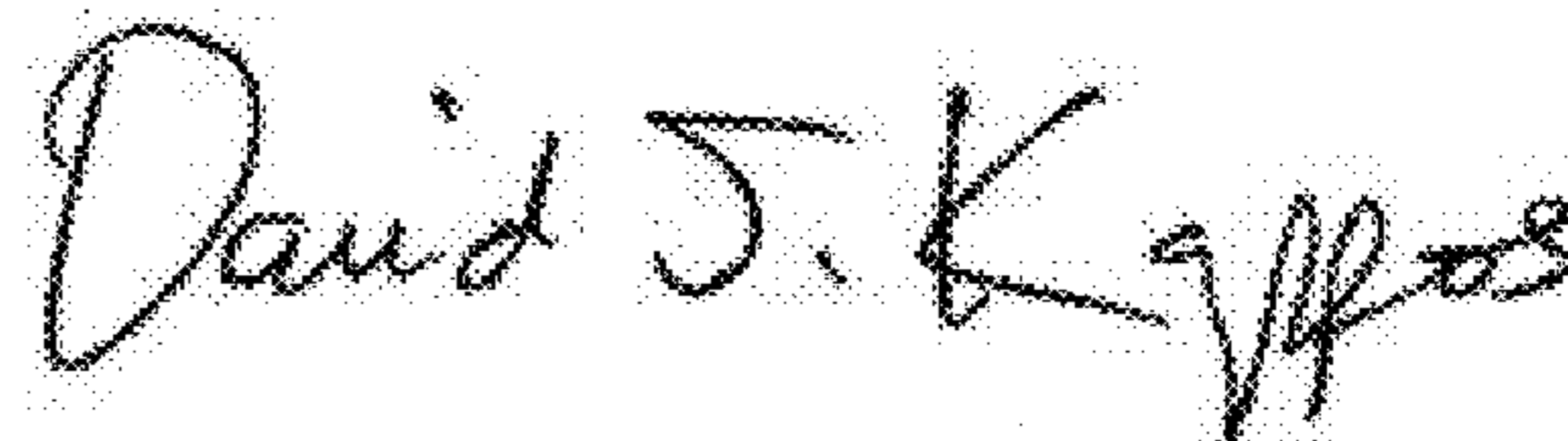
On the Title Page 3, Item (56), under "Other Publications", Line 25, delete "Lett." and insert -- Lett., --.

On the Title Page 3, Item (56), under "Other Publications", Line 41, delete "Lighwave" and insert -- Lightwave --.

On the Title Page 3, Item (56), under "Other Publications", Line 44, delete "Electon." and insert -- Electron. --.

On the Title Page 3, Item (56), under "Other Publications", Line 47, delete "Lighwave" and insert -- Lightwave --.

Signed and Sealed this
Fifth Day of July, 2011



David J. Kappos
Director of the United States Patent and Trademark Office

U.S. Pat. No. RE42,206 E

On the Title Page 3, Item (56), under “Other Publications”, Line 51, delete “Lighwave” and insert -- Lightwave --.

On the Title Page 3, Item (56), under “Other Publications”, Line 59, delete “Stablization” and insert -- Stabilization --.

On the Title Page 3, Item (56), under “Other Publications”, Line 52, delete “Lighwave” and insert -- Lightwave --.

On the Title Page 3, Item (56), under “Other Publications”, Line 59, delete “fiberts,” and insert -- fibers, --.

On the Title Page 4, Item (56), under “Other Publications”, Line 4, delete “efficiency” and insert -- efficiency --.

On the Title Page 4, Item (56), under “Other Publications”, Line 5, delete “Ofice” and insert -- Office --.

On the Title Page 4, Item (56), under “Other Publications”, Line 7, delete “Ofice” and insert -- Office --.

On the Title Page 4, Item (56), under “Other Publications”, Line 52, delete “Spectrographic” and insert -- Spectrograph --.

On the Title Page 5, Item (56), under “Other Publications”, Line 9, delete “Lighwave” and insert -- Lightwave --.

On the Title Page 5, Item (56), under “Other Publications”, Line 25, delete “Lighwave” and insert -- Lightwave --.

On the Title Page 5, Item (56), under “Other Publications”, Line 28, delete “Lighwave” and insert -- Lightwave --.

On the Title Page 5, Item (56), under “Other Publications”, Line 31, delete “pp. 204–2–5,” and insert -- pp. 204–205, --.

On the Title Page 5, Item (56), under “Other Publications”, Line 34, delete “Lighwave” and insert -- Lightwave --.

On the Title Page 5, Item (56), under “Other Publications”, Line 37, delete “Lighwave” and insert -- Lightwave --.

On the Title Page 5, Item (56), under “Other Publications”, Line 2, delete “Wavegront” and insert -- Wavefront --.

CERTIFICATE OF CORRECTION (continued)

U.S. Pat. No. RE42,206 E

On the Title Page 5, Item (56), under "Other Publications", Line 8, delete "Lighwave" and insert
-- Lightwave --.