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(54) METHOD AND SYSTEM FOR INTEGRATED DWDM TRANSMITTERS

VERFAHREN UND SYSTEM FÜR INTEGRIERTE DWDM-SENDER

PROCÉDÉ ET SYSTÈME CONÇUS POUR DES EMETTEURS DWDM INTÉGRÉS

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- **TERVONEN A ET AL: "Control of wavelength alignment in wavelength division multiple access passive optical network" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 39, no. 2, 23 January 2003 (2003-01-23), pages 229-230, XP006019735 ISSN: 0013-5194**

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Description

Field of the Technology

[0001] The present invention relates to fiber optical transport technologies, and more particularly, to a method for making an integrated DWDM transmitter apparatus and such an integrated DWDM transmitter apparatus.

Background of the Invention

[0002] The present invention is directed to a method for making an integrated DWDM transmitter apparatus according to the preamble of claim 1.

[0003] Since its first deployment in the middle of 1990s, dense wavelength division multiplexing (DWDM) has become a dominant technology for long haul and regional backbone transport networks, and is gradually making its way to metro area networks. In a conventional DWDM system, each optical component, be it a laser or a MUX filter, is individually packaged. A linecard is built around one or several optical components. For example, a transmitter card for a given wavelength includes a laser and a modulator (or an integrated laser/modulator). The laser chips sitting inside the laser packages are typically made of indium phosphide. (InP) semiconductor compounds. The optical outputs of multiple transmitter linecards at different wavelengths are combined through a multiplexer linecard, which includes some MUX filters. A commonly used MUX filter is based on array waveguide grating (AWG) made of silica-on-silicon. The optical connections between the linecards are through optical fibers. The optical output from the multiplexer linecard is then amplified by an optical amplifier and launched into the transmission fiber.

[0004] Even though these conventional DWDM systems are useful in some areas, they have many limitations that restrict their effectiveness in broader applications. Some of these limitations are discussed below, and then improved techniques based on embodiments of the present invention are presented.

[0005] EP 1 028503 A2 discloses a wavelength stable optical source, and the source comprises one adjustable wavelength optical source, a MMZI for receiving a signal from the adjustable source and providing a primary output and one or more secondary outputs, and a feedback arrangement responsive to the outputs for adjusting the wavelength source. Photodetectors coupled to the primary output and one or more of the secondary outputs provide feedback information for maintaining wave length stability.

[0006] The article "Design and applications of silica-based planar Lightwave circuits" by Kaneko et al published in IEE journal of Selected Topics in Quantum Electronics vol. 5, No 5, September/October 1999, discloses the recent progress and future prospects of PLC technologies including arrayed-waveguide grating multiplexers, optical add-drop multiplexers and hybrid optoelectronics integration technologies.

[0007] WO 01/33268 A1 discloses an asymmetric waveguide pair with a differential thermal response has an optical coupling frequency that may be thermo-optically tuned. Tuning may also be accomplished by applying an electric field across a liquid crystal portion or the waveguide structure.

[0008] The article "Control of wavelength alignment in wavelength division multiple access passive optical network" by Tervonen et al published in Electronics Letters vol. 39, No 2 in January 2003, discloses that in a wavelength division multiple access passive optical network based on spectral slicing, the wavelength drift of a multiplexer/demultiplexer due to varying ambient temperature in the passive outside plant is compensated by controlling the temperature of the other device at central office location to wavelength alignment.

Summary of the Invention

[0009] The present invention is directed to fiber optical transport systems. More particularly, the invention provides a method for reducing the size and cost of optical transport systems. Merely by way of example, the invention has been applied to DWDM optical transmitter systems. In particular, the invention relates to a method for making an integrated DWDM transmitter apparatus according to claim 1. The dependent claims relate to advantageous embodiments. Many benefits are achieved by way of the present invention over conventional techniques. For example, in certain embodiments, the invention provides methods and apparatus that use a, silica/silicon AWG as a substrate to mount semiconductor (InP) laser/modulator chips. Because the processing cost per unit area for silica-on-silicon can be two orders of magnitude lower than that for InP, the AWG according to embodiments of the present invention can be made at much lower cost. Silica-on-silicon AWGs is a much more mature technology. For example, transmission loss is much smaller in AWGs made of silica-on-silicon than those made of InP. Moreover according to an embodiment of the invention, without the AWG, the InP chip can be made much smaller. The high yield and the small size significantly reduce the cost of the InP chips used for hybrid integration in accordance to embodiments of the present invention. In term of finished device, the size of a hybrid integrated DWDM transmitter according to specific embodiments of the invention is comparable to that of a monolithically integrated DWDM transmitter. Thus the small size advantage of an integrated DWDM transmitter is retained according to embodiments of the present invention.

[0010] Various additional objects, features, and advantages of the present invention can be more fully appreciated with reference to the detailed description and accompanying drawings that follows.

Brief Description of the Drawings

[0011]

Figure 1A is a simplified top view diagram of an illustrative example of a hybrid integrated DWDM transmitter not falling under the claims;
Figure 1B is a simplified cross-sectional view diagram of the hybrid integrated DWDM transmitter of Figure 1A;
Figures 2A is a simplified expanded top view diagram of a hybrid integrated DWDM transmitter according to another illustrative example not falling under the claims;
Figure 2B is a simplified expanded cross-sectional view diagram of a hybrid integrated DWDM transmitter of Figure 2A;
Figure 3 a simplified view diagram of an integrated DWDM transmitter system according to an embodiment of the present invention;
Figure 4A is a simplified flowchart of an illustrative method for maintaining a target wavelength in an integrated DWDM transmitter according to the embodiment of the invention;
Figures 4B-4D are simplified wavelength diagrams illustrating the method for maintaining a target wavelength in an integrated DWDM transmitter according to the above embodiment of the invention; and
Figure 5 is a simplified flowchart of particular steps of a method for making an integrated DWDM transmitter according to the embodiment of the present invention.

Detailed Description of the Invention

[0012] The present invention is directed to fiber optical transport systems. More particularly, the invention provides a method and device for reducing the size and cost of optical transmitter systems. Merely by way of example, the invention has been applied to DWDM optical transport systems. But it would be recognized that the invention has a much broader range of applicability.

[0013] As discussed above, the optical components in a conventional DWDM system are usually individually packaged. To a great extent, the packaging cost determines the price of the components. For example, a bare distributed feedback (DFB) laser chip may cost only a few dollars, while a packaged DFB laser sells for several hundred dollars, mostly due to the cost of packaging. It is thus difficult to further reduce the cost with the conventional DWDM system design. In addition, the multiple linecards, each built with the individual components, make it difficult to reduce the size of the DWDM terminals.

[0014] In the last several years, there have been efforts to monolithically integrate multiple lasers/modulators and the AWG onto a single InP chip. In this way, the size of a DWDM terminal can be significantly reduced. Monolithic integration methods rely heavily on InP chip processing technologies, which have yet to reach maturity. The yield of InP processing is low compared to silicon processing, even for single element chips. With multiple elements integrated on a single chip, the yield tends to decrease exponentially. In addition, the AWG, which is a passive element, usually occupies much larger area of the integrated chip than the active elements, such as lasers. This results in an inefficient use of the expensive InP materials.

[0015] As a general rule of thumb, the size of InP wafers is an order of magnitude smaller than silicon wafers. For example, the diameters of InP wafers are typically 2" (5.08 cm) or 3" (7.62 cm), as compared to 8" (20.32 cm) or even 12" (30.48 cm) for silicon wafer. The processing cost per unit area for InP wafers can be two orders of magnitude higher than that for silicon wafers. The low chip yield, coupled with high processing cost, makes it uneconomical to monolithically integrate a DWDM transmitter on an InP chip. From the above, it is seen that an improved technique for DWDM transmitter design is desired.

[0016] The present invention includes various features, which may be used. These features include the following:

1. A silica-on-silicon planar lightwave circuit (PLC) is used as a bench to mount the InP chips, so that the passive waveguides of the PLC are optically coupled to the active InP waveguides, such as semiconductor lasers.

2. A hybrid integrated DWDM transmitter includes one or more multiple direct modulated laser (DML) array chips made of InP and an arrayed waveguide grating (AWG) made of silica-on-silicon planar lightwave circuit (PLC); and

3. A method is provided for maintaining the center wavelengths of integrated DWDM transmitter using an optical analyzer and a thermal electric cooler (TEC) coupled to the integrated transmitter.

[0017] As shown, the above features may be in one or more of the embodiments. These features are merely examples, which should not unduly limit the scope of the application. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0018] Figure 1A is a simplified, top view diagram, of a hybrid integrated DWDM transmitter according to an illustrative example not falling under the claims. This diagram is merely an example. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. As shown, hybrid integrated DWDM transmitter 100 includes a.silicon bench 101. In a specific example, the silicon bench 101 includes a silica-on-silicon substrate. Hybrid transmitter 100 also includes an optical multiplexer in the silicon bench. In a specific example, the optical multiplexer includes an arrayed waveguides grating (AWG) 110 made in a silica-on-silicon planar lightwave circuit (PLC) in the silicon bench. Hybrid transmitter 100 further includes one or more multiple laser array chips, e.g., 114 and 115. In a preferred example, the laser array chips include DML lasers made in InP. In a specific example, each InP laser array chip includes two or more lasers. Of course, there can be other variations, modifications, and alternatives.

[0019] In a specific example the AWG 110 includes one optical output port 112, multiple input ports 113, and grating waveguides 116. In an example, the output port 112 is optically coupled to an optical fiber 119, which may be coupled to an optical transmission system. The output and input ports, for example, can all be implemented in the form of waveguides. In a specific example, the grating waveguides 116 include a number of waveguides for coupling to the input and output ports. These waveguides have varying lengths for performing wavelength division multiplexing and demultiplexing functions. In some examples, each input port of the AWG has a center wavelength and pass band associated with light transmission. In a specific embodiment, the center wavelength corresponds to a particular wavelength associated with a frequency defined by ITU-T standards, for example, 193.1 THz.

[0020] Figure 1B is a simplified cross-sectional view diagram of the hybrid integrated DWDM transmitter 100 according to an example not falling under the claims This diagram is merely an example One of ordinary skill in the art would recognize other variations, modifications, and alternatives. As shown, a waveguide includes doped silica region 121 enclosed in an undoped silica layer 122 on a silicon substrate 124. In a specific example, the doped silica region 121 has a higher index of refraction than the undoped silica region. In a specific example, the doped silica region 121 has a index of refraction of about 1.47, and the undoped silica region has a index of refraction of about 1 45 In Figure 1B, waveguide 121 is used to illustrate a cross sectional view of parts of waveguides in input port 113, grating waveguides 116, and output port 112.

[0021] Integrated transmitter 100 includes one or more laser array chips, and each laser array chip may include two or more lasers In the specific example shown in Figure 1A, the integrated transmitter 100 includes two direct-modulated laser (DML) array chips 114 and 115 In this specific example, each of DML array chips 114 and 115 includes four direct-modulated lasers (DMLs) made in InP In a specific example, the DMLs are of the types of distributed feedback (DFB) lasers and hence are operated in single frequency mode. In some, example, each DML works around a particular wavelength (frequency) defined by ITU-T standards, for example, 193.1 THz. Of course, one of ordinary skill in the art would recognize other variations, modifications, and alternatives

[0022] The DML arrays can also be single DML chips The DMLs can be substituted by integrated CW lasers and modulators, for example, an integrated DFB laser with an electro-absorption (EA) modulator. The lasers can also be distributed Bragg grating (DBR) lasers. The AWG can be substituted by a broadband N x 1 PLC waveguide combiner An erbium doped fiber amplifier (EDFA) or an erbium doped waveguide amplifier (EDWA) can be used to compensate for the excess loss of the broadband combiner.

[0023] As shown in Figure 1A, the DML array chips are mounted on a portion of the silicon, bench 101, in the vicinity of the input ports 113 of the AWG 110. This mounting is performed using a p-side down, flip-chip method. Other bonding methods using suitable adhesives can also be used. In Figure 1B, the silicon bench 101 includes a silica-on-silicon substrate. A region of the silicon bench includes the AWG waveguide. In another region of the silicon bench, a portion of the silica is removed, and the DML array chips are mounted, on the surface of the remaining silica over the silicon substrate. Alternatively, the silica layer in a second region of the silicon bench is removed, and the DML array chips are mounted on the exposed silicon surface.

[0024] The silicon bench may be mounted on a support component 130, as shown in Figure 1B. The support component 130 may include an optional submount 132 and a temperature adjustment component 134. The temperature adjustment component keeps the optical components such as the waveguides, the AWG and the DMLs at a suitable operating temperature, for example ~25°C. In the specific embodiment, the temperature adjustment component includes a thermal electric cooler (TEC). In certain embodiments, integrated, transmitter 100 also includes a micro heater in a proximity to each of the lasers for temperature adjustment. At the operating temperature, the center wavelengths of the DMLs may be matched approximately to those of the AWG input ports, for example, 193.1 THz, 193.2 THz, 193.3 THz, etc. Typically, the center wavelengths of the AWG can shift with temperature by ~0.01nm/°C, and the center wavelengths of the InP lasers shift with temperature by ~0.1nm/°C. The support component 130 also includes a submount 132 on the temperature adjustment component 134. In an embodiment, the submount 132 is made of materials containing metal or ceramics which provide mechanic strength. The submount also has good thermal conductance as required for the temperature adjustment component to control the temperature of the optical components, such as the laser and waveguide.

[0025] According to an embodiment of the present invention, a main difficulty of hybrid integration is due to the spatial mode mismatch between the two types of waveguides. For applications in 1.550nm wavelength window, mode diameters of standard silica PLC are typically about 8-10μm, with output beam divergence of about 7-10°, similar to those of standard single mode fibers. Mode diameters of standard InP lasers, on the other hand, are typically about 2 μm, with output beam divergence of about 35°. Due to the mode mismatch, the optical coupling efficiency is low, with typical 10dB coupling loss. The required placement accuracy is also high due to the large divergence angle of the laser output. These drawbacks can severely limit the usefulness of the hybrid method

[0026] In specific embodiments of the present invention, mode converters (or beam expanders) in the InP chips are used to increase the laser output mode diameter comparable to that of the PLC waveguide. This reduces the coupling loss to ~3dB and to relax alignment requirements. According to embodiments of the invention, methods are provided for improved alignment and reduced coupling loss. Further details are discussed betow

[0027] Figures 2A is a simplified expanded top view diagram of a hybrid integrated DWDM transmitter according to an illustrative example. These diagrams are merely examples, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. As shown in Figure 2A, hybrid integrated DWDM transmitter 200 includes waveguides 212 and 213 that are coupled to an optical multiplexer, such as an arrayed waveguide grating (AWG) (not shown). As an example, the waveguides and the AWG are made in silica-on-silicon planar lightwave circuit (PLC), as described in Figure 1A. Integrated transmitter 200 also includes DFB lasers 214 and 215. Examples of DFB lasers were discussed above in connection with Figures 1A and 1B The waveguides 212 and 213 are positioned at a slanted angle with respect to the lasers 214 and 215, respectively, to minimize the reflection form the AWG input waveguide facets, since DFB laser's performance tends to be degraded by light reflections. This slanted arrangement is shown as 217 in Figure 2A The reflected light is at an angle of about 20° or greater off the laser axis.

[0028] Figure 2B is a simplified expanded cross-sectional view diagram of the hybrid integrated DWDM transmitter 200. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. As shown, the cross section view of transmitter 200 includes silica waveguide 213 enclosed in an undoped silica layer 222 on a silicon substrate 224. The laser waveguide 215 is aligned to the silica waveguide 213 both vertically and horizontally with accuracies about $\pm 2\ \mu$m. In some embodiments, there is no direct contact between facets (output ports) of laser 215 and the silica waveguide 213. In a specific example, the distance 218 between the facets is kept to within about 30 μm. Of course, there can be other variations, modifications, and alternatives.

[0029] The physical separation between the individual lasers in the array, and hence the separation between the corresponding AWG input waveguides may be kept large enough to minimize thermal crosstalk and electrical crosstalk due to the high speed data modulations. Merely as an example, as shown in Figure 2A, a suitable distance between lasers 214 and 215 is about 0.3-0.5 mm.

[0030] The laser chips, the AWG, and the support component including the TEC, after proper electrical wire bonding, may be put inside a single package to form a DWDM transmitter. Depending upon the embodiments, the transmitter can have various inputs and outputs. For example, the transmitter can have multiple electrical inputs that control and monitor the temperatures of the AWG and DMLs, the DC currents and RF modulations of the DMLs, etc. In another example, the transmitter has a single optical output, typically through an optical fiber pigtail, sending out the multiple-channel DWDM signals,

[0031] Another important issue in the hybrid integration is thermal expansion mismatch between InP and silicon. Thermal expansion coefficient of InP is about 4.6x10-6 °C-1, and that of silicon is about 2.6x 10-6°C-1. In a specific embodiment of the invention, the bonding of the DMLs and the AWG is performed at about 300°C, while the operating temperature of the transmitter is about 30°C. Thus a 2 mm chip, which is about the size of a four DML array, will shrink by $\sim 1.1\ \mu$m relative to the silicon substrate (AWG) after the bonding. Such mismatch would not only affect the waveguide alignment, but also introduces strains on the laser chip, which could degrade laser performance. For example, the strain may cause the center wavelengths of the lasers to shift away from the designed wavelengths.

[0032] The thermal mismatch problem can be minimized by using single DML chips. However, this will significantly increase the time to assemble the laser chips to the PLC bench. The problem can become more acute as the number of DWDM channels becomes large, for example, N = 40. According to another embodiment of the invention, multiple small DML arrays, each with size $\leq$ 2 mm, are preferred for the DWDM transmitter. Each DML laser array may include two or more lasers. Of course, there can be other variations, modifications, and alternatives. For example, by using a low-temperature bounding method, DML arrays with size > 2 mm can be included, according to some embodiments of the present invention.

[0033] A method may be employed for fine adjustment of the center wavelengths of the DMLs. Due to the manufacturing tolerance, the center wavelengths of the lasers may not fall exactly on the ITU-T grid at the temperature adjustment component operating temperature. The variation, for example is typically on the order of 1 nm. A micro heater is used to raise a temperature of a DML waveguide. For example, a micro heater is placed adjacent to each DML waveguide, either on the laser chip or on the PLC. According to a specific embodiment of the invention, by raising the local temperature to about 0-10 °C relative to the substrate, one can fine tune the center wavelengths of the DMLs to the ITU grids. Further details of the method are discussed below with reference to Figure 3.

[0034] Figure 3 is a simplified view diagram of an integrated DWDM transmitter system according to the embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. As shown, integrated transmitter system 300 includes a hybrid integrated transmitter 350 similar to transmitter 100 discussed above in connection with Figures 1A and 1B. For easy reference, corresponding parts of the devices are marked by identical numerals. As shown, hybrid integrated transmitter 350 includes a laser 115, a silica waveguide 121 formed in a silicon bench 101 which includes undoped silica layer 122 overlying a silicon layer 124. The silicon, substrate 124 overlies a support component 130, which includes temperature adjustment component 134, such as a thermal electric cooler (TEC), and an optional submount 132. In a specific embodiment, integrated transmitter system 300 also includes a micro heater 335 in a proximity to the laser 115, an optical analyzer 362, and a controller 364. The optical analyzer 362 is optically coupled to an output waveguides in the integrated DWDM transmitter, which may be optically coupled to an optical communication system through optical fiber 119. The controller 364 is electrically coupled to the optical analyzer 362 and the micro heater 335. A micro heater is placed adjacent to each laser, either on the laser chip or on the PLC. In a specific embodiment, the micro heater is a resistive element, such as a metal strip, deposited in a proximity to laser 115 as shown in Figure 3.

[0035] Although the above has been shown using a selected group of components for the integrated DWDM transmitter system, there can be many alternatives, modifications, and variations. For example, some of the components may be expanded and/or combined. Other components may be inserted to those noted above. Depending upon the embodiment, the arrangement of components may be interchanged with others replaced. For example, integrated transmitter 350 may include features in transmitter 200 discussed above in connection with Figures 2A and 2B.

[0036] Figure 4A is a simplified flowchart of a method for maintaining a target wavelength in an integrated DWDM transmitter according the invention. Figures 4B-4D are simplified wavelength diagrams according to the method. These diagrams are merely examples, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. The method can be briefly outlined below, with reference to the integrated DWDM system in Figure 3, the flowchart in Figures 4A, and the wavelength diagrams in Figure 4B-4D.

1. (Process 410) Determine laser wavelengths distribution at a predetermined global TEC temperature. An example of wavelength distribution at TEC temperature of 25°C is shown in Figure 4B.

2. (Process 420) Adjust the TEC to a second global temperature to shift the all laser wavelengths to below the target wavelengths for the corresponding ITU-T grids. An example is shown in Figure 4C.

3. (Process 430) For each laser, determine a center frequency at an output waveguide, using the optical analyzer 362;

4. (Process 440) Determine a deviation between the measured center wavelength and the target wavelength, using the controller 364;

5. (Process 450) Adjust a temperature of the micro heater 335, using the controller 364, to increase the center wavelength of the laser to approach the corresponding target wavelength according to the ITU-T grids. Figure 4D is an example of wavelengths shifted to the corresponding target wavelengths according to the ITU-T grids.

[0037] The above sequence of processes provides a method for maintaining a target wavelength associated with an integrated DWDM transmitter according to an embodiment of the invention. As shown, the method uses a combination of processes including a way of using the TEC to shift all laser wavelengths to the shorter wavelength side of the grids and using local micro heaters to increase the local temperature at each laser as needed to shift all laser wavelengths to the ITU-T grids. Other alternatives can also be provided in which steps are added, one or more steps are removed, or one or more steps are provided in a different sequence without departing from the scope of the claims herein. Further details of the present method can be found throughout the present specification.

[0038] Figure 5 is a simplified flowchart of particular steps of a method for making an integrated DWDM transmitter according to an embodiment of the invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. The method can be briefly-outlined below, with reference to the flowchart in Figure 5.

1. (Process 510) Provide a silicon layer;

2. (Process 520) Form an optical multiplexer in a silica layer over the silicon layer;

3. (Process 530) Remove at least a first portion of the silica layer to expose a surface;

4. (Process 540) Mount one or more semiconductor laser array chips to the surface; and

5. (Process 550) Attach the silicon layer to a support component

[0039] As shown, Figure 5 provides a method for making an integrated DWDM transmitter apparatus. The method includes (Process 510) providing a silicon layer and (Process 520) forming an optical multiplexer within a silica layer located on the silicon layer. In an embodiment, the optical multiplexer includes a plurality of input waveguides and at least an output waveguide. In a specific embodiment, the optical multiplexer includes an array waveguide grating. In Process 530, the method includes removing at least a first portion of the silica layer to expose a surface. Depending on the embodiment, the exposed surface can be a silicon surface or a silica surface. In Process 540 the method also includes mounting one or more semiconductor laser array chips to the surface. Each of the laser array chips includes two or more InP laser diodes. The mounting can be performed, for example, using a flip-chip mounting method. Each of the one or more laser array chips includes two or more lasers and each of the two or more lasers is optically coupled to a corresponding one of the plurality of input waveguides. The method includes (Process 550) attaching the silicon layer to a support component, the support component including a temperature adjustment component. In a specific embodiment, the process of forming the optical multiplexer (Process 520) includes the following processes: forming a first un-doped silica sub-layer on the silicon layer; forming a doped silica sub-layer on the first un-doped silica sub-layer; etching at least a second portion of the doped silica sub-layer; and depositing a second un-doped silica sub-layer on the etched doped silica sub-layer and the first un-doped silica sub-layer.

[0040] The above sequence of processes provides a method for making an integrated DWDM transmitter apparatus according to an embodiment of the invention. As shown, the method uses a combination of processes including a way of making an optical multiplexer in a silica-on-silicon substrate and mounting laser array chips on a portion of the substrate. Other alternatives can also be provided in which steps are added, one or more steps are removed, or one or more steps are provided in a different sequence without departing from the scope of the claims herein. Further details of the present method can be found throughout the present specification.

[0041] Many benefits are achieved by way of the present invention over conventional techniques. For example, in certain embodiments, the invention provides methods and apparatus that use a silica/silicon AWG as a substrate to mount semiconductor (InP) laser/modulator chips. Because the processing cost per unit area for silica-on-silicon can be two orders of magnitude lower than that for InP, the AWG according to embodiments of the present invention can be made at much lower cost. Silica-on-silicon A WGs is a much more mature technology. For example, transmission loss is much smaller in AWGs made of silica-on-silicon than those made of InP. Moreover according to an embodiment of the invention, without the AWG, the InP chip can be made much smaller. The high yield and the small size significantly reduce the cost of the InP chips used for hybrid integration in accordance to embodiments of the present invention. In term of finished device, the size of a hybrid integrated DWDM transmitter according to specific embodiments of the invention is comparable to that of a monolithically integrated DWDM transmitter. Thus the small size advantage of an integrated DWDM transmitter is retained according to embodiments of the present invention.

[0042] While the preferred embodiments of the invention have been illustrated and described, it will be clear that the invention is not limited to these embodiments only. Numerous modifications, changes, variations, substitutions and equivalents will be apparent to those skilled in the art without departing from the scope of the invention as described in the claims

Claims

1. A method for making an integrated DWDM transmitter apparatus, the method comprising:

    providing a silicon layer;
    forming an optical multiplexer within a silica layer, the silica layer being located on the silicon layer, the optical multiplexer including a plurality of input waveguides and at least an output waveguide;
    removing at least a first portion of the silica layer to expose a surface;
    mounting one or more semiconductor laser array chips to the surface, each of the one or more semiconductor laser array chips including two or more lasers, each of the two or more lasers being optically coupled to a corresponding one of the plurality of input waveguides;
    attaching the silicon layer to a support component, the support component including a temperature adjustment component;
    wherein the forming the optical multiplexer includes:

        forming a first un-doped silica sub-layer on the silicon layer;
        forming a doped silica sub-layer on the first un-doped silica sub-layer;
        etching at least a second portion of the doped silica sub-layer;
        depositing a second un-doped silica sub-layer on the etched doped silica sub-layer and the first un-doped silica sub-layer and **characterized by** that mounting one or more semiconductor laser array chips to the surface comprises:

    coupling each of the two or more lasers and the corresponding one of the plurality of input waveguides by a slanted angle of about 20° or greater,

providing a plurality of micro-heaters (335) for temperature adjustment, with each micro-heater being disposed adjacent to each of the two or more lasers;
providing an optical analyzer (362) and a contoller (364), with the optical analyzer being optically coupled to an output waveguide in the integrated DWDM transmitter apparatus, and the controller (364) being electrically coupled to the optical analyzer and the micro heaters (335).

2. The method of claim 1 wherein each of the one or more semiconductor laser array chips includes two or more laser diodes made in InP.

3. The method of claim 1 wherein the exposed surface is a silicon surface or a silica surface.

4. The method of claim 1 wherein the mounting of one or more semiconductor laser array chips is performed using a flip-chip mounting method.

5. The method of claim 1, wherein the temperature adjustment component is a thermal electric cooler (TEG).

6. The method of claim 1, wherein mounting one or more semiconductor laser array chips to the surface comprises:

separating the two or more lasers associated with each of the one or more laser array chips by a distance of about 0.3-0.5 mm.

7. The method of claim 1, wherein mounting one or more semiconductor laser array chips to the surface comprises:

coupling each of the two or more lasers and the corresponding one of the plurality of input waveguides by a gap of about 30 μm or smaller.

8. The method of claim 1, wherein each of the one or more semiconductor laser array chips is **characterized by** a width of 2 mm or smaller in the direction perpendicular to a laser axis.

9. The method of claim 1 wherein each of the one or more semiconductor laser array chips comprises one of the group consisting of:

direct-modulated lasers,
distributed feedback (DFB) lasers;
integrated DFB laser with an electro-absorption (EA) modulator, and
distributed Bragg grating (DBR) lasers.

10. An integrated, DWDM transmitter apparatus produced according to a method claimed in claims 1-9.

Patentansprüche

1. Verfahren zum Herstellen einer integrierten DWDM-Sendervorrichtung, wobei das Verfahren Folgendes umfasst:

Bereitstellen einer Siliciumschicht;
Bilden eines optischen Multiplexers in einer Siliciumdioxidschicht, wobei sich die Siliciumdioxidschicht auf der Siliciumschicht befindet, wobei der optische Multiplexer mehrere Eingangswellenleiter und wenigstens einen Ausgangswellenleiter enthält;
Entfernen wenigstens eines ersten Abschnitts der Siliciumdioxidschicht, um eine Oberfläche freizulegen;
Anbringen eines oder mehrerer Halbleiterlaser-Anordnungs-Chips auf der Oberfläche, wobei jeder der ein oder mehreren Halbleiterlaser-Anordnungs-Chips zwei oder mehr Laser enthält, wobei jeder der zwei oder mehr Laser mit einem entsprechenden der mehreren Eingangswellenleiter optisch gekoppelt ist;
Befestigen der Siliciumschicht an einer Halterungskomponente, wobei die Halterungskomponente eine Temperatureinstellkomponente enthält;
wobei das Bilden des optischen Multiplexers Folgendes enthält:

Bilden einer ersten undotierten Siliciumdioxid-Unterschicht auf der Siliciumschicht;
Bilden einer dotierten Siliciumdioxid-Unterschicht auf der ersten undotierten Siliciumdioxid-Unterschicht;
Ätzen wenigstens eines zweiten Abschnitts der dotierten Siliciumdioxid-Unterschicht;
Abscheiden einer zweiten undotierten Siliciumdioxid-Unterschicht auf der geätzten dotierten Siliciumdioxid-Unterschicht und der ersten undotierten Siliciumdioxid-Unterschicht und
dadurch gekennzeichnet, dass das Anbringen des einen oder der mehreren Halbleiterlaser-Anordnungs-Chips auf der Oberfläche Folgendes umfasst:

Koppeln jedes der zwei oder mehr Laser und des entsprechenden der mehreren Eingangswellenleiter in einem schrägen Winkel von etwa 20° oder größer,
Bereitstellen mehrerer Mikroheizvorrichtungen (335) für die Temperatureinstellung,
wobei jede Mikroheizvorrichtung jedem der zwei oder mehr Laser benachbart angeordnet ist;

Bereitstellen eines optischen Analysators (362) und einer Steuereinrichtung (364),
wobei der optische Analysator in der integrierten DWDM-Sendervorrichtung an einen Ausgangswellenleiter optisch gekoppelt ist und die Steuereinrichtung (364) an den optischen Analysator und die Mikroheizvorrichtungen (335) elektrisch gekoppelt ist.

2. Verfahren nach Anspruch 1, wobei jeder der ein oder mehreren Halbleiterlaser-Anordnungs-Chips zwei oder mehr Laserdioden enthält, die in InP hergestellt sind.

3. Verfahren nach Anspruch 1, wobei die freigelegte Oberfläche eine Siliciumoberfläche oder eine Siliciumdioxidoberfläche ist.

4. Verfahren nach Anspruch 1, wobei das Anbringen des einen oder der mehreren Halbleiterlaser-Anordnungs-Chips unter Verwendung eines Flip-Chip-Montageverfahrens ausgeführt wird.

5. Verfahren nach Anspruch 1, wobei die Temperatureinstellkomponente ein thermoelektrischer Kühler (TEC) ist.

6. Verfahren nach Anspruch 1, wobei das Anbringen des einen oder der mehreren Halbleiterlaser-Anordnungs-Chips auf der Oberfläche Folgendes umfasst:

Trennen der zwei oder mehr Laser, die jedem des einen oder der mehreren Laser-Anordnungs-Chips zugeordnet sind, um einen Abstand von etwa 0,3-0,5 mm.

7. Verfahren nach Anspruch 1, wobei das Anbringen des einen oder der mehreren Halbleiterlaser-Anordnungs-Chips auf der Oberfläche Folgendes umfasst:

Koppeln jedes der zwei oder mehreren Laser und des entsprechenden der mehreren Eingangswellenleiter mit einem Spalt von etwa 30 μm oder kleiner.

8. Verfahren nach Anspruch 1, wobei jeder der ein oder mehreren Halbleiterlaser-Anordnungs-Chips durch eine Breite von 2 mm oder kleiner in der Richtung senkrecht zur Laserachse gekennzeichnet ist.

9. Verfahren nach Anspruch 1, wobei jeder der ein oder mehreren Halbleiterlaser-Anordnungs-Chips einen aus der Gruppe umfasst, die aus Folgendem besteht:

direkt modulierte Laser;
Laser mit verteilter Rückkopplung (DFB-Laser);
integrierte DFB-Laser mit einem Elektroabsorptions-Modulator (EA-Modulator) und
verteilte Bragg-Gitter-Laser (DBR-Laser).

10. Integrierte DWDM-Sendervorrichtung, die nach einem Verfahren nach den Ansprüchen 1-9 hergestellt ist.

Revendications

1. Procédé de fabrication d'un appareil émetteur DWDM intégré, le procédé comprenant les étapes consistant à :

utiliser une couche de silicium ;
former un multiplexeur optique au sein d'une couche de silice, la couche de silice étant disposée sur la couche de silicium, le multiplexeur optique comportant une pluralité de guides d'ondes d'entrée et au moins un guide d'ondes de sortie ;
éliminer au moins une première partie de la couche de silice pour découvrir une surface ;
monter une ou plusieurs puces à réseaux de lasers à semiconducteur sur la surface, la ou chacune des puces à réseaux de lasers à semiconducteur comportant au moins deux lasers, chacun desdits au moins deux lasers étant couplé optiquement à un guide d'ondes d'entrée correspondant parmi la pluralité de guides d'ondes d'entrée ;
fixer la couche de silicium à un composant support, le composant support comportant un composant de réglage de la température ;
l'étape consistant à former le multiplexeur optique comportant les étapes consistant à:

former une première sous-couche de silice non dopée sur la couche de silicium ;
former une sous-couche de silice dopée sur la première sous-couche de silice non dopée ;
éliminer par attaque chimique au moins une deuxième partie de la sous-couche de silice dopée ;
déposer une deuxième sous-couche de silice non dopée sur la sous-couche de silice dopée ayant fait l'objet d'une attaque chimique et la première sous-couche de silice non dopée ; et
le procédé étant **caractérisé en ce que** l'étape consistant à monter une ou plusieurs puces à réseaux de lasers à semiconducteur sur la surface comprend les étapes consistant à :

coupler chacun desdits au moins deux lasers et le guide d'ondes d'entrée correspondant parmi

la pluralité de guides d'ondes d'entrée selon un angle d'inclinaison supérieur ou égal à environ 20° ;
utiliser une pluralité de micro-éléments de chauffage (335) pour assurer un réglage de la température, chaque micro-élément de chauffage étant disposé en position adjacente à chacun desdits au moins deux lasers ;
utiliser un analyseur optique (362) et une unité de commande (364), l'analyseur optique étant couplé optiquement à un guide d'ondes de sortie dans l'appareil émetteur DWDM intégré, et l'unité de commande (364) étant couplée électriquement à l'analyseur optique et aux micro-éléments de chauffage (335).

2. Procédé selon la revendication 1, la ou chacune des puces à réseaux de lasers à semiconducteur comportant au moins deux diodes laser constituées de InP.

3. Procédé selon la revendication 1, la surface découverte étant une surface de silicium ou une surface de silice.

4. Procédé selon la revendication 1, l'étape consistant à monter la ou les puces à réseaux de lasers à semiconducteur étant mise en oeuvre à l'aide d'un procédé de montage de type flip-chip.

5. Procédé selon la revendication 1, le composant de réglage de la température étant un refroidisseur thermoélectrique (TEC).

6. Procédé selon la revendication 1, l'étape consistant à monter la ou les puces à réseaux de lasers à semiconducteur sur la surface comprenant l'étape consistant à :

séparer lesdits au moins deux lasers associés à la ou à chacune des puces à réseaux de lasers d'une distance d'environ 0,3 à 0,5 mm.

7. Procédé selon la revendication 1, l'étape consistant à monter la ou les puces à réseaux de lasers à semiconducteur sur la surface comprenant l'étape consistant à :

coupler chacun desdits au moins deux lasers et le guide d'ondes d'entrée correspondant parmi la pluralité de guides d'ondes d'entrée en ménageant un espace inférieur ou égal à environ 30 μm.

8. Procédé selon la revendication 1, la ou chacune des puces à réseaux de lasers à semiconducteur étant **caractérisée par** une largeur inférieure ou égale à 2 mm dans la direction perpendiculaire à un axe de laser.

9. Procédé selon la revendication 1, la ou chacune des puces à réseaux de lasers à semiconducteur comprenant un élément choisi dans le groupe constitué par :

des lasers à modulation directe,
des lasers à rétroaction répartie (DFB),
un laser DFB intégré comportant un modulateur à électroabsorption (EA), et
des lasers à réseau de Bragg réparti (DBR).

10. Appareil émetteur DWDM intégré, fabriqué conformément à un procédé selon les revendications 1 à 9.

FIG. 1A

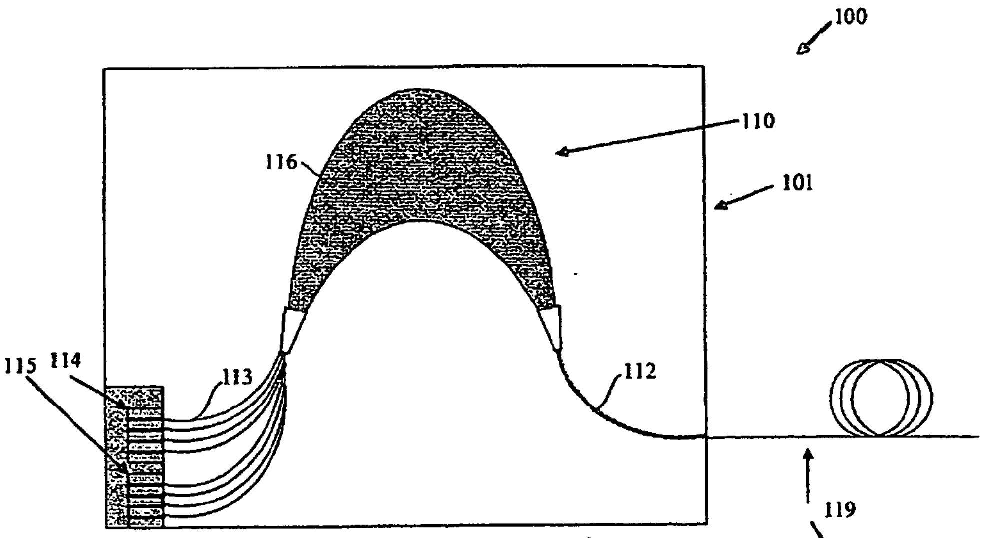

100
110
116
101
114
115
113
112
119

FIG. 1B

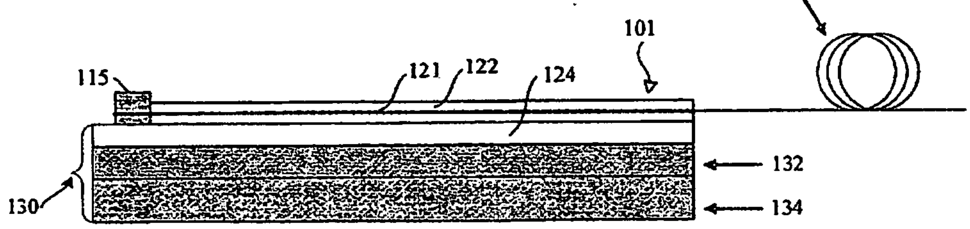

101
115
121
122
124
132
130
134

FIG. 2A

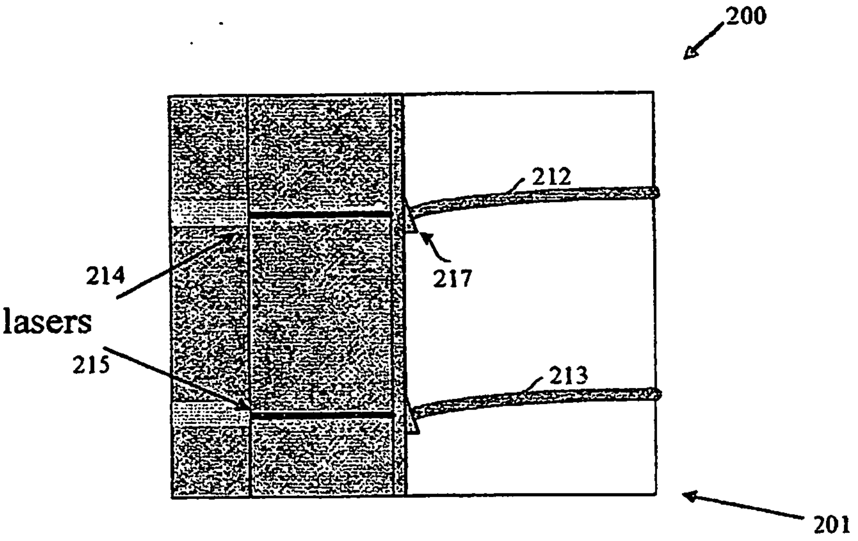
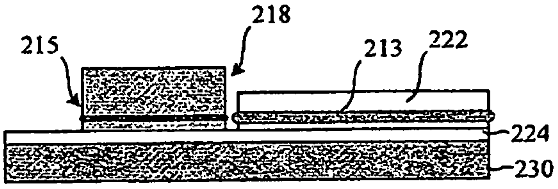


FIG. 2B



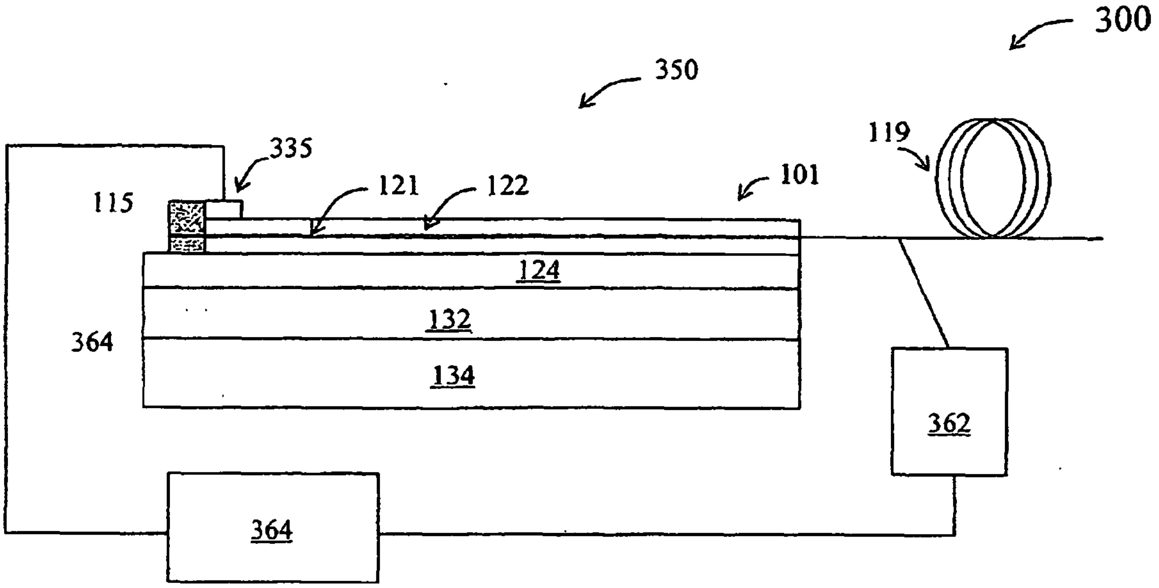


FIG. 3

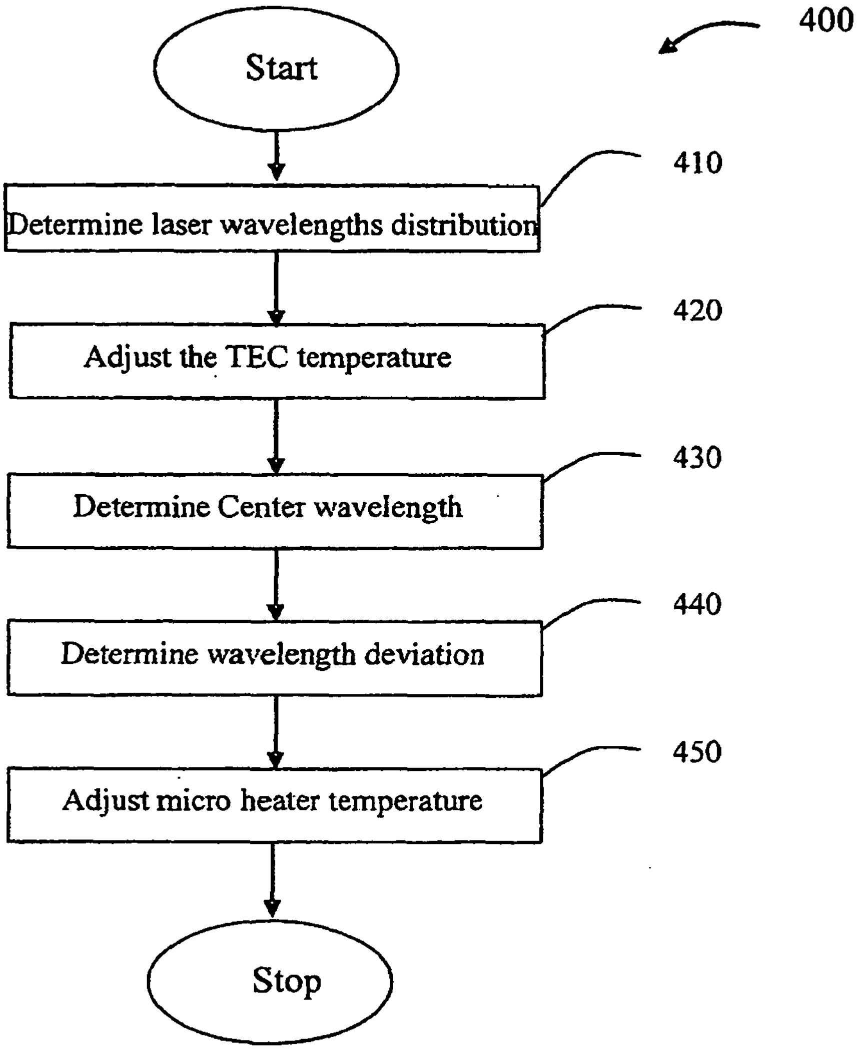

400
Start
410
Determine laser wavelengths distribution
420
Adjust the TEC temperature
430
Determine Center wavelength
440
Determine wavelength deviation
450
Adjust micro heater temperature
Stop

FIG. 4A

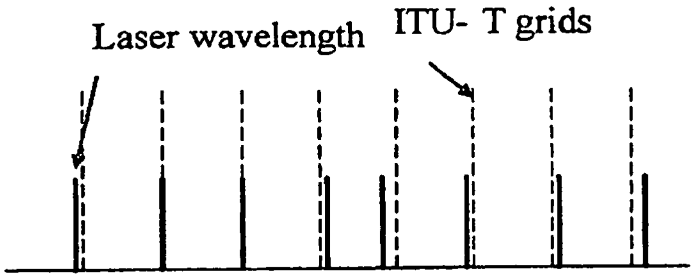


FIG. 4B

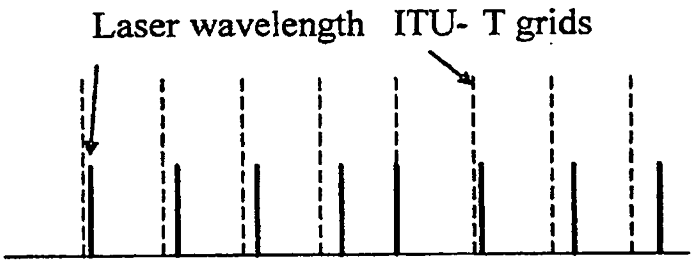


FIG. 4C

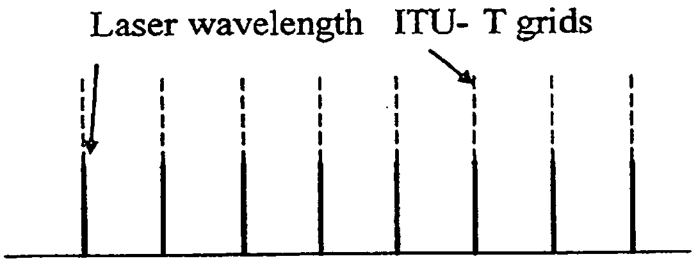


FIG. 4D

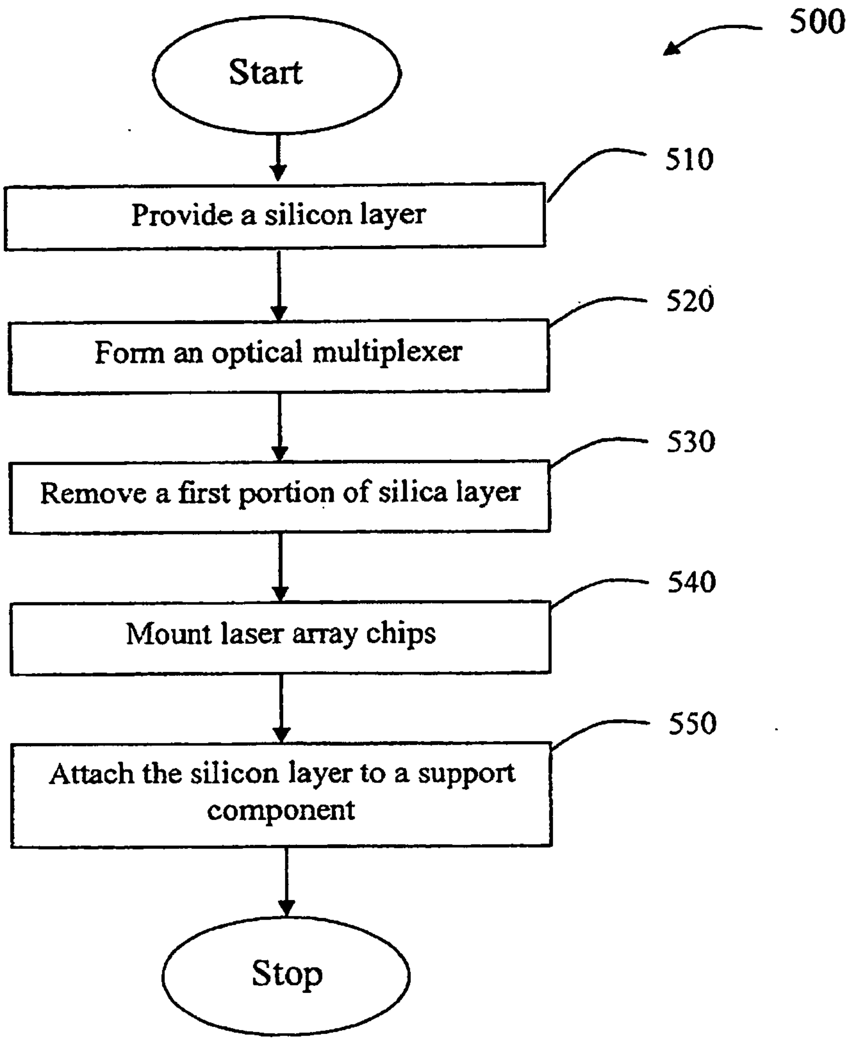

500
Start
510
Provide a silicon layer
520
Form an optical multiplexer
530
Remove a first portion of silica layer
540
Mount laser array chips
550
Attach the silicon layer to a support component
Stop

FIG. 5

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 1028503 A2 **[0005]**
- WO 0133268 A1 **[0007]**

Non-patent literature cited in the description

- **KANEKO et al.** Design and applications of silica-based planar Lightwave circuits. *IEE journal of Selected Topics in Quantum Electronics,* September 1999, vol. 5 (5 **[0006]**
- **TERVONEN et al.** Control of wavelength alignment in wavelength division multiple access passive optical network. *Electronics Letters,* January 2003, vol. 39 (2 **[0008]**