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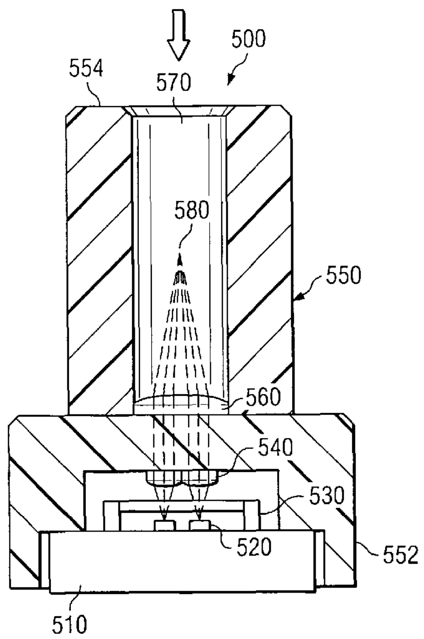
(54) **Title:** METHOD AND APPARATUS FOR WAVELENGTH DIVISION MULTIPLEXING



(57) **Abstract:** An apparatus and method of Wavelength Division Multiplexing (WDM) are provided. The WDM multiplexer (500) includes a plurality of lasers (520), a plurality of collimating lenses (540) and a single focusing lens (560). Each lens of the plurality of lenses (540) is positioned so as to collimate a beam of light emitted by a laser of the plurality of lasers (540). The focusing lens (560) is positioned to focus a plurality of collimated beams of light received from the plurality of lenses (540) into substantially a point of light (580). The WDM multiplexer (500) includes a receptacle (550) that houses the plurality of lasers (520), the plurality of collimating lenses (540) and the focusing lens (560).

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METHOD AND APPARATUS FOR WAVELENGTH DIVISION MULTIPLEXING

PROVISIONAL APPLICATIONS

The present invention claims benefit of priority to U.S. Provisional Patent Application Serial No. 60/506,795 entitled "GSE Laser Enabled WDM Mux," filed on September 29, 2003, and which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Technical Field:

The present invention is directed generally toward an apparatus and method for Wavelength Division Multiplexing (WDM). More specifically, the present invention is directed to a grating-coupled surface emitting (GSE) laser enabled WDM multiplexer and method of multiplexing using a GSE WDM multiplexer.

2. Description of Related Art:

Figure 1 is an exemplary diagram of a known 10GbE LX4 multiplexer (see IEEE standard P802.03ae) which is used to multiplex different wavelengths of light into a single multiplexed beam that is output via a fiber ferrule. As shown in **Figure 1,** in this known architecture, the LX4 multiplexer includes an edge emitting laser array **110** in which edge emitting lasers of different wavelength beams emit beams of light that pass through the collimating lens array **120** and filter array **130**. The filter array **130** contains a plurality of filters that pass through one particular wavelength of light while other wavelengths of light are reflected by the filter array **130**. The light beams that have wavelengths of light that pass through the filter array **130** enter glass block **140** which acts as a bounce cavity. The light beams entering the glass block **140** bounce down the length of the glass block **140** and exit an end of the glass block **140** and are reflected by mirror **150** toward focusing lens **160**. The lens **160** focuses the light beams reflected by the mirror **150** to a focal point. In this way, the multiple light beams from edge emitting laser array **110** are multiplexed into a single beam that is output via an exit channel into which a fiber ferrule may be plugged.

The above architecture for a 10GbE LX4 multiplexer permits combining or separating a plurality of light signals. However, this architecture has a number of drawbacks. The light beams emitted from the edge emitting laser array **110** lose power as they pass through the collimating lens array **120**, the filter array **130** and bounce down the bounce cavity provided by the glass block **140**. This means that to compensate for this loss in power, the light beams emitted from the edge emitting laser array **110** must have a higher initial intensity resulting in a large power requirement for the edge emitting laser array **110**.

Moreover, as shown in **Figure 1**, the light beam having a first wavelength λ_1 loses more power as it traverses the bounce cavity of the glass block **140** than the other wavelengths of light since the first wavelength light beam must perform more "bounces" down the bounce cavity with power loss at each "bounce." As a result, the first wavelength λ_1 light beam needs to be of a higher intensity than the second and higher wavelength light beams. Similarly, the second wavelength light beam must have a higher initial intensity than the third and higher wavelength light beams, and so on. Thus, the edge emitting lasers in the edge emitting laser array **110** must have different power requirements in order to provide different intensity light beam signals.

Figures 2A-2C show other configurations of known edge emitting laser based multiplexers. **Figure 2A** illustrates a known configuration of an edge emitting laser multiplexer in which the light beam signals from the edge emitting lasers **210** are passed through fiber optic lines **220** to a series of discrete fiber couplers **230** which couple two light beams together. **Figure 2B** illustrates a known configuration of an edge emitting laser multiplexer in which laser diode array **240** outputs light signals down channels **250** in waveguide multiplexer **260** which couples the light signals into a single channel **270** that passes through fiber pigtail in V-groove chip **280**. **Figure 2C** illustrates a known configuration of an edge emitting laser multiplexer similar to that illustrated in **Figure 1** above. As shown in **Figure 2C**, the edge emitting lasers **290** emit light beam signals through lens array **292** and filter array **294**. The light beam signals that pass through the filter array **294** are bounced by the mirror **296** and filter array **294** until they are focused by focusing lens **298** into fiber **299**.

In each of these configurations, large losses in signal power are experienced through the light signal travel path. These losses result in a low coupling efficiency of the light beam signals. For example, for the configurations shown in **Figures 2A** and **2B**, the maximum coupling efficiency is estimated to be 30% or less while the coupling efficiency for the configuration shown in **Figure 2C** is estimated to be at best 60%.

Another disadvantage of the prior art is the need for several assembly steps, many of which require active alignment, in order to obtain sufficient coupling efficiencies. The prior art has many piece parts that need to be assembled. This results in a relatively large piece-part costs and assembly costs. Thus, it would be beneficial to have an improved apparatus and method for Wavelength Division Multiplexing in which there are lower power losses in the travel path of the light beam signals and the efficiency of the light beam signal coupling is improved while achieving a lower cost multiplexer assembly.

SUMMARY OF THE INVENTION

The present invention provides a system, apparatus and method of Wavelength Division Multiplexing (WDM) in which the coupling efficiency is increased and sensitivity to offset of the lasers from an optimum position is made less sensitive. With the present invention, a WDM multiplexer includes a plurality of lasers, a plurality of collimating lenses and a single focusing lens. The term "laser" as it is used in the present description refers to semiconductor lasers rather than the large conventional solid state lasers. Examples of semiconductor lasers include edge emitting lasers, grating-coupled surface emitting (GSE) lasers, and the like.

Each lens of the plurality of lenses is positioned so as to collimate a beam of light emitted by a laser of the plurality of lasers. The focusing lens is positioned to focus a plurality of collimated beams of light received from the plurality of lenses into substantially a point of light. This point of light is a multiplexed light beam signal that is a combination of the individual light beam signals generated by the lasers in the plurality of lasers.

The WDM multiplexer includes a receptacle that houses the plurality of lasers, the plurality of collimating lenses and the focusing lens. The receptacle includes a ferrule sleeve for coupling the point of light to an optical fiber or fiber optic connector. The collimating lenses and focusing lens may be integrated with the receptacle such that they are fashioned as a single unit. Furthermore, at least one laser of the plurality of lasers, at least one lens of the second plurality of lenses, and the focusing lens are arranged in a confocal configuration.

The plurality of lasers may comprise any number of lasers and any configuration of lasers. For example, in one embodiment of the present invention, the plurality of lasers comprises an n-by-n array of lasers, such as a 2-by-2 rectangular array of lasers. Similarly, the plurality of collimating lenses may be an n-by-n array of lenses, such as a 2-by-2 rectangular array of collimating lenses. In another embodiment, the plurality of lasers is a radial array of lasers having 8 lasers in the radial array. Similarly, with this embodiment, the plurality of collimating lenses may be a radial array of 8 lenses.

The WDM multiplexer may further include one or more monitor photodetectors. The one or more monitor photodetectors may be coupled to one or more lasers of the plurality of lasers so as to monitor an energy output from the one or more lasers. The one or more photodetectors may be integrated into one or more of the lasers. Alternatively, the one or more photodetectors may be provided separate from the one or more lasers and be operable to receive a backside emission or edge emission of energy from the one or more lasers.

These and other features and advantages of the present invention will be described in, or will become apparent to those of ordinary skill in the art in view of, the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is a diagram of a known LX4 multiplexer configuration;

Figures 2A-2C are diagrams of other known light beam signal multiplexer configurations;

Figures 3A and **3B** are exemplary diagrams showing the difference in light beam dispersion between a GSE laser and a DFB edge emitting laser;

Figure 4 is an exemplary diagram of a plot of the coupling efficiency versus laser offset from optimum for a GSE laser implemented version of the LX4 multiplexer shown in **Figure 1**;

Figure 5 is an exemplary diagram illustrating a WDM multiplexer configuration in accordance with one exemplary embodiment of the present invention;

Figure 6 is an exemplary diagram illustrating a WDM multiplexer configuration in which monitor photodiodes are provided in accordance with one exemplary embodiment of the present invention;

Figure 7 is an exemplary diagram illustrating the layers of a WDM multiplexer package in accordance with one exemplary embodiment of the present invention;

Figures 8A-8C are exemplary diagrams showing a cutaway view of a WDM multiplexer package, a bottom view of the molded receptacle and an isometric view of the WDM multiplexer package according to one exemplary embodiment of the present invention;

Figures 9A and **9B** are exemplary diagrams illustrating two possible configurations for permitting light beams from the GSE lasers to become incident on monitor photodiodes in accordance with exemplary embodiments of the present invention;

Figures 10A and **10B** are exemplary diagrams illustrating the laser light beams before they pass through the focusing lens and after they pass through the focusing lens in accordance with one exemplary embodiment of the present invention;

Figure 11 is an exemplary diagram illustrating a plot of the coupling efficiency versus laser offset for an exemplary embodiment of the present invention;

Figure 12A-12C are exemplary diagrams of an alternative arrangement of GSE lasers and lenses in accordance with an alternative embodiment of the present invention; and

Figure 13 is an exemplary diagram illustrating a cut-away view of a WDM multiplexer package in accordance with the alternative embodiment shown in **Figure 12**.

DETAILED DESCRIPTION

As mentioned above, known Wavelength Division Multiplexing (WDM) multiplexers experience large losses due to the media, filters, etc. through which the light beam signals must travel while being multiplexed together to form a single beam output. It would be beneficial to reduce these losses to achieve a multiplexer with a higher coupling efficiency. It would further be beneficial to have a multiplexer whose coupling efficiency is less sensitive to offsets of the lasers from their optimum position. The present invention provides WDM multiplexer configurations that achieve these objectives as discussed hereafter.

As discussed above, the known multiplexer configuration shown in **Figure 1**, and the similar configuration shown in **Figure 2C**, achieve a coupling efficiency of approximately 60% meaning that 60% of the incident energy from the original beams is coupled into the output fiber, the rest being lost. Thus, a first attempt to achieve higher coupling efficiency and lower sensitivity to laser position offsets may be based on attempting to improve the configurations shown in **Figures 1** and **2C**. One type of improvement may be to replace the edge emitting lasers of the known configurations with grating-coupled surface emitting (GSE) lasers which are known to have a lower beam divergence. Details regarding GSE lasers may be found in commonly assigned U.S. Patent No. 6,760,359 B2, issued to Evans, entitled "Grating-Outcoupled Surface-Emitting Lasers with Flared Gain Regions", issued on July 6, 2004, and herein incorporated by reference.

Figures 3A and **3B** illustrate the difference in beam divergence between a GSE laser and a distributed feedback (DFB) laser, such as the edge emitting lasers of the known configuration. As shown in **Figure 3A**, with a GSE laser, since there is less divergence of the beam, a lens **310** is able to capture all of the beam **320**. With a DFB laser, such as shown in **Figure 3B**, because the divergence is much larger than the GSE laser, the lens **330** is unable to capture the entire DFB beam **340**. Thus, as a result, the DFB beam experiences larger losses as well as requires additional packaging, e.g., v-groove and lens, to properly align and couple the DFB beam into the multiplexer. As shown in **Figures 3A** and **3B**, the divergence of the GSE laser in the x and y directions is 3 degrees and 11 degrees, respectively, while in the DFB laser the divergence is 15 degrees and 28 degrees, respectively. Thus, one possible improvement to the known configurations is to make use of a GSE laser in the known configurations. For example, rather than using edge emitting lasers in the laser array **110** of the configuration shown in **Figure 1**, GSE lasers may be utilized.

However, it has been determined that replacing the edge emitting laser configuration of **Figure 1** with GSE lasers does not actually improve the coupling efficiency of the WDM multiplexer appreciably. **Figure 4** is an exemplary diagram of a plot of the coupling efficiency versus laser offset from optimum for a GSE laser implemented version of the LX4 multiplexer shown in **Figure 1**. As shown in **Figure 4**, the maximum coupling efficiency achieved by this configuration is approximately 63% coupling efficiency into the multimode fiber. This indicates that most of the loss in coupling efficiency is due to other factors in the configuration other than the laser beam divergence.

It has also been determined that the last channel coupling, i.e. the last wavelength light signal to be coupled by the multiplexer, may be up to 35% lower than the first channel light signal due to losses from multiple bounces in the bounce cavities. With each bounce a fraction of power is lost due to absorption by the filter and other loss mechanisms at the bounce interfaces.

The present invention provides a WDM multiplexer configuration that eliminates much of the loss in coupling efficiency and provides a configuration that is less sensitive to offsets of the lasers from an optimal position. The present invention uses a plurality of semiconductor lasers, e.g., GSE lasers, to provide the light beam signals with these light beam signals being multiplexed through a series of lenses that focus the light from the semiconductor lasers into a single light beam signal. The preferred embodiments of the present invention will be described in terms of using GSE lasers although it should be appreciated that the present invention may also make use of other types of lasers including edge emitting lasers and other types of semiconductor lasers without departing from the spirit and scope of the present invention.

With the configuration of the present invention, the coupling efficiency of the WDM multiplexer is increased by approximately 23% with the sensitivity of the laser placement being negligible up to approximately an 8 micron offset from the optimal position. As a result, it is likely that with the present invention, active positioning of the lasers may be avoided during packaging of the WDM multiplexer.

Figure 5 is an exemplary diagram illustrating a WDM multiplexer configuration in accordance with one exemplary embodiment of the present invention. As shown in **Figure 5**, the WDM multiplexer **500** includes a substrate **510** upon which are positioned an array of GSE lasers **520** in a hermetic enclosure **530**. In one exemplary embodiment, the array of GSE lasers **520** is a 2x2 array in which four GSE lasers **520** are provided for generating light beam signals at four different wavelengths that are to be multiplexed together.

Also provided is an array of collimating lenses **540** that are provided in receptacle **550**.

The receptacle **550** may be formed from any suitable material. In an exemplary embodiment, the receptacle **550** is formed from a molded plastic material, such as GE Ultem, that does not absorb the light beam signals emitted by the array of GSE lasers **520** with the collimating lens array **540** being positioned to align with the array of GSE lasers **520**. The receptacle **550** has a wider portion **552** in which the substrate **510**, the array of GSE lasers **520**, and the hermetic enclosure **530**, are enclosed. A narrower portion **554** of the receptacle **550** provides a mechanism for connecting the WDM multiplexer **500** to a fiber optic connector (not shown) that carries the multiplexed signal to the outside world.

Returning to the discussion of the collimating lens array **540**, in the depicted exemplary embodiment there is one collimating lens in the collimating lens array **540** for each GSE laser in the array of GSE lasers **520**. Thus, in an exemplary embodiment, the collimating lens array **540** is a 2x2 array of collimating lenses that are positioned such that each lens in the collimating lens array **540** is aligned with a respective one of the GSE lasers in the 2x2 array of GSE lasers **520**.

Also provided in the receptacle **550** is a single focusing lens **560**. The single focusing lens is provided at a position within the receptacle **550** at one end of a channel **570** formed in the receptacle **550**. At the opposite end of the channel **570**, a fiber-optic connector (not shown), such as a SC connector, may be coupled to the WDM multiplexer **500**. Both the collimating lens array **540** and the single focusing lens **560** may be integrated into the receptacle **550** such that the collimating lens array **540**, the single focusing lens **560** and the receptacle **550** may be fabricated as a single unit. The collimating lens array **540** and single focusing lens **560** are cut into the molding cavity along with the other features. The cavity is then injected with molten plastic forming the receptacle and lenses as a single piece. An optically transparent material, such as GE Ultem, is used in this case. At least one GSE laser of the array of GSE lasers **520**, at least one lens of the collimating lens array **540**, and the focusing lens **560** are arranged in a confocal configuration.

In operation, the GSE lasers in the array of GSE lasers **520** emit light beam signals through the hermetic enclosure **530**, which is transparent to the light beam signals. These light beam signals are captured by the collimating lenses of the collimating lens array **540**. Since there is a one to one correspondence between GSE lasers and collimating lenses in the arrays **520** and **540**, each collimating lens captures the light beam signal from its corresponding GSE laser. As shown in **Figure 5**, the collimating lenses adjust the direction of the light beam signals from being divergent, i.e. spreading, to a direction that is parallel with the axis of the lenses (the vertical straight lines illustrated in **Figure 5**). This redirects the light beam signals so that they are caught by the single focusing lens **560**. Transmission from the collimating lens array **540** and focusing lens **560** is within the material of the molded receptacle **550** which is transparent at the operating wavelengths.

The focusing lens **560** receives the light beam signals from all of the collimating lenses in the collimating lens array **540** and multiplexes them into a single light beam signal. Essentially, the focusing lens **560** focuses each of the light beam signals to a focal point **580** causing the light beam signals to be combined and multiplexed into a single light beam signal. This single light beam signal generated by the focusing lens **560** travels down the channel **570** so that it may pass to a fiber optic connector (not shown) for transmission through a fiber optic medium or the like. The primary application of this embodiment of the present invention is to provide 10 Gigabit Ethernet capability over 300 meters in accordance with IEEE 802.3ae – LX4 standard. Thus, the WDM multiplexer **500** may be utilized to provide multimode 10 Gigabit Ethernet data communication using multiplexed light beam signals.

Figure 6 is an exemplary diagram illustrating a WDM multiplexer configuration in which monitor photodiodes are provided in accordance with one exemplary embodiment of the present invention. The main difference between this embodiment and the previous embodiment of **Figure 5** is the inclusion of monitor photodetectors or photodiodes **610** on a photodetector/photodiode substrate **620** and positioned on an opposite side of the substrate **510** offset from the substrate **510** by interposer **630**. It will be assumed for purposes of this description that the photodetectors are photodiodes although other embodiments of the present invention may make use of different types of photodetectors from those illustrated herein. There is a separate monitor photodiode **610** for each of the GSE lasers in the array of GSE lasers **520** and the monitor photodiodes are positioned on the photodiode substrate **620** so as to be aligned with their corresponding GSE laser. The monitor photodiodes **610** are used to monitor the light beam signal output of the GSE lasers in order to determine the degradation of the GSE lasers over time and compensate for this degradation. The monitor photodiodes **610** receive backside emissions from the GSE lasers, monitor these backside emissions and provide indications of the degradation of the light beam signal to a control circuit that maintains the power output of the lasers at a constant level.

Although **Figure 6** illustrates the monitor photodiodes **610** being on a separate substrate **620** from the substrate of the GSE lasers, the present invention is not limited to such a configuration. To the contrary, the monitor photodiodes may be integrated within the GSE substrate or GSE die, and may monitor the actual light beam signal output of the GSE lasers rather than the backside emission of the GSE lasers. Thus, rather than being separated from the GSE lasers, the photodetectors or photodiodes **610** may be integrated into the GSE lasers. The integrated photodiodes are fabricated as part of the laser, as an extension of the laser ridge, and monitor a portion of the light in the main lasing cavity. An alternate method of monitor photodiode implementation is similar to conventional edge emitter techniques, where the photodiode is separate from the laser, and monitors the edge emission of the GSE ridge.

Figure 7 is an exemplary diagram illustrating the layers of a WDM multiplexer package in accordance with one exemplary embodiment of the present invention. The embodiment illustrated in **Figure 7** represents an embodiment in which the monitor photodiodes are provided on a separate substrate from that of the GSE lasers. However, as stated above, the present invention is not limited to such and other embodiments may be provided that integrate the monitor photodiodes into the same die as the GSE lasers or monitor edge emission.

As shown in **Figure 7**, the WDM multiplexer package includes the monitor photodiode substrate **710** upon which a plurality of monitor photodiodes **720** are positioned. An interposer **720** is provided atop the monitor photodiode substrate **710** for spacing the monitor photodiode substrate **710** from the GSE laser substrate **740**. The monitor photodiode substrate **710** and the GSE laser substrate **740** may be formed as a silicon substrate or other suitable material. Alternatively, the substrates may be Aluminum Oxide (Alumina) patterned substrates in which circuit patterns may be etched. The GSE lasers **750** are provided on the GSE laser substrate **740** and the entire package is housed in the receptacle **760**. The receptacle **760**, as discussed above, has the lens array and single focusing lens integrated therein in the wider section **762** of the receptacle **760**. The focusing lens is positioned at one end of the cylindrical section **764** of the receptacle **760** closest the lens array and the GSE lasers with a channel **770** being provided in the cylindrical section **764**. A fiber optic connector and/or optical fiber may be connected to the WDM multiplexer package at an opposite end **766** of the channel **770** from the focusing lens.

Figures 8A-8C are exemplary diagrams showing a cutaway view of a WDM multiplexer package, a bottom view of the receptacle and an isometric view of the WDM multiplexer package according to one exemplary embodiment of the present invention. Elements in **Figure 7** that are shown in each of the **Figures 8A-8C** are identified with similar reference numerals as shown in **Figure 7**.

Figures 9A and **9B** are exemplary diagrams illustrating two possible configurations for permitting light beams from the GSE lasers to become incident on monitor photodiodes in accordance with exemplary embodiments of the present invention. **Figure 9A** illustrates an arrangement in which the GSE laser substrate is transparent to the laser light wavelengths of the GSE lasers. As shown in **Figure 9A**, a GSE laser **910** emits a light beam **920** toward the collimating lens array while a backside light beam emission **930** is emitted towards the GSE laser die attach substrate **940**. These light beams **920** and **930** are emitted from an outcoupler region **980** of the GSE laser **910**. The backside light beam emission **930** falls incident on the monitor photodiode **950** which measures characteristics, such as intensity, of the backside light beam emission **930**. The monitor photodiode **950** is provided on monitor photodiode attach substrate **960** and is spaced from the GSE laser die attach substrate **940** by an interposer **970**. The area between the GSE laser die attach substrate **940** and the monitor photodiode attach substrate **960** is allowed to be filled with air, vacuum or any other optically transparent media.

Figure 9B illustrates an alternative arrangement in which the GSE laser **910** overhangs the GSE laser die attach substrate **920** such that there is no substrate between the outcoupler region **980** on the GSE laser **910** from which the backside light beam **930** is emitted. In this way, the GSE laser die attach substrate **920** may be made from a material that is non-transparent to the GSE laser light wavelengths yet the backside light beam **930** emission still falls incident on the monitor photodiode **950** since the GSE laser die attach substrate **920** is not present in the backside light beam path. This overhang may be provided as openings in the GSE laser die attach substrate **920** that are positioned so as to be in alignment with an outcoupler region **980** on the GSE laser **910**.

Figures 10A and **10B** are exemplary diagrams illustrating infrared camera images of the laser light beams before they pass through the focusing lens and after they pass through the focusing lens in accordance with one exemplary embodiment of the present invention. The illustrations in **Figures 10A** and **10B** are for a WDM multiplexer configuration in which there are four GSE lasers whose light beam signals are to be multiplexed together to form a single light beam signal.

As shown in **Figure 10A**, the four light beam signals from the GSE lasers are separate light beam signals at positions **P1-P4**. The GSE lasers and thus, the light beam signals are positioned in a rectangular configuration in which the sides of the square are approximately 500 microns. Preferably, the position of the GSE lasers and the light beam signals are within 5 microns of the target spacing of 500 microns.

As shown in **Figure 10B**, after the light beam signals pass through the focusing lens, the light beam signals are multiplexed together into a single light beam signal. A three dimensional intensity plot for this multiplexed light beam signal is provided below the infrared camera image.

Figure 11 is an exemplary diagram illustrating a plot of the coupling efficiency versus laser offset for an exemplary embodiment of the present invention. As shown in **Figure 11**, the present invention achieves approximately a maximum coupling efficiency into the multimode optical fiber of 86%. This coupling efficiency may be improved further through use of other optimizations such as refining and shaping the lenses of the WDM multiplexer package. Comparing this coupling efficiency with that of the known configurations, when modified to include GSE lasers, shown in **Figure 4**, the present invention achieves at least a 23% increase in coupling efficiency over these modified known systems. Furthermore, the present invention achieves at least a 26% increase in coupling efficiency with regard to unmodified known systems which only achieve approximately a 60% coupling efficiency.

Moreover, as shown in **Figure 11**, the coupling efficiency remains approximately the same within an 8 micron offset of the optimal position of the GSE lasers. This means that the present invention is relatively insensitive to errors in placement of the GSE lasers when those errors are within 8 microns of the optimal position. As a result, active placement of the GSE lasers may not be necessary when manufacturing the WDM multiplexer package and a less time consuming and expensive manufacturing process using a pick and place machine may be utilized. The known configuration shows approximately an 8% loss in coupling efficiency when the offset of the laser is 8 microns from the optimal position.

Thus, the present invention provides a WDM multiplexer package and method that results in a multiplexer and method of multiplexing that achieves a higher coupling efficiency and is less sensitive to placement errors of the lasers than known configurations. In addition, the present invention permits components, e.g., the collimating lenses, the focusing lens and the ferrule sleeve, of a WDM multiplexer to be combined into a single molded unit, thereby lowering piece-part costs and assembly costs. In addition, other components that are typically found in known WDM multiplexers are eliminated in the present invention, e.g., the filter array **130** and bounce cavity **140** in **Figure 1**, which results is lower piece-part costs and assembly costs.

While the above exemplary embodiments of the present invention have been described in terms of a four GSE laser array configured in a square configuration, the present invention is not limited to such. Rather, other configurations of the GSE laser array, collimating lens array, and monitor photodiodes may be used without departing from the spirit and scope of the present invention. Basically, any number and arrangement of GSE lasers, collimating lenses and monitor photodiodes is intended to be within the spirit and scope of the present invention.

Figures 12A-12C are exemplary diagrams of one possible alternative arrangement of GSE lasers and lenses in accordance with an alternative embodiment of the present invention. As shown in **Figures 12A-12C**, rather than the four GSE laser array described previously, this embodiment of the present invention utilizes an array of 8 GSE lasers configured in a radial arrangement. Since the collimating lenses and monitor photodiodes are to be in alignment with the GSE lasers, the same number and arrangement of collimating lenses and monitor photodiodes as that of the GSE lasers is provided in this alternative embodiment. This embodiment permits 8 different light beam signals having 8 different wavelengths to be multiplexed together into a single light beam signal that is output to an optical fiber. As will be readily apparent to those of ordinary skill in the art, other numbers of GSE lasers, collimating lenses and monitor photodiodes, as well as other arrangements of these elements, may be used without departing from the spirit and scope of the present invention. Thus, an nxn array of GSE lasers, collimating lenses and monitor photodiodes having any of a number of different arrangements may be used without departing from the spirit and scope of the present invention.

Figure 13 is an exemplary diagram illustrating a cut-away view of a WDM multiplexer package in accordance with the alternative embodiment shown in **Figure 12**. **Figure 13** is similar to **Figure 8** but illustrates the cutaway of the alternative embodiment shown in **Figure 12**. The same basic arrangement of layers is illustrated in **Figure 13** as is shown in **Figure 8** with the difference being primarily in the number and arrangement of the GSE lasers, the collimating lenses and the monitor photodiodes.

The description of the preferred embodiment of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention the practical application to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

CLAIMS

What is claimed is:

1. A laser-enabled multiplexing system, comprising:

a plurality of grating-outcoupled surface emitting (GSE) lasers;

a plurality of lenses, each lens of the plurality of lenses being positioned so as to collimate a beam of light emitted by a GSE laser of the plurality of GSE lasers; and

a focusing lens positioned to focus a plurality of collimated beams of light received from the plurality of lenses into substantially a point of light.

2. The laser-enabled multiplexing system of claim 1, further comprising:

a receptacle for coupling the point of light to an optical fiber.

3. The laser-enabled multiplexing system of claim 1, wherein at least one GSE laser of the plurality of GSE lasers, at least one lens of the second plurality of lenses, and the focusing lens are arranged in a confocal configuration.

4. The laser-enabled multiplexing system of claim 2, wherein the plurality of lenses, the focusing lens, and the receptacle are fabricated as a single unit.

5. The laser-enabled multiplexing system of claim 1, wherein the plurality of GSE lasers comprises a 2-by-2 rectangular array of GSE lasers.

6. The laser-enabled multiplexing system of claim 5, wherein the plurality of lenses comprises a 2-by-2 rectangular array of lenses.

7. The laser-enabled multiplexing system of claim 1, wherein the plurality of GSE lasers comprises an n-by-n array of GSE lasers.

8. The laser-enabled multiplexing system of claim 7, wherein the plurality of lenses comprises an n-by-n array of lenses.

9. The laser-enabled multiplexing system of claim 1, wherein the plurality of GSE lasers comprises a radial array of GSE lasers.

10. The laser-enabled multiplexing system of claim 1, wherein the plurality of GSE lasers comprises a radial array of 8 GSE lasers.

11. The laser-enabled multiplexing system of claim 1, wherein the plurality of lenses comprises a radial array of 8 lenses.

12. The laser-enabled multiplexing system of claim 1, further comprising:

a substrate, wherein the plurality of GSE lasers are attached to the substrate.

13. The laser-enabled multiplexing system of claim 1, wherein the multiplexing system comprises a Wavelength Division Multiplexer (WDM).

14. The laser-enabled multiplexing system of claim 1, further comprising:

at least one photodetector, wherein the at least one photodetector is coupled to at least one GSE laser of the plurality of GSE lasers so as to monitor an energy output from the at least one GSE laser.

15. The laser-enabled multiplexing system of claim 1, further comprising:

at least one photodetector, wherein the at least one photodetector is integrated into at least one GSE laser of the plurality of GSE lasers.

16. The laser-enabled multiplexing system of claim 1, further comprising:

at least one photodetector, wherein the at least one photodetector is operable to receive a backside emission of energy from at least one GSE laser of the plurality of GSE lasers.

17. An output monitor for a laser-enabled multiplexing system, comprising:

a plurality of lasers;

a substrate attached to the plurality of lasers for mounting the plurality of lasers, the substrate including a transparent portion; and

a plurality of photodetectors, each photodetector of the plurality of photodetectors being located adjacent to the transparent portion of the substrate on a side of the substrate opposite that of the plurality of lasers so as to receive a backside emission of energy from at least one laser of the plurality of lasers.

18. An output monitor for a laser-enabled multiplexing system, comprising:

a plurality of lasers, each laser of the plurality of lasers including an outcoupler region;

a substrate attached to the plurality of lasers for mounting the plurality of lasers, the substrate including a portion not attached to each outcoupler region of each laser of the plurality of lasers; and

a plurality of photodetectors, each photodetector of the plurality of photodetectors located adjacent to a corresponding outcoupler region of each laser of the plurality of lasers so as to receive a backside emission of energy from at least one laser of the plurality of lasers.

19. A method for multiplexing a plurality of laser beams, comprising the steps of:

emitting a beam of light from each grating-coupled surface emitting (GSE) laser of a plurality of GSE lasers;

collimating each beam of light emitted from each GSE laser of the plurality of GSE lasers; and

focusing the plurality of collimated beams of light into substantially a point of light.

20. A method of making a laser-enabled multiplexing system, comprising the steps of:

providing a plurality of lasers, wherein each laser of the plurality of lasers emits a beam of light;

attaching a substrate to the plurality of lasers, the substrate including a transparent portion; and

providing a plurality of photodetectors located adjacent to the transparent portion of the substrate on a side of the substrate opposite that of the plurality of lasers, wherein the photodetectors receive a backside emission of energy from at least one laser of the plurality of lasers.

21. The method of claim 20, wherein the plurality of lasers comprises a plurality of GSE lasers.

22. A method of making a laser-enabled multiplexing system, comprising:

providing a plurality of lasers, wherein each laser of the plurality of lasers emits a beam of light from an outcoupler region;

attaching a substrate to the plurality of lasers, the substrate including a portion not attached to each the outcoupler regions of each laser of the plurality of lasers; and

providing a plurality of photodetectors, each photodetector being adjacent to a corresponding outcoupler region of a laser of the plurality of lasers, wherein at least one photodetector of the plurality of photodetectors receives a backside emission of energy from at least one laser of the plurality of lasers.

23. The method of claim 22, wherein the plurality of lasers comprises a plurality of GSE lasers.

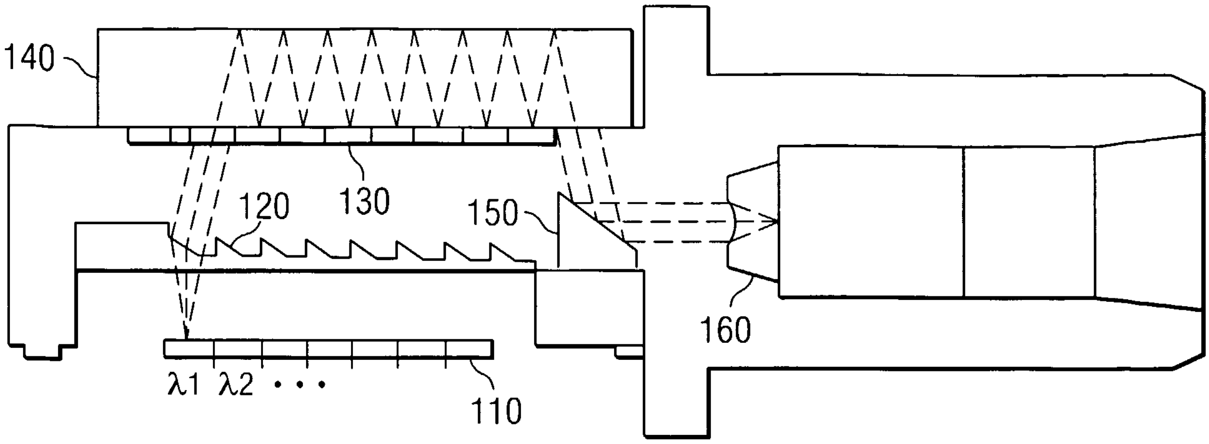
24. A method of providing a laser-enabled multiplexing system, comprising:

providing a plurality of grating-coupled surface emitting (GSE) lasers;

providing a plurality of lenses, each lens of the plurality of lenses being positioned so as to collimate a beam of light emitted by a GSE laser of the plurality of GSE lasers; and

providing a focusing lens positioned to focus a plurality of collimated beams of light received from the plurality of lenses into substantially a point of light.

FIG. 1



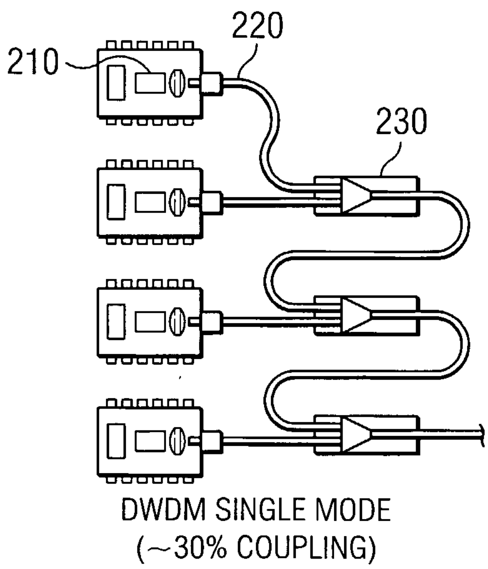


FIG. 2A

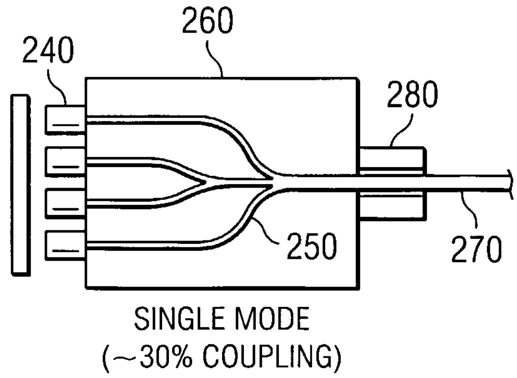


FIG. 2B

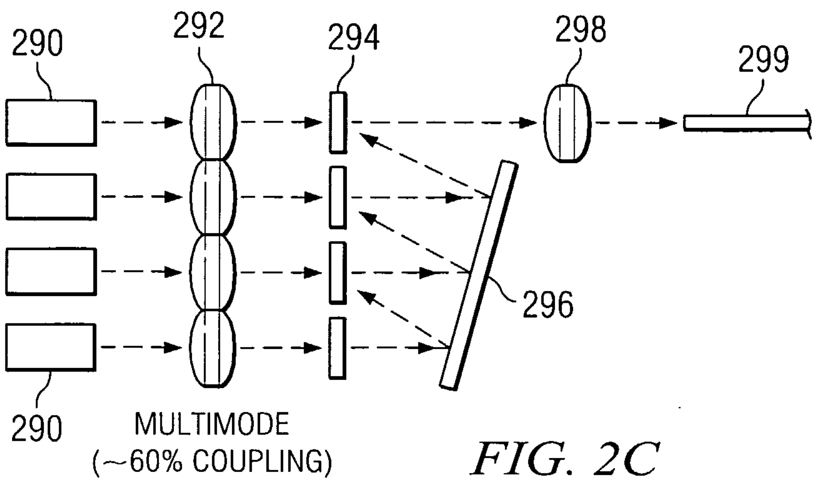


FIG. 2C

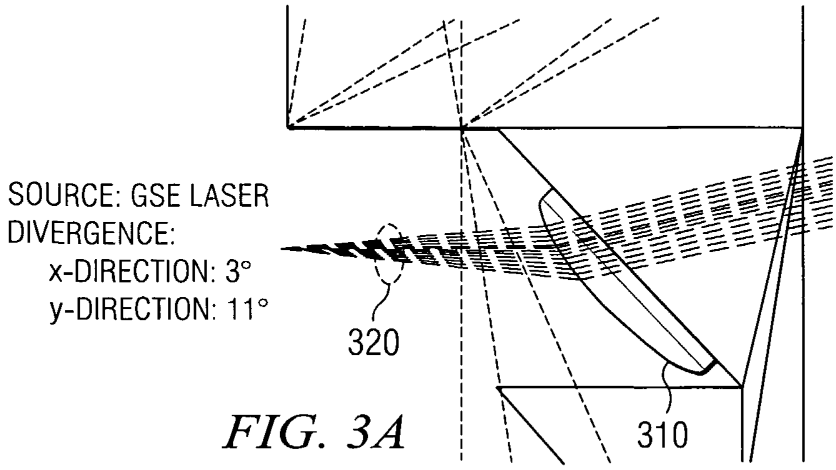


FIG. 3A

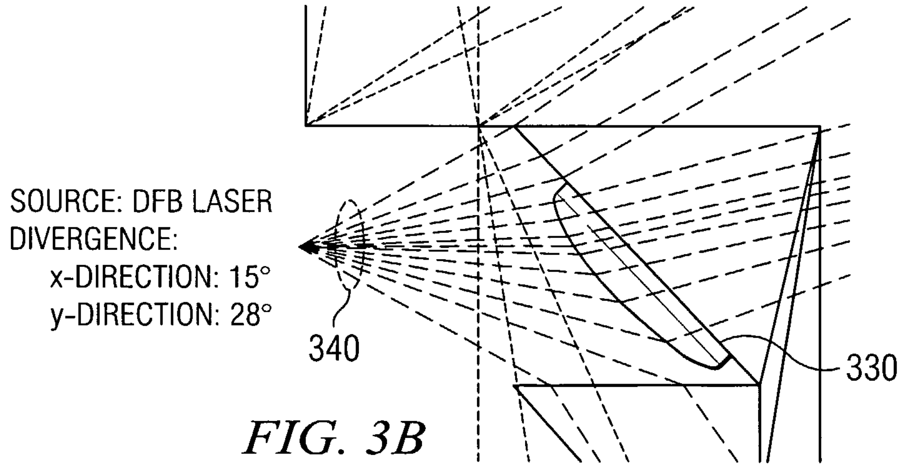


FIG. 3B

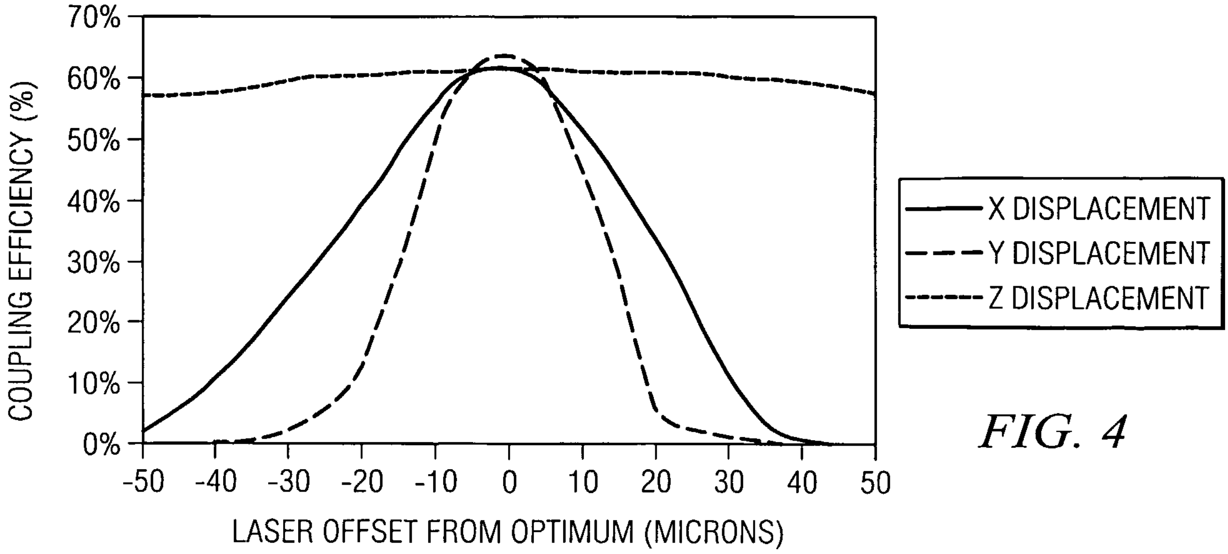


FIG. 4

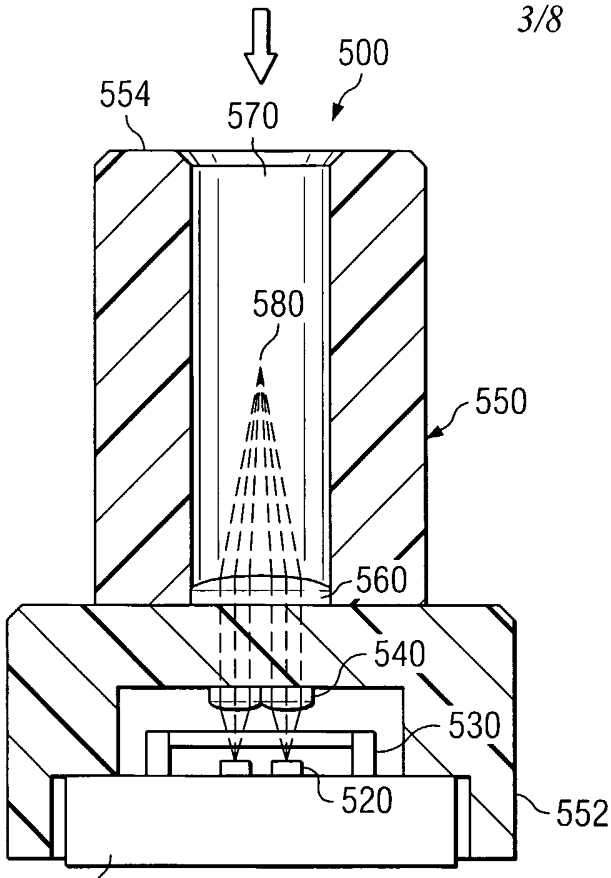

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FIG. 5

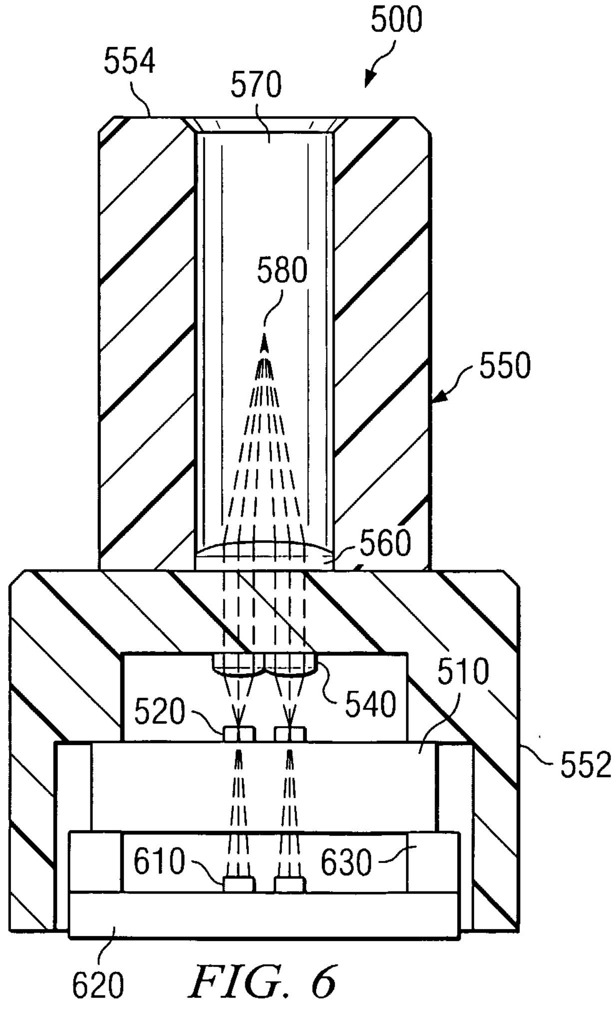
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FIG. 6

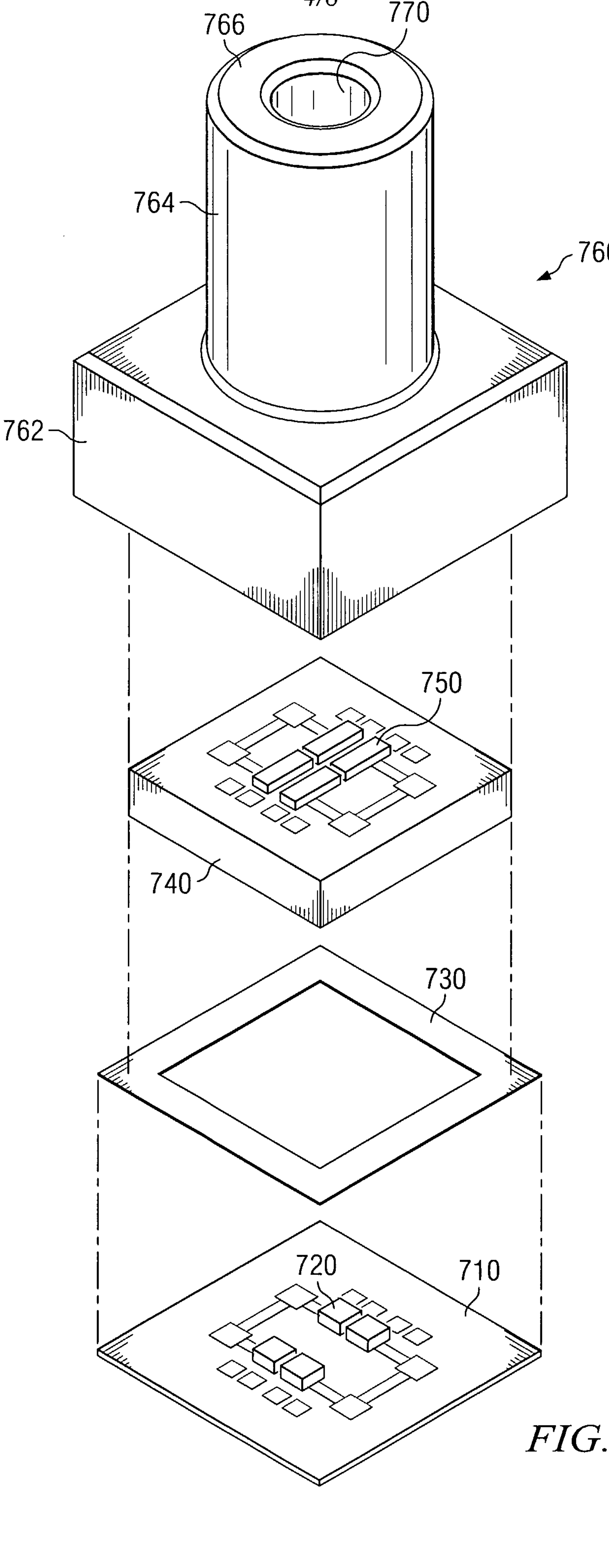


FIG. 7

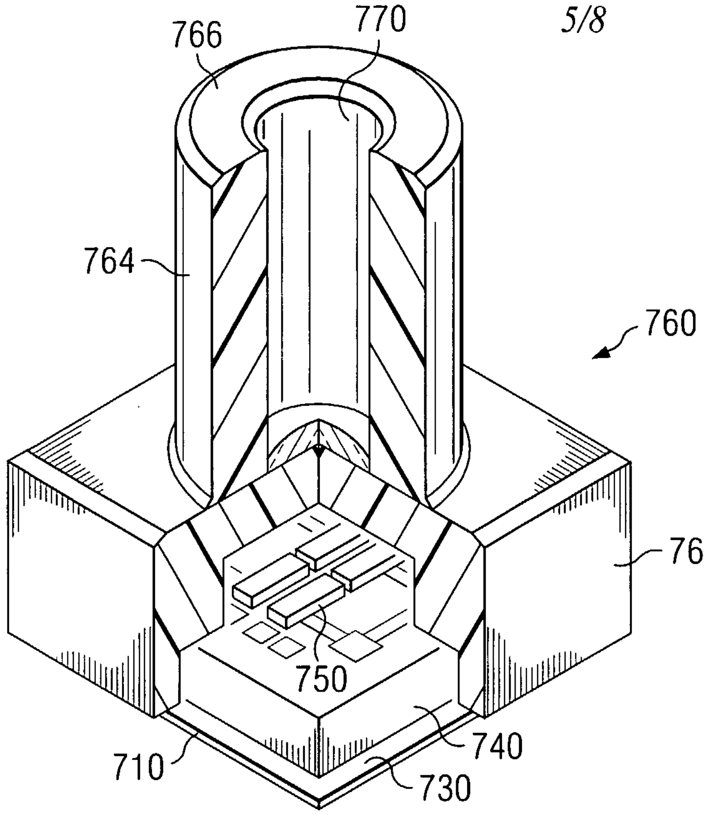


FIG. 8A

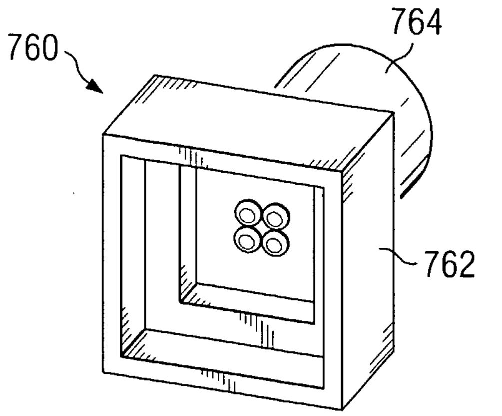


FIG. 8B

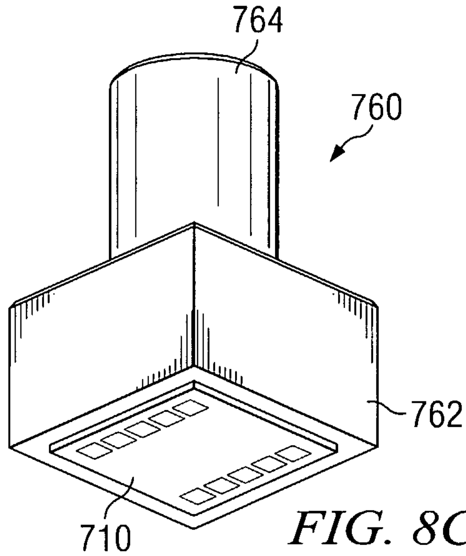


FIG. 8C

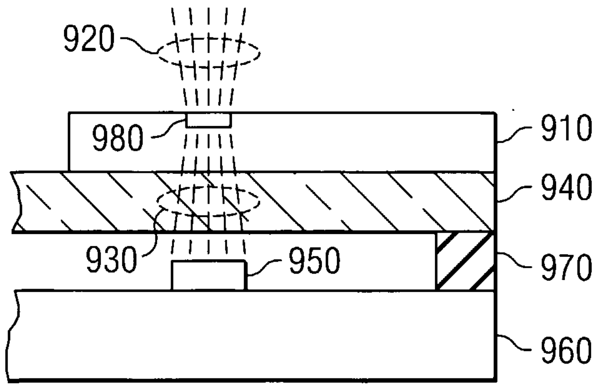


FIG. 9A

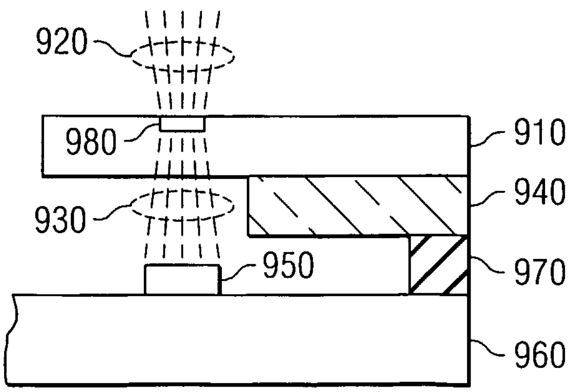


FIG. 9B

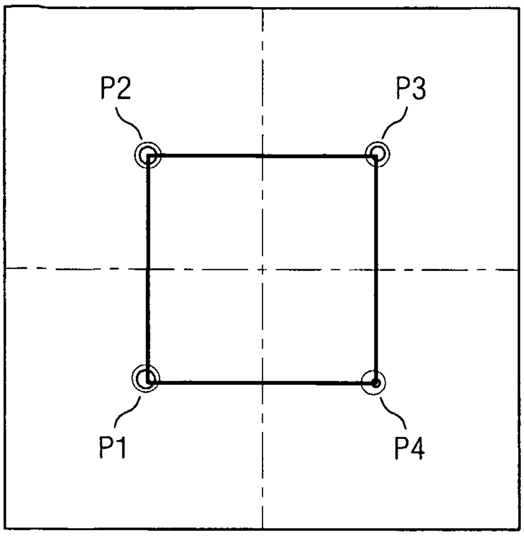
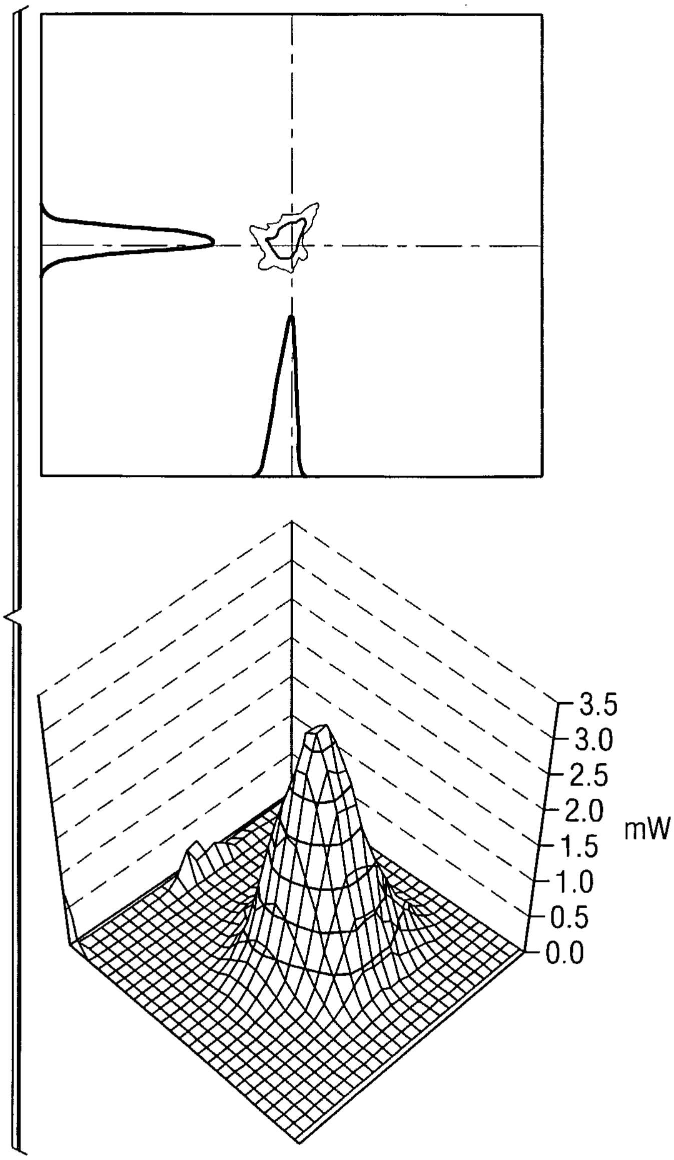


FIG. 10A

FIG. 10B



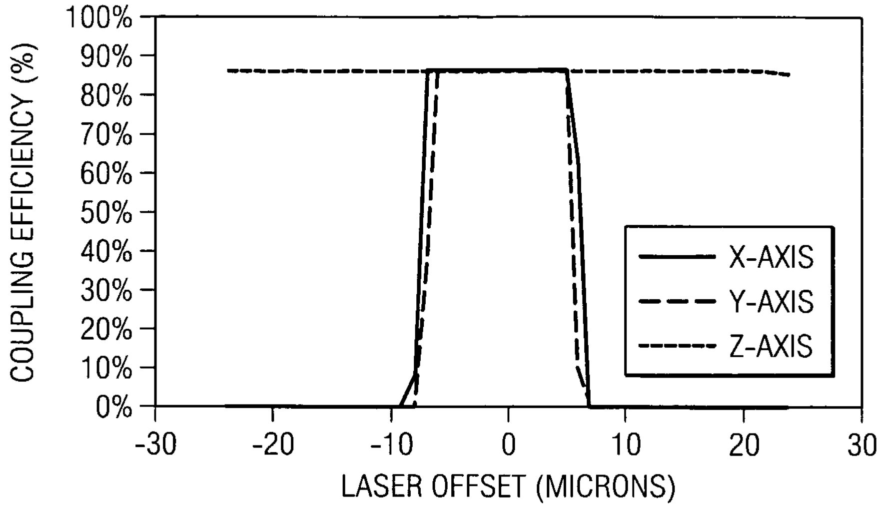


FIG. 11

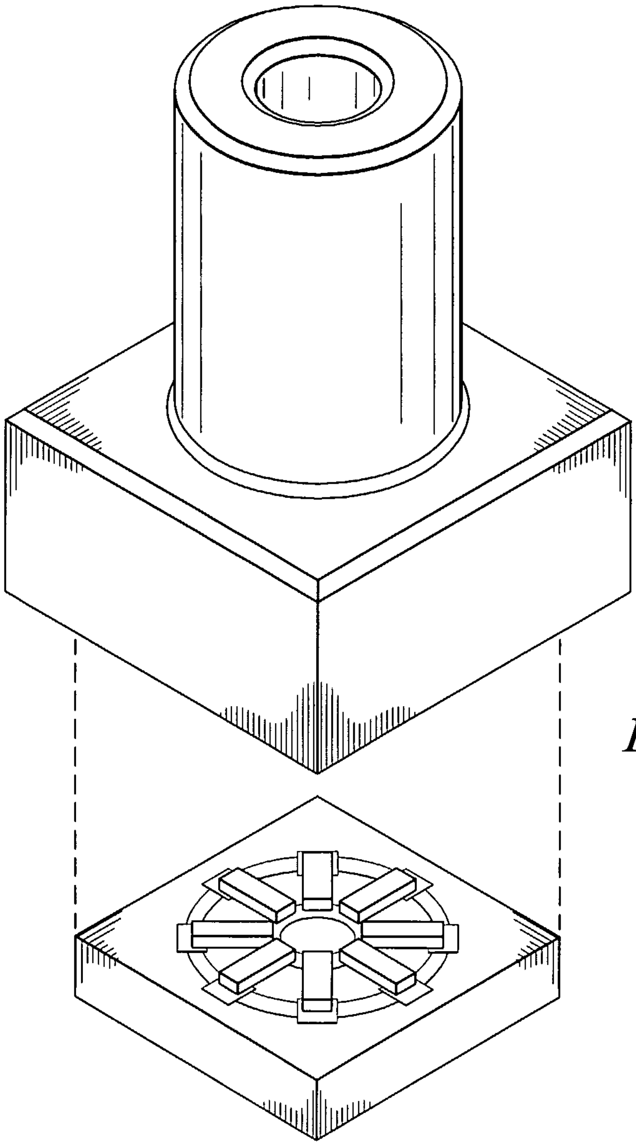


FIG. 12A

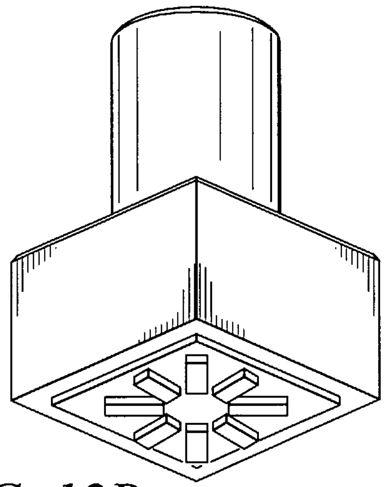


FIG. 12B

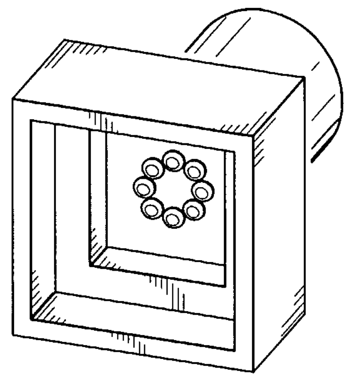


FIG. 12C

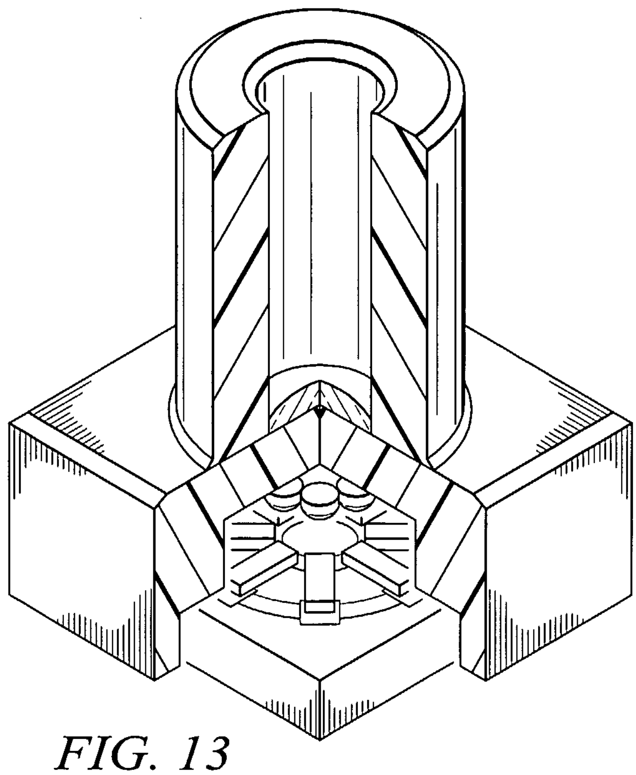


FIG. 13