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(54) Title: FIBER OPTIC COLLIMATOR ARRAY

(57) Abstract: In at least one embodiment, the apparatus of the present invention includes a collimating device for collimating an optical signal, the collimating device comprising a lens comprising a mounting portion, the lens having a focal length, a holder having a face and being capable of receiving and positioning an optical fiber such that a face of the optical fiber is substantially aligned with the face of the holder, and a spacer adjacent to the face of the holding portion and the mounting portion of the lens, the spacer providing a separation distance between the holder and the at least one lens. In at least one embodiment, the method of the present invention includes method of making a collimating device for collimating an optical signal, the method comprising providing a holder having a face, the holder being capable of receiving a fiber and positioning the face of a fiber, providing at least one lens, and connecting the holder to the at least one lens such that the lens parameters related to focal length are decoupled from the position of the face of the fiber. The method may further include fabrication of a lens arrays for a collimator comprising fabricating a wafer of lenses, the wafer of lenses comprising a mounting side and lenses, bonding a wafer of spacer material to the mounting side of the fabricated wafer of lenses, the spacer comprising a backside, and dicing the wafer of lenses and wafer of spacer material into individual lens arrays.



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FIBER OPTIC COLLIMATOR ARRAY

BACKGROUND

In the field of optics, minimization of coupling loss of an optical signal between an input source and an output source is of great importance. A primary source of coupling loss in optical signals can occur when a signal must leave one fiber, pass through free space, and enter a another fiber, such as in optical switching applications. Other situations which require an optical signal to pass through free space include, for example, variable optical attenuators, optical isolators, optical circulators and optical filter based products.

As an optical signal passes through the core of an optical fiber cable (hereinafter "fiber") 1, the light comprising a signal 2 travels by reflecting off of the interior surface of the fiber, depicted in FIG. 1. Also, as individual waves 3 exit the fiber and enter a different medium, they refract, shown in FIG. 2. Thus, reflection and/or refraction cause the individual waves of the signal 3 to leave the end of a fiber at an angle 4 towards the normal of the fiber core 1. As a result, the signal diffuses or "spreads out" upon exiting the fiber. This spreading out of the signal as it exits the fiber can cause significant coupling loss when trying to couple a signal between two fibers across free space.

In order to minimize signal coupling loss across free space, or optimally re-imaging the signal upon an output source, either the sending and receiving elements must be very close together as in FIG. 3, or the signal must be collimated or focused. A sending/receiving element may be either a fiber, a lens, a collimator, or a combination of these. As depicted in FIG. 4, collimation of signals effectively "straightens out" the vectors of the waves of an optical signal 5 as they leave a fiber. This can be accomplished by passing the signals through a lens 6. Once the signals are passed through the lens and collimated, the signal vectors may be effectively coupled between two fibers across free space.

While it is recognized that there are many fields of optical engineering in which collimators and lenses are utilized, this discussion will refer to optical telecommunications and optical switching as a medium in which to discuss the background of the present invention.

As optics based industries grow, such as the fiber based telecommunication industry, the number of optical signals that must be switched or processed will increase dramatically. In the past, and currently, there is a great need to efficiently switch an optical signal

between fibers within the telecommunication infrastructure. Typically, the optical signal is converted to an electrical signal. The electrical signal is then electronically switched between routes within a telecommunications switching system. After the electrical signal is switched, it is converted back into an optical signal and coupled into a fiber.

5 With the introduction of various all optical switching technologies, a signal no longer needs to be converted to an electrical signal. This greatly speeds up speed of telecommunication, but introduces difficulties in the switching of all optical signals. Currently, optical signals are switched between different fibers by a number of different methods. Typically, these methods utilize selective reflection of the optical signal off of a
10 reflective material, such as a mirror, into a fiber. However, in order to reflect off of some material, the optical signal must pass through free space from an input fiber to reach the mirror, and after reflection, pass through free space to an output fiber.

In order to minimize coupling loss of the optical signal (as discussed above) between an input and output fiber, there exists a need to collimate the optical signal. Further, with
15 growing demand for all optical components there exists a need for repeatable bulk manufacturing techniques for reliable collimators.

Turning to FIG. 5, in the production of collimators maintaining a particular focal length 7 from a lens 8 to a focal point 9 is of importance. The term "focal point" is used here to describe the aplanatic patch upon a focal plane 10 which desirably intersects with
20 the face of a fiber 11, the focal plane 10 being at a given focal length 7 of the lens. The focal plane 10 is that plane through which the lens 8 may focus depending upon the location of a light source 12 relative to the lens 8. In order to effectively collimate a signal from a fiber 13, the focal point 9 must be positioned very near or at the end of the fiber face 11, and be optically aligned with the center axis of the fiber face 11. Further, to properly position
25 the focal point 9, the lens must be positioned at a particular focal length 7 from the fiber face 11. If the fiber face 11 is not properly positioned with respect to the focal point 9, the optical signal will not be efficiently collimated, resulting in significant signal loss.

Return loss and other problems can also occur as a result of the polishing process typically used to remove anomalies which can affect optical transmission. The polishing
30 process makes the fiber face reflective, causing reflections of some portion of the signal back into the fiber, shown in FIG. 6. This back reflection also causes significant problems with lasers, amplifiers, detectors and other elements in an optical network. In order to minimize the effect of these back reflections, the fiber face is polished at an angle typically

5-10 degrees. This polish angle prevents the effective coupling of the back reflections into the fiber, depicted in FIG. 7. For focal point alignment purposes, the focal point should be aligned with the normal of the angled fiber face 11, and the center axis of the angled fiber face 11, as shown in FIG. 5.

5 Regarding prior approaches, there are numerous difficulties and drawbacks. Due to the exacting nature of the positioning of the focal point 9, and the fiber face 11 angle, the typical prior approach is to make each collimator one at a time. This provides for tight controls as to the focal length of the lens, which is tightly coupled to an assembly in which the lens is placed. The collimator is produced by placing the lens in a fixture, then
10 positioning the fiber face to correspond to the focal point of the lens. This approach is costly and inefficient as each collimator must be built individually, typically by hand. Further, as the focal length of each lens is tightly coupled to other parts of the collimator assembly, any problems with manufacturing repeatability will be very problematic. That is, if any part of the assembly, including optical parameters of a lens, is out of tolerance an
15 optical signal cannot be effectively collimated.

 In an attempt to overcome difficulties in focal point positioning on the fiber face, a gradient refractive index lens ("GRIN lens") is sometimes used.

 A GRIN lens typically has a cylindrical body with two flat ends. The location of the focal point of a GRIN lens is determined by the length of the material which makes up the
20 GRIN lens, as well as the index gradient of the material. This makes collimator production easier than with traditional lenses. However, similar to traditional lenses, the focal length of a GRIN lens is still tightly coupled to the tolerances of other elements of the collimator array.

 Ideally, the focal point is located in the center and flush with a flat end of a GRIN
25 lens. Theoretically, one need only place the fiber 14 face adjacent a flat end of the GRIN lens 15 and align the two for proper collimation, shown in FIG. 8. However, as a practical matter, this still requires making one collimator unit (a lens, a fiber, and alignment of that lens with the end of a single fiber) at a time, and the focal point of the GRIN lens is not always accurate (i.e. the focal point may not be located at the end of the GRIN lens and thus
30 not on the fiber face even when the face is butted up to the GRIN lens). Further, the use of GRIN lenses as in prior approaches present problems with mating the desirable angle polished face of a fiber with the flat portion of the GRIN lens.

A further problem with collimator units built as individual units is practical placement in, for example, fiber optic switches. In prior approaches, the individual lens/fiber units are positioned by hand and glued in place. Moreover, as a single fiber is connected to a single lens, any movement by the fiber may move the lens. Also, the fiber face may move relative to the lens focal point if the fiber itself is moved.

As shown in FIG. 9, another prior approach is to fabricate a V groove holder 16 for the fibers and GRIN lenses and align the fiber face 17 with the individual lens 18 (typically, but not necessarily, a GRIN lens) against the face of the fiber 17. The problems with this approach is that it is difficult to control the alignment of the individual lenses 18 relative to the fiber axes. The fiber placement is dependent upon the accuracy of the V grooves, and the inability to angle the individual lenses 18 to accommodate a fiber face 17 which is polished at an angle. This is because the lens tends to run into the V groove holder 16 when attempting to angle the lens and align it with the angled fiber face 17. Further, any error in the outer diameter tolerance of a GRIN lens 18 will result in further misalignment with a fiber central axis. This causes misalignment between the collimated beams.

A final example of another prior approach is shown in FIG. 10. A fiber V groove holder 19 holds fibers in place, which are aligned against a monolithic array of diffractive lenses, 20. It should be noted that diffractive lenses typically only cover a narrow band of wavelengths, on the order of 10 nm. The lenses 20 are all fabricated in an array, at the same time and as a single piece of material. here are numerous problems with this approach as well. The tolerances required fabricate the lenses 20 are tightly coupled to the whole assembly; if some tolerance in the lens array 20 (such as focal length or location of focal point) are not exactly in place, or some tolerance on the V groove holder 19 (or placement of the fibers in the V grooves), the assembly will not effectively collimate a signal. Further, in this type of configuration there is no angle polished fiber face to minimize optical coupling back into the fiber as discussed above.

Thus, what is needed is a collimator array which does not utilize single lenses, and in which lens array parameters are decoupled from the assembly of the collimator unit as a whole, allowing for reliable and repeatable production of collimator elements.

SUMMARY

In accordance with an embodiment of the present invention, the apparatus of the present invention is embodied in a collimating device for collimating an optical signal, the

collimating device comprising a lens the lens comprising a mounting portion, the lens having a focal length, a holder having a face and being capable of receiving and positioning an optical fiber such that a face of the optical fiber is substantially aligned with the face of the holder, and a spacer adjacent to the face of the holding portion and the mounting portion of the lens, the spacer providing a separation distance between the holder and the at least one lens.

The embodiment above may further comprise a spacer connected to the face of the holder and the mounting portion of the lens.

The lens in the above embodiment may be one of a plurality of lenses and the fiber may be one of a plurality of optical fibers.

The at least one lens may be comprised of a material which has a thermal coefficient of expansion at least similar to silicon.

The at least one lens may be one lens in a monolithic array of lenses.

In one embodiment the monolithic array of lenses is comprised of silicon.

In an alternative embodiment the monolithic array of lenses is comprised of at least one of a) silicon; b) germanium zinc-sulfide; c) silicon oxide; d) gallium phosphide; and e) gallium arsenide.

In one embodiment the spacer of the is comprised of a material having a thermal expansion coefficient substantially the same as that of silicon.

The spacer may comprise a material which is at least somewhat transparent to UV light. Further, the spacer may comprise at least one of a) glass; b) silicon; c) borosilicate glass.

The holder of the first mentioned embodiment may be comprised of a material having a thermal expansion coefficient about that of silicon. Further, the holder may be comprised of silicon. The holder may have at least one V-groove for receiving a fiber. Moreover, the holder may comprise at least one of a) glass; and b) plastic. The holder is capable of receiving and positioning an optical fiber having a face polished at an angle, the face of the holder being polished at an angle similar to and substantially aligned with the angle of the received and polished optical fiber face. The angle of the received and positioned optical fiber face is about in the range of 5 to 10 degrees. Further, the angle of the received and positioned optical fiber face is about 8 degrees.

The separation of the above embodiments is approximately the same as a focal length of the lens.

Strain relief for holding the received and positioned optical fiber is further provided.

In an alternative embodiment, the spacer comprises a material, and wherein the lens comprises a material, and wherein the material of the spacer has a thermal expansion coefficient substantially the same as the material of the lens.

5 An anti-reflective coating may be placed upon the lens in the above embodiment.

In another embodiment of the apparatus of the present invention, the apparatus comprises a collimating device for collimating an optical signal, the collimating device comprising a monolithic lens array comprising a mounting portion, each being capable of projecting an image onto a focal plane, a holder comprising silicon and having a face, and the holder being capable of receiving and positioning an optical fiber having a face, such that a face of the optical fiber is substantially aligned with the face of the holder, a spacer disposed between the face of the holder and the mounting portion of the lens, the spacer setting a separation distance between the holder and the at least one lens wherein the separation distance is approximately a focal length of at least one lens of the monolithic lens array.

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In accordance with an embodiment of the present invention, a method of the present invention comprises a method of making a collimating device for collimating an optical signal, the method comprising providing a holder having a face, the holder being capable of receiving a fiber and positioning the face of a fiber, providing at least one lens, and connecting the holder to the at least one lens such that the lens parameters related to focal length are decoupled from the position of the face of the fiber, wherein the a focal plane of the at least one lens is located upon the face of the holder.

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The method may additionally further comprise polishing the face of the holder. Further, the polishing step comprises polishing the face to an angle in the range of about 5 to 10 degrees. Moreover, the angle may be about 8 degrees.

25

The above method may further comprise coating the at least one lens with anti-reflective coating.

The holder of the above method is capable of receiving a fiber having a face polished at an angle, the face of the holder being capable of being aligned with the face of the fiber polished at an angle. Further, the face of the holder is polished at an angle in the range of about 5 to 10 degrees. Moreover, the face of the holder may be polished at an angle at about 8 degrees.

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In yet another embodiment of the apparatus of the present invention, the apparatus comprises a collimator comprising a plurality of optical fibers, a plurality of lenses, each of the plurality of lenses being part of a monolithic array of lenses, a spacer positioned between each of the plurality of optical fibers and plurality of lenses.

5 The above embodiment can further comprise a holding block, the holding block further comprising a plurality of V-grooves, the plurality of V-grooves holding the plurality of optical fibers in optical alignment with the plurality of lenses. The plurality of optical fibers can be held in the plurality of V-grooves by glue. Further may comprise epoxy, and the epoxy may be UV cured epoxy.

10 In an alternative embodiment the holding block assembly further comprises a cover plate covering the fibers held in the plurality of V-grooves.

 In the above embodiment the plurality of lenses may be comprised of silicon, and the cover plate may comprise a material with a thermal coefficient of expansion substantially the same as the thermal coefficient of expansion of silicon. The cover plate
15 may further comprise a UV transparent material, such as borosilicate glass.

 Further, in the above embodiment may alternatively comprise lenses coated with an anti-reflective coating.

 In an additional alternative embodiment of a method of the present invention, the method comprises a method of fabrication of a lens arrays for a collimator comprising
20 fabricating a wafer of lenses, the wafer of lenses comprising a mounting side and lenses, bonding a wafer of spacer material to the mounting side of the fabricated wafer of lenses, the spacer comprising a backside, and dicing the wafer of lenses and wafer of spacer material into individual lens arrays.

 In an embodiment of the above method, the wafer of lenses comprise silicon.
25 Further, the wafer of lenses is fabricated using a photoresist reflow process. Alternatively, the wafer of lenses is fabricated using a photoresist gray-scale mask process.

 In the embodiment above, the wafer of lenses may comprise lightly doped silicon.

 In the method above, the spacer material may be bonded to the wafer of lenses using an anodic bonding process. Alternatively, the spacer material is bonded to the wafer of
30 lenses using glue. Further, the spacer material is bonded to the wafer of lenses using epoxy.

 The method set forth above may further comprise setting the thickness of the spacer wafer to place the focal point of the lenses close to the back side of the spacer.

Additionally, the method above may further comprise coating the wafer of lenses with an anti-reflective coating.

In yet another embodiment of an apparatus of the present invention, the apparatus comprises a lens array for a collimator comprises a monolithic plurality of lenses, the plurality of lenses comprising a mounting side, and a spacer material bonded to the mounting side of the plurality of lenses, the spacer comprising a backside.

In this embodiment the plurality of lenses comprises a plurality of lenses which may be formed by a photoresist reflow process. Alternatively, the plurality of lenses comprises a plurality of lenses formed by a photoresist reflow process. Further, the wafer of lenses comprise a silicon containing material. The wafer of lenses may comprise lightly doped silicon.

In one aspect of this embodiment, the spacer material is bonded to the wafer of lenses using an anodic bonding process. Alternatively, the spacer material is bonded to the wafer of lenses using glue. Further, the spacer material may bonded to the wafer of lenses using epoxy.

Additionally, the spacer wafer is of a thickness to place a focal point of the lenses adjacent to the back side of the spacer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 depicts the activity of an optical signal as it travels the core of an optical fiber.

FIGURE 2 depicts an optical signal exiting an optical fiber core and entering a different medium.

FIGURE 3 depicts an optical signal traveling between optical fibers.

FIGURE 4 depicts an optical signal traveling from an optical fiber and through a lens.

FIGURE 5 depicts an optical signal traveling from an optical fiber and through a lens.

FIGURE 6 depicts back reflection into a fiber.

FIGURE 7 depicts an angled fiber face and back reflection into a fiber.

FIGURE 8 depicts a prior approach coupling of a fiber to a lens.

FIGURE 9 depicts a prior approach to constructing an array of collimating lenses and fibers.

FIGURE 10 depicts a prior approach, using a lens array.

FIGURE 11 depicts a collimator array in accordance with the present invention.

FIGURE 12 depicts fibers mounted in a holding block in accordance with the present invention.

FIGURE 13 depicts a side view of a collimator array in accordance with the present invention.

FIGURE 14 depicts a lens array in accordance the with present invention.

FIGURE 15 depicts a side view of a lens array in accordance with the present invention.

5 FIGURE 16 depicts a lens wafer and spacer in accordance with the present invention.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

10 In one embodiment, a collimator array in which the fabrication of the lens is decoupled from the fabrication of the collimation assembly is utilized. This approach allows the use of bulk fabrication of lens arrays, as well as reliable and repeatable mass production of collimator arrays.

As shown in FIG. 11, the collimator array 21 of the embodiment of FIG. 11 preferably comprises a monolithically fabricated array of refractive lenses 22, a spacer 23, and a fiber holding block 24, each discussed below.

15 Referring to FIG. 12, the fiber holding block 24 is preferably fabricated from silicon, although other materials may be used, such as borosilicate glass, fused silica plastic, or the like. Borosilicate glass may be readily purchased under the Pyrex trade name. In order to prepare a fiber for placement in the fiber block 24, a length of the fiber 25 cladding and buffer are stripped off of the core 26 (the core, as used here, is low index cladding and high index glassy core) longer than the length of a V groove 27. The fiber core 26 of a fiber (shown as dotted lines) is laid into the V groove 27 of the fiber holding block 24. It is understood that the cladding encases the glassy core of the fiber. The fiber core 26 should be flush or extending beyond the face 28 of the fiber holding block. The unstripped portion of the fiber 25 rests upon the shelf portion 38 of the fiber holding block 24. The shelf portion 38 is lower than the V groove 27 to accommodate the plastic buffer of the fiber 25. The unstripped portion of the fiber is bonded to the shelf portion 38 to provide strain relief for the fiber. The bonding may be carried out with glue or epoxy, and in one embodiment UV cured epoxy is utilized.

25 The fiber core 26 is then fixed in place by epoxy. The epoxy is preferably UV cured epoxy, but other glues or epoxies may be used. Prior to curing the epoxy, the exposed cladding of the fiber core 26 is covered with a thin plate of material 39, preferably borosilicate glass. Borosilicate glass is preferred because it has a similar coefficient of thermal expansion as the silicon which makes up the fiber holding block 24. It is

contemplated that materials other than borosilicate glass may be utilized, such as glass, silicon or plastic.

Referring to FIG. 17, once the fiber core 26 is bonded to the fiber holding block 24, the fiber block face 28 and fiber core face 31 are polished to remove anomalies from the fiber core face 31. This polishing is also utilized to angle 40 the fiber core face 31 and fiber block face 28. As discussed above, the fiber core face 31 is preferably polished at an angle 40 so as to inhibit coupling of back reflections into the fiber. The fiber core face is preferably polished to an angle 40 of about 8 degrees, but angles in a range from about 5-10 degrees are contemplated.

However, it is important to note that both the fiber block face 28 and the fiber core face 29 are polished together as a unit. As shown in FIG. 13, this avoids the problems in the prior approaches regarding proper lens 29 alignment with a fiber bonded to a monolithic holding block 24. This is particularly important in maintaining the alignment of the optical axis 30 of the angled fiber face 31 relative to the optical axis 32 of the lens.

Referring again to FIG. 13, the spacer 23 is mounted to the fiber block face 28 and fiber core face 31. The thickness of the spacer 23 is determined by the focal length of the lens 29 of the lens array 22 (fabrication of the lens array and spacer is discussed below). The spacer 23 allows the fabrication tolerances of the lens array 22 (discussed below) to be decoupled from the fabrication tolerances of the remainder of the collimator assembly 21. In other words, because the spacer 23 sets the distance from the lens array 22 from the fiber face 31, the focal length of the lenses on the lens array 22 is not a critical factor in the fabrication of other parts of the lens array 22. Further, proper positioning of the lens array, and thus the focal point, relative to the fiber face 31 becomes a relatively simple task. This allows for repeatable placement of the focal point 33 relative to the fiber face 31. Also, because both the fiber core face 31 and the fiber block face 28 are polished at an angle (discussed above), the spacer 23 is able to be reliably placed to meet and be aligned with the fiber face 31.

The spacer 23 is preferably made of borosilicate glass, because the thermal coefficient of borosilicate glass is similar to that of silicon. However, it is contemplated that other materials may be used, such as glass, silicon or plastic.

The spacer 23 may be bonded to the fiber block face 28 by anodic bonding. Anodic bonding is a process by which the lens array and spacer material are exposed to high temperature and high current. This causes the lens array material and spacer material to

chemically bond on at the crystalline level. Alternatively, the spacer 23 can be bonded to the fiber block face 28 with UV epoxy, but other glues and epoxies, such as a thermal epoxy, are also usable for this purpose.

Referring now to FIGS. 14 and 15, in some embodiments a lens array 22 is preferably fabricated from lightly doped silicon utilizing a photoresist reflow process. The individual lenses are preferably spherical lenses, although aspherical lenses may be utilized. Silicon is preferred in some embodiments because of its high index of refraction, fast etch rate, and the large body of knowledge available regarding silicon processing methods. Lenses fabricated by the photoresist reflow process are widely commercially available from many microlens foundries. An alternative process to fabricate the silicon lenses utilized in some embodiments is a photoresist gray-scale mask process. Lens arrays fabricated utilizing the photoresist gray-scale mask process are also widely available from microlens foundries. The lens array 22 preferably comprises a base 34 and one or more lenses 35 fabricated upon the base 34. Additionally, the lenses can receive an anti-reflective coating after fabrication, before being diced into individual lens arrays.

It is contemplated that the lens array of the present invention may be fabricated from materials other than silicon, as there are a wide variety of materials from which lenses may be made, such as glass and/or other refractive materials such as germanium, zinc-sulfide, fused silica, gallium phosphide, gallium arsenide. Further, while some embodiments employ a monolithic array of lenses as set forth above, it is contemplated that other embodiments may have individual lenses, having the focal length decoupled from the other components and assembly of the collimator array.

It is preferred that each of the lenses have the same optical parameters, namely focal length and location of the focal point. Such lenses typically are fabricated on a wafer scale, producing a large number of lenses with the same optical parameters may be reliably produced. As the lens arrays are fabricated utilizing highly precise semiconductor processing techniques discussed above, the location of the focal point (as well as other optical parameters) of each lens is a known quantity.

As stated above, a primary problem in prior approaches is proper positioning of the focal point of a lens. Repeatable positioning of the focal point can be carried out by coupling the lens array 22 to a spacer 21. After the optical parameters (such as focal point location) of lenses fabricated upon a wafer is determined, the lenses are mounted to a spacer

wafer. The focal point placement then becomes a matter of assembling the lens/spacer combination to the face of a holding block.

Referring to FIG. 16, the lens wafer 36 is bonded to a spacer wafer 37. This bonding is done on the wafer level. That is, after fabrication of the lens arrays upon a silicon wafer, the entire lens wafer 36 is bonded to a sheet of spacer material 37. The spacer wafer 37 is set at a thickness such that the focal point of each lens on the lens wafer 36 is positioned at the opposite side of the spacer wafer. The lens arrays are preferably bonded to the spacer material using anodic bonding. Anodic bonding is a process by which the lens array and spacer material are exposed to high temperature and high current. This causes the lens array material and spacer material to chemically bond on at the crystalline level. Alternatively, UV epoxy, and other glues and/or epoxies may be used for this purpose. If this alternative is used, a spacing mechanism should be used to maintain a constant thickness of epoxy between the lens wafer 36 and the spacer wafer 37. For example, a length of fiber with the buffer stripped off will provide a consistent space between the lens wafer 36 and the spacer wafer 37. Other spacing mechanisms may be used, limited only by the imagination of the process designer.

Referring now to FIG. 13, once bonded, each individual lens array 22, with spacer 23 attached, is diced according to the needs of the collimator array designer. The important factor is that the spacer 23 thickness is set such that the focal point 34 of the lens 29 is adjacent the side of the spacer 23 opposite the lens 29. This allows for ease of construction of the collimator array, as the lens array 22/spacer 23 combination greatly simplifies lens array 22 placement relative to the face of a fiber 31. That is, the distance from the lens 29 to the fiber face 31 is set by the thickness of the spacer 23. This allows decoupling of the lens array 22 parameters related to focal length parameter from the physical dimensions of other elements of the collimator array. This decoupling of the lens array 22 focal length parameter allows for tremendous simplification of assembly over the prior approaches.

While the present invention has been described in detail by specific reference to the preferred embodiments, it is understood that variations and modifications thereof may be made without departing from the true spirit and scope of the invention as set forth in the claims.

CLAIMS

We Claim:

1. A collimating device for collimating an optical signal, the collimating device
5 comprising:

a lens comprising a mounting portion, the lens having a focal length;

a holder having a face and being capable of receiving and positioning an optical
fiber such that a face of the optical fiber is substantially aligned with the face of the holder;

a spacer adjacent to the face of the holding portion and the mounting portion of the
10 lens, the spacer providing a separation distance between the holder and the at least one lens.

2. The collimating device of Claim 1 wherein the spacer is connected to the face of the
holder and the mounting portion of the lens.

15 3. The collimating device of Claim 1 comprising a plurality of lenses and a plurality of
optical fibers.

4. The collimating device of Claim 1 wherein the at least one lens is comprised of a
material which has a thermal coefficient of expansion at least similar to silicon.
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5. The collimating device of Claim 1 wherein the at least one lens comprises a
monolithic array of lenses.

25 6. The collimating device of Claim 5 wherein the monolithic array of lenses comprise
silicon.

7. The collimating device of Claim 5 wherein the monolithic array of lenses are
comprised of at least one of a) silicon; b) germanium; c) zinc-sulfide; d) fused silica; e)
gallium phosphide; and f) gallium arsenide.
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8. The collimating device of Claim 1 wherein the spacer is comprised of a material
having a thermal expansion coefficient substantially the same as that of silicon.

9. The collimating device of Claim 8 wherein the spacer comprises a material at least somewhat transparent to UV light.

10. The collimating device of Claim 1 wherein the spacer comprises at least one of a)
5 glass; b) silicon; c) borosilicate glass.

11. The collimating device of Claim 1 wherein the holder is comprised of a material having a thermal expansion coefficient about that of silicon.

10 12. The collimating device of Claim 11 wherein the holder is comprised of silicon.

13. The collimating device of Claim 12 wherein the holder has at least one V-groove for receiving a fiber.

15 14. The collimating device of Claim 1 wherein the holder comprises at least one of a) glass; and b) plastic.

15. The collimating device of Claim 1 wherein the holder is capable of receiving and positioning an optical fiber having a face polished at an angle, the face of the holder being
20 polished at an angle similar to and substantially aligned with the angle of the received and polished optical fiber face.

16. The collimating device of Claim 15 wherein the angle of the received and positioned optical fiber face is about in the range of 5 to 10 degrees.

25 17. The collimating device of Claim 16 wherein the angle of the received and positioned optical fiber face is about 8 degrees.

18. The collimating device of Claim 1 wherein the optical separation is approximately
30 the same as a focal length of the lens.

19. The collimating device of Claim 1 further comprising a strain relief for holding the received and positioned optical fiber, the strain relief comprising a shelf, the shelf being

attached to the holder, the shelf being capable of receiving a buffer of a received optical fiber.

20. The collimating device of Claim 1 wherein the spacer comprises a material, and wherein the lens comprises a material, and wherein the material of the spacer has a thermal expansion coefficient substantially the same as the material of the lens.

21. The collimating device of Claim 1 further comprising an anti-reflective coating upon the lens.

22. A collimating device for collimating an optical signal, the collimating device comprising:

a monolithic lens array comprising a mounting portion, each being capable of projecting an image onto a focal plane;

a holder comprising silicon and having a face, and the holder being capable of receiving and positioning an optical fiber having a face, such that a face of the optical fiber is substantially aligned with the face of the holder;

a spacer disposed between to the face of the holder and the mounting portion of the lens, the spacer setting an optical separation distance between the holder and the at least one lens wherein the optical separation distance is approximately a focal length of at least one lens of the monolithic lens array.

23. A method of making a collimating device for collimating an optical signal, the method comprising:

providing a holder having a face, the holder being capable of receiving a fiber and positioning the face of a fiber;

providing at least one lens;

connecting the holder to the at least one lens such that the lens parameters related to focal length are decoupled from the position of the face of the fiber.

24. The method of Claim 23 wherein the a focal plane of the at least one lens is located upon the face of the holder.

25. The method of Claim 23 further comprising polishing the face of the holder.

26. The method of Claim 25 wherein the polishing step comprises polishing the face to an angle in the range of about 5 to 10 degrees.

5

27. The method of Claim 26 wherein the angle is about 8 degrees.

28. The method of Claim 27 further comprising coating the at least one lens with anti-reflective coating.

10

29. The method of Claim 23 wherein the holder is capable of receiving a fiber having a face polished at an angle, the face of the holder being capable of being aligned with the face of the fiber polished at an angle.

15

30. The method of Claim 29 wherein the face of the holder is polished at an angle in the range of about 5 to 10 degrees.

31. The method of Claim 30 wherein the face of the holder is polished at an angle at about 8 degrees.

20

32. A collimator comprising
a plurality of optical fibers;
a plurality of lenses, each of the plurality of lenses being part of a monolithic array of lenses;

25

a spacer positioned between each of the plurality of optical fibers and plurality of lenses.

30

33. The collimator of Claim 32 further comprising a holding block, the holding block further comprising a plurality of V-grooves, the plurality of V-grooves holding the plurality of optical fibers evenly spaced relative to each other.

34. The collimator of Claim 33 wherein the plurality of optical fibers is held in the plurality of V-grooves by glue, the glue holding the plurality of optical fibers in optical alignment with the plurality of lenses

5 35. The collimator of Claim 34 wherein the glue comprises epoxy.

36. The collimator of Claim 35 wherein the epoxy is UV cured epoxy.

10 37. The collimator of Claim 34 further comprising a cover plate covering the fibers held in the plurality of V-grooves.

15 38. The collimator of Claim 37 wherein the plurality of lenses comprise silicon, and wherein the cover plate comprises a material with a thermal coefficient of expansion substantially the same as the thermal coefficient of expansion of silicon.

39. The collimator of Claim 38 wherein the cover plate comprises a UV transparent material.

20 40. The collimator of Claim 39 wherein the cover plate comprises borosilicate glass.

41. The collimator array of Claim 31 wherein the plurality of lenses further comprises anti-reflective coating.

25 42. A method of fabrication of a lens arrays for a collimator comprising:
fabricating a wafer of lenses, the wafer of lenses comprising a mounting side and lenses;

bonding a wafer of spacer material to the mounting side of the fabricated wafer of lenses, the spacer comprising a backside;

30 dicing the wafer of lenses and wafer of spacer material into individual lens arrays.

43. The method of Claim 42 wherein the wafer of lenses comprises silicon.

44. The method of Claim 43 wherein the wafer of lenses is fabricated using a photoresist reflow process.

45. The method of Claim 43 wherein the wafer of lenses is fabricated using a photoresist gray-scale mask process.

46. The method of Claim 45 wherein the wafer of lenses comprise lightly doped silicon.

47. The method of Claim 42 wherein the spacer material is bonded to the wafer of lenses using an anodic bonding process.

48. The method of Claim 42 wherein the spacer material is bonded to the wafer of lenses using glue.

49. The method of Claim 48 wherein the spacer material is bonded to the wafer of lenses using epoxy.

50. The method of Claim 42 further comprising setting the thickness of the spacer wafer to place the focal point of the lenses close to the back side of the spacer.

51. The method of Claim 42 further comprising coating the wafer of lenses with an anti-reflective coating.

52. A lens array for a collimator comprising:

a monolithic plurality of lenses, the plurality of lenses comprising a mounting side; and

a spacer material bonded to the mounting side of the plurality of lenses, the spacer comprising a backside.

53. The lens array of Claim 52 wherein the plurality of lenses comprises a plurality of lenses formed by a photoresist reflow process.

54. The lens array of Claim 52 wherein the plurality of lenses comprises a plurality of lenses formed by a gray scale mask process.

5 55. The lens array of Claim 53 wherein the wafer of lenses comprise a silicon containing material.

56. The lens array of Claim 54 wherein the wafer of lenses comprise lightly doped silicon.

10 57. The lens array of Claim 52 wherein the spacer material is bonded to the wafer of lenses using an anodic bonding process.

58. The lens array of Claim 52 wherein the spacer material is bonded to the wafer of lenses using glue.

15 59. The lens array of Claim 58 wherein the spacer material is bonded to the wafer of lenses using epoxy.

20 60. The lens array of Claim 52 further wherein the spacer wafer is of a thickness to place a focal point of the lenses adjacent to the back side of the spacer.

61. The lens array of Claim 52 further comprising an anti-reflective coating upon the monolithic plurality of lenses.

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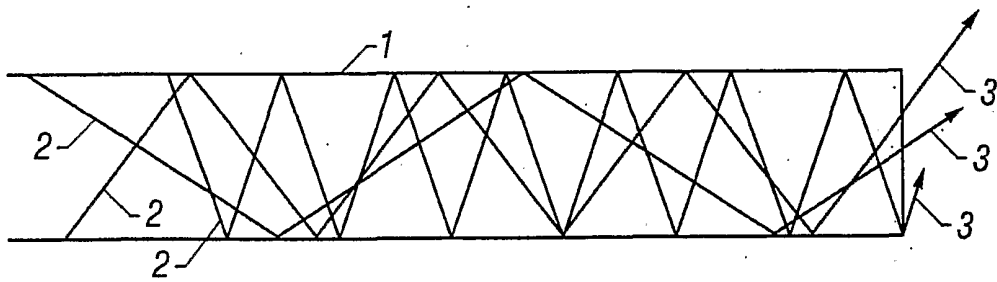


FIG. 1

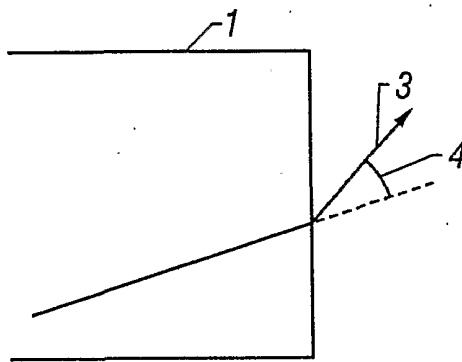


FIG. 2

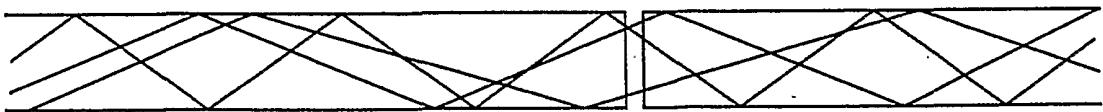


FIG. 3

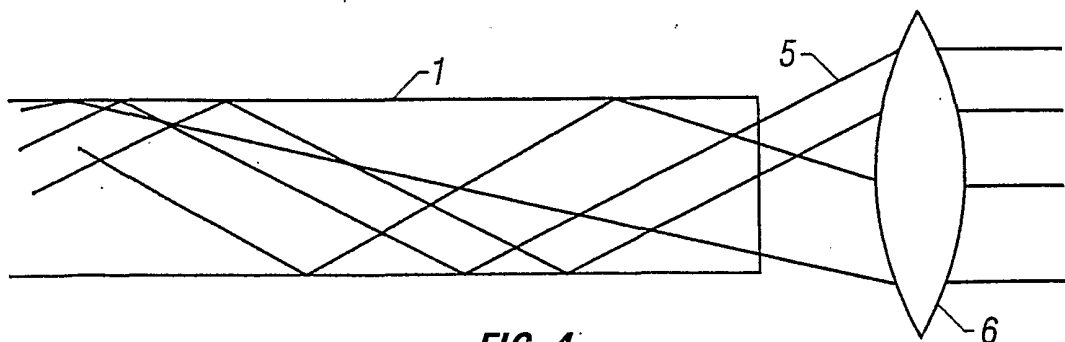


FIG. 4

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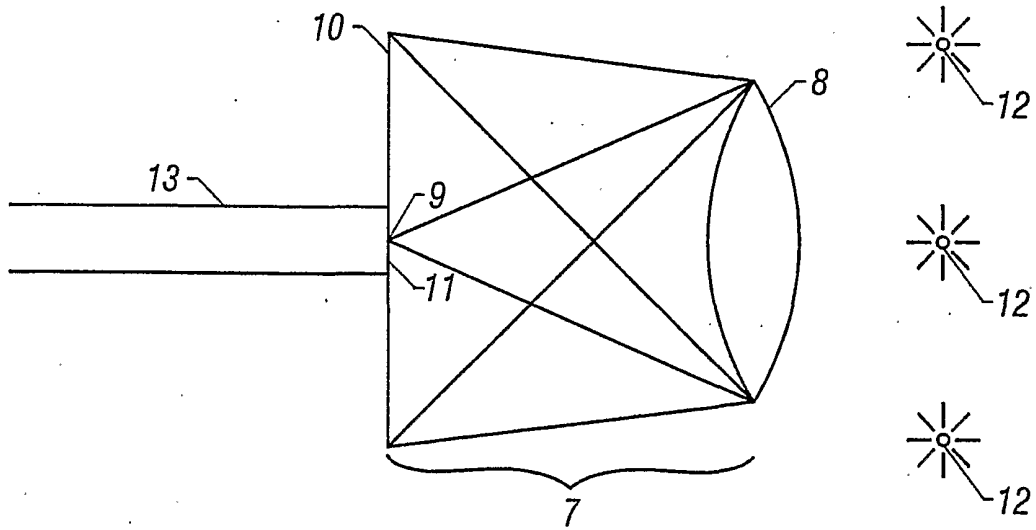


FIG. 5

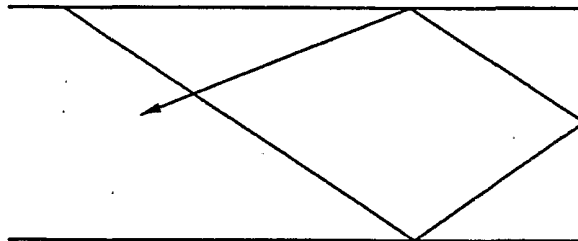


FIG. 6

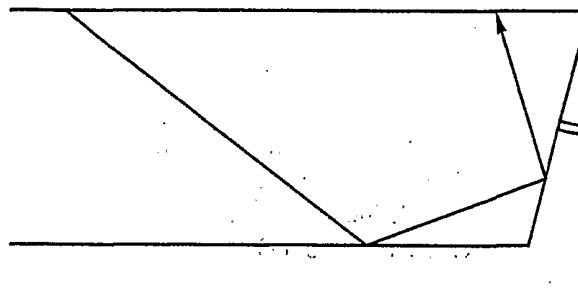


FIG. 7

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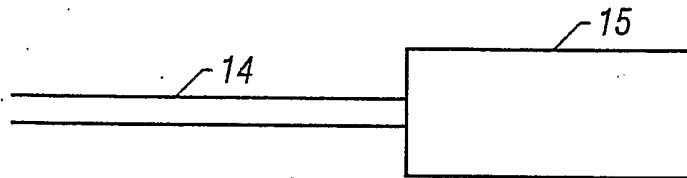


FIG. 8

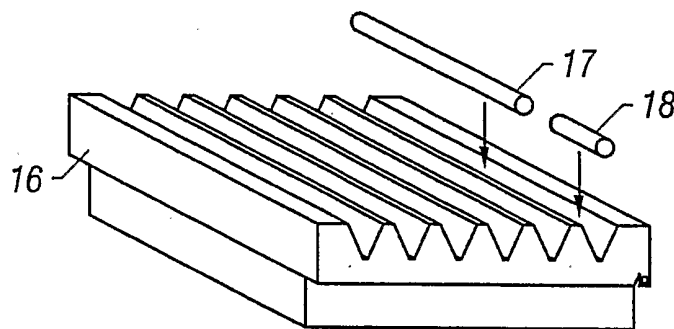


FIG. 9

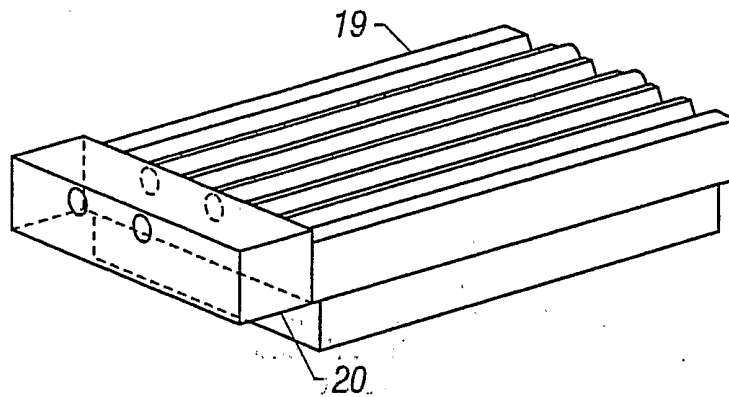


FIG. 10

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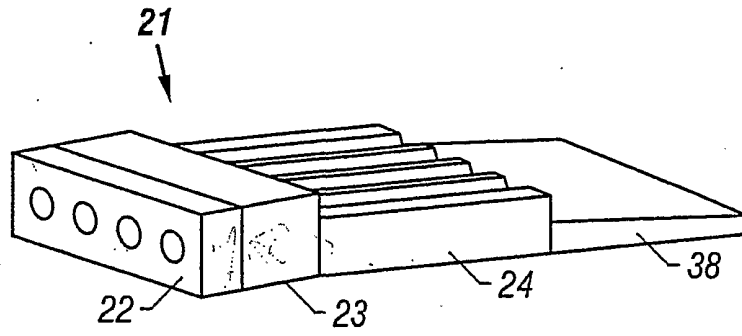


FIG. 11

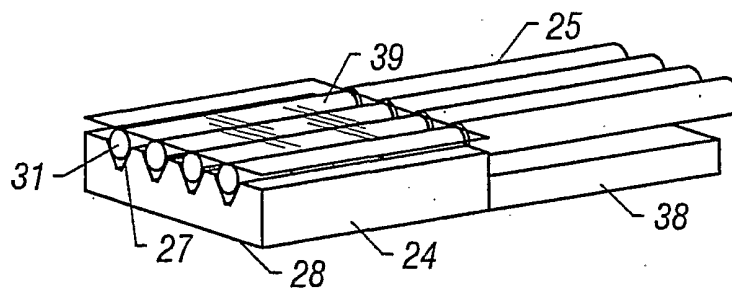


FIG. 12

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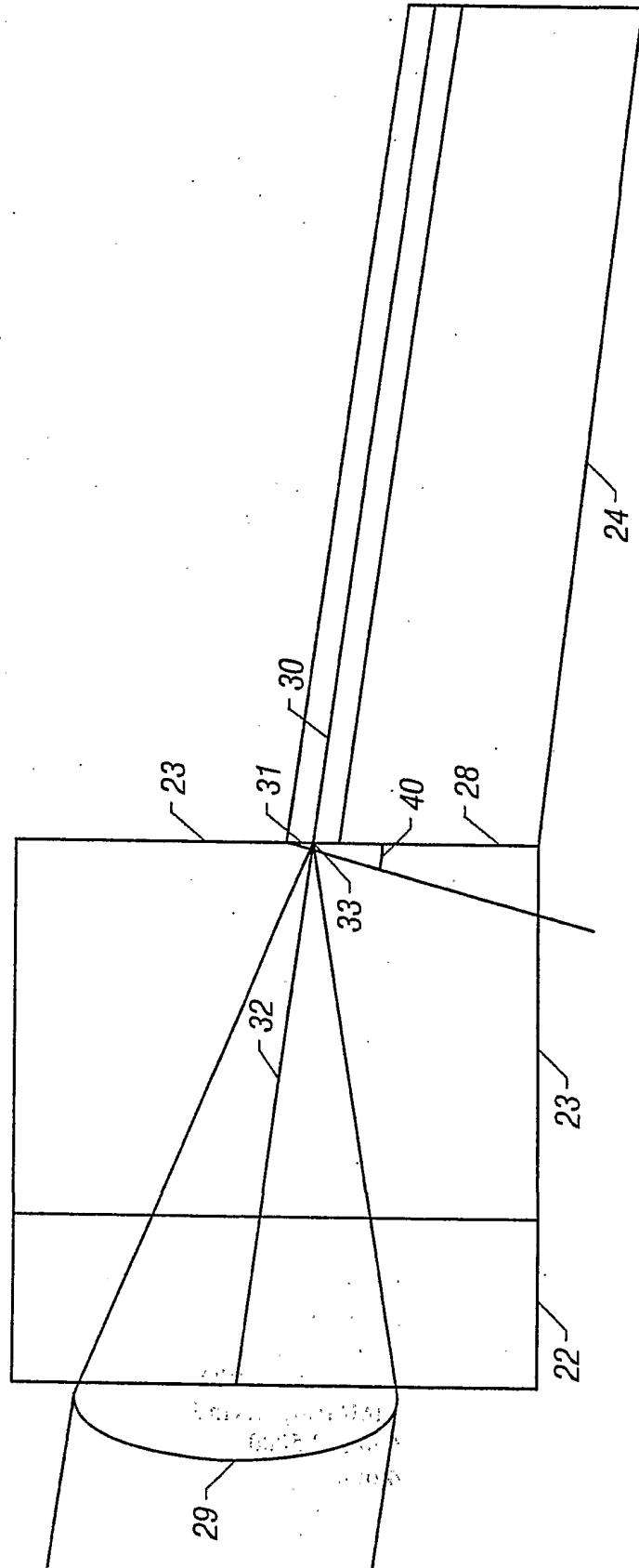


FIG. 13

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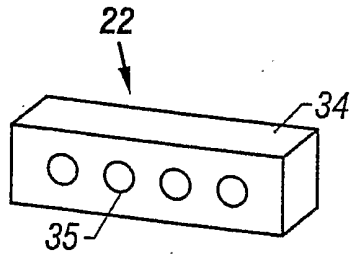


FIG. 14

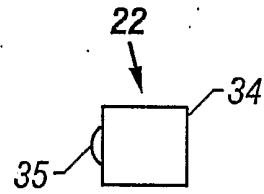


FIG. 15

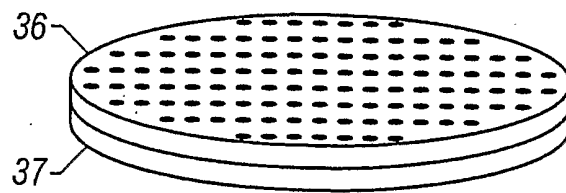


FIG. 16

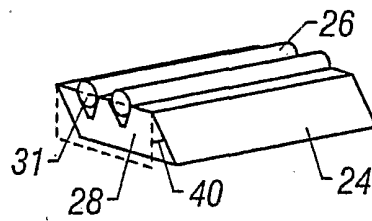


FIG. 17