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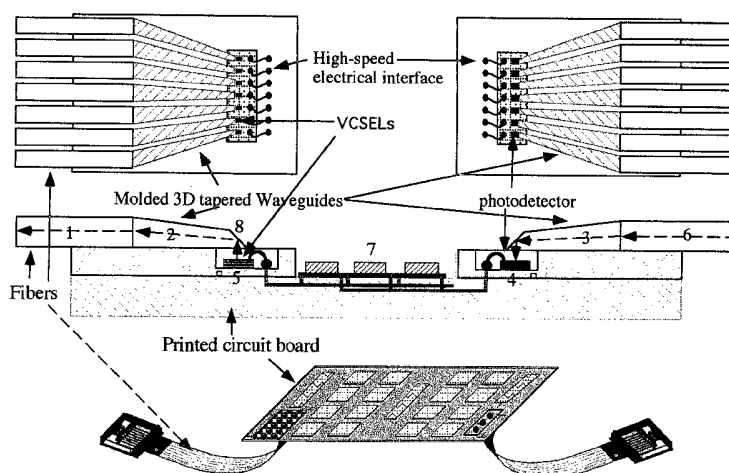
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(54) Title: COMPRESSION-MOLDED THREE-DIMENSIONAL TAPERED UNIVERSAL WAVEGUIDE COUPLERS



(57) **Abstract:** The present invention is a three-dimensional tapered waveguide coupler (2, 3) capable of interconnecting electro-optical devices (4, 5) with differing optical mode profiles. The ends of the waveguide are configured to match the optical mode profiles of the electro-optical devices that the waveguide interconnects. The waveguide adiabatically transmits the fundamental mode of the photo-optic signal from the electro-optical (4, 5) device at the waveguide's input end (6) to a different electro-optical device (4, 5) at the waveguide's output end (1). A single couple can be configured with one or more waveguides, each waveguide having different optical mode profiles at either end and different optical transmission characteristics.

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COMPRESSION-MOLDED THREE-DIMENSIONAL TAPERED
UNIVERSAL WAVEGUIDE COUPLERS

Field of the Invention

The present invention relates to waveguides, and more specifically to optical waveguide interconnectors.

Description of the Related Art

Communications and computing systems based on electronic interconnection schemes have nearly reached their limits of any further improvement, while demands for higher bandwidth and speed are ever increasing for military and civilian applications. This scenario has led researchers to seriously consider new computing architectures based on optoelectronic interconnects. Employment of optical technologies is already a reality in the area of communications. However, full commercial realization of optical computation and communications networks depends on the successful transmission and control of high-speed signals among processing elements, memories and other peripherals with minimal losses. In fact, by now, several key components and manufacturing technologies needed for this technological revolution have attained an appreciable state of maturity. A large variety of optoelectronic devices such as lasers, optical amplifiers, electro-optic switches, modulators, and detectors exhibit excellent performance characteristics. Also, the transmission characteristics achieved for optical waveguides and fibers allow optical transmission spans from intra-wafer interconnection to global optical communications.

The compatibility and reliability aspects of optoelectronic packaging are the major hurdles to taking full advantage of novel achievements in optoelectronic device technology. The difficulty in packaging mismatched discrete optoelectronic components generally results in high coupling losses. The mismatch is mainly a consequence of spatial and angular variations of individual optoelectronic components and separations of array devices. These components, which are often

1 fabricated on different substrates, have different mode sizes, numerical apertures and component
2 separations. For example, laser diodes can be made on GaAs, detectors made on silicon, and
3 modulators made on LiNbO₃. The dimensions of these discrete devices are pre-selected to optimize
4 their performance, and vary from a few microns (single-mode waveguides and vertical cavity
5 surface-emitting lasers) to hundreds of microns (photodetectors and multi-mode plastic fibers). The
6 requirements of individual element performance optimization make system integration very difficult
7 with comfortable alignment tolerance, and consequently integration results in high packaging costs.
8 In many scenarios, the packaging cost is approximately 50% of the total system cost. Achieving
9 efficient optical coupling among various devices with sufficient alignment tolerance is particularly
10 difficult when using prisms, gratings, or optical lenses.

11 Two-dimensional (2-D) tapered waveguides have been employed to improve optical coupling
12 among various optoelectronic devices. Coupling efficiency can be further improved if three-
13 dimensional (3-D) tapered waveguides can be fabricated and employed. However, none of the
14 existing optoelectronics or microelectronics fabrication methods available to optoelectronics
15 industrial sectors is suitable for making satisfactory 3-D tapered waveguide devices, varying from
16 a few microns to hundreds of microns in both horizontal and vertical directions. To grow a high-
17 index waveguide layer hundreds of microns in thickness is impractical using any existing waveguide
18 fabrication method used for inorganic materials such as GaAs, LiNbO₃ and glass. The 3-D
19 compression molded polymeric waveguide described herein is a solution to bridge the huge dynamic
20 range of different optoelectronic device-depths varying from a few microns to hundreds of microns.

21 The ends of the waveguide are designed to provide interfaces with fiber-optic cables. There
22 are three problems that have occurred at the ends, or interfaces, of the waveguide:

- 23 (1) inconveniently high coupling loss due to the optical mode mismatch,

1 (2) strict alignment tolerance which makes the packaged system vulnerable to harsh
2 environments, and

3 (3) separation mismatch when array devices (such as laser diode arrays, smart pixel
4 arrays, photodetector arrays and optical fiber/waveguide arrays) are employed.

5 Due to the planarized nature of these devices mentioned above, the most common approach
6 based on microlenses is bulky and very expensive because it requires complicated three-dimensional
7 spatial and angular alignments.

8 Conventional optoelectronic packaging technologies have failed to provide low-loss coupling
9 among various optoelectronic devices, including laser diodes, optical modulators, waveguide
10 splinters, single-mode optic fibers, multi-mode optic fibers and optical detectors. The above
11 mentioned three problems are solved by the present invention.

SUMMARY

The present invention discloses an apparatus and method for interconnecting electro-optical devices with differing optical mode profiles. The present invention is a three-dimensional tapered waveguide with a specified index of refraction that adiabatically transmits the fundamental mode of the photo-optic signal from an electro-optical device at the waveguide's input end to a different electro-optical device at the waveguide's output end. The input and output ends of the three-dimensional tapered waveguide are configured to match the optical mode profiles of the electro-optical devices that the waveguide interconnects.

The three-dimensional tapered waveguide can be configured in an array, to interconnect arrays of electro-optical devices with differing optical mode profiles and inter-device separation. Depending upon system packaging requirements, the waveguide can be manufactured on a substrate for interconnecting devices mounted on or near substrates such as printed circuit boards or silicon substrates, or encased in a plug-type arrangement for interconnecting electro-optical devices such as fiberoptic cables. The substrate or encasing material has a different index of refraction than the waveguide material.

Additionally, the present invention comprises a compression-molding technique for fabricating 3-D tapered polymeric waveguides. This embodiment of the present invention comprises a two-piece molding tool that includes a substrate and a mold plunger where the mold plunger provides a cavity having the shape of the desired 3-D-tapered waveguides. The present invention provides an appropriate amount of molding material that is spin-coated or laminated onto the substrate. The film thickness is equal to the maximum thickness of the tapered structure. The molding process begins with the heating of the mold plunger and the polymer film. Then the two parts of the mold are brought together under pressure that causes the polymer film, which is softened

1 by heat, to be compression molded into the shape of the stamp of the desired 3-D-tapered
2 waveguides.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an illustration of an optoelectronic interconnect module where the three-dimensional tapered polymeric waveguide couplers are employed for interconnecting an VCSEL array to an optic fiber array and a photodetector array to an optic fiber array.

FIG. 2 shows an illustration of an optical fiber MT-type coupler employing three-dimensional tapered polymeric waveguides used for connecting two MT-type fiberoptic connectors that have different mode profiles and fiber separations.

FIG. 3 shows a more detailed illustration of a polymeric waveguide coupler, which comprises an array of 3-D tapered waveguides. Each waveguide has different guided mode profiles at the two ends. The separation between each waveguide may also be different at the two ends in order to match the separation optoelectronic devices under connection.

FIG. 4 shows optimized taper profiles for an adiabatic transition of waveguide mode.

FIG. 5 shows an illustration of the compression-molding technique for fabricating 3-D tapered polymeric waveguides.

DETAILED DESCRIPTION OF THE INVENTION

The present invention comprises a novel universal optical coupler that comprises a unique three-dimensional tapered polymeric waveguide with different mode-profiles at the two ends that can match to two different optoelectronic devices respectively, for increasing the optical coupling efficiency and the alignment tolerance. These polymeric waveguide couplers are fabricated by the compression-molding technique. Additionally, the present invention also includes a unique compression-molding method for manufacturing three-dimensional tapered polymeric waveguides that comprises a compression step at the polymer phase transition state. Within this step, the 3-D waveguide structure is transferred from the mold plunger into a polymeric film that has been preapplied to any substrate of interest.

The most common approach for optical coupling among optoelectronic devices with different apertures is to employ an optical lens that is often too bulky compared to the optoelectronic devices to be coupled. Such an approach also is very expensive because it requires complicated three-dimensional spatial and angular alignments. Another conventional approach is to employ the two-dimensional tapered waveguide coupler that can be manufactured by standard photolithography technique. The innovative compression-molded three-dimensional polymeric waveguide of the present invention is an effective component for optical coupling among various optoelectronic devices, including laser diodes, optical amplifiers, electro-optic switches, modulators, optic fibers and photodetectors. The novel compression-molded polymeric waveguide is a solution to bridge the huge dynamic range of different optoelectronic components. It is also applicable wherever there is a need to interconnect optoelectronic components with different apertures, such as connecting telecommunication (single-mode) fibers to (multi-mode) local network fibers.

1 Compression molding is also one of the most effective methods for mass-producing high
2 quality low-cost optical polymeric waveguide devices. The compression molding methodology
3 disclosed herein adds the novel steps of compression molding a material that has been preapplied
4 to a substrate of interest, and performing that compression molding step when the preapplied
5 material is at the polymer transition stage.

6 The compression-molded three-dimensional universal waveguide couplers are made out of
7 optical polymers that can be compression-molded into optical channel waveguide format for
8 effective optical coupling. The 3-D tapered waveguide coupler has two different optical mode
9 profiles at the two ends. The two different optical mode profiles match the optical mode profiles of
10 two optoelectronic devices to be coupled and increase the optical coupling efficiency between the
11 two devices. The guided region of the 3-D waveguide coupler functions as a guided mode convertor
12 with a very small propagation loss. For optical coupling between two arrays of devices, a waveguide
13 coupler array provides both the different mode profiles at the two output ends and the required
14 channel separations.

15 The 3-D waveguide coupler can be molded directly onto any substrate of interest. The
16 substrate functions as a structural element, providing physical support for the waveguide during
17 manufacturing and operation. The substrate can also provide a convenient design solution to insure
18 that the optoelectronic devices to be coupled to the waveguide are properly aligned with the
19 waveguide, since such devices are often designed for mounting on typical electronic substrates such
20 as a printed circuit board or a silicon substrate. Alternatively, the 3-D waveguide coupler can be
21 enclosed or encased in a plug-type arrangement that provides the necessary physical support and
22 alignment, and is more convenient for interconnecting electro-optical cables such as fiberoptic
23 cables.

1 The process of compression-molding involves fabrication of mold plungers with the desired
2 3-D waveguide cavity, preparation of polymer films on a substrate, and formation of waveguides.
3 A two-piece compression-molding tool consists of a substrate and mold plunger that provides a
4 cavity having the shape of the desired 3-D-tapered waveguide. An appropriate amount of molding
5 polymer, polymer waveguide film in this case, is spincoated or laminated onto the substrate of
6 interest. The film thickness is equal to the maximum thickness of the tapered structure. The
7 molding process begins with the heating of the mold plunger and the polymer film. The two parts
8 of the mold are then brought together under force. The polymer film, softened by heat, is thereby
9 molded into the shape of the stamp. The last step is to harden and fix the molded waveguide shape.
10 The fundamental differences in polymers dictate the plastic processing method to be used for the
11 final step in the waveguide molding. For example, thermosetting polymers are further heated under
12 pressure, while thermoplastics are cooled to room temperature. After the polymer is cured (fixed),
13 the mold plunger is removed, leaving behind are the 3-D-tapered waveguide structures on the
14 substrate.

15 FIG. 1 is an illustration of an optoelectronic interconnect module where the
16 three-dimensional tapered polymeric waveguide couplers are employed for interconnecting a VCSEL
17 array to an optic fiber array and a photodetector array to an optic fiber array. The module shown in
18 FIG. 1 comprises an input optical fiber array 6, 3-D tapered waveguide couplers 2 and 3,
19 photodetectors 4, VCSELs 5, and an output optical fiber array 1, all of which are mounted on any
20 substrate of interest, such as a PC board or silicon substrate with electronics system 7. The incoming
21 photo-optic or light signal from optical fiber array 6 is coupled to the input end of a tapered
22 waveguide array 3 and converted to electrical signals by an array of fast photodetectors 4 at the
23 input-end of the electronic system 7. From the transmission end, the electrical signals from the

1 electronic system 7 are converted to photo-optical signals using an array of VCSELs 5 and then
2 routed to the output fiber array 1 by a tapered waveguide coupler 2 in conjunction with 45°
3 waveguide mirrors 8. Such 45° waveguide mirrors 8 can be molded simultaneously with the 3-D
4 tapered waveguides.

5 For successful coupling, it is crucial to (a) match the mode profiles at the input end of the
6 tapered waveguides 3 and 2 to the mode profiles of optical fibers 6 and VCSELs 5, respectively; (b)
7 maintain adiabatical propagation of the guided mode through the tapered waveguides 2 and 3; and
8 (c) match the mode profiles at the output ends of tapered waveguides 3 and 2 to the mode profiles
9 of the fast photodetector array 4 and the optical fiber array 1, respectively. Employing the 3-D
10 tapered waveguides allows alignment tolerances to be relaxed and reduces the coupling losses. The
11 3-D tapered waveguides provide a universal low-loss packaging scheme covering the huge dynamic
12 range of various optoelectronic devices, which have apertures ranging from a few micrometers to
13 hundreds of micrometers. The coupling technique shown in FIG. 1 is not only useful for
14 interconnecting optoelectronic multi-chip modules but also useful for any low-loss device-to-device
15 coupling.

16 FIG. 2 is an illustration of an optical fiber MT-type coupler 9 for connecting two MT
17 fiberoptic connectors 10 and 11 that have different mode profiles and fiber separations. The MT
18 coupler, comprising the 3-D tapered waveguides, is designed to couple standard single-mode and
19 multi-mode MT-type fiberoptic plugs 10 and 11 with very low insertion loss. Both the single-mode
20 and the multi-mode fiberoptic ribbons 12 and 13 typically have four or eight fibers in an array. A
21 clip 14 can be used to enhance the mechanical reliability of the connection.

22 FIG. 3 is a more detailed illustration of a polymeric waveguide coupler that comprises an
23 array of 3-D tapered waveguides. The polymeric waveguide coupler can be employed to improve

1 the optical coupling between a single-mode fiber array and a multi-mode fiber array. Each
2 waveguide has different guided mode profiles at its two ends. The separation between each
3 waveguide may also be different at the two ends of the coupler in order to match the separation of
4 optoelectronic devices under connection. All 3-D tapered waveguides are compression-molded at
5 the same time.

6 FIG. 3 also illustrates the top and side view of the 3-D tapered polymeric waveguide,
7 revealing its basic structure. In FIG. 3, A, B and a, b are the waveguide width and height at the ends
8 of 3-D tapered coupler, respectively. S and s are the waveguide separation at the two ends of
9 coupler. And, n_1 is the optical refractive index of polymer and n_2 is the refractive index of the
10 substrate. There is a tradeoff in determining the waveguide length L. The waveguide has to be long
11 enough to ensure adiabatic propagation of the guided modes. On the other hand, the length of the
12 waveguide should be minimized to reduce the waveguide propagation loss.

13 For efficient power-coupling between two different optoelectronic components facilitated
14 by the tapered waveguide couplers, the guided optical mode should propagate adiabatically through
15 the tapered region of the coupler. In other words, the waveguide must operate without any loss and
16 there should not be any power transfer to higher order local modes. Therefore, it is desirable to
17 maintain the lowest order mode in the waveguide without mode conversion to higher order mode
18 or to a radiation mode taking place.

19 In our analysis, a simplified approach based on the scalar wave equation is employed. We
20 assume that the tapered waveguide can be subdivided into many small waveguide segments labeled
21 by an index v , and defined by a refractive index distribution $n^v(x,y)$ independent of z . With the

notation $\Phi_m^v(x,y)$ and β_m^v for the local normal modes of order m and their associated propagation

constants, respectively, the scalar wave equation for segment v reads,

$$\left[\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + k^2 (n^v(x,y))^2 \right] \Phi_m^v(x,y) = (\beta_m^v)^2 \Phi_m^v(x,y). \quad (1)$$

Here $k = 2\pi/\lambda$ is the free space wave number. In order to calculate the evolution of the field along the tapered waveguide, we note that due to the completeness of the modes, the electric field distribution within each segment can be expressed as

$$E^v(x,y,z) = \sum_m a_m^v(z) \Phi_m^v(x,y). \quad (2)$$

Based on the modes calculated from Eq. (1), the field $a_m^v(z)$ propagating along the structure can be described entirely in terms of the complex amplitudes that can be solved by an iteration of two steps using a Fourier analytic approach. First, as long as both z and z+d lie within the same segment v, propagation is described by

$$a_m^v(z+d) = a_m^v(z) \exp(i\beta_m^v d). \quad (3)$$

Second, the requirement that the electric field be continuous at the interface $z^{v,v+1}$, between two consecutive segments v and v+1 leads to a simple relationship between the complex amplitudes

$$a_1^{v+1}(z^{v,v+1}) \text{ and } a_m^v(z^{v,v+1}), \text{ i.e.,}$$

$$a_1^{v+1}(z^{v,v+1}) = a_m^v \langle \Phi_1^{v+1} / \Phi_m^v \rangle a_m^v(z^{v,v+1}). \quad (4)$$

Hence, using Eqs. (3) and (4) with the modes $\Phi_m^v(x,y)$ and propagation constants β_m^v

obtained from Eq. (1), we can simulate the propagation of the optical field along the tapered sections.

The 3-D-tapered waveguide device is designed as an adiabatic device in which the optical power is predominantly guided by the fundamental mode. By keeping track of the excitation spectrum defined by the field $a_m^v(z)$, we can determine where deviations from adiabatic behavior

occur. The critical taper slope $(\frac{\partial r}{\partial z})_c$ for adiabatic operation can be given as

$$(\frac{\partial r}{\partial z})_c = (\beta_0 - kn_{clad}) / \langle |\frac{\partial \Phi_0}{\partial z}|^2 \rangle^{1/2} \quad (5)$$

where r is the half-width of the waveguide at longitudinal position z , β_0 is the propagation constant of the fundamental mode Φ_0 , $k=2\pi/\lambda$ is the free space wave number and n_{clad} is the cladding refractive index. The solution to Eq. 5 has to be simulated numerically for a tapered waveguide with near-square input and output cross sections.

FIG. 4 shows the optimized taper profiles that allow an adiabatic transition of a lowest order guided mode propagating along the waveguide taper under certain assumptions. In FIG. 4, the

1 tapered waveguide has a dimension of $5\text{ }\mu\text{m}$ at the small end with single-mode operation, n_1 and n_2
2 are the refractive index of polymer and substrate and λ is the optical wavelength. In the simulation,
3 $n_1 = 1.50$, $n_2 = 1.54$, and $\lambda = 1.3\text{ }\mu\text{m}$ are assumed.

4 FIG. 5 is an illustration of the compression-molding technique for fabricating 3-D tapered
5 polymeric waveguides. A two-piece molding tool comprising substrate 17 and mold plunger 15
6 provides a cavity having the shape of the desired 3-D-tapered waveguides 18. An appropriate amount
7 of molding material, polymer waveguide film 16 in this case, is spin-coated or laminated onto the
8 substrate of interest 17. The film thickness is equal to the maximum thickness of the tapered
9 structure. The molding process begins with the heating of the mold plunger 15 and the polymer film
10 16. Then the two parts of the mold are brought together under pressure. The polymer film 16,
11 softened by heat, is thereby molded (by the compression) into the shape of the stamp. The last step
12 is to harden and fix the molded waveguide shape. This final step depends on the type of polymeric
13 material used. For example, thermosetting polymers are further heated under pressure while the
14 thermoplastics are cooled to room temperature. The fundamental differences in polymers dictate the
15 plastic processing method to be used in the waveguide molding. After the polymer 16 is cured
16 (fixed), the mold plunger 15 is removed. This leaves behind the 3-D-tapered waveguide structures
17 on the substrate. The polymer materials described in this embodiment are exemplary only and non-
18 polymer materials may be substituted without departing from the present invention.

19 In summary, the present invention is a three-dimensional tapered waveguide coupler capable
20 of interconnecting electro-optical devices with differing optical mode profiles. The ends of the
21 waveguide are configured to match the optical mode profiles of the electro-optical devices that the
22 waveguide interconnects. The waveguide adiabatically transmits the fundamental mode of the photo-

1 optic signal from the electro-optical device at the waveguide's input end to a different electro-optical
2 device at the waveguide's output end. A single coupler can be configured with one or more
3 waveguides, each waveguide having different optical mode profiles at either end and different optical
4 transmission characteristics.

5 Additionally, the present invention comprises a compression-molding technique for
6 fabricating 3-D tapered polymeric waveguides. This embodiment of the present invention comprises
7 a two-piece molding tool that includes a substrate and a mold plunger where the mold plunger
8 provides a cavity having the shape of the desired 3-D-tapered waveguides. The present invention
9 provides an appropriate amount of molding material that is spin-coated or laminated onto the
10 substrate. The film thickness is equal to the maximum thickness of the tapered structure. The
11 molding process begins with the heating of the mold plunger and the polymer film. Then the two
12 parts of the mold are brought together under pressure that causes the polymer film, which is softened
13 by heat, to be compression molded into the shape of the stamp of the desired 3-D-tapered
14 waveguides.

15 Other embodiments of the invention will be apparent to those skilled in the art after
16 considering this specification or practicing the disclosed invention. The specification and examples
17 above are exemplary only, with the true scope of the invention being indicated by the following
18 claims.

CLAIMS

We claim:

1. An optical waveguide coupler for interconnection of a plurality of electro-optical devices that transfer a photo-optic signal, comprising:

a three-dimensional tapered waveguide, having an input end and an output end and a first index of refraction, said waveguide is configured to adiabatically transmit the fundamental mode of the photo-optic signal from said input end to said output end in a transmission direction, said input end of said waveguide matches the optical mode profile of the electro-optical device that transmits the photo-optic signal at said input end, said output end of said waveguide matches the optical mode profile of the electro-optical device that receives the photo-optic signal at said output end of said waveguide; and

a structural member coupled to said waveguide, said structural member has a second index of refraction that is unequal to said first index of refraction, said structural member physically supports said waveguide and allows for proper alignment of said waveguide to the electro-optical devices to be coupled.

2. The optical waveguide coupler of Claim 1, further comprising a plurality of waveguides, each waveguide within said plurality of waveguides having an input end and an output end and a first index of refraction, each waveguide within said plurality of waveguides is configured to adiabatically transmit the fundamental mode of the photo-optic signal from said input end to said output end in a transmission direction, said input end of each waveguide within said plurality of waveguides matches the optical mode profile of the electro-optical device that transmits the photo-optic signal at said input end of each waveguide within said plurality of waveguides, said output end of each waveguide within said plurality of waveguides matches the optical mode profile of the electro-optical device that

receives the photo-optic signal at said output end of each waveguide within said plurality of waveguides.

3. The optical waveguide coupler of Claim 1, further comprising a port for receiving the photo-optic signal in a direction non-parallel with said transmission direction, said port coupled to said input end of said waveguide.

4. The optical waveguide coupler of Claim 3, further comprising a reflector coupled to said waveguide, said reflector configured to reflect the photo-optic signal received from said port from a direction non-parallel with said transmission direction to a direction parallel with said transmission direction.

5. A system that interconnects a plurality of electro-optical devices together by transferring a photo-optic signal, comprising:

a three-dimensional tapered waveguide, having an input end and an output end and a first index of refraction, said waveguide is configured to adiabatically transmit the fundamental mode of the photo-optic signal from said input end to said output end in a transmission direction, said input end of said waveguide matches the optical mode profile of the electro-optical device that transmits the photo-optic signal at said input end, said output end of said waveguide matches the optical mode profile of the electro-optical device that receives the photo-optic signal at said output end of said waveguide; and

a structural member coupled to said waveguide, said structural member has a second index of refraction that is unequal to said first index of refraction, said structural member physically supports said waveguide and allows for proper alignment of said waveguide to the electro-optical devices to be coupled.

6. The optical interconnection system of Claim 5, further comprising a plurality of waveguides, each waveguide within said plurality of waveguides having an input end and an output end and a first index of refraction, each waveguide within said plurality of waveguides is configured to adiabatically transmit the fundamental mode of the photo-optic signal from said input end to said output end in a transmission direction, said input end of each waveguide within said plurality of waveguides matches the optical mode profile of the electro-optical device that transmits the photo-optic signal at said input end of each waveguide within said plurality of waveguides, said output end of each waveguide within said plurality of waveguides matches the optical mode profile of the electro-optical device that receives the photo-optic signal at said output end of each waveguide within said plurality of waveguides.

7. The optical interconnection system of Claim 5, further comprising a port for receiving the photo-optic signal in a direction non-parallel with said transmission direction, said port coupled to said input end of said waveguide.

8. The optical interconnection system of Claim 7, further comprising a reflector coupled to said waveguide, said reflector configured to reflect the photo-optic signal received from said port from a direction non-parallel with said transmission direction to a direction parallel with said transmission direction.

9. A method of interconnecting a plurality of electro-optical devices that transfer a photo-optic signal, comprising:

providing a three-dimensional tapered waveguide, having an input end and an output end and a first index of refraction, said waveguide is configured to adiabatically transmit the fundamental mode of the photo-optic signal from said input end to said output end in a transmission direction, said input end of said waveguide matches the optical mode profile of the electro-optical device that

transmits the photo-optic signal at said input end, said output end of said waveguide matches the optical mode profile of the electro-optical device that receives the photo-optic signal at said output end of said waveguide; and

coupling a structural member to said waveguide, said structural member has a second index of refraction that is unequal to said first index of refraction, said structural member physically supports said waveguide and allows for proper alignment of said waveguide to the electro-optical devices to be coupled.

10. The method of Claim 9, further comprising providing a plurality of waveguides, each waveguide within said plurality of waveguides having an input end and an output end and a first index of refraction, each waveguide within said plurality of waveguides is configured to adiabatically transmit the fundamental mode of the photo-optic signal from said input end to said output end in a transmission direction, said input end of each waveguide within said plurality of waveguides matches the optical mode profile of the electro-optical device that transmits the photo-optic signal at said input end of each waveguide within said plurality of waveguides, said output end of each waveguide within said plurality of waveguides matches the optical mode profile of the electro-optical device that receives the photo-optic signal at said output end of each waveguide within said plurality of waveguides.

11. The method of Claim 9, further comprising providing a port configured to receive the photo-optic signal in a direction non-parallel with said transmission direction, said port coupled to said input end of said waveguide.

12. The method of Claim 11, further comprising providing a reflector coupled to said waveguide, said reflector configured to reflect the photo-optic signal received from said port from a direction non-parallel with said transmission direction to a direction parallel with said transmission direction.

1 13. A method that transfers a photo-optic signal through an interconnection of a plurality of
2 electro-optical devices, comprising:

3 adiabatically transmitting the fundamental mode of a photo-optic signal through a three-
4 dimensional tapered waveguide in a transmission direction, said waveguide having an input end and
5 an output end and a first index of refraction, said input end of said waveguide matches the optical
6 mode profile of the electro-optical device that transmits the photo-optic signal at said input end, said
7 output end of said waveguide matches the optical mode profile of the electro-optical device that
8 receives the photo-optic signal at said output end of said waveguide; and

9 structurally supporting and aligning said waveguide to the electro-optical devices to be
10 coupled with a structural member, said structural member has a second index of refraction that is
11 unequal to said first index of refraction.

1 14. The method of Claim 13, further comprising adiabatically transmitting the fundamental mode
2 of a plurality of photo-optic signals through a plurality of three-dimensional tapered waveguides in
3 a transmission direction, each waveguide within said plurality of waveguides having an input end and
4 an output end and a first index of refraction, said input end of each waveguide within said plurality
5 of waveguides matches the optical mode profile of the electro-optical device that transmits the photo-
6 optic signal at said input end of each waveguide within said plurality of waveguides, said output end
7 of each waveguide within said plurality of waveguides matches the optical mode profile of the
8 electro-optical device that receives the photo-optic signal at said output end of each waveguide within
9 ~~said plurality of waveguides.~~

1 15. The method of Claim 13, further comprising receiving the photo-optic signal from a direction
2 non-parallel with said transmission direction through a port, said port coupled to said input end of
3 said waveguide.

- 1 16. The method of Claim 15, further comprising reflecting the photo-optic signal received from
2 said port from a direction non-parallel with said transmission direction to a direction parallel with said
3 transmission direction.

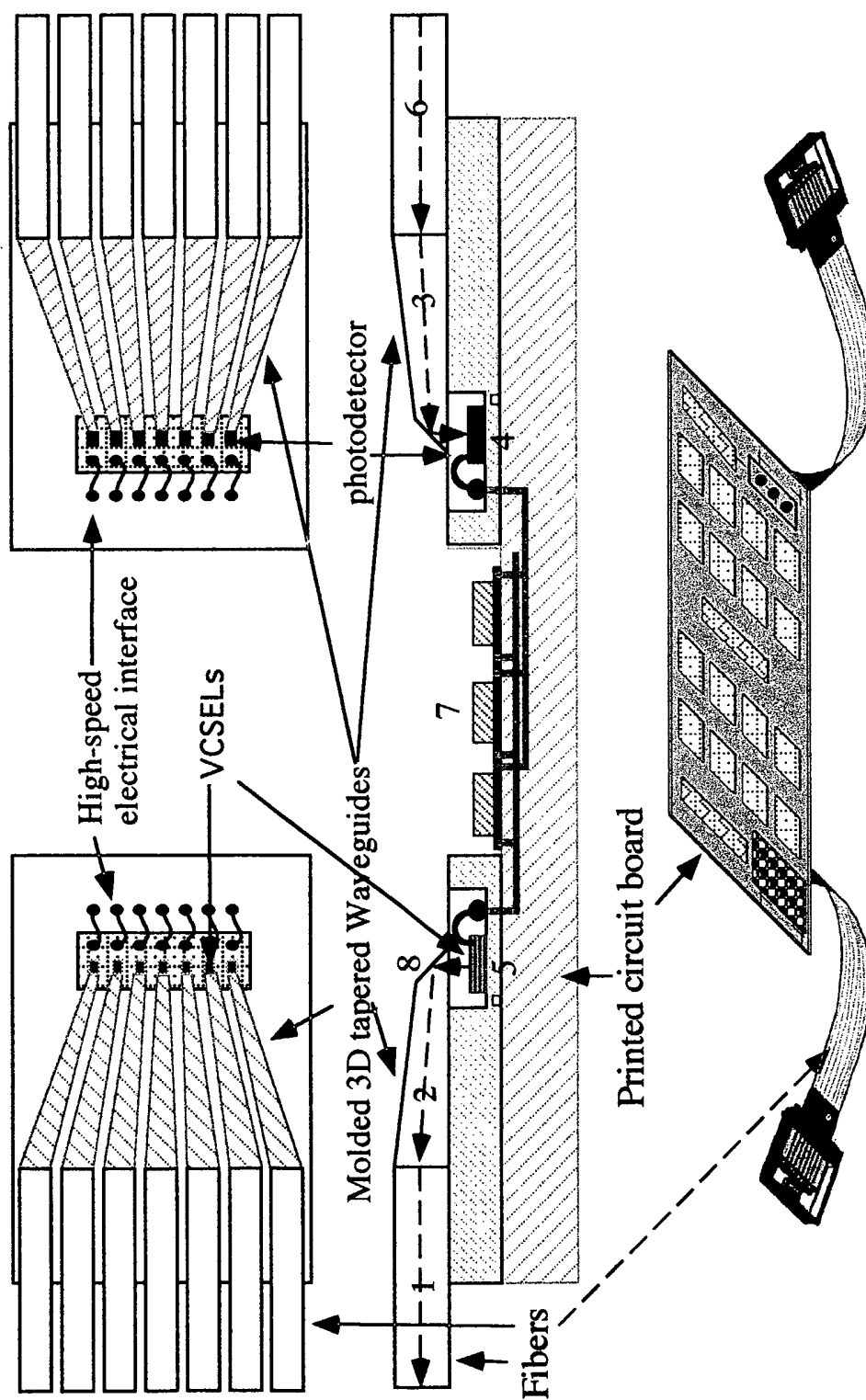


Fig. 1

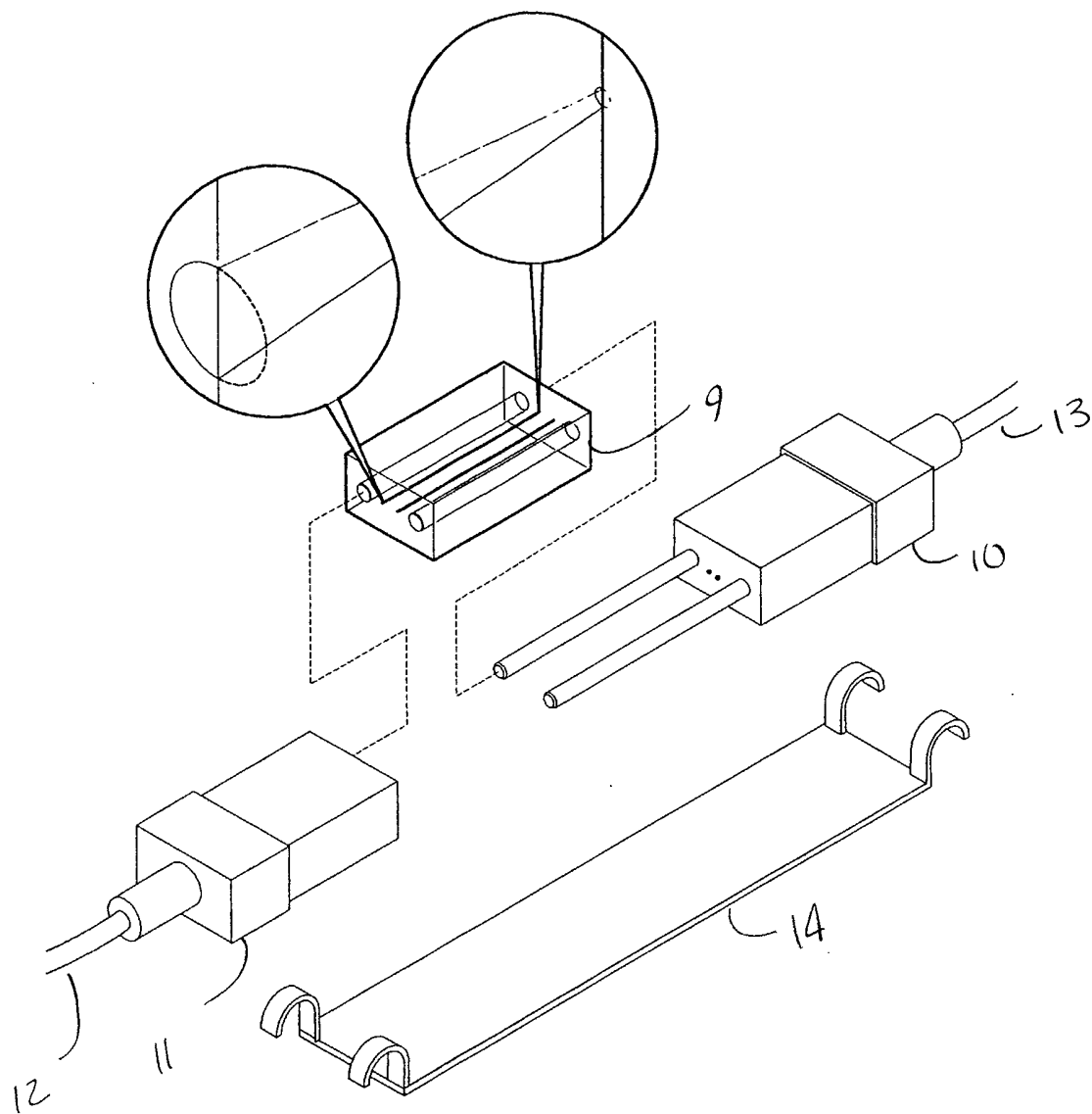


Fig. 2

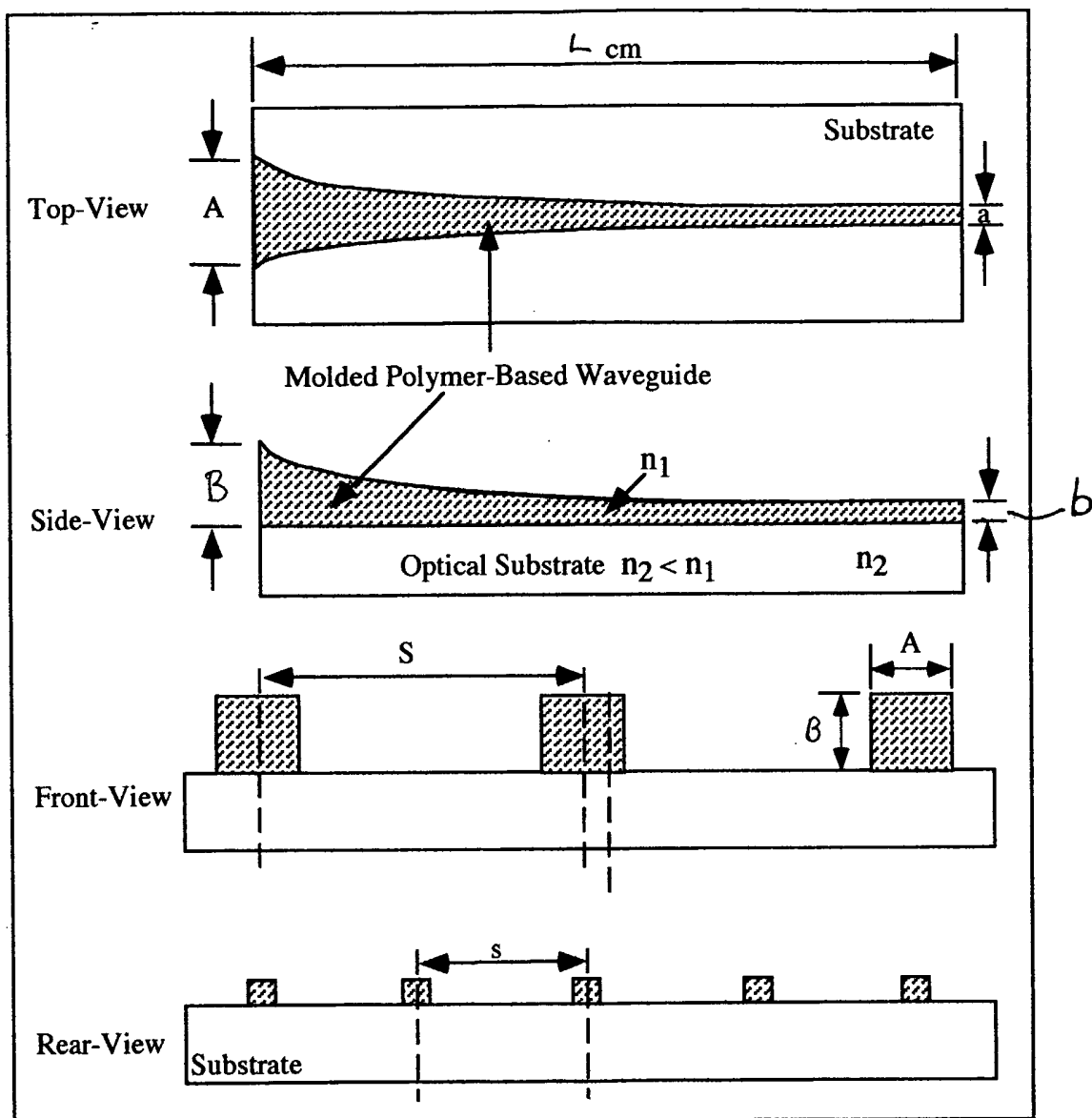


Fig. 3

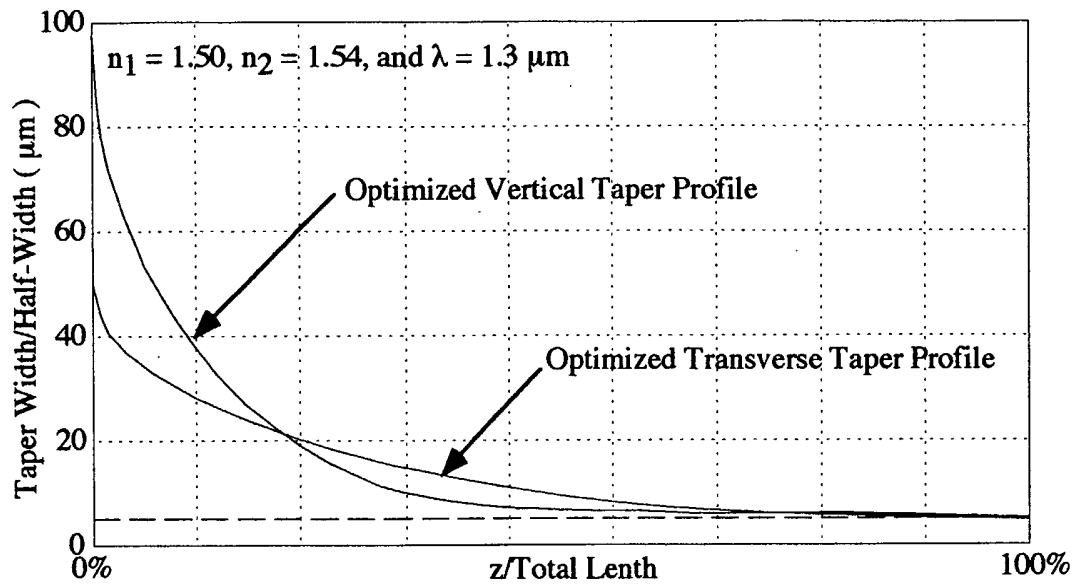


Fig. 4

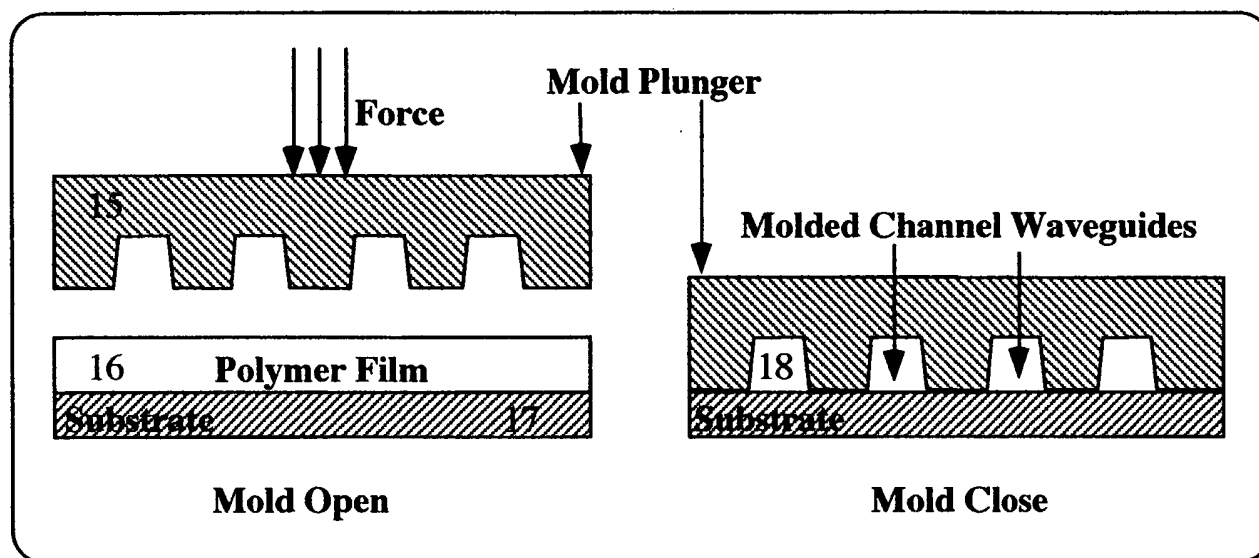


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/26869

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G02B 6/26, 6/42

US CL : 385/27, 28, 43

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/27, 28, 43

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS EAST

search terms: index near\$, refract\$, adiabatic\$, electro near\$ optic\$, connect\$, waveguide\$

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,E	US 6,470,117 B1 (TANG et al) 22 October 2002 (22.10.2002), column 2, line 37 - column 5, line 34; column 8, line 7 - column 9, line 13.	1-16
X --- A	US 5,513,196 A (BISCHEL et al) 30 April 1996 (30.04.1996), see entire document.	1,2,5,6,9,10,13, 14 ----- 3,4,7,8,11,12,15, 16



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

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28 OCTOBER 2002

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