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Koch et al.

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(54) **OPTICAL PRINTED CIRCUIT BOARD WITH POLYMER ARRAY STITCH**

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G02B 6/12 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/12002*** (2013.01); ***G02B 6/13*** (2013.01)

(58) **Field of Classification Search**
CPC .. G02B 6/12; G02B 6/12002; G02B 6/02033; G02B 6/4228; G02B 6/4239; G02B 6/43; H05K 1/0274; H05K 2201/10121
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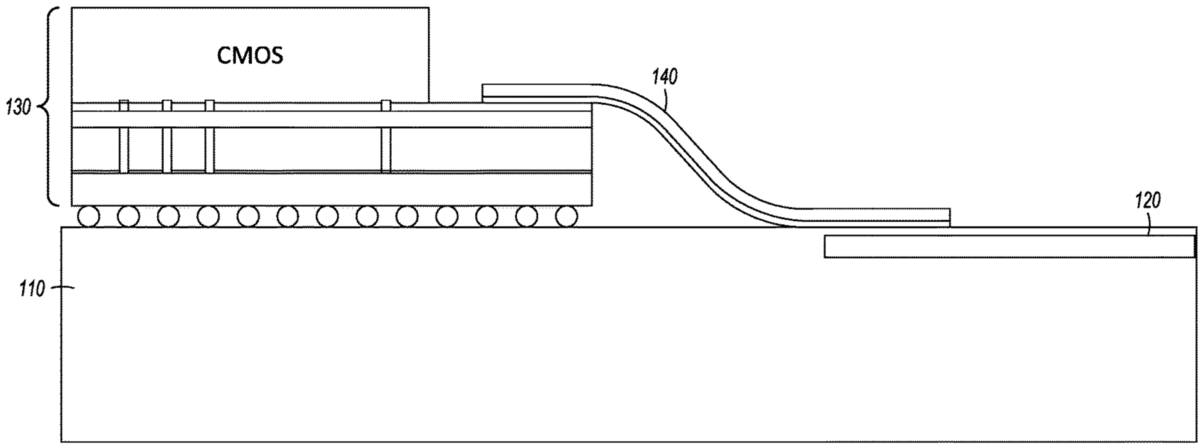
(57) **ABSTRACT**

A flexible polymer waveguide array structure serves as a stitch or jumper on an optical printed circuit board (OPCB). The flexible polymer waveguide array structure can be attached to the OPCB so that it can provide a chip-to-OPCB optical connection. The waveguide(s) in the flexible polymer waveguide array structure may be prefabricated before the flexible polymer waveguide array structure is attached to the OPCB. Alternatively, the waveguides may be fabricated after the flexible polymer waveguide array structure has been attached to the OPCB. The waveguide(s) may be subsequently formed using a printing process such as photolithography. As a consequence of forming the waveguide(s) after attachment of the flexible polymer waveguide array to the OPCB, the precision in the lateral align-

(Continued)



ment that is required when placing the flexible polymer waveguide array structure on the OPCB is generally significantly less than is required when the waveguide(s) are prefabricated.

21 Claims, 7 Drawing Sheets

(58) **Field of Classification Search**
USPC 385/14, 30–32, 50, 129–132, 143, 145
See application file for complete search history.

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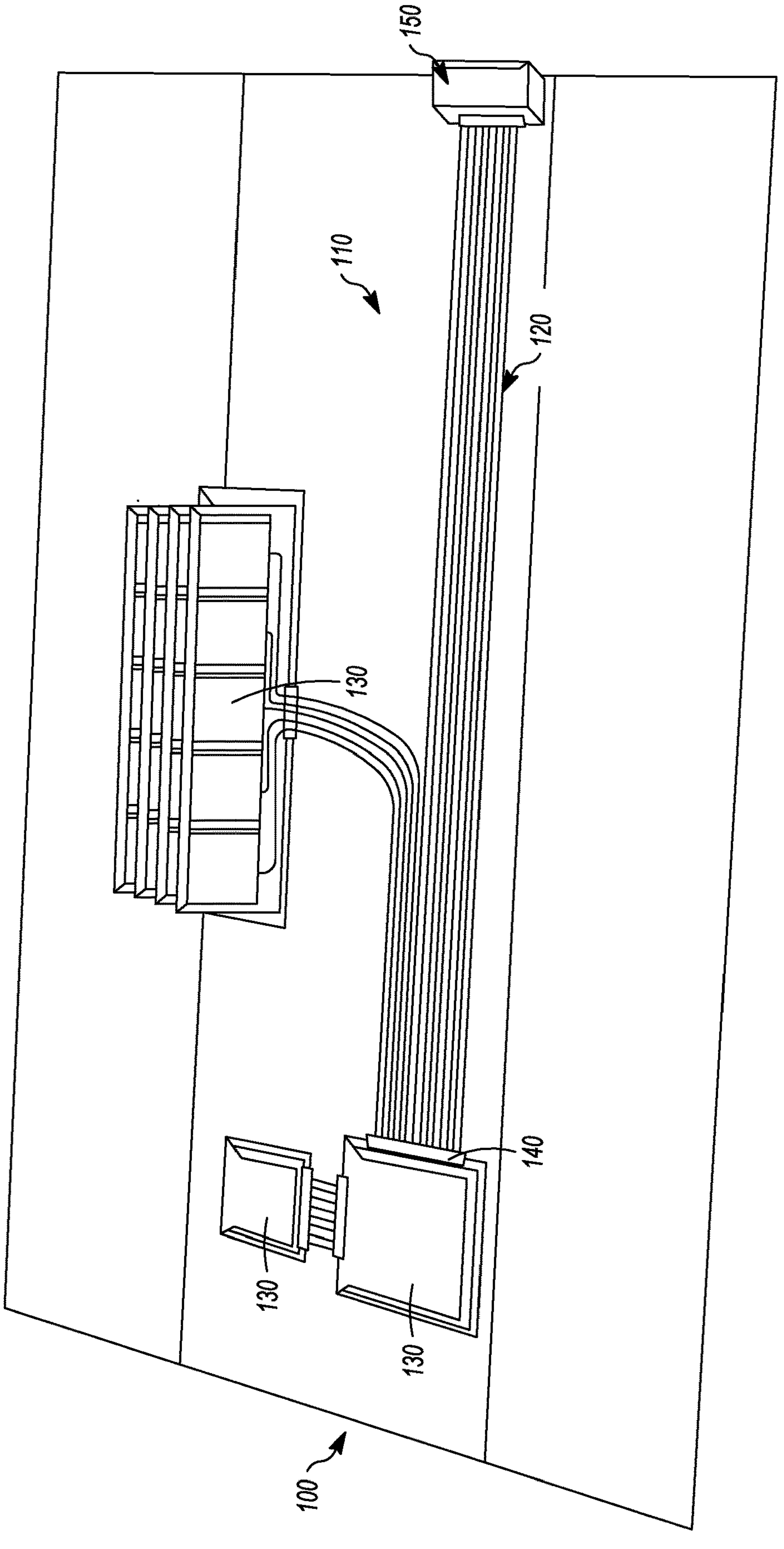

FIG. 1

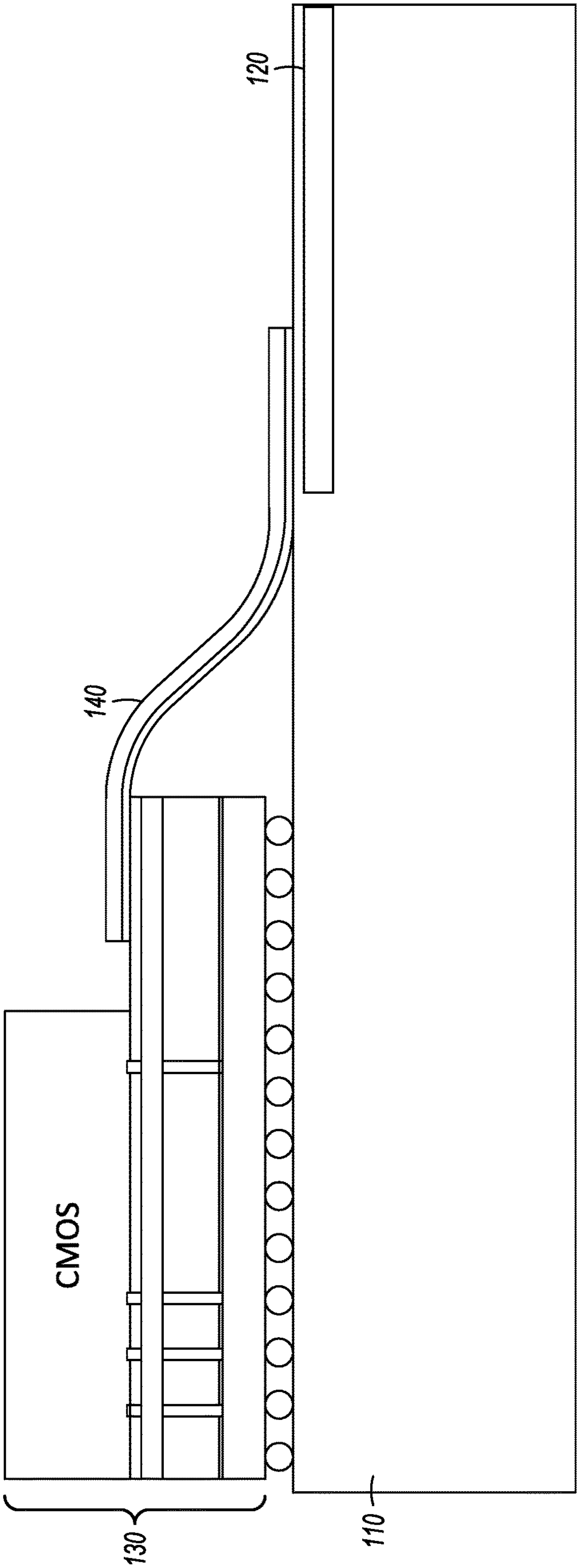

FIG. 2

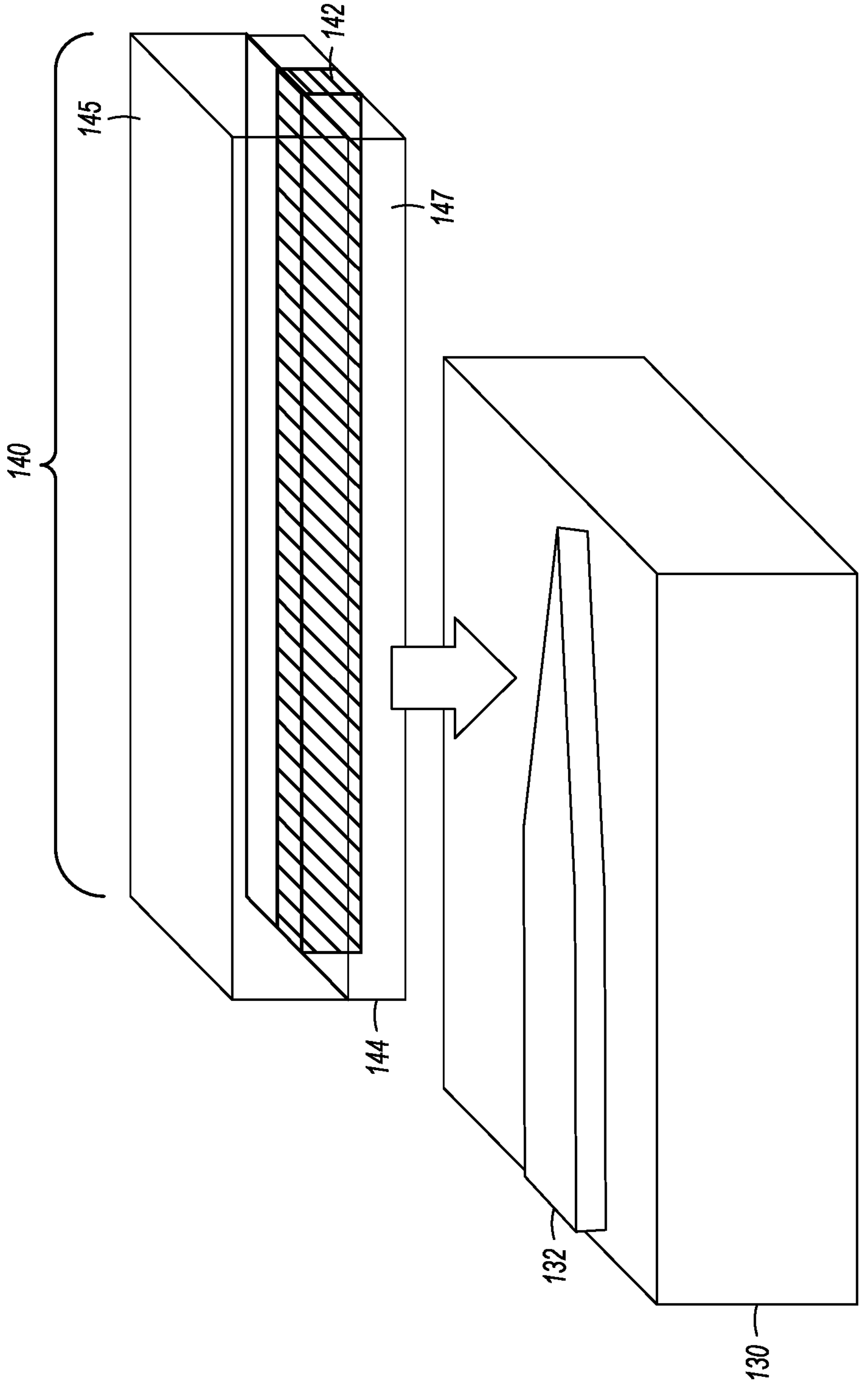

FIG. 3

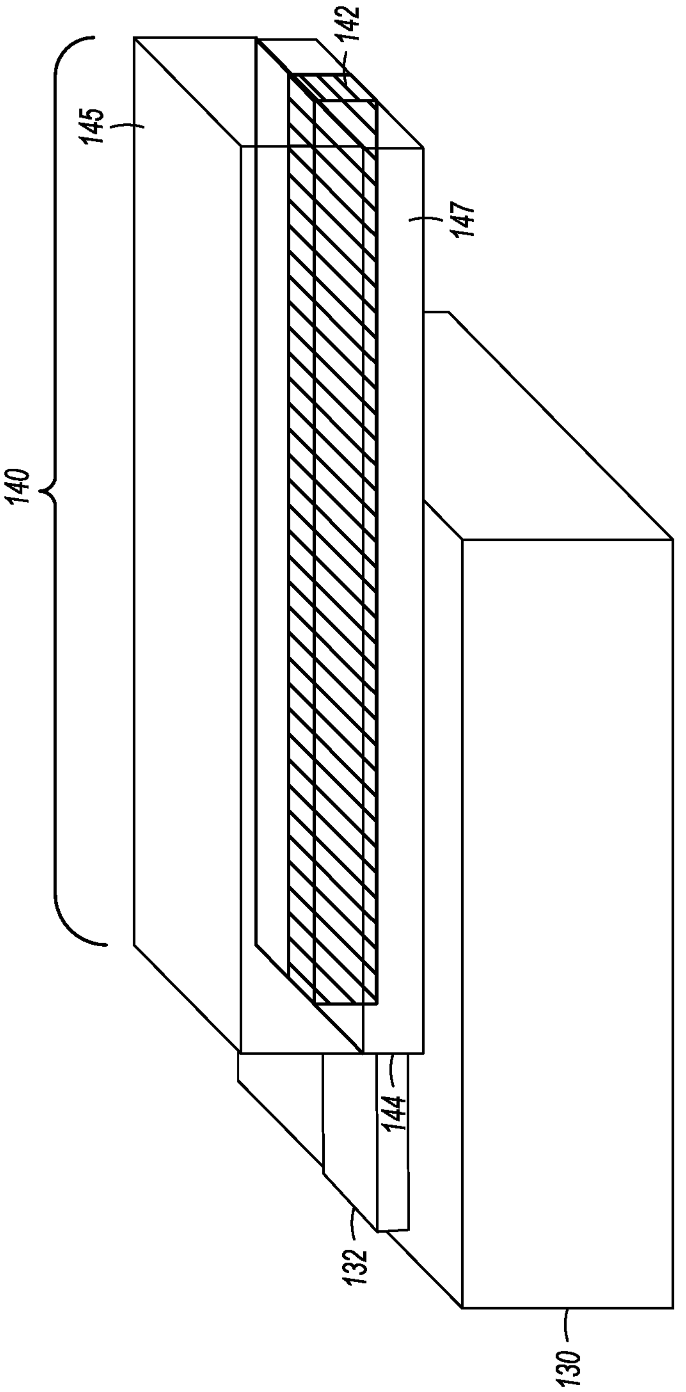

FIG. 4

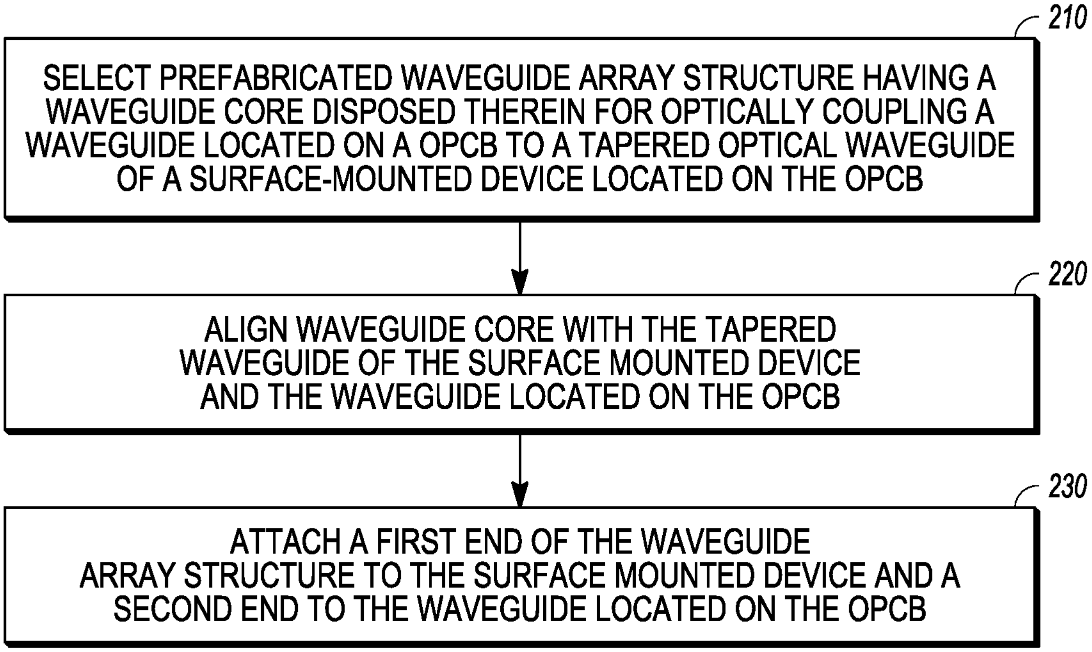
210
SELECT PREFABRICATED WAVEGUIDE ARRAY STRUCTURE HAVING A WAVEGUIDE CORE DISPOSED THEREIN FOR OPTICALLY COUPLING A WAVEGUIDE LOCATED ON A OPCB TO A TAPERED OPTICAL WAVEGUIDE OF A SURFACE-MOUNTED DEVICE LOCATED ON THE OPCB
220
ALIGN WAVEGUIDE CORE WITH THE TAPERED WAVEGUIDE OF THE SURFACE MOUNTED DEVICE AND THE WAVEGUIDE LOCATED ON THE OPCB
230
ATTACH A FIRST END OF THE WAVEGUIDE ARRAY STRUCTURE TO THE SURFACE MOUNTED DEVICE AND A SECOND END TO THE WAVEGUIDE LOCATED ON THE OPCB

FIG. 5

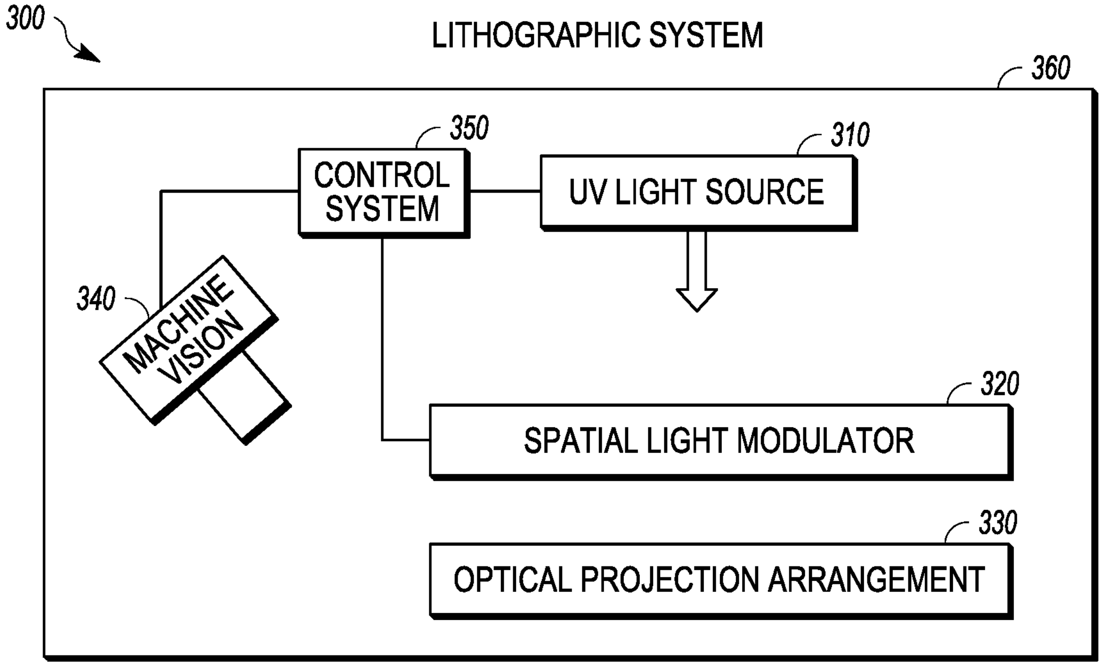
300
LITHOGRAPHIC SYSTEM
360
350
CONTROL SYSTEM
310
UV LIGHT SOURCE
340
MACHINE VISION
320
SPATIAL LIGHT MODULATOR
330
OPTICAL PROJECTION ARRANGEMENT

FIG. 6

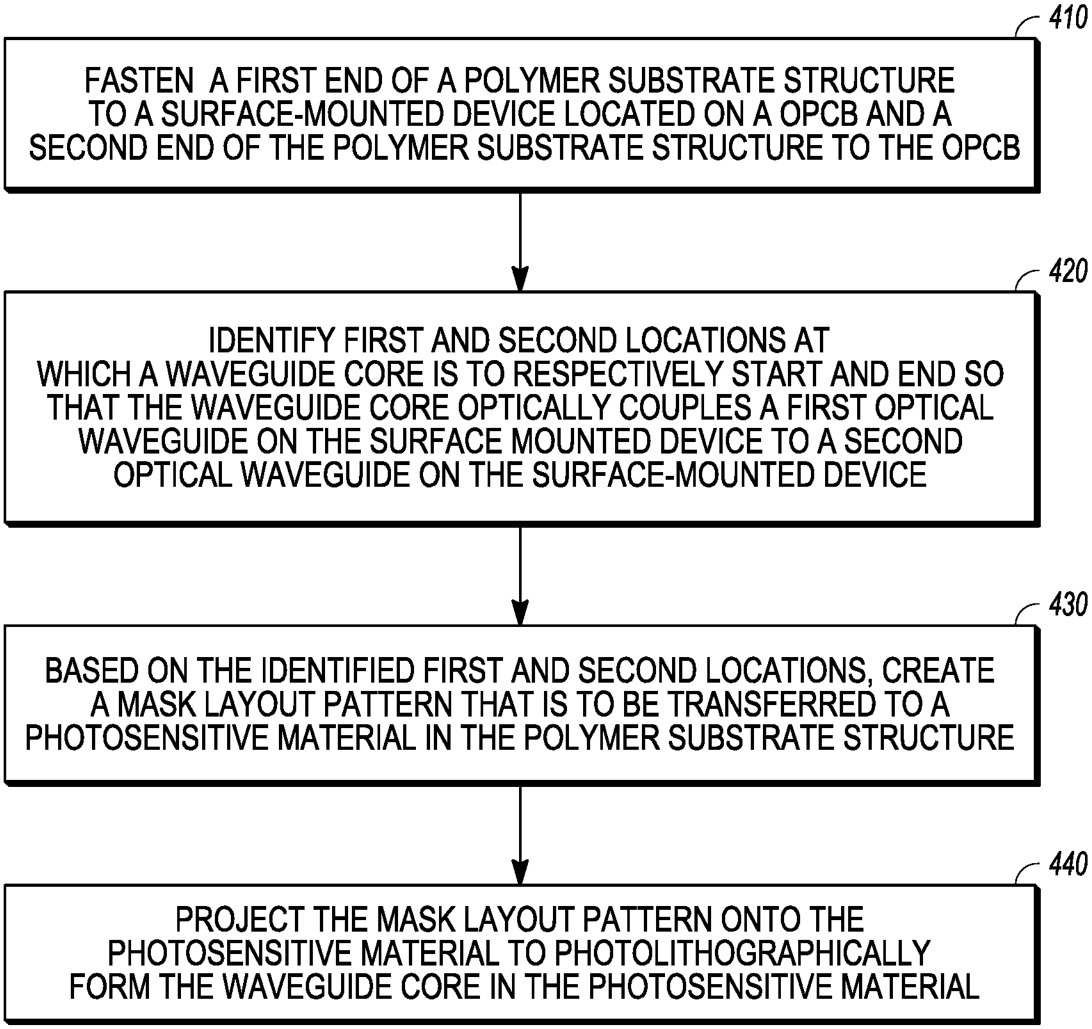
410
FASTEN A FIRST END OF A POLYMER SUBSTRATE STRUCTURE TO A SURFACE-MOUNTED DEVICE LOCATED ON A OPCB AND A SECOND END OF THE POLYMER SUBSTRATE STRUCTURE TO THE OPCB
420
IDENTIFY FIRST AND SECOND LOCATIONS AT WHICH A WAVEGUIDE CORE IS TO RESPECTIVELY START AND END SO THAT THE WAVEGUIDE CORE OPTICALLY COUPLES A FIRST OPTICAL WAVEGUIDE ON THE SURFACE MOUNTED DEVICE TO A SECOND OPTICAL WAVEGUIDE ON THE SURFACE-MOUNTED DEVICE
430
BASED ON THE IDENTIFIED FIRST AND SECOND LOCATIONS, CREATE A MASK LAYOUT PATTERN THAT IS TO BE TRANSFERRED TO A PHOTOSENSITIVE MATERIAL IN THE POLYMER SUBSTRATE STRUCTURE
440
PROJECT THE MASK LAYOUT PATTERN ONTO THE PHOTOSENSITIVE MATERIAL TO PHOTOLITHOGRAPHICALLY FORM THE WAVEGUIDE CORE IN THE PHOTOSENSITIVE MATERIAL

FIG. 7

OPTICAL PRINTED CIRCUIT BOARD WITH POLYMER ARRAY STITCH

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Ser. No. 62/330,003, filed 29 Apr. 2016 entitled "OPTICAL PRINTED CIRCUIT BOARD WITH POLYMER ARRAY STITCH", which is hereby incorporated by reference in its entirety.

GOVERNMENT FUNDING

This invention was made with government support under Grant No. FA8650-15-2-5220, awarded by Air Force Material Command. The government has certain rights in the invention.

BACKGROUND

An important problem in optical packaging involves the optical interconnection of planar-integrated photonic integrated circuits (chip-chip connections) and the connection of such circuits to the external world. Photonic integrated circuits (PICs) refer to waveguide-based photonic components, including optical integrated devices such as lasers, optical amplifiers, switches, filters, modulators, splitters, phase shifters, variable attenuators, detectors, and the like. PICs can also include integration with semiconductor devices such as CMOS electronic devices. PICs allow systems with high complexity and multiple functions to be integrated on a single substrate to thereby allow the generation, detection, propagation and modulation of both optical and electrical signals. PICs may employ a variety of different material systems, including silicon, silicon nitride, polymer, silicon dioxide, ion-exchange glass, lithium niobate, InP, GaAs, and graphene, and optical interconnection processes should be compatible with these material systems.

In copending patent application Ser. No. 15/764,064, polymer waveguides are used to interconnect optical devices such as PICs. The polymer waveguide is designed to create connections over small distances, such as 1 mm to 10 mm. For optical connections over larger distances (e.g., greater than 10 mm), the polymer waveguide concept in UA16-053 has several disadvantages. If the polymer waveguide is fabricated by a maskless lithography system, the waveguide array likely requires a long exposure time because of the large write areas required. Such a long exposure time may not be practical in a manufacturing setting. While this problem can be addressed by using large-area, mask-based lithography, in addition, polymer waveguides generally have higher losses than on-board glass waveguides. Thus, there is a need to develop a technique for providing low loss optical interconnections over large distances, which addresses both efficiently coupling to individual optical devices, such as silicon photonic chips, and propagating light over distances ranging up to tens of centimeters.

SUMMARY

In one aspect, the disclosed subject matter provides a flexible polymer waveguide array structure that serves as a stitch or jumper on an optical printed circuit board (OPCB). The flexible polymer waveguide array structure can be attached to the OPCB so that it can provide a chip-to-OPCB optical connection.

In one embodiment, the waveguide(s) in the flexible polymer waveguide array structure may be prefabricated before the flexible polymer waveguide array structure is attached to the OPCB. Accordingly, in this embodiment, the flexible polymer waveguide array structure needs to be carefully aligned in the lateral direction with the OPCB waveguides to which they are being optically coupled.

In another embodiment, the waveguide(s) in the flexible polymer waveguide array structure may be fabricated after the flexible polymer waveguide array structure has been attached to the OPCB. The waveguide(s) may be subsequently formed using a printing process such as photolithography. As a consequence of forming the waveguide(s) after attachment of the flexible polymer waveguide array to the OPCB, the precision in the lateral alignment that is required when placing the flexible polymer waveguide array structure on the OPCB is generally significantly less than is required when the waveguide(s) are prefabricated.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** show a perspective view of one example of an optical printed circuit board (OPCB) on which surface-mounted devices and optical waveguide arrays may be located.

FIG. **2** is a side view of a portion of the optical arrangement shown in FIG. **1**.

FIG. **3** shows a perspective view of a surface mounted device on which a nano-tapered waveguide is formed to couple optical signals to and from the surface mounted device and the polymer waveguide structure that is to be attached to it.

FIG. **4** shows the surface mounted device of FIG. **3** after the polymer waveguide structure has been attached to it.

FIG. **5** is a flowchart showing one example of a process for optically coupling one of the waveguides located on the OPCB to the optical waveguide of the surface-mounted device that is surface mounted on the OPCB.

FIG. **6** is a block diagram view of an illustrative maskless lithography system that may be used to form the waveguide cores in the polymer waveguide structure.

FIG. **7** is a flowchart showing another example of a process for optically coupling one of the waveguides located on the OPCB to the optical waveguide of the surface-mounted device that is located on the OPCB.

DETAILED DESCRIPTION

FIG. **1** show a perspective view of one example of an optical arrangement to which the techniques described herein may be applied. The optical arrangement **100** includes a substrate **110** such as an optical printed circuit board (OPCB) that serves as a carrier component. The OPCB **110** has one or more surface areas on which surface mounted devices **130** can be located. Illustrative examples of such surface mounted devices **130** include PICs and other electronic devices (e.g., ASIC, processor, interposer, memory). One or more optical and electrical connectors **150** are provided at the edge of the OPCB **110** to communicate optical and electrical signals between the optical arrangement and external devices and system. The surface mounted devices **130** may be optically interconnected to one another and/or the optical and electrical connectors **150** by a prefabricated array of low loss optical waveguides **120** and electronic circuit traces (not shown) that are formed in the OPCB **110**. In one embodiment the optical waveguides **120** are laminate waveguides formed on or in the OPCB **110**. In another embodiment the optical waveguides **120** are prefabricated ion exchanged waveguides.

In accordance with one aspect of the subject matter disclosed herein, optical signals from the surface-mounted devices **130** are connected to the on-board array of waveguides **120** by a short, polymer waveguide array structure **140**. The polymer waveguide array structure **140**, which is best seen in the side view of an expanded portion of the optical arrangement **100** shown in FIG. **2**, may be fabricated in accordance with a number of different techniques.

In one embodiment the polymer waveguide array structure **140** is prefabricated and subsequently secured to the surface mounted device **130** and the OPCB **110**. The polymer waveguide array structure **140** may be flexible to facilitate its attachment to components such as the surface mounted device **130** and the OPCB **110**, which are typically located in different planes. The polymer waveguide array structure **140** will typically be attached to the top of the OPCB **110**, suitably aligned with the underlying OPCB waveguides.

It should be noted that the polymer waveguide array structure **140** is a free-standing, self-supporting (and possibly flexible) structure and is not to be construed as a thin film layer that is itself formed on a free-standing, self-supporting structure.

FIG. **3** shows a perspective view of a surface mounted device **130** on which a nano-tapered waveguide **132** is formed to couple optical signals to and from the surface mounted device **130**. FIG. **3** also shows the prefabricated polymer waveguide array structure **140** being placed on the surface mounted device **130** to establish optical coupling between the nano-tapered waveguide **132** and the prefabricated polymer waveguide array structure **140**. FIG. **4** shows the polymer waveguide array structure **140** connected to the surface-mounted device **130**.

The polymer waveguide array structure **140** includes an array of waveguide cores **142** embedded in a substrate **144**. It should be noted that for clarity of illustration the perspective views shown in FIGS. **3** and **4** only illustrate a single polymer waveguide core **142** in the polymer waveguide array structure **140**. More generally, however, the polymer waveguide array structure **140** may include any desired number of waveguide cores **142**, which would correspond to an equal number of nano-tapered waveguides **132**.

The waveguide cores **142** of the polymer waveguide array structure **140** are aligned with the underlying waveguides of the surface-mounted device **130** and the OPCB **110**. The polymer waveguide array structure **140** connects to the nano-tapered waveguides **132** on the surface-mounted devices **130** to the on-board array of waveguides **120** with increased lateral placement tolerance. In one embodiment, the required lateral placement precision is expected to be about 3 to 5 microns, for example. The bonding of the polymer waveguide array structure **140** can be performed using an adhesive layer that is provided on the substrate **144**, by high temperature treatment combined with pressure, or other techniques.

FIG. **5** is a flowchart showing one example of the process described above for optically coupling one of the waveguides **120** located on the OPCB **110** to the tapered optical waveguide **132** of the surface-mounted device **130** that is surface mounted on the OPCB **110**. The method begins at block **210** when a suitable prefabricated waveguide array structure **140** having at least one waveguide **142** disposed therein is selected to optically couple the two waveguides **120** and **132**. Next, at block **220**, the waveguide core **142** in the waveguide array structure **140** is aligned with the tapered waveguide **132** of the surface mounted device **130** and the particular waveguide on the OPCB **110** to which the tapered waveguide **132** is to be coupled. After alignment, a first end of the waveguide array structure **140** is attached to the surface mounted device **130** and a second end to the OPCB **110** at block **230** so that light can be optically coupled between the waveguide **120** and the tapered waveguide **132** via the waveguide core **142** in the waveguide array structure **140**. The attachment step may be performed in any suitable manner using e.g., an adhesive or a heat and pressure treatment.

While the example shown in the flowchart of FIG. **5** uses a single prefabricated waveguide core to optically couple a single waveguide on the surface-mounted device to a single waveguide on the OPCB, more generally the prefabricated waveguide array structure may include any number of waveguides to couple an equal number of waveguides on the surface-mounted device to any equal number of waveguides on the OPCB.

In the second embodiment, the substrate **144** of the polymer waveguide array structure **140** is secured to the surface-mounted device **130** and the OPCB **110** before the waveguide cores **142** are fully formed therein. In some cases, illustrated in FIG. **4**, the substrate **144** may comprise two or more layers or films. In one embodiment the first or upper layer **145** is generally formed from a flexible, optically transparent material that is relatively thick (e.g., approximately 10-100 microns) so that it can be free-standing and self-supporting. The first layer **145** may also advantageously have a refractive index below that of the finally formed waveguide cores **142** so that it can serve as a cladding. The second or lower layer **147** of the substrate **144** underlies the first layer **145** and initially serves as a slab waveguide if the refractive indices are appropriately chosen. That is, although the second layer **147** can confine light in one direction, perpendicular to the plane of the waveguide, it does not have a predefined core in the lateral directions, parallel to the plane of the waveguide. The second layer **147** is formed from a photosensitive material in which the laterally confining waveguide cores **142** can be defined using, for example, the fabrication process described in U.S. application Ser. No. 15/764,064, which is hereby incorporated by reference in its entirety.

Before the laterally confining waveguide cores **142** are defined in the second layer **147**, the substrate **144** (including the first and second layers **145** and **147**) is securely fastened to the surface mounted device **130** and the OPCB **110**. As in the first embodiment a thin (e.g., about 1-50 nm) adhesive layer may be placed on the substrate **144** to facilitate the fastening of the substrate **144** onto the surface-mounted device **130** and the OPCB **110**. The placement of the substrate **144** can be performed using a pick-and-place tool with only rough alignment capabilities. The degree of placement precision that is required in this second embodiment is expected to be much less than that in the first embodiment because it is not necessary to align the nano-tapered waveguides **132** on the surface-mounted devices **130** and the optical waveguide array **120** with the waveguide cores **142** in the substrate **144** since the laterally confining waveguide cores **142** are not fabricated in advance of placement.

After the substrate **144** is securely fastened, a maskless lithographic tool may be used to create the waveguide cores **142**. The lithographic tool can utilize a vision system to measure the position of the alignment marks on the surface mounted devices **130** and on the OPCB **110**. Based on the locations of the alignment marks, the starting and ending points of the waveguide cores **142** are determined. A pattern to create the waveguide cores **142** is calculated and exposed on the substrate **144** through the optically transparent first layer **145** to create the array of waveguide cores **142** with the lithographic tool. Any of a variety of different polymer materials may be used to form the waveguide cores **142**. For example, the material may be SU8. Exposure of SU8 by ultraviolet light, followed by baking (e.g., at 90 C to 170 C) lowers the refractive index of the SU8. Thus, the polymer waveguide cores **142** can be printed directly, without any wet processing, on the substrate **144**, with the waveguide cores **142** connecting the surface mounted device **130** to the waveguide array **120** on the OPCB **110** at locations determined by the alignment marks.

FIG. **6** is a block diagram view of an illustrative maskless lithography system **300** that may be used to form the waveguide cores **142**. The maskless lithography system **300** includes a light source **310** such as the aforementioned mercury lamp source or ultraviolet laser. The light from the light source **310** is directed to a programmable SLM **320**. The programmable SLM **320** is configured to receive image pattern data, also referred to as mask layout data, representative of a desirable lithographic pattern, and direct light representative of the image to an optical projection arrangement **330**. The light from the optical projection arrangement **330** then falls onto the photosensitive material in the second layer **147** of the substrate **144**. The optical projection arrangement **330** reduces the dimensions of the image received from the programmable SLM **320** and projects the reduced image onto the photosensitive material of the substrate **144**.

The lithography system **300** also includes a control system **350** and a vision system **340** to measure the locations on the substrate **144** at which the interconnections are to be made. The vision system **340** may be, by way of illustration, a machine vision camera, a microscope with scanning and stitching capabilities, an x-ray inspection system, or a scanning electron microscope. The control system **350** includes a computer processor, a memory, and a user interface configured to enable a user to input data for instructing the system **300** to produce a printed pattern on the photosensitive second layer of the substrate **144** in which the waveguide core **142** is to be formed. The entire lithographic system **300** is mounted on a scanning stage or robotic arm **360** whose movement over the OPCB **110** is determined by the control system **350** using information obtained from the vision system **350**.

The vision system **340** is used to precisely measure the locations of the starting and ending points of the optical cores to be formed in the substrate **144**. The control system **350** processes the information from the vision system **340** in real time and converts it to the mask layout data that is be projected onto the photosensitive surface of the substrate. In this way the pattern is projected onto the substrate based on the locations measured by the vision system **340**. The pattern may be projected using a sequence of different exposures. In some cases each exposure may form a two-dimensional layer portion of a three-dimensional optical interconnect structure such as a waveguide.

FIG. **7** is a flowchart showing one example of the method described above which uses a photolithographic process for optically coupling at least one of the optical waveguides **120** located on the OPCB **110** to a tapered optical waveguide **132** of a surface-mounted device **130** secured to the OPCB **110**. The method begins at block **410** when a first end of the polymer substrate **144** is fastened to the surface-mounted device **130** and a second end of the polymer substrate **144** is fastened to the OPCB **110** with an alignment precision that can be significantly less than that required when the waveguide core has been prefabricated. At block **420** first and second locations are identified on the polymer substrate **144** at which the waveguide core **142** is to respectively start and end so that the waveguide core **142** optically couples the optical waveguide **120** to the tapered optical waveguide **132**. The locations may be identified using, for example, the vision system **340**. Based on the first and second locations that are determined, at block **430** a mask layout pattern is created that is to be transferred to a photosensitive material in the polymer substrate **144**. The mask layout pattern is projected onto the photosensitive material at block **440** to photolithographically form the waveguide core **142** in the photosensitive material.

While the example shown in the flowchart of FIG. **7** forms a single waveguide core using a photolithographic technique to optically couple a single waveguide on the surface-mounted device to a single waveguide on the OPCB, more generally any number of waveguide cores may be formed in the polymer substrate to couple an equal number of waveguides on the surface-mounted device to any equal number of waveguides on the OPCB.

Instead of SU8, alternative materials that may be used to form the second layer **147** of the substrate **144** in which the waveguide cores **142** are formed may include, by way of example, ZPU12/ZPU13, Lightlink, Ormocer, acrylate copolymers, EpoCore/EpoClad, SEO 250, MAPTMS/ZPO and RHTi1. Illustrative examples of materials that may be employed for the first layer **145** of the substrate **144** include TPX polymethylpentene, poly(perfluoroalkoxy alkanes) (PFA), poly(ethylene tetrafluoroethylene (ETFE), polystyrene, cellulose, polycarbonate, polydimethylsiloxane (PDMS), polycarbonate and CYCLOTENE™ 3000 & 4000 Series. Ideal properties of the first layer **145** of the substrate **144** include transparency at ultraviolet wavelengths and low loss at signal wavelengths, a lower refractive index compared to the waveguide core material a similar coefficient of thermal expansion to the waveguide core material, durability, flexibility, and conducive to high temperature processing and cycling. Of course, the selected material need not necessarily have all of these properties.

In some embodiments the substrate **144** may be formed from a single photosensitive material, thereby eliminating the need for the first layer **145** described above.

Existing waveguide array structures are optimized primarily for wide latitude in vertical displacement, and, to a lesser degree, lateral displacement. In some embodiments the waveguide in the structure may be designed for wide latitude in lateral displacement. In this way the precision requirement for placement of the waveguide array structure on the OPCB can be reduced.

In one alternative embodiment optical connections can be fabricated using photonic wire bonding such as described in N. Lindenmann et al., "Photonic wire bonding: a novel concept for chip-scale interconnects," Optics Express 20:17667, 2012. This technique utilizes a 3D laser lithography system to expose SU-8 2075 photoresist (Microchem Corp, Westborough Mass.) to create 3D polymer waveguides. High resolution is achieved by two-photon polymerization. However, this process is expected to have relatively low throughput and also potentially suffers from reliability concerns.

It should be noted that large bending of the polymer waveguide array structure **140** can lead to high optical loss. Moreover, in the second embodiment in which the polymer waveguide is formed after the substrate **144** is attached to the OPCB **110**, the maximum height difference between the tapered waveguide **132** and the waveguides **120** is limited by the lithographic tool. In one embodiment, the substrate **110** can have a recess, such that the height of the surface mounted devices **110** and the waveguide **132** is close to the height of the waveguide **120**. In this case, the bending of waveguide **140** is reduced.

While exemplary embodiments and particular applications of this invention have been shown and described, it is apparent that many other modifications and applications of this invention are possible without departing from the inventive concepts herein disclosed. For example, in some embodiments, instead of a lithographic technique, a direct laser writing technique may be employed in which a scanning laser is used to write the optical interconnect structure in the photosensitive material.

The invention claimed is:

1. A method for optically coupling at least a first waveguide located on an optical printed circuit board (OPCB) to a second optical waveguide of a surface-mounted device surface mounted on the OPCB, comprising:

providing a flexible waveguide array structure having at least a third waveguide disposed therein;

attaching a first end of the flexible waveguide array structure to the surface-mounted device for side coupling light between the second and third optical waveguides; and

attaching a second end of the flexible waveguide array structure to the OPCB for side coupling light between the first optical waveguide and the third optical waveguide, wherein the flexible waveguide array structure includes an adhesive layer for attaching the first and second ends to the surface-mounted device and the OPCB, respectively, and wherein the first waveguide is a tapered waveguide.

2. The method of claim **1**, wherein the flexible waveguide array structure is a polymer waveguide array structure.

3. The method of claim **1**, wherein attaching the first end of the flexible waveguide array structure to the surface mounted device includes aligning the third waveguide and the second waveguide to establish optical coupling there between and attaching the second end of the flexible waveguide array structure to the OPCB includes aligning the third waveguide and the first waveguide to establish optical coupling there between.

4. The method of claim **1**, wherein the surface mounted device is a photonic integrated circuit (PIC).

5. A method for optically coupling at least a first waveguide located on an optical printed circuit board (OPCB) to a second optical waveguide of a surface-mounted device surface mounted on the OPCB, comprising:

providing a flexible substrate structure configured as a slab waveguide to confine light in a first direction;

attaching a first end of the flexible substrate structure to the surface-mounted device; and

attaching a second end of the flexible substrate structure to the OPCB; and

subsequent to attaching the first and second ends of the flexible substrate structure, forming at least a third optical waveguide in the flexible substrate structure using a direct write process so that light can be (i) confined in a lateral direction perpendicular to the first direction as well as in the first direction and (ii) side coupled between the second and third waveguides and side coupled between the first and third optical waveguides, wherein the first waveguide is a tapered waveguide.

6. The method of claim **5**, wherein the flexible substrate structure includes a photosensitive material and forming said at least third optical waveguide includes photolithographically forming said at least third optical waveguide.

7. The method of claim **6**, wherein the flexible substrate structure further comprises an optically transparent supporting layer on which the photosensitive material is located.

8. The method of claim **7**, wherein the optically transparent supporting layer has a refractive index lower than that of the photosensitive material.

9. The method of claim **5**, wherein said at least first, second and third waveguides each comprise a waveguide array.

10. The method of claim **5**, wherein the surface mounted device is a photonic integrated circuit (PIC).

11. The method of claim **5** wherein the flexible substrate structure includes a plurality of optical layers, an underlying one of the plurality of optical layers serving as the slab waveguide confining light in the first direction and an overlying one of the plurality of optical layers serving as a cladding layer, the third waveguide being formed in the underlying one of the plurality of optical layers.

12. An optical arrangement, comprising:

an optical printed circuit board (OPCB) having at least a first optical waveguide formed therein;

at least one surface-mounted device mounted to the OPCB, the surface-mounted device including at least a second optical waveguide, wherein the second waveguide is a tapered waveguide; and

a flexible waveguide array structure having at least a third waveguide disposed therein, a first end of the flexible waveguide array structure being surface mounted to the surface-mounted device for side coupling light between the second and third optical waveguides and a second end of the flexible waveguide array structure being surface mounted to the OPCB for side coupling light between the first optical waveguide and the third optical waveguide, wherein the flexible waveguide array structure includes an adhesive layer securing the first and second ends to the surface mounted device and the OPCB, respectively.

13. The optical arrangement of claim **12**, wherein the flexible waveguide array structure is a polymer waveguide array structure.

14. The optical arrangement of claim **12**, wherein the flexible substrate structure includes a photosensitive material and said at least third optical waveguide is a photolithographically formed optical waveguide.

15. The optical arrangement of claim **14**, wherein the flexible substrate structure further comprises an optically transparent supporting layer on which the photosensitive material is located.

16. The optical arrangement of claim **15**, wherein the optically transparent supporting layer has a refractive index lower than that of the photosensitive material.

17. The optical arrangement of claim **12**, wherein said at least first, second and third waveguides each comprise a waveguide array.

18. The optical arrangement of claim **12**, wherein the surface mounted device is a photonic integrated circuit (PIC).

19. A method for optically coupling at least a first optical waveguide located on an optical printed circuit board (OPCB) to a second optical waveguide of a surface-mounted device surface mounted on the OPCB, comprising:

fastening a first end of a polymer substrate structure to a surface-mounted device located on the OPCB, the polymer substrate structure being configured as a slab waveguide to confine light in a first direction;

fastening a second end of the polymer substrate structure to the OPCB;

determining first and second locations at which a waveguide core is to respectively start and end so that the waveguide core optically side couples the first optical waveguide to the second optical waveguide, wherein the first optical waveguide is a tapered optical waveguide;

based on the identified first and second locations, creating a mask layout pattern that is to be transferred to a photosensitive material in the polymer substrate structure; and

projecting the mask layout pattern onto the photosensitive material to photolithographically form the waveguide core in the photosensitive material so that the waveguide core is configured to confine light in a lateral direction perpendicular to the first direction as well as in the first direction.

20. The method of claim **19** wherein the polymer substrate structure includes a plurality of optical layers, an underlying one of the plurality of optical layers serving as the slab waveguide confining light in the first direction and an overlying one of the plurality of optical layers serving as a cladding layer, the third waveguide being formed in the underlying one of the plurality of optical layers.

21. The method of claim **19**, wherein determining the first and second locations at which the waveguide core is to respectively start and end is performed by a machine vision system.

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