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(54) **CONNECTING A COMPONENT WITH AN EMBEDDED OPTICAL FIBER**

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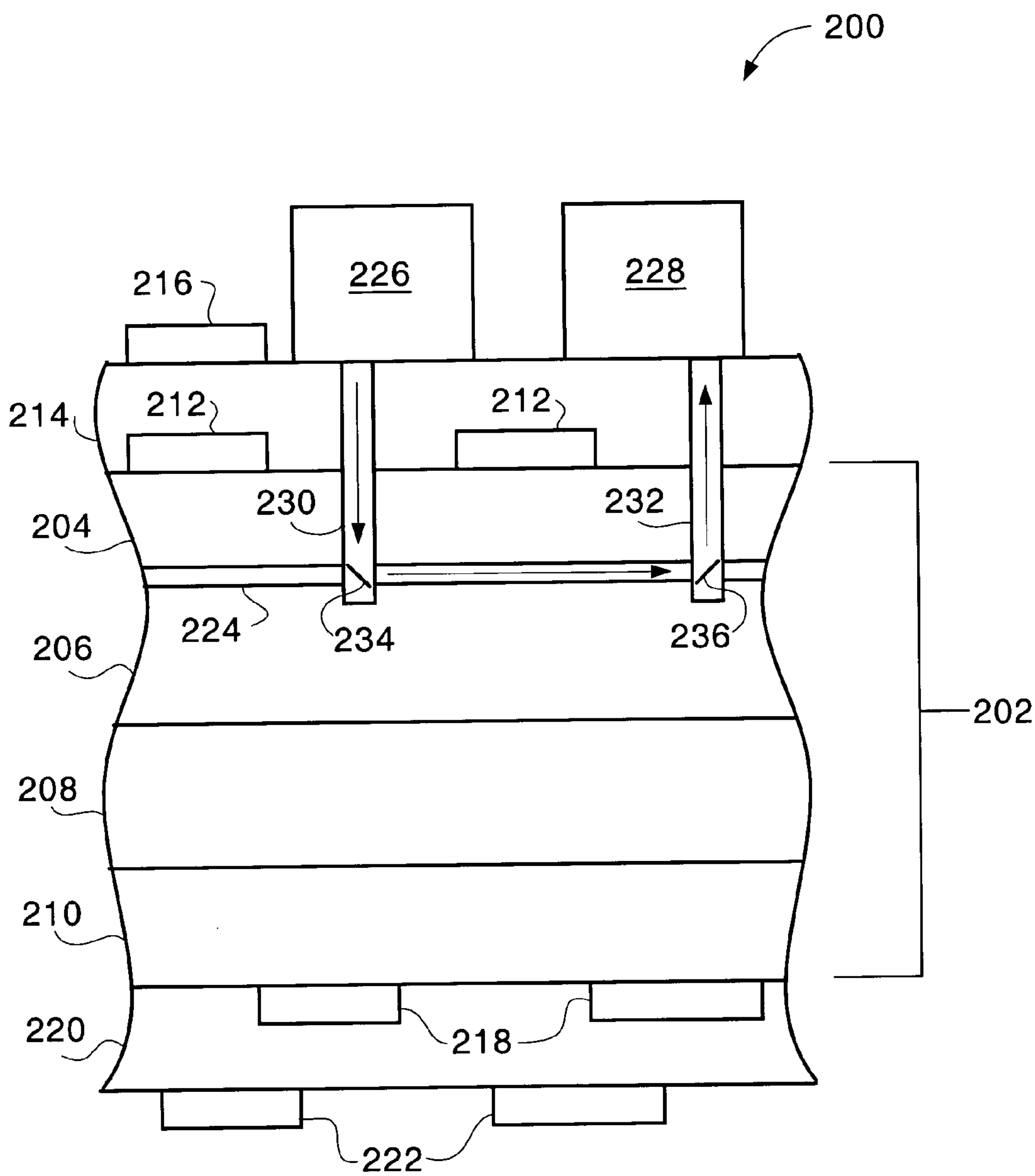
(57) **ABSTRACT**

The invention provides an optical connection between a component on a printed circuit board ("PCB") and an optical fiber embedded in the PCB. By optically connecting the component with the optical fiber, the component may use the optical fiber for high speed optical data communication.



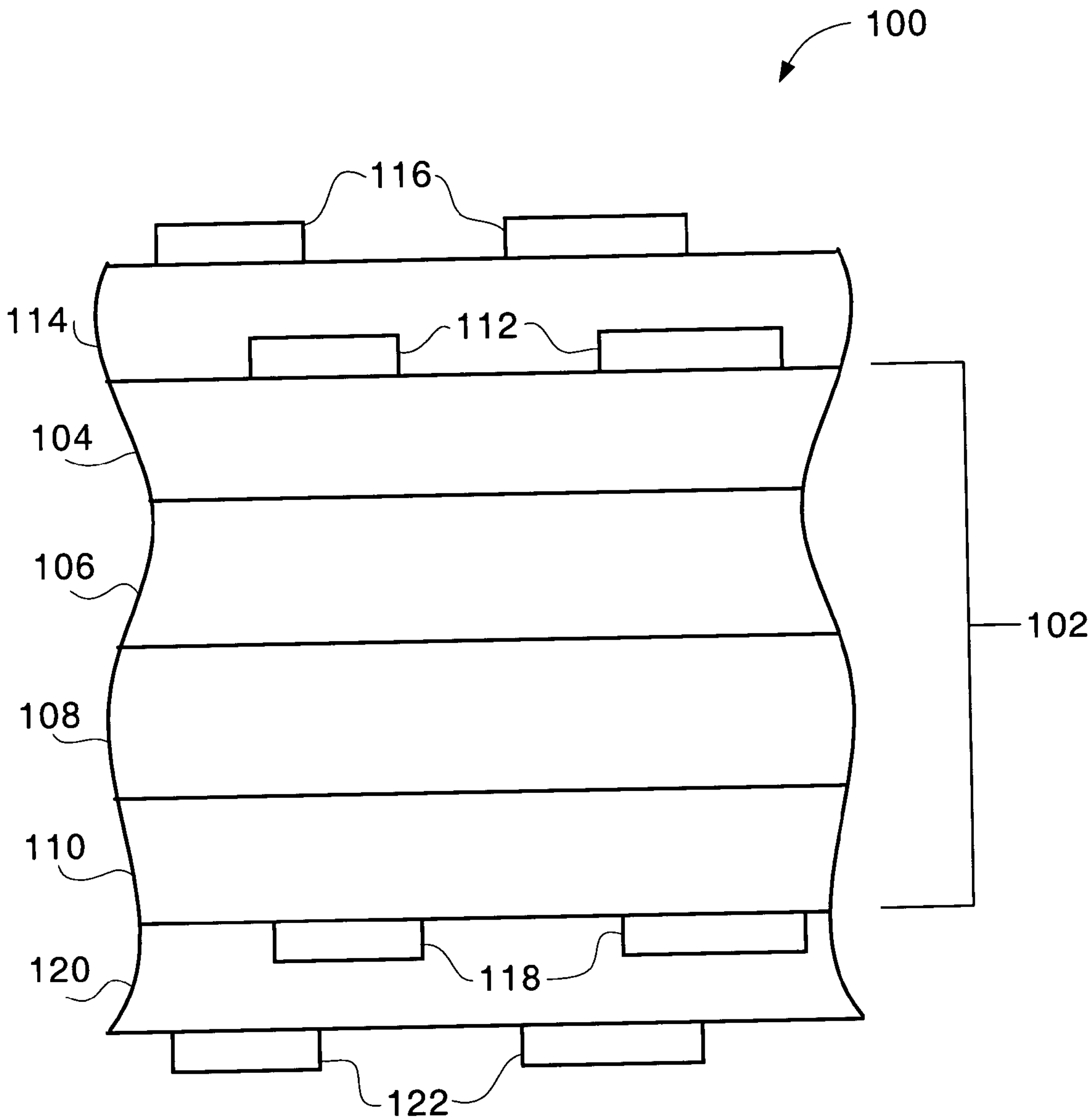


Fig. 1
(Prior Art)

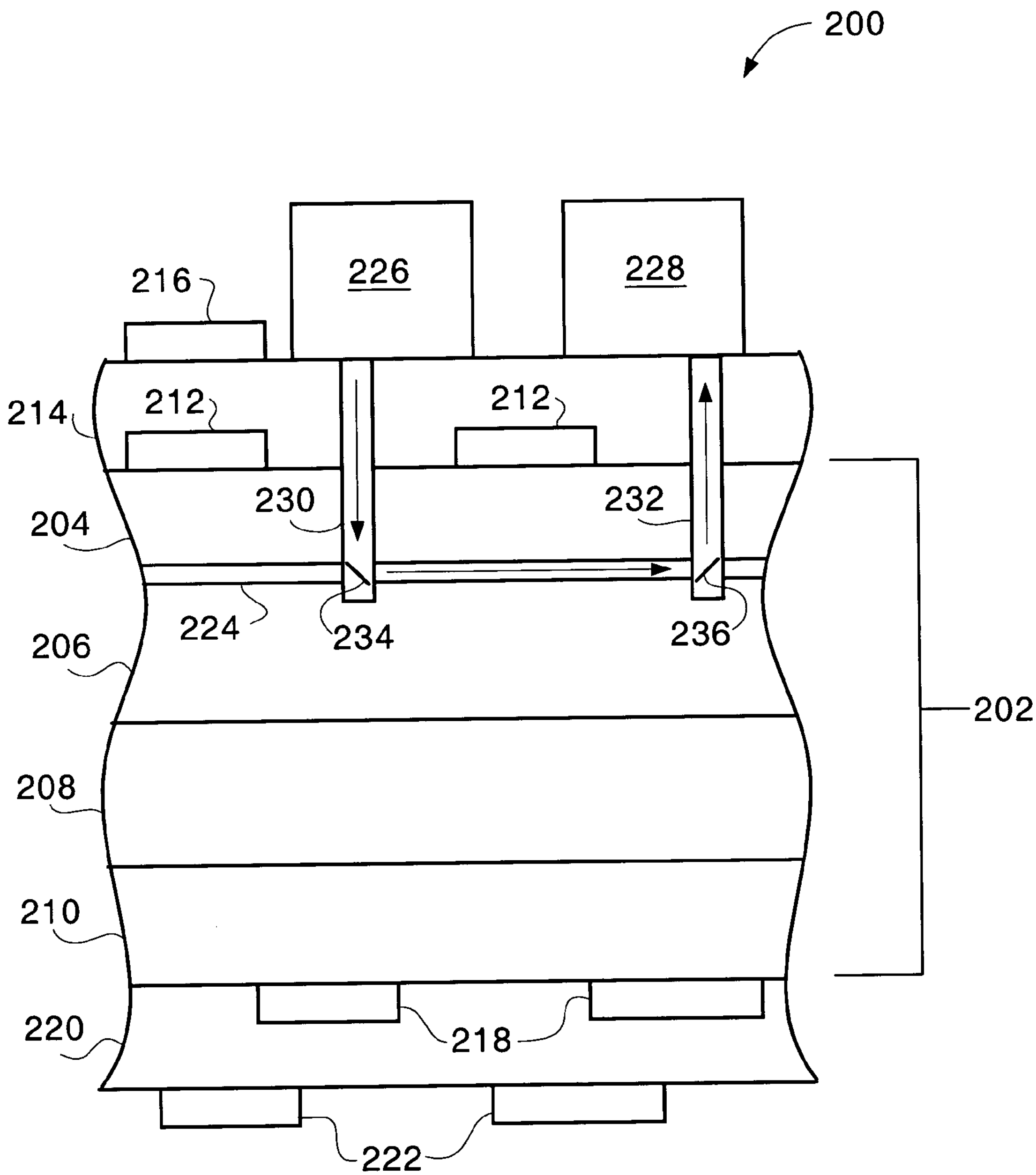

200
226
228
216
212
214
212
230
232
204
224
234
236
206
202
208
210
220
218
222

Fig. 2

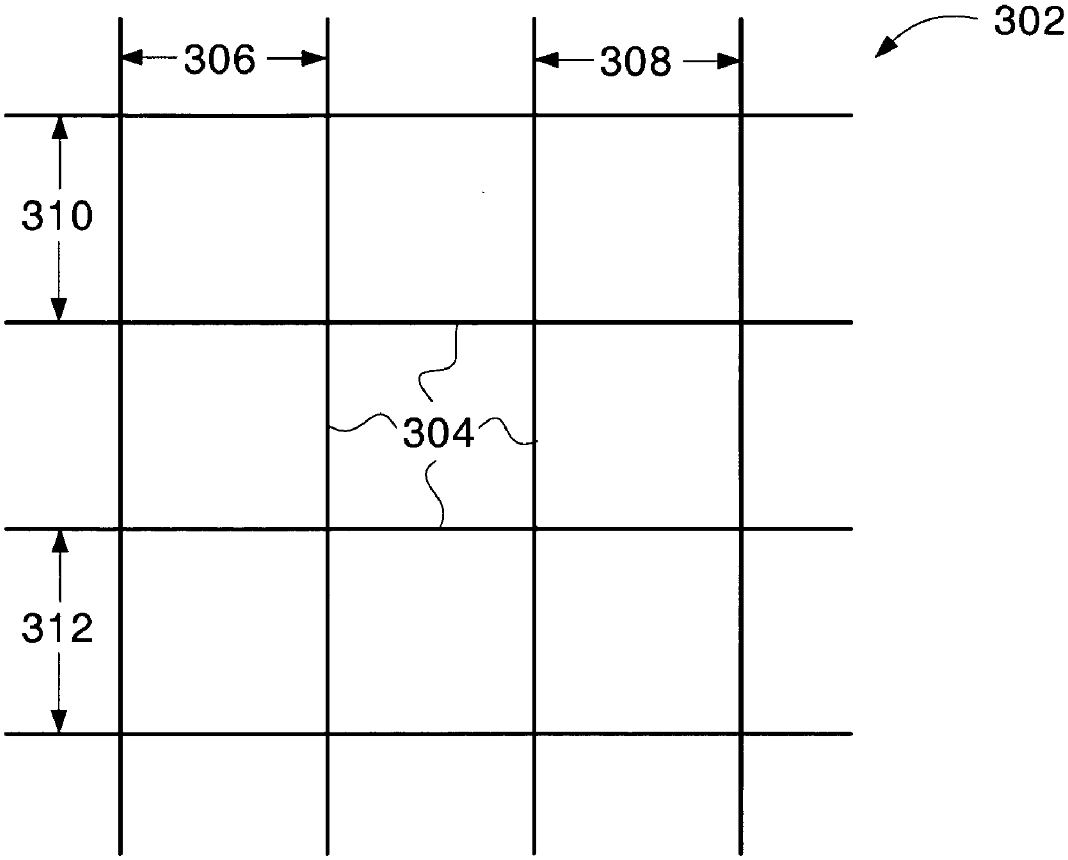


Fig. 3a

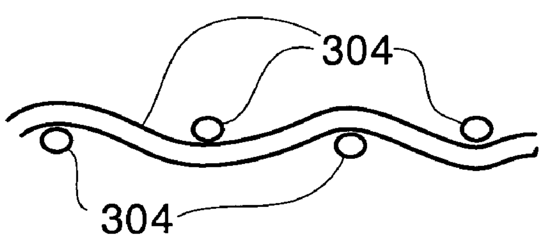


Fig. 3b

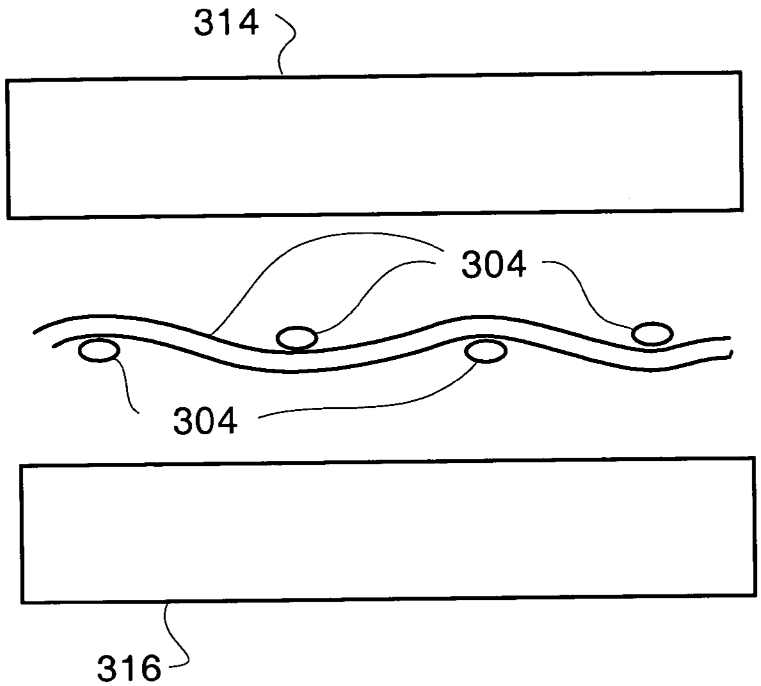


Fig. 3c

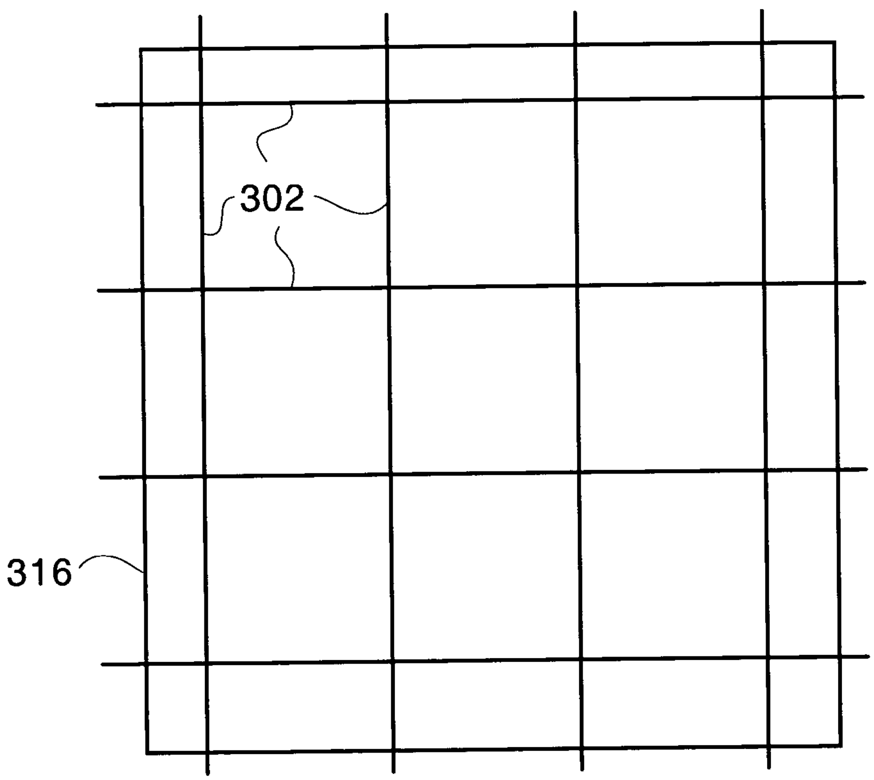


Fig. 3d

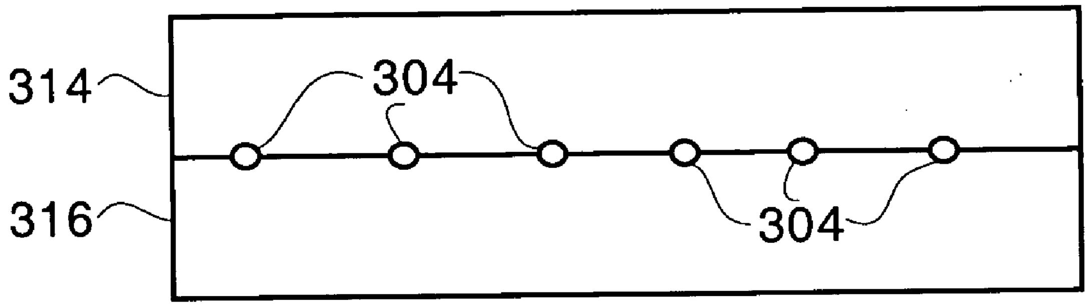


Fig. 3e

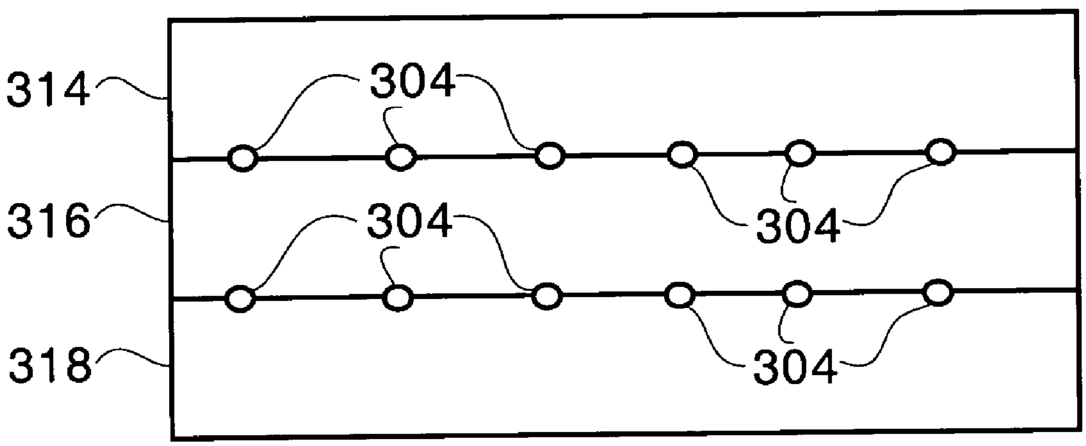


Fig. 3f

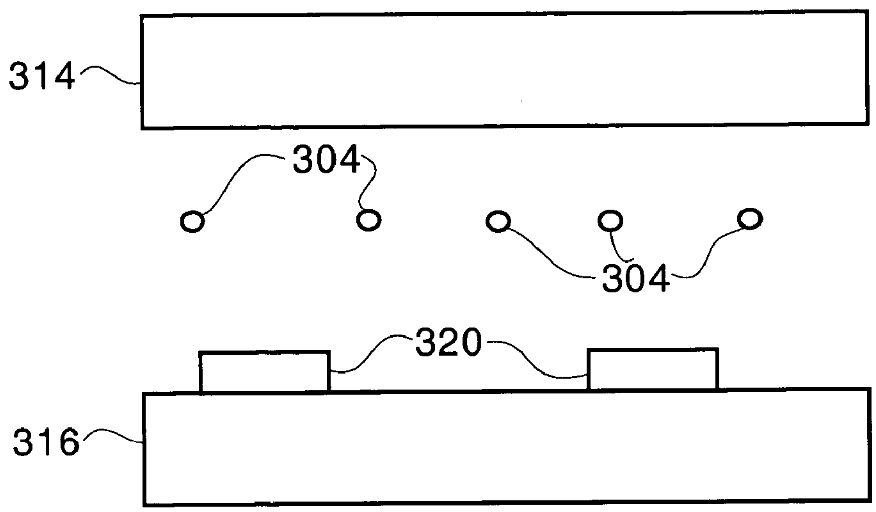


Fig. 3g

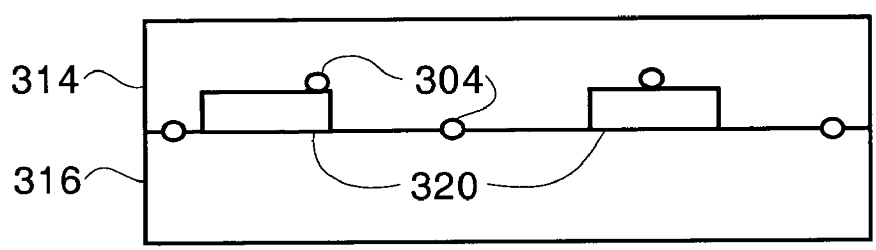


Fig. 3h

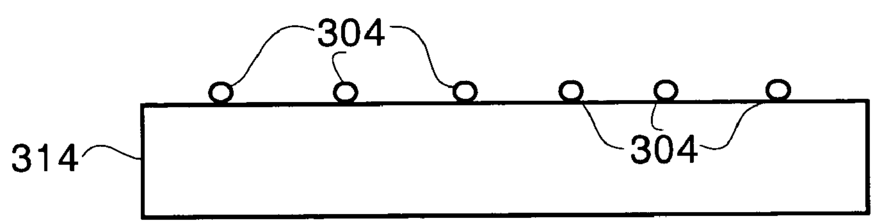


Fig. 3i

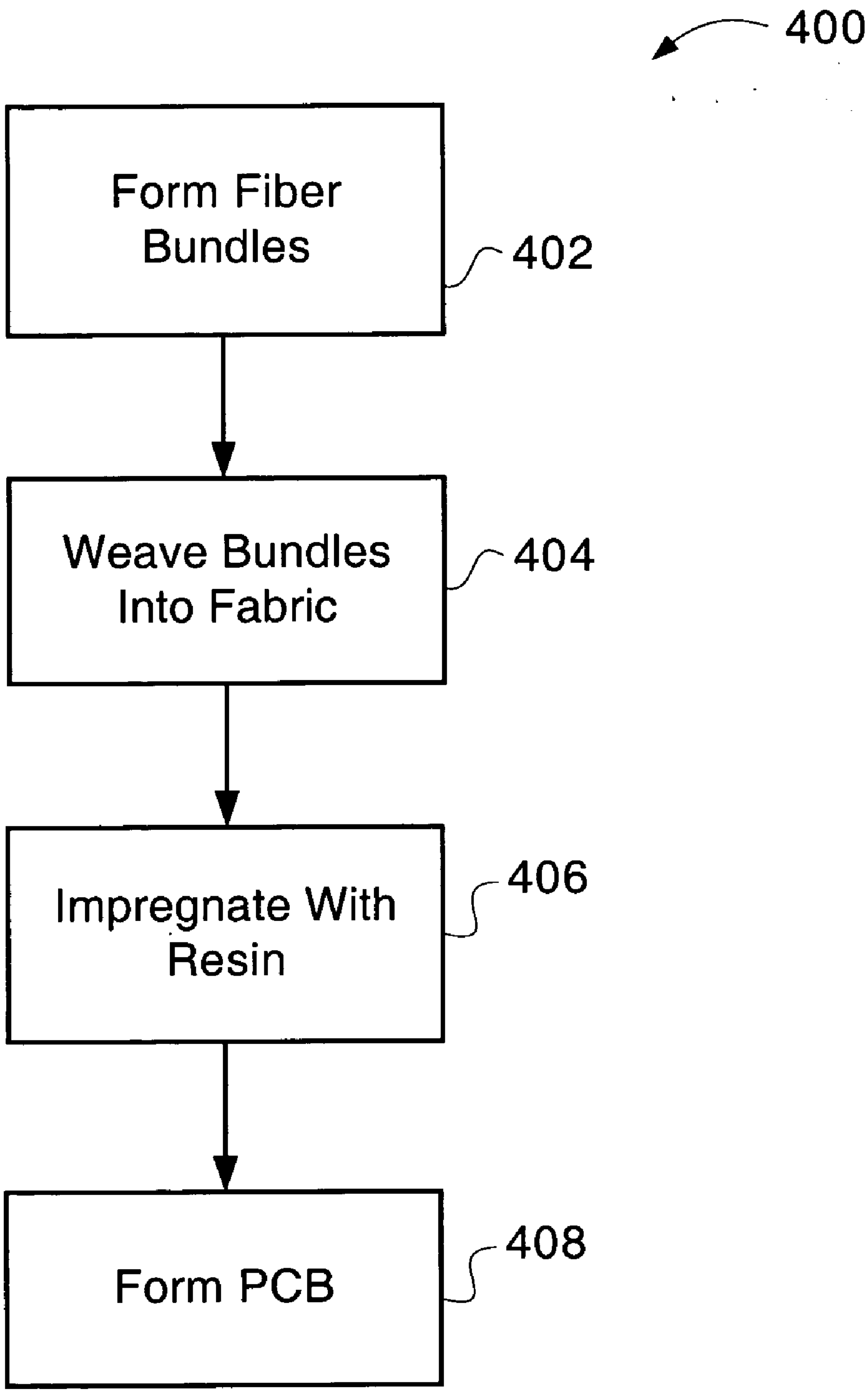

400
Form Fiber Bundles
402
Weave Bundles Into Fabric
404
Impregnate With Resin
406
Form PCB
408

Fig. 4a

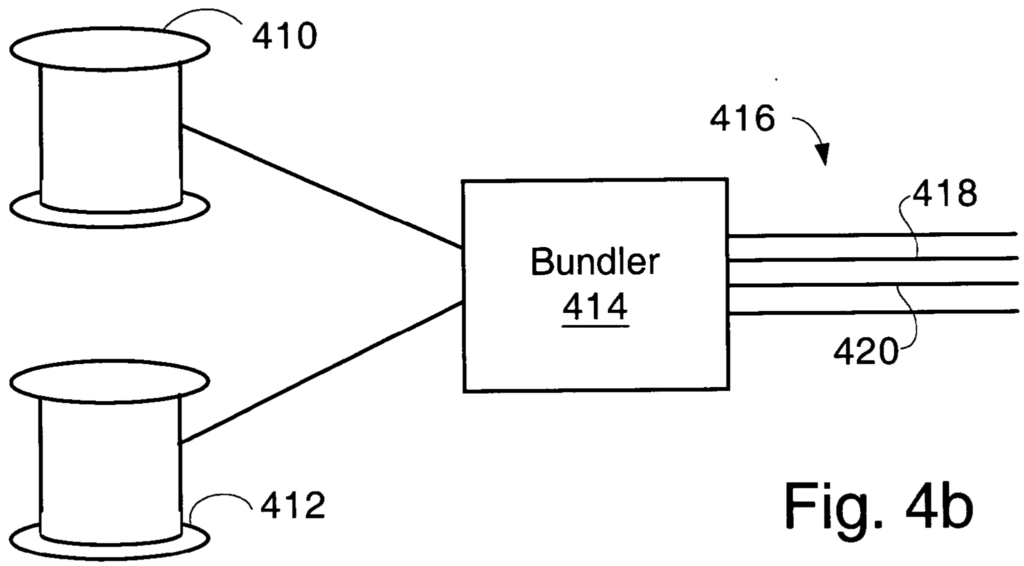

410
416
418
Bundler
414
420
412

Fig. 4b

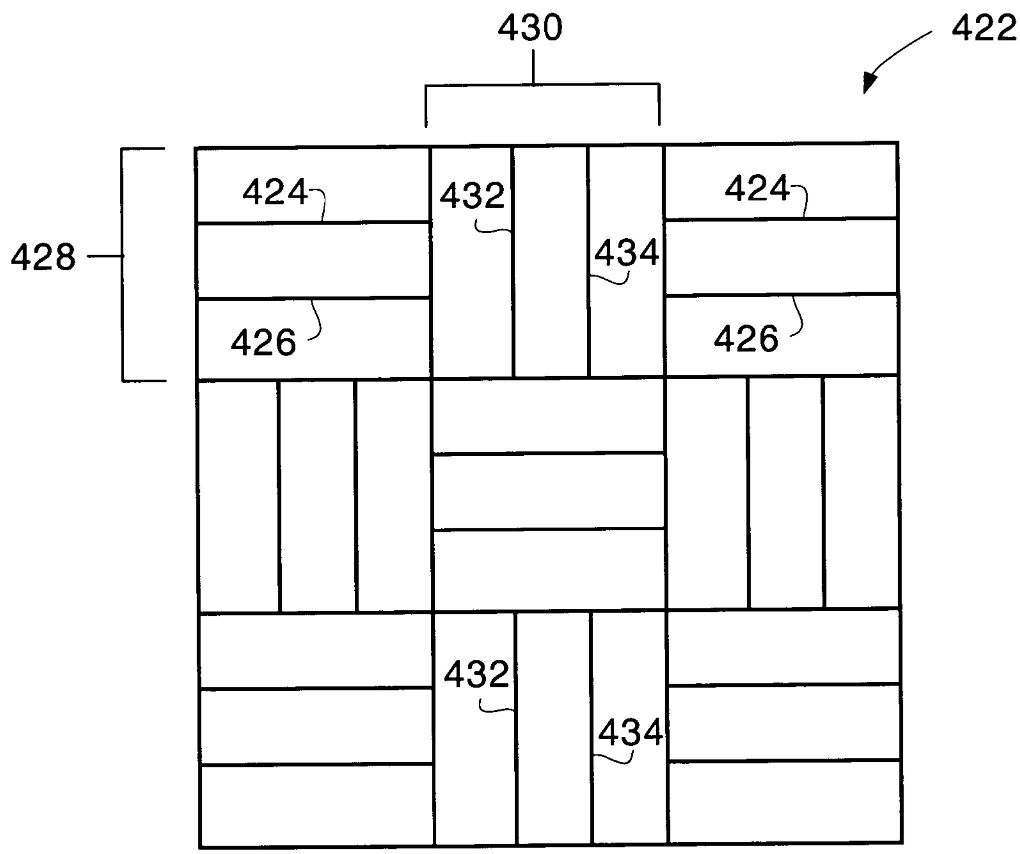

430
422
428
424
432
434
424
426
426
432
434

Fig. 4c

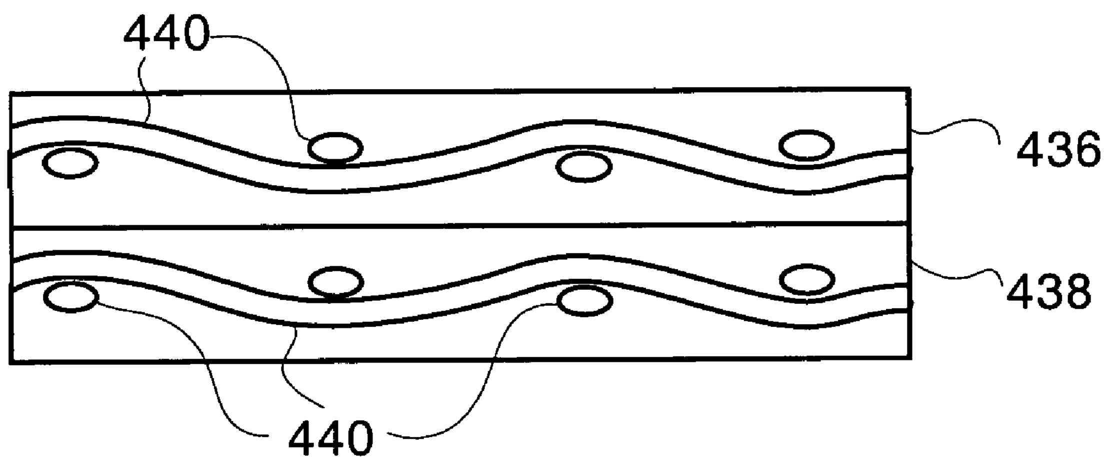


Fig. 4d

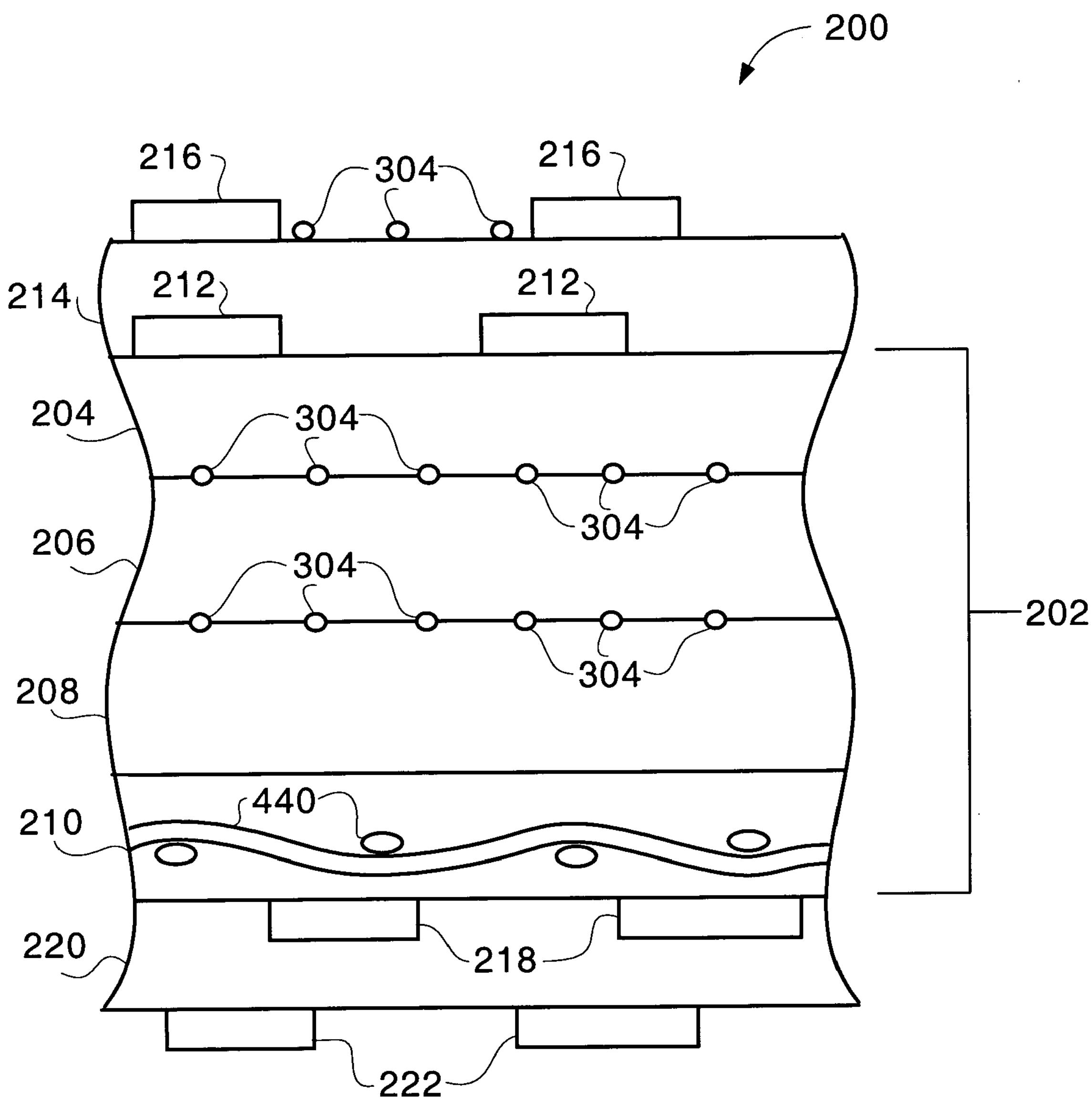

200
216
304
216
214
212
212
204
304
304
206
304
304
202
208
210
440
220
218
222

Fig. 5

Fig. 6a

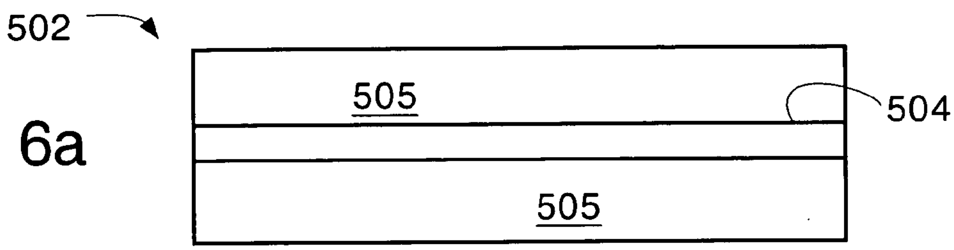


Fig. 6b

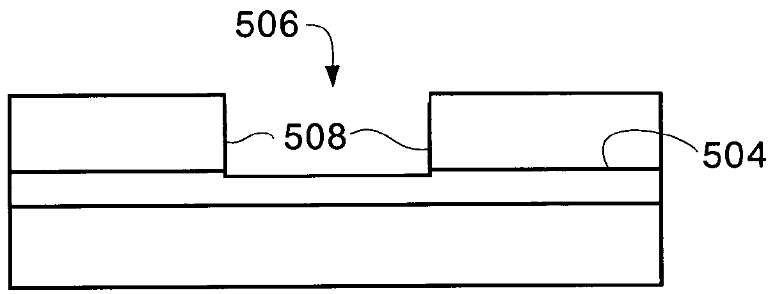


Fig. 6c

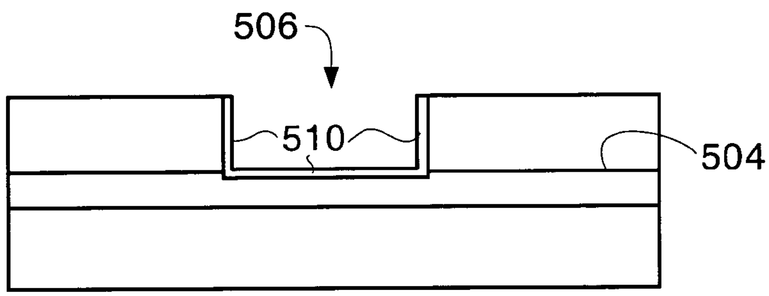


Fig. 6d

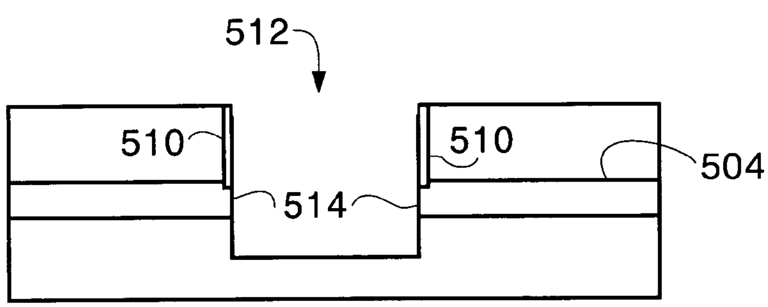
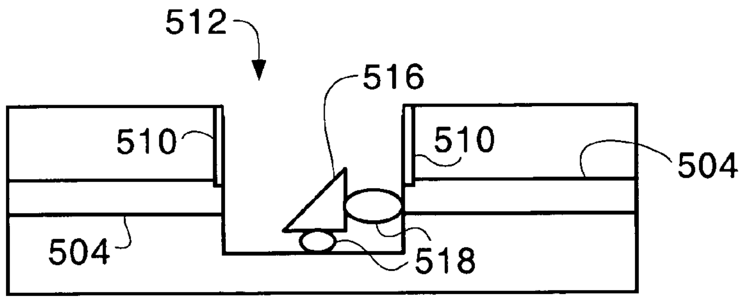


Fig. 6e



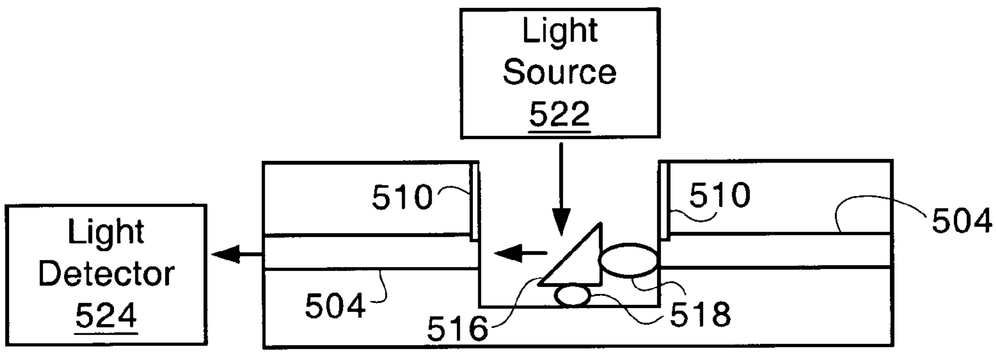


Fig. 6f

Fig. 6g

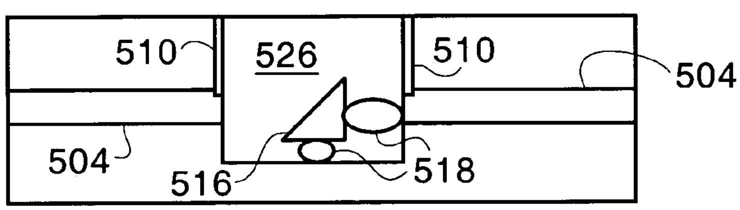


Fig. 6h

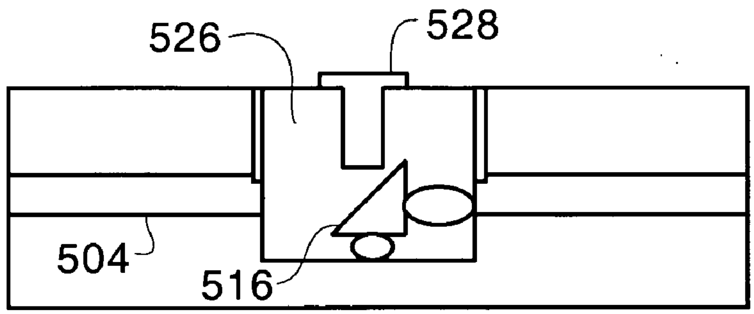
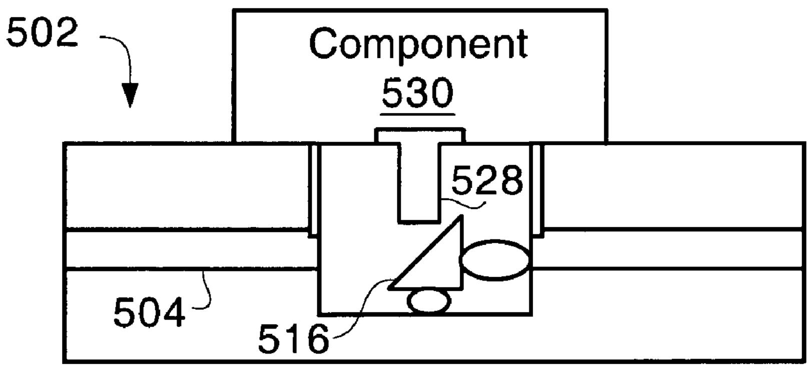


Fig. 6i



CONNECTING A COMPONENT WITH AN EMBEDDED OPTICAL FIBER

BACKGROUND

[0001] 1. Field of the Invention

[0002] This invention relates to printed circuit boards, and more particularly to use of optical fibers in printed circuit boards for communication.

[0003] 2. Background of the Invention

[0004] A printed circuit board ("PCB") is a structure to which electronic devices are attached. The PCB has one or more structural layers as well as patterned conductors. The structural layers support the electronic devices while the conductors provide power to the electronic devices and allow devices to communicate through use of electronic signals.

[0005] **FIG. 1** is a cross-sectional side view of a portion of a typical conventional PCB **100**. The illustrated conventional PCB **100** has a structural core **102**. This structural core **102** provides a rigid support to which other parts of the PCB **100** may be applied or electronic devices may be attached. The structural core **102** in this case has four core structural layers **104**, **106**, **108**, **110**. These core structural layers **104**, **106**, **108**, **110** are each a fiberglass/resin composite material. The core structural layers **104**, **106**, **108**, **110** have been pressed together and cured to form the structural core **102**.

[0006] Above the top core structural layer **104** is a first top layer of conductive traces **112**. These conductive traces **112** provide electronic connections to electronic devices that will be attached to the PCB **100**. The conductive traces **112** may provide power or ground, or may allow electronic devices to communicate through use of electronic signals conducted by the traces **112**. The first layer of conductive traces **112** is covered by a structural layer **114**. This structural layer **114** is applied on top of the first layer of conductive traces **112** and cured. This process allows the structural layer **114** to fill in gaps between the traces **112** and adhere to the top layer **104** of the core **102** as well as to the traces **112** themselves. On top of the structural layer **114** is a second top layer of conductive traces **116**. These traces **116** may also provide power or ground, or may allow electronic devices to communicate. The structural layer **114** separates the first and second top layers of conductive traces **112**, **116**, and insulates the traces **112**, **116** from each other.

[0007] Similarly, below the bottom core structural layer **110** is a first bottom layer of conductive traces **118**, a structural layer **120**, and a second bottom layer of conductive traces **122**. Like the top layers of conductive traces **112**, **116**, the bottom layers of conductive traces **118**, **120** may provide power or ground, or may allow electronic devices to communicate. The structural layer **120** separates the first and second bottom layers of conductive traces **118**, **120**, and insulates the traces **118**, **120** from each other.

[0008] As modern electronic devices increase in complexity, speed, and capabilities, their requirements for communication capacity also has risen. Such modern devices may require more communication capacity than can be provided by even PCBs **100** with multiple layers of conductive traces **112**, **116**, **118**, **120**, such as the PCB **100** shown in **FIG. 1**.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] **FIG. 1** is a cross-sectional side view of a portion of a typical conventional printed circuit board ("PCB").

[0010] **FIG. 2** is a cross-sectional side view of a system according to one embodiment of the present invention.

[0011] **FIGS. 3***a* through **3***i* illustrate a first embodiment of how optical fibers are embedded in a PCB.

[0012] **FIGS. 4***a* through **4***d* illustrate a second embodiment of how optical fibers are embedded in a PCB.

[0013] **FIG. 5** is a cross-sectional side view showing various ways that optical fibers may be integrated in a PCB.

[0014] **FIGS. 6***a* through **6***i* are cross sectional side views that illustrate how an optical fiber embedded in a PCB is coupled to an optical signal source or destination.

DETAILED DESCRIPTION

[0015] In the following detailed description of embodiments of the invention, reference is made to the accompanying drawings in which like references indicate similar elements. The illustrative embodiments described herein are disclosed in sufficient detail to enable those skilled in the art to practice the invention. The following detailed description is therefore not to be taken in a limiting sense, and the scope of the invention is defined only by the appended claims.

[0016] System Overview

[0017] **FIG. 2** is a cross-sectional side view of a portion of a system according to one embodiment of the present invention where devices **226**, **228** or other devices attached to a printed circuit board ("PCB") **200** communicate via optical fibers **224** integrated with the PCB **200**. By allowing optical communication, the system with the PCB **200** allows much higher data communication rates than prior systems. The term "optical communication" in this document is used broadly to encompass many uses of optical signals, including transmitting, sending, receiving, or carrying optical signals for purposes including voice communication, data transfer, and other purposes.

[0018] The PCB **200** may have a structural core **202**. This structural core **202** provides a rigid support to which other parts of the PCB **200** may be applied or electronic devices may be attached. The structural core **202** in this case has four core structural layers **204**, **206**, **208**, **210**, although in other embodiments other numbers of layers may make up the structural core **202**, or the PCB **200** may lack a separate structural core **202**. In an embodiment, the core structural layers **204**, **206**, **208**, **210** are each a composite material that includes fiberglass and a resin, although other materials may also be used in addition to, or in place of the fiberglass and resin. In an embodiment of such a fiberglass/resin structural core **202**, the core is made by stacking prepreg fiberglass plies (fiberglass fabric impregnated with resin) together. The stacked plies are then pressed and cured. The core structural layers **204**, **206**, **208**, **210** are pressed together and cured to form the structural core **202** in an embodiment.

[0019] Above the top core structural layer **204** may be a first top layer of conductive traces **212**. These conductive traces **212** may provide electronic connections to electronic devices attached to the PCB **200**. The conductive traces **212** may provide power or ground, or may allow electronic devices to communicate through use of electronic signals conducted by the traces **212**. The first layer of conductive traces **212** may be covered by a structural layer **214**. This structural layer **214** may be applied on top of the first layer of conductive traces **212** and cured. This process may allow the structural layer **214** to fill in gaps between the traces **212** and adhere to the top layer **204** of the core **202** as well as to the traces **212** themselves. On top of the structural layer **214** may be a second top layer of conductive traces **216**. These traces **216** may also provide power or ground, or may allow electronic devices to communicate. The structural layer **214** separates the first and second top layers of conductive traces **212**, **216**, and insulates the traces **212**, **216** from each other.

[**0020**] Similarly, below the bottom core structural layer **210** may be a first bottom layer of conductive traces **218**, a structural layer **220**, and a second bottom layer of conductive traces **222**. Like the top layers of conductive traces **212**, **216**, the bottom layers of conductive traces **218**, **220** may provide power or ground, or may allow electronic devices to communicate. The structural layer **220** separates the first and second bottom layers of conductive traces **218**, **220**, and insulates the traces **218**, **220** from each other.

[**0021**] The PCB **200** may also have one or more optical fibers **224** embedded within the PCB **200**. In the illustrated embodiment, an optical fiber **224** is embedded in the PCB **200** between two of the core structural layers **204**, **206**. One or more optical fibers **224** may be embedded between core structural layers **204**, **206**, **208**, **210**, within a single core structural layer **204**, **206**, **208**, **210**, between other layers such as between a layer of conductive traces **212** and a structural layer **214**, or within other layers, such as within structural layer **220**. In an embodiment, multiple optical fibers **224** are embedded within the PCB **200** in a predetermined pattern with known spacings between the optical fibers.

[**0022**] In the illustrated embodiment, a first device **226** and a second device **228** are attached to the PCB **200**. These devices **226**, **228** may be connected to conductive traces **212**, **216** to provide power and ground connections, for example. The electronic devices **226**, **228** may also be connected to conductive traces **212**, **216** so that the traces **212**, **216** provide some communication. However, the devices **226**, **228** may be capable of communicating optically. In an embodiment, the devices **226**, **228** may be electronic-to-optical and/or optical-to-electronic converters for sending and receiving optical information and converting it for use by electronic components. In another embodiment, the devices **226**, **228** may be primarily electronic devices capable of optical communication through internal electronic-to-optical and/or optical-to-electronic converters. In other embodiments, the devices **226**, **228** may be other types of devices or components.

[**0023**] In an embodiment the first device **226** may be connected to a first optical via **230**. The first optical via **230** may allow transmission of light to or from the first device **226** to a first optical redirector **234**. The first optical via **230** may be a tube that directs light to or from the first optical redirector **234**, may be a well defined by sidewalls of the layers **214**, **204** through which it passes, or may be another structure that allows light to travel between the surface of the PCB **200** to the optical redirector **234**. The first optical redirector **234** redirects light traveling down the first optical via **230** so that the light is directed into the optical fiber **224**, and redirects light received from the optical fiber **224** so that the light travels up the first optical via **230**. The first optical redirector **234** may be a mirror, a prism, or another device that is capable of redirecting light. The optical fiber **224** provides a pathway for light to travel through the PCB **200**. A second optical redirector **236** redirects light received from the optical fiber **224** so that the light travels up a second optical via **232** or redirects light traveling down the second optical via **232** so that the light is directed into the optical fiber **224**. Like the first optical redirector **230**, the second optical redirector **236** may be a mirror, a prism, or another device that is capable of redirecting light. A second device **228** may be connected to the second optical via **232**, which allows transmission of light to or from the second device **228**. Like the first optical via **230**, the second optical via **232** may be a tube that directs light to or from the second optical redirector **236**, may be a well defined by sidewalls of the layers **214**, **204** through which it passes, or may be another structure that allows light to travel between the surface of the PCB **200** to the optical redirector **236**.

[**0024**] As an example of the system in action, the first device **226** communicates optically with the second device **228**. The first device **226** generates an optical signal, in the form of light, and outputs this light to the first optical via **230**. The light travels down the first optical via **230** to the first optical redirector **230**. The first optical redirector **230** redirects the light so the light is coupled into the optical fiber **224**. The light travels along the optical fiber to the second optical redirector **236**. The second optical redirector **236** redirects the light received from the optical fiber **224** so that it travels up the second optical via **232**. The light that travels up the second optical via **232** is received by the second device **228**. This allows the first and second devices **226**, **228** to communicate optically, which allows for transfer of data at much higher rates than electronic communication.

[**0025**] It is readily seen that the system illustrated in **FIG. 2** allows communication in both directions: from the first device **226** to the second device **228** (as described above) as well as from the second device **228** to the first device **226**. Also, the optical fiber **224** or fibers embedded in the PCB **200** may be used in many ways for communications. For example, a first device **226** attached to the PCB **200** may communicate with a separate device (not shown) that is not attached to the PCB **200**. In such a case the first device **226** may be connected to an optical fiber **224** as shown in **FIG. 2**, but the separate device with which the first device **226** communicates may be optically connected by another scheme. The light from the first device **226** may travel along the optical fiber **224** to a boundary of the PCB **200**, where another optical device or devices, such as a wave guide or another device, couples the light with the separate device. In another example, a device **226** may be connected to more than one optical fiber **224** to communicate with more than one other component.

[**0026**] As a simplified summary, the PCB **200** may be considered to have one or more optical fibers **224** embedded in a matrix material. In the embodiment illustrated in **FIG. 2**, the matrix material includes several layers **204**, **206**, **208**, **210**, **212**, **214**, **216**, **218**, **220**, **222**, and the optical fibers **224** are embedded between two different layers. The optical fibers **224** may also be embedded within a single layer. In another embodiment, the PCB **200** may include more or fewer layers that are considered as the matrix material, or may have one homogeneous piece of matrix material in which the optical fibers **224** are embedded. The PCB **200** may also include additional structures as part of the matrix material. Having optical fibers **224** within matrix material may allow optical communication through the PCB **200**.

[0027] Embedding Optical Fibers in a Printed Circuit Board

[0028] **FIGS. 3***a* through **3***i* illustrate a first embodiment of how optical fibers may be embedded in a PCB **200**. In this first embodiment, the optical fibers are embedded between layers of a PCB **200**.

[0029] **FIG. 3***a* is a top view of an embodiment of an optical fiber pattern **302** that may be embedded in the PCB **200** between layers. The optical fiber pattern **302** may include multiple optical fibers **304**. As illustrated, the optical fibers **304** make up a pattern **302** that is a grid, with equal horizontal spacings **306**, **308** and vertical spacings **310**, **312** between optical fibers **304**. Grid patterns **302** may also have differing horizontal spacings, such as if spacing **306** were different from spacing **308**, and/or differing vertical spacings, such as if spacing **310** were different from spacing **312**. Many different spacing schemes and patterns **302** may be used, including non-grid patterns **302** in other embodiments. For example, a single optical fiber **304** may be the entire pattern **302**, or the pattern **302** may even be optical fibers **304** randomly distributed. In another embodiment, the optical fibers **304** are positioned in a pattern **302** to form a point to point optical communication network for a particular arrangement of components to be coupled to the PCB **200**. A file such as a Gerber file may be generated, which may provide the information necessary to correctly place the optical fibers **304** to allow components coupled to the PCB **200** to use the optical fibers **304** for optical communication.

[0030] In some embodiments, the patterns **302**, including any spacings **306**, **308**, **310**, **312** between optical fibers **304**, may be preselected and known so that the locations of optical fibers **304** in relation to each other are known. In an embodiment, the spacings **306**, **308**, **310**, **312** between optical fibers **304** are chosen based on the spacings of devices that will be attached to the PCB **200**. For example, the spacings may be chosen to be 0.75 mm, 1 mm, or 1.27 mm in some embodiments.

[0031] **FIG. 3***b* is a cross sectional side view of the pattern **302** of **FIG. 3***a*. In the embodiment illustrated in **FIG. 3***b*, horizontal optical fibers **304** are woven to alternate passing above and below vertical optical fibers **304**, and vertical optical fibers **304** alternate passing above and below horizontal optical fibers **304**. In other embodiments, the optical fibers **304** may be placed differently. All horizontal fibers **304** may be above all vertical fibers **304** rather than woven, or a horizontal fiber **304** may pass above two vertical fibers **304** then below one vertical fiber **304**, or other placement schemes may be used.

[0032] **FIGS. 3***c* and **3***d* illustrate the optical fiber pattern **302** in relation to structural layers **314**, **316** prior to the optical fiber pattern **302** being embedded in the PCB **200**. **FIG. 3***c* is a cross sectional view that illustrates an embodiment where the optical fibers **304** in the optical fiber pattern **302** are to be embedded in the PCB **200** by being placed between two structural layers **314**, **316** or other layers. The layers **314**, **316** may be two structural layers, such as layers structural layers **204**, and **206** illustrated in **FIG. 2**, or may be other layers. The optical fiber pattern **302** may be positioned between the two layers **314**, **316**, prior to the layers **314**, **316** being coupled together. "Coupled together" means the layers **314**, **316** and the optical fibers **304** are stacked then pressed together and cured in one embodiment where the layers include fiberglass and resin. **FIG. 3***d* is a top view that illustrates the optical fiber pattern **302** positioned above the bottom layer **316** prior to the two layers **314**, **316** being coupled together. In one alternative embodiment, the optical fiber pattern **302** may be formed on the surface of a prepreg layer, such as layer **316**, rather than the more discrete optical fiber pattern **302** layer shown in the stack of **FIG. 3***c*.

[0033] **FIG. 3***e* is a side cross sectional view that illustrates the optical fibers **304** in the optical fiber pattern **302** between the two layers **314**, **316** after the layers **314**, **316** have been coupled together. For clarity, in **FIG. 3***e* the cross section is taken so that only optical fibers **304** normal to the plane of the page are shown. In an embodiment where the layers **314**, **316** are core structural layers, such as layers **204**, and **206** illustrated in **FIG. 2**, and are made of materials including fiberglass and resin, the layers **314**, **316** may be pressed together and cured with the optical fiber pattern **302** between them. This may result in the optical fibers **304** of the optical fiber pattern **302** being located between, or "sandwiched" by, the two layers **314**, **316** after the two layers **314**, **316** are coupled together. The layers **314**, **316** may flow around the optical fibers **304** in the curing process to make contact and adhere with each other as well as the optical fibers **304**. In an embodiment, the locations of the optical fibers **304** within the optical fiber pattern **302** may be known, and the thicknesses of the layers **314**, **316** may be known, so that the locations of the optical fibers **304** as illustrated in **FIG. 3***e* may be known and may be accessed by drilling or other methods. In an embodiment, the optical fibers **304** may shift location slightly as the layers **314**, **316** are coupled together, but the drilling or other method used to create a hole to access the fibers **304** creates holes large enough that the optical fibers **304** may still be accessed using knowledge of their position prior to being embedded in the PCB **200** between the two layers **314**, **316**.

[0034] **FIG. 3***f* is a side cross sectional view that illustrates two separate optical fiber patterns **302** with optical fibers **304** embedded between three layers **314**, **316**, **318**. There may be a first optical fiber pattern **302** with optical fibers **304** embedded between layers **314** and **316**, and a second optical fiber pattern **302** with optical fibers embedded between layers **316** and **318**. Embedding the optical fibers **304** between layers **316** and **318** may be done similarly to embedding optical fibers **304** between layers **314** and **316**, as described above. **FIG. 3***f* shows that more than one optical fiber pattern **302** may be embedded in the PCB **200**, at multiple different levels.

[0035] **FIGS. 3***g* and **3***h* are side cross sectional views that illustrate how optical fibers **304** may be embedded between a layer **314**, which may be a structural layer, and a layer of conductive traces **320**, such as layer **212** in **FIG. 2**. **FIG. 3***g* illustrates the layer of conductive traces **320** on layer **316**, optical fibers **304** in a pattern **302** positioned above the conductive traces **320**, and a layer **314**, which may be a structural layer, above the optical fibers **304** prior to coupling the fibers **304** and layers **314**, **316**, **320** together. **FIG. 3***h* illustrates the optical fibers **304** and layers **314**, **316**, **320** after they have been coupled together. In the illustrated embodiment, layer **314** flows around the conductive traces **320** during the curing process to meet and adhere with layer **316** as well as the traces **320**. The optical fibers **304** above the traces **320** in **FIG. 3***g* remain above the traces **320** after the fibers **304** and layers **314**, **316**, **320** are coupled together. Thus, the optical fibers **304** may be no longer substantially located in a plane between two layers, such as layer **314** and layer **316**; rather, the optical fibers **304** above the traces **320** may be located at different heights than other optical fibers **304**.

[**0036**] **FIG. 3***i* is a side cross sectional view that illustrates a slight variation of embedding a pattern of optical fibers **302** between two layers. In **FIG. 3***i*, the optical fibers **304** are adhered to the top of a layer **314**. The layer **314** with the adhered optical fibers **304** may be stacked with another layer above and pressed together to result in the optical fibers being between two layers. The layer **314** may also be an external layer of the PCB **200** to result in the optical fibers remaining exposed on the surface of the PCB **200**.

[**0037**] As a simplified summary, the PCB **200** may be considered to have one or more integrated optical fibers **304** embedded in a matrix material. In the embodiment illustrated in **FIGS. 3***a* through **3***h*, the matrix material includes two or more layers, such as layers **314**, **316**, **318**, **320**, and the optical fibers **304** are embedded between two different layers. In such an embodiment, the two or more layers may be considered to be the matrix material in which the optical fibers **304** are embedded. The PCB **200** may also include additional structures as part of the matrix material. Having optical fibers **304** within matrix material that makes up the PCB **200** may allow optical communication through the PCB **200**. In **FIG. 3***i*, the optical fibers **304** are adhered to matrix material. In such cases, the optical fiber **304** may be considered integrated with the matrix material in the PCB **200**, since the optical fibers **304** are a part of the PCB **200** to which components will then be coupled.

[**0038**] **FIGS. 4***a* through **4***d* illustrate a second embodiment of how optical fibers may be embedded in a PCB **200**. In this second embodiment, the optical fibers are embedded within one or more layers, such as within layer **204**, **206**, **208**, or **210**, of a PCB **200**.

[**0039**] **FIG. 4***a* is a flow chart **400** that explains how a layer, such as **204**, **206**, **208**, or **210**, of a PCB **200** is made with optical fibers embedded within that layer. In the described embodiment, the PCB **200** is made out of fiberglass fibers, one or more optical fibers, and resin, although in other embodiments, other materials and methods could be used to make the PCB **200**. The fiberglass fibers may be structural fibers that add strength to the PCB **200**.

[**0040**] Fiber bundles may be formed **402** out of the fiberglass fibers and one or more optical fibers. Referring now to **FIG. 4***b*, the bundling of fibers according to one embodiment is shown. There is a fiberglass fiber supply **410** and an optical fiber supply **412**. A bundler **414** may receive the fiberglass fibers and optical fibers from the supplies **410**, **412**. This bundler **414** may combine multiple fibers into a group, or "bundle,"**416** of fibers. In an embodiment, the fibers within the bundle **416** may be generally oriented substantially parallel with the bundle **416**. The bundle **416** may include one or more optical fibers among the fiberglass fibers, such as optical fibers **418** and **420**. In an embodiment, the location of optical fibers **418**, **420** within the bundle **416** may be preselected and known, and the size of the bundle **416** is preselected and known. In an embodiment, the bundle **416** may have a substantially circular cross section with a diameter of about 0.005 inches.

[**0041**] Returning to **FIG. 4***a*, the bundles may then be woven **404** into a fabric. Referring now to **FIG. 4***c*, a top view of a fabric **422** woven from the bundles **416** is illustrated. In the illustrated embodiment, each bundle **416** in a first (horizontal or vertical) is woven to alternate being above and below a bundle **416** in a second (the other of vertical and horizontal) direction, although in other embodiments different weaving methods may be used. For example, horizontal bundle **428**, which includes optical fibers **424** and **426**, starts above vertical bundles on the left side of **FIG. 4***c*, is woven beneath vertical bundle **430** in the middle of **FIG. 4***c*, then returns to being above the vertical bundle on the right side of **FIG. 4***c*. Similarly, vertical bundle **430**, which includes optical fibers **432** and **434**, starts above horizontal bundle **428** at the top of **FIG. 4***c*, is woven beneath the horizontal bundle in the middle of **FIG. 4***c*, then returns to being above the horizontal bundle at the bottom of **FIG. 4***c*. As shown in **FIG. 4***c*, in some embodiments, the optical fibers within the fabric **422** substantially retain their relative position within a bundle within the fabric **422**. For example, optical fiber **424** substantially retains its position within bundle **428** all the way from the left side to the right side of the fabric **422**. As in some embodiments, both the size of the bundles **428**, **430** within the fabric **422** and the location of the optical fibers **424**, **426**, **432**, **434** within the bundles are known, the location of the optical fibers **424**, **426**, **432**, **434** within the fabric **422** is also substantially known, so that the optical fibers **424**, **426**, **432**, **434** may be accessed after being embedded in a PCB **200**. In other embodiments, not every bundle **416** that is woven **404** into a fabric **422** may include an optical fiber.

[**0042**] Returning to **FIG. 4***a*, the fabric **422** may be impregnated with resin to form a composite material for a layer of the PCB **200**. The PCB **200** may then be formed **408** with one or more of these layers. In an embodiment, this may be done by curing the resin. Referring to **FIG. 4***d*, a cross sectional side view is shown that illustrates two coupled together layers **436**, **438** with embedded optical fibers **440** that may be part of a PCB **200**. The two layers **436**, **438** may be two core structural layers **204**, **206** of the PCB **200**, for example, or they may be different layers of the PCB **200** or part of a different embodiment of a PCB **200**. As shown in **FIG. 4***d*, the optical fibers **440** within each layer **436**, **438** are woven within the layer **436**, **438** itself (for clarity, the fiberglass fibers are not shown). In an embodiment, two pieces of fabric **422** may be woven **404** from formed **402** bundles with optical fibers, impregnated **406** with resin, then pressed together and cured to form **408** a PCB **200** that includes the two-layer structure illustrated in **FIG. 4***d*, where each layer **436**, **438** includes embedded optical fibers **440**. One, some or all of layers in a PCB **200** may include such embedded optical fibers, which may allow for high speed optical data communication.

[**0043**] As a simplified summary, the PCB **200** may be considered to have one or more integrated optical fibers **440** embedded in a matrix material. In the embodiment illustrated in **FIGS. 4***a* through **4***d*, the matrix material includes one or more layers, such as layers **436** and/or **438**, and the optical fibers **440** are embedded within a layer. In such an embodiment, the one or more layers may be to be the matrix material in which the optical fibers **440** are embedded. The PCB **200** may also include additional structures as part of the matrix material. Having optical fibers **440** within matrix material may allow optical communication through the PCB **200**.

[0044] **FIG. 5** is a side cross sectional view that illustrates the PCB **200** of **FIG. 2** with some different ways optical fibers **304**, **440** may be embedded, according to the two embodiments of embedding described above. In the illustrated embodiment, optical fibers **304** are embedded between layers in the structural core **202**. There are optical fibers **304** between core structural layers **204** and **206** and between core structural layers **206** and **208**, although in other embodiments, optical fibers **304** may be embedded between different layers. The locations of the optical fibers **304** may be substantially known in some embodiments. In one embodiment, the optical fibers **304** may be arranged in a grid pattern to allow their use for optical communications by many different arrangements of components on the PCB **200**. In another embodiment, the optical fibers **304** may be arranged in a pattern **302** that is specific to create a point to point optical communications network for a particular arrangement of components on the PCB **200**. Also, different PCBs **200** with different layer structures may have one or more optical fibers **304** embedded within their layers. There may also be optical fibers **304** integrated in the PCB **200** by being adhered to the top surface layer **214** of the PCB **200**. These fibers **304** may be in a pattern **302** to create a specific point to point network, a grid pattern, or another pattern. They may be designed and placed on the layer **214** similarly to the design and placement of metal traces **216**. Finally, there are optical fibers **440** embedded within a single layer **210** of the PCB **200**. Any or all of these methods of embedding or integrating one or more optical fibers with a PCB **200** may be used to allow for high speed optical data communication. Other combinations of methods of integrating optical fibers beyond that illustrated in **FIG. 5** may also be created.

[0045] Coupling Optical Signals to and from Embedded Optical Fiber

[0046] **FIGS. 6***a* through **6***i* are cross sectional side views that illustrate one embodiment of how an optical fiber embedded in a PCB **200** is coupled to an optical signal source or destination, to allow use of the optical fiber within the PCB **200** for optical communications. In some embodiments, this may be done by making an optical via to allow light to reach the optical fiber from the surface of the PCB **200**.

[0047] **FIG. 6***a* is a cross sectional side view of a simplified illustration of a PCB **502** with an embedded optical fiber **504**. For clarity, the simplified illustration of the PCB **502** only shows that an optical fiber **504** is embedded within matrix material **505** of the PCB **502**, and does not show the various structures and layers that may make up the PCB **502** in various embodiments. The optical fiber **504** within the PCB **502** may be used by a device attached to the surface of the PCB **502** for optical communications. The matrix material **505** of the PCB **502** may be, for example, one or more layers of a fiberglass/resin composite, although other materials may also be used. If there are layers or discrete sections of multiple different materials that form the PCB **502**, such as layers **204**, **206**, **208**, **210**, **212**, **214**, ect. of **FIG. 2**, all these materials, sections and layers may be considered the matrix material **505**.

[0048] **FIG. 6***b* is a cross sectional side view that illustrates the PCB **502** after a first well **506** is formed through the matrix material **505** to access the optical fiber **504**. Side walls **508** of the matrix material **505** that extend from the surface of the PCB **502** may define sides of the first well **506**.

[0049] In some embodiments of PCBs **502** with embedded optical fibers **504**, the angle of the optical fiber **504** may not be parallel with the surface of the PCB **502**, and the exact distance of the optical fiber **504** beneath the surface of the PCB **502** may not be known. In an embodiment, the angle may be up to 15 degrees away from parallel with the surface of the PCB **502**, with the precise angle not being known. In an embodiment, the distance of the optical fiber **504** beneath the surface of the PCB **502** may be known to a margin of error of plus or minus 0.003 inches. In an embodiment, the distance of the optical fiber **504** beneath the surface of the PCB **502** may be known to a margin of error of plus or minus 0.001 inches. In other embodiments, the distance of the optical fiber **504** beneath the surface of the PCB **502** may be known to varying other degrees of precision. Also, the locations of the optical fibers **504** within the plane of the PCB **502** may not be precisely known. In an embodiment where the optical fibers **504** are part of a pattern **302**, the PCB **502** may be tested to find one optical fiber **504**, then the known spacings **306**, **308**, **310**, **312** between optical fibers **504** may be used to determine the location of the other optical fibers **504**. In an embodiment where the optical fibers **504** are part of a pattern **302**, the locations of the optical fibers **504** may be known with a margin of error of plus or minus 0.003 inches. Similarly, if the optical fibers **504** are embedded within a layer, the locations of the optical fibers **504** may be known with a margin of error of plus or minus 0.003 inches in an embodiment, with the spacings between optical fibers **504** provided by the size of the bundles **416**.

[0050] Thus, in some embodiments where the depth, location and angle of the optical fiber **504** are not exactly known, the first well **506** may extend down to reach the topmost surface of the optical fiber **504**, may extend partially through the matrix **505** but not reach the optical fiber **504**, or may extend into the optical fiber **504** so that the bottom of the first well **506** is below the top surface of the optical fiber **504** (illustrated in **FIG. 6***b*).

[0051] The first well **506** may be created by multiple different methods. In an embodiment, the well may be formed by high power lasers. Lower power laser may be used to smooth the sidewalls **508** of the first well **506**. Other methods, such as chemical etching, may also be used. In an embodiment, the diameter of the first well **506** may be significantly larger than the diameter of the optical fiber **504** so that the well **506** is more likely to reach the optical fiber **504** even if the precise location of the optical fiber **504** is not known. For example, the first well **506** may have a circular cross section that has a diameter twice as large as a diameter of the optical fiber **504** in an embodiment. In another embodiment, the first well **506** may have a substantially circular cross section with a diameter of approximately

0.010 inches. In another embodiment, the first well **506** may have a substantially circular cross section with a diameter greater than the margin of error of the known location of the optical fiber. In other embodiments, the first well **506** may be other sizes and have other, non-circular shapes.

[**0052**] **FIG. 6***c* is a cross sectional side view that illustrates the PCB **502** after a light blocking layer **510** has been deposited on the surfaces of the first well **506**. In an embodiment, the light blocking layer **510** may prevent some or all of light traveling between the surface of the PCB **502** and the optical fiber **504** from diffusing or refracting into the matrix material **505** of the PCB **502**. In another embodiment, the light blocking layer **510** may add structural reinforcement to the matrix material **505** that defines the side walls **508** of the first well **506**. The light blocking layer **510** may be deposited through a plating or metallization method, or another method. The light blocking layer **510** may reflect some or all incident light, or prevent some or all incident light from passing through.

[**0053**] **FIG. 6***d* is a cross sectional side view that illustrates the PCB **502** after a second well **512** is formed through the optical fiber **504**. The second well **512** may expose the light transmissive surfaces **514** on the cross section of the optical fiber **504** so that light may be coupled into the optical fiber **504** from a source or coupled from the optical fiber **504** to a destination. This second well **512** may be thought of as a tube or an optical via to allow light to travel from the PCB **502** surface to the optical fiber **504**. In an embodiment, the second well **512** may be created by multiple different methods. In an embodiment, the well **512** may be formed by high power lasers. Lower power laser may be used to smooth sidewalls of the second well **512**. Other methods, such as chemical etching, may also be used to form the second well **512**. The method used to create the second well **512** may leave the light transmissive surfaces **514** of the optical fiber **504** sufficiently smooth for coupling light to and from the optical fiber. However, in some embodiments further smoothing is performed. This may be done by a polishing slurry, such as alumina or diamond, a polishing tool, or through other methods.

[**0054**] In another embodiment, only one well that extends from the surface of the PCB **502** to the expose the light transmissive surfaces **514** of the optical fiber **504** may be formed. In such embodiments, a separate tube may be formed extending at least partially from the surface of the PCB **502** to the optical fiber **504** to prevent light from diffusing or refracting into the matrix material **505**. Alternately, a mask may cover the light transmissive surfaces **514** of the optical fiber **504** so that a light blocking layer **510** may be deposited to prevent light from diffusing or refracting into the matrix material **505**, while leaving the transmissive surfaces **514** of the optical fiber **504** free from the light blocking layer **510**. In yet another embodiment, no separate tube or light blocking layer **510** may be used; sufficient light reaches the optical fiber **504** without such structures.

[**0055**] **FIG. 6***e* is a cross sectional side view that illustrates the PCB **502** after a light redirector **516** is inserted into the second well **512**. In an embodiment, glue **518** may hold the light redirector **516** in place. The glue **518** may not be cured yet at this point in an embodiment, and may be reworked so that the position of the light redirector **516** (also known as an "optical redirector") may be altered. In other embodiments, different attachment materials **518** may be used to hold the light redirector **516** in place. In some embodiments, these attachment materials **518** may hold the light redirector **516** in place as desired, but may be reworkable or alterable through the application or force or other means so that the position of the light redirector **516** may be altered. The light redirector **516** may be a mirror, a prism, or another device that redirects light.

[**0056**] **FIG. 6***f* is a cross sectional side view that illustrates how the angle and depth of the light redirector **516** may be positioned to correctly couple light to and from the optical fiber **504**. In the illustrated embodiment, a light source **522** directs light toward the light redirector **516**. The light redirector **516** redirects the light into the optical fiber **504**, which outputs the light to a light detector **524**. Feedback from the light detector **524** may be used to determine whether enough (or any) light is being redirected from the light source **522** into the optical fiber **504** by the light redirector **516**. If not enough light is being redirected into the optical fiber **504**, the position and angle of the light redirector **516** may be changed. Thus, by monitoring the light received by the light detector **524** and adjusting the light redirector **516** accordingly, the light redirector **516** may be correctly positioned. In some embodiments, the glue **518** may not have not cured before the light redirector **516** is correctly positioned, so that the light redirector's **516** position may be altered. After the light redirector **516** is correctly positioned, the glue **518** or other attachment material **518** is cured or set to keep the light redirector **516** in the correct position in an embodiment. Other methods for positioning the light redirector **516** may also be used. For example, the light detector **524** may be positioned adjacent the light source **522** at the top of the second well **512**. The light detector **524** would then detect light that has been reflected and not coupled into the optical fiber **504**. More light coupled into the optical fiber **504** means less reflected light. The light redirector **516** would be adjusted until a satisfactorily small amount of light is detected by the light detector **524**.

[**0057**] **FIG. 6***g* is a cross sectional side view that illustrates the PCB **502** after the second well **512** is filled with an optically neutral material **526**. This optically neutral material **526** may allow most or all of the light to pass through. The material **526** may also prevent the light redirector **516** from being damaged or repositioned, and may add structural support to the PCB **502**. In embodiments where the attachment material **518** is not set in place to prevent further adjustment of the position of the light redirector **516**, the optically neutral material **526** may be used to hold the light redirector **516** in place.

[**0058**] **FIG. 6***h* is a cross sectional side view that illustrates the PCB **502** after a light guide **528** has been added. The light guide **528** may help direct light between the light redirector **516** and the surface of the PCB **502**. In an embodiment, a hole may be formed in the optically neutral material **526**. The light guide **528** may then be inserted into the hole. Optionally, the side walls of the hole may be coated with a material to form the light guide **528** rather than have a light guide **528** inserted into the hole. In other embodiments, the light guide **528** may be ommitted.

[**0059**] Thus, an optical via has been formed. The optical via may allow light to travel from the surface of the PCB **502** to the optical fiber **504** or optical redirector **516**. The optical via may simply be a hole, such as the second well **512**, or it may be filled with an optically neutral material **526**, such as seen in **FIG.** 6*g*, or it may include a light guide **528**, such as seen in **FIG.** 6*h*, or may take other forms with other structures.

[**0060**] **FIG.** 6*i* is a cross sectional side view that illustrates the PCB **502** with an attached optical component **530**. The optical component **530** may be an optical device, an electronic device with a module that performs electronic-to-optical and/or optical-to-electronic conversions, a component **530** that couples light to a device that is not attached to the PCB **502**, or another type of component **530**. Thus the component **530** may use the optical fiber **504** for optical communications. When the component **530** transmits an optical signal, the signal may travel from the component **530** to the light redirector **516** (possibly aided by the light guide **528** in some embodiments). The light redirector **516** may couple the light into the optical fiber **504**, along which the light may travel to a destination. Similarly, when the component **530** receives an optical data signal, the signal may travel along the optical fiber **504** to the light redirector **516**. The light redirector **516** may redirect the signal so it travels up the optical via to the component **530** (possibly aided by the light guide **528** in some embodiments). The PCB **502** with embedded optical fibers **504** may allow components **530** to optically transfer data at high speeds.

[**0061**] Although the invention is described herein with reference to specific embodiments, many modifications will readily occur to those of ordinary skill in the art. Further, the foregoing description of embodiments of the invention and the claims following include terms, such as left, right, over, under, upper, lower, first, second, etc. that are used for descriptive purposes only and are not to be construed as limiting. The embodiments of a device or article described herein can be manufactured, used, or shipped in a number of positions and orientations. Accordingly, all such variations and modifications are included within the intended scope of the invention as defined by the following claims.

I claim:

1. A method, comprising:

forming an optical via in a printed circuit board to access an optical fiber embedded in the printed circuit board;

placing an optical redirector within the optical via; and

adjusting the optical redirector to redirect light directed into the optical via so that the light is coupled into the optical fiber.

2. The method of claim 1, wherein forming an optical via comprises forming a well in matrix material of the printed circuit board.

3. The method of claim 2, wherein forming an optical via further comprises forming a light blocking layer on at least part of side walls of the well to prevent at least some light from entering the matrix material of the printed circuit board as the light travels along the optical via.

4. The method of claim 1, further comprising depositing optically neutral material within the optical via and around the optical redirector.

5. The method of claim 4, further comprising forming a light guide to direct light through the optically neutral material along the optical via.

6. The method of claim 1, wherein forming an optical via comprises:

forming a first well in matrix material of the printed circuit board;

depositing a light blocking material on side walls of the first well; and

forming a second well in matrix material of the printed circuit board, the second well having a depth greater than the first well and exposing light transmissive surfaces of the optical fiber.

7. The method of claim 1, wherein when the optical redirector is placed within the optical via it is attached to the printed circuit board with an adjustable attachment material.

8. The method of claim 7 wherein adjusting the optical redirector comprises:

directing light from a source into the optical via to the light redirector;

redirecting, by the optical redirector, the light from the source;

detecting, with a light detector, light from the source that has traveled along the optical fiber after being redirected by the optical redirector;

measuring the detected light; and

changing the position of the optical redirector.

9. A device, comprising:

a surface;

a matrix material;

an embedded optical fiber;

an optical via for allowing light to travel through the matrix material between the surface and the embedded optical fiber; and

an optical redirector for redirecting light received from the optical fiber along the optical via toward the surface of the device and for redirecting light received from the optical via into the optical fiber.

10. The device of claim 9, wherein the optical via comprises side walls that define a boundary between the matrix material and the optical via.

11. The device of claim 10, further comprising a layer of light blocking material covering at least part of the side walls to prevent at least some light from entering the matrix material as the light travels along the optical via.

12. The device of claim 9, further comprising attachment material for attaching the optical redirector to the device.

13. The device of claim 9, further comprising optically neutral material within the optical via and around the optical redirector.

14. The device of claim 13, further comprising a light guide to direct light through the optically neutral material along the optical via.

15. The device of claim 9, further comprising:

a layer of light blocking material covering at least part of side walls that define a boundary between the matrix material and the optical via to prevent at least some light from entering the matrix material as the light travels along the optical via;

attachment material for attaching the optical redirector to the device;

optically neutral material that substantially fills otherwise empty space within the optical via and around the optical redirector; and

a light guide to direct light through the optically neutral material along the optical via.

16. A device, comprising:

a circuit board comprising:

a surface;

a matrix material;

an embedded optical fiber;

a first optical via for allowing light to travel through the matrix material between the surface and the embedded optical fiber;

a second optical via to allow light to travel through the matrix material between the surface and the embedded optical fiber;

a first optical redirector to redirect light received from the optical fiber along the first optical via toward the surface of the device and to redirect light received from the first optical via into the optical fiber; and

a second optical redirector to redirect light received from the optical fiber along the second optical via toward the surface of the device and to redirect light received from the second optical via into the optical fiber; and

a first optical component connected to the circuit board and optically connected to the first optical via to transmit optical signals along the first optical via to the first optical redirector and to receive optical signals that travel up the first optical via from the first optical redirector;

a second optical component connected to the circuit board and optically connected to the second optical via to transmit optical signals along the second optical via to the second optical redirector and to receive optical signals that travel up the second optical via from the second optical redirector.

17. The device of claim 16, wherein optical signals transmitted from the first optical component along the first optical via to the first optical redirector are redirected into the embedded optical fiber to the second optical redirector, which redirects the optical signals up the second optical via to be received by the second optical component.

18. The device of claim 16, wherein the circuit board comprises a plurality of layers and the embedded optical fiber is between a first and a second of the plurality of layers.

19. The device of claim 16, wherein the circuit board comprises at least one layer and the embedded optical fiber is within a first layer.

20. The device of claim 16, wherein:

the matrix material includes a layer with a plurality of woven structural fibers; and

the embedded optical fiber is woven with the structural fibers to form the layer.

* * * * *