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(54) **OPTICAL DEVICE AND OPTICAL COUPLING MODULE**

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G02B 6/34 (2006.01)
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CPC G02B 6/43; G02B 6/4243; G02B 6/32; G02B 6/34; G02B 6/425; G02B 6/131

See application file for complete search history.

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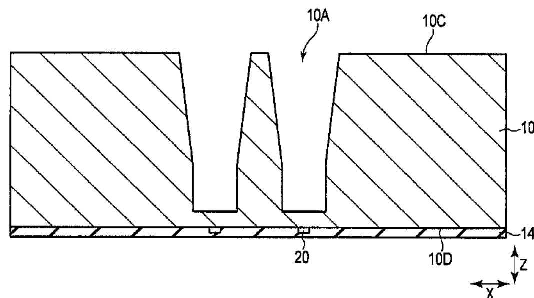
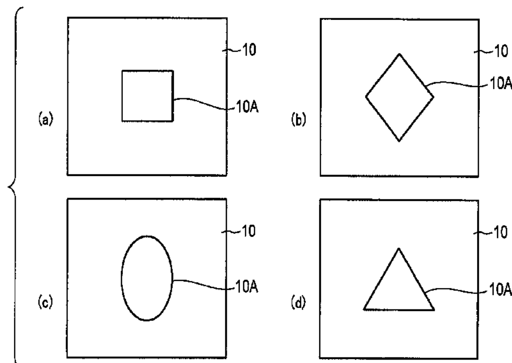
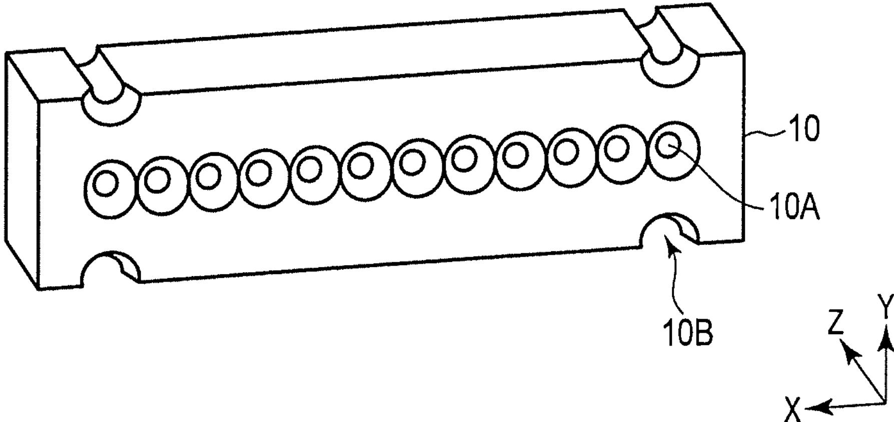
(57) **ABSTRACT**

According to one embodiment, an optical device includes an optical element and a via. The optical element is provided directly on a second main surface opposed to a first main surface of a semiconductor substrate. The via is aligned with the optical element and formed to extend halfway in a thickness direction from the first main surface of the semiconductor substrate.

30 Claims, 14 Drawing Sheets







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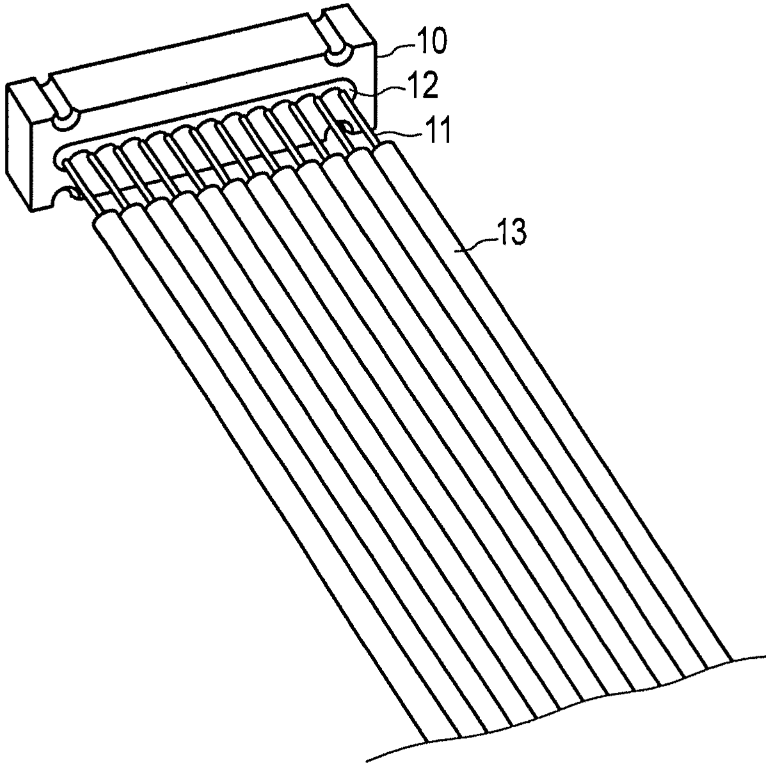

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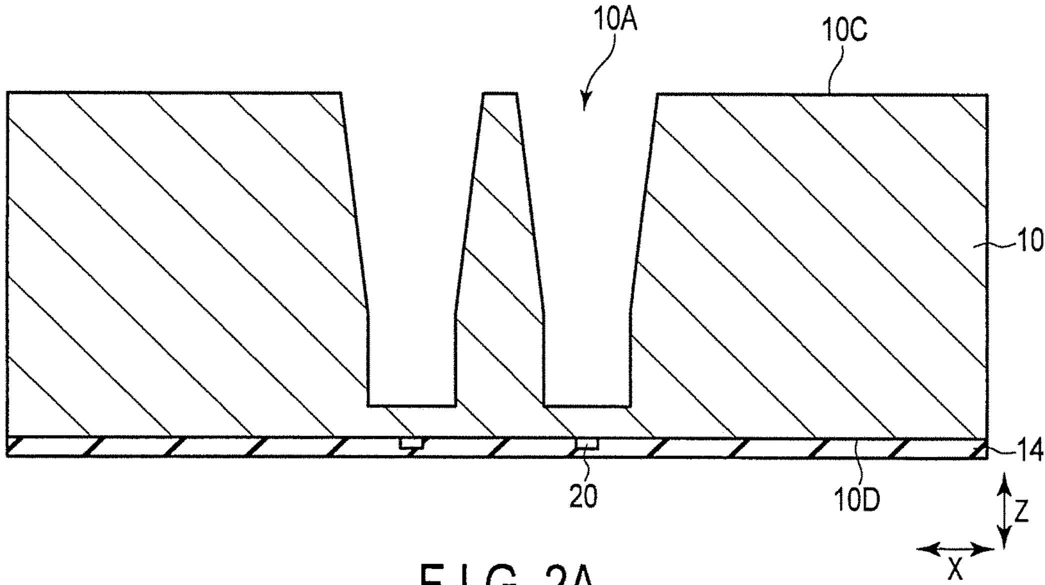

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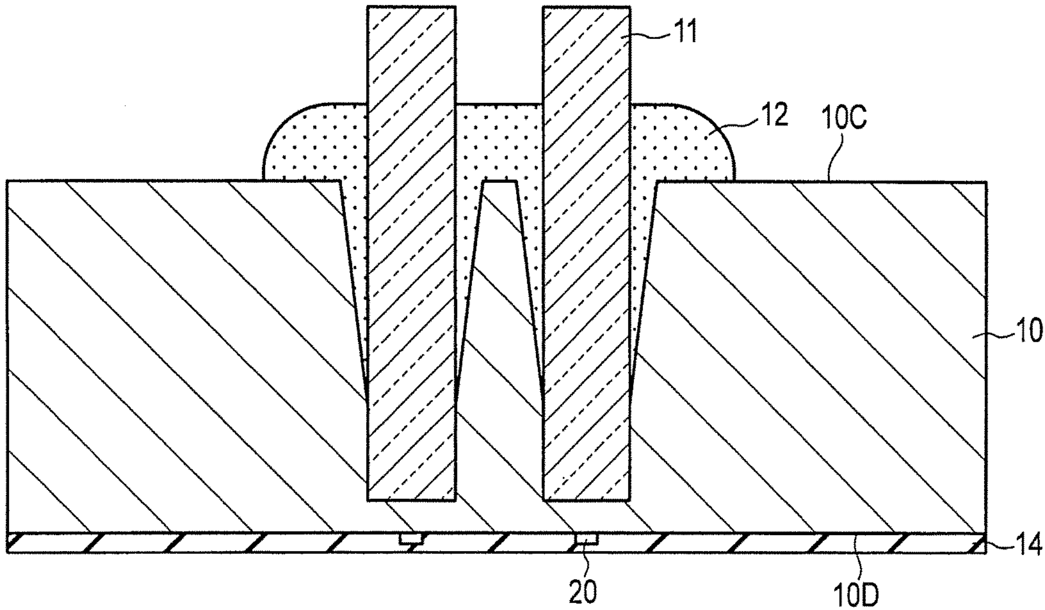

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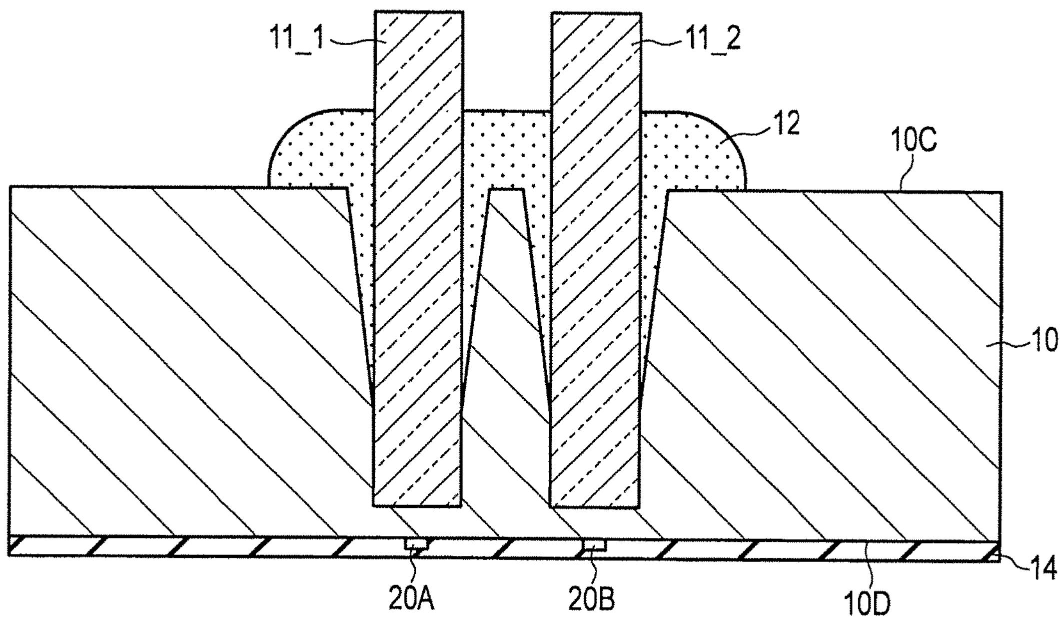

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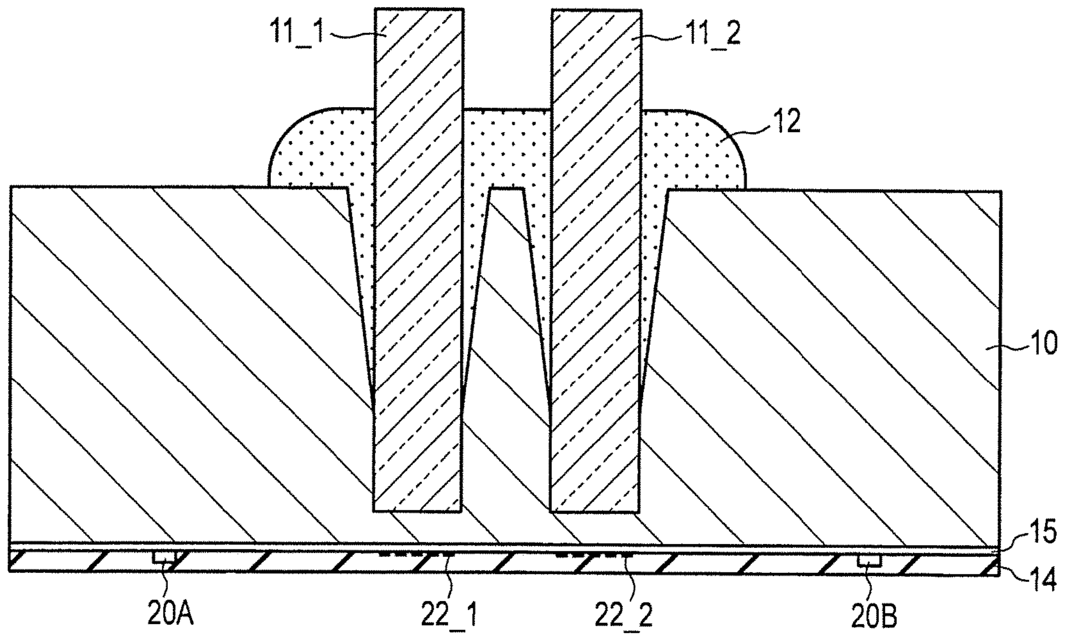

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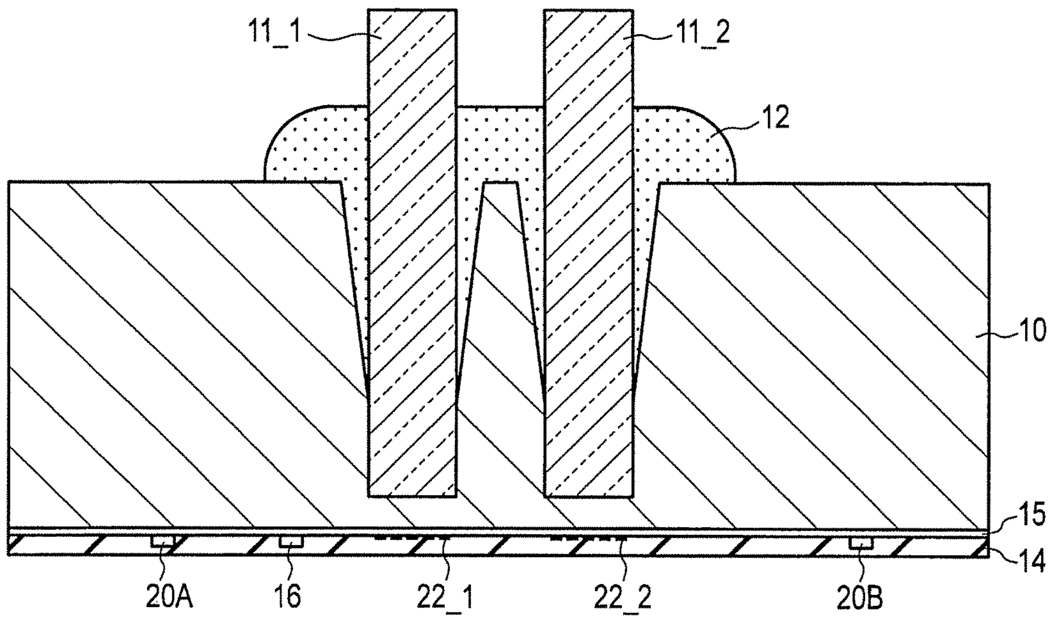

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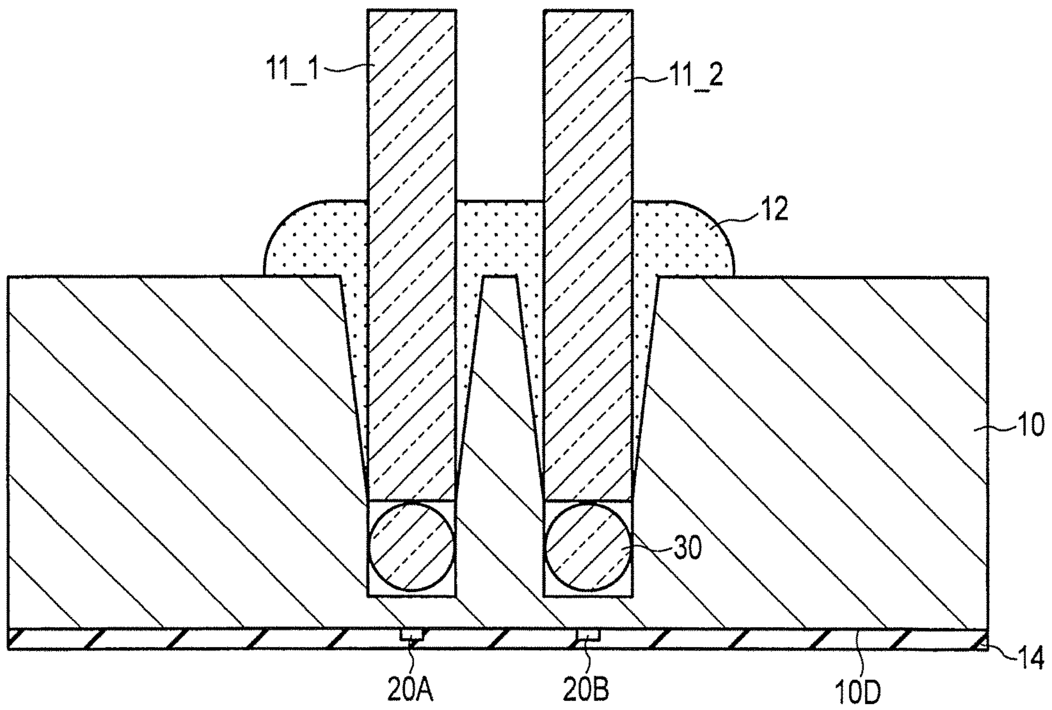

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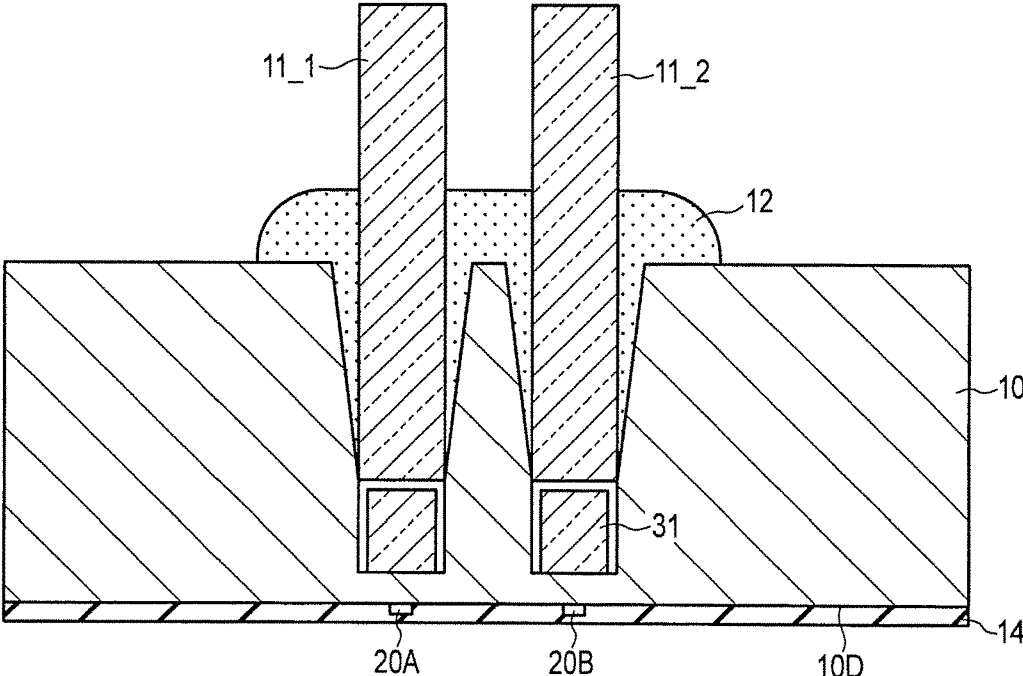

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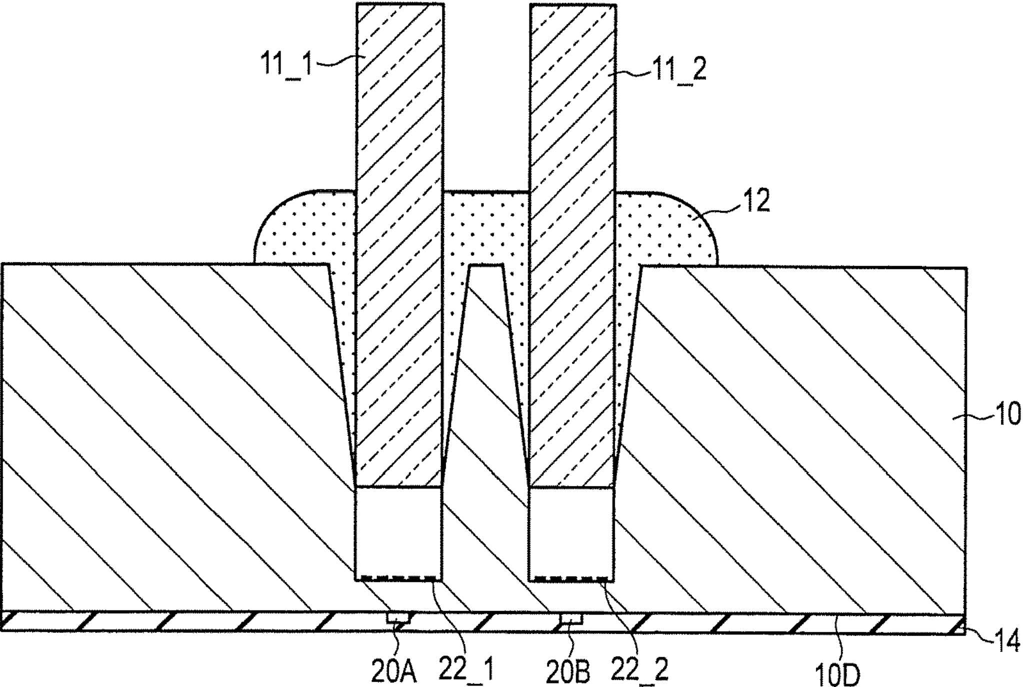

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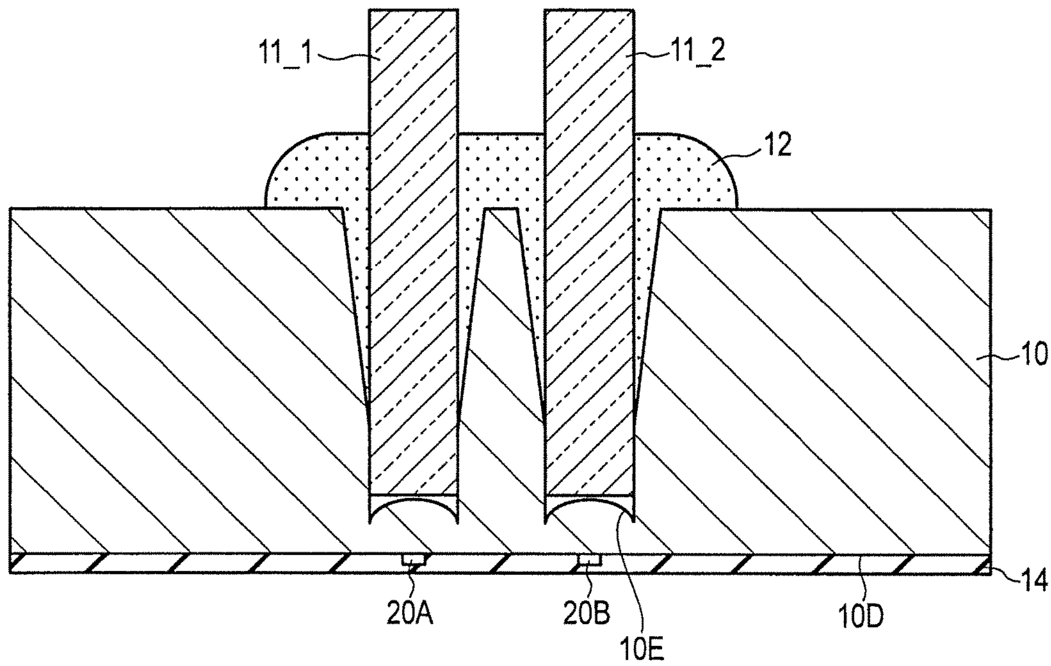

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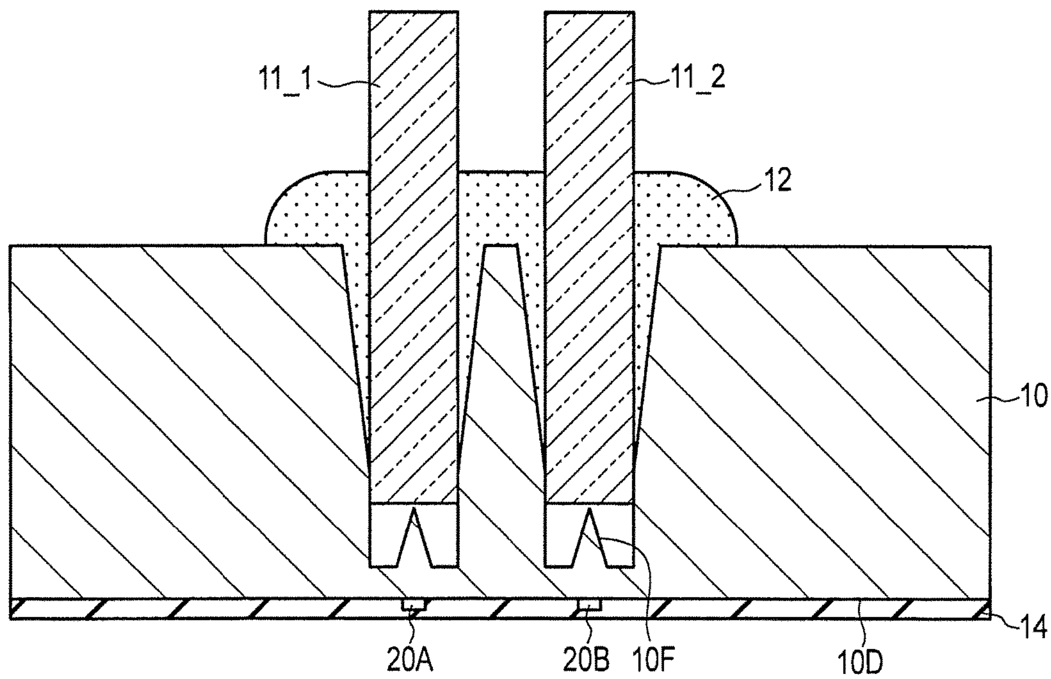

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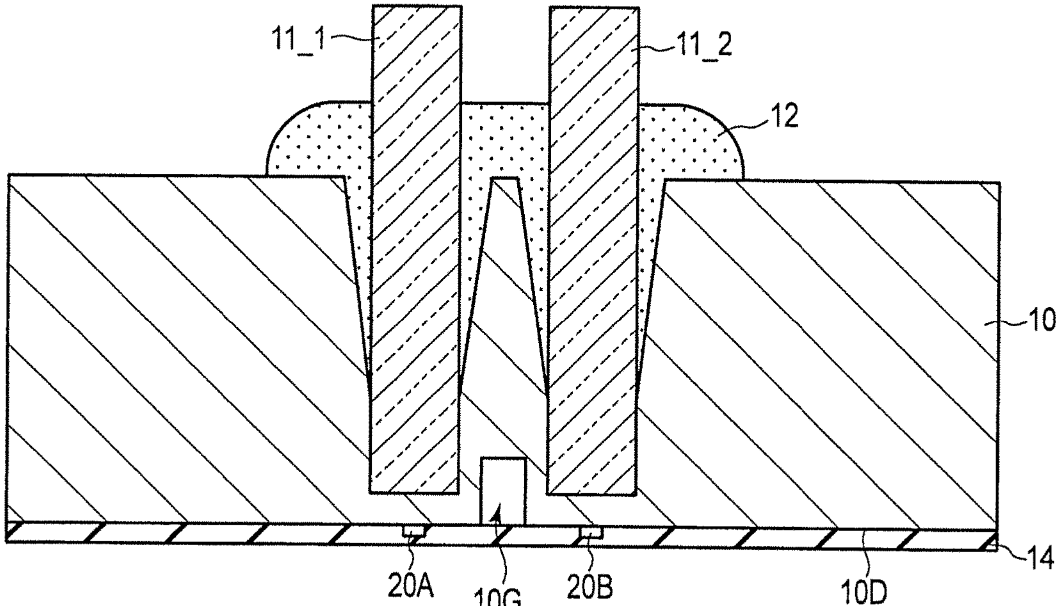

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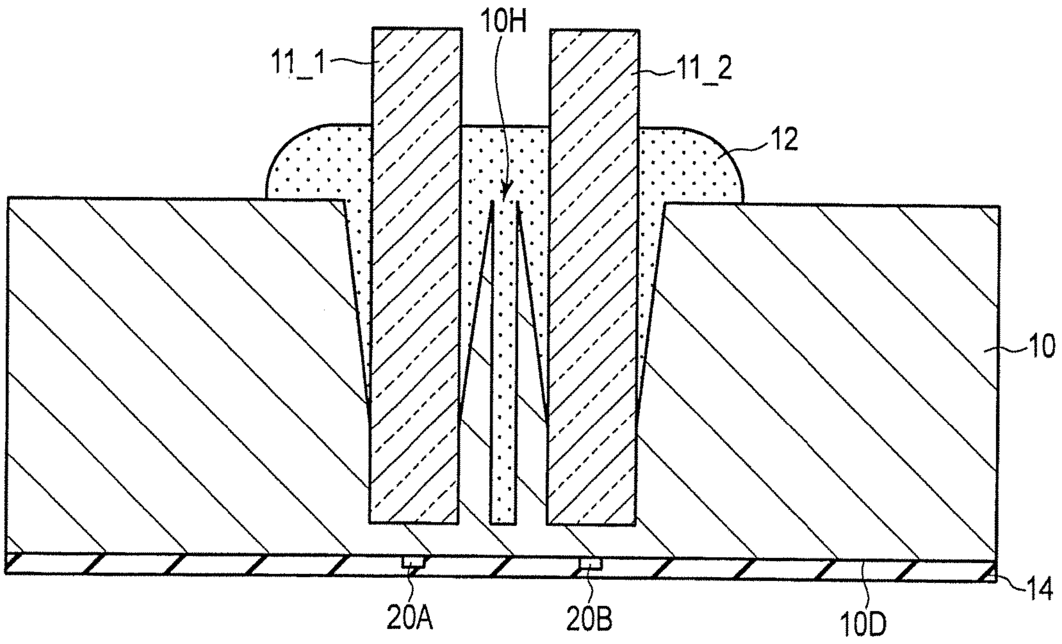

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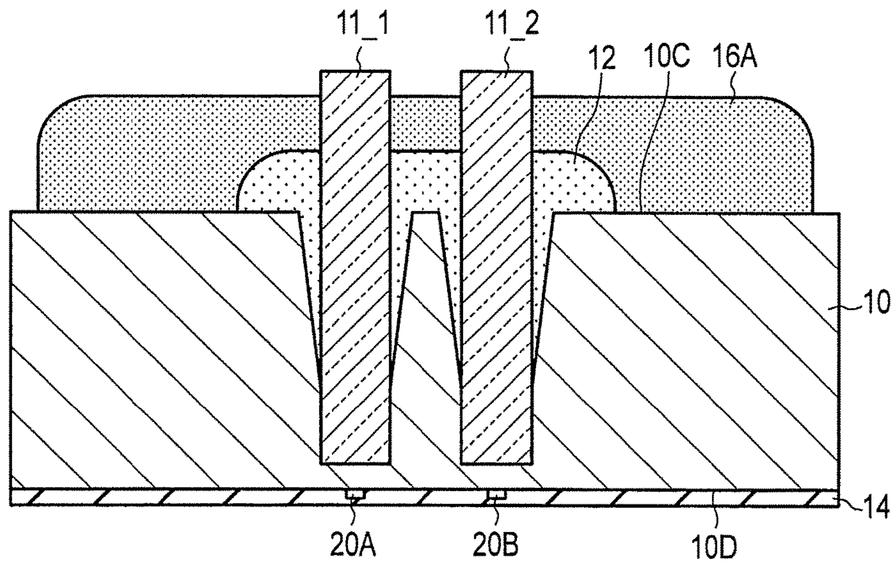

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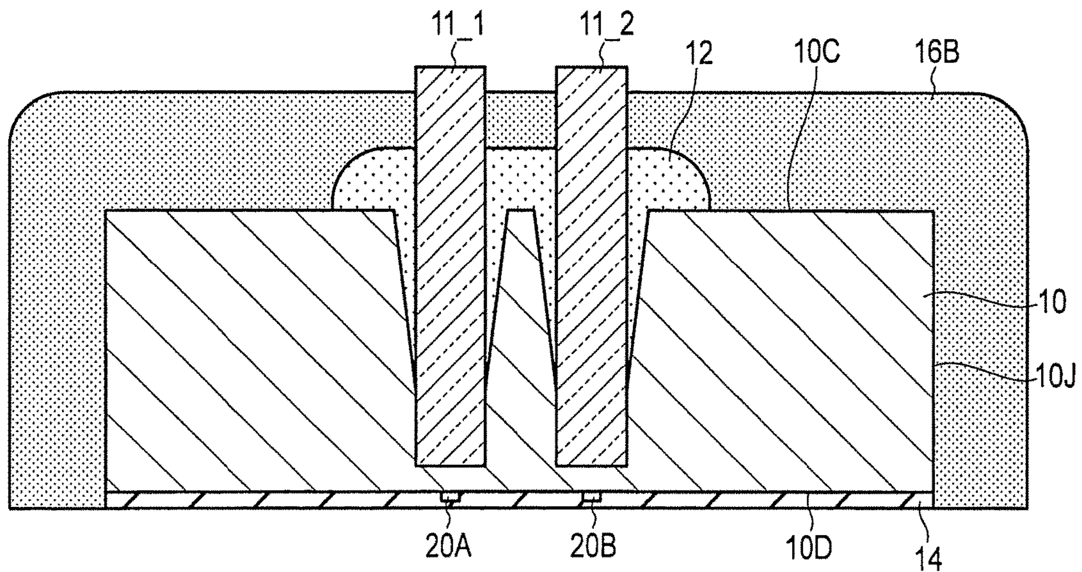

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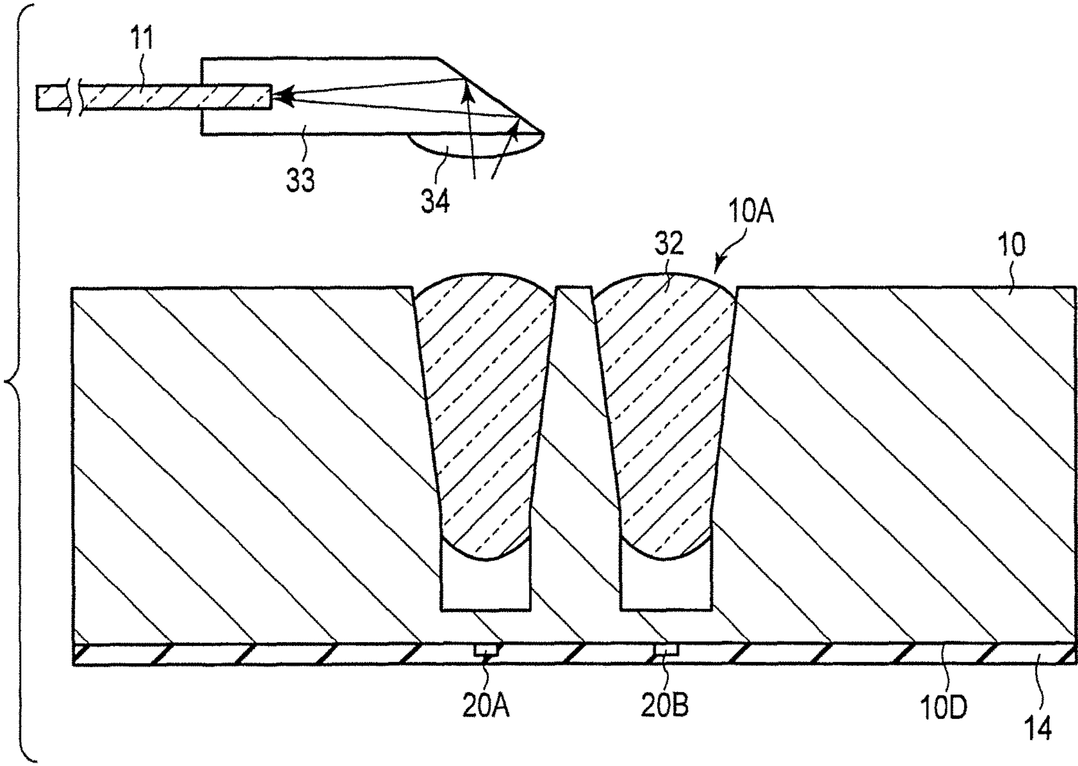
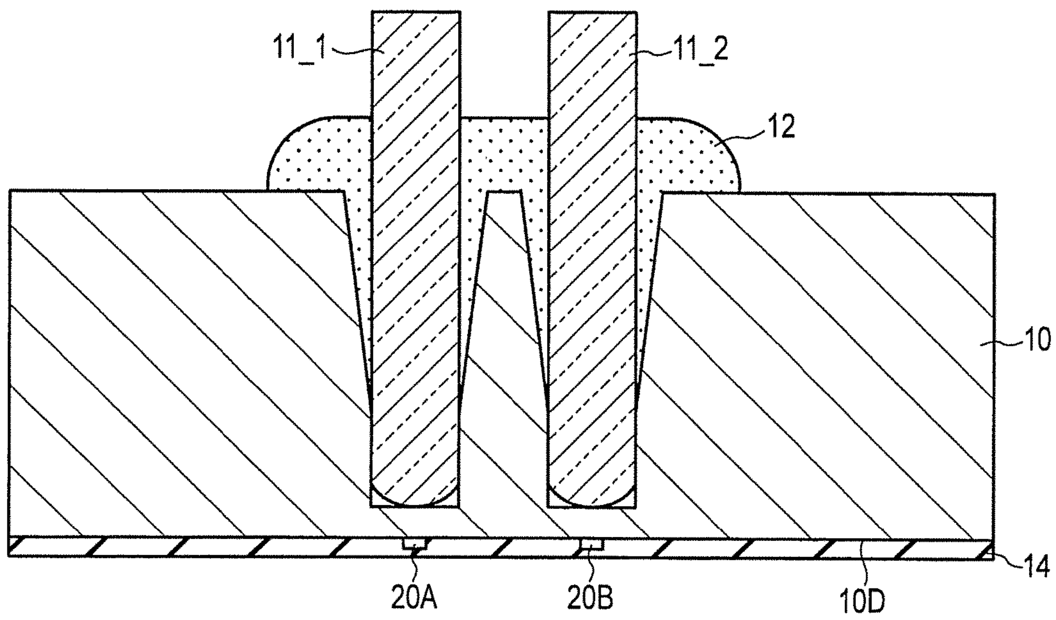


FIG. 13



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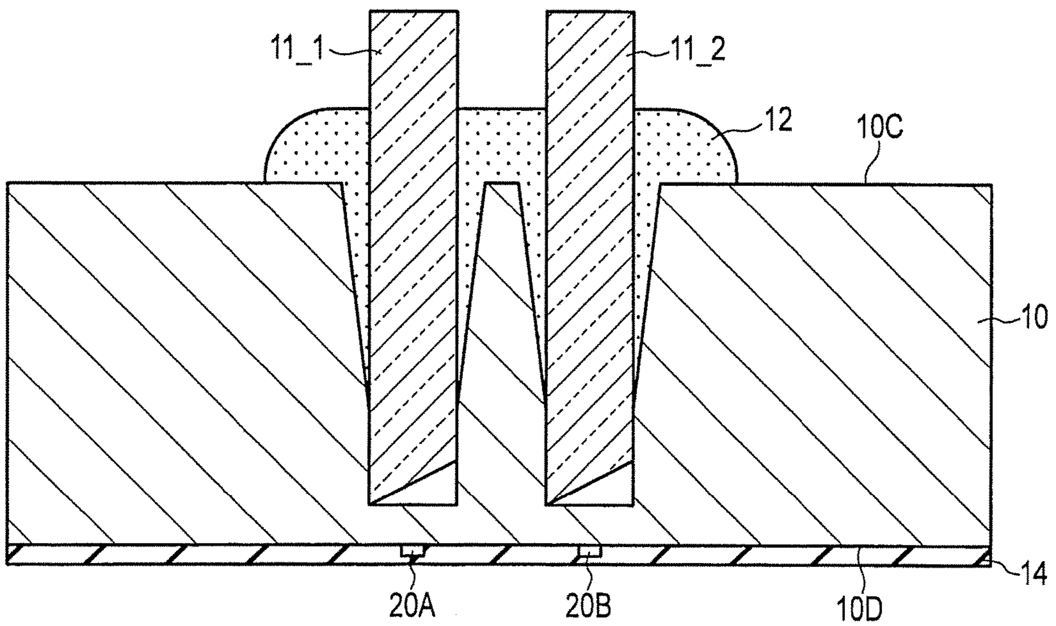

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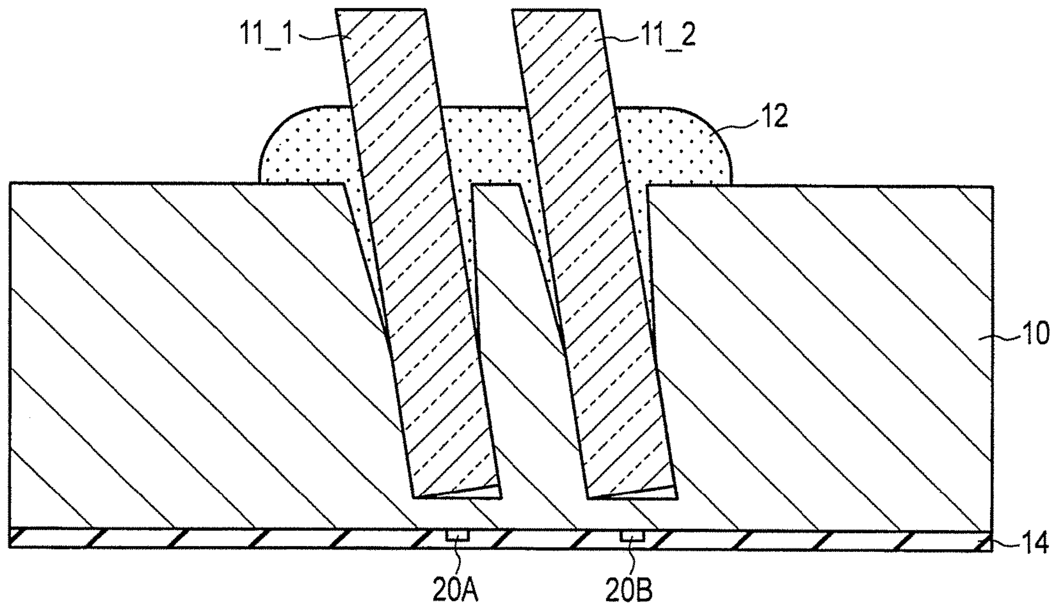

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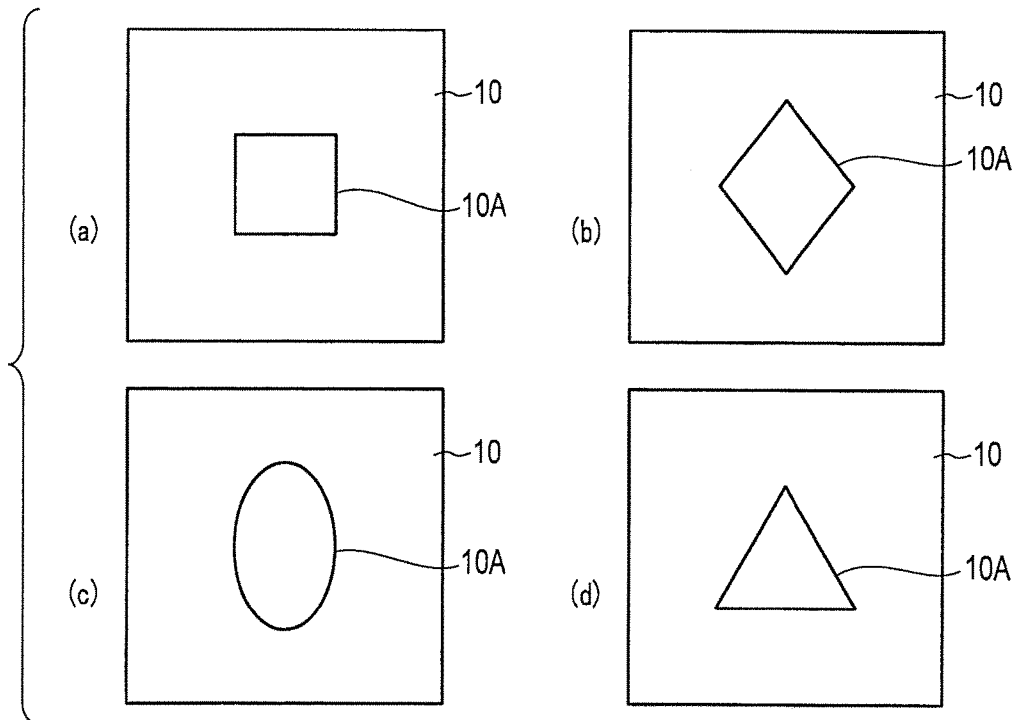

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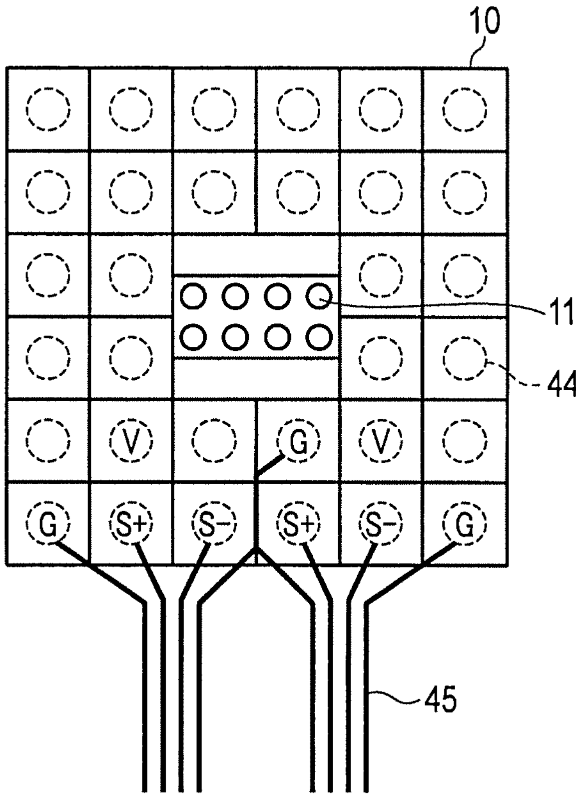


FIG. 18A

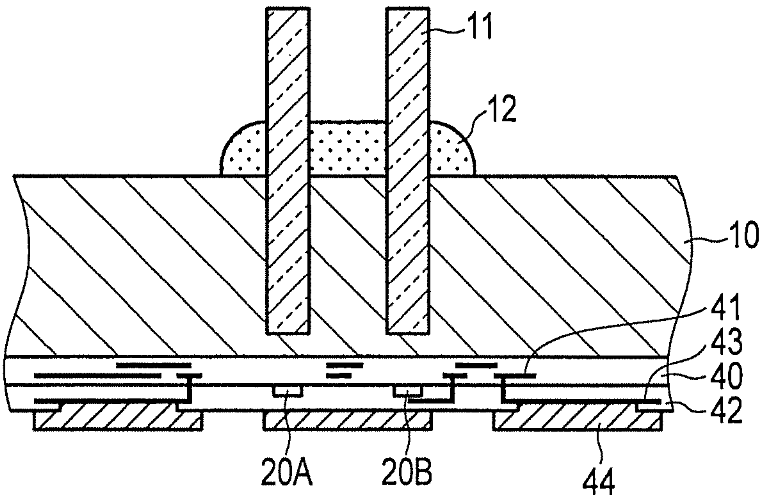


FIG. 18B

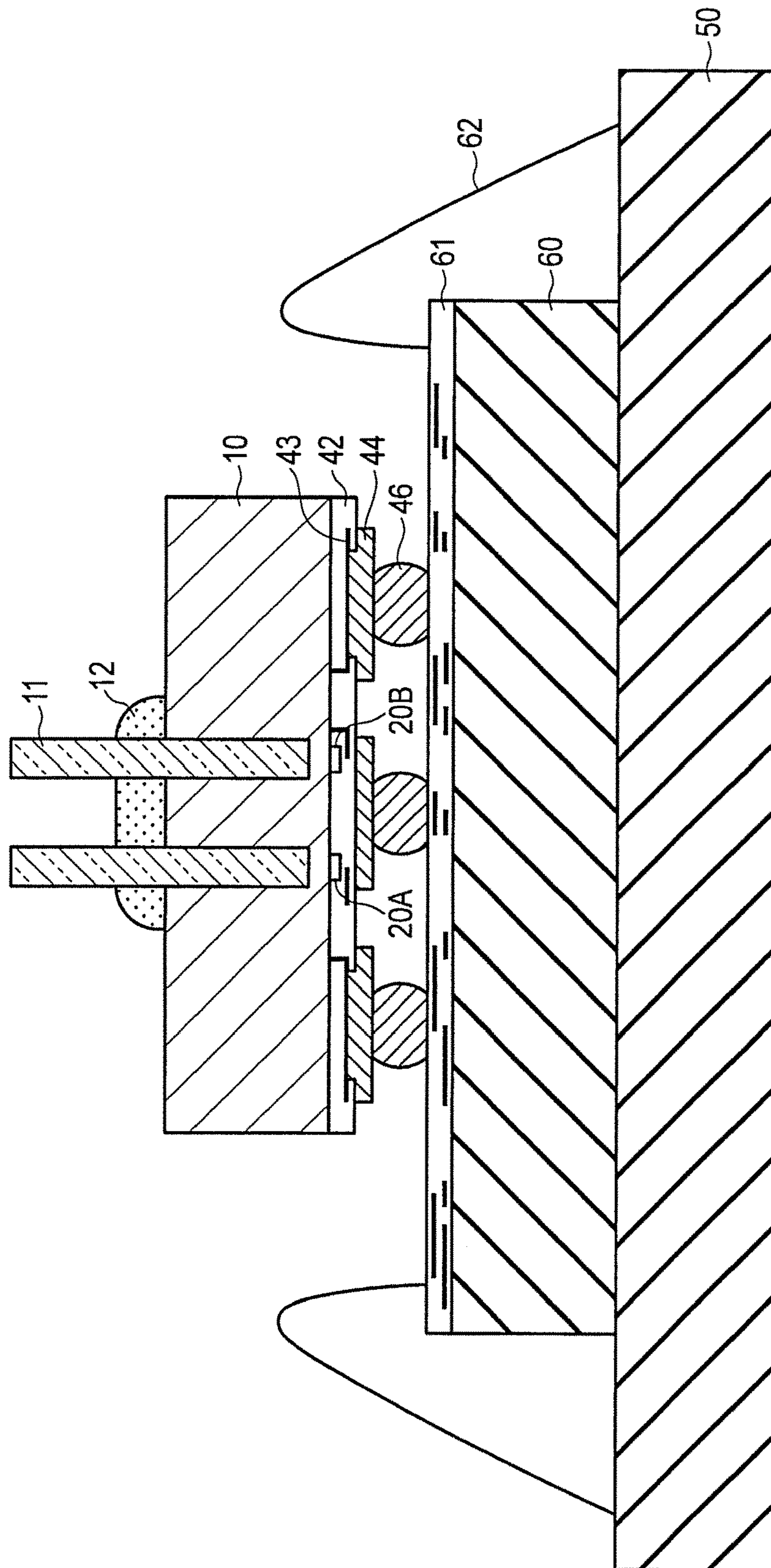
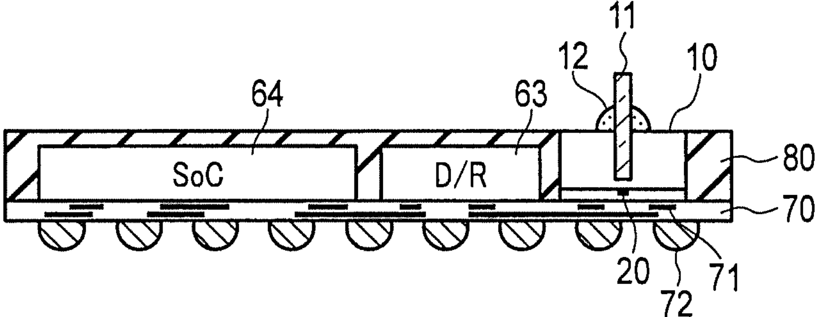
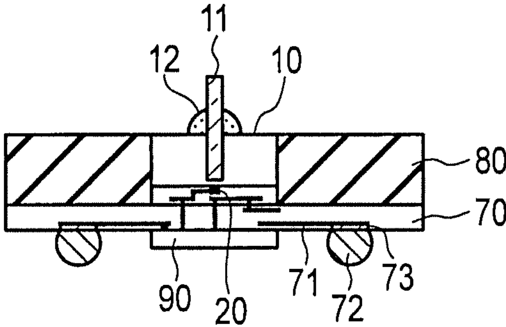


FIG. 19



F I G. 20



F I G. 21

OPTICAL DEVICE AND OPTICAL COUPLING MODULE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2015-234100, filed Nov. 30, 2015, the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to an optical device having a light-emitting or light-receiving function, and an optical coupling module having the optical device and optical fibers which are optically coupled to the optical device.

BACKGROUND

In optical communications using optical fibers, a light-emitting/light-receiving module (referred to as an optical coupling module hereinafter) is employed in which the optical fibers are optically coupled to optical elements (light-emitting elements or light-receiving elements).

BRIEF DESCRIPTION OF THE DRAWING

FIGS. **1**A and **1**B are perspective views showing configurations of an optical device and an optical coupling module according to a first embodiment.

FIGS. **2**A and **2**B are cross-sectional views showing configurations (1) of an optical device and an optical coupling module according to the first embodiment.

FIG. **3** is a cross-sectional view showing another example of the configuration (1) of the optical coupling module according to the first embodiment.

FIG. **4** is a cross-sectional view showing a configuration (2) of an optical coupling module according to the first embodiment.

FIG. **5** is a cross-sectional view showing a configuration (3) of an optical coupling module according to the first embodiment.

FIG. **6** is a cross-sectional view showing a configuration (4) of an optical coupling module according to the first embodiment.

FIG. **7** is a cross-sectional view showing a configuration (5) of an optical coupling module according to the first embodiment.

FIG. **8** is a cross-sectional view showing a configuration (6) of an optical coupling module according to the first embodiment.

FIG. **9** is a cross-sectional view showing a configuration (7) of an optical coupling module according to the first embodiment.

FIG. **10** is a cross-sectional view showing a configuration (8) of an optical coupling module according to the first embodiment.

FIGS. **11**A and **11**B are cross-sectional views showing configurations (9) of optical coupling modules according to the first embodiment.

FIGS. **12**A and **12**B are cross-sectional views showing configurations (10) of optical coupling modules according to the first embodiment.

FIG. **13** is a cross-sectional view showing a configuration (11) of an optical coupling module according to the first embodiment.

FIGS. **14**, **15** and **16** are cross-sectional views of blind vias in optical coupling modules according to the first embodiment.

FIG. **17** is plan views showing shapes of the blind vias in the optical coupling module according to the first embodiment.

FIGS. **18**A and **18**B are illustrations of an optical coupling module device (**1**) according to a second embodiment.

FIG. **19** is an illustration of an optical coupling module device (**2**) according to the second embodiment.

FIG. **20** is an illustration of an optical coupling module device (**3**) according to the second embodiment.

FIG. **21** is an illustration of an optical coupling module device (**4**) according to the second embodiment.

DETAILED DESCRIPTION

Embodiments will be described below with reference to the accompanying drawings. In the following descriptions, components having like functions and like configurations are given like reference numerals.

In general, according to one embodiment, an optical device includes an optical element and a via. The optical element is provided directly on a second main surface opposed to a first main surface of a semiconductor substrate. The via is aligned with the optical element and formed to extend halfway in a thickness direction from the first main surface of the semiconductor substrate.

[1] First Embodiment

Configurations of an optical device and an optical coupling module according to a first embodiment will be described.

[1-1] Configurations of Optical Device and Optical Coupling Module

FIG. **1**A is a perspective view showing a configuration of an optical device according to the first embodiment. FIG. **1**B is a perspective view showing an optical coupling module in which optical fibers are inserted into the optical device.

As shown in FIG. **1**A, the optical device includes a semiconductor substrate, e.g. a silicon substrate **10**. One or more optical elements (light-emitting elements, light-receiving elements, diffraction gratings or the like), which are not shown, are formed on one surface of the silicon substrate **10**, and blind vias (or fiber sockets) **10**A are formed on the other surface of the silicon substrate **10** in alignment with the portions (which correspond to light-emitting or light-receiving portions if the optical elements are light-emitting or light-receiving elements) through which light of the optical elements passes. Through vias **10**B are formed close to their respective corners of the silicon substrate **10**. For example, the through vias **10**B can be used to fix the optical device. The optical elements are not limited to elements for converting electrical signals into optical signals or elements for converting optical signals into electrical signals, such as the light-emitting elements and light-receiving elements, but include an element that changes a light traveling direction or an element that reflects light.

In the first embodiment, an XYZ orthogonal coordinate system is introduced for convenience of descriptions. In this coordinate system, two directions which are parallel to the main surface of the silicon substrate **10** and orthogonal to

each other are defined as X and Y directions, and a direction which is orthogonal to both the X and Y directions is defined as a Z direction.

The outside dimensions of the optical device are, for example, 3.5 mm in the direction (X direction) in which the blind vias **10**A are arranged, 1 mm in the direction (Y direction) which is orthogonal to the X direction of the blind vias **10**A, and 0.73 mm in the depth direction (Z direction) of the blind vias **10**A.

As shown in FIG. **1**B, the optical coupling module is so configured that optical fibers **11** are inserted into the blind vias **10**A of the foregoing optical device and the optical fibers **11** are fixed to the silicon substrate **10** by a transparent resin **12** or the like. Covering sections **13** are provided to cover the optical fibers **11**. The blind vias **10**A, optical fibers **11** and optical elements will be described in detail later.

In the first embodiment, silicon is used as the semiconductor substrate; however, an element other than silicon can be used as the semiconductor substrate.

[1-1-1] Configuration Examples (1) of Optical Device and Optical Coupling Module

An optical coupling structure including the blind vias **10**A, optical fibers **11** and optical elements in the optical device and the optical coupling module will be described in detail.

FIG. **2**A is a cross-sectional view of blind vias of the optical device shown in FIG. **1**A. The number of blind vias **10**A shown in the following cross-sectional views including FIG. **2**A is two; however, it may be one or three or more.

As shown in FIG. **2**A, blind vias **10**A are formed in the silicon substrate **10**. The blind vias **10**A are formed to extend halfway in the thickness direction (Z direction) of the silicon substrate **10** and does not go through the silicon substrate **10**. More specifically, if the silicon substrate **10** has a first main surface **10**C and a second main surface **10**D opposed to the first main surface, the blind vias **10**A extend halfway in the thickness direction from the first main surface **10**C and does not reach the second main surface **10**D. The distance between the bottom of each of the blind vias **10**A and the second main surface **10**D is, for example, 20 μm through 40 μm.

On the second main surface **10**D of the silicon substrate **10**, optical elements (light-emitting elements or light-receiving elements) **20** are formed. The blind vias **10**A are formed in alignment with light-emitting sections or light-receiving sections of the optical elements **20**. More specifically, the blind vias **10**A are formed such that the light-emitting sections or light-receiving sections of the optical elements **20** are located on the optical axes of the optical fibers **11** described later to allow the optical elements **20** and the optical fibers **11** to be optically coupled to each other.

Structures and materials to operate the optical elements **20** at a wavelength that makes the semiconductor substrate transparent are used for the optical elements **20**. If the semiconductor substrate is the silicon substrate **10**, the emission wavelength of the light-emitting elements is longer than, e.g. 1.3 μm, and the light-emitting elements are formed by, e.g. GaInAsP and AlInGaAs materials that are lattice-matched with an InP substrate. The light-receiving elements are formed by materials capable of receiving light at the emission wavelength of the light-emitting elements, and, for example, InGaAs that is lattice-matched with an InP substrate is formed as a light absorption layer.

The optical elements **20** can be manufactured by the method disclosed in, e.g. Japanese Patent No. 3723177. It is desirable to form the optical elements **20** with the silicon substrate **10** flatted and it is also desirable to form them before the blind vias **10**A. However, the optical elements **20** can be formed after the blind vias **10**A. Either will do if the light-emitting and light-receiving sections of the optical elements **20** are so aligned that they are optically coupled to the optical fibers **11**.

The optical elements **20** are made of compound semiconductor (e.g. III-V group semiconductor) materials and include a crystal growth layer that is formed by crystallizing and growing the compound semiconductor materials on a compound semiconductor substrate other than the silicon substrate (semiconductor substrate) **10**. The compound semiconductor materials can be stuck on the second main surface of the silicon substrate **10** to form an optical element active section.

The optical elements **20** can be provided directly on the second main surface **10**D of the silicon substrate **10**. The "provided directly" includes a case where the optical elements **20** are not mounted via bumps or the like but provided directly by sticking a compound semiconductor material other than the silicon substrate **10** onto the second surface of the silicon substrate **10** and a case where the optical elements **20** are crystallized and grown on (formed integrally with) the second main surface of the silicon substrate **10**.

Furthermore, some of the functional structures of the optical elements **20** can be provided on the silicon substrate **10** as an aspect in which the optical elements **20** are provided directly on the second main surface **10**D of the silicon substrate **10**. For example, the optical elements **20** are surface-emitting semiconductor lasers. If paired reflecting mirrors that constitute a laser resonator are vertically provided with a light-emitting layer therebetween, one of the reflecting mirrors is buried in the surface or inner area of the silicon substrate **10**, and a compound semiconductor material other than the silicon substrate **10**, which includes the light-emitting layer and the other reflecting mirror, can be stuck on the second main surface of the silicon substrate **10** such that they are formed integrally as one component.

The light-emitting or light-receiving sections of the optical elements **20** are not placed directly on the optical axes of the optical fibers **11**, but optical coupling structures such as diffraction gratings can be arranged as the optical elements on the extensions of the optical axes of the optical fibers **11** on the second main surface **10**D of the silicon substrate **10** to guide light, via an optical waveguide or the like, to the light-emitting sections of the light-emitting elements or the light-receiving sections of the light-receiving elements arranged in different locations on the second main surface **10**D of the silicon substrate **10**. The light-emitting elements or light-receiving elements can also be provided outside and separately from the optical coupling module.

The blind vias **10**A can be formed in such a manner that their inner walls are perpendicular to the first main surface **10**C; however, as shown in FIG. **2**A, the blind vias **10**A can be tapered in such a manner that their diameters become small gradually toward their depth direction from the first main surface **10**C. The blind vias **10**A can also be formed to have a compound shape of both the perpendicular shape and the tapered shape. Furthermore, the optical elements **20** include electrodes if they are light-emitting elements or light-receiving elements, and a resin layer **14** can be formed on the optical elements, and the electrodes of the optical elements **20** can electrically be connected to different portions of the second main surface using metal wiring lines on the resin layer **14**.

FIG. **2**B is a cross-sectional view of the blind vias in the optical coupling module shown in FIG. **1**B. As shown in FIG. **2**B, the optical coupling module is so configured that

the optical fibers **11** are inserted into the blind vias **10**A of the optical device shown in FIG. **2**A. The optical fibers **11** are inserted into the blind vias **10**A and fixed to the silicon substrate **10** by the transparent resin **12** or the like. Accordingly, the optical fibers **11** are optically coupled to the optical elements **20** on the second main surface **10**D.

The optical coupling module with the configuration shown in FIG. **2**B performs the following operations.

Light emitted from each optical element **20** is transmitted through the silicon substrate between the optical element **20** and the bottom of the corresponding blind via **10**A and is incident upon one end of the corresponding optical fiber **11**. The light incident upon the one end of the optical fiber **11** propagates through the optical fiber **11** and is incident upon a light-receiving element (not shown) disposed at the other end of the optical fiber **11**.

Light emitted from each optical fiber **11** is transmitted through the silicon substrate between the bottom of the corresponding blind via **10**A and the corresponding optical element **20** and is incident upon the optical element **20**. The light incident upon the optical element **20** is photoelectrically converted into an electrical signal by the optical element **20**.

FIG. **3** shows an example of the optical coupling module in which a light-emitting element **20**A and a light-receiving element **20**B are paired as the optical elements **20** shown in FIGS. **2**A and **2**B and their light-emitting and light-receiving sections are integrated into one module. As the light-emitting element **20**A, for example, a surface-emitting semiconductor laser can be used. As the light-receiving element **20**B, for example, a pin photodiode and a metal-semiconductor-metal (MSM) photodiode can be used. Hereinafter, two optical fibers will be referred to as optical fibers **11_1** and **11_2** and an optical fiber **11** when mentioned in this way indicates each of the optical fibers **11_1** and **11_2**.

As shown in FIG. **3**, the light-emitting element **20**A and light-receiving element **20**B are provided on the second main surface **10**D of the silicon substrate **10**. The light-emitting element **20**A is placed on the optical axis of the optical fiber **11_1** and the light-emitting element **20**B is placed on the optical axis of the optical fiber **11_2**. Furthermore, a resin layer **14** is formed on the light-emitting element **20**A, the light-receiving element **20**B and the second main surface.

[1-1-2] Configuration Example (2) of Optical Coupling Module

Hereinafter, a configuration that differs mainly from the configuration of the optical coupling module shown in FIG. **3** will be described. This configuration example (2) is an example where the light-emitting element **20**A or light-receiving element **20**B is not placed directly on the optical axis of the corresponding optical fiber **11**.

FIG. **4** is a cross-sectional view of the blind vias in the configuration example (2) of the optical coupling module shown in FIG. **1**B. As shown in FIG. **4**, an optical waveguide **15** is disposed on the second main surface **10**D of the silicon substrate **10**, and diffraction gratings (or reflecting mirrors) **22_1** and **22_2** are disposed on the optical waveguide **15** as optical elements on the optical axes of the optical fibers **11**. Furthermore, the light-emitting element **20**A and light-receiving element **20**B are disposed on the optical waveguide **15** but outside the optical axes of the optical fibers **11_1** and **11_2**.

The diffraction grating **22_1** diffracts light emitted from the light-emitting element **20**A and bends the light to the optical fiber **11_1**. The diffraction grating **22_2** diffracts light emitted from the optical fiber **11_2** and bends the light to the light-receiving element. The optical waveguide **15** transmits the light emitted from the light-emitting element **20**A to the diffraction grating **22_1**. The optical waveguide **15** also transmits the light diffracted by the diffraction grating **22_2** to the light-receiving element **20**B. A resin layer **14** is formed on the light-emitting element **20**A, the light-receiving element **20**B and the optical waveguide **15**.

The optical coupling module with the configuration shown in FIG. **4** performs the following operations.

Light emitted from the light-emitting element **20**A is incident upon the diffraction grating **22_1** through the optical waveguide **15**. The light incident upon the diffraction grating **22_1** is diffracted by the diffraction grating **22_1**, transmitted through the silicon substrate between the second main surface **10**D and the bottom of the blind via **10**A and is incident upon one end of the optical fiber **11_1**. The light incident upon the one end of the optical fiber **11_1** propagates through the optical fiber **11_1** and is incident upon a light-receiving element (not shown) provided at the other end of the optical fiber **11_1**.

Light emitted from the optical fiber **11_2** is transmitted through the silicon substrate between the bottom of the blind via **10**A and the optical waveguide **15** and is incident upon the diffraction grating **22_2**. The light incident upon the diffraction grating **22_2** is diffracted by the diffraction grating **22_2** and is incident upon the light-receiving element **20**B through the optical waveguide **15**. The light incident upon the light-receiving element **20**B is photoelectrically converted into an electrical signal by the light-receiving element **20**B.

[1-1-3] Configuration Example (3) of Optical Coupling Module

The configuration example (3) is an example where a light modulator is placed between the light-emitting element **20**A and the diffraction grating **22_1** in the configuration shown in FIG. **3**.

FIG. **5** is a cross-sectional view of the blind vias in the configuration example (3) of the optical coupling module shown in FIG. **1**B. As shown in FIG. **5**, a light modulator **16** is placed between the light-emitting element **20**A and the diffraction grating (or reflecting mirror) **22_1**. The light modulator **16** modulates the wavelength of light emitted from the light-emitting element **20**A and emits the wavelength-modulated light to the optical waveguide **15**.

The optical coupling module with the configuration shown in FIG. **5** performs the following operations.

Light emitted from the light-emitting element **20**A is incident upon the light modulator **16** through the optical waveguide **15**. The wavelength of the light incident upon the light modulator **16** is modulated by the light modulator **16**, and the wavelength-modulated light is incident upon the diffraction grating **22-1** through the optical waveguide **15**. The light incident upon the diffraction grating **22_1** is diffracted by the diffraction grating **22_1**, transmitted through the silicon substrate and is incident upon one end of the optical fiber **11_1**.

[1-1-4] Configuration Example (4) of Optical Coupling Module

The configuration example (4) is an example where a ball lens is placed between one end of an optical fiber and the bottom of a blind via in the configuration shown in FIG. **3**.

FIG. **6** is a cross-sectional view of the blind vias in the configuration example (4) of the optical coupling module shown in FIG. **1**B. As shown in FIG. **6**, a ball lens **30** is placed between one end of each of the optical fibers **11_1** and **11_2** and the bottom of the corresponding blind via **10**A. The space between the ball lens **30** and the bottom of the

blind via **10**A can be filled with resin **12** and may contain air. The ball lens **30** is made of silicon, glass or the like.

The optical coupling module with the configuration shown in FIG. **6** performs the following operations.

Light emitted from the light-emitting element **20**A is transmitted through the silicon substrate between the second main surface **10**D and the bottom of the blind via **10**A and is incident upon one end of the optical fiber **11_1** through the ball lens **30**.

Light emitted from the optical fiber **11_2** is transmitted through the ball lens **30**, transmitted through the silicon substrate between the bottom of the blind via **10**A and the second main surface **10**D, and is incident upon the light-receiving element **20**B.

[1-1-5] Configuration Example (5) of Optical Coupling Module

The configuration example (5) is an example where a coaxial lens is placed between one end of an optical fiber and the bottom of a blind via in the configuration shown in FIG. **3**.

FIG. **7** is a cross-sectional view of the blind vias in the configuration example (5) of the optical coupling module shown in FIG. **1**B. As shown in FIG. **7**, a coaxial lens (e.g. a coaxial refractive-index modulation rod lens) **31** is placed between one end of each of the optical fibers **11_1** and **11_2** and the bottom of the corresponding blind via **10**A. The coaxial lens **31** can be made of silicon, glass or the like.

The optical coupling module with the configuration shown in FIG. **7** performs the following operations.

Light emitted from the light-emitting element **20**A is transmitted through the silicon substrate between the second main surface **10**D and the bottom of the blind via **10**A and is incident upon one end of the optical fiber **11_1** through the coaxial lens **31**.

Light emitted from the optical fiber **11_2** is transmitted through the coaxial lens **31**, transmitted through the silicon substrate between the bottom of the blind via **10**A and the second main surface **10**D, and is incident upon the light-receiving element **20**B.

[1-1-6] Configuration Example (6) of Optical Coupling Module

The configuration example (6) is an example where a diffraction optical element (e.g. a diffraction lens and a Fresnel lens) is formed and placed on the bottom of each of the blind vias **10**A in the configuration shown in FIG. **3**.

FIG. **8** is a cross-sectional view of the blind vias in the configuration example (6) of the optical coupling module shown in FIG. **1**B. As shown in FIG. **8**, diffraction gratings **22_1** and **22_2** are arranged on the bottoms of the blind vias **10**A, respectively. Air having a function of a lens is present between one end of each of the optical fibers **11_1** and **11_2** and the bottom of the corresponding blind via **10**A.

The optical coupling module with the configuration shown in FIG. **8** performs the following operations.

Light emitted from the light-emitting element **20**A is transmitted through the silicon substrate between the second main surface **10**D and the bottom of the blind via **10**A, diffracted by the diffraction grating **22_1** and is incident upon one end of the optical fiber **11_1**.

Light emitted from the optical fiber **11_2** is diffracted by the diffraction grating **22_2**, transmitted through the silicon substrate between the bottom of the blind via **10**A and the second main surface **10**D, and is incident upon the light-receiving element **20**B.

[1-1-7] Configuration Example (7) of Optical Coupling Module

The configuration example (7) is an example where the bottom of each of the blind vias **10**A has a concave shape in the configuration shown in FIG. **3**.

FIG. **9** is a cross-sectional view of the blind vias in the configuration example (7) of the optical coupling module shown in FIG. **1**B. As shown in FIG. **9**, each of the blind vias **10**A has a concave bottom **10**E.

The optical coupling module with the configuration shown in FIG. **9** performs the following operations.

Light emitted from the light-emitting element **20**A is transmitted through the silicon substrate between the second main surface **10**D and the bottom of the blind via **10**A and then through the concave bottom **10**E and is incident upon one end of the optical fiber **11_1**.

Light emitted from the optical fiber **11_2** is transmitted through the concave bottom **10**E of the blind via **10**A and then through the silicon substrate between the bottom of the blind via **10**A and the second main surface **10**D, and is incident upon the light-receiving element **20**B.

[1-1-8] Configuration Example (8) of Optical Coupling Module

The configuration example (8) is an example where each of the blind vias **10**A has a pin-shaped bottom in the configuration shown in FIG. **3**.

FIG. **10** is a cross-sectional view of the blind vias in the configuration example (8) of the optical coupling module shown in FIG. **1**B. As shown in FIG. **10**, each of the blind vias **10**A has a pin-shaped bottom, e.g. a conic bottom **10**F.

The optical coupling module with the configuration shown in FIG. **10** performs the following operations.

Light emitted from the light-emitting element **20**A is transmitted through the silicon substrate between the second main surface **10**D and the bottom of the blind via **10**A and then through the conic bottom **10**F, and is incident upon one end of the optical fiber **11_1**.

Light emitted from the optical fiber **11_2** is transmitted through the conic bottom **10**F of the blind via **10**A and then through the silicon substrate between the bottom of the blind via **10**A and the second main surface **10**D, and is incident upon the light-receiving element **20**B.

[1-1-9] Configuration Example (9) of Optical Coupling Module

The configuration example (9) is an example where a groove is formed between adjacent blind vias **10**A in the configuration shown in FIG. **3**.

FIGS. **11**A and **11**B are cross-sectional views of the blind vias in the configuration example (9) of the optical coupling module shown in FIG. **1**B.

As shown in FIG. **11**A, a groove **10**G is formed between the blind vias **10**A, or between the optical fibers **11_1** and **11_2** to extend from the second main surface **10**D of the silicon substrate **10**. In other words, the silicon substrate **10** has a groove **10**G in its second main surface **10**D between the optical fibers **11_1** and **11_2**.

As shown in FIG. **11**B, a groove **10**H is formed between the blind vias **10**A, or between the optical fibers **11_1** and **112** to extend from the first main surface **10**C of the silicon substrate **10**. In other words, the silicon substrate **10** has a groove **10**H in its first main surface **10**C between the optical fibers **11_1** and **11_2**.

These grooves **10**G and **10**H have a function of shielding scattered light generated from one end of each of the optical fibers and the bottom of each of the blind vias.

Like the configuration shown in FIG. **3**, the configurations shown in FIGS. **11**A and **11**B make it possible to transmit and receive light between the optical fiber **11_1** and the light-emitting element **20**A and between the optical fiber

11_1 and the light-receiving element **20**B and also to reduce scattered light generated from one end of each of the optical fibers and the bottom of each of the blind vias.

[1-1-10] Configuration Example (10) of Optical Coupling Module

The configuration example (10) is an example where a light absorbing resin is formed on the transparent resin for fixing the optical fibers in the configuration shown in FIG. **3**.

FIGS. **12**A and **12**B are cross-sectional views of the blind vias in the configuration example (10) of the optical coupling module shown in FIG. **1**B.

As shown in FIG. **12**A, a light absorbing resin **16**A is placed only on the first main surface **10**C and around the blind vias **10**A into which the optical fibers **11_1** and **11_2** are fixed. As shown in FIG. **12**B, a light absorbing resin **16**B is placed on the first main surface **10**C and the side surface **10**J of the silicon substrate **10** around the blind vias **10**A.

These light absorbing resins **16**A and **16**B are opaque to the emission wavelength of the light-emitting element **20**A and their surfaces or side surfaces absorb scattered light generated from the bottoms of the blind vias and the like.

This controls crosstalk (e.g. stray light) to the optical fibers or optical elements in other blind vias and, in other words, scattered light generated from, e.g. the bottoms of the blind vias is cut.

[1-1-11] Configuration Example (11) of Optical Coupling Module

FIG. **13** is a cross-sectional view of the blind vias in a modification to the optical coupling module. In this modification, a resin lens **32** is disposed in each of the blind vias **10**A. A lens molding part (or a holder) **33** in which the optical fiber **11** is fixed is provided above the blind vias **10**A. The lens molding part **33** includes a lens **34**, and the lens **34** is placed on the optical axis of the resin lens **32** (and the light-emitting element **20**A or the light-receiving element **20**B). Furthermore, the light-emitting element **20**A and the light-receiving element **20**B are placed on their respective optical axes of the resin lenses **32** and on the second main surface of the silicon substrate **10**. Light is transmitted and received between one of the light-emitting and light-receiving elements **20**A and **20**B and the optical fiber **11** through the resin lens **32** and the lens **34** of the lens molding part **33**.

Other different configuration examples of the optical coupling module will be described below.

FIGS. **14**, **15** and **16** are cross-sectional views of the blind vias in the optical coupling module shown in FIG. **1**B.

As shown in FIG. **14**, one end of each of the optical fibers **11_1** and **11_2** is formed spherically and, in other words, one end of each of the optical fibers **11_1** and **11_2** inserted into the blind vias **10**A has a sphere shape. It is thus possible to improve optical coupling between the optical fibers and the light-emitting element **20**A or the light-receiving element **20**B. For example, when light is received from the light-emitting element **20**A, reflected light fed back to the light-emitting element can be reduced.

As shown in FIG. **15**, one end of each of the optical fibers **11_1** and **11_2** is formed obliquely and, in other words, one end of each of the optical fibers **11_1** and **11_2** inserted into the blind vias **10**A has an oblique shape with respect to the first main surface **10**C or the second main surface **10**D. Thus, when light is received from the light-emitting element **20**A, reflected light fed back to the light-emitting element can be controlled. For example, an externally induced noise due to the reflected feedback light, which causes a problem when the light-emitting element **20**A is a semiconductor laser, can be controlled.

As shown in FIG. **16**, one end of each of the optical fibers **11_1** and **11_2** has a surface parallel to the first main surface **10**C (or the second main surface **10**D), and the blind vias **10**A are inclined relative to the first main surface **10**C and, in other words, the depth direction of the blind vias **10**A (the insertion direction of the optical fibers **11_1** and **11_2**) is not perpendicular to the first main surface **10**C but oblique. The "oblique" means that an angle between the first main surface **10**C (or the second main surface **10**D) and the depth direction of the blind vias **10**A (or the optical fibers) is smaller than 90 degrees.

Thus, when light is received from the light-emitting element **20**A, reflected light fed back to the light-emitting element can be controlled. For example, an externally induced noise due to the reflected feedback light, which causes a problem when the light-emitting element **20**A is a semiconductor laser, can be controlled. The surface of one end of each optical fiber is not limited to the surface parallel to the first main surface but can be shaped spherically, obliquely or the like.

[1-1-12] Configuration Example of Openings of Blind Vias

FIG. **17** is plan views each showing the shape of an opening of each of the blind via **10**A, viewed from above the blind via **10**A.

The opening of the blind via **10**A need not always have a shape that matches the circular section of the optical fiber **11**, but may have the shape of an area that does not contact the side surface of the optical fiber **11**, such as a square, a rhombus, an ellipse and a triangle as shown in (a) to (d) in FIG. **17**

If, therefore, the opening of the blind via **10**A has an area that does not contact the side surface of the optical fiber **11**, a gap is formed to remove an excess transparent resin **12** and bubbles when the optical fiber **11** is inserted in the blind via **10**A, thus making it easy to insert and assemble the optical fiber.

[1-2] Advantages of First Embodiment

According to the first embodiment, there can be provided an optical device and an optical coupling module which are capable of simplifying optical coupling between the optical fibers and the optical elements to decrease in size and costs.

Advantages of the first embodiment will be described in detail below.

In the first embodiment, the optical elements **20** are disposed on the second main surface **10**D that is opposed to the first main surface **10**C of the silicon substrate **10**, the blind vias **10**A are formed in the first main surface **10**C of the silicon substrate **10**, and the optical fibers **11** are inserted and fixed into their respective blind vias **10**A. The optical fibers **11** (or the blind vias **10**A) and the optical elements **20** are so aligned that the optical axes of the optical fibers **11** and those of the optical elements **20** coincide with each other. Accordingly, any holder for holding the optical fibers **11** need not be provided, but the optical fibers **11** and the optical elements **20** can be aligned with each other with high accuracy, with the result that the optical coupling between the optical fibers **11** and the optical elements **20** can be achieved by a simple and small configuration.

Since the blind vias **10**A into which the optical fibers **11** are inserted do not penetrate the silicon substrate **10**, the optical elements **20** can be formed on the undersides (second main surface) of the blind vias **10**A. Thus, the silicon

substrate **10** has a function of fixing the optical fibers **11** and fixing the optical elements **20** on the optical axes of the optical fibers **11**.

Furthermore, the optical elements **20** that are made of a compound semiconductor are formed on the second main surface of the silicon substrate **10**, or the optical elements **20** are formed directly on the second main surface of the silicon substrate **10**, with the result that a large number of optical devices can be manufactured from a wafer, their quality control can be facilitated, and the manufacturing can be decreased in costs.

[2] Second Embodiment

The second embodiment will be described with respect to (1) an optical coupling module device in which an integrated circuit is formed integrally with the silicon substrate **10** of the optical coupling module according to the first embodiment, (2) an optical coupling module device in which the silicon substrate **10** is bonded to an integrated circuit chip, (3) an optical coupling module device in which the silicon substrate **10** is bonded to a redistribution layer, and (4) another optical coupling module device in which the silicon substrate **10** is bonded to a redistribution layer.

[2-1] Optical Coupling Module Device (**1**)

FIG. **18**A is a plan view showing a configuration of an optical coupling module device (**1**) according to the second embodiment, and FIG. **18**B is a cross-sectional view of the optical coupling module device (**1**). The cross-sectional view of FIG. **18**B shows two optical fibers **11** and does not show any other optical fibers, any optical elements, or the like.

The optical fibers **11** are inserted into the blind vias **10**A formed in the first main surface of the silicon substrate **10** and fixed by the transparent resin **12**. A layer **40** in which an integrated circuit is formed is disposed on the second main surface of the silicon substrate **10**. Wiring **41** is formed in the layer **40**. A light-emitting element **20**A and a light-receiving element **20**B are arranged on the layer **40**. The light-emitting element **20**A and light-receiving element **20**B are arranged on their respective optical axes of the optical fibers **11**.

A resin layer **42** is formed on the light-emitting element **20**A, light-receiving element **20**B and layer **40**, and wiring **43** is formed in the resin layer **42**. Electrodes **44** are formed on the resin layer **42**. The electrodes **44** are electrically connected to the integrated circuit, light-emitting element **20**A and light-receiving element **20**B through wiring **43** and wiring **41**.

Furthermore, wiring **45** is connected to the electrode **44** from a wiring substrate (not shown). In FIG. **18**A, S+ and S− each represent a differential signal voltage, V represents a power supply voltage, and G represents a ground voltage. The other configuration is the same as that of the first embodiment described above.

[2-2] Optical Coupling Module Device (**2**)

FIG. **19** is a cross-sectional view showing a configuration of the optical coupling module device (**2**) according to the second embodiment. A semiconductor substrate, e.g. a silicon substrate **60** is disposed on a wiring substrate **50**. An optical coupling module is jointed to the silicon substrate **60** by, e.g. a solder ball **46**.

The silicon substrate **60** includes a layer **61** in which an integrated circuit is formed. The integrated circuit is electrically connected to wiring (not shown) on the wiring substrate **50** by a bonding wire **62**.

In the optical coupling module, the optical fibers **11** are fixed into the blind vias **10**A of the silicon substrate **10** by the transparent resin **12**. A light-emitting element **20**A and a light-receiving element **20**B are arranged on the second main surface of the silicon substrate **10**. The light-emitting element **20**A and light-receiving element **20**B are arranged on their respective optical axes of the optical fibers **11**.

A resin layer **42** is formed on the light-emitting element **20**A, the light-receiving element **20**B and the second main surface, and wiring **43** is formed in the resin layer **42**. Electrodes **44** are formed on the resin layer **42** and electrically connected to solder balls **46**. Thus, the integrated circuit formed on the silicon substrate **60** is electrically connected to the light-emitting element **20**A and light-receiving element **20**B through the solder balls **46**, electrodes **44**, wiring **43** and the like. The other configuration is the same as that of the first embodiment described above.

[2-3] Optical Coupling Module Device (**3**)

FIG. **20** is an illustration of a configuration of the optical coupling module device (**3**) according to the second embodiment. A redistribution layer **70** is bonded to the second main surface of the optical device (silicon substrate **10**). Wiring **71** is formed in the redistribution layer **70**. The redistribution layer **70** is formed to extend to a region outside the second main surface of the optical device. On the extended redistribution layer **70**, an integrated circuit chip, e.g. a driver/receiver (D/R) **63** and a system-on-a-chip (SoC) **64** are placed. The side surfaces of the optical device are coated with resin **80**. Solder balls **72** are formed on the redistribution layer **70**.

In the optical device, an optical fiber **11** is fixed into the blind via **10**A of the silicon substrate **10** by transparent resin **12**. An optical element **20** is disposed on the second main surface of the silicon substrate **10**. The optical element **20** is placed on the optical axis of the optical fiber **11**.

The optical element **20**, the driver/receiver (D/R) **63** and SoC **64** are electrically connected to the solder balls **72** by the wiring **71** provided in the redistribution layer **70**. The other configuration is the same as that of the first embodiment described above.

[2-4] Optical Coupling Module Device (**4**)

FIG. **21** is an illustration of a configuration of the optical coupling module device (**4**) according to the second embodiment. A redistribution layer **70** is bonded to the second main surface of the optical device (silicon substrate **10**). Electrodes **73** are formed in the redistribution layer **70** and connected to their corresponding wirings **71**. The redistribution layer **70** is formed to extend to a region outside the second main surface of the optical device. An integrated circuit chip **90** is bonded to the surface opposed to the surface on which the optical device of the redistribution layer **70** is disposed. The integrated circuit chip **90** is located opposite to the optical device. The side surfaces of the optical device are coated with resin **80**. Solder balls **72** are formed on the redistribution layer **70**.

In the optical device, an optical fiber **11** is fixed into the blind via **10**A of the silicon substrate **10** by transparent resin **12**. An optical element **20** is disposed on the second main surface of the silicon substrate **10**. The optical element **20** is placed on the optical axis of the optical fiber **11**.

The optical element **20** and the integrated circuit chip **90** are electrically connected to the solder balls **72** by the wirings **71** and electrodes **73** provided in the redistribution layer **70**. The other configuration is the same as that of the first embodiment described above.

[2-5] Advantages of the Second Embodiment

According to the second embodiment, an integrated circuit is formed integrally with the silicon substrate **10** of the optical coupling module, the silicon substrate **10** is bonded to an integrated circuit chip, and the silicon substrate **10** is bonded to a redistribution layer. It is thus possible to provide an optical coupling module device that is capable of decreasing in size, decreasing in costs and improving in performance. The other advantages are the same as those of the first embodiment.

[3] Modifications and the Like

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. An optical device comprising:

an optical element provided directly on a second main surface opposed to a first main surface of a semiconductor substrate;

a via aligned with the optical element and formed to extend part way in a thickness direction from the first main surface of the semiconductor substrate; and

a first wiring layer provided on the second main surface of the semiconductor substrate,

wherein the optical element is made of a compound semiconductor, and the compound semiconductor is formed integrally with the second main surface of the semiconductor substrate,

wherein the via has a region where inner walls on both sides of the via extend in a first direction parallel to the thickness direction from a bottom side of the via,

and in a cross section of the via along a plane parallel to the first main surface, the via is other than circular.

2. The optical device according to claim **1**, wherein the first wiring layer includes a wiring configured to transmit at least one of an electrical signal or an optical signal.

3. The optical device according to claim **1**, further comprising:

a resin layer provided at least one of on the second main surface or on a side surface of the semiconductor substrate, and

a second wiring layer provided on the resin layer.

4. The optical device according to claim **1**, wherein in a cross section of the via parallel to a direction orthogonal to the first main surface, directions of inner walls on both sides of the via extend in the first direction from the bottom side of the via and extend in directions to widen the interval between the inner walls on both sides in a middle of reaching the first main surface.

5. The optical device according to claim **1**, wherein the semiconductor substrate includes a silicon substrate.

6. An optical coupling module comprising:

a via formed to extend part way in a thickness direction from a first main surface of a semiconductor substrate;

an optical fiber fixed into the via;

an optical element placed on a second main surface opposed to the first main surface of the semiconductor substrate; and

a first wiring layer provided on the second main surface of the semiconductor substrate,

wherein the optical element is made of a compound semiconductor, and the compound semiconductor is formed integrally with the second main surface of the semiconductor substrate,

wherein the via has a region where inner walls on both sides of the via extend in a first direction parallel to the thickness direction from a bottom side of the via,

and in a cross section of the via along a plane parallel to the first main surface, the cross section of the via is different from a cross section of the optical fiber.

7. The optical coupling module according to claim **6**, wherein the optical element includes the compound semiconductor provided directly on the second main surface of the semiconductor substrate.

8. The optical coupling module according to claim **6**, wherein the optical element includes a crystal growth layer provided on the second main surface of the semiconductor substrate.

9. The optical coupling module according to claim **6**, wherein the optical element is placed on an optical axis of the optical fiber.

10. The optical coupling module according to claim **6**, further comprising:

a diffraction grating serving as the optical element and placed on an optical axis of the optical fiber; and

an optical waveguide which guides light diffracted by the diffraction grating to another optical element.

11. The optical coupling module according to claim **6**, further comprising a ball lens disposed between an end of the optical fiber and a bottom of the via.

12. The optical coupling module according to claim **6**, wherein the via has a convex bottom.

13. The optical coupling module according to claim **6**, wherein the via has a conical bottom.

14. The optical coupling module according to claim **6**, further comprising a plurality of vias including said via; and

a groove formed between the vias to shield light from the optical fiber.

15. The optical coupling module according to claim **6**, further comprising resin which covers at least part of the first main surface excluding the optical fiber and absorbs light scattered from one of the optical fiber and the optical element.

16. The optical coupling module according to claim **6**, wherein the via is partly tapered in such a manner that a diameter of the via becomes small gradually toward a depth direction from the first main surface of the semiconductor substrate.

17. The optical coupling module according to claim **6**, wherein the via has an opening including an area that does not contact a side surface of the optical fiber.

18. The optical coupling module according to claim **6**, further comprising:

a lens provided in the via.

19. The optical coupling module according to claim 6, wherein the first wiring layer includes a wiring configured to transmit at least one of an electrical signal or an optical signal.

20. The optical coupling module according to claim 6, further comprising:

a resin layer provided at least one of on the second main surface or on a side surface of the semiconductor substrate, and

a second wiring layer provided on the resin layer.

21. The optical coupling module according to claim 6, wherein a width of the compound semiconductor is narrower than a width of the optical fiber in a cross section crossing the via.

22. The optical coupling module according to claim 6, further comprising:

a second wiring layer provided to extend to a region outside the second main surface of the semiconductor substrate, the second wiring layer having a wiring.

23. The optical coupling module according to claim 22, further comprising an integrated circuit provided at a side of the semiconductor substrate.

24. The optical coupling module according to claim 22, further comprising an integrated circuit provided on a surface of the second wiring layer, which is opposite to a surface on which the semiconductor substrate is provided.

25. The optical coupling module according to claim 6, wherein in a cross section of the via parallel to a direction orthogonal to the first main surface, directions of inner walls on both sides of the via extend in the first direction from the bottom side of the via and extend in directions to widen the interval between the inner walls on both sides in a middle of reaching the first main surface.

26. The optical coupling module according to claim 6, wherein the semiconductor substrate includes a silicon substrate.

27. An optical coupling module comprising:

a via formed to extend part way in a thickness direction from a first main surface of a semiconductor substrate;

an optical fiber fixed into the via;

an optical element placed on a second main surface opposed to the first main surface of the semiconductor substrate; and

a first wiring layer provided on the second main surface of the semiconductor substrate,

wherein the optical element is made of a compound semiconductor, and a width of the compound semiconductor is narrower than a width of the optical fiber in a cross section crossing the via,

wherein the via has a region where inner walls on both sides of the via extend in a first direction parallel to the thickness direction from a bottom side of the via,

and in a cross section of the via along a plane parallel to the first main surface, the cross section of the via is different from a cross section of the optical fiber.

28. The optical coupling module according to claim 27, wherein the compound semiconductor includes a crystal growth layer on a compound semiconductor substrate other than the semiconductor substrate, and the compound semiconductor is stuck on the semiconductor substrate to form an optical element active section.

29. The optical coupling module according to claim 27, wherein in a cross section of the via parallel to a direction orthogonal to the first main surface, directions of inner walls on both sides of the via extend in the first direction from the bottom side of the via and extend in directions to widen the interval between the inner walls on both sides in a middle of reaching the first main surface.

30. The optical coupling module according to claim 27, wherein the semiconductor substrate includes a silicon substrate.

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