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(54) **OPTICAL MODULE AND METHOD FOR MANUFACTURING OPTICAL MODULE**

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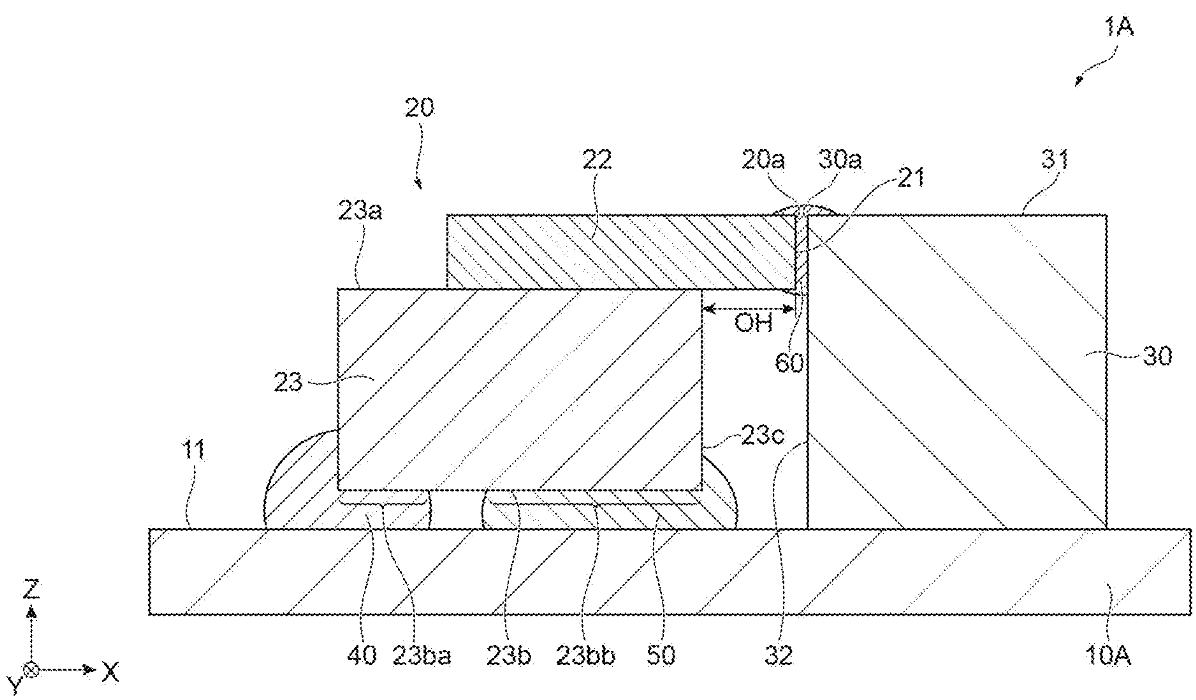
(57) **ABSTRACT**

An optical module includes a base material, an optical semiconductor element, an optical circuit element, a first adhesive, and a second adhesive. The base material has a first surface. The optical semiconductor element has a first optical port and is provided on the first surface. The optical circuit element has a second optical port, which faces the first optical port and is optically coupled to the first optical port, in a side surface thereof. The optical circuit element is disposed alongside the optical semiconductor element on the first surface. The first adhesive mainly includes a UV curable material. The first adhesive fixes the optical semiconductor element to the first surface and has a first thermal conductivity. The second adhesive mainly includes a thermosetting material and has a second thermal conductivity higher than the first thermal conductivity. The second adhesive fixes the optical semiconductor element to the first surface.



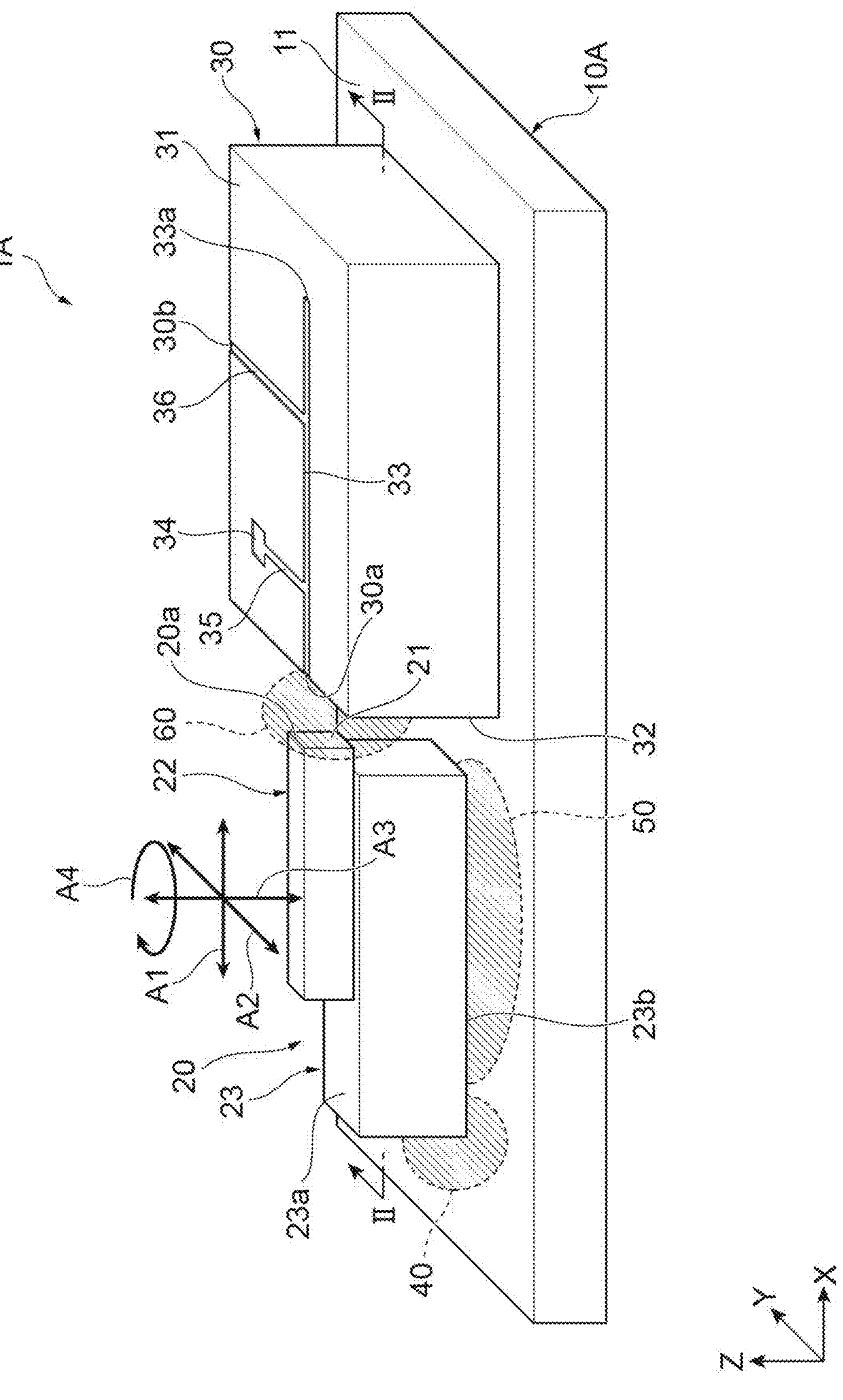

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Fig.1

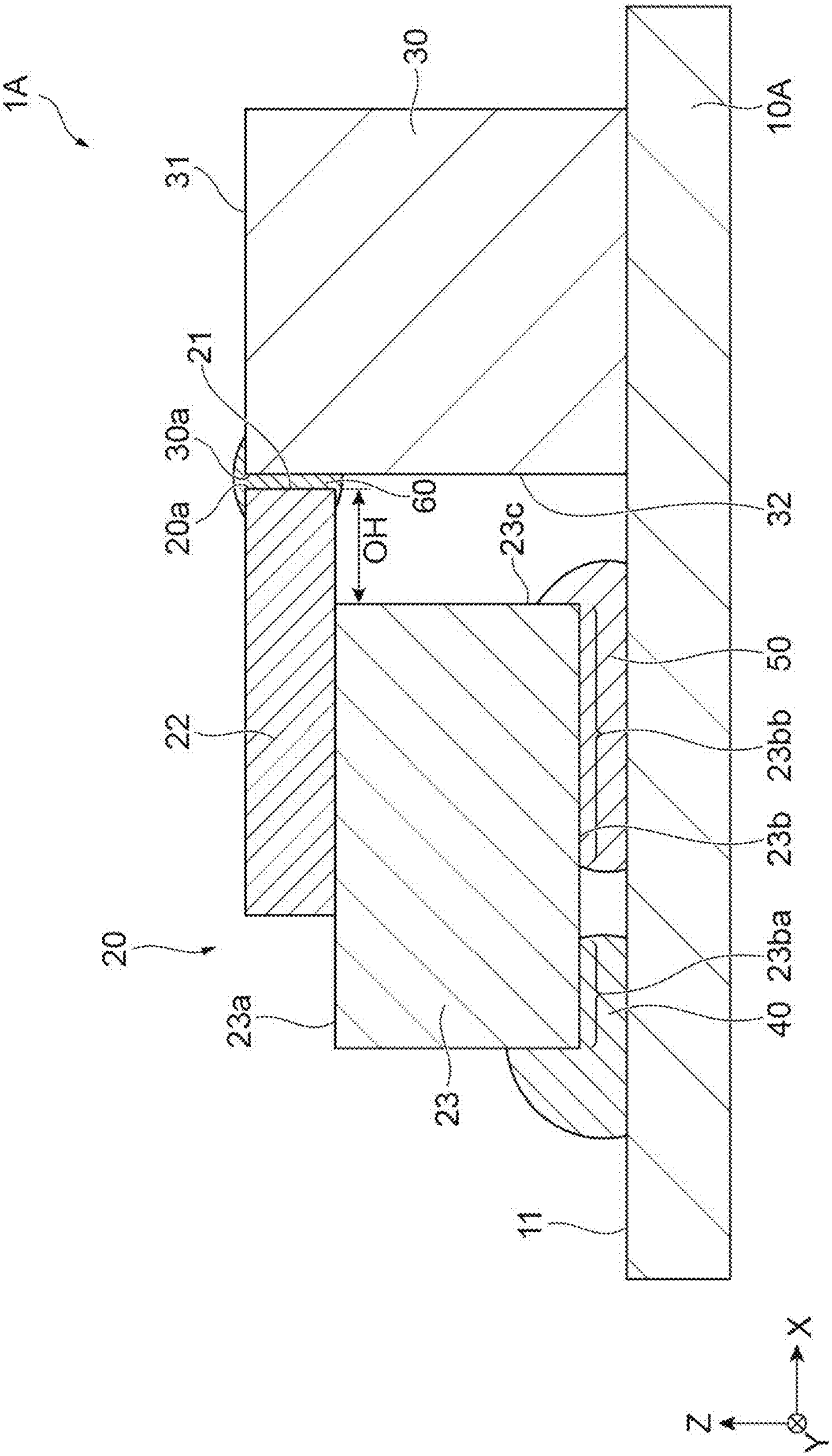
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Fig.2

Fig.3

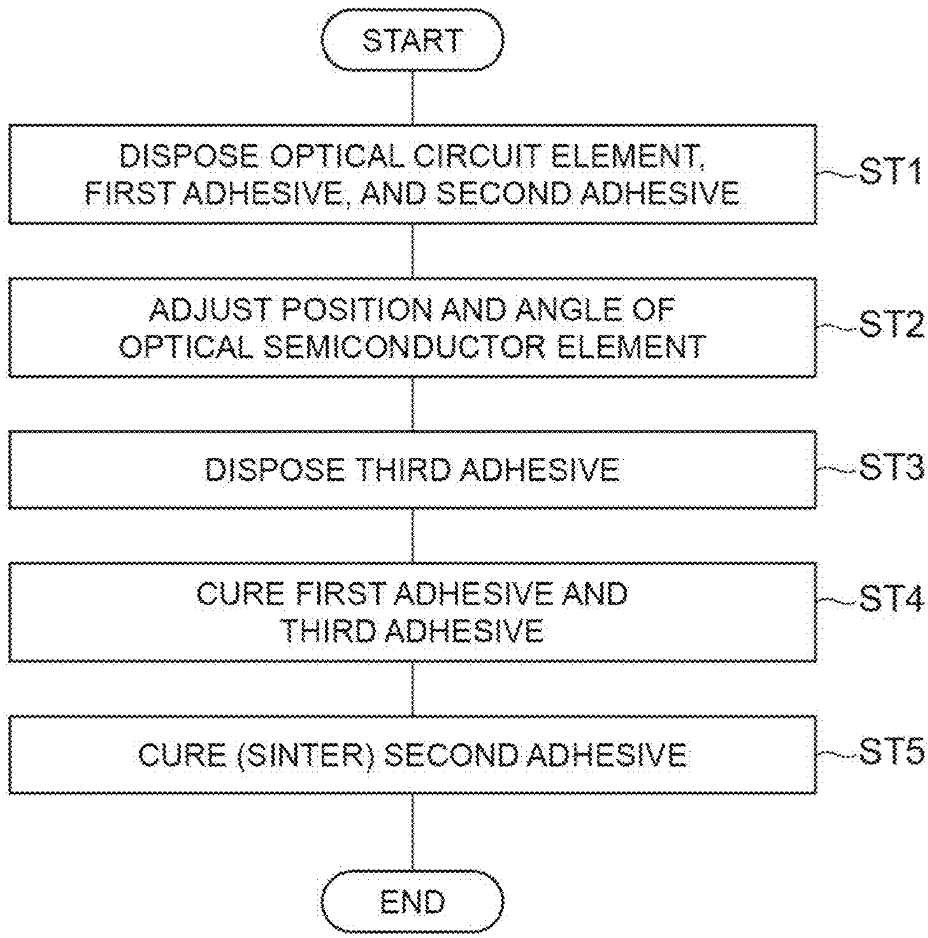
START
DISPOSE OPTICAL CIRCUIT ELEMENT, FIRST ADHESIVE, AND SECOND ADHESIVE
ST1
ADJUST POSITION AND ANGLE OF OPTICAL SEMICONDUCTOR ELEMENT
ST2
DISPOSE THIRD ADHESIVE
ST3
CURE FIRST ADHESIVE AND THIRD ADHESIVE
ST4
CURE (SINTER) SECOND ADHESIVE
ST5
END

Fig.4

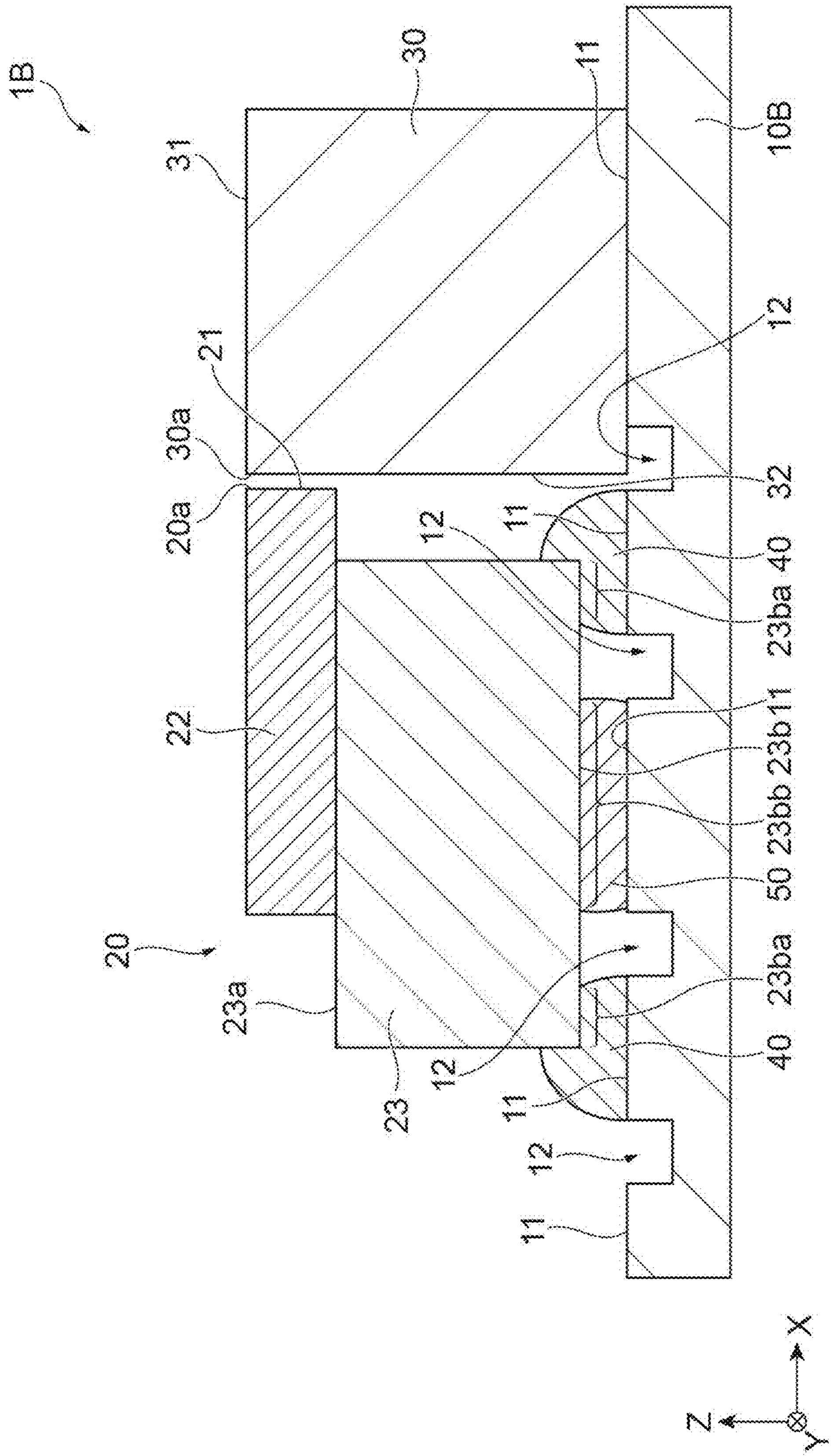
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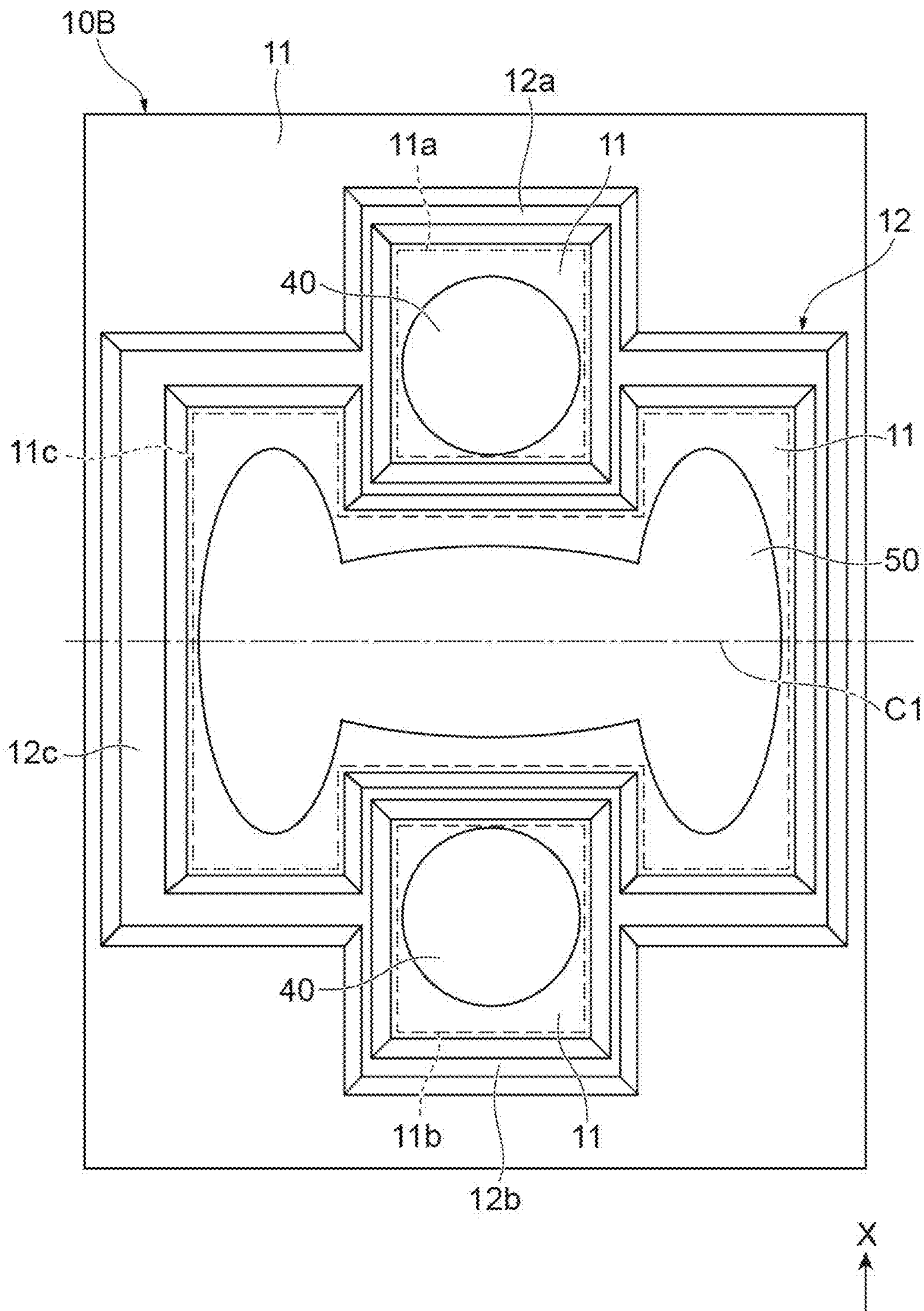
Fig.5



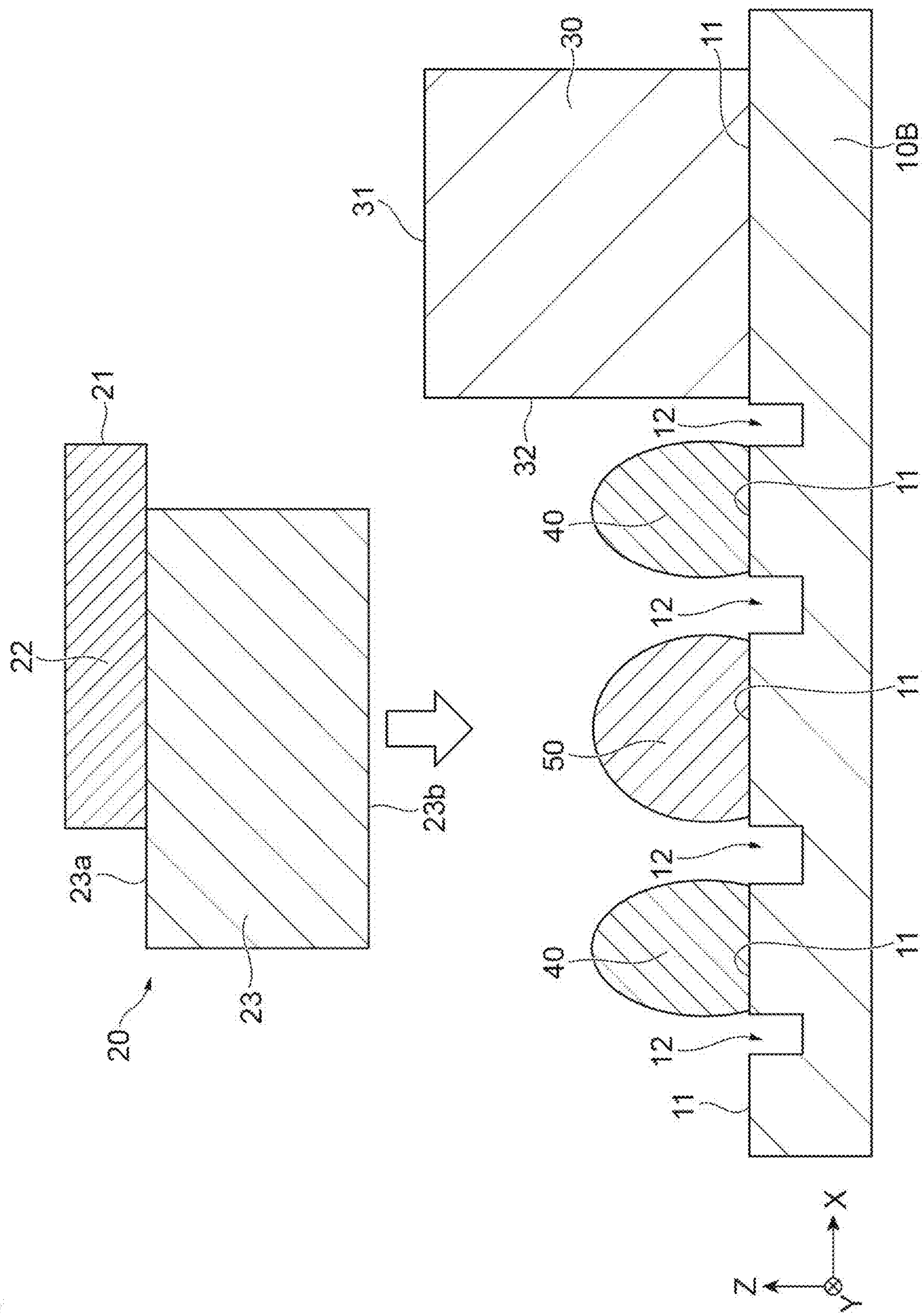


Fig.6

Fig.7

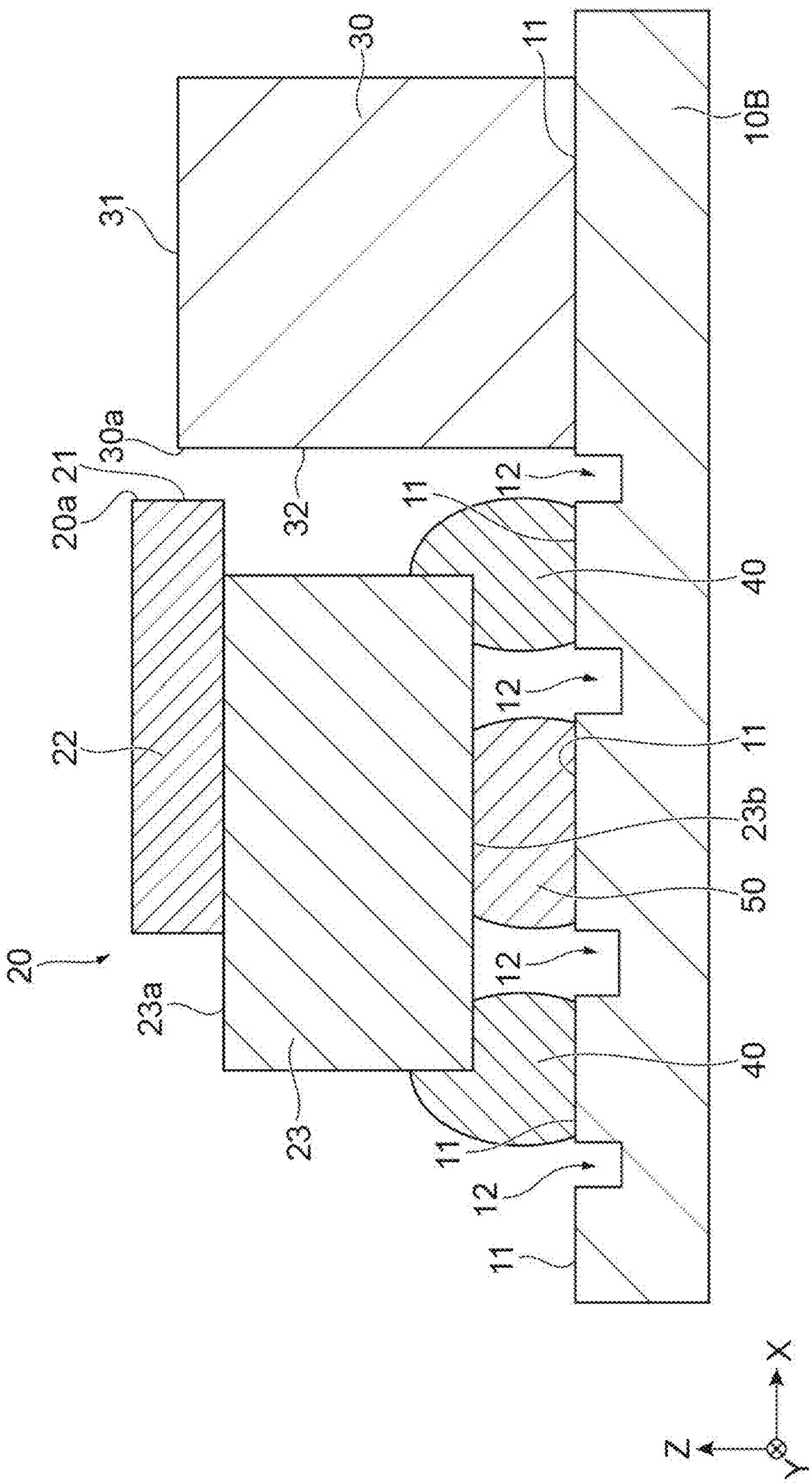

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Fig.8

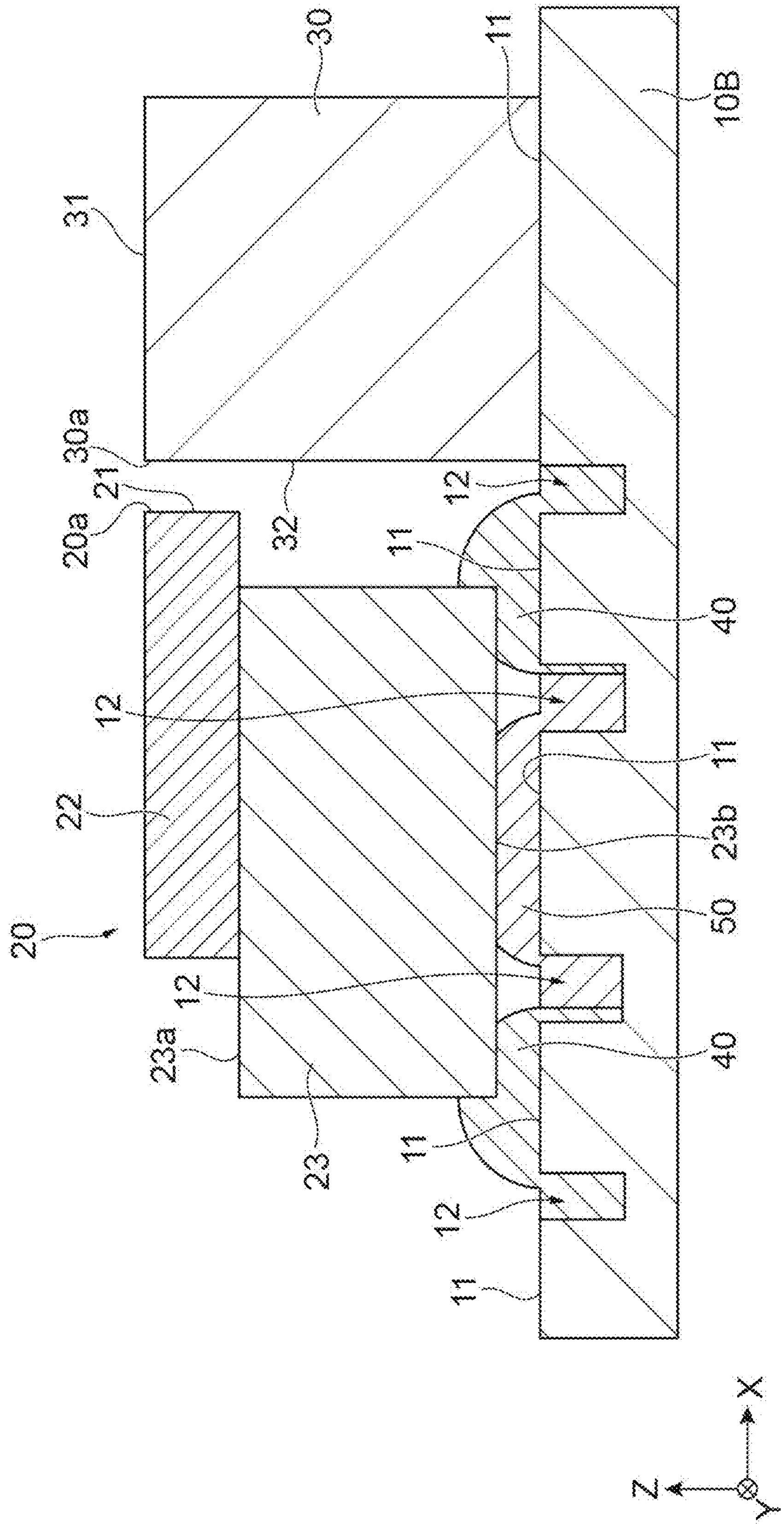
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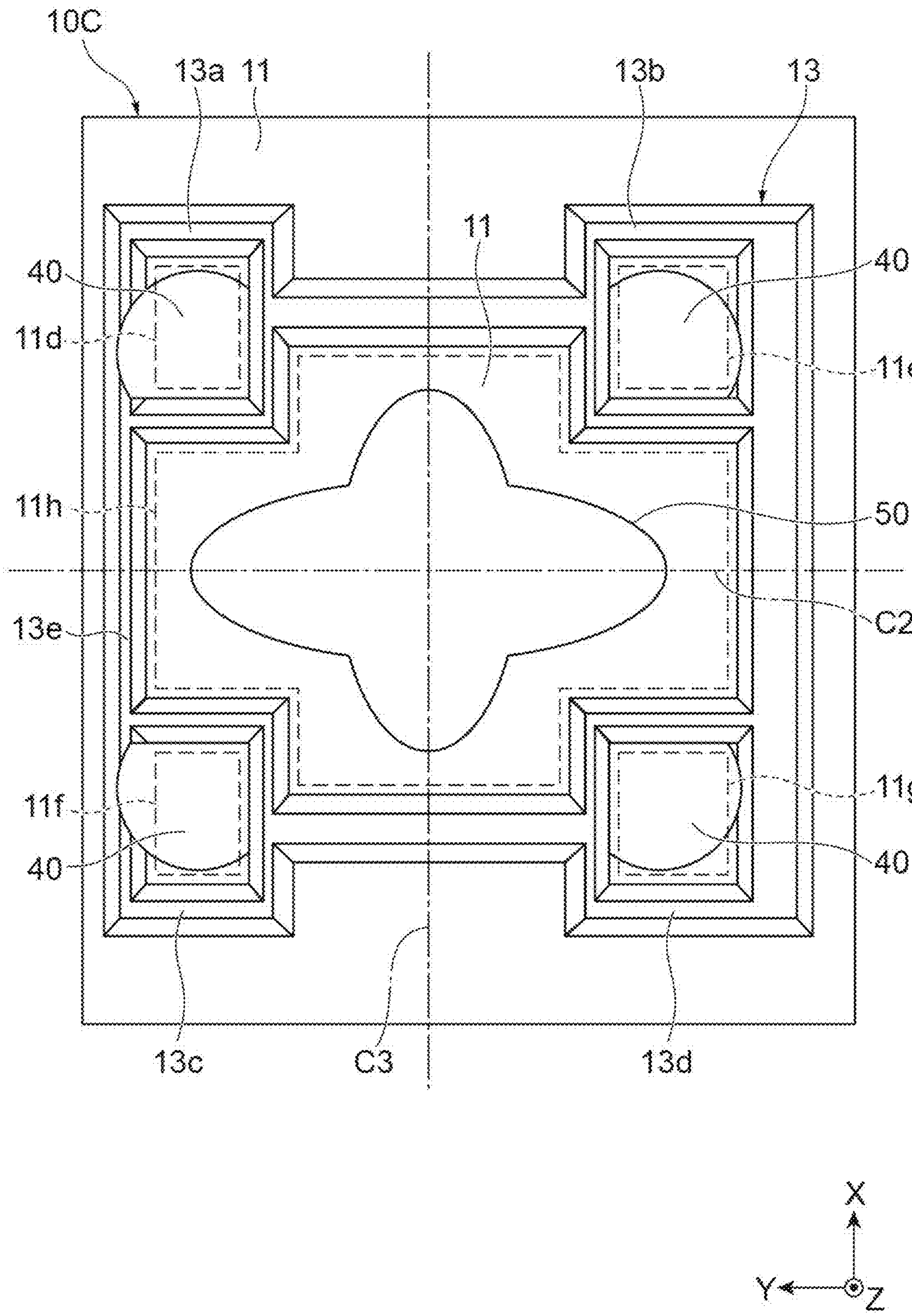
Fig.9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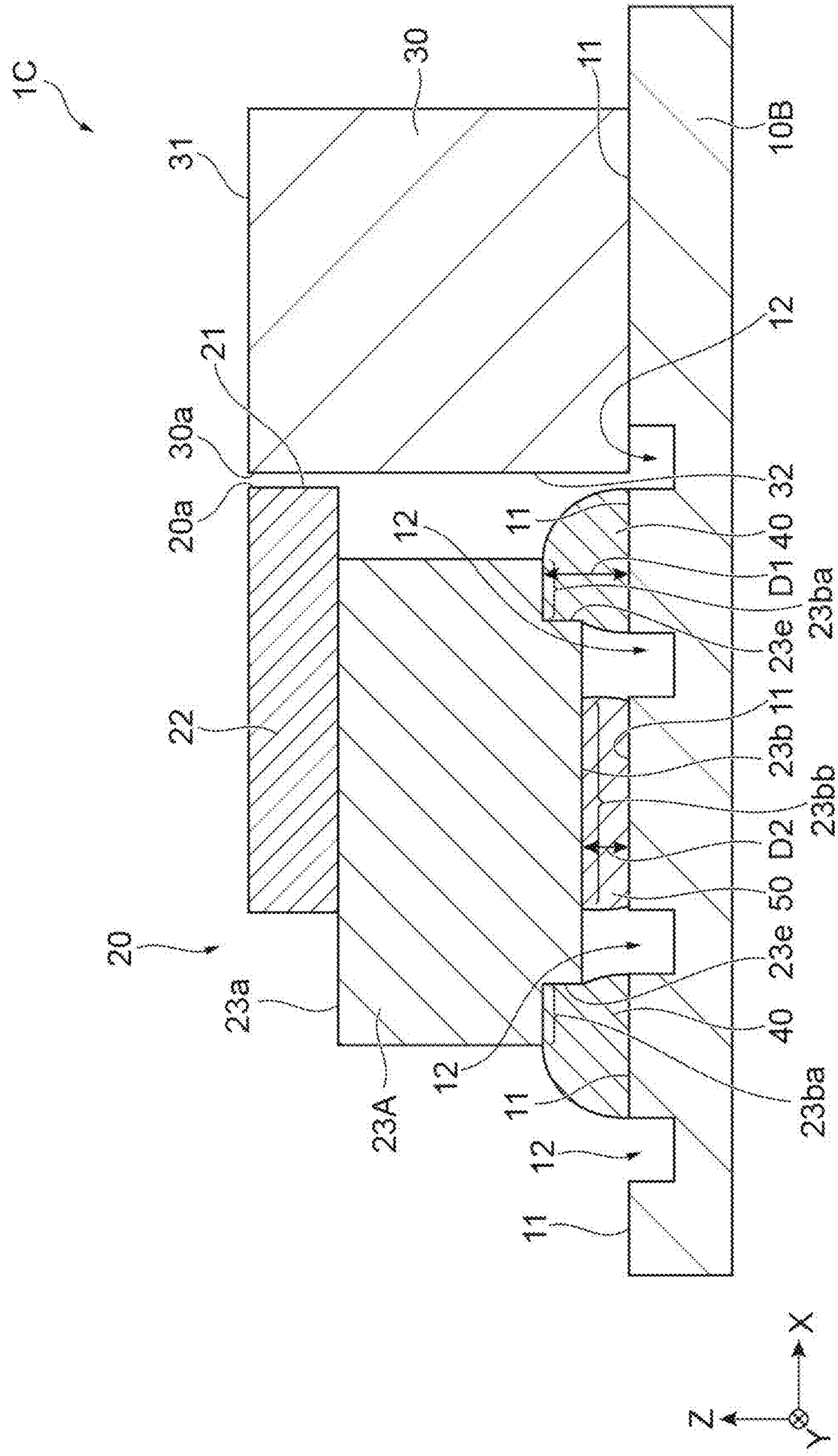
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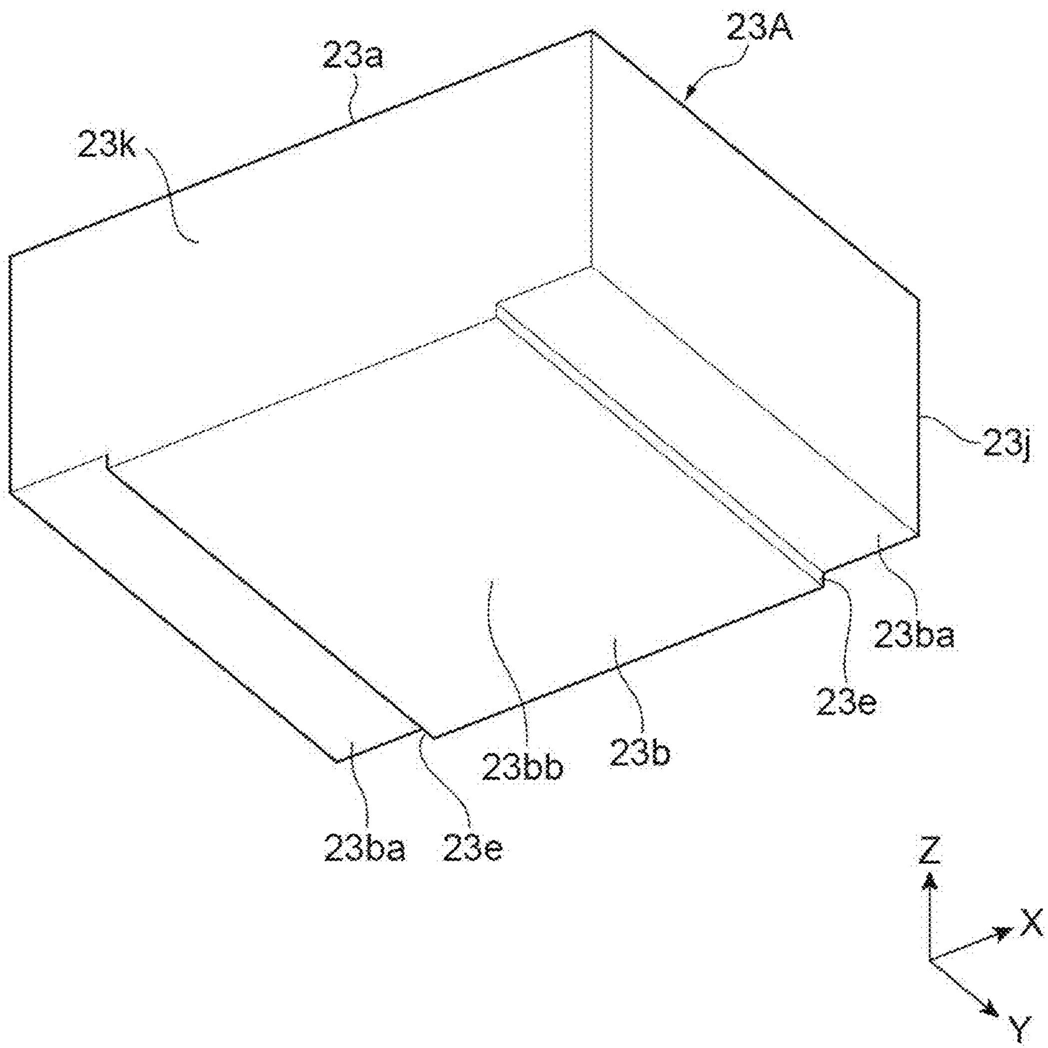
Fig. 10

Fig.11



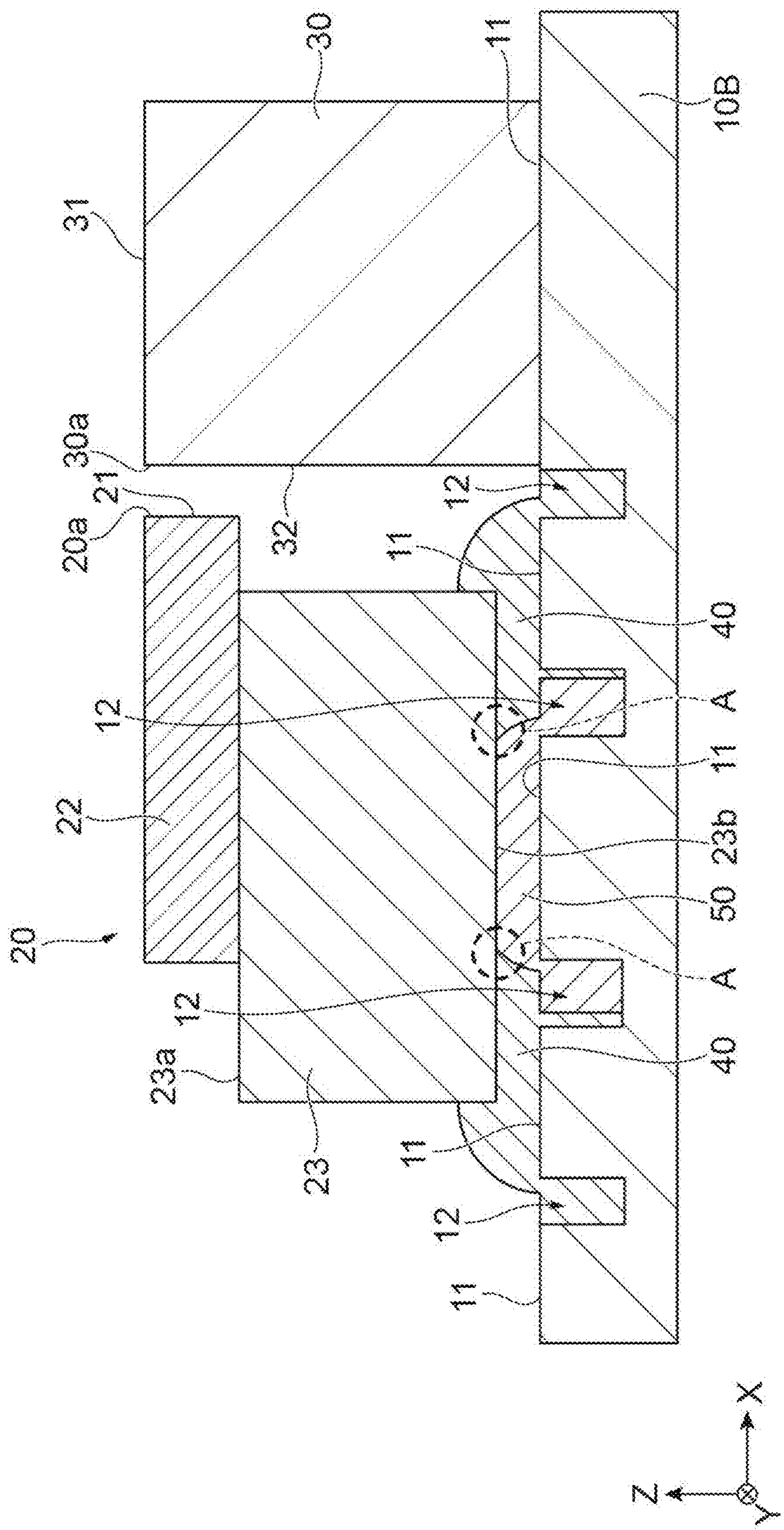

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Fig.12

Fig.13

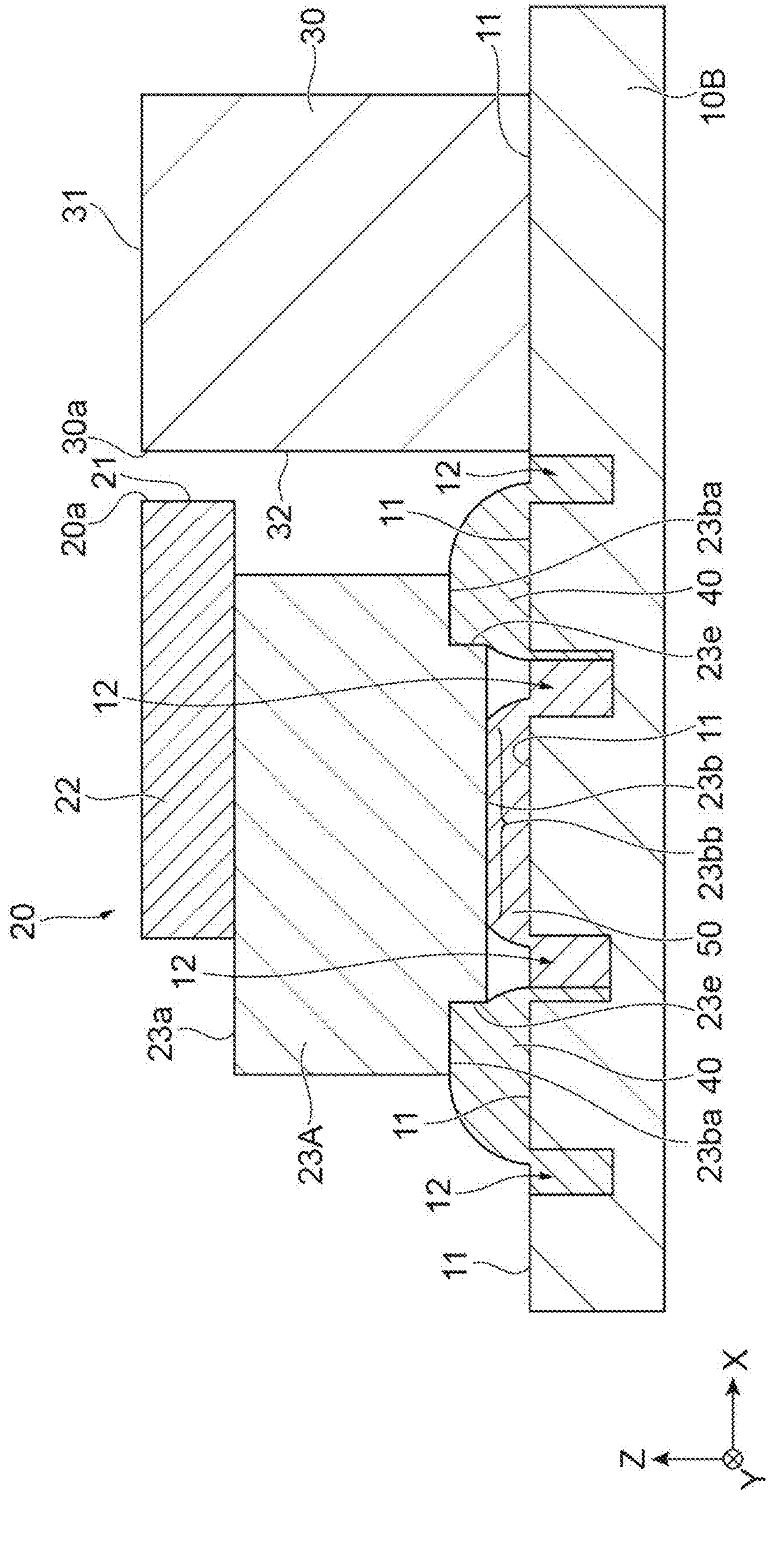
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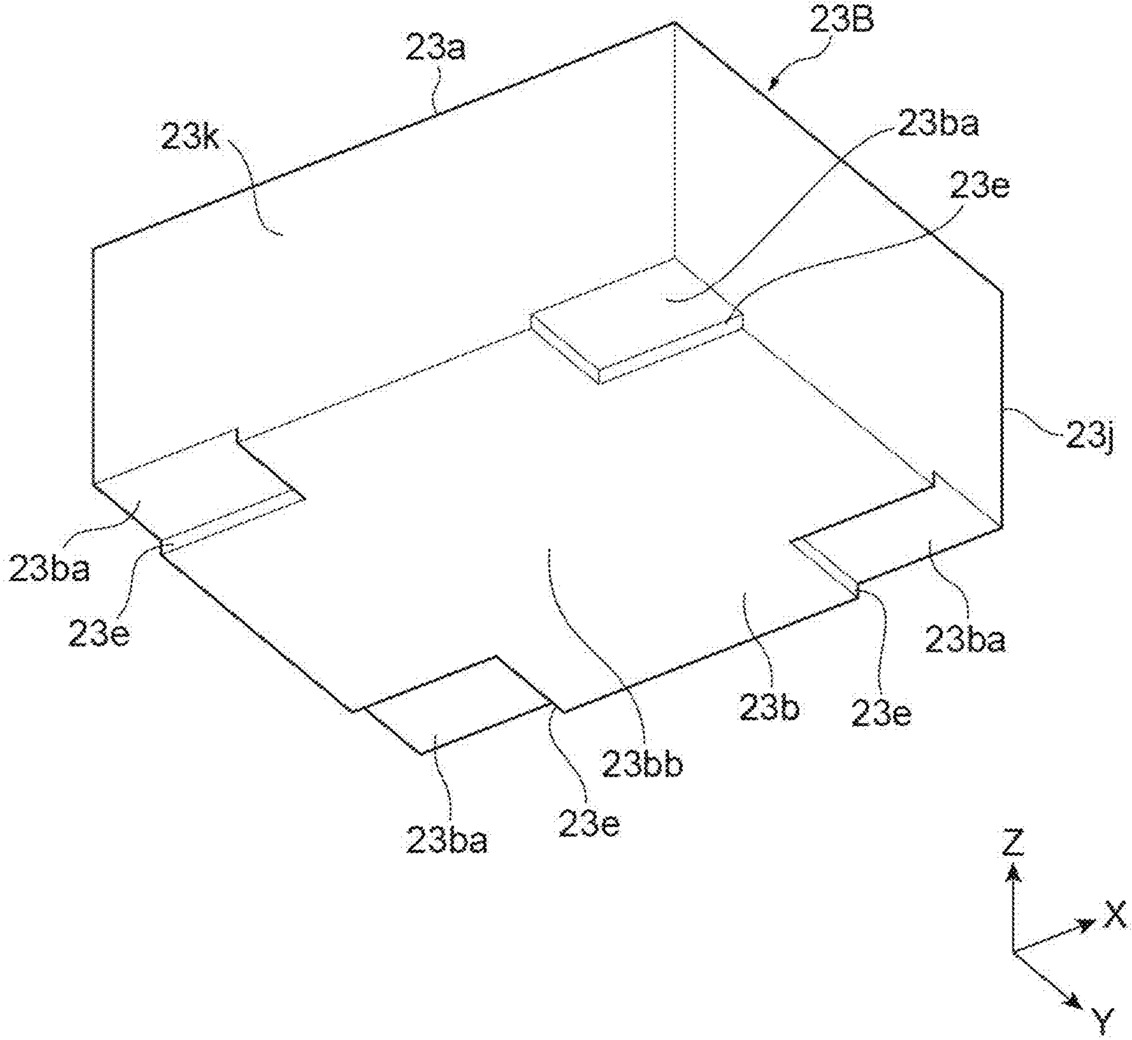
Fig.14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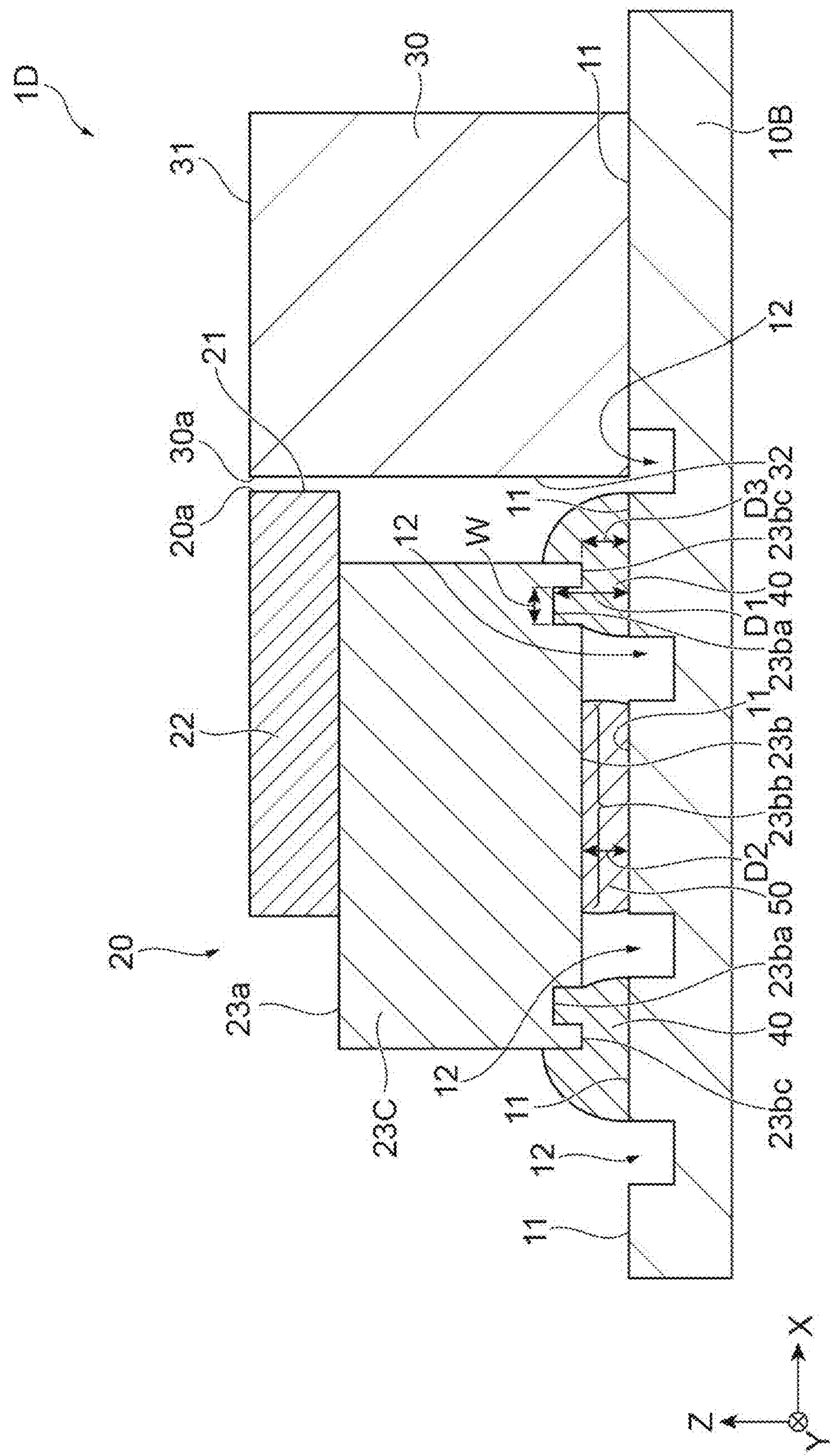

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Fig. 15

Fig.16

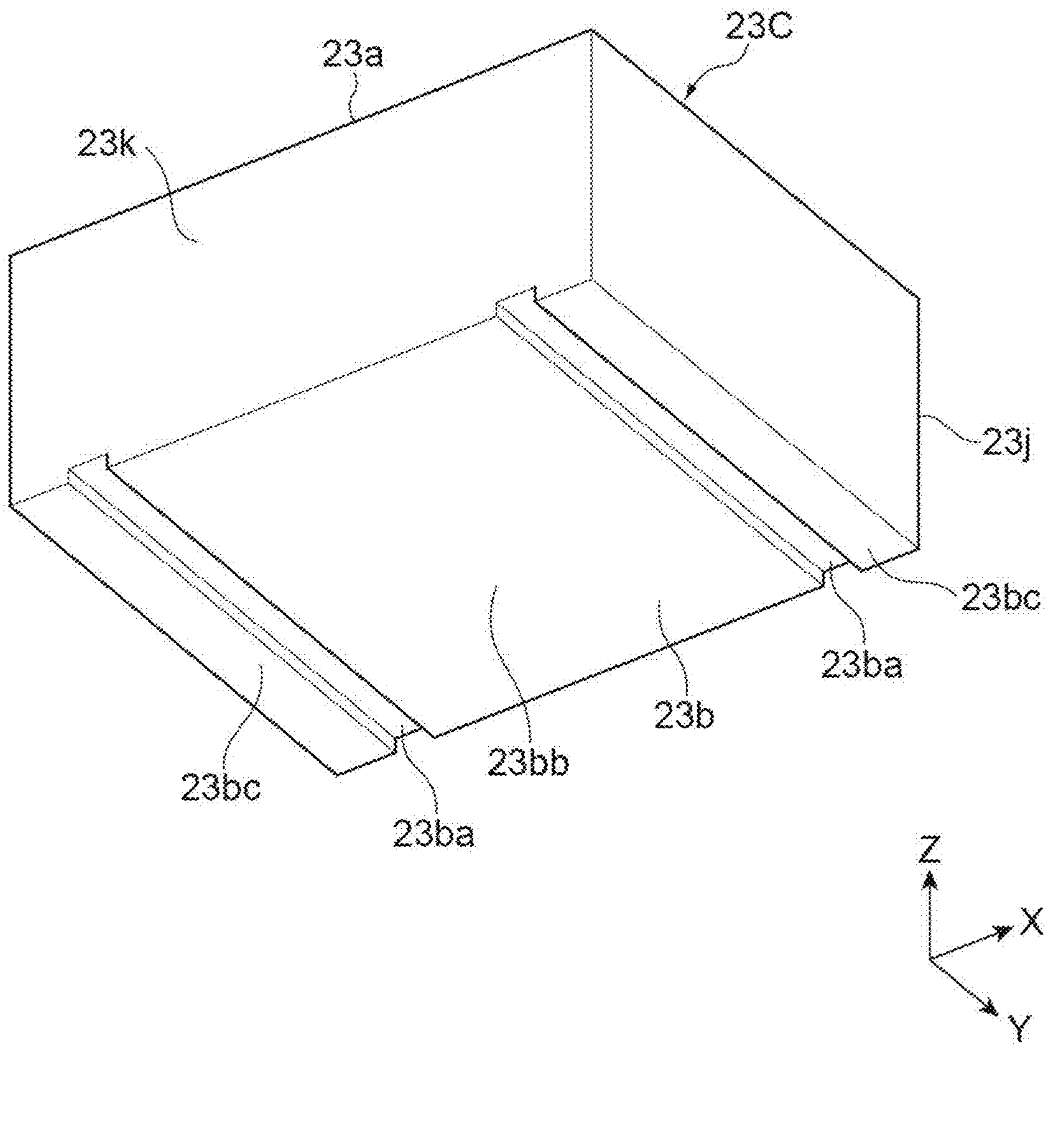

Fig.17

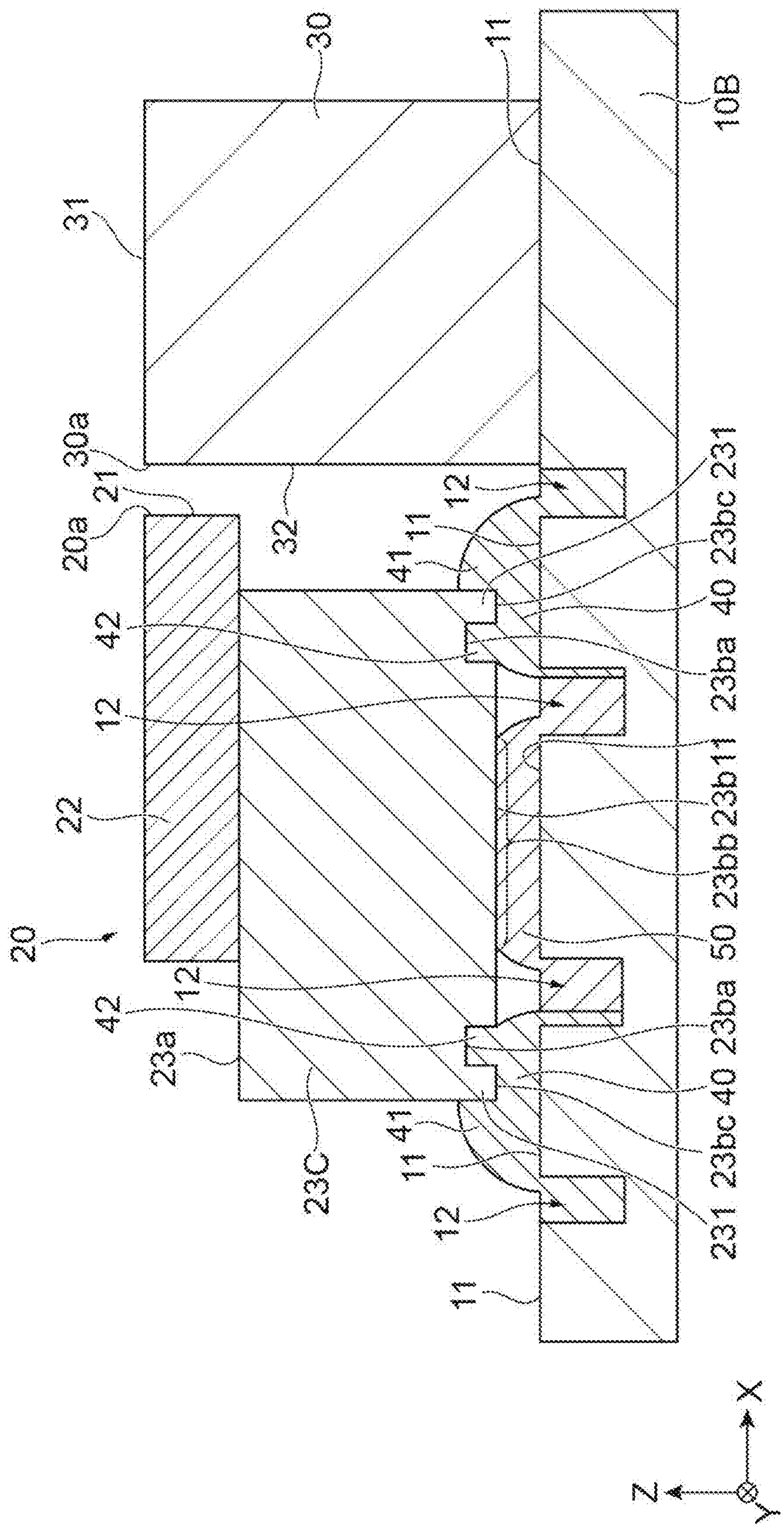
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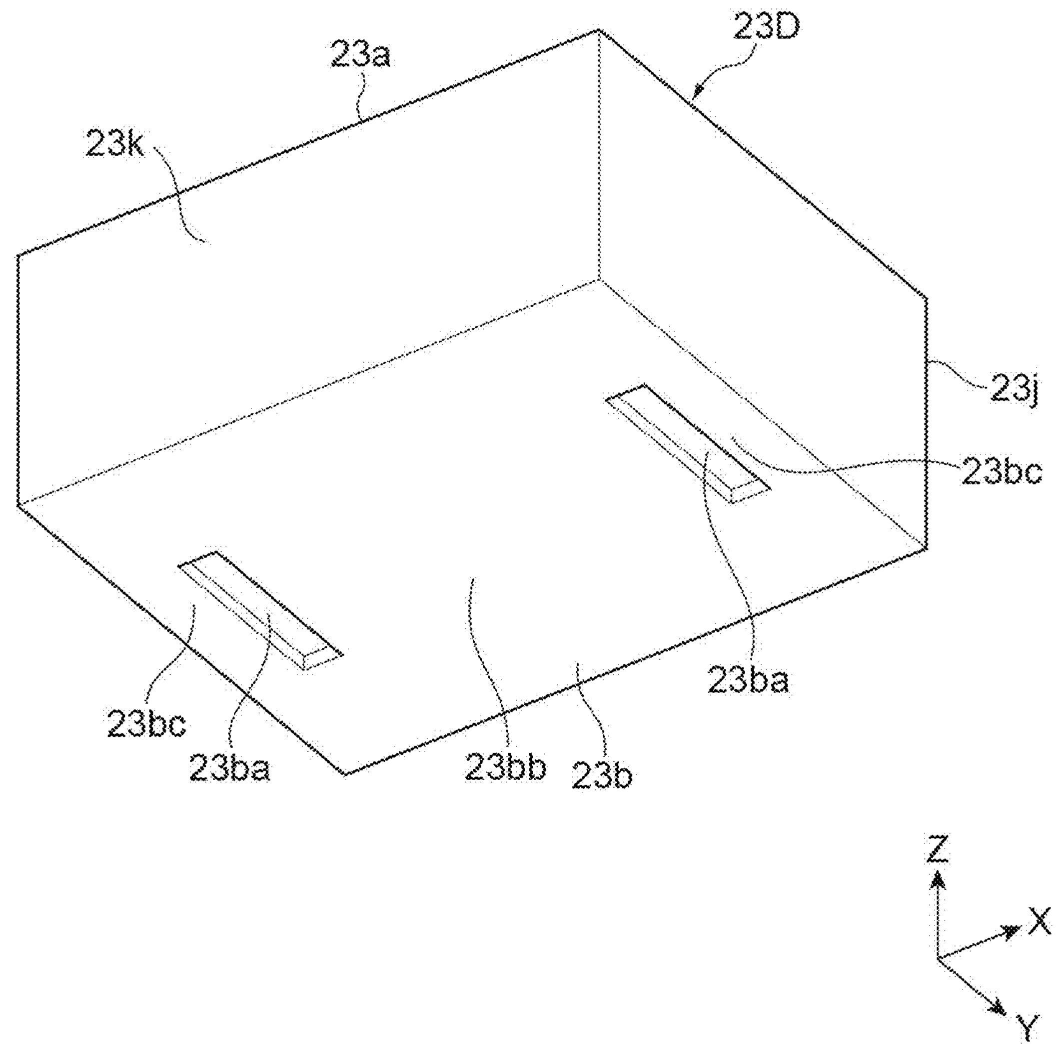
Fig.18



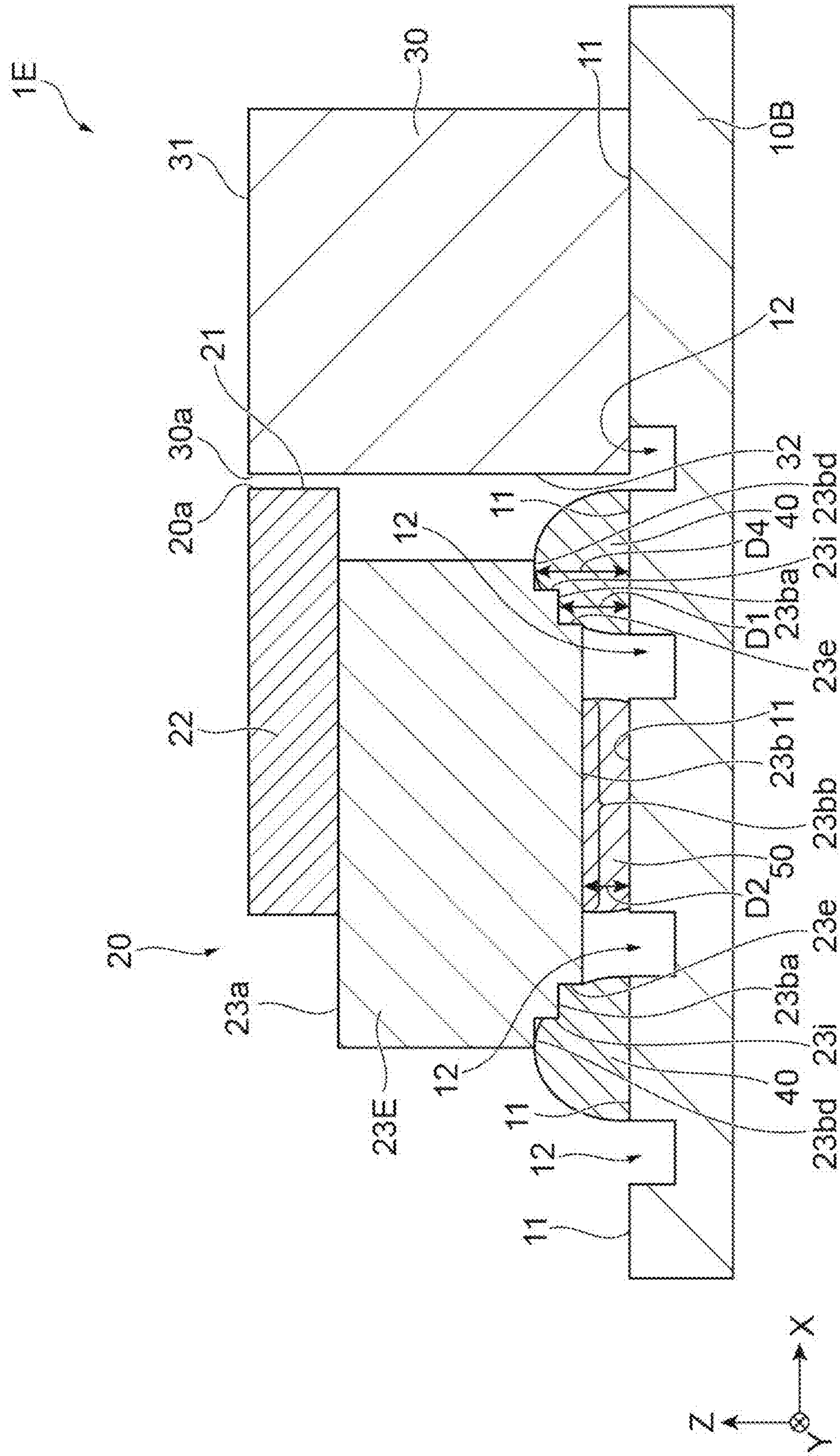

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Fig.19

OPTICAL MODULE AND METHOD FOR MANUFACTURING OPTICAL MODULE

CROSS-REFERENCE

[0001] This application claims priority to Japanese Application No. 2024-019621, filed on Feb. 13, 2024, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to an optical module and a method for manufacturing an optical module.

BACKGROUND

[0003] Japanese Unexamined Patent Publication No. 2000-236002 discloses a flip chip connection method. This method includes a first step and a second step. In the first step, a conductive paste is transferred to a bump provided on a semiconductor chip. In the second step, the bump is connected to a conductive pattern on a substrate, and a portion in which the bump is not formed in the semiconductor chip is bonded to the substrate by an adhesive sealing resin.

[0004] Japanese Unexamined Patent Publication No. 2006-108238 discloses a light emitting device. The light emitting device includes a semiconductor light emitting element, a conductive member, a conductive paste, and a fixing resin. The conductive paste electrically connects an electrode of the semiconductor light emitting element and the conductive member. The fixing resin covers a lower side surface of the semiconductor light emitting element and a portion in which the conductive paste is not applied in a bottom surface to fix the semiconductor light emitting element to the conductive member.

[0005] Japanese Unexamined Patent Publication No. 2017-092389 discloses a semiconductor device. The semiconductor device includes a semiconductor element, a support, sintered silver for bonding the semiconductor element to the support, and a resin for bonding the semiconductor element to the support. The resin is formed in at least a portion of a contour region along a contour of the semiconductor element. Japanese Unexamined Patent Publication No. 2022-522796 discloses a method for controlling a wavelength of an external-cavity tunable laser using silicon photonics.

SUMMARY

[0006] An optical module according to an embodiment of the present disclosure includes a base material, an optical semiconductor element, an optical circuit element, a first adhesive, and a second adhesive. The base material has a first surface. The optical semiconductor element has a first optical port for light incidence, light emission, or light incidence and emission in a side surface thereof and is provided on the first surface. The optical circuit element has a second optical port, which is for light incidence, light emission, or light incidence and emission, faces the first optical port, and is optically coupled to the first optical port, in a side surface thereof. The optical circuit element is disposed alongside the optical semiconductor element on the first surface. The first adhesive mainly includes a UV curable material. The first adhesive is disposed between the optical semiconductor element and the first surface to fix the optical semiconductor element to the first surface. The first adhesive has a first thermal conductivity. The second adhesive mainly includes a thermosetting material and has a second thermal conductivity higher than the first thermal conductivity. The second adhesive is disposed between the optical semiconductor element and the first surface to fix the optical semiconductor element to the first surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a perspective view showing an optical module according to an embodiment of the present disclosure.

[0008] FIG. **2** is a cross-sectional view showing the optical module taken along a line II-II of FIG. **1**.

[0009] FIG. **3** is a flowchart showing a method for manufacturing an optical module according to this embodiment.

[0010] FIG. **4** is a cross-sectional view showing an optical module according to a first modification.

[0011] FIG. **5** is a plan view showing a base material, a first adhesive, and

[0012] a second adhesive.

[0013] FIG. **6** is a cross-sectional view showing a second step in a process of manufacturing the optical module.

[0014] FIG. **7** is a cross-sectional view showing the second step in the process of manufacturing the optical module.

[0015] FIG. **8** is a cross-sectional view showing the second step in the process of manufacturing the optical module.

[0016] FIG. **9** is a plan view showing a base material, a first adhesive, and a second adhesive according to a second modification.

[0017] FIG. **10** is a cross-sectional view showing an optical module according to a third modification.

[0018] FIG. **11** is a perspective view showing an appearance of a carrier according to the third modification.

[0019] FIG. **12** is a diagram for explaining issues associated with an optical module.

[0020] FIG. **13** is a cross-sectional view showing how a spread portion of the first adhesive is dammed by a step.

[0021] FIG. **14** is a perspective view showing an appearance of a carrier as another form of the third modification.

[0022] FIG. **15** is a cross-sectional view of an optical module according to a fourth modification.

[0023] FIG. **16** is a perspective view showing the appearance of the carrier according to the fourth modification.

[0024] FIG. **17** is a cross-sectional view showing how spread of the first adhesive to a second contact surface is prevented.

[0025] FIG. **18** is a perspective view showing an appearance of a carrier as another form of the fourth modification.

[0026] FIG. **19** is a cross-sectional view of an optical module according to a fifth modification.

DETAILED DESCRIPTION

[0027] In some cases, an optical semiconductor element having an optical port in a side surface thereof is fixed to a base material after optical axis adjustment is performed for an optical circuit element having another optical port in a side surface thereof. It is desirable to fix the optical semiconductor element to the base material using a thermosetting material, such as sintered silver, having a high thermal conductivity in order to dissipate heat from the optical semiconductor element. However, extremely high temperature is required to cure the thermosetting material such as sintered silver. Therefore, it is difficult to cure the thermosetting material while holding the optical semiconductor element, whose optical axis has been adjusted, with a chuck or the like. Further, when the optical semiconductor element is fixed to the base material using a UV curable material, such as a UV curable resin, it is easy to irradiate the UV curable material with ultraviolet light while holding the optical semiconductor element, whose optical axis has been adjusted, with the chuck or the like, and it is possible to easily cure the UV curable material. However, in this case, there is a concern that the dissipation of heat from the optical semiconductor element will be insufficient due to the low thermal conductivity of the UV curable material.

[0028] An object of the present disclosure is to provide an optical module and a method for manufacturing an optical module that can fix an optical semiconductor element subjected to optical axis adjustment to a base material using a thermosetting material with high heat dissipation performance while maintaining a position of the optical semiconductor element.

Description of Embodiment of the Present Disclosure

[0029] First, the contents of an embodiment of the present disclosure will be listed and described. [1] An optical module according to an embodiment of the present disclosure includes a base material, an optical semiconductor element, an optical circuit element, a first adhesive, and a second adhesive. The base material has a first surface. The optical semiconductor element has a first optical port for light incidence, light emission, or light incidence and emission in a side surface thereof and is provided on the first surface. The optical circuit element has a second optical port, which is for light incidence, light emission, or light incidence and emission, faces the first optical port, and is optically coupled to the first optical port, in a side surface thereof. The optical circuit element is disposed alongside the optical semiconductor element on the first surface. The first adhesive mainly includes a UV curable material. The first adhesive is disposed between the optical semiconductor element and the first surface to fix the optical semiconductor element to the first surface. The first adhesive has a first thermal conductivity. The second adhesive mainly includes a thermosetting material and has a second thermal conductivity higher than the first thermal conductivity. The second adhesive is disposed between the optical semiconductor element and the first surface to fix the optical semiconductor element to the first surface.

[0030] In the optical module according to [1], the optical semiconductor element is fixed to the first surface of the base material by the first adhesive and the second adhesive. The first adhesive mainly includes the UV curable material. The second adhesive has the second thermal conductivity higher than the first thermal conductivity of the first adhesive and mainly includes the thermosetting material. When this optical module is manufactured, irradiation with ultraviolet light can be performed while the position of the optical semiconductor element subjected to optical axis adjustment is maintained by a chuck or the like to cure the first adhesive. Then, the second adhesive can be cured by heating in a state in which the position of the optical semiconductor element subjected to the optical axis adjustment is maintained by the first adhesive. Therefore, according to the optical module of [1], it is possible to fix the optical semiconductor element to the base material using the thermosetting material with high heat dissipation performance while maintaining the position of the optical semiconductor element subjected to the optical axis adjustment.

[0031] [2] In the optical module according to [1], the optical semiconductor element may include: an optical semiconductor chip having the first optical port; and a carrier on which the optical semiconductor chip mounted and fixed to the first surface by the first adhesive and the second adhesive. In this case, even when the thickness of the optical semiconductor chip is smaller than the thickness of the optical circuit element, the height of the first optical port can be matched with the height of the second optical port.

[0032] [3] In the optical module according to [1] or [2], the UV curable material may be a UV curable resin. In this case, it is possible to easily fix the optical semiconductor element to the base material.

[0033] [4] In the optical module according to any one of [1] to [3], the thermosetting material may be sintered silver. Since the sintered silver has an extremely high thermal conductivity, in this case, it is possible to efficiently transfer heat from the optical semiconductor element to the base material.

[0034] [5] In the optical module according to any one of [1] to [3], the thermosetting material may be epoxy-containing sintered silver. When the second adhesive includes the epoxy-containing sintered silver, it is possible to suppress shrinkage of the second adhesive during sintering, and the second adhesive can be less likely to peel from the optical semiconductor element.

[0035] [6] In the optical module according to any one of [1] to [5], the first adhesive and the second adhesive may be spaced apart from each other on the first surface. In this case, the mixing of the first adhesive and the second adhesive before curing is avoided. Therefore, it is possible to prevent the curing of the first adhesive from being hindered by the second adhesive.

[0036] [7] In the optical module according to any one of [1] to [6], the base material may have a recessed portion formed between the first adhesive and the second adhesive when viewed from a normal direction to the first surface. There is a variation in the height from a bottom surface of the optical semiconductor element to the first optical port due to manufacturing errors. Since the height position of the first optical port is determined by the height position of the second optical port of the optical circuit element, the variation in the height from the bottom surface of the optical semiconductor element to the first optical port is absorbed by the thickness of the first adhesive and the second adhesive. When the thickness of the first adhesive and the second adhesive is small, the first adhesive and the second adhesive spread in a lateral direction (a direction along the first surface) and approach each other. Since the base material has the recessed portion formed between the first adhesive and the second adhesive, the first adhesive and the second adhesive that have spread in the direction in which the adhesives approach each other can be dropped into the recessed portion. Therefore, the mixing of the first adhesive and the second adhesive on the first surface before curing is avoided. As a result, it is possible to prevent the curing of the first adhesive on the first surface from being hindered by the second adhesive.

[0037] [8] The optical module according to any one of [1] to [7] may further include a third adhesive that mainly includes a UV curable material having a higher curing speed than the UV curable material of the first adhesive and is disposed between the first optical port and the second optical port. In this case, the third adhesive is cured faster than the first adhesive when irradiation with ultraviolet light is performed. Therefore, it is possible to more firmly maintain the optically coupled state between the first optical port and the second optical port after the optical axis adjustment.

[0038] [9] In the optical module according to any one of [1] to [8], a contact area between the second adhesive and the optical semiconductor element may be larger than a contact area between the first adhesive and the optical semiconductor element. In this case, it is possible to more efficiently transfer heat from the optical semiconductor element to the base material.

[0039] [10] In the optical module according to any one of [1] to [9], the first adhesive may be provided on a plurality of regions, between which the second adhesive is interposed, on the first surface. In this case, when the second adhesive is cured by heating, it is possible to more stably maintain the position of the first optical port after the optical axis adjustment.

[0040] [11] In the optical module according to [10], the plurality of regions may be disposed so as to be line-symmetric with respect to an axis line along the first surface. In this case, it is possible to more stably maintain the position of the first optical port after the optical axis adjustment.

[0041] [12] In the optical module according to any one of [1] to [11], the optical semiconductor element may have a bottom surface facing the first surface. The first adhesive and the second adhesive may be spaced apart from each other on the bottom surface of the optical semiconductor element. In this case, the mixing of the first adhesive and the second adhesive before curing is avoided. Therefore, it is possible to prevent the curing of the first adhesive from being hindered by the second adhesive.

[0042] [13] In the optical module according to any one of [2] to [12], the carrier may have a bottom surface facing the first surface. The bottom surface may include a first contact surface that the first adhesive contacts and a second contact surface that the second adhesive contacts. The distance between the second contact surface and the first surface may be smaller than the distance between the first contact surface and the first surface. In this case, even if the first adhesive spreads along the bottom surface of the carrier before curing, the spread portion of the first adhesive is dammed by the step between the first contact surface and the second contact surface to prevent the first adhesive from spreading to the second contact surface. Therefore, according to the optical module of [13], it is possible to avoid the mixing of the first adhesive and the second adhesive on or near the bottom surface of the carrier, and to prevent the curing of the first adhesive on or near the bottom surface of the carrier from being hindered by the second adhesive. Furthermore, it is possible to prevent the first adhesive from entering between the second adhesive and the bottom surface of the carrier to increase the area of the second contact surface. Therefore, heat dissipation can be improved.

[0043] [14] In the optical module according to [13], the bottom surface of the carrier may further include a third contact surface that the first adhesive contacts. As viewed from the normal direction of the bottom surface of the carrier, the first contact surface may be positioned between the second contact surface and the third contact surface. The distance between the third contact surface and the first surface may be smaller than the distance between the first contact surface and the first surface. In this case, the portion of the first adhesive located on the side surface of the carrier and the portion of the first adhesive located on the first contact surface sandwich a part of the carrier, that is, the part of the carrier between the side surface and the first contact surface, from both sides. This enhances the fixation strength between the carrier and the substrate.

[0044] [15] In the optical module according to [13], the bottom surface of the carrier may further include a third contact surface that the first adhesive contacts. As viewed from the normal direction of the bottom surface of the carrier, the first contact surface may be positioned between the second contact surface and the third contact surface. The distance between the third contact surface and the first surface may be larger than the distance between the first contact surface and the first surface. In this case, the spread portion of the first adhesive before curing is further dammed by the step between the first contact surface and the third contact surface. Therefore, the first adhesive is more effectively prevented from spreading to the second contact surface.

[0045] [16] A method for manufacturing an optical module according to another embodiment of the present disclosure includes disposing, disposing, curing a first adhesive, and curing a second adhesive. In the first disposing, an optical circuit element having a second optical port for light incidence, light emission, or light incidence and emission in a side surface thereof, the first adhesive mainly including a UV curing material and having a first thermal conductivity, and the second adhesive that mainly includes a thermosetting material and has a second thermal conductivity higher than the first thermal conductivity are disposed on a first surface of a base material. In the second disposing, a position of an optical semiconductor element having a first optical port for light incidence, light emission, or light incidence and emission in a side surface thereof is disposed. During the second disposing, a position of the optical semiconductor element is adjusted such that the first optical port is optically coupled to the second optical port while the optical semiconductor element is brought into contact with the first adhesive and the second adhesive. Such adjustment may be performed by an active alignment method or a passive alignment method. In the curing the first adhesive, the first adhesive is cured using irradiation with ultraviolet light while the optical semiconductor element is maintained at a position adjusted for optical coupling. In the curing the second adhesive, the second adhesive is cured by heating in a state in which the first adhesive is already cured.

[0046] In the manufacturing method according to [16], the optical semiconductor element is fixed to the first surface of the base material by the first adhesive and the second adhesive. The first adhesive mainly includes the UV curable material. The second adhesive has the second thermal conductivity higher than the first thermal conductivity of the first adhesive and mainly includes the thermosetting material. In the curing the first adhesive, irradiation with ultraviolet light can be performed while the position of the optical semiconductor element subjected to optical axis adjustment is maintained by a chuck or the like to cure the first adhesive. Then, In the curing the second adhesive, the second adhesive can be cured by heating in a state in which the position of the optical semiconductor element subjected to the optical axis adjustment is maintained by the first adhesive. Therefore, according to the manufacturing method of [16], it is possible to fix the optical semiconductor element to the base material using the thermosetting material with high heat dissipation performance while maintaining the position of the optical semiconductor element subjected to the optical axis adjustment.

Details of Embodiment of the Present Disclosure

[0047] Specific examples of the present disclosure will be described below with reference to the drawings. The present disclosure is not limited to these examples, but is defined by the scope of the claims. The present disclosure is intended to include all modifications within the meaning and scope equivalent to the scope of the claims. In the description of the drawings, the same elements are denoted by the same reference numerals, and redundant description will be omitted.

[0048] FIG. **1** is a perspective view showing an optical module **1**A according to an embodiment of the present disclosure. FIG. **2** is a cross-sectional view showing the optical module **1**A taken along a line II-II of FIG. **1**. As shown in FIGS. **1** and **2**, the optical module **1**A according to this embodiment includes a base material **10**A, an optical semiconductor element **20**, an optical circuit element **30**, a first adhesive **40**, a second adhesive **50**, and a third adhesive **60**. FIG. **1** schematically shows the first adhesive **40**, the second adhesive **50**, and the third adhesive **60**.

[0049] The base material **10**A has a flat first surface **11**. FIG. **1** shows the first surface **11** having a rectangular planar shape as an example. The planar shape of the first surface **11** is not limited thereto. The base material **10**A is, for example, an insulating substrate. A metal film to be fixed to the second adhesive **50** is formed on the first surface **11**.

[0050] The optical semiconductor element **20** is provided on the first surface **11**. The optical semiconductor element **20** has a first optical port **20***a* for light incidence, light emission, or light incidence and emission in a side surface **21** thereof. The optical semiconductor device **20** shown in the example includes an optical semiconductor chip **22** and a carrier **23**.

[0051] The optical semiconductor chip **22** has an end surface constituting the side face **21** and has the first optical port **20***a* in the end surface. The optical semiconductor chip **22** is, for example, a semiconductor optical amplifier (SOA). For example, the optical semiconductor chip **22** is made of a compound material such as indium phosphide (InP). The carrier **23** has a substantially rectangular parallelepiped appearance and has a mounting surface **23***a* and a bottom surface **23***b* opposite to the mounting surface **23***a*. The optical semiconductor chip **22** is mounted on the mounting surface **23***a*. The bottom surface **23***b* faces the first surface **11**. The bottom surface **23***b* is also the bottom surface of the optical semiconductor element **20**. The bottom surface **23***b* is a flat surface in this embodiment. The carrier **23** is obtained by forming a metal film, such as a gold (Au) film, on a surface of a ceramic material such as aluminum nitride (AlN). A back electrode of the optical semiconductor chip **22** is conductively bonded to the metal film provided on the mounting surface **23***a* of the carrier **23**.

[0052] The optical circuit element **30** is disposed alongside the optical semiconductor element **20** on the first surface **11**. For example, the optical circuit element **30** is fixed to the first surface **11** by an adhesive (not shown). The optical circuit element **30** is, for example, a silicon photonics chip (SiPh) having an optical circuit formed on a main surface **31**. The optical circuit element **30** has a second optical port **30***a* for light incidence, light emission, or light incidence and emission in a side surface **32** thereof. The second optical port **30***a* faces the first optical port **20***a* and is optically coupled to the first optical port **20***a*. The third adhesive **60** is provided between the first optical port **20***a* and the second optical port **30***a*. When the third adhesive **60** is not provided, only air is present between the first optical port **20***a* and the second optical port **30***a*. An optical component, such as a lens, is not provided between the first optical port **20***a* and the second optical port **30***a*. This form is called edge coupling. A distance between the first optical port **20***a* and the second optical port **30***a* is, for example, several micrometers.

[0053] As an example, the optical circuit element **30** further includes a linear optical waveguide **33**, a built-in photodiode **34**, and a monitoring optical port **30***b*. The optical waveguide **33** is formed on the main surface **31**. A first end of the optical waveguide **33** is the second optical port **30***a*. A second end of the optical waveguide **33** is a reflecting end **33***a*, and light introduced from the second optical port **30***a* is reflected at the reflecting end **33***a* and is emitted from the second optical port **30***a*. Therefore, the optical waveguide **33** and an optical waveguide provided in the optical semiconductor chip **22** form a laser resonator. A spot size converter may be provided between the second optical port **30***a* and the first end of the optical waveguide **33**. Laser light generated by the optical semiconductor chip **22** and the optical waveguide **33** is emitted, for example, from an optical port (not shown) of the optical semiconductor chip **22** opposite to the first optical port **20***a* to the outside of the optical module **1**A.

[0054] The built-in photodiode **34** is formed on the main surface **31**. The built-in photodiode **34** is optically coupled to the optical waveguide **33** through an optical waveguide **35** formed on the main surface **31**. The built-in photodiode **34** outputs an electrical signal corresponding to the intensity of the laser light generated in the optical waveguide **33**. For example, a control device provided outside the optical module **1**A controls the gain of the optical semiconductor element **20** on the basis of the electrical signal. The monitoring optical port **30***b* is optically coupled to the optical waveguide **33** through an optical waveguide **36** formed on the main surface **31**. A portion of the laser light generated in the optical waveguide **33** is provided from the monitoring optical port **30***b* to the outside of the optical module **1**A.

[0055] The first adhesive **40** is disposed between the optical semiconductor element **20** and the first surface **11**. In the shown example, the first adhesive **40** is disposed between the bottom surface **23***b* of the carrier **23** and the first surface **11** and is in contact with both the bottom surface **23***b* and the first surface **11**. In other words, the bottom surface **23***b* of the carrier **23** includes a first contact surface **23***ba,* which the first adhesive **40** contacts. The first adhesive **40** may further be in contact with the side surface of the carrier **23**. The first adhesive **40** mainly includes a UV curable material cured by irradiation with ultraviolet light (UV). The UV curable material may be a UV curable resin. The first adhesive **40** fixes the optical semiconductor element **20** (the carrier **23** in the shown example) to the first surface **11**. The thickness of the first adhesive **40**, in other words, a gap between the bottom surface **23***b* of the carrier **23** and the first surface **11** is, for example, equal to or greater than 20 μm and equal to or less than 70 μm in a state in which the first adhesive **40** is cured. The first adhesive has a thermal conductance (first thermal conductance). The first thermal conductivity may be lower than 1 W/m·K after the first adhesive is cured.

[0056] The second adhesive **50** is disposed alongside the first adhesive **40** on the first surface **11** and is disposed between the optical semiconductor element **20** and the first surface **11**. In the shown example, the second adhesive **50** is disposed between the bottom surface **23***b* of the carrier **23** and the first surface **11** and is in contact with both the bottom surface **23***b* and the first surface **11**, more specifically, with both the metal films formed on the bottom surface **23***b* and the first surface **11**, respectively. In other words, the bottom surface **23***b* of the carrier **23** includes a second contact surface **23***bb,* which the second adhesive **50** contacts. The second adhesive **50** may further be in contact with the side surface of the carrier **23**, more specifically, the metal film formed on the side surface of the carrier **23**. The second adhesive **50** mainly includes a thermosetting material cured by heating. The thermosetting material may be sintered silver or may be epoxy-containing sintered silver. The second adhesive **50** has a thermal conductivity (second thermal conductivity) higher than the thermal conductivity (first thermal conductivity) of the first adhesive **40**. The second thermal conductivity may be larger than 20 W/m·K after the second adhesive is cured. The second thermal conductivity may be more than twenty times of the first thermal conductivity. The sintered silver may have a thermal conductivity higher than 100 W/m·K. The second thermal conductivity may be more than one hundred times of the first thermal conductivity. The second adhesive **50** fixes the optical semiconductor element **20** (the carrier **23** in the shown example) to the first surface **11**. Moreover, the second adhesive transfers heat generated within the optical semiconductor element **20** to the base material **10**A more efficiently than the first adhesive.

[0057] As shown in FIG. **2**, the first adhesive **40** and the second adhesive **50** are not in contact with each other and are spaced apart from each other on the first surface **11** (or the bottom surface **23***b* of the carrier **23**) in the cured state. In the cured state, the width of the gap between the first adhesive **40** and the second adhesive **50** is, for example, 0.05 mm or more, and, for example, 0.25 mm or less. A contact area between the second adhesive **50** and the optical semiconductor element **20** (the carrier **23** in the shown example) is larger than a contact area between the first adhesive **40** and the optical semiconductor element **20** (the carrier **23** in the shown example).

[0058] The third adhesive **60** is disposed between the first optical port **20***a* and the second optical port **30***a* and is in contact with both the first optical port **20***a* and the second optical port **30***a*. The third adhesive **60** may further be in contact with one or both of an upper surface of the optical semiconductor element **20** (an upper surface of the optical semiconductor chip **22** in the shown example) and the main surface **31** of the optical circuit element **30**. The third adhesive **60** mainly includes a UV curable material having a higher UV irradiation curing speed than the UV curable material of the first adhesive **40**. The UV curable material may be a UV curable resin. The third adhesive **60** is transparent to light propagating between the first optical port **20***a* and the second optical port **30***a* and performs refractive index matching between the first optical port **20***a* and the second optical port **30***a*. The third adhesive **60** is, for example, an epoxy resin, and its refractive index after curing may be between 1.4 and 1.6. Meanwhile, the optical semiconductor chip **22** protrudes in the X direction towards the optical circuit element **30** from the side surface **23***c* of the carrier **23** that faces the optical circuit element **30**. Therefore, in the X direction, the side surface **21** of the optical semiconductor chip **22** is positioned between the side surface **23***c* of the carrier **23** and the optical circuit element **30**. The optical semiconductor device **20** has a distance OH between the side surface **21** of the optical semiconductor chip **22** and the side surface **23***c* of the carrier **23** in the X direction. By providing the protrusion with the distance OH, it is possible to prevent the second adhesive **50** from coming into contact with the third adhesive **60** when the second adhesive **50** creeps up along the side surface **23***c* towards the optical semiconductor chip **22** in the Z direction. The distance OH may be, for example, 0.05 mm or more, and further, 0.1 mm or less.

[0059] FIG. **3** is a flowchart showing a method for manufacturing the optical module **1**A according to this embodiment. As shown in FIG. **3**, this manufacturing method includes a first step ST**1**, a second step ST**2**, a third step ST**3**, a fourth step ST**4**, and a fifth step ST**5**. In the first step ST**1**, the optical circuit element **30**, the first adhesive **40**, and the second adhesive **50** are disposed on the first surface **11** of the base material **10**A. At this time, the first adhesive **40** and the second adhesive **50** are applied to the first surface **11**. The thickness of the first adhesive **40** and the second adhesive **50** at this time, in other words, the height from the first surface **11** to the vertex of each of the first adhesive **40** and the second adhesive **50** is, for example, equal to or greater than 70 μm and is, for example, 100 μm. This height indicates the height before optical axis adjustment which will be described below is performed.

[0060] In the second step ST**2**, the optical semiconductor element **20** is held by a chuck or the like. Then, light is emitted from the first optical port **20***a* of the optical semiconductor element **20** by supplying a driving current to the optical semiconductor element **20** through the chuck or the like. The position and angle of the optical semiconductor element **20** are adjusted such that the first optical port **20***a* is optically coupled to the second optical port **30***a* while the optical semiconductor element **20** (specifically, the bottom surface **23***b* of the carrier **23**) is brought into contact with the first adhesive **40** and the second adhesive **50** (optical axis adjustment). The optically coupled state between the first optical port **20***a* and the second optical port **30***a* can be known, for example, by detecting the magnitude of an electric signal output from the built-in photodiode **34** or the intensity of the light emitted from the monitoring optical port **30***b*. The adjustment of the position and angle of the optical semiconductor element **20** includes adjustment of the position in an optical axis direction (an arrow A**1** shown in FIG. **1**), adjustment of the position in a lateral direction intersecting the optical axis direction (an arrow A**2** shown in FIG. **1**), adjustment of the position in a normal direction to the first surface **11** (an arrow A**3** shown in FIG. **1**), and adjustment of the angle around an axis along a normal line to the first surface **11** (an arrow A**4** shown in FIG. **1**). The optical axis adjustment is performed such that the magnitude of the electric signal output from the built-in photodiode **34** or the intensity of the light emitted from the monitoring optical port **30***b* is greater than a predetermined value. The thickness of the first adhesive **40** and the second adhesive **50** can be changed by adjusting the position in the normal direction to the first surface **11** during the optical axis adjustment. Before curing, each of the first adhesive **40** and the second adhesive **50** is likely to be deformed by an external force. Further, in the following description, for convenience, in some cases, the optical axis direction is referred to as an X direction, the lateral direction intersecting the optical axis direction is referred to as a Y direction, and a height direction intersecting the X direction and the Y direction is referred to as a Z direction.

[0061] In the third step ST**3**, the third adhesive **60** is disposed (applied) between the first optical port **20***a* and the second optical port **30***a* while the optical semiconductor element **20** subjected to the optical axis adjustment is held at the position adjusted for the optical coupling by the chuck or the like and the position and angle of the optical semiconductor element **20** are maintained. In the fourth step ST**4**, the first adhesive **40** and the third adhesive **60** are cured by irradiation with ultraviolet light while the optical semiconductor element **20** subjected to the optical axis adjustment is held by the chuck or the like and the position and angle of the optical semiconductor element **20** are maintained. As described above, since the third adhesive **60** mainly includes the UV curing material having a higher curing speed than the UV curing material of the first adhesive **40**, the third adhesive **60** is cured faster than the first adhesive **40** at this time. When the third adhesive **60** is cured, the periphery of the exposed first adhesive **40** may be temporarily covered with a shielding material such that the first adhesive **40** is not exposed to ultraviolet light.

[0062] In the fifth step ST**5**, in a state in which the first adhesive **40** and the third adhesive **60** are already cured, the second adhesive **50** is cured (sintered) by heating. In the fifth step ST**5**, a plurality of works in progress that have been subjected to the fourth step ST**4** may be put into a heating furnace, and the second adhesives **50** of the plurality of works in progress may be collectively cured. The optical module **1**A according to this embodiment is manufactured by the above-described steps.

[0063] The effects obtained by the optical module **1**A and the method for manufacturing the optical module **1**A according to this embodiment described above will be described. In the optical module **1**A according to this embodiment, the optical semiconductor element **20** is fixed to the first surface **11** of the base material **10**A by the first adhesive **40** and the second adhesive **50**. The first adhesive **40** mainly includes the UV curable material. The second adhesive **50** has a thermal conductivity (second thermal conductivity) than a thermal conductivity (first thermal conductivity) of the first adhesive **40** and mainly includes the thermosetting material. When the optical module **1**A is manufactured, the optical axis adjustment is performed in a state in which the first adhesive **40** and the second adhesive **50** can be deformed, and the first adhesive **40** can be cured by performing irradiation with ultraviolet light while maintaining the position of the optical semiconductor element **20** subjected to the optical axis adjustment using the chuck or the like. Then, the second adhesive **50** can be cured by heating in a state in which the position of the optical semiconductor element **20** subjected to the optical axis adjustment is maintained by the first adhesive **40**. Therefore, according to the optical module **1**A of this embodiment, it is possible to fix the optical semiconductor element **20** to the base material **10**A using the thermosetting material with high heat dissipation performance while maintaining the position of the optical semiconductor element **20** subjected to the optical axis adjustment. As a result, it is possible to improve the heat dissipation performance from the optical semiconductor element **20** to the base material **10**A while preventing the deviation between the optical axes of the first optical port **20***a* and the second optical port **30***a* when the second adhesive **50** is thermally cured. In addition, thermal resistance from the bottom surface **23***b* of the carrier **23** to the first surface **11** is, for example, equal to or less than 5 K/W.

[0064] As in this embodiment, the optical semiconductor element **20** may include the optical semiconductor chip **22** having the first optical port **20***a* and the carrier **23** that has the optical semiconductor chip **22** mounted thereon and is fixed to the first surface **11** by the first adhesive **40** and the second adhesive **50**. In that case, even when the thickness of the optical semiconductor chip **22** is smaller than the thickness of the optical circuit element **30**, the height of the first optical port **20***a* can be matched with the height of the second optical port **30***a*.

[0065] As described above, the UV curable material may be a UV curable resin. In this case, it is possible to easily fix the optical semiconductor element **20** to the base material **10**A after the optical axis adjustment. Therefore, the optical semiconductor element **20** can be fixed to the base material **10**A with sufficient strength by the first adhesive **40**. As a result, it is possible to prevent the deviation between the optical axes of the first optical port **20***a* and the second optical port **30***a* when the second adhesive **50** is thermally cured.

[0066] As described above, the thermosetting material may be sintered silver. The sintered silver has an extremely high thermal conductivity. Therefore, in this case, it is possible to reduce the thermal resistance between the optical semiconductor element **20** and the base material **10**A. This makes it possible to more efficiently transfer heat from optical semiconductor element **20** to the base material **10**A.

[0067] As described above, the thermosetting material may be epoxy-containing sintered silver. When the second adhesive **50** includes the epoxy-containing sintered silver, the adhesion between the second adhesive **50** and the optical semiconductor element **20** is increased. As a result, it is possible to suppress shrinkage of the second adhesive **50** during sintering, and the second adhesive **50** can be less likely to peel from the optical semiconductor element **20**.

[0068] As in this embodiment, the first adhesive **40** and the second adhesive **50** may be spaced apart from each other on the first surface **11** (or the bottom surface **23***b* of the carrier **23**). In this case, the mixing of the first adhesive **40** and the second adhesive **50** before curing is avoided. Therefore, it is possible to prevent the curing of the first adhesive **40** from being hindered by the second adhesive **50**.

[0069] As in this embodiment, the optical module **1**A may further include the third adhesive **60** disposed between the first optical port **20***a* and the second optical port **30***a*. The third adhesive **60** may mainly include a UV curable material having a faster curing speed (that is, higher reactivity) than the UV curable material of the first adhesive **40**. In this case, when irradiation with ultraviolet light is performed, the third adhesive **60** is cured faster than the first adhesive **40**. Therefore, it is possible to more firmly maintain the optically coupled state between the first optical port **20***a* and the second optical port **30***a* after the optical axis adjustment. In addition, when it is possible to selectively irradiate only the third adhesive **60** with ultraviolet light without irradiating the first adhesive **40** with ultraviolet light, the curing speed of the UV curable material of the third adhesive **60** may be the same as the curing speed of the UV curable material of the first adhesive **40**.

[0070] As in this embodiment, the contact area between the second adhesive **50** and the optical semiconductor element **20** may be larger than the contact area between the first adhesive **40** and the optical semiconductor element **20**. Heat from the optical semiconductor element **20** can be more efficiently transferred to the base material **10**A by making the contact area of the second adhesive **50** larger than the contact area of the first adhesive **40** while setting the contact area of the first adhesive **40** to a value at which fixing strength can be sufficiently ensured. The fixing strength of the first adhesive **40** is, for example, equal to or greater than a value at which it is possible to suppress the deviation between the optical axes of the first optical port **20***a* and the second optical port **30***a* when the second adhesive **50** is thermally cured.

[0071] In the manufacturing method according to this embodiment, the optical semiconductor element **20** is fixed to the first surface **11** of the base material **10**A by the first adhesive **40** and the second adhesive **50**. The first adhesive **40** mainly includes a UV curable material. The second adhesive **50** has a thermal conductivity (second thermal conductivity) higher than a thermal conductivity (first thermal conductivity) of the first adhesive **40** and mainly includes a thermosetting material. In the step of curing the first adhesive **40**, irradiation with ultraviolet light can be performed while the position of the optical semiconductor element **20** subjected to the optical axis adjustment is maintained by the chuck or the like to cure the first adhesive **40** in a state in which the second adhesive **50** is uncured. Then, in the step of curing the second adhesive **50**, the second adhesive **50** can be cured by heating in a state in which the position of the optical semiconductor element **20** subjected to the optical axis adjustment is maintained by the cured first adhesive **40**. Therefore, according to the manufacturing method of this embodiment, it is possible to fix optical semiconductor element **20** to the base material **10**A using the thermosetting material with high heat dissipation performance while maintaining the position of the optical semiconductor element **20** subjected to the optical axis adjustment. As a result, it is possible to efficiently transfer the heat from the optical semiconductor element **20** to the base material **10**A while preventing the deviation between the optical axes of the first optical port **20***a* and the second optical port **30***a*.

First Modification

[0072] FIG. **4** is a cross-sectional view showing an optical module **1**B according to a first modification of the above-described embodiment. The optical module **1**B according to this modification differs from the optical module **1**A according to the above-described embodiment in the following points and is the same as the optical module **1**A according to the above-described embodiment in points other than the following points. In the optical module **1**B according to this modification, the provision of the third adhesive **60** is omitted. In addition, the optical module **1**B according to this modification includes a base material **10**B instead of the base material **10**A. FIG. **5** is a plan view showing the base material **10**B, the first adhesive **40**, and the second adhesive **50**. Further, in the optical module **1**B according to this modification, the provision of the third adhesive **60** is omitted, but the third adhesive **60** may be provided as in the optical module **1**A. For example, the third adhesive **60** may be provided for refractive index matching between the first optical port **20***a* and the second optical port **30***a*. The third adhesive **60** has a refractive index closer to the refractive index of the optical semiconductor chip **22** and the optical circuit element **30** than to the refractive index of air (refractive index matching). This suppresses reflection between the first optical port **20***a* and the second optical port **30***a*. In the optical modules **1**A and **1**B, the optical semiconductor element **20** is mainly fixed to the base material **10**A or **10**B by the first adhesive **40** and the second adhesive **50**.

[0073] As shown in FIGS. **4** and **5**, in this modification, the first adhesive **40** is provided on two regions, between which the second adhesive **50** is interposed, on the first surface **11**. In other words, one region in which the first adhesive **40** is provided, a region in which the second adhesive **50** is provided, and another region in which the first adhesive **40** is provided are arranged side by side in this order. The arrangement direction may coincide with the arrangement direction (X direction) of the optical semiconductor elements **20** and the optical circuit elements **30**. Additionally, on the bottom surface **23***b* of the carrier **23**, the first contact surface **23***ba,* which the first adhesive **40** contacts, the second contact surface **23***bb,* which the second adhesive **50** contacts, and another first contact surface **23***ba,* which the first adhesive **40** contacts, are arranged in this order.

[0074] The base material **10**B has the first surface **11** and a groove **12** (recessed portion) formed in the first surface **11**. The groove **12** is formed at least between the first adhesive **40** and the second adhesive **50** when viewed from a normal direction (Z direction) to the first surface **11**. As shown in FIG. **4**, in a cross section extending in the X direction and the Z direction, the groove **12** can have various shapes such as a rectangular shape, an inverted trapezoidal shape, and a semicircular shape. For example, the width (the length in the X direction in FIG. **4**) of the groove **12** is 0.1 mm, and the depth (the length in the Z direction) of the groove **12** is 0.12 mm. The groove **12** may be further formed on the opposite side of the second adhesive **50** when viewed from the first adhesive **40** and on the opposite side of the first adhesive **40** when viewed from the second adhesive **50**. In the example shown in FIG. **5**, the groove **12** includes a portion **12***a,* a portion **12***b,* and a portion **12***c.* The portion **12***a* surrounds one region **11***a* in which the first adhesive **40** is provided. The portion **12***b* surrounds another region **11***b* in which the first adhesive **40** is provided. The portion **12***c* surrounds a region **11***c* in which the second adhesive **50** is provided. The shape of the portion **12***a* and the portion **12***b* when viewed from the normal direction (Z direction) to the first surface **11** is, for example, a square shape or a rectangular shape. The shape of the portion **12***c* when viewed from the normal direction (Z direction) to the first surface **11** may be a square shape or a rectangular shape. Alternatively, the shape of the portion **12***c* when viewed from the normal direction (Z direction) to the first surface **11** may be a shape obtained by cutting out the portion **12***a* and the portion **12***b* from a shape square or a rectangular shape as shown in FIG. **5**. In this case, the region in which the second adhesive **50** is provided has a shape such as an H-shape. In FIG. **5**, the portion **12***a* and the portion **12***b* are arranged in the X direction with the region **11***c* interposed therebetween. The portion **12***a* and the portion **12***b* may be arranged in the Y direction with the region **11***c* interposed therebetween.

[0075] FIGS. **6**, **7** and **8** are cross-sectional views showing a second step ST**2** (see FIG. **3**) in a process of manufacturing the optical module 1B. First, the optical semiconductor element **20** held by the chuck or the like is brought close to the first adhesive **40** and the second adhesive **50** disposed on the first surface **11** (see FIG. **6**). At this time, the first adhesive **40** and the second adhesive **50** are applied thickly in advance, considering a variation in the height from the bottom surface **23***b* of the optical semiconductor element **20** to the first optical port **20***a* due to manufacturing errors. Then, the optical semiconductor element **20** (specifically, the bottom surface **23***b* of the carrier **23**) is brought into contact with the first adhesive **40** and the second adhesive **50** (see FIG. **7**). Then, the position and angle of the optical semiconductor element **20** are adjusted such that the first optical port **20***a* is optically coupled to the second optical port **30***a* (see FIG. **8**). At this time, since the height position of the first optical port **20***a* is determined by the height position of the second optical port **30***a*, the variation in the height from the bottom surface **23***b* of the optical semiconductor element **20** to the first optical port **20***a* is absorbed by the deformation of the first adhesive **40** and the second adhesive **50** (a change in the thickness in the Z direction). When the height from the bottom surface **23***b* to the first optical port **20***a* is large, the first adhesive **40** and the second adhesive **50** are pressed by the optical semiconductor element **20**, and the thickness of the first adhesive **40** and the second adhesive **50** is reduced. In this case, excess portions of the first adhesive **40** and the second adhesive **50** spread in the X direction and approach each other. In addition, the excess portions of the first adhesive **40** and the second adhesive **50** also spread in the Y direction.

[0076] In this modification, since the base material **10**B has the groove **12** formed between the first adhesive **40** and the second adhesive **50**, the excess portions of the first adhesive **40** and second adhesive **50** that have spread in the direction in which the excess portions approach each other can be dropped into the groove **12**. Therefore, the mixing of the first adhesive **40** and the second adhesive **50** on the first surface **11** before curing is avoided. As a result, it is possible to prevent the curing of the first adhesive **40** on the first surface **11** from being hindered by the second adhesive **50**. For example, when uncured sintered silver is mixed with an uncured UV curable resin, there is a concern that the UV curable resin will not be cured sufficiently. In this case, the first adhesive **40** and the second adhesive **50** mix within the groove **12**. However, even if the curing of the first adhesive **40** within the groove **12** is insufficient, the impact on the fixation strength between the substrate **10**B and the carrier **23**, as well as the impact on the heat dissipation through the second adhesive **50**, is minimal.

[0077] In this modification, the first adhesive **40** is provided on a plurality of regions **11***a* and **11***b*, between which the second adhesive **50** is interposed, on the first surface **11**. In this case, when the second adhesive **50** is cured by heating, it is possible to suppress the inclination of the optical semiconductor element **20** with respect to the first surface **11** and to more stably maintain the position of the first optical port **20***a* after the optical axis adjustment. As a result, it is possible to more reliably prevent the deviation between the optical axes of the first optical port **20***a* and the second optical port **30***a*.

[0078] As shown in FIG. **5**, the regions **11***a* and **11***b* may be disposed so as to be line-symmetric with respect to an axis line C**1** along the first surface **11**. In this case, it is possible to suppress the inclination of the optical semiconductor element **20** after the first adhesive **40** is cured and to more stably maintain the position of the first optical port **20***a* after the optical axis adjustment. The axis line C**1** may be a center line of the region **11***c* in the X direction.

[0079] As in this modification, the region **11***a* in which the first adhesive **40** is provided may be surrounded by the portion **12***a* of the groove **12**, and the region **11***b* in which the first adhesive **40** is provided may be surrounded by the portion **12***b* of the groove **12**. In this case, since surface tension caused by an edge portion of the groove **12** occurs in the first adhesive **40**, it is possible to increase the thickness of the first adhesive **40** having low thixotropy before the optical semiconductor element **20** is brought into contact with the first adhesive **40**. As a result, it is possible to increase the absorption width of the variation in the height from the bottom surface **23***b* of the optical semiconductor element **20** to the first optical port **20***a* due to manufacturing errors, that is, the range in which the thickness of the first adhesive **40** can be changed.

Second Modification

[0080] FIG. **9** is a plan view showing a base material **10**C, a first adhesive **40**, and a second adhesive **50** according to a second modification. In this modification, four regions **11***d*, **11***e*, **11***f*, and **11***g* in which the first adhesive **40** is provided are disposed at four corners of a region **11***h* in which the second adhesive **50** is provided, respectively. The base material **10**C has a groove (recessed portion) **13**. The groove **13** includes a portion **13***a*, a portion **13***b*, a portion **13***c*, a portion **13***d*, and a portion **13***e*. The portions **13***a* to **13***d* surround the four regions **11***d* to **11***g* in which the first adhesive **40** is provided, respectively. The portion **13***e* surrounds the region **11***h* in which the second adhesive **50** is provided. The shape of the portions **13***a* to **13***d* when viewed from the normal direction (Z direction) to the first surface **11** is, for example, a square shape or a rectangular shape. The shape of the portion **13***e* when viewed from the normal direction (Z direction) to the first surface **11** may be a square shape or a rectangular shape. Alternatively, the shape of the portion **13***e* when viewed from the normal direction (Z direction) to the first surface **11** may be a shape obtained by cutting out parts of the portions **13***a* to **13***d* from a shape square or a rectangular shape as shown in FIG. **9**. In this case, the region **11***h* in which the second adhesive **50** is provided has a shape such as a cross shape.

[0081] Even in the example shown in FIG. **9**, since the base material **10**C has the groove **13** formed between the first adhesive **40** and the second adhesive **50**, the first adhesive **40** and the second adhesive **50** that have spread in the direction in which the adhesives approach each other during the optical axis adjustment can be dropped into the groove **13**. Therefore, the mixing of the uncured first adhesive **40** and the uncured second adhesive **50** on the first surface **11** is avoided. As a result, it is possible to prevent the curing of the first adhesive **40** on the first surface **11** from being hindered by the mixing of the second adhesive **50**.

[0082] Even in the example shown in FIG. **9**, the first adhesive **40** is provided on the plurality of regions **11***d*, **11***e*, **11***f*, and **11***g*, between which the second adhesive **50** is interposed, on the first surface **11**. In this case, when the second adhesive **50** is cured by heating, the optical semiconductor element **20** is fixed to the first surface **11** by the first adhesive **40** cured in advance. Therefore, it is possible to suppress the inclination of the optical semiconductor element **20** and to more stably maintain the position of the first optical port **20***a* after the optical axis adjustment. As a result, it is possible to more reliably prevent the deviation between the optical axes of the first optical port **20***a* and the second optical port **30***a*.

[0083] Even in the example shown in FIG. **9**, the regions **11***d* to **11***g* are disposed so as to be line-symmetric with respect to axis lines C**2** and C**3** along the first surface **11**. In this case, it is possible to suppress the inclination of the optical semiconductor element **20** after the first adhesive **40** is cured and to more stably maintain the position of the first optical port **20***a* after the optical axis adjustment. The axis line C**2** may be a center line of the region **11***h* in the X direction, and the axis line C**3** may be a center line of the region **11***h* in the Y direction.

[0084] Even in the example shown in FIG. **9**, the regions **11***d* to **11***g* in which the first adhesive **40** is provided may be surrounded by the portions **13***a* to **13***d* of the groove **13**, respectively. In this case, since surface tension caused by an edge portion of the groove **13** is occurs in the first adhesive **40**, it is possible to increase the thickness of the first adhesive **40** having low thixotropy before the optical semiconductor element **20** is brought into contact with the first adhesive **40**. As a result, it is possible to increase the absorption range of the variation in the height from the bottom surface **23***b* of the optical semiconductor element **20** to the first optical port **20***a* due to manufacturing errors, that is, the range in which the thickness of the first adhesive **40** can be changed.

Third Modification

[0085] FIG. **10** is a cross-sectional view of the optical module **1**C according to a third modification. The optical module **1**C of this modification differs from the optical module **1**B of the first modification in the following points and is the same as the optical module **1**B of the first modification in points other than the following points. The optical module **1**C of this modification includes a carrier **23**A instead of the carrier **23**. Similar to the carrier **23** of the above embodiment, the carrier **23**A has a substantially rectangular parallelepiped appearance and includes a mounting surface **23***a* and a bottom surface **23***b*. The optical semiconductor chip **22** is mounted on the mounting surface **23***a*. The bottom surface **23***b* faces the first surface **11**. The material of the carrier **23**A is the same as that of the carrier **23** of the above embodiment.

[0086] FIG. **11** is a perspective view showing the appearance of the carrier **23**A. As shown in FIGS. **10** and **11**, in the carrier **23**A, both the first contact surface **23***ba* and the second contact surface **23***bb* are flat surfaces, and the distance D**2** between the second contact surface **23***bb* and the first surface **11** is smaller than the distance D**1** between the first contact surface **23***ba* and the first surface **11**. In other words, the first contact surface **23***ba* is recessed in the direction toward the mounting surface **23***a* relative to the second contact surface **23***bb*. That is, the first contact surface **23***ba* is positioned closer to the mounting surface **23***a* relative to a virtual plane including the second contact surface **23***bb*. Therefore, a step **23***e* is formed between the first contact surface **23***ba* and the second contact surface **23***bb*. The surface of the step **23***e* is either perpendicular to or inclined to the bottom surface **23***b*. The difference between the distance D**2** and the distance D**1** (D**2**−D**1**), that is, the height of the step **23***e*, is, for example, 20 μm or more and 50 μm or less. The distance D**1** is, for example, 20 μm or more and 70 μm or less.

[0087] One of the two first contact surfaces **23***ba* of the carrier **23**A extends along the Y direction while contacting the first adhesive **40** provided on the region **11***a* (see FIG. **5**). The other of the two first contact surfaces **23***ba* extends along the Y direction while contacting the first adhesive **40** provided on the region **11***b* (see FIG. **5**). Both ends of these first contact surfaces **23***ba* reach the pair of side surfaces of the carrier **23**A, namely, the side surfaces **23***j* and **23***k*, which intersect the Y direction and face each other.

[0088] The position of the step **23***e* in the X direction may be determined based on the relative positional relationship with the groove **12**. That is, as viewed from the normal direction of the bottom surface **23***b*, the step **23***e* may be positioned over the groove **12** or positioned outward relative to the groove **12**.

[0089] The effects obtained by this modification will be described. FIG. **12** is a diagram for explaining the issues associated with the optical module according to the above-described embodiment and each modification. As described above, on the first surface **11**, the first adhesive **40** and the second adhesive **50** are spaced apart from each other. In the first and second modifications, the excess portions of the first adhesive **40** and the second adhesive **50**, which spread in the direction approaching each other before curing, are dropped into the groove **12**. However, the first adhesive **40**, which has relatively high fluidity before curing, may spread along the bottom surface **23***b* of the carrier **23**, and in such a case, the first adhesive **40** may contact the second adhesive **50** on and near the bottom surface **23***b* as shown in part A of FIG. **12**. As a result, the first adhesive **40** and the second adhesive **50** may mix on the first surface **11**, and the curing of the first adhesive **40** on the first surface **11** may be hindered by the second adhesive **50**. Additionally, if the first adhesive **40** enters between the second adhesive **50** and the bottom surface **23***b*, the area of the second contact surface **23***bb* decreases, and heat dissipation is reduced.

[0090] In response to the above issues, in this modification, the distance D**2** between the second contact surface **23***bb* and the first surface **11** is smaller than the distance D**1** between the first contact surface **23***ba* and the first surface **11**, on the bottom surface **23***b* of the carrier **23**A. In this case, as shown in FIG. **13**, even if the first adhesive **40** spreads along the bottom surface **23***b* before curing, the spread portion of the first adhesive **40** is dammed by the step **23***e*, so that the first adhesive **40** is prevented from spreading to the second contact surface **23***bb*. Therefore, according to this modification, it is possible to avoid the mixing of the first adhesive **40** and the second adhesive **50** on or near the bottom surface **23***b*, and to prevent the curing of the first adhesive **40** on or near the bottom surface **23***b* from being hindered by the second adhesive **50**. Furthermore, it is possible to prevent the first adhesive **40** from entering between the second adhesive **50** and the bottom surface **23***b* to increase the area of the second contact surface **23***bb*, so that heat dissipation is improved.

[0091] FIG. **14** is a perspective view showing the appearance of the carrier **23**B as another form of this modification. The carrier **23**B differs from the carrier **23**A in that the carrier **23**B has the first contact surface **23***ba* at each of the four corners of the bottom surface **23***b*. By using this carrier **23**B in the second modification shown in FIG. **9**, the effects of this modification described above can be obtained.

Fourth Modification

[0092] FIG. **15** is a cross-sectional view of the optical module **1**D according to a fourth modification. The optical module **1**D of this modification differs from the optical module **1**C of the third modification in the following points and is the same as the optical module **1**C of the third modification in points other than the following points. The optical module **1**D of this modification includes a carrier **23**C instead of the carrier **23**A. Similar to the carrier **23** of the above embodiment, the carrier **23**C has a substantially rectangular parallelepiped appearance and includes a mounting surface **23***a* and a bottom surface **23***b*. The optical semiconductor chip **22** is mounted on the mounting surface **23***a*. The bottom surface **23***b* faces the first surface **11**. The material of the carrier **23**C is the same as that of the carrier **23** of the above embodiment.

[0093] FIG. **16** is a perspective view showing the appearance of the carrier **23**C. As shown in FIGS. **15** and **16**, the bottom surface **23***b* of the carrier **23**C includes a third contact surface **23***bc* that the first adhesive **40** contacts in addition to the first contact surface **23***ba* and the second contact surface **23***bb*. As viewed from the normal direction of the bottom surface **23***b*, the first contact surface **23***ba* is positioned between the second contact surface **23***bb* and the third contact surface **23***bc*. In other words, the third contact surface **23***bc* is positioned outward relative to the first contact surface **23***ba* and on the opposite side of the first contact surface **23***ba* relative to the second contact surface **23***bb*. The third contact surface **23***bc* is a flat surface similarly to the first contact surface **23***ba* and the second contact surface **23***bb*. The distance D**3** between the third contact surface **23***bc* and the first surface **11** is smaller than the distance DI between the first contact surface **23***ba* and the first surface **11**. In other words, the third contact surface **23***bc* protrudes toward the first surface **11** from the first contact surface **23***ba*. That is, the third contact surface **23***bc* is positioned closer to the first surface **11** relative to a virtual plane including the first contact surface **23***ba*. Therefore, the first contact surface **23***ba* forms the bottom surface of a groove sandwiched between the second contact surface **23***bb* and the third contact surface **23***bc*. The side surfaces of the groove are either perpendicular to or inclined to the bottom surface **23***b*. The shape of the groove in a cross-section perpendicular to the extending direction of the first contact surface **23***ba* is, for example, rectangular. The cross-sectional shape of the groove is not limited to this and various shapes such as trapezoidal or semicircular can be applied. The width W of the groove in the direction orthogonal to the extending direction is, for example, 50 μm or more and 140 μm or less. The depth of the groove, that is, the difference between the distance D2 and the distance D**1** (D**2**–D**1**), is, for example, 50 μm or more and 100 μm or less.

[0094] The first adhesive **40** enters the groove and contacts the inner surface of the groove. As shown in FIG. **16**, the groove and the first contact surface **23***ba* extend linearly along the Y direction. This allows the groove to be easily formed using, for example, a dicing blade. Both ends of the groove and the first contact surface **23***ba* reach the side surfaces **23***j* and **23***k* of the carrier **23**A. The distance D**3** may be greater than, smaller than, or equal to the distance D**2** between the second contact surface **23***bb* and the first surface **11**.

[0095] In this modification as well, the distance D**2** between the second contact surface **23***bb* and the first surface **11** is smaller than the distance D**1** between the first contact surface **23***ba* and the first surface **11**. Therefore, as shown in FIG. **17**, the first adhesive **40** is prevented from spreading to the second contact surface **23***bb*. Thus, it is possible to avoid the mixing of the first adhesive **40** and the second adhesive **50** on or near the bottom surface **23***b* to prevent the curing of the first adhesive **40** on or near the bottom surface **23***b* from being hindered by the second adhesive **50**.

[0096] Additionally, as shown in FIG. **17**, in case the cured first adhesive **40** reaches the side surface of the carrier **23**C, the portion **41** of the first adhesive **40** located on the side surface of the carrier **23**C and the portion **42** of the first adhesive **40** located on the first contact surface **23***ba* (i.e., inside the groove) sandwich a part of the carrier **23**C, that is, the part **231** of the carrier **23**C including the third contact surface **23***bc*, from both sides. This enhances the fixation strength between the carrier **23**C and the substrate **10**B.

[0097] FIG. **18** is a perspective view showing the appearance of the carrier **23**D as another form of this modification. The carrier **23**D differs from the carrier **23**C in that the ends of the groove with the first contact surface **23***ba* as the bottom do not reach both the side surfaces **23***j* and **23***k*. In other words, there is a gap between the first contact surface **23***ba* and each of the side surfaces **23***j* and **23***k*. Even in this form, the effects of this modification described above can be obtained. However, in the form shown in FIG. **18**, since the groove cannot be formed using a dicing blade, the groove is formed by sandblasting or other methods.

Fifth Modification

[0098] FIG. **19** is a cross-sectional view of the optical module **1**E according to a fifth modification. The optical module **1**E of this modification differs from the optical module **1**C of the third modification in the following points and is the same as the optical module **1**C of the third modification in points other than the following points. The optical module **1**E of this modification includes a carrier **23**E instead of the carrier **23**A. Similar to the carrier **23** of the above embodiment, the carrier **23**E has a substantially rectangular parallelepiped appearance and includes a mounting surface **23***a* and a bottom surface **23***b*. The optical semiconductor chip **22** is mounted on the mounting surface

23*a*. The bottom surface 23*b* faces the first surface **11**. The material of the carrier **23**E is the same as that of the carrier **23** of the above embodiment.

[0099] As shown in FIG. **19**, the bottom surface **23***b* of the carrier **23**E includes, in addition to the first contact surface **23***ba* and the second contact surface **23***bb*, a third contact surface **23***bd* that the first adhesive **40** contacts. As viewed from the normal direction of the bottom surface **23***b*, the first contact surface **23***ba* is positioned between the second contact surface **23***bb* and the third contact surface **23***bd*. In other words, the third contact surface **23***bd* is positioned outward relative to the first contact surface **23***ba* and on the opposite side of the first contact surface **23***ba* relative to the second contact surface **23***bb*. The third contact surface **23***bd* is a flat surface similarly to the first contact surface **23***ba* and the second contact surface **23***bb*. The distance D**4** between the third contact surface **23***bd* and the first surface **11** is larger than the distance D**1** between the first contact surface **23***ba* and the first surface **11**. In other words, the third contact surface **23***bd* is recessed in the direction toward the mounting surface **23***a* relative to the first contact surface **23***ba*. That is, the third contact surface **23***bd* is positioned closer to the mounting surface **23***a* relative to the virtual plane including the first contact surface **23***ba*. Therefore, a step **23***i* is formed between the first contact surface **23***ba* and the third contact surface **23***bd*. The surface of the step **23***i* is either perpendicular to or inclined to the bottom surface **23***b*. The difference between the distance D**4** and the distance D**1** (D**4**−D**1**), that is, the height of the step **23***i*, is, for example, 0.01 mm or more and 0.05 mm or less.

[0100] In this modification as well, the distance D**2** between the second contact surface **23***bb* and the first surface **11** is smaller than the distance D**1** between the first contact surface **23***ba* and the first surface **11**. Therefore, the first adhesive **40** is prevented from spreading to the second contact surface **23***bb*. Additionally, in this modification, the distance D**4** between the third contact surface **23***bd* and the first surface **11** is greater than the distance D**1** between the first contact surface **23***ba* and the first surface **11**. In this case, the first adhesive **40** is further dammed by the step **23***i* to prevent the first adhesive **40** from spreading to the second contact surface **23***bb* more effectively. Therefore, according to this modification, it is more effectively possible to avoid the mixing of the first adhesive **40** and the second adhesive **50** on or near the bottom surface **23***b* to prevent the curing of the first adhesive **40** on or near the bottom surface **23***b* from being hindered by the second adhesive **50**. Furthermore, it is more effectively possible to prevent the first adhesive **40** from entering between the second adhesive **50** and the bottom surface **23***b* to increase the area of the second contact surface **23***bb*, so that heat dissipation is improved even more.

[0101] The optical module and the method for manufacturing the optical module according to the present disclosure are not limited to the above-described embodiment and modifications and various other modifications can be made. For example, the disposition of the first adhesive **40** and the second adhesive **50** is not limited to the above-described embodiment and modifications. In the above-described embodiment and modifications, the optical semiconductor element **20** in which the optical semiconductor chip **22** is mounted on the carrier **23** is given as an example. The carrier **23** may be omitted, and the optical semiconductor element **20** may be configured only by the optical semiconductor chip **22**. The optical semiconductor chip **22** is not limited to the semiconductor optical amplifier (SOA) and may be another optical semiconductor chip such as a semiconductor laser. The optical circuit element **30** is not limited to the silicon photonics chip and may be another optical circuit element such as an optical waveguide substrate.

[0102] Additionally, the third modification, the fourth modification, and the fifth modification illustrate cases where the substrate **10**B with the groove **12** is used. Not limited to this example, the substrate **10**A of the embodiment (see FIG. **1**) may also be used in the third modification, the fourth modification, and the fifth modification.

What is claimed is:

1. An optical module comprising:

a base material having a first surface;

an optical semiconductor element that has a first optical port for light incidence, light emission, or light incidence and emission in a side surface thereof and is provided on the first surface;

an optical circuit element that has a second optical port for light incidence, light emission, or light incidence and emission in a side surface thereof and is disposed alongside the optical semiconductor element on the first surface, the second optical port facing the first optical port and being optically coupled to the first optical port;

a first adhesive that mainly includes a UV curable material and is disposed between the optical semiconductor element and the first surface to fix the optical semiconductor element to the first surface, the first adhesive having a first thermal conductivity; and

a second adhesive that mainly includes a thermosetting material, has a second thermal conductivity higher than the first thermal conductivity, and is disposed between the optical semiconductor element and the first surface to fix the optical semiconductor element to the first surface.

2. The optical module according to claim **1**,

wherein the optical semiconductor element includes:

an optical semiconductor chip having the first optical port; and

a carrier on which the optical semiconductor chip mounted and fixed to the first surface by the first adhesive and the second adhesive.

3. The optical module according to claim **1**,

wherein the UV curable material is a UV curable resin.

4. The optical module according to claim **1**,

wherein the thermosetting material is sintered silver.

5. The optical module according to claim **1**,

wherein the thermosetting material is epoxy-containing sintered silver.

6. The optical module according to claim **1**,

wherein the first adhesive and the second adhesive are spaced apart from each other on the first surface.

7. The optical module according to claim **1**,

wherein the base material has a recessed portion formed between the first adhesive and the second adhesive when viewed from a normal direction to the first surface.

8. The optical module according to claim **1**, further comprising:

a third adhesive that mainly includes a UV curable material having a higher curing speed than the UV curable material of the first adhesive and is disposed between the first optical port and the second optical port.

9. The optical module according to claim **1**,
wherein a contact area between the second adhesive and the optical semiconductor element is larger than a contact area between the first adhesive and the optical semiconductor element.

10. The optical module according to claim **1**,
wherein the first adhesive is provided on a plurality of regions, between which the second adhesive is interposed, on the first surface.

11. The optical module according to claim **10**,
wherein the plurality of regions are disposed so as to be line-symmetric with respect to an axis line along the first surface.

12. The optical module according to claim **1**,
wherein the optical semiconductor element has a bottom surface facing the first surface, and
wherein the first adhesive and the second adhesive are spaced apart from each other on the bottom surface of the optical semiconductor element.

13. The optical module according to claim **2**,
wherein the carrier has a bottom surface facing the first surface,
wherein the bottom surface includes a first contact surface that the first adhesive contacts and a second contact surface that the second adhesive contacts, and
wherein a distance between the second contact surface and the first surface is smaller than a distance between the first contact surface and the first surface.

14. The optical module according to claim **13**,
wherein the bottom surface further includes a third contact surface that the first adhesive contacts,
wherein, as viewed from a normal direction of the bottom surface, the first contact surface is positioned between the second contact surface and the third contact surface, and
wherein a distance between the third contact surface and the first surface is smaller than a distance between the first contact surface and the first surface.

15. The optical module according to claim **13**,
wherein the bottom surface further includes a third contact surface that the first adhesive contacts,
wherein, as viewed from a normal direction of the bottom surface, the first contact surface is positioned between the second contact surface and the third contact surface, and
wherein a distance between the third contact surface and the first surface is larger than a distance between the first contact surface and the first surface.

16. A method for manufacturing an optical module, the method comprising:
disposing, on a first surface of a base material, an optical circuit element having a second optical port for light incidence, light emission, or light incidence and emission in a side surface thereof, a first adhesive mainly including a UV curing material and having a first thermal conductivity, and a second adhesive that mainly includes a thermosetting material and has a second thermal conductivity higher than the first thermal conductivity;
disposing an optical semiconductor element having a first optical port for light incidence, light emission, or light incidence and emission in a side surface thereof such that the first optical port is optically coupled to the second optical port while bringing the optical semiconductor element into contact with the first adhesive and the second adhesive;
curing the first adhesive using irradiation with ultraviolet light while maintaining the optical semiconductor element at a position adjusted for optical coupling; and
curing the second adhesive using heating in a state in which the first adhesive is already cured.

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