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(54) **OPTICAL MODULE**

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(57) **ABSTRACT**

An optical module includes a wiring substrate and an optical waveguide device mounted on the wiring substrate. The wiring substrate includes a core substrate, a wiring structure formed on an upper surface of the core substrate, and a notch extending through the wiring structure in a thickness direction and exposing a peripheral portion of the core substrate. The optical waveguide device is mounted on an upper surface of the wiring structure at a position proximate to the notch.

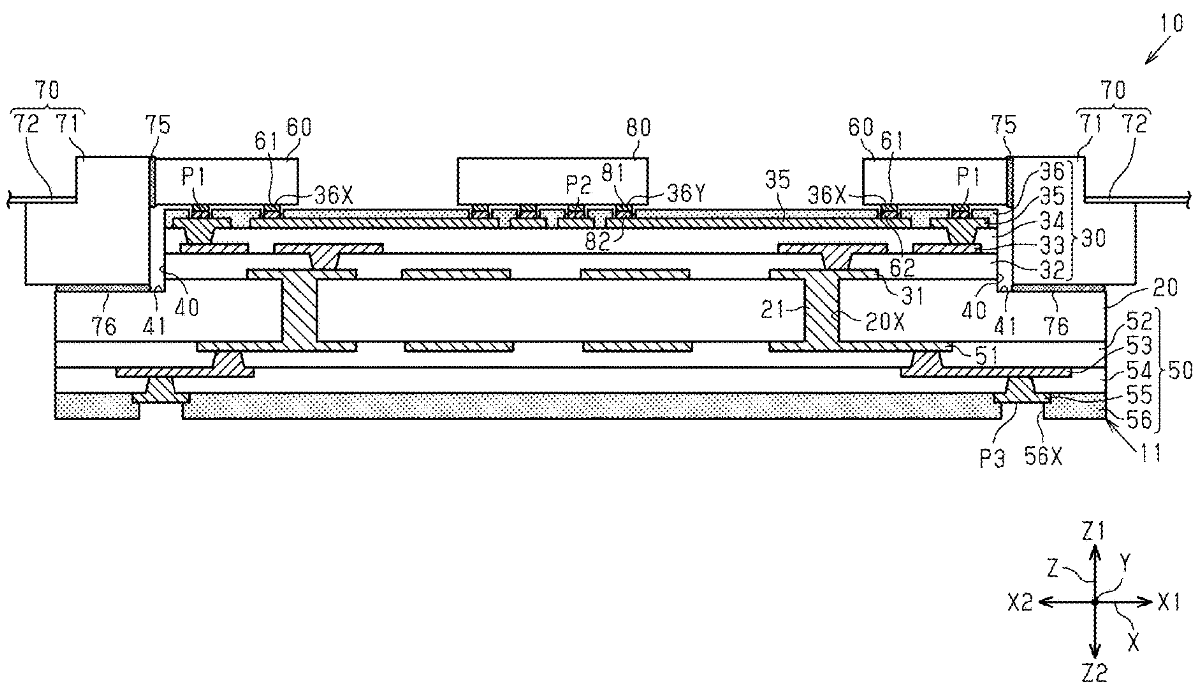

Fig.1

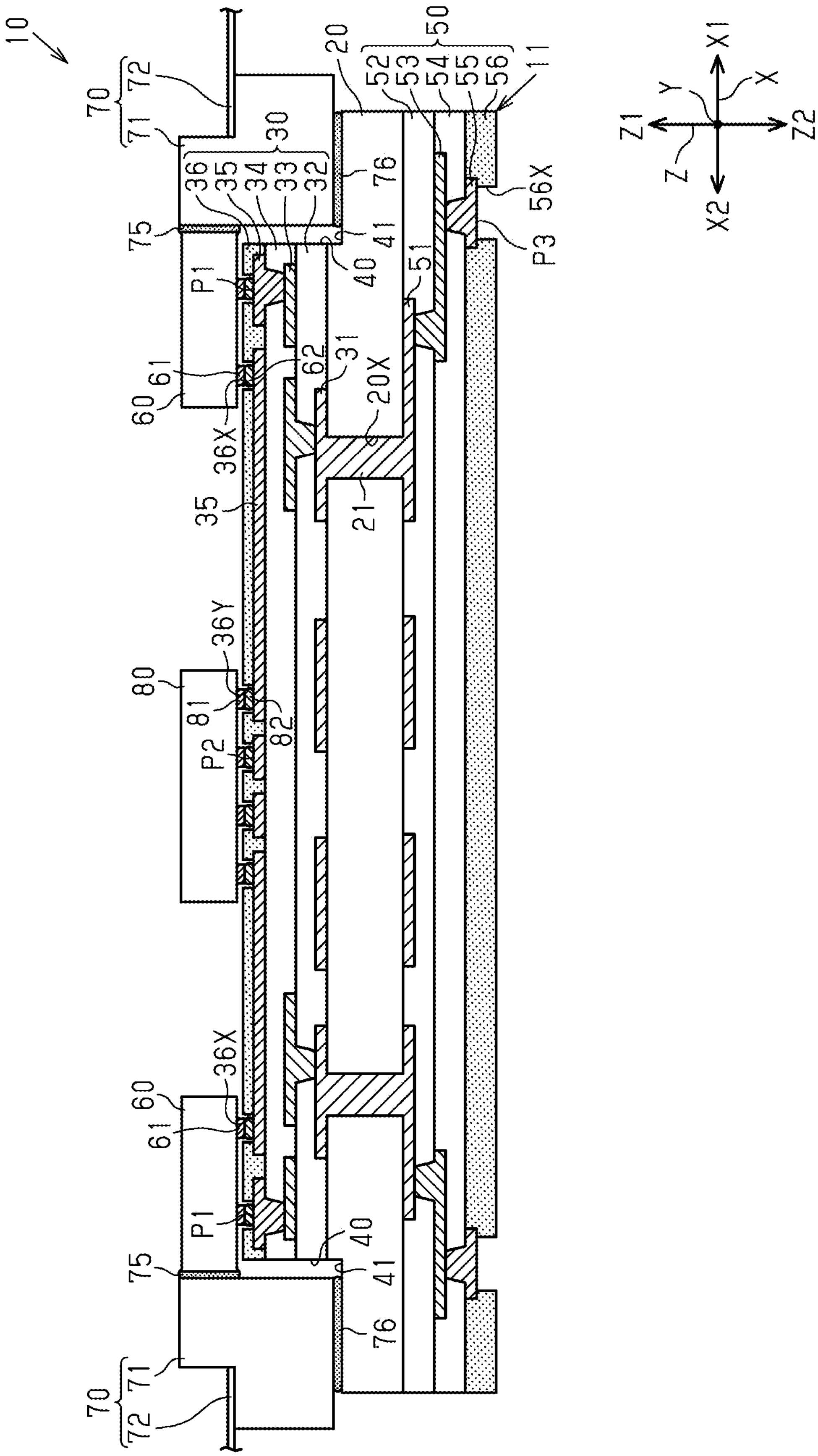
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Fig.2

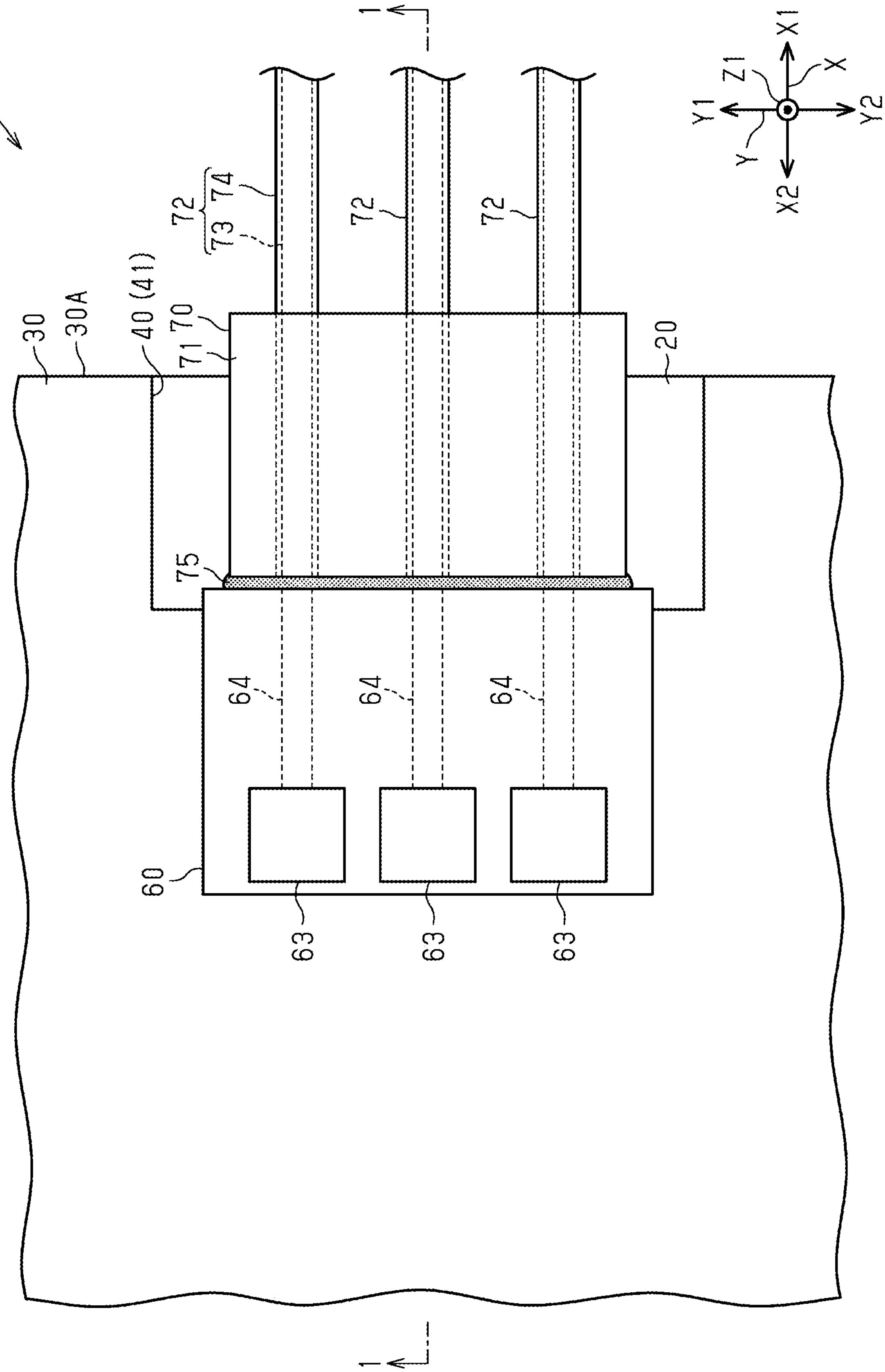
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Fig.3

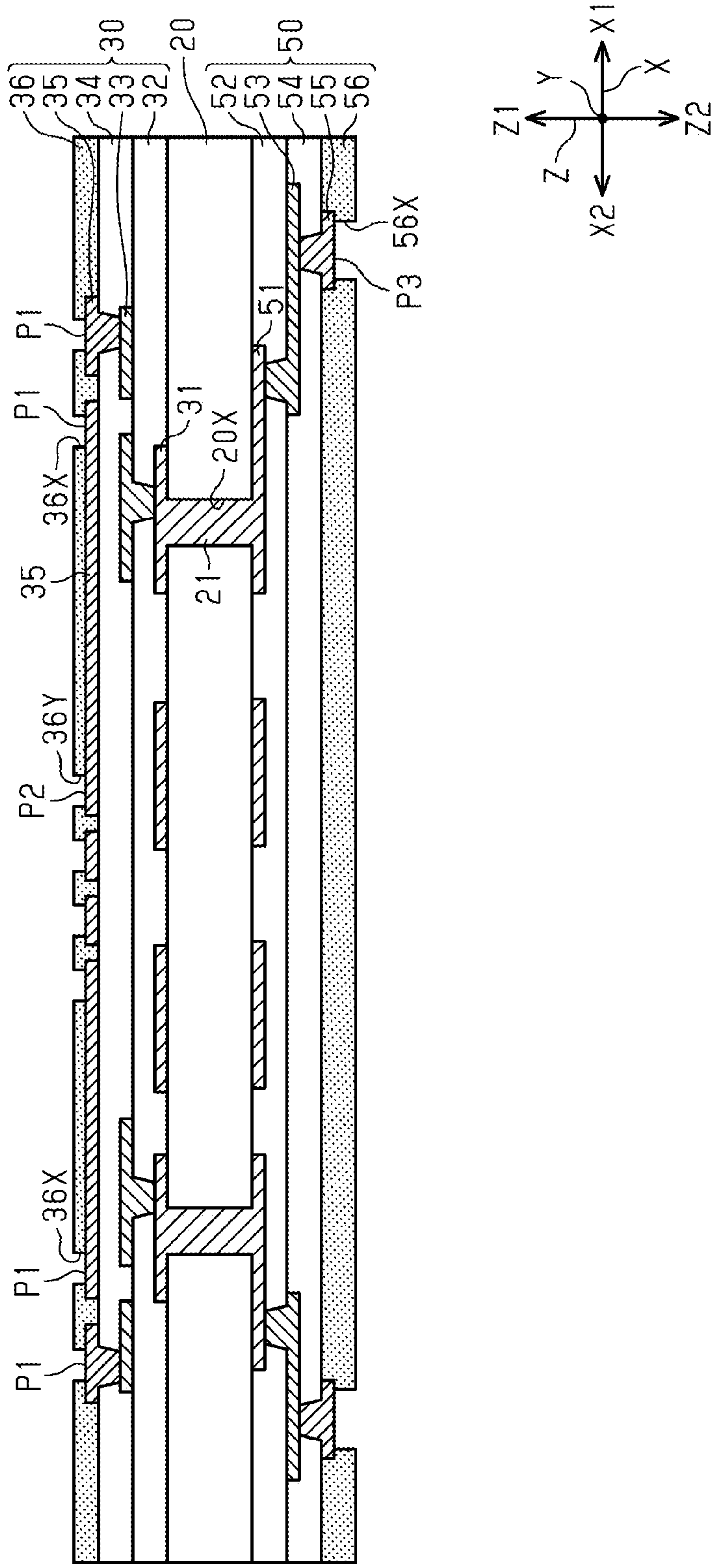
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Fig.4

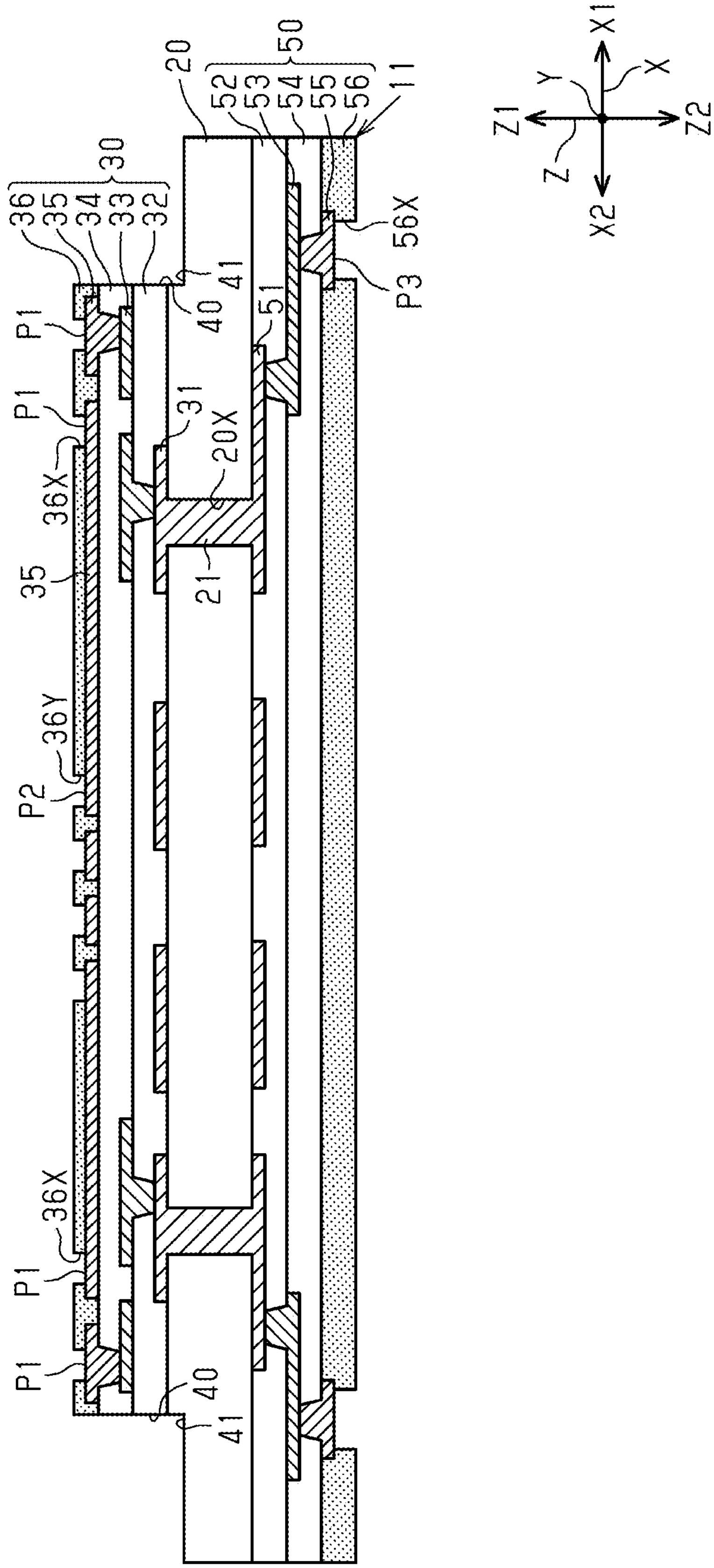

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Fig.5

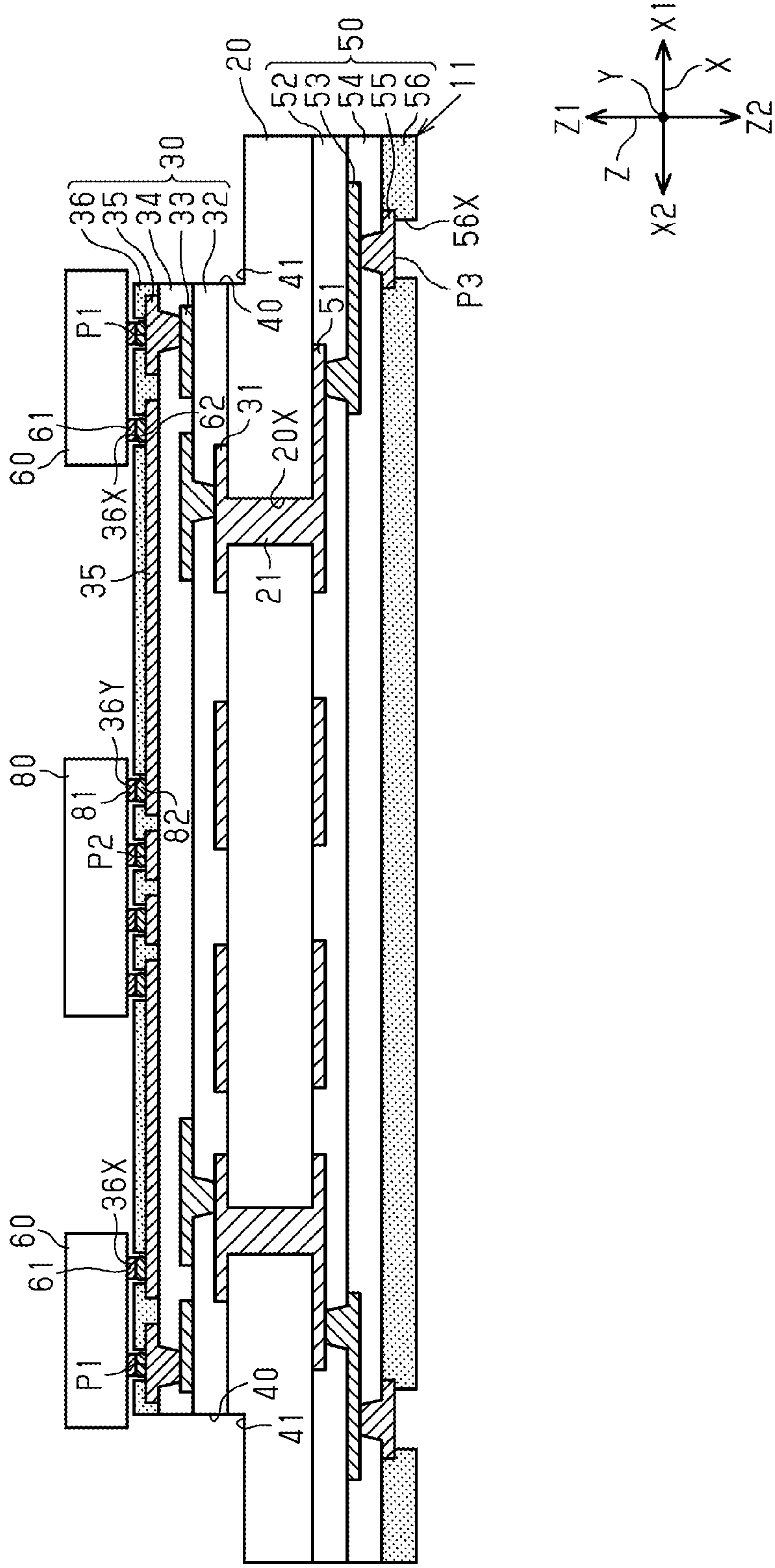
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Fig.6

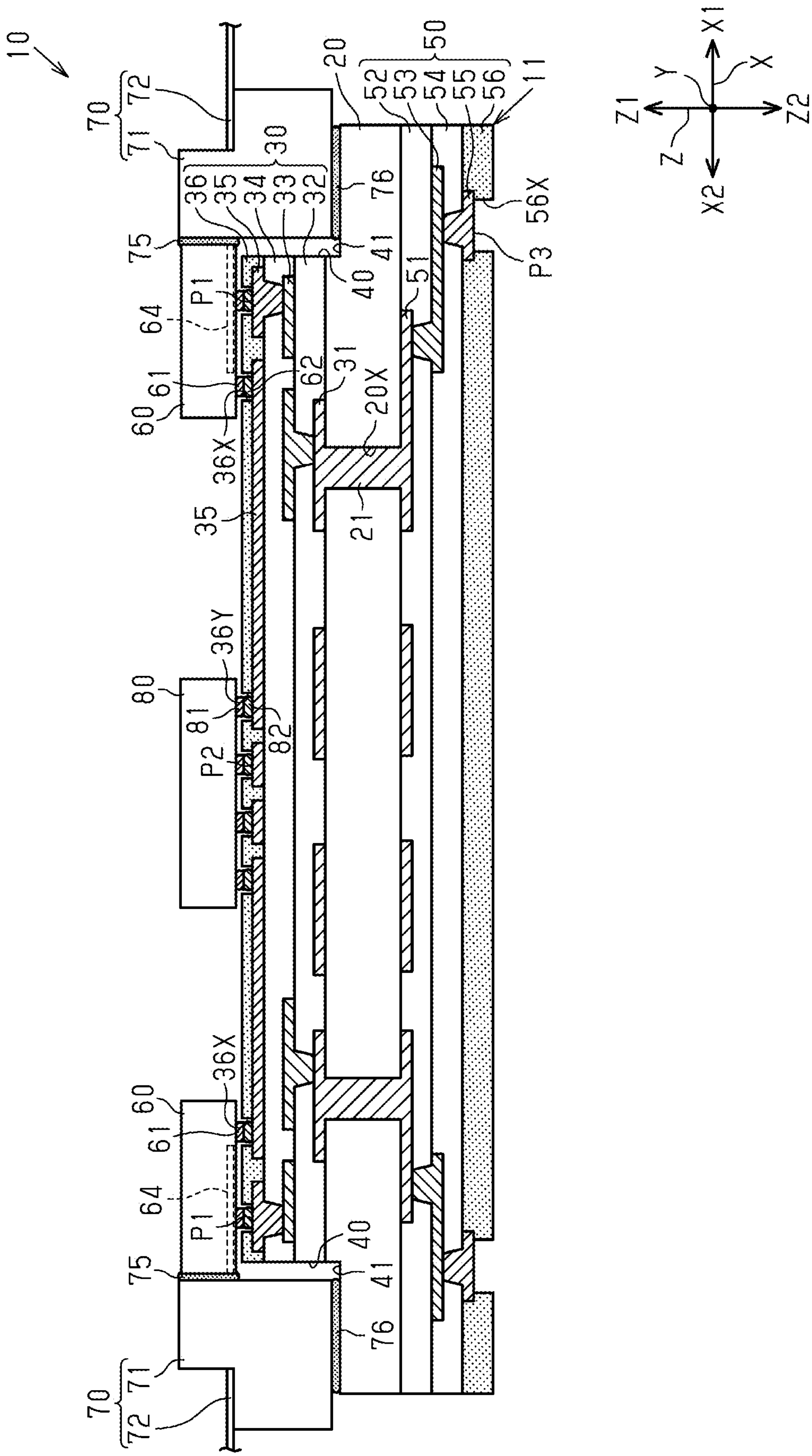
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Fig.7

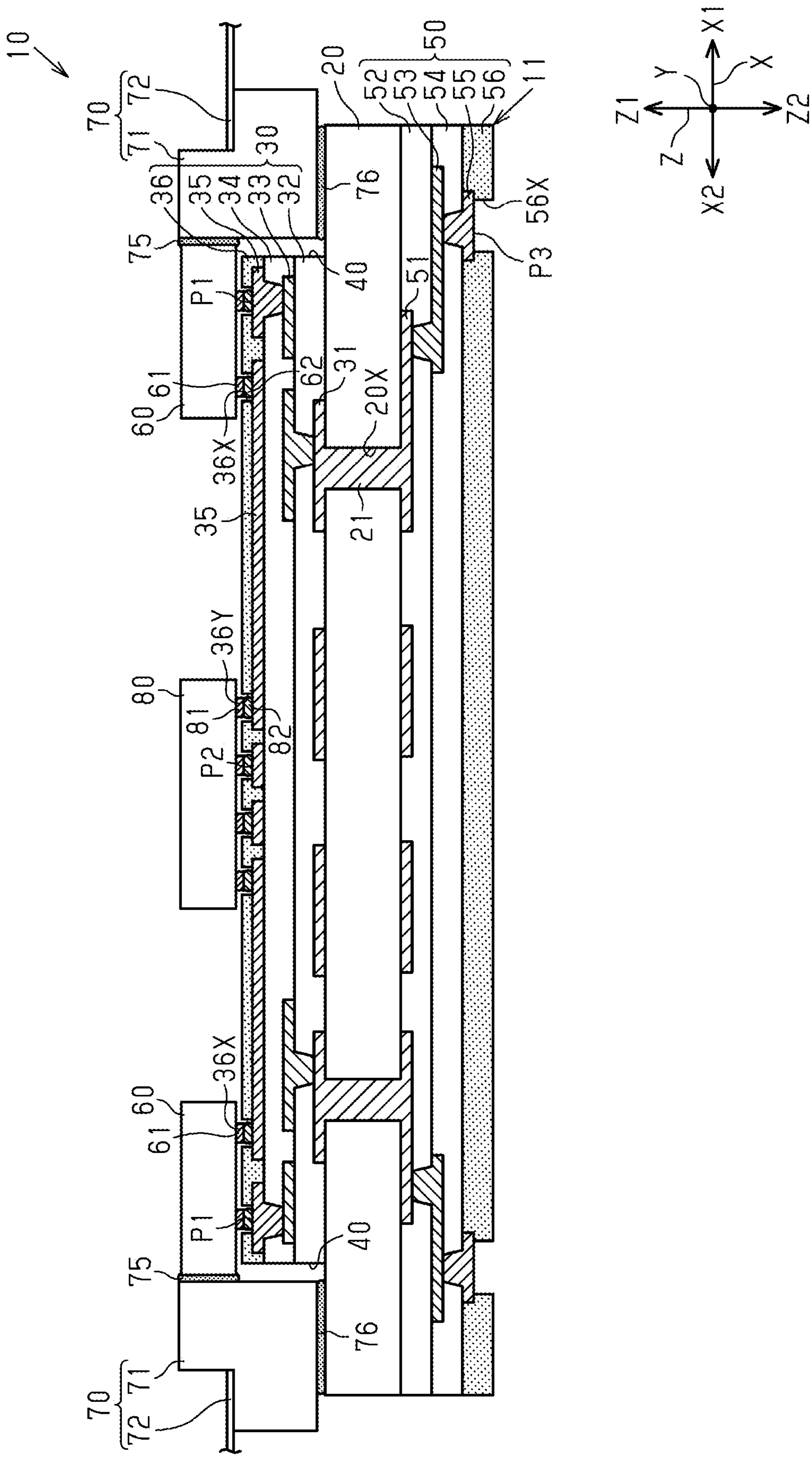
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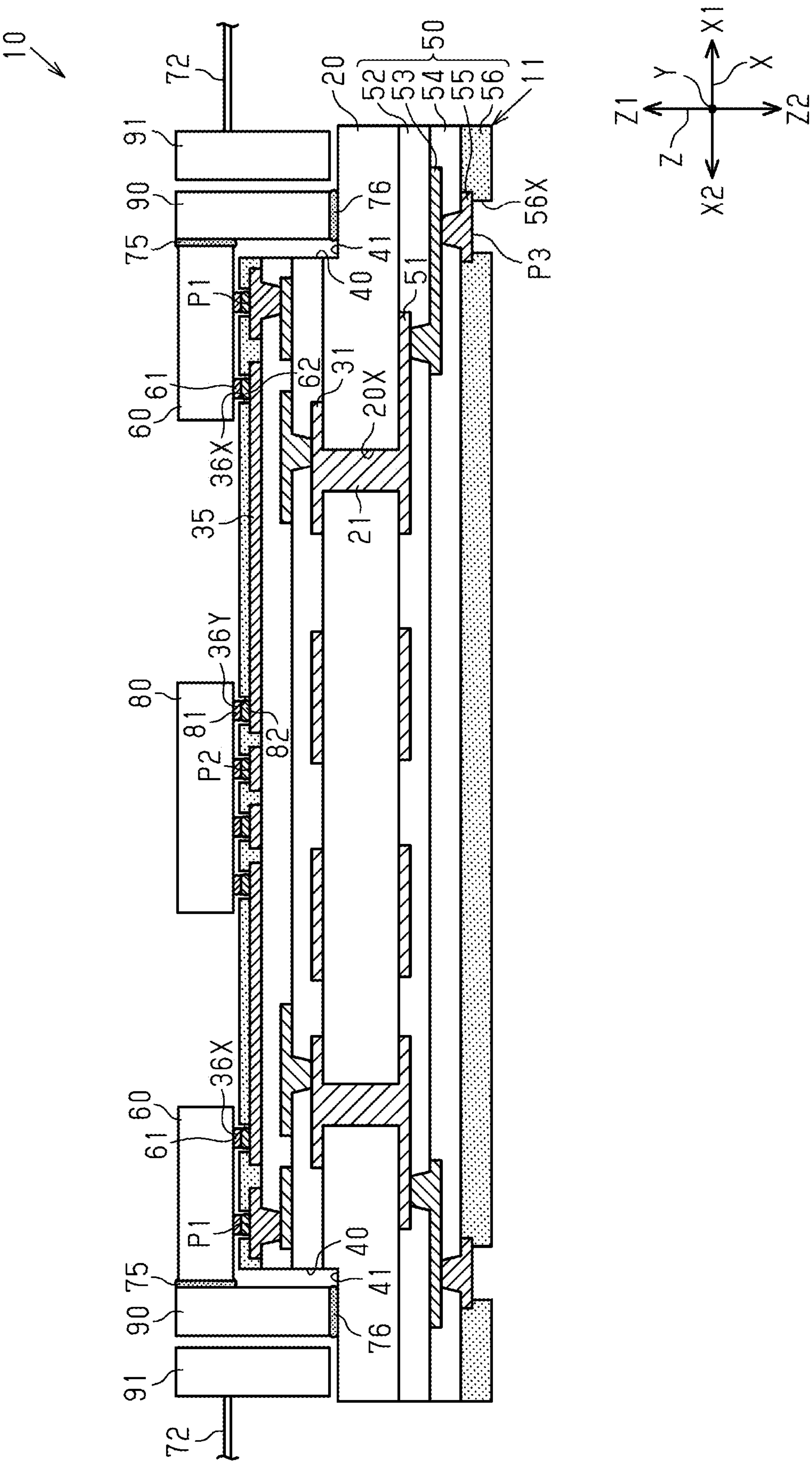
Fig.8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OPTICAL MODULE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2024-021161, filed on Feb. 15, 2024, the entire contents of which are incorporated herein by reference.

BACKGROUND

1. Field

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

2. Description of Related Art

[0003] A known optical module used for optical communication includes a wiring substrate, an optical waveguide device mounted on the wiring substrate, and an optical component coupled to the waveguide device (refer to Japanese Laid-Open Patent Publication No. 2020-64211). The optical waveguide device may be, for example, a planar lightwave circuit, an optical fiber array, or the like.

SUMMARY

[0004] In the above described optical module, it is desirable that the coupling reliability of the optical waveguide device and the optical component be improved.

[0005] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0006] In one general aspect, an optical module includes a wiring substrate and an optical waveguide device mounted on the wiring substrate. The wiring substrate includes a core substrate, a wiring structure located on an upper surface of the core substrate, and a notch extending through the wiring structure in a thickness direction and exposing a peripheral portion of the core substrate. The optical waveguide device is mounted on an upper surface of the wiring structure at a position proximate to the notch.

[0007] Other features and aspects will be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a schematic cross-sectional view of an optical module in accordance with one embodiment (cross-sectional view taken along line **1-1** in FIG. **2**).

[0009] FIG. **2** is a schematic plan view of part of the optical module illustrated in FIG. **1**.

[0010] FIGS. **3**, **4**, **5**, and **6** are schematic cross-sectional views illustrating a method for manufacturing the wiring substrate of FIG. **1**.

[0011] FIG. **7** is a schematic cross-sectional view illustrating a modified optical module.

[0012] FIG. **8** is a schematic cross-sectional view illustrating another modified optical module.

[0013] Throughout the drawings and the detailed description, the same reference numerals refer to the same elements. The drawings may not be to scale, and the relative size, proportions, and depiction of elements in the drawings may be exaggerated for clarity, illustration, and convenience.

DETAILED DESCRIPTION

[0014] This description provides a comprehensive understanding of the methods, apparatuses, and/or systems described. Modifications and equivalents of the methods, apparatuses, and/or systems described are apparent to one of ordinary skill in the art. Sequences of operations are exemplary, and may be changed as apparent to one of ordinary skill in the art, with the exception of operations necessarily occurring in a certain order. Descriptions of functions and constructions that are well known to one of ordinary skill in the art may be omitted.

[0015] Exemplary embodiments may have different forms, and are not limited to the examples described. However, the examples described are thorough and complete, and convey the full scope of the disclosure to one of ordinary skill in the art.

[0016] In this specification, "at least one of A and B" should be understood to mean "only A, only B, or both A and B."

[0017] One embodiment will now be described with reference to the drawings.

[0018] In the accompanying drawings, elements are illustrated for simplicity and clarity and have not necessarily been drawn to scale. In the cross-sectional views, to facilitate understanding of the cross-sectional structure of each member, hatching lines may be replaced by shadings or may not be illustrated. In the plan views, to facilitate understanding of the planar shapes of each member, hatching lines may be added to some of the members. Each drawing indicates an X-axis, a Y-axis, and a Z-axis, which are orthogonal to each other. The drawings indicate a first direction X**1** that extends toward one side along the X-axis, and a first opposite direction X**2** that extends opposite the first direction X**1**. Further, the drawings indicate a second direction Y**1** that extends toward one side along the Y-axis, and a second opposite direction Y**2** that extends opposite the second direction Y**1**. Further, the drawings indicate a third direction Z**1** that extends toward one side along the Z-axis, and a third opposite direction Z**2** that extends opposite the third direction Z**1**. In this specification, "plan view" refers to a view of a subject taken in the Z-axis direction unless otherwise specified. Further, in this specification, "planar shape" refers to a shape of a subject as viewed in the Z-axis direction unless otherwise specified. Also, in this specification, the term "face" is used to indicate that surfaces or members are arranged in front of each other. In this case, the surfaces or members do not have to be entirely in front of each other and may be partially in front of each other. Moreover, in this specification, the term "face" will also be used to describe situations including a case in which two members are separated from each other in addition to a case in which two members are in contact with each other. Further, unless otherwise specified, a numerical range of "X**1** to X**2**," which is specified by upper limit value X**1** and lower limit value X**2**, refers to a range that is greater than or equal to X**1** and less than or equal to X**2**.

Overall Structure of Optical Module **10**

[0019] As illustrated in FIG. **1**, an optical module **10** includes a wiring substrate **11** and one or more (two in the present embodiment) optical waveguide devices **60** mounted on the wiring substrate **11**. The optical module **10** further includes, for example, one or more (two in the present embodiment) optical fiber arrays **70** mounted on the wiring substrate **11**, and at least one (one in the present embodiment) electronic component **80** mounted on the wiring substrate **11**. Each optical fiber array **70** is an example of an optical component.

Structure of Wiring Substrate **11**

[0020] The wiring substrate **11** includes a core substrate **20**, a wiring structure **30** located on an upper surface of the core substrate **20**, and a wiring structure **50** located on the lower surface of the core substrate **20**. The wiring structure **30** is formed by sequentially stacking a wiring layer **31**, an insulation layer **32**, a wiring layer **33**, an insulation layer **34**, a wiring layer **35**, and a solder resist layer **36** on the upper surface of the core substrate **20**. The wiring structure **50** is formed by sequentially stacking a wiring layer **51**, an insulation layer **52**, a wiring layer **53**, an insulation layer **54**, a wiring layer **55**, and a solder resist layer **56** on the lower surface of the core substrate **20**.

[0021] The wiring layers **31**, **33**, **35**, **51**, **53**, and **55** may be formed from, for example, copper or a copper alloy. The wiring layers **31**, **33**, **35**, **51**, **53**, and **55** may each have a coefficient of thermal expansion (CTE) of, for example, approximately 15 ppm/° C. to 18 ppm/° C. Further, the wiring layers **31**, **33**, **35**, **51**, **53**, and **55** may each have a thickness of, for example, approximately 5 μm to 20 μm.

[0022] The insulation layers **32**, **34**, **52**, and **54** may be formed from, for example, an insulative thermosetting resin. The insulative thermosetting resin may be an insulative resin such as an epoxy resin, a polyimide resin, or a cyanate resin. The insulation layers **32**, **34**, **52**, and **54** may contain, for example, a filler of silica or alumina. The insulation layers **32**, **34**, **52**, and **54** may each have a coefficient of thermal expansion of, for example, approximately 20 ppm/° C. to 40 ppm/° C. The insulation layers **32**, **34**, **52**, and **54** may each have a thickness of, for example, approximately 10 μm to 30 μm.

[0023] The solder resist layers **36** and **56** may be formed from, for example, an insulative resin of which the main component is a photosensitive resin such as a phenolic resin or a polyimide resin. the solder resist layers **36** and **56** may contain, for example, a filler of silica or alumina. The solder resist layers **36** and **56** may each have a coefficient of thermal expansion of, for example, approximately 20 ppm/° C. to 40 ppm/° C. The solder resist layers **36** and **56** may each have a thickness of, for example, approximately 10 μm to 30 μm.

Structure of Core Substrate **20**

[0024] The core substrate **20** is arranged in, for example, the middle part of the wiring substrate **11** in the thickness direction. The core substrate **20** has the form of, for example, a flat plate. The core substrate **20** may have any planar shape. The core substrate **20** may have, for example, a rectangular planar shape.

[0025] The core substrate **20** is an insulation layer having higher rigidity than the insulation layers **32** and **34** of the wiring structure **30**. The core substrate **20** is, for example, thicker than the insulation layers **32** and **34**. The core substrate **20** may have a thickness of, for example, approximately 50 μm to 500 μm. Preferably, the core substrate **20** is formed from a material having a coefficient of thermal expansion similar to that of the optical waveguide devices **60** and the optical fiber arrays **70**. The material of the core substrate **20** may be, for example, glass, silicon, or the like. The core substrate **20** is configured by, for example, a single layer. That is, the core substrate **20** is a single member.

[0026] The core substrate **20** has, for example, approximately the same coefficient of thermal expansion as the optical waveguide devices **60**. The core substrate **20** has, for example, approximately the same coefficient of thermal expansion as the optical fiber arrays **70**. In the present specification, "approximately the same" in the phrase of "approximately the same coefficient of thermal expansion" refers to a range in which the difference in the coefficient of thermal expansion between the core substrate **20** and the optical waveguide devices **60** or the optical fiber arrays **70** is within a range of 10 ppm/° C. or less. The coefficient of thermal expansion of the optical waveguide devices **60** may be, for example, approximately 3 ppm/° C. to 6 ppm/° C. The coefficient of thermal expansion of the optical fiber arrays **70** may be, for example, approximately 3 ppm/° C. to 6 ppm/° C. The coefficient of thermal expansion of the core substrate **20** may be, for example, approximately 3 ppm/° C. to 12 ppm/° C.

[0027] The difference in the coefficient of thermal expansion between the core substrate **20** and the optical waveguide devices **60** is, for example, less than the difference in the coefficient of thermal expansion between the wiring structure **30** and the optical waveguide devices **60**. In the example of FIG. **1**, the difference in the coefficient of thermal expansion between the core substrate **20** and the optical waveguide devices **60** is, for example, less than the difference in the coefficient of thermal expansion between wiring layers **31**, **33**, and **35** of the wiring structure **30** and the optical waveguide devices **60**. Further, the difference in the coefficient of thermal expansion between the core substrate **20** and the optical waveguide devices **60** is, for example, less than the difference in the coefficient of thermal expansion between the insulation layers **32** and **34** of the wiring structure **30** and the optical waveguide devices **60**. The difference in the coefficient of thermal expansion between the core substrate **20** and the optical waveguide devices **60** is, for example, less than the difference in the coefficient of thermal expansion between the solder resist layer **36** of the wiring structure **30** and the optical waveguide devices **60**.

[0028] The difference in the coefficient of thermal expansion between the core substrate **20** and the optical fiber arrays **70** is, for example, less than the difference in the coefficient of thermal expansion between the wiring structure **30** and the optical fiber arrays **70**. In the example of FIG. **1**, the difference in the coefficient of thermal expansion between the core substrate **20** and the optical fiber arrays **70** is, for example, less than the difference in the coefficient of thermal expansion between the wiring layers **31**, **33**, and **35** and the optical fiber arrays **70**. Further, the difference in the coefficient of thermal expansion between the core substrate **20** and the optical fiber arrays **70** is, for example, less than the difference in the coefficient of thermal expansion between the insulation layers **32** and **34** and the optical fiber arrays **70**. The difference in the coefficient of thermal expansion between the core substrate **20** and the optical fiber arrays **70** is, for example, less than the difference in the coefficient of thermal expansion between the solder resist layer **36** and the optical fiber arrays **70**.

[0029] The core substrate **20** includes through holes **20**X extending through the core substrate **20** in the thickness direction. A through-electrode **21** extending through the core substrate **20** in the thickness direction is arranged in each through hole **20**X.

Wiring Structure **30**

[0030] The wiring layer **31** is formed on the upper surface of the core substrate **20**. The wiring layer **31** is electrically connected by the through-electrodes **21** to the wiring layer **51**. The insulation layer **32**, which covers the wiring layer **31**, is located on the upper surface of the core substrate **20**. The wiring layer **33** is located on the upper surface of the insulation layer **32**. The wiring layer **33** is, for example, formed integrally with via wiring extending through the insulation layer **32** in the thickness direction, and is electrically connected by the via wiring to the wiring layer **31**. The insulation layer **34**, which covers the wiring layer **33**, is located on the upper surface of the insulation layer **32**. The wiring layer **35** is located on the upper surface of the insulation layer **34**. The wiring layer **35** is, for example, formed integrally with via wiring extending through the insulation layer **34** in the thickness direction, and is electrically connected by the via wiring to the wiring layer **33**. The wiring layer **35** includes, for example, wiring electrically connecting the electronic component **80** and the optical waveguide devices **60** to one another. The solder resist layer **36**, which covers the wiring layer **35**, is located on the upper surface of the insulation layer **34**. The solder resist layer **36** is the outermost insulation layer (in this case, uppermost insulation layer) of the wiring substrate **11**.

[0031] The solder resist layer **36** includes openings **36**X exposing parts of the upper surface of the wiring layer **35** as connection pads P**1**. Further, the solder resist layer **36** includes openings **36**Y exposing parts of the upper surface of the wiring layer **35** as connection pads P**2**. The connection pads P**1** are, for example, connected to the optical waveguide devices **60**. The connection pads P**2** are, for example, connected to the electronic component **80**.

[0032] A surface-processed layer is formed, if necessary, on the upper surface of the wiring layer **35** exposed at the bottom of each of the openings **36**X and **36**Y. Examples of the surface-processed layer includes a gold (Au) layer, a nickel (Ni) layer/Au layer (metal layer in which Ni layer serves as bottom layer, and Au layer is formed on Ni layer), a Ni layer/palladium (Pd) layer/Au layer (metal layer in which Ni layer serves as bottom layer, Ni layer, Pd layer, and Au layer are sequentially formed in this order). Further examples of the surface-processed layer include a Ni layer/Pd layer (metal layer in which Ni layer is bottom layer, and Pd layer is formed on Ni layer) and a Pd layer/Au layer (metal layer in which the Pd layer is bottom layer, and/Au layer is formed on the Pd layer). An Au layer is a metal layer formed from Au or an Au alloy, a Ni layer is a metal layer formed from Ni or a Ni alloy, and a Pd layer is a metal layer formed from Pd or a Pd alloy. An Au layer, a Ni layer, and a Pd layer may each be, for example, a metal layer formed through an electroless plating process (electroless plating layer) or a metal layer formed through an electrolytic plating process (electrolytic plating layer). Further, the surface-processed layer may be an organic solderability preservative (OSP) film formed on the upper surface of the wiring layer **35** through an anti-oxidation process such as an OSP process. The OSP film may be, for example, an organic coating of an azole compound or an imidazole compound. When the surface-processed layer is formed on the upper surface of the wiring layer **35**, the surface-processed layer acts as the connection pads P**1** and P**2**.

Wiring Structure **50**

[0033] The wiring layer **51** is formed on the lower surface of the core substrate **20**. The wiring layer **51** is electrically connected by the through-electrodes **21** to the wiring layer **31**. The insulation layer **52**, which covers the wiring layer **51**, is located on the lower surface of the core substrate **20**. The wiring layer **53** is located on the lower surface of the insulation layer **52**. The wiring layer **53** is, for example, formed integrally with via wiring extending through the insulation layer **52** in the thickness direction, and is electrically connected by the via wiring to the wiring layer **51**. The insulation layer **54**, which covers the wiring layer **53**, is located on the lower surface of the insulation layer **52**. The wiring layer **55** is located on the lower surface of the insulation layer **54**. The wiring layer **55** is, for example, formed integrally with via wiring extending through the insulation layer **54** in the thickness direction, and is electrically connected by the via wiring to the wiring layer **53**. The solder resist layer **56**, which covers the wiring layer **55**, is located on the lower surface of the insulation layer **54**. The solder resist layer **56** is the outermost insulation layer (in this case, lowermost insulation layer) of the wiring substrate **11**.

[0034] The solder resist layer **56** includes openings **56**X exposing parts of the lower surface of the wiring layer **55** as external connection pads P**3**. The external connection pads P**3** are connected to external connection terminals (not illustrated) used when mounting the optical module **10** on a mounting substrate such as a motherboard.

[0035] A surface-processed layer is formed, if necessary, on the lower surface of the wiring layer **55** exposed at the bottom of each of the openings **56**X. Examples of the surface-processed layer include an OSP film or a metal layer such as a Au layer, a Ni layer/Au layer, a Ni layer/Pd layer/Au layer, a Ni layer/Pd layer, or a Pd layer/Au layer.

[0036] In the present example, external connection terminals (not illustrated) are arranged on the lower surface of the wiring layer **55**. Instead, the wiring layer **55** exposed at the bottom of each opening **56**X may be used as the external connection terminals. Alternatively, when a surface-processed layer is formed on the lower surface of the wiring layer **55**, the surface-processed layer may be used as the external connection terminals.

[0037] The wiring substrate **11** includes one or more notches **40**. The wiring substrate **11** of the present embodiment includes two notches **40**. In FIG. **1**, the wiring substrate **11** includes two notches **40** respectively corresponding to the two optical fiber arrays **70**. Since the two notches **40** are identical in structure, the description hereafter will focus on the notch **40** located in the end of the wiring substrate **11** in the first direction X**1** (right side as viewed in FIG. **1**). Thus, the description will also apply to the other notch **40** located at the opposite side.

[0038] The notch **40** extends through the wiring structure **30** in the thickness direction and exposes the peripheral portion of the core substrate **20**. The notches **40** exposes, for example, part of the peripheral portion of the core substrate **20**. As illustrated in FIG. **2**, the notch **40** is sized to receive the corresponding optical fiber array **70** on the part of the peripheral portion of the core substrate **20**. The notch **40** extends through the solder resist layer **36** in the thickness direction, and extends through the insulation layers **32** and **34** in the thickness direction.

[0039] With reference to FIG. **2**, the end surface **30**A of the wiring structure **30** in the first direction X**1** is cut out in the first opposite direction X**2** to form the notch **40**. Thus, the notch **40** is indented from the end surface **30**A in the first opposite direction X**2**. As illustrated in FIG. **1**, the notch **40** is open in the first direction X**1** and in the third direction Z**1**. As illustrated in FIG. **2**, the notch **40** has, for example, a rectangular planar shape. The notch **40** is not limited to a rectangular planar shape and may have any planar shape. The notch **40** extends from the end surface **30**A in the first opposite direction X**2** and in the second direction Y**1**. The notch **40** extends, for example, over only part of the wiring structure **30** in the second direction Y**1**. The notch **40** extends, for example, over an intermediate portion of the wiring structure **30** in the second direction Y**1**.

[0040] The notch **40** is smaller in dimension in the second direction Y**1** than the wiring structure **30**. The notch **40** is larger in dimension in the second direction Y**1** than the corresponding optical waveguide device **60**. The notch **40** is larger in dimension in the second direction Y**1** than the corresponding optical fiber array **70**.

[0041] As illustrated in FIG. **1**, the inner end surface of the notch **40**, that is, the end surface of the notch **40** in the first opposite direction X**2**, is defined by, for example, the end surface of the insulation layer **32**, the end surface of the insulation layer **34**, and the end surface of the solder resist layer **36**. In one example, the end surface of the insulation layer **32**, the end surface of the insulation layer **34**, and the end surface of the solder resist layer **36**, which define the inner end surface of the notch **40**, are flush with one another.

[0042] The upper surface of the core substrate **20** exposed by the notch **40** includes, for example, a recess **41**. The recess **41** is recessed from the upper surface of the core substrate **20** toward the wiring structure **50** (i.e., in third opposite direction Z**2**). The recess **41** does not extend through the core substrate **20** in the thickness direction. The recess **41** has a bottom surface located at an intermediate position of the core substrate **20** in the thickness direction. In other words, the core substrate **20** includes a thin portion that is reduced in thickness by the recess **41** so that an upper surface of the thin portion defines the bottom surface of the recess **41**. This defines a thin portion having an upper surface corresponding to the bottom surface of the recess **41**. The recess **41** is, for example, in communication with the notch **40**. The recess **41** is formed in, for example, the entire part of the upper surface of the core substrate **20** that is exposed by the notch **40**. In this case, the recess **41** and the notch **40** are identical in planar shape. Further, the recess **41** and the notch **40** have the same planar size.

[0043] The optical waveguide devices **60**, the optical fiber arrays **70**, and the electronic component **80** are mounted on the wiring substrate **11**. Optical functional elements other than the optical waveguide devices **60** and the optical fiber arrays **70** may be mounted on the wiring substrate **11**. Examples of optical functional elements include an optical modulator, an optical amplifier, and an optical attenuator.

Structure of Optical Waveguide Device **60**

[0044] Each optical waveguide device **60** includes electrode pads **61** formed on one surface (in this case, lower surface) of the optical waveguide device **60**. The optical waveguide device **60** is mounted on the upper surface of the wiring substrate **11**. The optical waveguide device **60** is, for example, flip-chip mounted on the upper surface of the wiring structure **30** of the wiring substrate **11**. The electrode pads **61** of the optical waveguide device **60** are electrically connected by a bonding member **62** to the connection pads P**1** of the wiring substrate **11**. Thus, the optical waveguide device **60** is electrically connected by the electrode pads **61** and the bonding member **62** to the wiring layer **35** of the wiring substrate **11**.

[0045] The electrode pads **61** respectively face the connection pads P**1**. Each electrode pad **61** is, for example, cylindrical and projects downward from the lower surface of the optical waveguide device **60**. Each electrode pad **61** is, for example, a metal post. The electrode pads **61** may be formed from, for example, copper or a copper alloy.

[0046] The bonding member **62** may include, for example, gold bumps or solder bumps. The material of the solder bumps may be, for example, an alloy including lead (Pb), an alloy of tin (Sn) and Au, an alloy of Sn and Cu, an alloy of Sn and silver (Ag), or an alloy of Sn, Ag, and Cu.

[0047] Since the two optical waveguide devices **60** are identical in structure, the description hereafter will focus on the optical waveguide device **60** located on the end of the wiring substrate **11** in the first direction X**1** (right side as viewed in FIG. **1**). Thus, the description will also apply to the other optical waveguide device **60** located at the opposite side.

[0048] As illustrated in FIG. **2**, the optical waveguide device **60** includes, for example, one or more (three in the present embodiment) optical elements **63** and one or more (three in the present embodiment) optical waveguides **64**. The optical waveguide device **60** is, for example, a silicon photonics component. Each optical waveguide **64** is, for example, a silicon optical waveguide.

[0049] Each optical element **63** may be, for example, a light emitting element, for example, a surface emitting semiconductor laser, such as a vertical cavity surface emitting laser (VCSEL), or a light emitting diode (LED). The optical element **63** may also be, for example, a light receiving element such as a photodiode or an avalanche photodiode.

[0050] The optical waveguides **64** are, for example, respectively coupled (optically coupled) to the optical elements **63**. The optical waveguides **64**, for example, couple the optical elements **63** to the optical fiber array **70**. The optical waveguides **64** are, for example, elongated in the first direction X**1**. The end of each optical waveguide **64** in the first direction X**1** is optically coupled to the optical fiber array **70**, and the end of each optical waveguide **64** in the first opposite direction X**2** is optically coupled to the corresponding optical element **63**. Each optical waveguide **64** extends, for example, from the corresponding optical element **63** to the end surface of the optical waveguide device **60** in the first direction X**1**. The optical waveguides **64** are arranged, for example, next to one another in the second direction Y**1**. Although not illustrated in the drawings, each optical waveguide **64** includes, for example, a core, which transmits optical signals, and cladding, which surrounds the core.

[0051] The optical waveguide device **60** is located proximate to the notch **40**. The optical waveguide device **60** is mounted on the upper surface of the wiring structure **30** at a position proximate to the notch **40**. As illustrated in FIG. **1**, the notch **40** defines a step between the upper surface of the wiring structure **30** and the upper surface of the core substrate **20**. The optical waveguide device **60** is mounted on the upper surface of the wiring structure **30** so that a part of the optical waveguide device **60** projects beyond a wall of the step into the notch **40** in plan view. The optical waveguide device **60** is arranged, for example, so that the end of the optical waveguide device **60** in the first direction **X1** overlaps the notch **40** in plan view. The end of the optical waveguide device **60** in the first direction **X1** projects in the first direction **X1** from the inner end surface of the notch **40** (wall of step), namely, the end surface of the notch **40** in the first opposite direction X**2**.

Structure of Optical Fiber Array **70**

[0052] Each optical fiber array **70** includes a housing **71** and one or more (three in the present embodiment) optical fibers **72**. The housing **71** holds three optical fibers **72**. The housing **71** holds the three optical fibers **72**, for example, in a state arranged next to one another in the second direction Y**1**.

[0053] Each optical fiber **72** includes, for example, a core **73**, which transmits optical signals, and cladding **74**, which surrounds the core **73**. The core **73** extends, for example, over the entire length of the optical fiber **72** in the longitudinal direction of the optical fiber **72**. The cladding **74** extends, for example, over the entire length of the optical fiber **72** in the longitudinal direction. The end of each optical fiber **72** in the first opposite direction X**2** is, for example, located at the same position as the end surface of the housing **71** in the first opposite direction X**2**. Each optical fiber **72** extends, for example, further in the first direction **X1** from the end of the housing **71** in the first direction **X1**.

[0054] The optical fiber array **70** faces the end surface of the optical waveguide devices **60** in the first direction **X1**. The optical fiber array **70** is arranged, for example, so that the end surface of each optical fiber **72** in the first opposite direction X**2** faces the end surface of the corresponding optical waveguide **64** in the first direction **X1**. The optical fiber array **70** is arranged so that the center axis of the core **73** in each optical fiber **72** is aligned with the center axis of the core in the corresponding optical waveguide **64**. Namely, the optical fiber array **70** is arranged so that the optical axis of the core **73** in each optical fiber **72** is aligned with the optical axis of the core of the corresponding optical waveguide **64**.

[0055] The optical fiber array **70** projects further in the first direction **X1** from the end surface **30**A of the wiring structure **30** in the first direction **X1**. The optical fiber array **70** is arranged so that the end surface of the optical fiber array **70** in the first opposite direction X**2** contacts the end surface of the optical waveguide device **60** in the first direction **X1**. In this state, a gap may form between the optical fiber array **70** and the optical waveguide device **60**.

[0056] The optical fiber array **70** is bonded by an optical adhesive **75** to the optical waveguide device **60**. Each optical fiber **72** is, for example, optically coupled by the optical adhesive **75** to the corresponding optical waveguide **64** of the optical waveguide device **60**. The optical adhesive **75**, for example, fills the gap between the optical waveguide device **60** and the optical fiber array **70**. The optical adhesive **75**, which fills the gap between the optical waveguide device **60** and the optical fiber array **70**, prevents air reflection and increases the coupling efficiency of the optical waveguides **64** and the optical fibers **72**. The optical adhesive **75**, for example, entirely covers the end surface of each optical fiber **72** in the first opposite direction X**2**. The optical adhesive **75**, for example, entirely covers the end surface of each optical waveguide **64** in the first direction **X1**. The optical adhesive **75** may be, for example, of an ultraviolet curable type. The optical adhesive **75** may have a refractive index that is close to the refractive index of the core of each optical waveguide **64** or the refractive index of the core **73** of each optical fiber **72**.

[0057] As illustrated in FIG. **1**, the optical fiber arrays **70** are mounted on the parts of the core substrate **20** exposed by the notches **40**. Each optical fiber array **70** is fixed to, for example, the bottom surface of the corresponding recess **41**. The housing **71** of the optical fiber array **70** is, for example, adhered by the adhesive agent **76** to the bottom surface of the recess **41**. The adhesive agent **76** bonds the lower surface of the housing **71** to the core substrate **20**, which defines the bottom surface of the recess **41**. The adhesive agent **76** may be, for example, of an ultraviolet curing type of a thermal curing type.

Structure of Electronic Component **80**

[0058] The electronic component **80** includes electrode pads **81** formed on one surface (in this case, lower surface) of the electronic component **80**. The electronic component **80** is mounted on the upper surface of the wiring substrate **11**. The electronic component **80** is, for example, flip-chip mounted on the upper surface of the wiring structure **30** of the wiring substrate **11**. The electrode pads **81** of the electronic component **80** are electrically connected by a bonding member **82** to the connection pads P**2** of the wiring substrate **11**. Thus, the electronic component **80** is electrically connected by the electrode pads **81** and the bonding member **82** to the wiring layer **35** of the wiring substrate **11**. The electronic component **80** is, for example, electrically connected by the wiring layers **31**, **33**, and **35** of the wiring substrate **11** and the like to the optical waveguide devices **60**. A single electronic component **80** may be provided for each optical waveguide device **60**. Alternatively, a single electronic component **80** may be provided for multiple optical waveguide devices **60**.

[0059] The electronic component **80** may be, for example, an IC chip such as a driver that drives the optical elements **63** (refer to FIG. **2**) of each optical waveguide device **60**. Further, the electronic component **80** may be, for example, an IC chip that incorporates a digital signal processor (DSP) for processing optical output signals from the optical elements **63** (refer to FIG. **2**) of each optical waveguide device **60**, or an IC chip that incorporates an amplifier for amplifying the optical output signals.

[0060] The electrode pads **81** respectively face the connection pads P**2**. Each electrode pad **81** is, for example, cylindrical and projects downward from the lower surface of the electronic component **80**. Each electrode pad **81** is, for example, a metal post. The electrode pads **81** may be formed from, for example, copper or a copper alloy.

[0061] The bonding member **82** may include, for example, gold bumps or solder bumps. The material of the solder bumps may be an alloy including Pb, an alloy of Sn and Au, an alloy of Sn and Cu, an alloy of Sn and Ag, or an alloy of Sn, Ag, and Cu.

Method for Manufacturing Optical Module **10**

[0062] A method for manufacturing the optical module **10** will now be described with reference to FIGS. **3** to **6**. To simplify illustration, elements that will ultimately become the final elements of the optical module **10** are given the same reference characters as the final elements.

[0063] First, in the step illustrated in FIG. **3**, a structural body is formed including the core substrate **20**, the wiring structure **30** on the upper surface of the core substrate **20**, and the wiring structure **50** on the lower surface of the core substrate **20**. The structural body may be formed through a process that is known in the art. Thus, the process will not be described in detail.

[0064] In the step illustrated in FIG. **4**, the notches **40** are formed extending through the wiring structure **30** in the thickness direction and exposing parts of the core substrate **20**. In the present embodiment, the formation of the notches **40** also forms the recesses **41**, which are in communication with the notches **40**. The bottom surface of each recess **41** is located downward from the upper surface of the core substrate **20**. The notches **40** and the recesses **41** may be formed by, for example, machining the wiring structure **30** from the upper surface with a router. In the present embodiment, the core substrate **20** exposed by the notches **40** is machined from the upper surface of the core substrate **20** to form the recess **41** in communication with the notches **40**. The wiring substrate **11** is manufactured through the steps described above.

[0065] Then, in the step illustrated in FIG. **5**, the optical waveguide devices **60** are mounted on the wiring substrate **11**, and the electronic component **80** is mounted on the wiring substrate **11**. In this step, the electrode pads **61** of the optical waveguide devices **60** are bonded by the bonding member **62** to the connection pads P**1** of the wiring substrate **11**. For example, when the bonding member **62** is a solder layer, the electrode pads **61** are aligned with the connection pads P**1**. Then, a reflow process is performed to melt the bonding member **62**, which is a solder layer. This electrically connects the electrode pads **61** to the connection pads P**1**. Further, in this step, the electrode pads **81** of the electronic component **80** are bonded by the bonding member **82** to the connection pads P**2** of the wiring substrate **11**. For example, when the bonding member **82** is a solder layer, the electrode pads **81** are aligned with the connection pads P**2**. Then, a reflow process is performed to melt the bonding member **82**. This electrically connects the electrode pads **81** and the connection pads P**2**. The optical waveguide devices **60** are arranged to partially overlap the corresponding notches **40** in plan view.

[0066] In the step illustrated in FIG. **6**, the optical fiber arrays **70**, in a state optically coupled to the optical waveguide devices **60**, are mounted on the parts of the core substrate **20** exposed by the notches **40**. The optical fiber arrays **70** are firstly aligned with the optical waveguide devices **60**. That is, the optical fiber arrays **70** are positioned relative to the optical waveguide devices **60** so that the optical axis of each optical waveguide **64** is aligned with the optical axis of the corresponding optical fiber **72**. Such positioning is performed through, for example, active alignment. By mounting the optical fiber arrays **70** on the parts of the core substrate **20** exposed by the notches **40**, the optical axis of each optical fiber **72** is aligned with the optical axis of the corresponding optical waveguide **64** in the Z-axis direction. In other words, the depth of the recesses **41** is adjusted so that when the optical fiber arrays **70** are mounted on the parts of the core substrate **20** exposed by the notches **40**, namely, on the bottom surfaces of the recesses **41**, the optical axis of each optical fiber **72** is aligned with the optical axis of the corresponding optical waveguide **64** in the Z-axis direction.

[0067] Then, the optical waveguide devices **60** are bonded to the optical fiber arrays **70** with the optical adhesive **75**. Further, the optical fiber arrays **70** are bonded to the bottom surfaces of the recesses **41** with the adhesive agent **76**. For example, a dispenser or the like is used to apply the optical adhesive **75** in an uncured state between the optical waveguide devices **60** and the optical fiber arrays **70**. A dispenser or the like is also used to apply the adhesive agent **76** in an uncured state between the optical fiber arrays **70** and the bottom surfaces of the recess **41**. The optical adhesive **75** and the adhesive agent **76** are then irradiated with ultraviolet light and cured. This bonds the optical waveguide devices **60** and the optical fiber arrays **70** with the optical adhesive **75**, and bonds the optical fiber arrays **70** to the bottom surfaces of the recesses **41** with the adhesive agent **76**. The optical module **10** in accordance with the present embodiment is manufactured through the steps described above.

[0068] The present embodiment has the advantages described below.

[0069] (1) The optical module **10** includes the wiring substrate **11**, the optical waveguide devices **60**, which are mounted on the wiring substrate **11**, and the optical fiber arrays **70**, which are connected to the optical waveguide devices **60**. The wiring substrate **11** includes the core substrate **20**, the wiring structure **30**, which is formed on the upper surface of the core substrate **20**, and the notches **40**, which extend through the wiring structure **30** in the thickness direction and expose parts of the core substrate **20**. The optical waveguide devices **60** are mounted on the upper surface of the wiring structure **30** at positions proximate to the notches **40**. The optical fiber arrays **70** are mounted on the parts of the core substrate **20** exposed by the notches **40**.

[0070] In this structure, the optical fiber arrays **70** are connected to the optical waveguide devices **60** and fixed to the core substrate **20**. Thus, the optical fiber arrays **70** are joined with the optical waveguide devices **60** and also joined with the core substrate **20**. Compared with when only the optical waveguide devices **60** are joined with the optical fiber arrays **70**, the optical fiber arrays **70** are joined with higher rigidity to the optical waveguide devices **60** and the core substrate **20**. In other words, the optical fiber arrays **70**, which are bonded to the core substrate **20**, reinforce the strength of the bonding of the optical waveguide devices **60** and the optical fiber arrays **70**. As a result, the coupling reliability of the optical waveguide devices **60** and the optical fiber arrays **70** is improved. For example, when an unexpected external force is applied to the optical fiber arrays **70**, the optical waveguide devices **60** and the optical fiber arrays **70** will resist the external force and remain coupled.

[0071] (2) The recesses **41** are formed in the upper surface of the core substrate **20** at the parts exposed by the notches

40, and the optical fiber arrays **70** are fixed to the bottom surfaces of the recess **41**. This structure allows the depth of the recesses **41** to be adjusted in order to facilitate positional adjustment of the optical axes of the optical fibers **72** in the Z-axis direction. Thus, adjustment of the depth of the recesses **41** in accordance with the thickness of the wiring structure **30**, the optical waveguide device **60**, and the optical fiber array **70** allows the optical axes of the optical fibers **72** to be positioned in the Z-axis direction. Accordingly, even when the wiring structure **30**, the optical waveguide devices **60**, and the optical fiber arrays **70** have varying thicknesses, the depth of the recesses **41** may be adjusted to align the optical axes of the optical fibers **72** with the optical axes of the optical waveguides **64** in the Z-axis direction.

[0072] (3) The end of the optical waveguide device **60** in the first direction **X1** overlaps the corresponding notch **40** in plan view. In this structure, the end of the optical waveguide device **60** in the first direction **X1** projects from the inner end surface of the notch **40** in the first direction **X1**. This allows the optical fiber array **70** to be arranged so that the end of the optical fiber array **70** in the first opposite direction **X2** contacts the end of the optical waveguide device **60** in the first direction **X1**.

[0073] (4) The difference in the coefficient of thermal expansion between the core substrate **20** and the optical fiber arrays **70** is less than the difference in the coefficient of thermal expansion between the wiring structure **30** and the optical fiber arrays **70**. In comparison with when the optical fiber arrays **70** are fixed to the wiring structure **30**, the difference in the coefficient of thermal expansion is less between the parts to which the optical fiber arrays **70** are fixed (core substrate **20** in the present embodiment) and the optical fiber arrays **70**. Thus, even when the optical module **10** is exposed to, for example, a high-temperature environment, the difference in the amount of thermal deformation will be limited between the core substrate **20** and the optical fiber arrays **70**. This obviates optical axis displacement of the optical fibers **72** that would result from the difference in thermal deformation.

[0074] (5) The difference in the coefficient of thermal expansion between the core substrate **20** and the optical waveguide devices **60** is less than the difference in the coefficient of thermal expansion between the wiring structure **30** and the optical waveguide devices **60**. This decreases the difference in the coefficient of thermal expansion of the core substrate **20**, to which the optical fiber arrays **70** are fixed, from the coefficient of thermal expansion of the optical fiber arrays **70** and the coefficient of thermal expansion of the optical waveguide devices **60**. Thus, even when the optical module **10** is exposed to, for example, a high-temperature environment, the difference in the amount of thermal deformation will be limited between the core substrate **20**, the optical fiber arrays **70**, and the optical waveguide devices **60**. This obviates optical axis displacement of the optical fibers **72** and the optical waveguides **64** that would result from the difference in thermal deformation.

[0075] (6) The wiring structure **30** may include a recess, and the optical fiber array **70** may be fixed to the bottom surface of the recess. In this case, when the depth of the recess changes, the coefficient of thermal expansion may change at the part where the optical fiber array **70** is fixed. The wiring structure **30** is formed by stacking a number of members. Thus, in accordance with the depth of the recess, the member exposed by the recess will change, that is, the member acting as the part to which the optical fiber array **70** is fixed will change. Accordingly, when the depth of the recess changes, the coefficient of thermal expansion of the part to which the optical fiber array **70** is fixed will change.

[0076] In this respect, in the optical module **10** in accordance with the present embodiment, the core substrate **20** is configured by a single layer. That is, the core substrate **20** is configured by a single member. Thus, even when the depth of the recess **41** is changed, the coefficient of thermal expansion of the core substrate **20**, which is the part to which the optical fiber array **70** is fixed, will vary subtly.

[0077] (7) The gap between each optical waveguide device **60** and the corresponding optical fiber array **70** is filled with the optical adhesive **75**. Thus, even when a gap forms between the optical waveguide device **60** and the optical fiber array **70**, air reflection will be prevented at the gap. This will increase the coupling efficiency of the optical waveguide device **60** and the optical fiber array **70**.

[0078] (8) The optical fiber arrays **70** are adhered by the adhesive agent **76** to the core substrate **20**. This firmly fixes the optical fiber arrays **70** to the core substrate **20**.

MODIFIED EXAMPLES

[0079] The above embodiments may be modified as described below. The above embodiments and the modified examples described below may be combined as long as there is no technical contradiction.

[0080] In the above embodiment, the part in the upper surface of the core substrate **20** exposed by each notch **40** entirely includes the recess **41**. This, however, is not a limitation. For example, the recess **41** may be provided in only a portion of the part in the upper surface of the core substrate **20** exposed by each notch **40**.

[0081] The depth of the recesses **41** in the above embodiment may be changed.

[0082] For example, as illustrated in FIG. **7**, the recesses **41** may be omitted. In this case, the optical fiber arrays **70** are fixed to the parts in the upper surface of the core substrate **20** exposed by the notches **40**. Further, the parts in the upper surface of the core substrate **20** exposed by the notches **40** are flush with the other parts in the upper surface of the core substrate **20**.

[0083] In the above embodiment, each notch **40** extends over only part of the wiring structure **30** in the second direction **Y1**. For example, the notch **40** may extend over the entire length of the wiring structure **30** in the second direction **Y1**. For example, the notch **40** may extend over the entire periphery of the wiring structure **30**. In this case, the peripheral portion of the core substrate **20** is entirely exposed by the notch **40**.

[0084] Each optical fiber array **70** includes three optical fibers **72** in the above embodiment. However, there is no particular limitation to the number of optical fibers **72**. The number of optical fibers **72** in the optical fiber array **70** may be one, two, four, or more.

[0085] In the optical module **10** of the above embodiment, the optical component connected to each optical waveguide device **60** is the optical fiber array **70**. This, however, is not a limitation.

[0086] For example, as illustrated in FIG. **8**, the optical component connected to each optical waveguide device **60** is an optical connector **90**. The optical connector **90** is optically coupled to the optical waveguide device **60** and fixed to the part of the core substrate **20** exposed by the corresponding notch **40**. For example, the optical connector **90** is bonded by the optical adhesive **75** to the optical waveguide device **60** and bonded by the adhesive agent **76** to the core substrate **20**. The optical connector **90** is, for example, configured to be attached in a removable manner to a mating connector **91** including one or more optical fibers **72**.

[0087] Instead of the optical fiber array **70** and the optical connector **90**, the optical component connected to each optical waveguide device **60** may be, for example, a planar lightwave circuit.

[0088] Each optical waveguide device **60** in the above embodiment includes three optical waveguide **64**. However, the optical waveguides **64** are not particularly limited in number. The number of the optical waveguides **64** may be one, two, four, or more.

[0089] Each optical waveguide device **60** includes three optical elements **63**. However, the optical elements **63** are not particularly limited in number. The number of the optical elements **63** may be one, two, four, or more.

[0090] In each optical waveguide device **60** of the above embodiment, a single optical element **63** is provided for each optical waveguide **64**. This, however, is not a limitation. For example, a single optical element **63** may be provided for a number of optical waveguides **64**.

[0091] In the wiring structure **30** of the above embodiment, the wiring layers **31**, **33**, and **35** may be replaced by any number of layers and be laid out in any manner. Further, the insulation layers **32** and **34** may be replaced by any number of layers.

[0092] In the wiring structure **50** of the above embodiment, the wiring layers **51**, **53**, and **55** may be replaced by any number of layers and be laid out in any manner. Further, the insulation layers **52** and **54** may be replaced by any number of layers.

[0093] The wiring structure **50** of the above embodiment may be omitted.

[0094] In the wiring substrate **11** of the above embodiment, the solder resist layers **36** and **56** may be omitted.

[0095] In the optical module **10** of the present embodiment, the optical waveguide devices **60**, the optical fiber arrays **70**, and the electronic component **80** are not particularly limited in number.

Clauses

[0096] This disclosure further encompasses the following embodiments.

[0097] 1. A method for manufacturing an optical module, the method including:

- **[0098]** forming a wiring substrate that includes a core substrate and a wiring structure formed on an upper surface of the core substrate;
- **[0099]** forming a notch extending through the wiring structure and exposing a peripheral portion of the core substrate;
- **[0100]** mounting an optical waveguide device on an upper surface of the wiring structure; and
- **[0101]** coupling an optical component to the optical waveguide device and fixing the optical component to the peripheral portion of the core substrate exposed from the notch.

[0102] Various changes in form and details may be made to the examples above without departing from the spirit and scope of the claims and their equivalents. The examples are for the sake of description only, and not for purposes of limitation. Descriptions of features in each example are to be considered as being applicable to similar features or aspects in other examples. Suitable results may be achieved if sequences are performed in a different order, and/or if components in a described system, architecture, device, or circuit are combined differently, and/or replaced or supplemented by other components or their equivalents. The scope of the disclosure is not defined by the detailed description, but by the claims and their equivalents. All variations within the scope of the claims and their equivalents are included in the disclosure.

1. An optical module, comprising:
- a wiring substrate; and
- an optical waveguide device mounted on the wiring substrate, wherein
- the wiring substrate includes
  - a core substrate,
  - a wiring structure located on an upper surface of the core substrate, and
  - a notch extending through the wiring structure in a thickness direction and exposing a peripheral portion of the core substrate, and
- the optical waveguide device is mounted on an upper surface of the wiring structure at a position proximate to the notch.

2. The optical module according to claim **1**, further comprising an optical component that is fixed to the peripheral portion of the core substrate exposed by the notch and is coupled to the optical waveguide device.

3. The optical module according to claim **1**, wherein
- the notch defines a step between the upper surface of the wiring structure and the upper surface of the core substrate, and
- the optical waveguide device is mounted on the upper surface of the wiring structure so that a part of the optical waveguide device projects beyond a wall of the step into the notch in plan view.

4. The optical module according to claim **2**, wherein the notch is sized to expose a part of the peripheral portion of the core substrate and receive the optical component on the part of the peripheral portion of the core substrate.

5. The optical module according to claim **2**, wherein
- the core substrate includes a recess in the upper surface of the core substrate exposed by the notch,
- the recess includes a bottom surface that is defined by an upper surface of a thin portion of the core substrate that is reduced in thickness by the recess, and
- the optical component is fixed to the bottom surface of the recess.

6. The optical module according to claim **2**, wherein
- an end surface of the wiring structure in a first direction is cut out in a first opposite direction that is opposite the first direction to define the notch,
- the notch is open in the first direction, and
- an end of the optical waveguide device in the first direction overlaps the notch in plan view.

7. The optical module according to claim **6**, wherein the notch has a dimension that is greater than that of the optical component in a second direction that is orthogonal to the first direction in plan view.

8. The optical module according to claim **2**, wherein a difference in coefficient of thermal expansion between the core substrate and the optical component is less than a difference in coefficient of thermal expansion between the wiring structure and the optical component.

9. The optical module according to claim **8**, wherein a difference in coefficient of thermal expansion between the core substrate and the optical waveguide device is less than a difference in coefficient of thermal expansion between the wiring structure and the optical waveguide device.

10. The optical module according to claim **2**, wherein the core substrate is configured by a single layer.

11. The optical module according to claim **2**, further comprising:

an optical adhesive that bonds the optical waveguide device and the optical component; and

an adhesive agent that bonds the optical component and the core substrate,

wherein the optical adhesive fills a gap between the optical waveguide device and the optical component.

* * * * *