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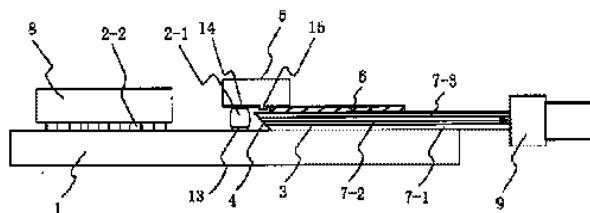
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(54) Title of the Invention: Optical Module and Method for Mounting an Optical Module

(57) Abstract:

[Problem] To control the gap between a surface-emitting optical element and an optical waveguide with high accuracy and a simple structure.

[Solution] A VCSEL mounting pad 13, an LSI mounting pad, and an optical waveguide 3 are formed on substrate 1. One end of the optical waveguide 3 is formed into a 45-degree inclined end to function as a 45-degree inclined mirror 4. The VCSEL 5 is mounted with its light-emitting portion 15 facing downward, abutting the upper surface of the optical waveguide as a reference surface. When mounting a VCSEL 5 having a protruding light-emitting portion 15, a spacer 6 is disposed between the VCSEL 5 and the optical waveguide 3. The laser light emitted from the VCSEL 5 enters from the upper surface of the optical waveguide 3, is reflected by the 45-degree inclined mirror 4 and is then directed to the waveguide core.



Patent Claims

Claim 1: An optical module characterized in that it comprises: A substrate having substrate-side pads formed thereon for mounting a surface-emitting or surface-detecting optical element wherein a light-emitting or light-receiving portion and a surface-emitting optical element-side pad are provided on the same side surface;

An optical waveguide formed on the substrate and provided with an inclined mirror on an end surface; and

The surface-emitting or surface-detecting optical element mounted on an upper surface of the optical waveguide in such a manner that the light-emitting or light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the substrate-side pads and the surface-emitting optical element-side pads are connected using solder bumps.

Claim 2: An optical module characterized in that it comprises: A substrate having substrate-side pads formed thereon for mounting a surface-emitting or surface-detecting optical element wherein a light-emitting or light-receiving portion and a surface-emitting optical element-side pad are provided on the same side surface;

An optical waveguide formed on the substrate;

An inclined mirror formed on the substrate at a position where the optical path of the surface-emitting or surface-detecting optical element after mounting and the optical path of the optical waveguide intersect; and

The surface-emitting or surface-detecting optical element mounted on an upper surface of the optical waveguide in such a manner that the light-emitting or light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the substrate-side pads and the surface-emitting optical element-side pads are connected using solder bumps.

Claim 3: An optical module characterized in that it comprises: A substrate having a first substrate-side electrode pad for mounting a surface-emitting or surface-detecting optical element wherein a light-emitting or light-receiving portion and a surface-emitting optical element-side electrode pad are provided on the same side surface, a second substrate-side electrode pad for mounting a semiconductor device, and electrical wiring for electrically connecting the first and second substrate-side electrode pads, formed thereon in advance;

An optical waveguide formed on the substrate and provided with an inclined mirror on an end surface;

The surface-emitting or surface-detecting optical element mounted on an upper surface of the optical waveguide in such a manner that the light-emitting or light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the first substrate-side electrode pad and the surface-emitting optical element-side electrode pad are flip-chip connected; and

The semiconductor device mounted on the substrate and having an electrode connected to the second substrate-side electrode pad.

Claim 4: An optical module characterized in that it comprises: A substrate having a first substrate-side electrode pad for mounting a surface-emitting or surface-detecting optical

element wherein a light-emitting or light-receiving portion and a surface-emitting optical element-side electrode pad are provided on the same side surface, a second substrate-side electrode pad for mounting a semiconductor device, and electrical wiring for electrically connecting the first and second substrate-side electrode pads, formed thereon in advance;

An optical waveguide formed on the substrate;

An inclined mirror formed on the substrate at a position where the optical path of the surface-emitting or surface-detecting optical element after mounting and the optical path of the optical waveguide intersect;

The surface-emitting or surface-detecting optical element mounted on an upper surface of the optical waveguide in such a manner that the light-emitting or light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the first substrate-side electrode pad and the surface-emitting optical element-side electrode pad are flip-chip connected; and

The semiconductor device mounted on the substrate and having an electrode connected to the second substrate-side electrode pad.

Claim 5: An optical module according to claim 1, 2, 3, or 4, wherein:

The surface-emitting or surface-detecting optical element comprises a plurality of the light-emitting or light-receiving portions;

The optical waveguides are formed in plurality on the substrate corresponding to the plurality of the light-emitting or light-receiving portions; and

The surface-emitting or surface-detecting optical element is supported by the plurality of optical waveguides.

Claim 6: The optical module according to claim 5, wherein the optical waveguides are formed in a plurality of directions on the substrate.

Claim 7: The optical module according to claim 1, 2, 3, or 4, wherein a spacer having a thickness greater than the height of the light-emitting or light-receiving portion is disposed between a lower surface of the surface-emitting or surface-detecting optical element and an upper surface of the optical waveguide so as to avoid the light-emitting or light-receiving portion, with respect to the surface-emitting or surface-detecting optical element having the protruding light-emitting or light-receiving portion.

Claim 8: The optical module according to claim 1, 2, 3, or 4, wherein the optical waveguide has a groove portion deeper than the height of the light-emitting or light-receiving portion at a position on the upper surface of the optical waveguide corresponding to the light-emitting or light-receiving portion, with respect to the surface-emitting or surface-detecting optical element having the protruding light-emitting or light-receiving portion.

Claim 9: The optical module according to claim 1, 2, 3, or 4, further comprising a stopper on the upper surface of the

optical waveguide for locking an end surface of the surface-emitting or surface-detecting optical element.

Claim 10: The optical module according to claim 1 or 3, wherein the inclined mirror is created from an inclined surface formed on the end surface of the optical waveguide.

Claim 11: The optical module according to claim 1, 2, 3, or 4, wherein the optical waveguide is an optical waveguide having an exposed core layer.

Claim 12: The optical module according to claim 1, 2, 3, or 4, wherein the substrate has a groove for accommodating the optical waveguide.

Claim 13: A method for mounting an optical module, wherein a light-emitting portion or a light-receiving portion and a planar optical element side pad are provided on the same side surface, with the method comprising the steps of:
forming a substrate-side pad for mounting the planar optical element on the substrate;
forming an optical waveguide on the substrate and forming an inclined mirror on an end surface of the optical waveguide;
positioning the light-emitting portion or the light-receiving portion of the planar optical element and the optical waveguide so that they are optically coupled via the inclined mirror, and then bringing a lower surface of the planar optical element into contact with an upper surface of the optical waveguide, and connecting the planar optical element side pad of the planar optical element and the substrate-side pad using solder bumps, thereby mounting the planar optical element on the optical waveguide.

Claim 14: A method for mounting an optical module, wherein a light-emitting portion or a light-receiving portion and a planar optical element side pad are provided on the same side surface, with the method comprising the steps of:
forming a substrate-side pad for mounting the planar optical element on the substrate;
forming an optical waveguide on the substrate;
forming an inclined mirror on the substrate at a position where the optical path of the planar optical element after mounting and the optical path of the optical waveguide intersect;
positioning the light-emitting portion or the light-receiving portion of the planar optical element and the optical waveguide so that they are optically coupled via the inclined mirror, and then bringing a lower surface of the planar optical element into contact with an upper surface of the optical waveguide, and connecting the planar optical element side pad of the planar optical element and the substrate-side pad by solder bumps, thereby mounting the planar optical element on the optical waveguide.

Claim 15: A method for mounting an optical module, comprising the steps of:
Forming, on a substrate, a first substrate-side electrode pad for mounting a surface-emitting or surface-detecting type optical element wherein a light-emitting or light-receiving portion and a surface-emitting optical element-side electrode pad are provided on the same side surface, a second substrate-side

electrode pad for mounting a semiconductor device, and electrical wiring electrically connecting the first and second substrate-side electrode pads;

Forming an optical waveguide on the substrate and forming an inclined mirror on an end face of the optical waveguide;

Positioning the light-emitting or light-receiving portion of the surface-emitting optical element and the optical waveguide so that they are optically coupled via the inclined mirror, bringing a lower surface of the surface-emitting optical element into contact with an upper surface of the optical waveguide, and mounting the surface-emitting optical element on the optical waveguide by flip-chip connecting the surface-emitting optical element-side electrode pad and the first substrate-side electrode pad; and

Mounting the semiconductor device on the substrate by connecting an electrode of the semiconductor device and the second substrate-side electrode pad.

Claim 16: A method for mounting an optical module, comprising the steps of:

Forming, on a substrate, a first substrate-side electrode pad for mounting a surface-emitting or surface-detecting type optical element wherein a light-emitting or light-receiving portion and a surface-emitting optical element-side electrode pad are provided on the same side surface, a second substrate-side electrode pad for mounting a semiconductor device, and electrical wiring electrically connecting the first and second substrate-side electrode pads;

Forming an optical waveguide on the substrate;

Forming an inclined mirror on the substrate at a position where an optical path of the surface-emitting optical element after mounting and an optical path of the optical waveguide intersect;

Positioning the light-emitting or light-receiving portion of the surface-emitting optical element and the optical waveguide so that they are optically coupled via the inclined mirror, bringing a lower surface of the surface-emitting optical element into contact with an upper surface of the optical waveguide, and mounting the surface-emitting optical element on the optical waveguide by flip-chip connecting the surface-emitting optical element-side electrode pad and the first substrate-side electrode pad; and

Mounting the semiconductor device on the substrate by connecting an electrode of the semiconductor device and the second substrate-side electrode pad.

Claim 17: The optical module mounting method according to any one of claims 13, 14, 15, or 16, further comprising the step of:

Forming solder bumps on the substrate-side pad or the first substrate-side electrode pad, said solder bumps extending beyond the upper surface of the optical waveguide; melting the solder bumps to fuse them with the surface-emitting optical element-side pad or the surface-emitting optical element-side electrode pad; lowering the surface-emitting optical element until it abuts the optical waveguide; and cooling the solder bumps to solidify them, thereby establishing a connection between the surface-emitting optical element-side pad or the surface-emitting optical element-side electrode pad and the substrate-side pad or the first substrate-side electrode pad.

Claim 18: The optical module mounting method according to any one of claims 13, 14, 15, or 16, further comprising the step of:

Forming a plurality of optical waveguides on the substrate in accordance with a surface-emitting optical element having a plurality of light-emitting portions or light-receiving portions and supporting the surface-emitting optical element with the plurality of optical waveguides.

Claim 19: The optical module mounting method according to claim 18, wherein the optical waveguides are formed in a plurality of directions on the substrate.

Claim 20: The optical module mounting method according to any one of claims 13, 14, 15, or 16, wherein when mounting the surface-emitting optical element having a protruding light-emitting portion or light-receiving portion on the optical waveguide, a spacer thicker than the height of the light-emitting portion or light-receiving portion is disposed between the lower surface of the surface-emitting optical element and the upper surface of the optical waveguide, thereby ensuring clearance around the light-emitting portion or light-receiving portion.

Claim 21: The optical module mounting method according to claim 20, wherein the spacer is manufactured by spin-coating a resin on a wafer and peeling the film-like resin from the wafer after curing.

Claim 22: The optical module mounting method according to any one of claims 13, 14, 15, or 16, wherein a relief portion deeper than the height of the light-emitting portion or light-receiving portion is provided at a position on the upper surface of the optical waveguide corresponding to the light-emitting portion or light-receiving portion of the surface-emitting optical element having the protruding light-emitting portion or light-receiving portion.

Claim 23: The optical module mounting method according to claim 22, wherein the relief portion on the upper surface of the optical waveguide is formed by wet etching or dry etching.

Claim 24: The optical module mounting method according to any one of claims 13, 14, 15, or 16, wherein a stopper for locking an end face of the surface-emitting optical element is formed on the upper surface of the optical waveguide.

Claim 25: The optical module mounting method according to any one of claims 13, 14, 15, or 16, wherein the mounting of the surface-emitting optical element on the optical waveguide is performed by a flip-chip bonder, and during this mounting, the surface-emitting optical element is held by a collet larger than the surface-emitting optical element so that the surface-emitting optical element is always parallel to the substrate surface.

Claim 26: The optical module mounting method according to claim 13 or 15, wherein the inclined mirror is created by

forming an inclined surface on the end face of the optical waveguide.

Claim 27: The optical module mounting method according to any one of claims 13, 14, 15, or 16, wherein the optical waveguide is an optical waveguide with an exposed core layer.

Claim 28: The optical module mounting method according to any one of claims 13, 14, 15, or 16, wherein the optical waveguide is accommodated in a groove provided in the substrate.

Detailed Description of the Invention

[0001]

Technical Field of the Invention

The present invention relates to an optical module that mounts a surface-emitting optical element, a planar optical waveguide, and a semiconductor device, and to a method for mounting the optical module.

[0002]

Description of the Related Art

In order to increase the speed of signal transmission paths within information processing equipment, chip-to-chip optical connections, which connect LSIs such as CPUs and memory modules with optical signals, are effective. In chip-to-chip optical connections, LSIs are mounted on a circuit board equipped with an optical waveguide, and input/output signals of one LSI are converted into optical signals using a VCSEL, propagated through the optical waveguide, and then converted back into electrical signals using a PD at the other end to connect to another LSI. This setup is considered advantageous. In such a structure, optical coupling between a surface-emitting optical element such as a vertical-cavity surface-emitting laser (VCSEL) or a photodiode (PD) and an optical waveguide with a right-angle optical path conversion is a challenge.

[0003] Conventionally, as a structure for optically coupling a VCSEL or PD to an optical waveguide at a right angle, a structure has been proposed, as disclosed in Japanese Patent Laid-Open No. 2000-332301 and Japanese Patent Laid-Open No. 2001-185752, in which a surface-emitting element array is directly mounted on an LSI chip by bumps, and the LSI chip is further mounted on an optoelectronic circuit board by another bump. The emitted light from the surface-emitting element is reflected by a 45-degree mirror provided at the end of the optical waveguide and coupled to the optical waveguide.

[0004] Fig. 9(a) is a perspective view showing the structure of an optical module disclosed in Japanese Patent Laid-Open No. 2000-332301, and Fig. 9(b) is an enlarged view of a part of the A-A cross-section in Fig. 9(a). A surface-emitting optical element array 72, such as a surface-emitting optical element array or a surface-detecting optical element array, has a surface-emitting optical element positive electrode 72a and a negative electrode 72b on the opposite side of the surface-emitting optical element light-emitting portion 72c or light-receiving portion 72d and is directly connected to an electrode

pad 71a for a surface-emitting optical element formed in the peripheral portion of the LSI chip 71 using a solder bump 73.

[0005] A metal post 71b is formed at the center of the LSI chip 71 and is covered with a mold resin 74. A solder bump 75 is formed on the opposite side of electrode 71c on the LSI chip 71 side of the metal post 71b. An optical waveguide 76 is formed in advance on the printed circuit board 77 corresponding to the optical signal input/output position of the semiconductor device to be mounted. The end 76c of the optical waveguide 76 is processed to form a 45-degree angle with respect to the input/output light of the surface-emitting optical element array 72, and functions as a TIR (Total Internal Reflection) mirror or a reflective mirror formed by attaching a metal film or the like to the 45-degree end face, to optically couple the input/output light of the surface-emitting optical element array 72 located above by converting the optical path by 90 degrees to the core layer 76a of the optical waveguide 76.

[0006] The LSI chip 71 on which the surface-emitting optical element array 72 is mounted is positioned so that the surface on which the surface-emitting optical element 72 is mounted faces the printed circuit board 77 and the solder bump 75 faces the electrode pad 77a on the printed circuit board 77 and is surface-mounted by a solder reflow process. In this case, since both the surface-emitting optical element 72 and the optical waveguide 76 are positioned at predetermined positions, not only electrical connection but also optical connection is performed via the solder bump 75.

[0007] Fig. 10(a) is a cross-sectional view of an optical module disclosed in Japanese Patent Laid-Open No. 2001-185752, and Fig. 10(b) is an enlarged view of portion (a) in Fig. 10(a). A surface light-emitting element array 82a and a surface light-receiving element array 82b are fixed on an LSI chip 81 by solder bumps 83 so that their respective optical input/output surfaces 82c face the printed circuit board 90 and are electrically connected to the semiconductor integrated circuit of the LSI chip 81 via the solder bumps 83.

[0008] The LSI chip 81 is electrically and structurally connected to a tape carrier 84a on which an electrical wiring layer 84c is formed. Solder bumps 85 are formed on the electrical wiring ends on the tape carrier 84a and are connected to electrode pads 89 on the printed circuit board 90 by surface mount technology. The LSI chip 81, the surface light-emitting element array 82a, and the surface light-receiving element array 82b are sealed with a transparent resin 86, and microlenses 88a are formed in a two-dimensional array on the surface of the transparent resin 86 corresponding to the positions of the respective elements.

[0009] A multilayer optical waveguide is provided on the printed circuit board 90. The end of the input-side multilayer optical waveguide 91b has a reflective surface that changes the direction of the input signal light toward the surface light-receiving element array 82b, and the end of the output-side multilayer optical waveguide 91a has a reflective surface that changes the direction of the output signal light emitted by the

surface light-emitting element array 82a toward the waveguide direction of the output-side multilayer optical waveguide 91a. The beam 101a emitted from the surface light-emitting element array 82a becomes collimated light 101b by the microlens 88a and becomes converged light 101c by the microlens 88b before entering the core 93a. The input signal light propagated through the input-side multilayer optical waveguide 91b is changed in direction by approximately 90 degrees at the multilayer optical waveguide end 92 and follows an optical path opposite to that of the output signal light to enter the surface light-receiving element array 82b.

[0010]

Problems to be Solved by the Invention

However, the above-described conventional optical modules have a problem in that it is difficult to control the gap between the optical element and the optical waveguide with high accuracy. If the gap between the optical element and the optical waveguide cannot be controlled with high accuracy, problems arise in that this gap has a significant effect on characteristics such as optical output and light-receiving sensitivity.

[0011] For example, the gap between the optical element and the optical waveguide significantly affects characteristics such as optical output and light-receiving sensitivity when the emission angle of the surface-emitting optical element is large and the optical coupling efficiency rapidly decreases as the distance between the optical element and the optical waveguide increases; when a PD with a small light-receiving surface is used, such as a PIN photodiode that emphasizes high-speed response; or when a lens is interposed between the optical waveguide and the optical element.

[0012] In such cases, it may be necessary to control at least four factors with an accuracy of about 10 μm or less: the chip thickness of the optical element, the height of the bump that joins the optical element to the LSI chip, the thickness of the mold resin that raises the mounting height of the LSI chip, and the height of the bump that mounts the LSI chip on the optoelectronic circuit board. The total height of these elements may exceed 200 μm in some cases, and it is difficult to control them with an accuracy of about 10 μm or less.

[0013] A structure that eliminates the influence of bump height errors, uses a pedestal provided on the substrate as a reference surface, and brings an optical element into contact with this pedestal by applying a load is disclosed in Japanese Patent No. 2823044. Fig. 11(a) is a perspective view of the optical module disclosed in Japanese Patent No. 2823044 before mounting the optical element, Fig. 11(b) is a cross-sectional view before mounting the optical element, Fig. 11(c) is a perspective view after mounting the optical element, and Fig. 11(d) is a cross-sectional view after mounting the optical element. In this optical module, after a first lower cladding layer 112 is formed on a substrate 111, a thin film serving as a mask for etching stop is formed, and the optical element mounting portion of this thin film is removed. The portion where the thin film has been removed and the portion where

the thin film remains are denoted as 116a and 116b, respectively.

[0014] Thereafter, a second lower cladding layer 113 and a core layer 115 are sequentially formed, the core layer 115 is patterned into a waveguide shape and etched, and then an upper cladding layer 114 is formed. Then, the optical waveguide forming layer in the portion where the optical element 117 is to be mounted is etched. In the portion 116a where the thin film of the optical element mounting portion has been removed, etching proceeds to the surface of the substrate 111, and etching stops when the substrate surface is exposed. In the portion 116b where the thin film of the optical element mounting portion remains, etching stops when the thin film is exposed.

[0015] This exposed portion 116b where the thin film remains serves as a pedestal, and the optical element 117 is mounted on this pedestal. Since the positioning in the height direction is performed by 116b, highly accurate alignment is maintained regardless of the height of the solder bump 119. Thus, according to the optical module of Japanese Patent No. 2823044, highly accurate alignment is possible, but in this example, since the pedestal serving as the reference surface needs to be controlled independently of the thickness of the optical waveguide, a simpler method is considered desirable.

[0016] An object of the present invention is to solve the above-described problems and to provide an optical module and an optical module mounting method that can control the gap between a surface-emitting optical element and a planar optical waveguide with high accuracy and a simple structure in an optical coupling structure between the surface-emitting optical element and the planar optical waveguide.

[0017]

Means for Solving the Problems

The optical module of the present invention comprises: a substrate (1) on which a substrate-side pad (13) for mounting a surface-emitting optical element (5, 5a) having a light-emitting portion (15) or a light-receiving portion and a surface-emitting optical element-side pad (14) on the same side surface is formed in advance; an optical waveguide (3, 3a) formed on the substrate and having an inclined mirror (4) on an end face; and the surface-emitting optical element mounted on the upper surface of the optical waveguide so that the light-emitting portion or the light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the substrate-side pad and the surface-emitting optical element-side pad are connected using solder bumps.

The optical module of the present invention also comprises: a substrate (1) on which a substrate-side pad (13) for mounting a surface-emitting optical element (5, 5a) having a light-emitting portion (15) or a light-receiving portion and a surface-emitting optical element-side pad (14) on the same side surface is formed in advance; an optical waveguide (3b, 3c) formed on the substrate; an inclined mirror (11) formed on the substrate at a position where the optical path of the surface-emitting optical element after mounting and the optical path of the optical waveguide intersect; and the

surface-emitting optical element mounted on the upper surface of the optical waveguide so that the light-emitting portion or the light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the substrate-side pad and the surface-emitting optical element-side pad are connected using solder bumps.

Further, the optical module of the present invention comprises: a substrate (1) on which a first substrate-side electrode pad (13) for mounting a surface-emitting optical element (5, 5a) having a light-emitting portion (15) or a light-receiving portion and a surface-emitting optical element-side electrode pad (14) on the same side surface, a second substrate-side electrode pad for mounting a semiconductor device (8), and electrical wiring electrically connecting the first and second substrate-side electrode pads are formed in advance; an optical waveguide (3, 3a) formed on the substrate and having an inclined mirror (4) on an end face; the surface-emitting optical element mounted on the upper surface of the optical waveguide so that the light-emitting portion or the light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the first substrate-side electrode pad and the surface-emitting optical element-side electrode pad are flip-chip connected; and the semiconductor device mounted on the substrate and connected to the second substrate-side electrode pad by an electrode.

In the present invention, in order to eliminate the difficulty in controlling the bump height when the gap between the surface-emitting optical element and the optical waveguide becomes a problem, the upper surface of the optical waveguide having an inclined mirror formed on the end face at an angle of 45 degrees with respect to the core optical axis is used as a reference surface, the lower surface of the surface-emitting optical element on which the light-emitting portion or the light-receiving portion is formed is brought into contact with the upper surface of the optical waveguide for mounting, and the surface-emitting optical element is flip-chip connected to the substrate instead of the upper surface of the optical waveguide, thereby electrically connecting the substrate and the surface-emitting optical element using solder bumps.

Further, the optical module of the present invention comprises: a substrate (1) on which a first substrate-side electrode pad (13) for mounting a surface-emitting optical element (5, 5a) having a light-emitting portion (15) or a light-receiving portion and a surface-emitting optical element-side electrode pad (14) on the same side surface, a second substrate-side electrode pad for mounting a semiconductor device (8), and electrical wiring electrically connecting the first and second substrate-side electrode pads are formed in advance; an optical waveguide (3b, 3c) formed on the substrate; an inclined mirror (11) formed on the substrate at a position where the optical path of the surface-emitting optical element after mounting and the optical path of the optical waveguide intersect; the surface-emitting optical element mounted on the upper surface of the optical waveguide so that the light-emitting portion or the light-receiving portion and the optical waveguide are optically coupled via the inclined mirror, and the first substrate-side electrode pad and the surface-emitting optical element-side electrode pad are flip-chip connected; and the semiconductor device mounted on the

substrate and connected to the second substrate-side electrode pad by an electrode.

[0018] Furthermore, in one configuration example of the optical module of the present invention, the surface-emitting optical element (5a) includes a plurality of light-emitting portions or light-receiving portions, and the optical waveguide is formed in plurality on the substrate corresponding to the plurality of light-emitting portions or light-receiving portions, and the surface-emitting optical element is supported by the plurality of optical waveguides. In another configuration example of the optical module of the present invention, the optical waveguides are formed in a plurality of directions on the substrate.

In yet another configuration example of the optical module of the present invention, for the surface-emitting optical element having a protruding light-emitting portion or light-receiving portion, a spacer (6) thicker than the height of the light-emitting portion or light-receiving portion is disposed between the lower surface of the surface-emitting optical element and the upper surface of the optical waveguide, thereby ensuring clearance around the light-emitting portion or light-receiving portion. Thus, by using the spacer, a gap can be formed between the light-emitting portion or light-receiving portion of the surface-emitting optical element and the upper surface of the optical waveguide.

Furthermore, in one configuration example of the optical module of the present invention, for the surface-emitting optical element having a protruding light-emitting portion or light-receiving portion, a relief portion (10) deeper than the height of the light-emitting portion or light-receiving portion is provided at a position on the upper surface of the optical waveguide corresponding to the light-emitting portion or light-receiving portion. Thus, by providing the relief portion at the position on the upper surface of the optical waveguide corresponding to the light-emitting portion or light-receiving portion, a gap can be formed between the light-emitting portion or light-receiving portion of the surface-emitting optical element and the upper surface of the optical waveguide.

[0019] Furthermore, in one configuration example of the optical module of the present invention, a stopper (12) for locking the end face of the surface-emitting optical element is provided on the upper surface of the optical waveguide. Thus, a stopper is provided on the upper surface of the optical waveguide in order to achieve passive alignment of the surface-emitting optical element in the horizontal direction as well.

In another configuration example of the optical module of the present invention, the inclined mirror is formed from an inclined surface formed on the end face of the optical waveguide.

In yet another configuration example of the optical module of the present invention, the optical waveguide is an optical waveguide with an exposed core layer (7-2). By using an optical waveguide with an exposed core layer, the gap between the surface-emitting optical element and the optical waveguide core is reduced.

Furthermore, in one configuration example of the optical module of the present invention, the substrate (1a) has a groove (16) for accommodating the optical waveguide.

[0020] Furthermore, the optical module mounting method of the present invention is configured to perform the following steps: forming, on a substrate, a substrate-side pad for mounting a surface-emitting optical element wherein a light-emitting portion or a light-receiving portion and a surface-emitting optical element-side pad are provided on the same side surface; forming an optical waveguide on the substrate and forming an inclined mirror on an end face of the optical waveguide; positioning the light-emitting portion or the light-receiving portion of the surface-emitting optical element and the optical waveguide so that they are optically coupled via the inclined mirror, bringing the lower surface of the surface-emitting optical element into contact with the upper surface of the optical waveguide, and mounting the surface-emitting optical element on the optical waveguide by connecting the surface-emitting optical element-side pad of the surface-emitting optical element and the substrate-side pad using solder bumps.

The optical module mounting method of the present invention is also configured to perform the following steps: forming, on a substrate, a substrate-side pad for mounting a surface-emitting optical element wherein a light-emitting portion or a light-receiving portion and a surface-emitting optical element-side pad are provided on the same side surface; forming an optical waveguide on the substrate; forming an inclined mirror at a position on the substrate where the optical path of the surface-emitting optical element after mounting and the optical path of the optical waveguide intersect; positioning the light-emitting portion or the light-receiving portion of the surface-emitting optical element and the optical waveguide so that they are optically coupled via the inclined mirror, bringing the lower surface of the surface-emitting optical element into contact with the upper surface of the optical waveguide, and mounting the surface-emitting optical element on the optical waveguide by connecting the surface-emitting optical element-side pad of the surface-emitting optical element and the substrate-side pad with solder bumps.

Furthermore, the optical module mounting method of the present invention is configured to perform the following steps: forming, on a substrate, a first substrate-side electrode pad for mounting a surface-emitting optical element wherein a light-emitting portion or a light-receiving portion and a surface-emitting optical element-side electrode pad are provided on the same side surface, a second substrate-side electrode pad for mounting a semiconductor device, and electrical wiring electrically connecting the first and second substrate-side electrode pads; forming an optical waveguide on the substrate and forming an inclined mirror on an end face of the optical waveguide; positioning the light-emitting portion or the light-receiving portion of the surface-emitting optical element and the optical waveguide so that they are optically coupled via the inclined mirror, bringing the lower surface of the surface-emitting optical element into contact with the upper surface of the optical waveguide, and mounting the surface-emitting optical element on the optical waveguide by flip-chip

connecting the surface-emitting optical element-side electrode pad and the first substrate-side electrode pad; and mounting the semiconductor device on the substrate by connecting an electrode of the semiconductor device and the second substrate-side electrode pad.

The optical module mounting method of the present invention is also configured to perform the following steps: forming, on a substrate, a first substrate-side electrode pad for mounting a surface-emitting optical element wherein a light-emitting portion or a light-receiving portion and a surface-emitting optical element-side electrode pad are provided on the same side surface, a second substrate-side electrode pad for mounting a semiconductor device, and electrical wiring electrically connecting the first and second substrate-side electrode pads; forming an optical waveguide on the substrate; forming an inclined mirror at a position on the substrate where the optical path of the surface-emitting optical element after mounting and the optical path of the optical waveguide intersect; positioning the light-emitting portion or the light-receiving portion of the surface-emitting optical element and the optical waveguide so that they are optically coupled via the inclined mirror, bringing the lower surface of the surface-emitting optical element into contact with the upper surface of the optical waveguide, and mounting the surface-emitting optical element on the optical waveguide by flip-chip connecting the surface-emitting optical element-side electrode pad and the first substrate-side electrode pad; and mounting the semiconductor device on the substrate by connecting an electrode of the semiconductor device and the second substrate-side electrode pad.

[0021] Furthermore, one configuration example of the optical module mounting method of the present invention is configured to form solder bumps higher than the upper surface of the optical waveguide on the substrate-side pad or the first substrate-side electrode pad, melt these solder bumps and fuse them with the surface-emitting optical element-side pad or the surface-emitting optical element-side electrode pad, lower the surface-emitting optical element until it comes into contact with the optical waveguide, and cool and solidify the solder bumps to connect the surface-emitting optical element-side pad or the surface-emitting optical element-side electrode pad to the substrate-side pad or the first substrate-side electrode pad.

In another configuration example of the optical module mounting method of the present invention, a plurality of optical waveguides are formed on the substrate in accordance with a surface-emitting optical element having a plurality of light-emitting portions or light-receiving portions, and the surface-emitting optical element is supported by the plurality of optical waveguides.

In yet another configuration example of the optical module mounting method of the present invention, the optical waveguides are formed in a plurality of directions on the substrate.

Furthermore, one configuration example of the optical module mounting method of the present invention is configured to dispose, when mounting the surface-emitting optical element having a protruding light-emitting portion or light-receiving portion on the optical waveguide, a spacer

thicker than the height of the light-emitting portion or light-receiving portion between the lower surface of the surface-emitting optical element and the upper surface of the optical waveguide, thereby ensuring clearance around the light-emitting portion or light-receiving portion.

In another configuration example of the optical module mounting method of the present invention, the spacer is manufactured by spin-coating a resin on a wafer, and peeling the film-like resin from the wafer after curing.

Furthermore, one configuration example of the optical module mounting method of the present invention is configured to provide, for the surface-emitting optical element having a protruding light-emitting portion or light-receiving portion, a relief portion deeper than the height of the light-emitting portion or light-receiving portion at a position on the upper surface of the optical waveguide corresponding to the light-emitting portion or light-receiving portion.

In yet another configuration example of the optical module mounting method of the present invention, the relief portion on the upper surface of the optical waveguide is formed by wet etching or dry etching.

[0022] Furthermore, one configuration example of the optical module mounting method of the present invention is configured to form a stopper on the upper surface of the optical waveguide for locking an end face of the surface-emitting optical element.

In another configuration example of the optical module mounting method of the present invention, the mounting of the surface-emitting optical element on the optical waveguide is performed by a flip-chip bonder, and during this mounting, the surface-emitting optical element is held by a collet larger than the surface-emitting optical element so that the surface-emitting optical element is always parallel to the substrate surface.

In yet another configuration example of the optical module mounting method of the present invention, the inclined mirror is formed by forming an inclined surface on the end face of the optical waveguide.

Furthermore, in one configuration example of the optical module mounting method of the present invention, the optical waveguide is an optical waveguide with an exposed core layer.

In another configuration example of the optical module mounting method of the present invention, the optical waveguide is accommodated in a groove provided in the substrate.

[0023]

Embodiments of the Invention

[First Embodiment]

Hereinafter, embodiments of the present invention will be described in detail with reference to the accompanying drawings in order to clarify the objects, features, and advantages of the present invention. Fig. 1 is a cross-sectional view showing the structure of an optical module according to the first embodiment of the present invention. This embodiment is an example of mounting a vertical-cavity surface-emitting laser (VCSEL) having a laser light emission

wavelength of 650 nm, 850 nm, 1300 nm, 1550 nm, or the like, on an optical waveguide substrate.

[0024] An optical waveguide 3 is formed on a substrate 1 made of an organic resin, ceramic, glass, silicon, or the like. A first substrate-side electrode pad 13 for mounting a VCSEL 5, which is a surface-emitting optical element, a second substrate-side electrode pad (not shown) for mounting an LSI 8, which is a semiconductor device, and electrical wiring (not shown) for electrically connecting the pads 13 and 14 are formed on the substrate 1 with a metal pattern.

[0025] The optical waveguide 3, as shown in Fig. 1, has a structure in which an optical waveguide core 7-2 layer is formed on a lower first cladding layer 7-1, and the optical waveguide core 7-2 is covered with an upper second cladding layer 7-3. The optical waveguide 3 is composed of an organic resin such as polyimide resin, epoxy resin, or siloxane polymer, or glass. One end of this optical waveguide 3 is formed into a 45-degree inclined end to function as a 45-degree inclined mirror 4.

[0026] As a method for forming the 45-degree inclined mirror 4, there are a method of attaching a separately manufactured film-like optical waveguide having a 45-degree end face processed, or a method of laminating and forming a vertical end face optical waveguide 3 on the substrate 1, and then tilting the substrate 1 by 45 degrees and etching the end face of the optical waveguide 3 to a 45-degree angle by RIE (Reactive Ion Etching) or the like. In order to improve the reflectivity of the 45-degree inclined mirror 4, it is desirable to deposit a metal such as aluminum, gold, silver, copper, or titanium on the mirror 4.

[0027] The substrate-side electrode pad 13 is formed in a circular, octagonal, or rectangular shape with a diameter of 70 μm , and the spacing between the substrate-side electrode pads 13 is set to 105 μm . It is desirable to form the electrode pad 14 of the VCSEL 5 with the same dimensions as the substrate-side electrode pad 13. For the substrate-side electrode pad 13 formed on the substrate 1, a metal pattern larger than the pad surface may be used, with its peripheral portion covered with an insulating resin, and the opening not covered with the insulating resin may be used as the pad. The insulating resin at this time may be formed by the first cladding layer 7-1 or the optical waveguide core 7-2 of the optical waveguide.

[0028] Next, a solder bump 2-1 made of a tin-lead alloy solder, a silver-tin solder, a gold-tin solder, or a silver-tin solder, etc., is formed on the first substrate-side electrode pad 13 on the substrate 1 to a height equal to or higher than the height of the optical waveguide 3. A solder bump 2-2 made of the same material is also formed on the second substrate-side electrode pad (not shown).

[0029] The VCSEL 5 has an electrode pad 14 and a light-emitting portion 15 on the same side surface. The VCSEL 5 is mounted with the electrode pad 14 and the light-emitting portion 15 facing downward, using the upper surface of the optical waveguide 3 as a reference surface, and bringing the

VCSEL 5 into contact with the upper surface of the optical waveguide 3. In this embodiment, an example is shown in which a VCSEL 5 having a protruding light-emitting portion 15 is mounted. Therefore, in order to prevent the light-emitting portion 15 of the VCSEL 5 from being damaged during mounting, a spacer 6 thicker than the height of the light-emitting portion 15 is disposed between the VCSEL 5 and the optical waveguide 3. The thickness of the spacer 6 is, for example, about 15 to 20 μm when the height of the light-emitting portion 15 is 10 μm .

[0030] As for the material of the spacer 6, polyimide or the like having high heat resistance to the processing temperature during mounting of the surface-emitting optical element is preferable. When manufacturing the spacer 6, polyimide or the like is spin-coated on a wafer, then cured and peeled off to form a film, whereby a spacer having a highly accurate thickness can be obtained. Then, the manufactured spacer 6 is bonded to the optical waveguide 3 with an adhesive.

[0031] Next, in order to mount the VCSEL 5, the solder bump 2-1 is melted, and the electrode pad 14 of the VCSEL 5 is brought into contact with the solder bump 2-1, so that the melted solder bump 2-1 is fused to the electrode pad 14 by surface tension. Then, the VCSEL 5 is lowered until it comes into contact with the spacer 6, and then the solder bump 2-1 is cooled and solidified, so that the lower surface of the VCSEL 5 is brought into contact with the upper surface of the spacer 6, and the VCSEL 5 is mounted so that the height of the solder bump 2-1 matches the height of the upper surface of the spacer 6.

[0032] The laser light emitted from the light-emitting portion 15 of the VCSEL 5 enters from the upper surface of the optical waveguide 3, is reflected by the 45-degree inclined mirror 4, enters the optical waveguide core 7-2, and is transmitted to the optical connector 9. Thus, the VCSEL 5 and the optical waveguide 3 are optically coupled by performing an approximately 90-degree optical path conversion at the 45-degree inclined mirror 4.

[0033] As described above, the electrical connection between the VCSEL 5 and the substrate 1 is made by flip-chip connection using the solder bump 2-1. Similarly, the LSI 8 is mounted on the substrate 1 by melting the solder bump 2-2 and bringing the electrode pad (not shown) of the LSI 8 into contact with the solder bump 2-2.

[0034] The material of the optical waveguide 3, whether it is polymer-based or quartz-based, has low thermal conductivity, and mounting the VCSEL 5 or LSI 8 on the upper surface of the optical waveguide 3 impairs heat dissipation. In addition, when only the VCSEL 5 is mounted on the optical waveguide 3 and the LSI 8 and other electronic components are mounted on the substrate 1 as in this embodiment, a step is generated in the electrical wiring between the VCSEL 5 and the LSI 8, which makes the wiring pattern formation process difficult and also impairs the transmission frequency characteristics.

[0035] Such problems can be solved by the solder bumps 2-1 and 2-2. That is, by directly flip-chip connecting the VCSEL 5 and LSI 8 to the substrate 1 using the solder bumps 2-1 and 2-2, heat can be dissipated via the solder bumps 2-1 and 2-2, and the VCSEL 5 and LSI 8 can be well connected by electrical wiring (not shown) without steps on the substrate 1.

[0036] Although the present embodiment exemplifies a structure in which the spacer 6 is provided on the second cladding layer 7-3 of the embedded optical waveguide 3, a ridge waveguide in which the upper second cladding layer 7-3 is not provided and the optical waveguide core 7-2 is exposed may be employed as the optical waveguide 3. By placing the spacer 6 on the exposed optical waveguide core 7-2 and mounting the surface-emitting optical element thereon, the gap between the surface-emitting optical element and the optical waveguide core 7-2 is reduced, so that the divergence of the light beam from the surface-emitting optical element can be reduced.

[0037] As described above, in this embodiment, by mounting only the surface-emitting optical element on the optical waveguide 3, flip-chip connecting the surface-emitting optical element and the semiconductor device to the substrate 1, and connecting the surface-emitting optical element and the semiconductor device by electrical wiring on the substrate 1, the optical coupling between the surface-emitting optical element and the optical waveguide and the electrical connection between the surface-emitting optical element and the semiconductor device can be realized with a simple structure, and the gap between the surface-emitting optical element and the optical waveguide can be controlled with high accuracy.

[0038] **[Second Embodiment]** Fig. 2 is a cross-sectional view showing the structure of an optical module according to the second embodiment of the present invention, in which the same components as in Fig. 1 are denoted by the same reference numerals. In the first embodiment, the VCSEL 5 was mounted on the optical waveguide 3 via the spacer 6 in order to protect the protrusion of the light-emitting portion 15 of the VCSEL 5. However, as shown in Fig. 2, a relief portion 10, which is a cutout or groove deeper than the height of the light-emitting portion 15, may be formed at a position on the upper surface of the optical waveguide 3a corresponding to the light-emitting portion 15.

[0039] The relief portion 10 can be formed by photolithography and wet etching using an alkali solution, or dry etching such as RIE (Reactive Ion Etching). In this embodiment, when mounting the VCSEL 5, the electrode pad 14 of the VCSEL 5 is brought into contact with the melted solder bump 2-1, and the VCSEL 5 is lowered until its lower surface comes into contact with the upper surface of the optical waveguide 3a. Then, the solder bump 2-1 is cooled and solidified, so that the lower surface of the VCSEL 5 abuts the upper surface of the optical waveguide 3a, and the VCSEL 5 is mounted so that the height of the solder bump 2-1 matches the height of the upper surface of the optical waveguide 3a.

[0040] In the first embodiment using the spacer 6, it is necessary to pay attention to the type of adhesive used to adhere the spacer 6 to the optical waveguide 3 and the heat resistance of the spacer 6 to the processing temperature during VCSEL mounting. However, an advantage of this embodiment is that this is no longer necessary.

[0041] **[Third Embodiment]** Fig. 3 is a cross-sectional view showing the structure of an optical module according to the third embodiment of the present invention, in which the same components as in Fig. 1 are denoted using the same reference numerals. In the first embodiment, an optical waveguide 3 having an inclined mirror at its end face was used. However, as shown in Fig. 3, the end face of the optical waveguide 3b may be a vertical end face, and an inclined mirror 11 having a 45-degree mirror surface may be provided on the substrate 1 for vertical conversion of the optical path. In this case, the inclined mirror 11 is formed at a position where the optical path of the VCSEL 5 after mounting and the optical path of the optical waveguide 3b are expected to intersect. The inclined mirror 11 can be formed, for example, as shown in Fig. 4(a), by depositing a metal 101 in a V-shaped groove formed in a silicon substrate 100 by anisotropic etching, and then pressing the metal 101 onto the substrate 1 by turning this structure upside down as shown in Fig. 4(b) (Fig. 4(c)). In this way, the same effect as in the first embodiment can be obtained.

[0042] **[Fourth Embodiment]** Fig. 5 is a cross-sectional view showing the structure of an optical module according to the fourth embodiment of the present invention, in which the same components as in Fig. 1 are denoted by the same reference numerals. In the third embodiment, when the end face of the optical waveguide 3b is a vertical end face and the inclined mirror 11 is provided on the substrate 1, the end face of the optical waveguide 3c may be an inclined surface as shown in Fig. 5. This inclined surface is inclined, for example, by about 7 degrees or 8 degrees with respect to the vertical direction of the substrate 1.

[0043] As a method for forming the end face of the optical waveguide 3c, there are a method of attaching a separately manufactured film-like optical waveguide having an inclined end face to the end face of the optical waveguide 3c, or a method of laminating and forming a vertical end face optical waveguide 3c on the substrate 1, and then tilting the substrate 1 and etching the end face of the optical waveguide 3c by RIE or the like. In this embodiment, the influence of Fresnel reflection at the end face of the optical waveguide 3c can be suppressed. It goes without saying that the second embodiment may be combined with the third and fourth embodiments.

[0044] **[Fifth Embodiment]** Fig. 6 is a perspective view showing the structure of an optical module according to the fifth embodiment of the present invention, in which the same components as in Fig. 1 are denoted by the same reference numerals. In this embodiment, a stopper 12 for positioning the VCSEL 5 in the horizontal direction is provided on the optical waveguide 3.

[0045] Polyimide or the like, which has high heat resistance to the processing temperature during VCSEL 5 mounting and is easy to form, is suitable as the material to be used for the stopper 12. When forming the stopper 12, polyimide or the like can be spin-coated on the upper surface of the optical waveguide 3 and cured, and then patterned by photolithography and wet etching using an alkali solution, or dry etching such as RIE (Reactive Ion Etching).

[0046] The horizontal position of the VCSEL 5 is determined by locking the end face of the VCSEL 5 to the stopper 12. Thus, in this embodiment, it is possible to position the VCSEL 5 in the vertical direction by the optical waveguide 3 and in the horizontal direction by the stopper 12, eliminating the need to provide a marker on the optical waveguide 3 as in the prior art. The first to fourth embodiments can be appropriately combined with this embodiment.

[0047] **[Sixth Embodiment]** Fig. 7 is a cross-sectional view showing the structure of an optical module according to the sixth embodiment of the present invention, in which the same components as in Fig. 1 are denoted by the same reference numerals. In the first to fifth embodiments, a single-row multi-channel VCSEL 5 in which a plurality of light-emitting portions 15 are arranged in one row (in the depth direction of Figs. 1 to 3 and 5), or a single-channel VCSEL 5 having only one light-emitting portion 15 was described as an example. In this embodiment, a two-row multi-channel two-dimensional VCSEL 5a in which a plurality of light-emitting portions 15 are arranged in two rows is mounted on the substrate 1.

[0048] Since there is one row of light-emitting portions 15 on the left and right, the optical waveguide 3 and the spacer 6 are also provided in plurality at positions corresponding to the left and right of the VCSEL 5a according to the number of light-emitting portions 15, and the VCSEL 5a is mounted in the same manner as in the first embodiment to optically couple the left and right light-emitting portions 15 to the corresponding optical waveguides 3. Thus, in this embodiment, since both ends of the VCSEL 5a are supported by the left and right optical waveguides 3, the VCSEL 5a can be mounted more stably than in the first embodiment. The first to fifth embodiments can be appropriately combined with this embodiment.

[0049] **[Seventh Embodiment]** Fig. 8 is a cross-sectional view showing the structure of an optical module according to the seventh embodiment of the present invention, in which the same components as in Fig. 1 are denoted by the same reference numerals. In the first to sixth embodiments, when the thickness of the optical waveguide is large, for example, exceeding 150 μm , and the pitch of the solder bump 2-1 is narrow, for example, about 125 μm , there is a concern that the solder bump 2-1 may become large and adjacent bumps 2 may bridge (short-circuit).

[0050] Therefore, in this embodiment, a groove 16 having a height lower than the upper surface of the substrate 1a on which the substrate-side electrode pad 13 is formed is

provided, and the optical waveguide 3 is formed in this groove 16. The method of mounting the VCSEL 5 is the same as in the first embodiment. When forming the groove 16 in the substrate 1a, if the substrate material is silicon, the groove can be formed by wet etching with a potassium hydroxide solution, and if the substrate is a ceramic substrate, the groove can be formed by devising the shape of the sheet to be laminated.

[0051] Thus, in this embodiment, since the optical waveguide 3 is formed at a position lower than the upper surface of the substrate 1a on which the substrate-side electrode pad 13 is formed, the height of the solder bump 2-1 can be reduced and bridging of adjacent bumps 2 can be avoided. The first to sixth embodiments can be appropriately combined with this embodiment.

[0052] In the first to seventh embodiments described above, the mounting of a VCSEL, which is a surface-emitting optical element, was described as an example of a surface-emitting optical element. However, the present invention may also be applied to the mounting of a surface light-receiving element such as a photodiode (PD).

[0053] **[Eighth Embodiment]** Hereinafter, more specific embodiments of the present invention will be described. In the first to seventh embodiments, it is desirable to perform the mounting of the surface-emitting optical element by a flip-chip mounter. As a mounting method, first, the surface-emitting optical element is sucked by a collet and held parallel to the substrate 1, 1a, and alignment in the in-plane direction is performed. The alignment is usually performed by adjusting the position so that the substrate-side electrode pad 13 on the substrate surface and the surface-emitting optical element-side electrode pad 14 coincide by viewing the double image of these electrode pads 13 and 14 with upward and downward cameras provided in the flip-chip bonder. However, when mounting with a positional deviation of $\pm 1 \mu\text{m}$ or less is required for higher accuracy, the alignment is performed by transmitting infrared light through the substrate 1, 1a and the surface-emitting optical element and adjusting the position by viewing the transmitted light.

[0054] Next, while heating the substrate 1, 1a and the collet to melt the solder bump 2-1, a load is applied to the surface-emitting optical element to bring its lower surface into contact with the upper surface of the optical waveguide 3, 3a, 3b, 3c (or the spacer 6). Finally, the substrate 1, 1a and the collet are cooled, and the solder bump 2-1 is solidified to complete the mounting. The hole diameter of the collet needs to be about 0.1 mm.

[0055] Here, the size of the collet must be larger than the surface-emitting optical element to be mounted. The reason for this is that if a surface-emitting optical element is pressed onto the upper surface of the optical waveguide 3, 3a, 3b, 3c using a collet smaller than the surface-emitting optical element, the surface-emitting optical element may tilt. This collet sucks the surface-emitting optical element so that it is always parallel to the substrate surface.

[0056] The thickness of the optical waveguide 3, 3a, 3b, 3c is typically about 30 μm for single mode and about 100 μm for multimode. The breakdown is about 15 μm for the first cladding layer 7-1, 5 μm for the optical waveguide core 7-2, and 10 μm for the second cladding layer 7-3 in the case of single mode, and about 30 μm for the first cladding layer 7-1, 40 μm for the optical waveguide core 7-2, and 30 μm for the second cladding layer 7-3 in the case of multimode.

[0057] While the ideal angle for the 45-degree inclined mirror 4 and the inclined mirror 11 is 45 degrees, it is not necessary to be 45 degrees when mounting a PD instead of the VCSEL 5. That is, when mounting a surface light-receiving type PD on the substrate 1, a mirror having an angle of, for example, 41 degrees or 49 degrees may be formed on the end face of the optical waveguide 3, 3a or on the substrate. Thereby, the light emitted from the optical waveguide 3, 3a and reflected by the mirror is tilted by 8 degrees from the vertical direction of the substrate 1 and enters the horizontal light-receiving surface of the PD at an angle, so that the reflected light at the PD can be prevented from traveling back along the same optical path as the incident light in the opposite direction through the optical waveguide 3, 3a.

[0058] In the first to sixth embodiments, in order to ensure bump melting and connection, the height of the solder bump 2-1 before mounting the surface-emitting optical element extends beyond the thickness of the optical waveguide 3, 3a, 3b, 3c (when the spacer 6 is not used). When the spacer 6 is used, the height of the solder bump 2-1 before mounting the surface-emitting optical element is made higher than the total thickness of the optical waveguide 3, 3a, 3b, 3c and the spacer 6. For example, for a substrate on which a multimode optical waveguide is formed, a solder bump 2-1 having a diameter of 150 μm or 110 μm and a height equal to or greater than the thickness of the optical waveguide, which is 100 μm , is formed.

[0059] The material of the solder bumps 2-1 and 2-2 is preferably Au-Sn, which has a proven track record in terms of reliability. However, if the material of the substrate 1, 1a or the optical waveguide 3, 3a, 3b, 3c has low heat resistance, it is necessary to use a lower melting point material such as an Ag-Sn based material. As another solder bump 2-1, a metal plating of 80 μm thickness such as copper, gold, or nickel may be formed on the substrate-side electrode pad 13, and a gold-tin or silver-tin plating of about 30 μm may be formed thereon to form a solder bump 2-1 having a height equal to the thickness of the optical waveguide 3 plus the thickness of the spacer 6. In this case, the substrate-side electrode pad 13 on which the solder bump 2-1 is formed can be made to have a diameter of about 30 μm , and the gap between the substrate-side electrode pads 13 can also be reduced to about 40 μm .

[0060] The solder bump 2-1 may also be formed as follows. That is, the peripheral portion of the metal pattern larger than the pad surface is covered with an organic resin of the first cladding layer 7-1 and the optical waveguide core 7-2 of the optical waveguide 3, 3a, 3b, 3c, and the opening not covered with this organic resin is used as the pad surface of the

substrate-side electrode pad 13. A metal plating is formed on this substrate-side electrode pad 13 up to the upper surface of the optical waveguide core 7-2, and then a second cladding layer 7-3 having an opening larger than the dimensions of the pad surface is formed at the position of the substrate-side electrode pad 13.

[0061] Then, a gold-tin or silver-tin solder bump 2-1 is formed on the metal plating formed on the substrate-side electrode pad 13 to a position higher than the upper surface of the second cladding layer 7-3. By this method, the substrate-side electrode pad 13 can be formed at a position matching the formation position of the optical waveguide 3, 3a, 3b, 3c, and moreover, since the volume of the gold-tin or silver-tin solder bump 2-1 to be heated and melted can be reduced, the substrate-side electrode pads 13 can be formed at a small gap with high density.

[0062] As for the material of the substrate 1, 1a, silicon, ceramic, glass epoxy, etc. are conceivable, but there is no element that particularly limits the selection of the substrate material in implementing the present invention.

[0063] The present invention is not limited to the above-described embodiments, and it is obvious that the embodiments can be appropriately modified within the scope of the technical idea of the present invention. For example, in the above embodiments, the solder bump 2-1 also serves as an electrical connection, but the solder bump may be used only for the purpose of mounting the surface-emitting optical element and dissipating heat. In this case, it goes without saying that the substrate-side electrode pad 13 becomes a substrate-side pad, and the surface-emitting optical element-side electrode pad 14 becomes a surface-emitting optical element-side pad. Furthermore, although VCSEL and PD are described as examples of the surface-emitting optical element, the present invention is not limited to these and can also be applied to a light-emitting diode (LD).

[0064]

Effects of the Invention

According to the present invention, by mounting the surface-emitting optical element on the upper surface of the optical waveguide, the optical coupling between the surface-emitting optical element and the optical waveguide can be realized with a simple structure, and the gap between the surface-emitting optical element and the optical waveguide can be reduced to zero. Further, since the surface-emitting optical element and the substrate are connected using solder bumps, the heat generated by the surface-emitting optical element can be efficiently dissipated to the substrate through the solder bumps. Furthermore, by forming the solder bumps on the substrate side in advance, the solder bumps can be melted with minimal heat applied to the surface-emitting optical element during mounting, thereby reducing the deterioration of the surface-emitting optical element due to thermal stress.

[0065] Furthermore, by mounting only the surface-emitting optical element on the optical waveguide and flip-chip connecting both the surface-emitting optical element and the

semiconductor device to the substrate, and connecting the surface-emitting optical element and the semiconductor device by electrical wiring on the substrate, the optical coupling between the surface-emitting optical element and the optical waveguide, as well as the electrical connection between the surface-emitting optical element and the semiconductor device, can be achieved with a simple structure, and the gap between the surface-emitting optical element and the optical waveguide can be reduced to zero. Moreover, since the surface-emitting optical element and the substrate are flip-chip connected, the heat generated by the surface-emitting optical element can be efficiently dissipated to the substrate through the solder bumps. Additionally, by flip-chip connecting the surface-emitting optical element and the semiconductor device to the substrate, the wiring connection between the surface-emitting optical element and the semiconductor device can be made on the substrate plane without any steps, which simplifies the process and is advantageous for high-speed transmission. Furthermore, by forming the solder bumps on the substrate side in advance, the solder bumps can be melted with minimal heat applied to the surface-emitting optical element during mounting, thereby reducing the deterioration of the surface-emitting optical element due to thermal stress.

[0066] Moreover, by forming the inclined mirror at a position on the substrate where the optical path of the surface-emitting optical element after mounting and the optical path of the optical waveguide intersect, the same effect can be obtained as when the inclined mirror is formed on the end face of the optical waveguide.

[0067] Furthermore, by forming solder bumps on the substrate-side pad or the first substrate-side electrode pad that are higher than the upper surface of the optical waveguide, melting these solder bumps and fusing them with the surface-emitting optical element-side pad or the surface-emitting optical element-side electrode pad, lowering the surface-emitting optical element until it comes into contact with the optical waveguide, and then cooling and solidifying the solder bumps, the connection between the surface-emitting optical element-side pad or the surface-emitting optical element-side electrode pad and the substrate-side pad or the first substrate-side electrode pad can be reliably made. In addition, by melting the solder bumps and mounting the surface-emitting optical element while lowering it, the surface-emitting optical element can be mounted in contact with the upper surface of the optical waveguide.

[0068] Furthermore, by supporting the surface-emitting optical element with a plurality of optical waveguides, the surface-emitting optical element can be mounted stably.

[0069] Moreover, by disposing a spacer thicker than the height of the light-emitting portion or light-receiving portion between the lower surface of the surface-emitting optical element and the upper surface of the optical waveguide, thereby ensuring clearance around the light-emitting portion or light-receiving portion, damage to the light-emitting portion or light-receiving portion during mounting can be prevented when the light-

emitting portion or light-receiving portion of the surface-emitting optical element is protruding.

[0070] Furthermore, by providing a relief portion deeper than the height of the light-emitting portion or light-receiving portion at a position on the upper surface of the optical waveguide corresponding to the light-emitting portion or light-receiving portion, damage to the light-emitting portion or light-receiving portion during mounting can be prevented without using a spacer when the light-emitting portion or light-receiving portion of the surface-emitting optical element is protruding. As a spacer is not used, it is not necessary to pay attention to the type of adhesive used to adhere the spacer to the optical waveguide or the heat resistance of the spacer to the processing temperature during mounting of the surface-emitting optical element.

[0071] Furthermore, by providing a stopper for locking the end face of the surface-emitting optical element on the upper surface of the optical waveguide, the vertical position of the surface-emitting optical element can be determined by the optical waveguide, and the horizontal position of the surface-emitting optical element can be mechanically determined by the stopper, eliminating the need to provide a marker on the optical waveguide as in the prior art.

[0072] Furthermore, by holding the surface-emitting optical element with a collet larger than the surface-emitting optical element during mounting so that the surface-emitting optical element is always parallel to the substrate surface, the surface-emitting optical element can be mounted horizontally on the upper surface of the optical waveguide.

[0073] Furthermore, by utilizing an inclined surface formed on the end face of the optical waveguide as the inclined mirror, the inclined mirror can be easily formed.

[0074] Additionally, by employing an optical waveguide with an exposed core layer, the gap between the surface-emitting optical element and the core layer can be reduced, thereby minimizing the divergence of the light beam from the surface-emitting optical element.

[0075] Moreover, by providing a groove in the substrate to accommodate the optical waveguide, the optical waveguide can be formed at a position lower than the upper surface of the substrate where the first electrode pad is formed. This allows for a reduction in the height of the solder bumps, thus preventing bridging between adjacent solder bumps.

Brief Description of the Drawings

[Fig. 1] Cross-sectional view showing the structure of an optical module according to the first embodiment of the present invention.

[Fig. 2] Cross-sectional view showing the structure of an optical module according to the second embodiment of the present invention.

[Fig. 3] Cross-sectional view showing the structure of an optical module according to the third embodiment of the present invention.

[Fig. 4] Diagram showing a method for forming an inclined mirror in the third embodiment of the present invention.

[Fig. 5] Cross-sectional view showing the structure of an optical module according to the fourth embodiment of the present invention.

[Fig. 6] Perspective view showing the structure of an optical module according to the fifth embodiment of the present invention.

[Fig. 7] Cross-sectional view showing the structure of an optical module according to the sixth embodiment of the present invention.

[Fig. 8] Cross-sectional view showing the structure of an optical module according to the seventh embodiment of the present invention.

[Fig. 9] Perspective view and cross-sectional view showing the structure of a conventional optical module.

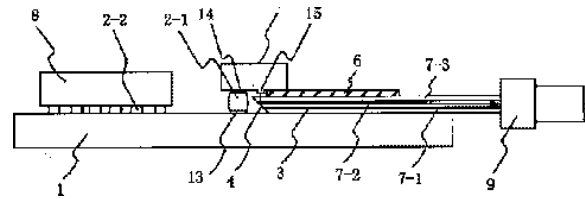
[Fig. 10] Cross-sectional view showing the structure of another conventional optical module.

[Fig. 11] Perspective views and cross-sectional views of another conventional optical module before and after mounting an optical element.

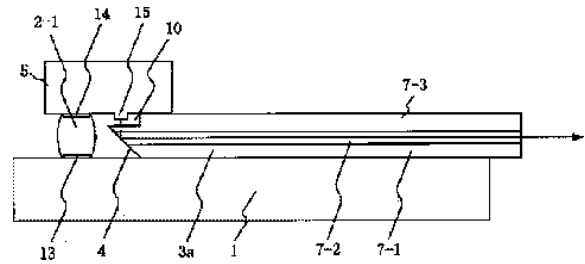
[Legend]

- 1, 1a... Substrate
- 2-1, 2-2... Solder bump
- 3, 3a, 3b, 3c... Optical waveguide
- 4... 45-degree inclined mirror
- 5, 5a... VCSEL
- 6... Spacer
- 7-1... First cladding layer
- 7-2... Optical waveguide core
- 7-3... Second cladding layer
- 8... LSI
- 9... Optical connector
- 10... Relief portion
- 11... Inclined mirror
- 12... Stopper
- 13... Substrate-side electrode pad
- 14... Surface-emitting optical element-side electrode pad
- 15... Light-emitting portion
- 16... Substrate groove

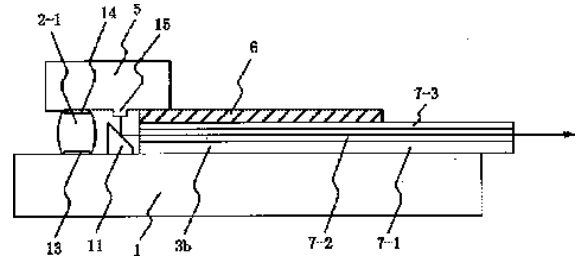
[Figure 1]



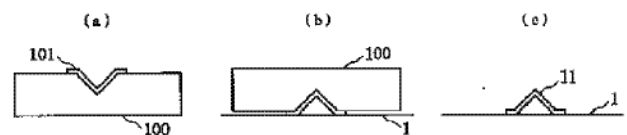
[Figure 2]



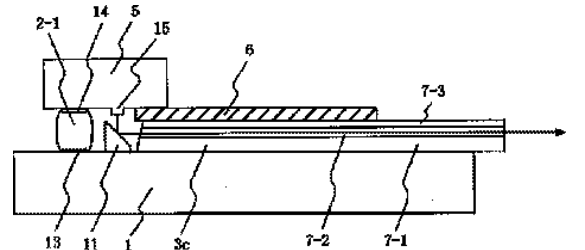
[Figure 3]

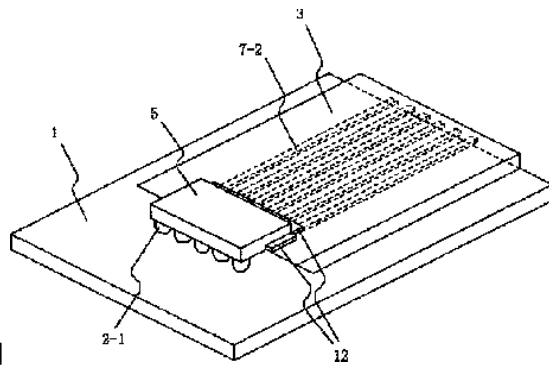


[Figure 4]



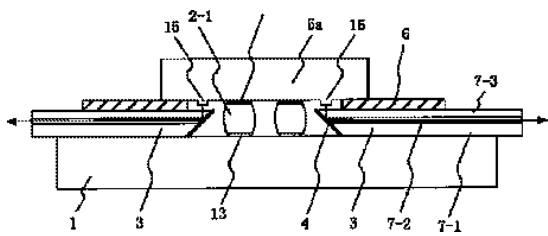
[Figure 5]



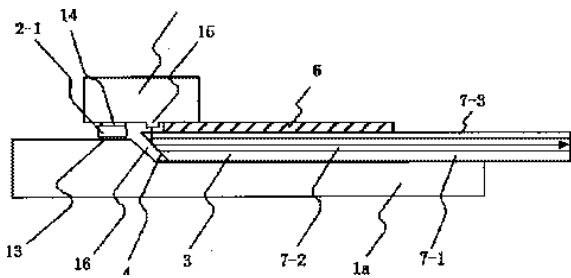


[Figure 6]

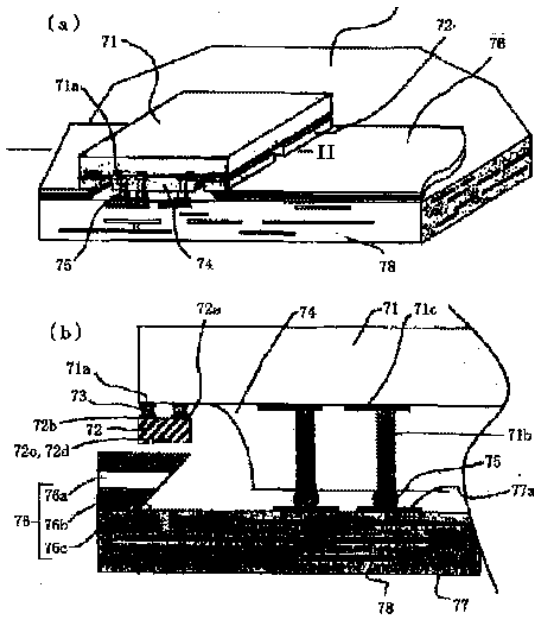
[Figure 7]



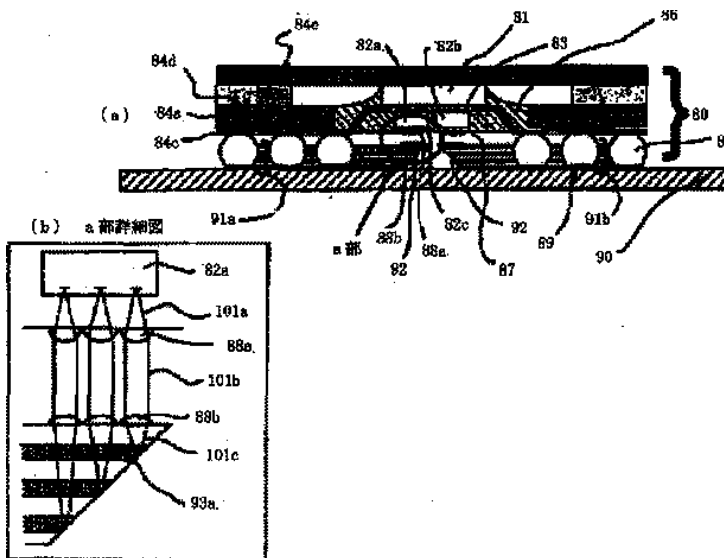
[Figure 8]



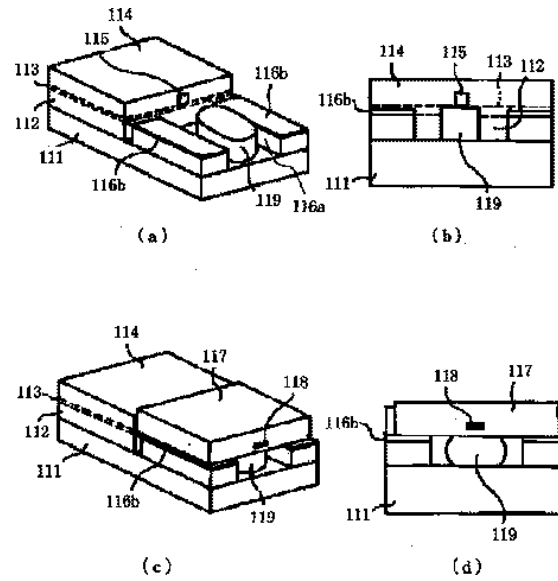
[Figure 9]



[Figure 10]



[Figure 11]



TRANSLATION CERTIFICATION

Date: 2025/01/08

To whom it may concern:

This is to certify that the attached translation is an accurate representation of the documents received by this office. The translation was completed from:

- Japanese

To:

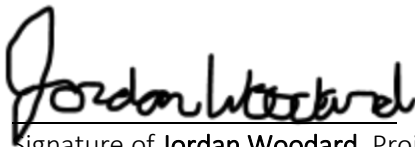
- English (USA)

The documents are designated as:

- CIGUSA-AOI000471_JP-PUB-2003-215371

Jordan Woodard, Project Manager in this company, attests to the following:

“To the best of my knowledge, all statements contained in the translation are true and correct and the aforementioned documents are a true, full and accurate translation of the specified documents. I acknowledge that these statements are subject to the penalties for perjury.”



Signature of **Jordan Woodard**, Project Manager

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