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Substrate with optical waveguide and optical communication device

Abstract

A substrate with optical waveguide includes an interconnect substrate and an optical waveguide formed on the interconnect substrate, wherein the optical waveguide includes a first cladding layer, a first protrusion formed on the first cladding layer, the first protrusion having an upper surface and an inclined surface connected to, and sloping relative to, the upper surface, a first metal film formed at least on the inclined surface, a core layer formed on the first cladding layer such as to cover part of the first metal film, and a second cladding layer formed on the first cladding layer such as to cover the core layer, wherein in plan view, a perimeter of a first surface region constituted by both the upper surface and the inclined surface does not have a corner where two lines meet, except for a part thereof where the inclined surface meets the first cladding layer.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

(1) The present application is based on and claims priority to Japanese Patent Application No. 2022-114561 filed on Jul. 19, 2022, with the Japanese Patent Office, the entire contents of which are incorporated herein by reference.

FIELD

(2) The invention relates to substrates with optical waveguides and optical communication devices.

BACKGROUND

(3) In some technology known in the art, a substrate has an optical waveguide that includes a core layer sandwiched between a first cladding layer and a second cladding layer, and has a protrusion having an inclined surface that slopes at approximately 45 degrees relative to the direction of light propagation through the core layer, with a metal film formed on the inclined surface. The metal film is formed on the protrusion by, for example, vapor deposition or the like performed through a mask made of metal or the like placed above the protrusion.

(4) When the mask is placed above the protrusion for forming a metal film, the mask may come into contact with the protrusion, which may result in the breakage of the protrusion.

(5) Accordingly, there may be a need for a substrate having an optical waveguide in which a protrusion for forming a metal film has such shape as to be unlikely to break.

RELATED ART DOCUMENTS

Patent Document

(6) [Patent Document 1] Japanese Laid-Open Patent Publication No. 2009-69668

SUMMARY

(7) According to an aspect of the embodiment, a substrate with optical waveguide includes an interconnect substrate and an optical waveguide formed on the interconnect substrate, wherein the optical waveguide includes a first cladding layer, a first protrusion formed on an upper surface of the first cladding layer, the first protrusion having an upper surface and an inclined surface, the inclined surface being connected to the upper surface of the first protrusion, the inclined surface sloping relative to the upper surface of the first protrusion, a first metal film formed at least on the inclined surface of the first protrusion, a core layer formed on the upper surface of the first cladding layer such as to cover part of the first metal film, and a second cladding layer formed on the upper surface of the first cladding layer such as to cover at least an upper surface and side surfaces of the core layer, wherein in plan view, a perimeter of a first surface region constituted by both the upper surface and the inclined surface of the first protrusion does not have a corner where two lines meet, except for a part thereof where the inclined surface meets the upper surface of the first cladding layer.

(8) The object and advantages of the embodiment will be realized and attained by means of the elements and combinations particularly pointed out in the claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

Description

BRIEF DESCRIPTION OF DRAWINGS

- (1) FIGS. 1A and 1B are drawings illustrating an example of the structure of a substrate with optical waveguides according to a first embodiment;
- (2) FIG. 2 is an enlarged plan view of a protrusion for forming a first metal film and a protrusion for forming a second metal film according to the first embodiment;
- (3) FIGS. 3A through 3C are drawings illustrating an example of a method of making the substrate with optical waveguides according to the first embodiment;
- (4) FIGS. 4A and 4B are drawings illustrating an example of the method of making the substrate with optical waveguides according to the first embodiment;
- (5) FIGS. 5A and 5B are drawings illustrating an example of the method of making the substrate with optical waveguides according to the first embodiment;
- (6) FIGS. 6A and 6B are drawings illustrating an example of the method of making the substrate with optical waveguides according to the first embodiment;
- (7) FIGS. 7A through 7C are drawings illustrating an example of the method of making the substrate with optical waveguides according to the first embodiment;
- (8) FIGS. 8A and 8B are drawings illustrating an example of the method of making the substrate with optical waveguides according to the first embodiment;
- (9) FIGS. 9A and 9B are drawings illustrating an example of the method of making the substrate with optical waveguides according to the first embodiment;
- (10) FIG. 10 is an enlarged plan view of the protrusion for forming a first metal film and the protrusion for forming a second metal film according to a variation of the first embodiment;
- (11) FIG. 11 is an enlarged plan view of the protrusion for forming a first metal film and the protrusion for forming a second metal film according to another variation of the first embodiment;
- (12) FIG. 12 is a cross-sectional view illustrating an example of an optical transceiver according to a second embodiment; and
- (13) FIG. 13 is a cross-sectional view illustrating an example of an optical transceiver according to a variation of the second embodiment.

DESCRIPTION OF EMBODIMENTS

(14) In the following, embodiments of the present invention will be described with reference to the accompanying drawings.

(15) Embodiments for carrying out the invention will be described below with reference to the accompanying drawings. In the drawings, the same components are referred to by the same numerals, and a duplicate description thereof may be omitted.

First Embodiment

(16) Structure of Substrate with Optical Waveguide

(17) In the following, the structure of a substrate with an optical waveguide will be described.

FIGS. 1A and 1B are drawings illustrating an example of the structure of a substrate with optical waveguides according to a first embodiment, FIG. 1A is a plan view, and FIG. 1B is a cross-sectional view taken along the line A-A in FIG. 1A. In FIG. 1A, a second cladding layer 33 illustrated in FIG. 1B is omitted. In FIGS. 1A and 1B, the X direction, Y direction and Z direction perpendicular to each other are defined for reference purposes. Similar definitions of directions may be provided in some of the remaining drawings as necessary.

(18) As illustrated in FIGS. 1A and 1B, a substrate 1 with optical waveguides according to the first embodiment includes an interconnect substrate 10 and an optical waveguide 30 formed on the interconnect substrate 10. In this example, the plane shape of the interconnect substrate 10 is rectangular, the long sides of the rectangle are parallel to the X direction, and the short sides of the rectangle are parallel to the Y direction. The Z direction is the direction in which the layers constituting the interconnect substrate 10 are stacked.

(19) Interconnect Substrate

(20) The interconnect substrate 10 is structured such that interconnect layers and insulating layers are stacked on both sides of a core substrate 10C. Specifically, the interconnect substrate 10 includes an interconnect layer 12, an insulating layer 13, an interconnect layer 14, and a solder resist layer 15 stacked in this order on one surface (i.e., upper surface) of the core substrate 10C. Further, an interconnect layer 22, an insulating layer 23, an interconnect layer 24, and a solder resist layer 25 are stacked in this order on the other surface (i.e., lower surface) of the core substrate 10C.

(21) The core substrate 10C may be, for example, a glass epoxy substrate as known in the art, in which a glass cloth is impregnated with an insulating resin such as an epoxy-based resin. The core substrate 10C may alternatively be a substrate in which a woven or nonwoven fabric such as glass fiber, carbon fiber, or aramid fiber is impregnated with an epoxy-based resin, a polyimide-based resin, or the like. The thickness of the core substrate 10C may be, for example, about 60 μm to 400 μm . The core substrate 10C has through-holes 10x extending through the core substrate 10C in the thickness direction. The plane shape of each through-hole 10x is, for example, circular.

(22) The interconnect layer 12 is formed on the upper surface of the core substrate 10C. The interconnect layer 22 is formed on the lower surface of the core substrate 10C. The interconnect layer 12 and the interconnect layer 22 are electrically connected by through-interconnects 11 formed in the through-holes 10x. The interconnect layers 12 and 22 are each patterned in a predetermined plane shape. Copper (Cu) or the like, for example, may be used as a material for the interconnect layers 12 and 22 and the through-interconnects 11. The thickness of the interconnect layers 12 and 22 may be, for example, about 10 μm to 30 μm . The interconnect layer 12, the interconnect layer 22 and the through-interconnects 11 may be formed together as one seamless continuous piece.

(23) The insulating layer 13 covers the interconnect layer 12 on the upper surface of the core substrate 10C. The material of the insulating layer 13 may be, for example, an insulating resin mainly composed of epoxy-based resin or polyimide-based resin. The thickness of the insulating layer 13 may be, for example, about 30 μm to 40 μm . The insulating layer 13 may contain a filler such as silica (SiO₂).

(24) The interconnect layer 14 is formed on the upper surface of the insulating layer 13. The

interconnect layer **14** includes interconnect patterns formed on the upper surface of the insulating layer **13** and via interconnects filling via holes **13x** that extend through the insulating layer **13** to expose the upper surface of the interconnect layer **12**. The interconnect layer **14** is electrically connected to the interconnect layer **12**. The via holes **13x** may be an inverted frustoconical recess in which the diameter of the top opening toward the solder resist layer **15** is larger than the diameter of the bottom opening at the upper surface of the interconnect layer **12**. The material of the interconnect layer **14** and the thickness of the interconnect patterns constituting the interconnect layer **14** may be the same as, for example, those of the interconnect layer **12**.

(25) The solder resist layer **15** is the outermost layer on the upper side of the interconnect substrate **10**, and is formed on the upper surface of the insulating layer **13** to cover the interconnect layer **14**. The solder resist layer **15** may be made of, for example, a photosensitive resin such as an epoxy-based resin or an acrylic-based resin. The thickness of the solder resist layer **15** may be, for example, about 15 μm to 35 μm .

(26) The solder resist layer **15** has openings **15x**, and part of the upper surface of the interconnect layer **14** is exposed at the bottom of the openings **15x**. The plane shape of each opening **15x** may be, for example, circular. According to need, the upper surface of the interconnect layer **14** exposed inside the openings **15x** may have a metal film formed thereon or subjected to an antioxidant treatment such as OSP (organic solderability preservative) treatment. Examples of such a metal film include an Au layer, a Ni/Au layer (i.e., a metal film composed of a Ni layer and an Au layer stacked in this order), a Ni/Pd/Au layer (i.e., a metal film composed of a Ni layer, a Pd layer and an Au layer stacked in this order), etc.

(27) External connection terminals **19** are formed on the interconnect layer **14** exposed in the openings **15x**. The external connection terminals **19** are, for example, solder bumps. The material of the solder bumps may be, for example, an alloy containing Pb, an alloy of Sn and Cu, an alloy of Sn and Ag, an alloy of Sn, Ag and Cu, or the like. The external connection terminals **19** are for electrical connection to light emitting or light receiving devices.

(28) The insulating layer **23** is formed on the lower surface of the core substrate **10C** to cover the interconnect layer **22**. The material and thickness of the insulating layer **23** may be the same as, for example, those of the insulating layer **13**. The insulating layer **23** may contain a filler such as silica (SiO_2). The interconnect layer **24** is formed on the lower surface of the insulating layer **23**. The interconnect layer **24** includes interconnect patterns formed on the lower surface of the insulating layer **23**, and includes via interconnects filling via holes **23x** that extend through the insulating layer **23** to expose the lower surface of the interconnect layer **22**. The interconnect layer **24** is electrically connected to the interconnect layer **22**. The via holes **23x** may each be a frustoconical recess in which the diameter of the lower opening toward the solder resist layer is larger than the diameter of the upper opening **25** at the lower surface of the interconnect layer **22**. The material and thickness of the interconnect layer **24** may be the same as, for example, those of the interconnect layer **12**.

(29) The solder resist layer **25** is the outermost layer on the lower side of the interconnect substrate and is formed on the lower surface of the insulating layer **23** to cover the interconnect layer **24**. The material and thickness of the solder resist layer **25** may be the same as, for example, the solder resist layer **15**. The solder resist layer **25** has openings **25x**, and part of the lower surface of the interconnect layer **24** is exposed in the openings **25x**. The plane shape of each opening **25x** may be, for example, circular. The interconnect layer **24** exposed in the openings **25x** may be used as pads for electrical connection with a system board (not shown) such as a motherboard. According to need, the lower surface of the interconnect layer **24** exposed in the openings **25x** may have a metal film as previously described formed thereon, or may be subjected to an antioxidant treatment such as OSP treatment.

(30) Optical Waveguide

(31) The optical waveguide **30** is formed on the solder resist layer **15** of the interconnect substrate

10. The optical waveguide **30** includes a first cladding layer **31**, a core layer **32**, a second cladding layer **33**, a protrusion **35** for forming a first metal film, a protrusion **36** for forming a second metal film, a first metal film **351**, and a second metal film **361**.

(32) The first cladding layer **31** is formed of, for example, a photosensitive material. Specifically, the first cladding layer **31** may be formed of a polymer such as, for example, a polyimide-based resin, an acrylic-based resin, an epoxy-based resin, a polyolefin-based resin, or a polynorbornene-based resin. The thickness of the first cladding layer **31** may be, for example, about 10 μm to 30 μm . The first cladding layer **31** is disposed on the interconnect substrate **10** such as to be approximately parallel to the interconnect substrate **10**.

(33) The core layer **32** is selectively formed on the upper surface of the first cladding layer **31**. The core layer **32** covers part of the first metal film **351** and part of the second metal film **361**. Although two elongated strips of the core layer **32** each extending in the X direction are disposed side by side on the top surface of the first cladding layer **31** in the example illustrated in FIG. 1, this is only an example. Only one strip of the core layer **32** may be formed, or three or more strips may be formed. The pitch of the strips of the core layer **32** arranged side by side may be, for example, about 200 μm to 300 μm . The core layer **32** may be formed of substantially the same material as the first cladding layer **31**. The thickness of the core layer **32** may be, for example, about 15 μm to 35 μm . The shape of the transverse cross section of each strip of the core layer **32** may be, for example, square.

(34) The second cladding layer **33** is formed on the upper surface of the first cladding layer **31** such as to cover at least the upper surface and side surfaces of the core layer **32**. The second cladding layer **33** may be formed of substantially the same material as the first cladding layer **31**. The thickness of the second cladding layer **33** may be, for example, about 10 μm to 30 μm .

(35) The first cladding layer **31**, the core layer **32** and the second cladding layer **33** may be formed of the same material as described above, but the refractive index of the core layer **32** is higher than the refractive indexes of the first cladding layer **31** and the second cladding layer **33**. By including an additive for refractive index control such as Ge in the core layer **32**, the refractive index of the core layer **32** is set higher than the refractive indexes of the first cladding layer **31** and the second cladding layer **33**. The refractive indexes of the first cladding layer **31** and the second cladding layer **33** may be, for example, 1.5, and the refractive index of the core layer **32** may be, for example, 1.6.

(36) The protrusion **35** for forming the first metal film is formed on the upper surface of the first cladding layer **31**. The protrusion **35** for forming the first metal film has an upper surface **35a** and an inclined surface **35b** that is connected to the upper surface **35a** at an angle to the upper surface **35a**. The upper surface **35a** of the protrusion **35** for forming the first metal film is parallel to the upper surface of the first cladding layer **31**, for example. The angle between the upper surface of the first cladding layer **31** and the inclined surface **35b** is, for example, 45 degrees. In addition to the upper surface **35a** and the inclined surface **35b**, the protrusion **35** for forming the first metal film may have a surface parallel to or perpendicular to the upper surface of the first cladding layer **31**.

(37) In a plan view illustrated in FIG. 2, the perimeter of a first region **35c** constituted by the upper surface **35a** and the inclined surface **35b** of the protrusion **35** for forming the first metal film does not have a corner where two lines meet, except for the part where the inclined surface **35b** meets the upper surface of the first cladding layer **31**. It may be noted that the two points surrounded by dashed lines in the first region **35c** are corners where two lines meet.

(38) The upper surface **35a** of the protrusion **35** for forming the first metal film is demarcated by, for example, a straight-line segment **L1** that forms a boundary with the inclined surface **35b** and a curved line segment **L2** directly connected to both ends of the straight-line segment **L1**. The upper surface **35a** of the protrusion **35** for forming the first metal film is, for example, semicircular. The upper surface **35a** of the protrusion **35** for forming the first metal film may alternatively be

semielliptical. The upper surface **35a** of the protrusion **35** for forming the first metal film may have a shape other than semicircular and semielliptical, which is demarcated by the straight-line segment **L1** and the curved line segment **L2**.

(39) Returning to FIGS. **1A** and **1B**, the protrusion **36** for forming the second metal film is formed on the upper surface of the first cladding layer **31**. The protrusion **36** for forming the second metal film has an upper surface **36a** and an inclined surface **36b** that is connected to the upper surface **36a** at an angle to the upper surface **36a**. The upper surface **36a** of the protrusion **36** for forming the second metal film is parallel to the upper surface of the first cladding layer **31**, for example. The angle between the upper surface of the first cladding layer **31** and the inclined surface **36b** is, for example, 45 degrees. In addition to the upper surface **36a** and the inclined surface **36b**, the protrusion **36** for forming the second metal film may have a surface parallel to or perpendicular to the upper surface of the first cladding layer **31**.

(40) In the plan view illustrated in FIG. **2**, the perimeter of a second region **36c** constituted by the upper surface **36a** and the inclined surface **36b** of the protrusion **36** for forming the second metal film does not have a corner where two lines meet, except for the part where the inclined surface **36b** meets the upper surface of the first cladding layer **31**. It may be noted that the two points surrounded by dashed lines in the second region **36c** are corners where two lines meet.

(41) The upper surface **36a** of the protrusion **36** for forming the second metal film is demarcated by, for example, a straight-line segment **L3** forming a boundary with the inclined surface **36b** and a curved line segment **L4** directly connected to both ends of the straight-line segment **L3**. The upper surface **36a** of the protrusion **36** for forming the second metal film is, for example, semicircular. The upper surface **36a** of the protrusion **36** for forming the second metal film may alternatively be semielliptical. The upper surface **36a** of the protrusion **36** for forming the second metal film may have a shape other than semicircular and semielliptical, which is demarcated by the straight-line segment **L3** and the curved line segment **L4**. The upper surface **36a** of the protrusion **36** for forming the second metal film may or may not have the same shape as the upper surface **35a** of the protrusion **35** for forming the first metal film. Here, the definition of the term “same shape” includes a shape that coincides with the other when one is rotated by a predetermined angle.

(42) Referring to FIG. **1** again, the first metal film **351** is formed at least on the inclined surface **35b** of the protrusion **35** for forming the first metal film. At the inclined surface **35b**, the first metal film **351** is situated at the center portion covered with the core layer **32**, and extends beyond the core layer **32** to both sides thereof in the Y direction. The second metal film **361** is formed at least on the inclined surface **36b** of the protrusion **36** for forming the second metal film. At the inclined surface **36b**, the second metal film **361** is situated at the center portion covered with the core layer **32**, and extends beyond the core layer **32** to both sides thereof in the Y direction.

(43) The second metal film **361** formed at the inclined surface **36b** is disposed in a generally opposing relationship to the first metal film **351** formed at the inclined surface **35b**. The interface between the core layer **32** and the first metal film **351** and the interface between the core layer **32** and the second metal film **361** become reflection surfaces that change the direction of propagation of incident light. The first metal film **351** and the second metal film **361** are, for example, each a gold (Au) film with a thickness of 0.2 μm to 0.5 μm .

(44) Method of Making Substrate with Optical Waveguide

(45) In the following, a method of making the substrate **1** with optical waveguides will be described. FIGS. **3A** through **3C** to FIGS. **9A** and **9B** illustrate an example of the method of making the substrate with optical waveguides according to the first embodiment. FIG. **4A**, FIG. **5A**, FIG. **6A**, and FIG. **8A** are cross-sectional views, and FIG. **4B**, FIG. **5B**, FIG. **6B**, and FIG. **8B** are plan views.

(46) In the step illustrated in FIG. **3A**, an interconnect substrate **10** is prepared. The interconnect substrate **10** may be manufactured by, for example, a build-up method known in the art. The interconnect substrate **10** may be a commercially purchased product.

(47) In the step illustrated in FIG. 3B, a first cladding layer **31** is formed on the upper surface of the solder resist layer **15** of the interconnect substrate **10**. The thickness of the first cladding layer **31** is, for example, about 10 μm . In the step illustrated in FIG. 3C, an ultraviolet-curable resin **300** covering the first cladding layer **31** is laminated on the upper surface of the solder resist layer **15** of the interconnect substrate **10**. The thickness of the ultraviolet-curable resin **300** is, for example, about 35 μm .

(48) In the steps illustrated in FIG. 4A through FIG. 6B, the ultraviolet-curable resin **300** is patterned such that only remaining portions thereof are the portions that are to become the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film, which results in the formation of resin protrusions **350** and **360**.

(49) Specifically, as illustrated in FIG. 4A and FIG. 4B, a mask **400**, for example, is disposed on the ultraviolet-curable resin **300**, and has openings **400x** at positions corresponding to the portions that are to become the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film. In the plan view, the openings **400x** correspond in shape to the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film illustrated in FIG. 1.

(50) Subsequently, as illustrated in FIG. 5A and FIG. 5B, the ultraviolet-curable resin **300** is exposed to ultraviolet light through the mask **400** and patterned by the exposure. The portions of the ultraviolet-curable resin **300** exposed through the openings **400x** are cured and become the resin protrusions **350** and **360**. The unnecessary portion of the ultraviolet-curable resin **300** is then removed by development to form the resin protrusions **350** and **360** as illustrated in FIG. 6A and FIG. 6B.

(51) In the step illustrated in FIG. 7A, the resin protrusions **350** and **360** are cut to, for example, 45 degrees so that the inclined surfaces are in a generally opposing relationship to each other. Cutting may be performed by, for example, dicing with a dicer blade **410** and/or polishing with a polishing plate. When scratches, dents, or the like are made in the inclined surfaces **35b** and **36b** made by the cutting process, it is preferable to smooth the inclined surfaces **35b** and **36b** by irradiating the cut surfaces with a laser beam or applying a resin solution to the cut surfaces. Through these steps, the protrusion **35** for forming the first metal film is formed with the inclined surface **35b** sloping relative to the upper surface of the first cladding layer **31**, and the protrusion **36** for forming the second metal film is formed with the inclined surface **36b** sloping relative to the upper surface of the first cladding layer **31**.

(52) In the steps illustrated in FIG. 7B to FIG. 8B, a first metal film **351** is formed on at least the inclined surface **35b** of the protrusion **35** for forming the first metal film, and a second metal film **361** is formed on at least the inclined surface **36b** of the protrusion **36** for forming the second metal film.

(53) Specifically, as illustrated in FIG. 7B, a mask **500** is placed above the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film, and has openings **500x** at the positions where the first metal film **351** and the second metal film **361** are to be formed. The mask **500** may be, for example, made of metal. The openings **500x** in the plan view may have any shape, such as circular or rectangular, as long as the positions where the first metal film **351** and the second metal film **361** are to be formed are exposed.

(54) As illustrated in FIG. 7C, the first metal film **351** and the second metal film **361** are formed on at least the inclined surface **35b** and the inclined surface **36b**, respectively, exposed in the opening **500x** by sputtering or vapor deposition performed through the mask **500**. The first metal film **351** and the second metal film **361** are, for example, gold films. Part of the first metal film **351** and part of the second metal film **361** may be formed on the upper surface of both the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film and also on the upper surface of the first cladding layer **31**.

(55) As illustrated in FIG. 8A and FIG. 8B, the mask **500** is removed. Although two sets of

protrusions, each set including the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film, are formed in this example, this is non-limiting. Only one set of protrusions, including the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film, may be formed, or three or more sets may be formed.

(56) In the step illustrated in FIG. **9A**, a core layer **32** made of a photosensitive resin is formed on the upper surface of the first cladding layer **31** such as to cover part of the first metal film **351** and part of the second metal film **361**. The core layer **32** is formed, for example, by placing an uncured photosensitive resin film on the first cladding layer **31** and performing exposure and development through the same mask. The upper surface of the core layer **32** is flush with, for example, the upper surfaces of the first metal film **351** and the second metal film **361**. The upper surfaces of the first metal film **351** and the second metal film **361** may be exposed outside the core layer **32**. In the illustrated example, two elongated strips of the core layer **32** extending in the X direction are formed on the upper surface of the first cladding layer **31**. In general, strips of the core layer **32** are formed such as to correspond in number to the sets of the protrusions, each set including the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film.

(57) In the step illustrated in FIG. **9B**, a second cladding layer **33** is laminated on the core layer **32**. The second cladding layer **33** may be formed into a predetermined pattern by, for example, placing an uncured photosensitive resin film on the upper surface of the first cladding layer **31** such as to cover at least the upper surface and side surfaces of the core layer **32**, and then exposing and developing the photosensitive resin film. Through the steps described heretofore, the substrate **1** with optical waveguides in which the optical waveguides **30** are mounted on the interconnect substrate **10** are completed in final form.

(58) As was previously described, the substrate **1** with optical waveguides is configured such that in the plan view, the perimeter of the first region **35c** constituted by the upper surface **35a** and the inclined surface **35b** of the protrusion **35** for forming the first metal film does not have a corner where two lines meet except for the part where the inclined surface **35b** comes in contact with the upper surface of the first cladding layer **31**. In the plan view, the perimeter of the second region **36c** constituted by the upper surface **36a** and the inclined surface **36b** of the protrusion **36** for forming the second metal film does not have a corner where the two lines meet, except for the part where the inclined surface **36b** comes in contact with the upper surface of the first cladding layer **31**.

(59) If the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film were rectangular in the plan view, the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film would have substantially right-angle corners where two lines meet in the plan view on the opposite side from the inclined surfaces. In this case, if the mask **500** placed above the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film in the step illustrated in FIG. **7B** were to come into contact with the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film, the material at the corners would be likely to be damaged. In the case of the substrate **1** with optical waveguides, the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film do not have a corner where two lines meet in the plan view on the opposite side from the inclined surfaces, so that the risk of breakage is greatly reduced even if contact with the mask **500** occurs. That is, the curved line segments **L2** and **L4** of the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film have shapes that are not easily broken even if contact with the mask **500** occurs.

(60) This embodiment is directed to the configuration in which both the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film are provided. Alternatively, the configuration may be such that only one of the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film is provided.

Variation of First Embodiment

(61) A variation of the first embodiment is directed to another example of the plane shape of the first and second regions. With respect to the variation of the first embodiment, a description of the same components as those in the previously described embodiment may be omitted.

(62) FIG. **10** is an enlarged plan view of the protrusion for forming a first metal film and the protrusion for forming a second metal film according to the variation of the first embodiment. The first region **35c** and the second region **36c** may be shaped as illustrated in FIG. **10**.

(63) In the plan view illustrated in FIG. **10** also, the first region **35c** constituted by the upper surface **35a** and the inclined surface **35b** of the protrusion **35** for forming the first metal film does not have a corner where the two lines meet, except for the part where the inclined surface **35b** meets the upper surface of the first cladding layer **31**. In the plan view, the second region **36c** constituted by the upper surface **36a** and the inclined surface **36b** of the protrusion **36** for forming the second metal film does not have a corner where the two lines meet, except for the part where the inclined surface **36b** meets the upper surface of the first cladding layer **31**.

(64) In FIG. **10**, the upper surface **35a** of the protrusion **35** for forming the first metal film is demarcated by, for example, a straight-line segment **M1** forming a boundary with the inclined surface **35b**, a straight-line segment **M2** connected to one end of the straight-line segment **M1**, a straight-line segment **M3** connected to the other end of the straight-line segment **M1**, and a curved line segment **M4** connecting the ends of the straight-line segments **M2** and **M3**.

(65) Further, the upper surface **36a** of the protrusion **36** for forming the second metal film is demarcated by, for example, a straight-line segment **M5** forming a boundary with the inclined surface **36b**, a straight-line segment **M6** connected to one end of the straight-line segment **M5**, a straight-line segment **M7** connected to the other end of the straight-line segment **M5**, and a curved line segment **M8** connecting the ends of the straight-line segments **M6** and **M7**.

(66) As described above, the upper surface **35a** of the protrusion **35** for forming the first metal film may be demarcated by the straight-line segment **M1** forming a boundary with the inclined surface **35b**, the curved line segment **M4** connected via other straight-line segments to the opposite ends of the straight-line segment **M1**, and the noted straight-line segments. Further, the upper surface **36a** of the protrusion **36** for forming the second metal film may be demarcated by the straight-line segment **M5** forming a boundary with the inclined surface **36b**, the curved line segment **M8** connected via other straight-line segments to the opposite ends of the straight-line segment **M5**, and the noted straight-line segments. The upper surface **35a** of the protrusion **35** for forming the first metal film and the upper surface **36a** of the protrusion **36** for forming the second metal film may include a semicircular part or a semielliptical part.

(67) FIG. **11** is an enlarged plan view of the protrusion for forming a first metal film and the protrusion for forming a second metal film according to another variation of the first embodiment. The first region **35c** and the second region **36c** may be shaped as illustrated in FIG. **11**.

(68) In the plan view illustrated in FIG. **11** also, the first region **35c** constituted by the upper surface **35a** and the inclined surface **35b** of the protrusion **35** for forming the first metal film does not have a corner where the two lines meet, except for the part where the inclined surface **35b** meet the upper surface of the first cladding layer **31**. In the plan view, the second region **36c** constituted by the upper surface **36a** and the inclined surface **36b** of the protrusion **36** for forming the second metal film does not have a corner where the two lines meet, except for the part where the inclined surface **36b** meets the upper surface of the first cladding layer **31**.

(69) In FIG. **11**, the upper surface **35a** of the protrusion **35** for forming the first metal film is demarcated by a straight-line segment **N1** forming a boundary with the inclined surface **35b**, a curved line segment **N4** connected via a straight-line segment **N2** to one end of the straight-line segment **N1**, a curved line segment **N5** connected via a straight-line segment **N3** to the other end of the straight-line segment **N1**, and a straight-line segment **N6** connecting the ends of the curved line segments **N4** and **N5**. The straight-line segments **N1** and **N6** may or may not be parallel to each other. The curved line segments **N4** and **N5** may or may not be arc-shaped. As an alternative

configuration, the curved line segment **N4** may be directly connected to one end of the straight-line segment **N1** without the intervening straight-line segment **N2**, and the curved line segment **N5** may be directly connected to the other end of the straight-line segment **N1** without the intervening straight-line segment **N3**.

(70) The upper surface **36a** of the protrusion **36** for forming the second metal film is demarcated by a straight-line segment **N7** forming a boundary with the inclined surface **36b**, a curved line segment **N10** connected via a straight-line segment **N8** to one end of the straight-line segment **N7**, a curved line segment **N11** connected via a straight-line segment **N9** to the other end of the straight-line segment **N7**, and a straight-line segment **N12** connecting the ends of the curved line segments **N10** and **N11**. The straight-line segments **N7** and **N12** may or may not be parallel to each other. The curved line segments **N10** and **N11** may or may not be arc-shaped. As an alternative configuration, the curved line segment **N10** may be directly connected to one end of the straight-line segment **N7** without the intervening straight-line segment **N8**, and the curved line segment **N11** may be directly connected to the other end of the straight-line segment **N7** without the intervening straight-line segment **N9**.

(71) As in the case of the structure illustrated in FIG. 2, the structures illustrated in FIG. 10 and FIG. 11 are such that the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film do not have a corner where two lines meet in plan view on the opposite sides from the inclined surfaces, which results in the risk of breakage being greatly reduced even if contact with the mask **500** occurs. It may be noted that each of the upper surfaces of the protrusion **35** for forming the first metal film and the protrusion **36** for forming the second metal film more preferably has a perimeter that is free of any straight-line part in the plan view, except for the boundary with the inclined surface, and constituted only by curved line parts as illustrated in FIG. 2, for example. Such a configuration provides the highest strength.

Second Embodiment

(72) The second embodiment is directed to an example of an optical communication device that includes a substrate on which an optical waveguide is mounted according to the first embodiment, and that includes either a light emitting device emitting light to the optical waveguide or a light receiving device that receives light emitted from the optical waveguide, or both, mounted on the substrate. In the second embodiment, a description of the same components as those described in the previous embodiments may be omitted.

(73) FIG. 12 is a cross-sectional view illustrating an example of an optical transceiver according to the second embodiment. As illustrated in FIG. 12, an optical transceiver **5** includes a substrate **1** with an optical waveguide, a light emitting device **110**, a light receiving device **120**, and underfill resins **150** and **160**.

(74) The light emitting device **110** includes a main part **111**, a bump **112**, and a light emitting part **113**, and emits light to the optical waveguide **30**. The bump **112** and the light emitting part **113** are disposed on the same side of the main part **111** as the interconnect substrate **10**. The bump **112** is, for example, an Au bump and is electrically connected to the external connection terminal **19** of the interconnect substrate **10**. The light emitting part **113** is arranged at such a position as to emit light to the first metal film **351**. The light emitting device **110** may be, for example, a surface emitting laser (VCSEL: vertical cavity surface emitting laser), a light emitting diode (LED), or the like.

(75) The underfill resin **150** is provided between the light emitting device **110** and part of both the solder resist layer **15** and the optical waveguide **30**. The underfill resin **150** may be, for example, a light transmissive resin capable of transmitting light emitted from the light emitting device **110**.

(76) The light receiving device **120** includes a main part **121**, a bump **122**, and a light receiving part **123**, and receives light emitted from the optical waveguide **30**. The bump **122** and the light receiving part **123** are disposed on the same side of the main part **121** as the interconnect substrate **10**. The bump **122** is, for example, an Au bump and is electrically connected to the external connection terminal **19** of the interconnect substrate **10**. The light receiving part **123** is arranged at

such a position as to receive light reflected by the second metal film **361**. The light receiving device **120** may be, for example, a photodiode or an avalanche photodiode (APD).

(77) The underfill resin **160** is provided between the light receiving device **120** and part of both the solder resist layer **15** and the optical waveguide **30**. The underfill resin **160** may be, for example, a light transmissive resin capable of transmitting light that is to be received by the light receiving device **120**.

(78) In FIG. **12**, light L emitted from the light emitting part **113** of the light emitting device **110** passes through the underfill resin **150** and the second cladding layer **33** to enter the core layer **32**, and reaches the first metal film **351** to be totally reflected by the first metal film **351**, which results in an approximately 90-degree change in the light propagation direction. The light L then propagates in the core layer **32**, and reaches the second metal film **361** to be totally reflected by the second metal film **361**, which results in an approximately 90-degree change in the light propagation direction. The light L then exits from the core layer **32** to pass through the second cladding layer **33** and the underfill resin **160**, and is received by the light receiving part **123** of the light receiving device **120**.

(79) Since the optical transceiver **5** has the optical waveguide **30** in which the protrusions for forming a metal film have such shape as to be unlikely to break, a highly reliable device may be realized.

(80) FIG. **13** is a cross-sectional view illustrating an example of an optical transceiver according to a variation of the second embodiment. As illustrated in FIG. **13**, an optical transceiver **6** differs from the optical transceiver **5** (see FIG. **12**) in that the optical waveguide **30** is replaced with an optical waveguide **30A**, and an optical fiber **130** for signal transmission is provided in place of the light receiving device **120**.

(81) The optical waveguide **30A** differs from the optical waveguide **30** in that the protrusion **36** for forming the second metal film and the second metal film **361** are not provided. The optical fiber **130** is arranged on the solder resist layer **15** of the interconnect substrate **10** such that the incident surface of the optical fiber **130** and the end surface of the optical waveguide **30A** on the far side from the first metal film **351** face each other across a small gap. The optical axis of the optical fiber **130** coincides with the optical axis of the optical waveguide **30A**.

(82) Light L perpendicularly incident on the optical waveguide **30A** from the light emitting part **113** of the light emitting device **110** is reflected by the first metal film **351** at an angle of 90 degrees, and passes through the core layer **32** of the optical waveguide **30A**, followed by exiting from the end face of the optical waveguide **30A** to enter the optical fiber **130**, thereby being transmitted as an optical signal. As an alternative configuration, the light emitting device **110** may be replaced with a light receiving device, and light exiting from the optical fiber **130** enters the optical waveguide **30A**, followed by being reflected by the first metal film **351** at an angle of 90 degrees and then received by the light receiving device.

(83) Since the optical transceiver **6** has the optical waveguide **30A** in which the protrusion for forming a metal film has such shape as to be unlikely to break, a highly reliable device may be realized.

(84) According to at least one embodiment, a substrate having an optical waveguide is provided for which the optical waveguide has a protrusion for forming a metal film that has such shape as to be unlikely to break.

(85) All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiment(s) of the present inventions have been described in detail, it should be understood that the various changes,

substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

Claims

1. A substrate with optical waveguide, comprising: an interconnect substrate; and an optical waveguide formed on the interconnect substrate, wherein the optical waveguide includes a first cladding layer, a first protrusion formed on an upper surface of the first cladding layer, the first protrusion having an upper surface and an inclined surface, the inclined surface being connected to the upper surface of the first protrusion, the inclined surface sloping relative to the upper surface of the first protrusion, a first metal film formed at least on the inclined surface of the first protrusion, a core layer formed on the upper surface of the first cladding layer such as to cover part of the first metal film, and a second cladding layer formed on the upper surface of the first cladding layer such as to cover at least an upper surface and side surfaces of the core layer, wherein in plan view, a perimeter of a first surface region constituted by both the upper surface and the inclined surface of the first protrusion does not have a corner where two lines meet, except for a part thereof where the inclined surface meets the upper surface of the first cladding layer.
 2. The substrate with optical waveguide as claimed in claim 1, wherein the upper surface of the first protrusion is demarcated by line segments, the line segments including at least both a straight-line segment forming a boundary with the inclined surface and a curved line segment connected to both ends of the straight-line segment directly or through other straight-line segments.
 3. The substrate with optical waveguide as claimed in claim 2, wherein the upper surface of the first protrusion includes a semicircular part.
 4. The substrate with optical waveguide as claimed in claim 2, wherein the upper surface of the first protrusion includes a semielliptical part.
 5. The substrate with optical waveguide as claimed in claim 1, wherein the upper surface of the first protrusion is demarcated by line segments, the line segments including a first straight-line segment forming a boundary with the inclined surface, a first curved line segment connected to one end of the first straight-line segment directly or through another straight-line segment, a second curved line segment connected to another end of the first straight-line segment directly or through another straight-line segment, and a second straight-line segment connecting an end of the first curved line segment and an end of the second curved line segment.
 6. The substrate with optical waveguide as claimed in claim 1, further comprising: a second protrusion formed on the upper surface of the first cladding layer, the second protrusion having an upper surface and an inclined surface, the inclined surface of the second protrusion being connected to the upper surface of the second protrusion, the inclined surface of the second protrusion sloping relative to the upper surface of the second protrusion; and a second metal film formed at least on the inclined surface of the second protrusion, wherein in plan view, a perimeter of a second surface region constituted by the upper surface and the inclined surface of the second protrusion does not have a corner where two lines meet, except for a part thereof where the inclined surface of the second protrusion meets the upper surface of the first cladding layer.
 7. The substrate with optical waveguide as claimed in claim 6, wherein the upper surface of the second protrusion has a same shape as the upper surface of the first protrusion.
 8. An optical communication device comprising: the substrate with optical waveguide of claim 1; and either a light emitting device emitting light to the optical waveguide, a light receiving device receiving light emitted from the optical waveguide, or both.
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