US012386116B2

(12) United States Patent
Okimoto et al.

(10) Patent No.: US 12,386,116 B2
(45) Date of Patent: Aug. 12, 2025

(54) **SEMICONDUCTOR OPTICAL DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 308 days.

(21) Appl. No.: **18/125,428**

(22) Filed: **Mar. 23, 2023**

(65) **Prior Publication Data**

US 2023/0408766 A1 Dec. 21, 2023

(30) **Foreign Application Priority Data**

Jun. 21, 2022 (JP) 2022-099561

(51) **Int. Cl.**
G02B 6/122 (2006.01)
G02B 6/12 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G02B 6/1228*** (2013.01); ***H10F 77/1248*** (2025.01); ***H10F 77/306*** (2025.01);
(Continued)

(58) **Field of Classification Search**
CPC . G02B 6/1228; G02B 6/12004; H10F 77/306; H10F 77/413; H10F 77/206; H10F 77/1248; H10F 30/223; H10F 30/225
See application file for complete search history.

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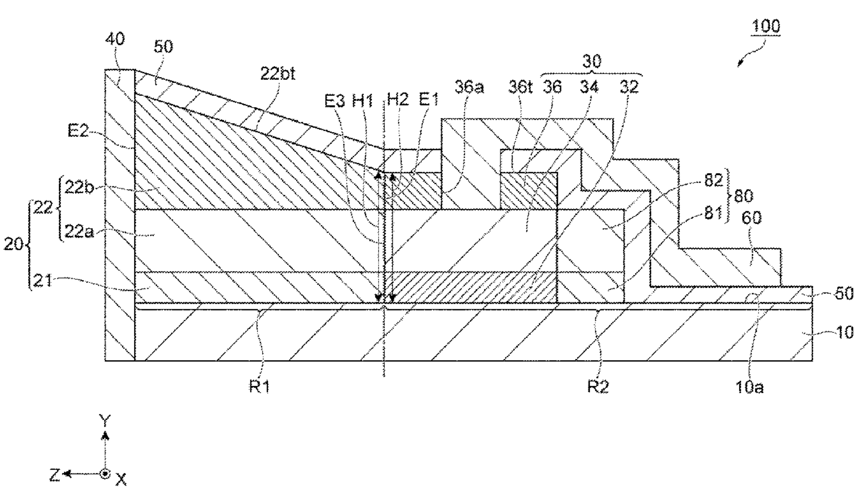
(57) **ABSTRACT**

A semiconductor optical device includes a substrate a spot-size converter, an optical detector, a core layer and a first III-V compound semiconductor layer, the core layer is disposed between the substrate and the first III-V compound semiconductor layer, the optical detector includes a light absorbing layer, a second III-V compound semiconductor layer, and an insulating film,

the light absorbing layer is disposed between the substrate and the second III-V compound semiconductor layer, the second III-V compound semiconductor layer is disposed between the light absorbing layer and the insulating film, the light absorbing layer is optically coupled to the core layer, the spot-size converter has a first end face connected to the optical detector and a second end face opposite to the first end face, and the first III-V compound semiconductor layer is connected to the second III-V compound semiconductor layer and the insulating film at the first end face.

10 Claims, 10 Drawing Sheets



(51) **Int. Cl.**
H10F 77/124 (2025.01)
H10F 77/20 (2025.01)
H10F 77/30 (2025.01)
H10F 77/40 (2025.01)
H10F 30/225 (2025.01)

(52) **U.S. Cl.**
CPC . ***H10F 77/413*** (2025.01); *G02B 2006/12138* (2013.01); *H10F 30/225* (2025.01); *H10F 77/206* (2025.01)

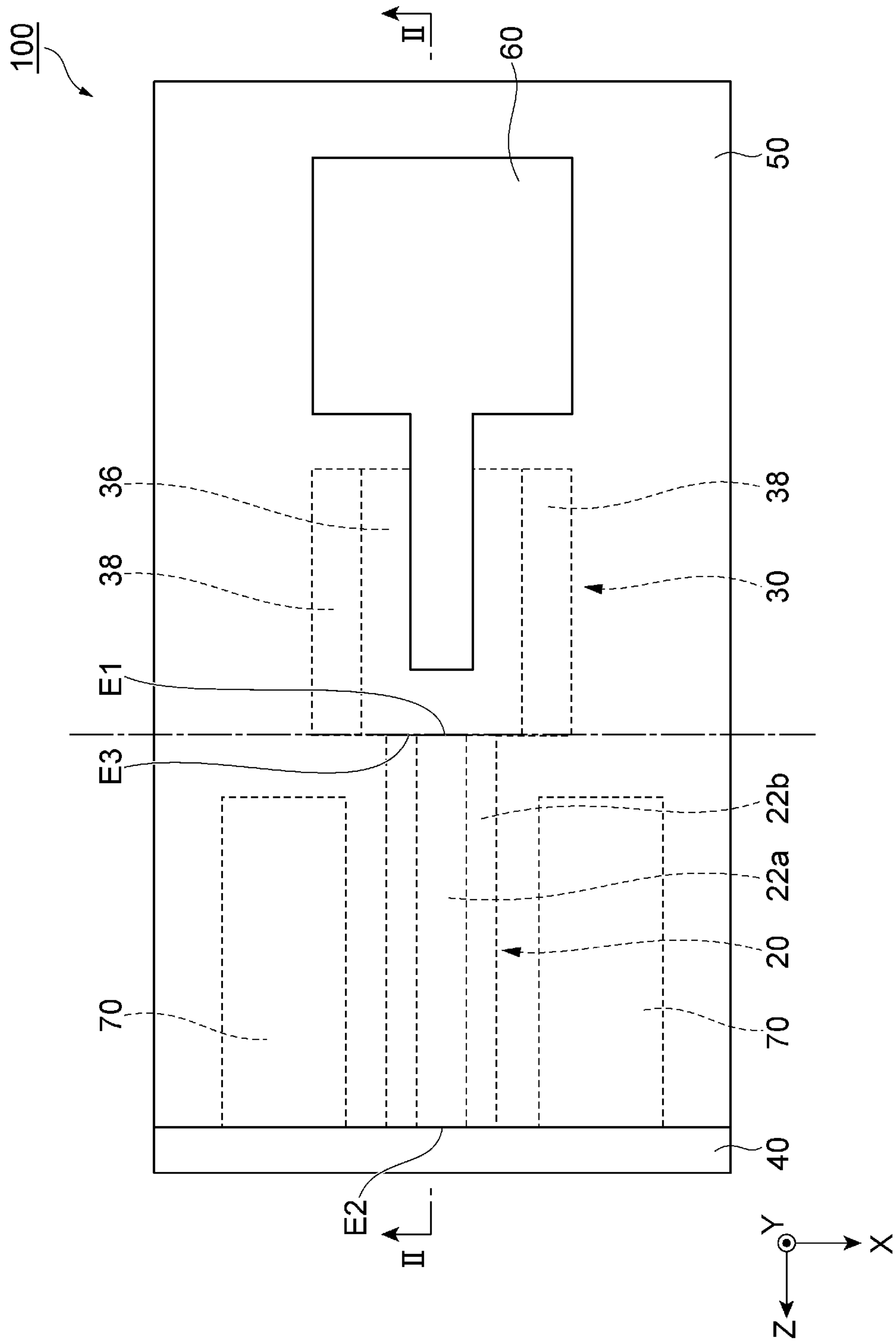


FIG. 1

FIG. 2

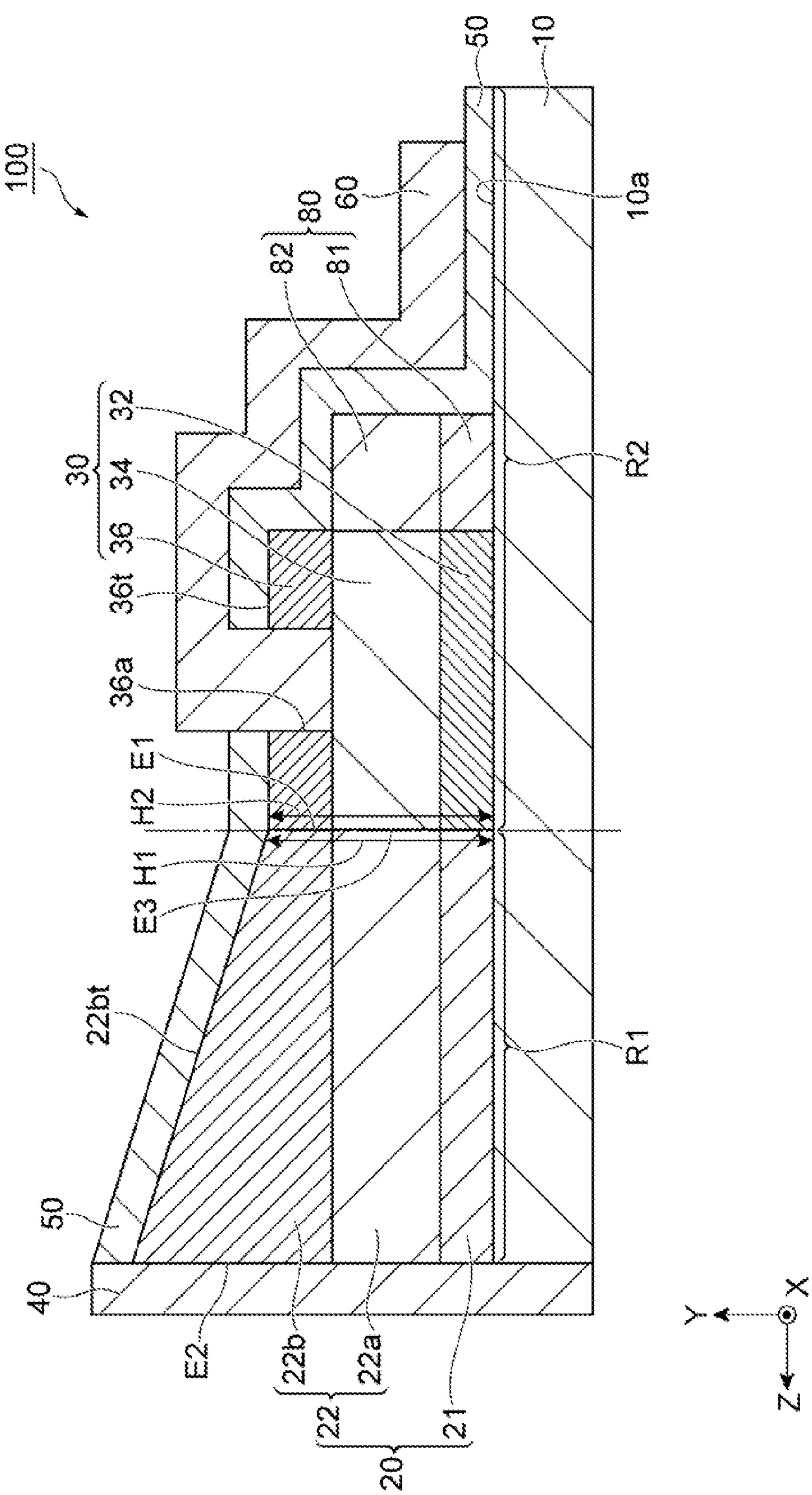

100
50
10
60
10a
80
82
81
30
32
34
36
36t
36a
E1
H2
H1
E3
R2
R1
22bt
50
40
E2
22b
22a
22
21
20
Y
X
Z

FIG. 3

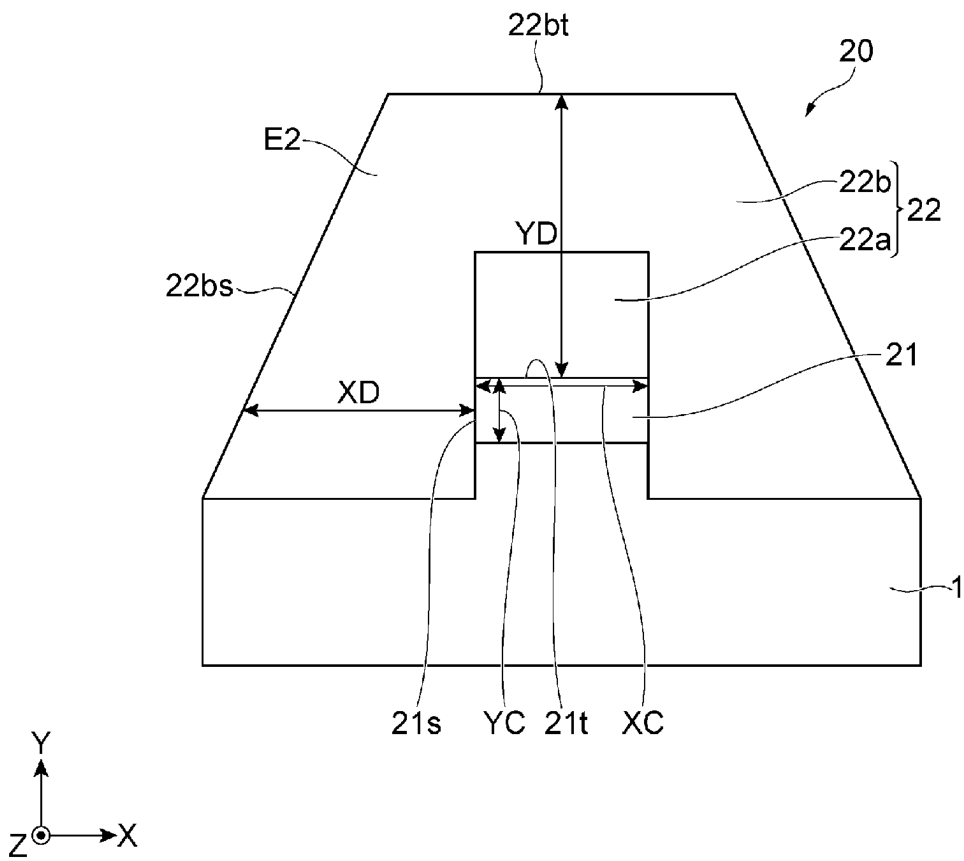


FIG. 4

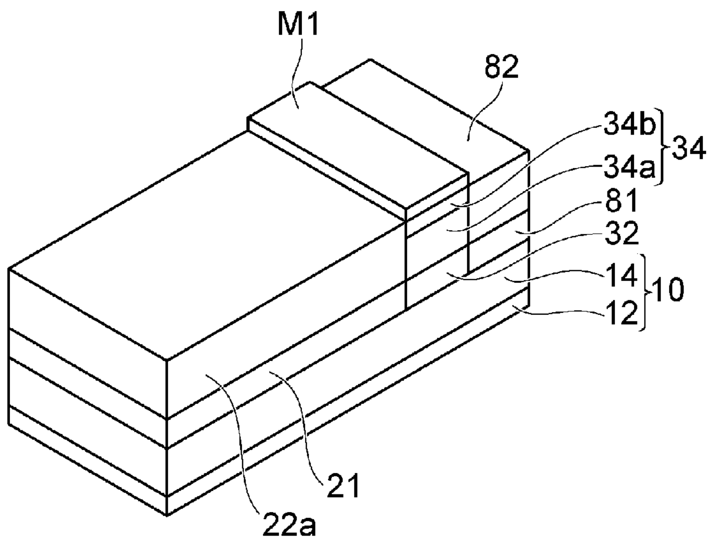

M1
82
34b
34a
34
81
32
14
10
12
21
22a

FIG. 5

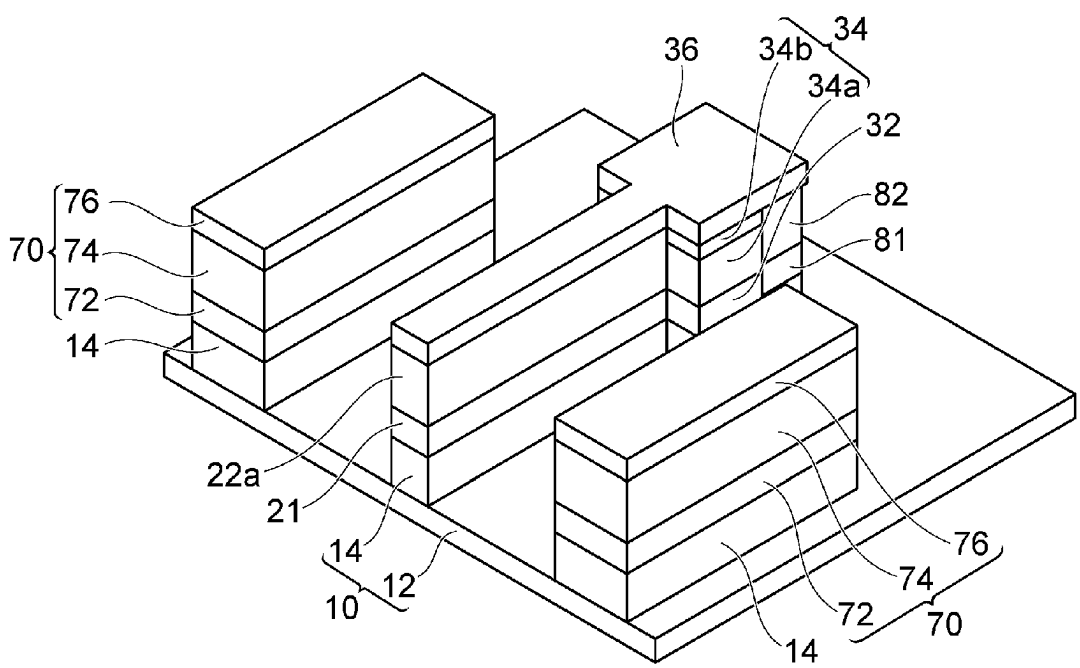

36
34b
34
34a
32
82
81
76
70
74
72
14
22a
21
14
12
10
76
74
72
70
14

FIG. 6

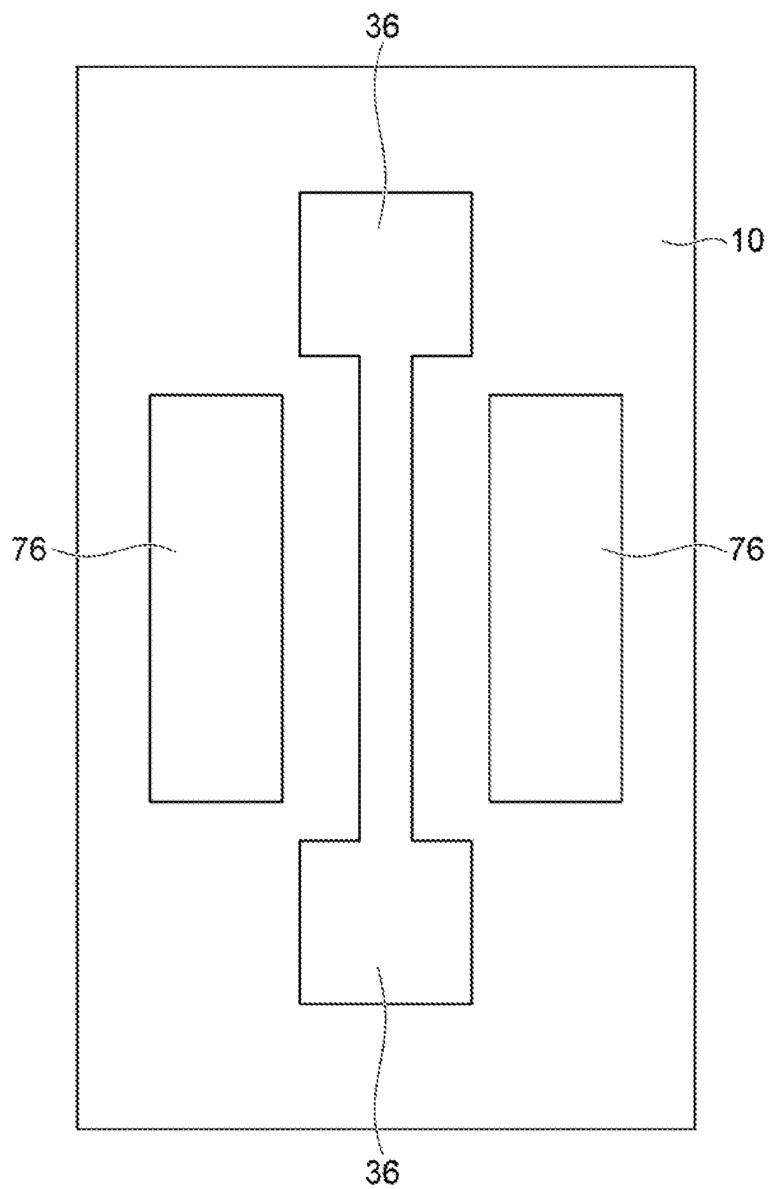


FIG. 7

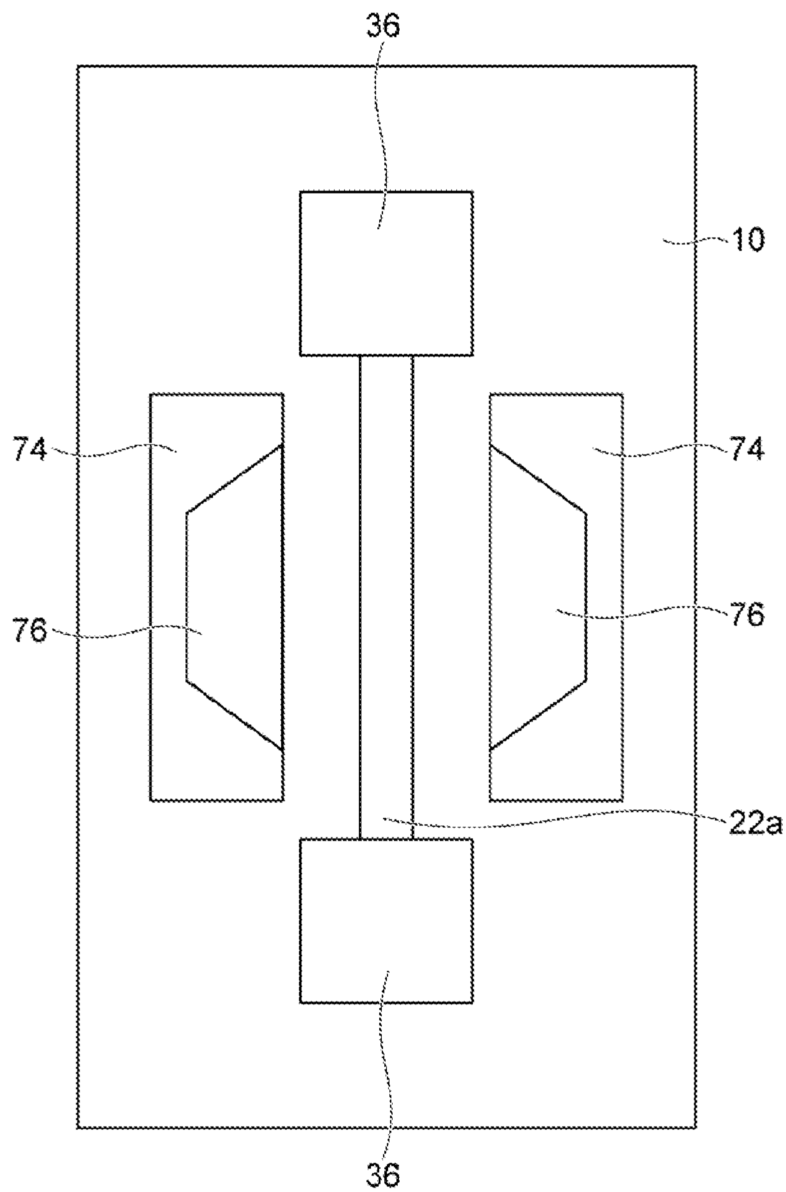


FIG. 8

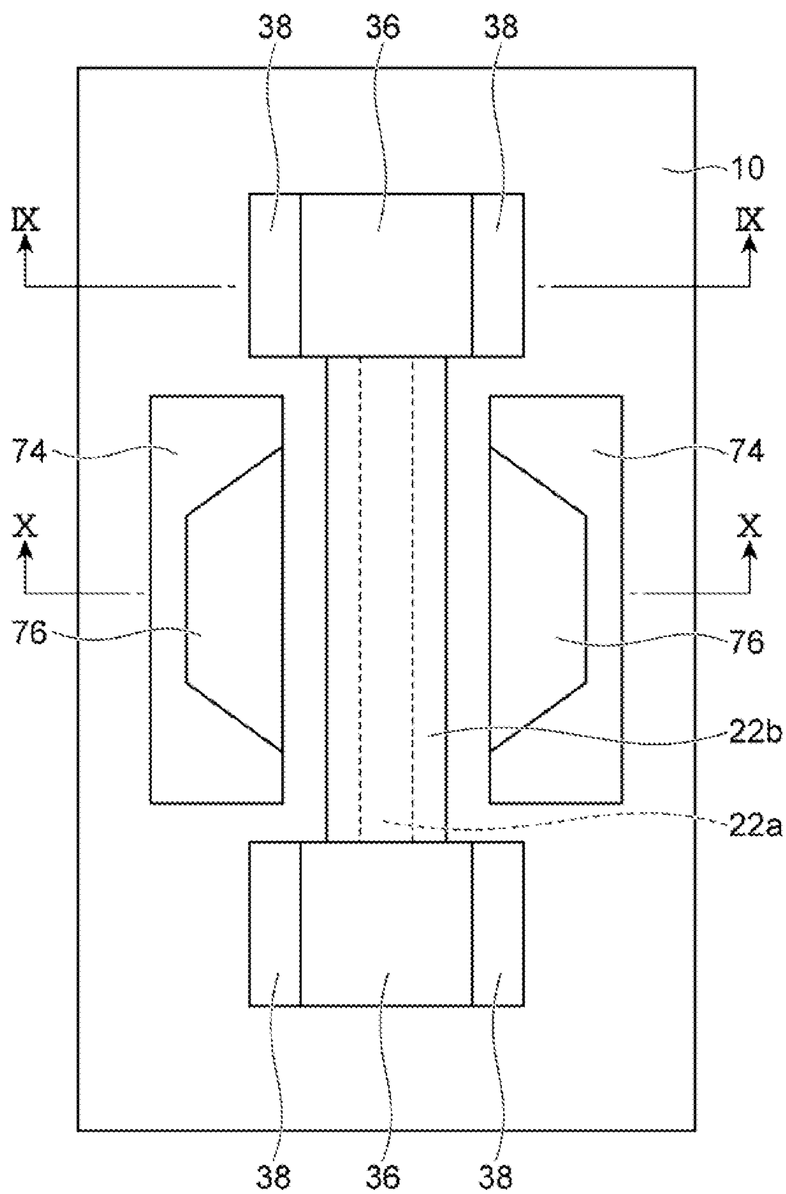


FIG. 9

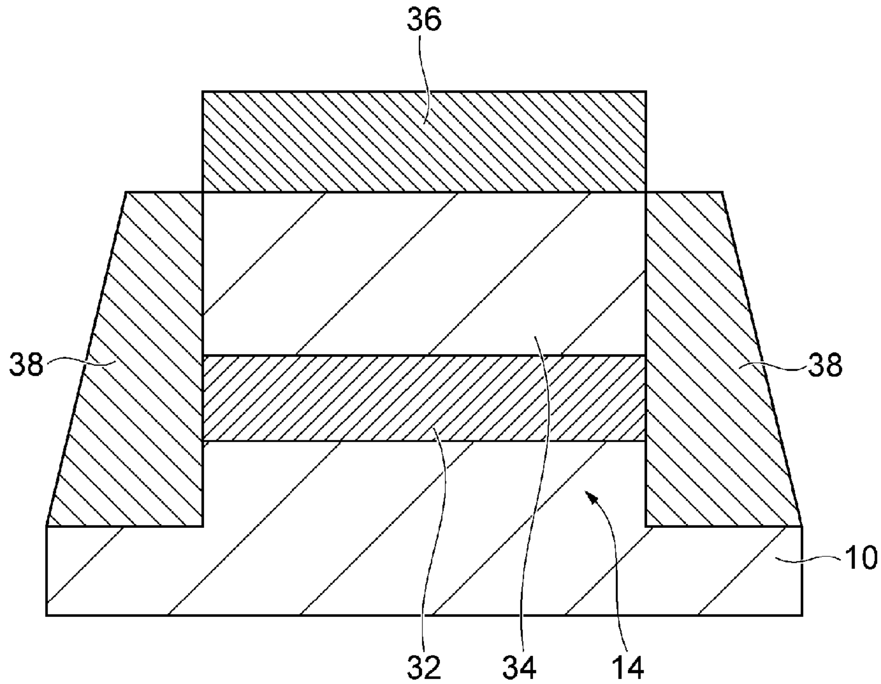


FIG. 10

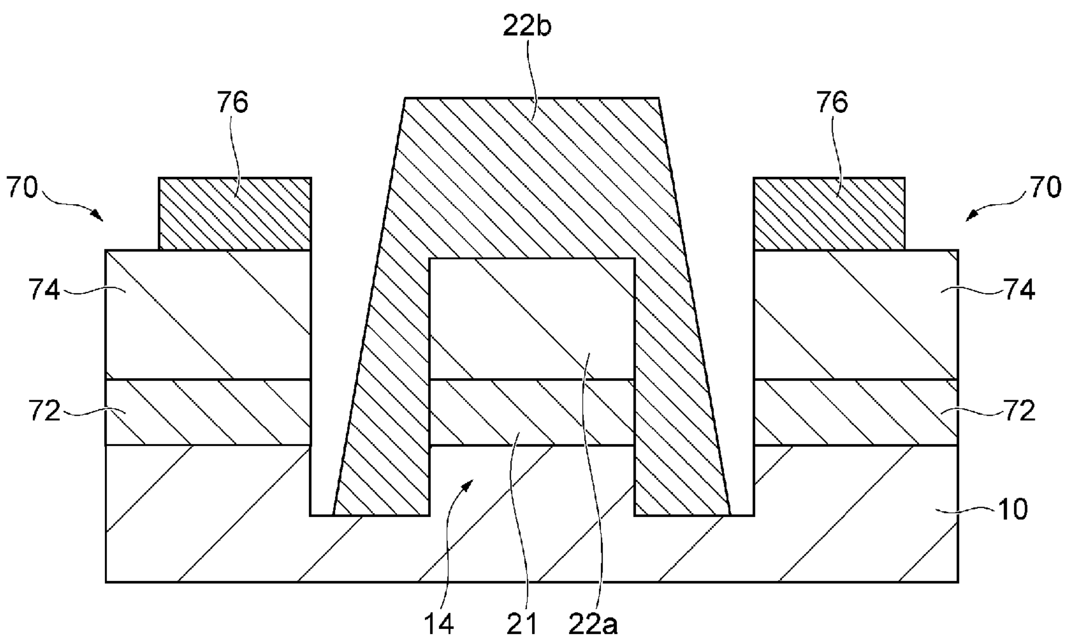


FIG. 11

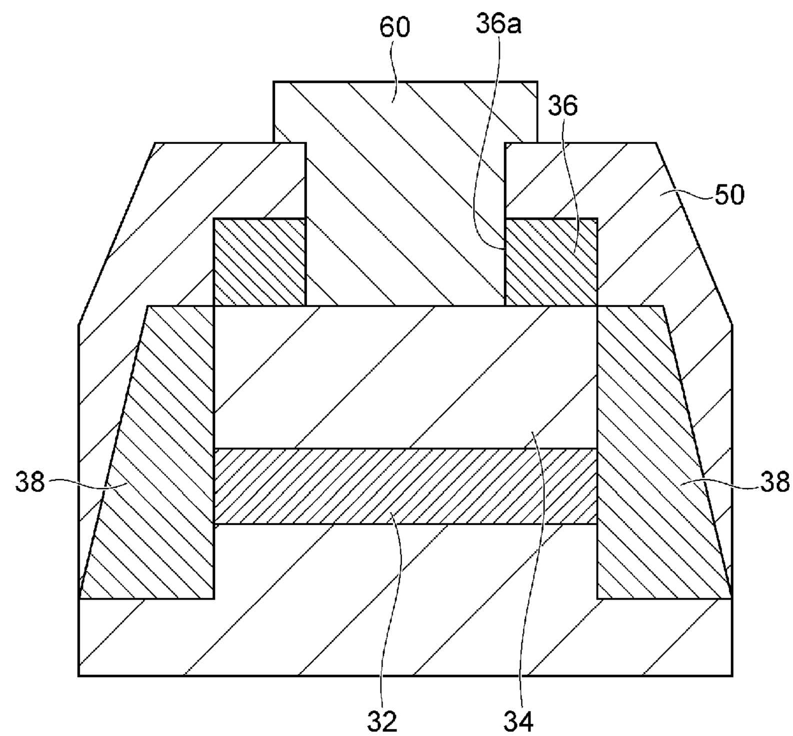


FIG. 12

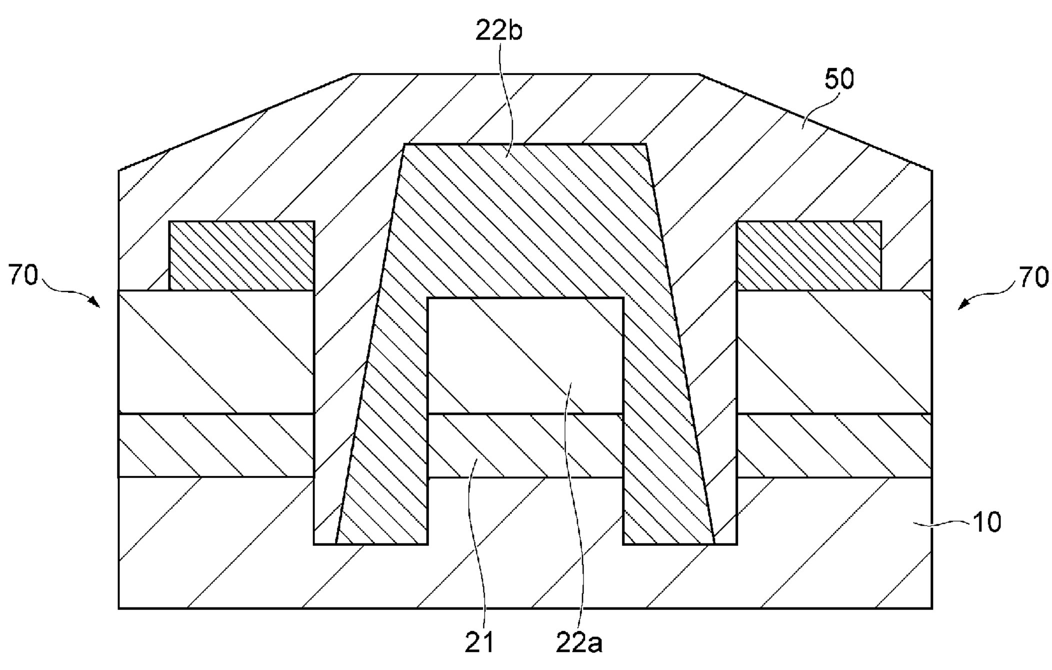
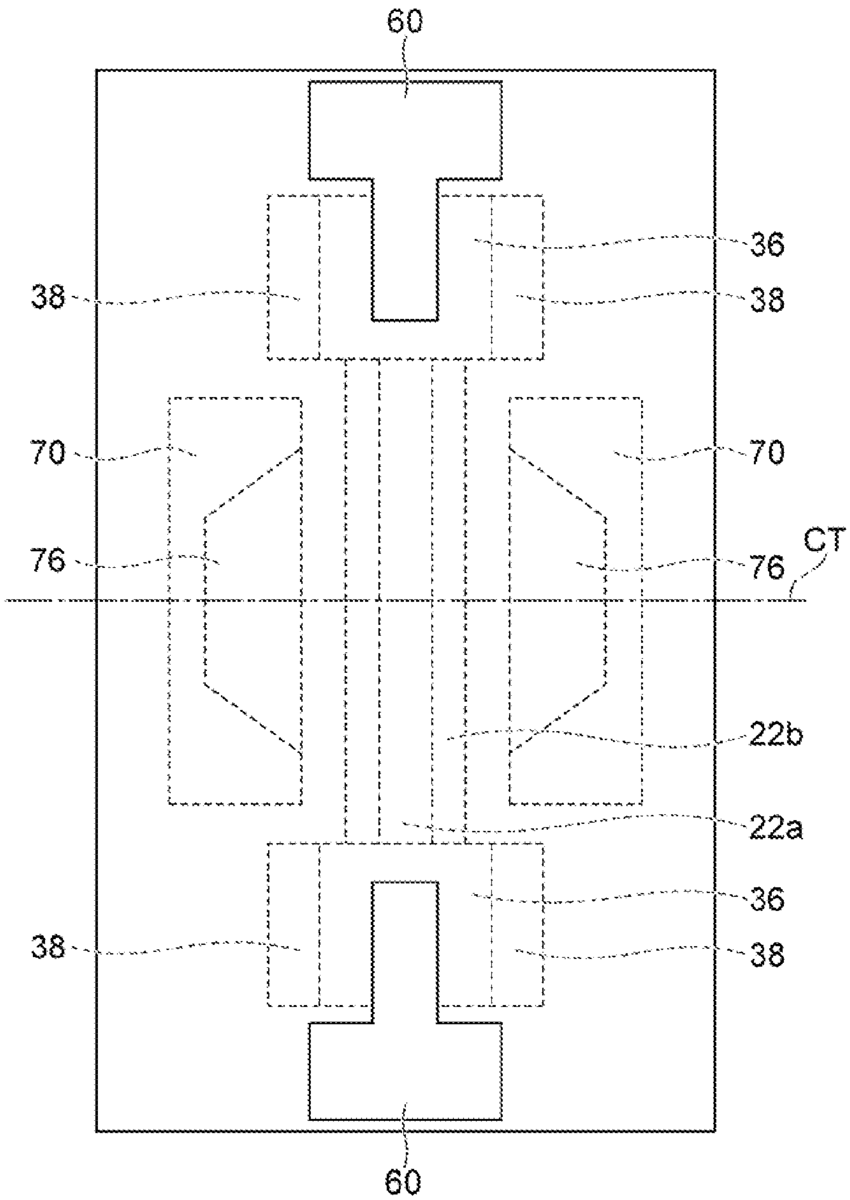


FIG. 13



SEMICONDUCTOR OPTICAL DEVICE

This application claims priority based on Japanese Patent Application No. 2022-099561 filed on Jun. 21, 2022, and the entire contents of the Japanese patent application are incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to a semiconductor optical device.

BACKGROUND ART

Japanese Unexamined Patent Application Publication No. 2001-127333 discloses a semiconductor light receiving device including a substrate, an optical detector formed on the substrate, and a waveguide formed on the substrate. The waveguide makes light incident on a light-receiving layer of the optical detector.

Japanese Unexamined Patent Application Publication No. 2014-220413 discloses a semiconductor optical device including a substrate, a spot-size converter, a waveguide portion, and a photodiode unit. The spot-size converter, the waveguide portion and the photodiode unit are provided on a substrate. The waveguide portion is disposed between the spot-size converter and the photodiode unit. The spot-size converter comprises a core layer and an upper cladding layer on the core layer. The thickness of the upper cladding layer varies in the direction of the waveguide axis. The photodiode unit includes a light absorbing layer and an upper cladding layer. The light reaches the light absorbing layer from the core layer through the waveguide portion.

A semiconductor optical device including a substrate, a spot-size converter, and a photodiode unit is disclosed (T. Okimoto, et al, "106-Gb/sWaveguide AlInAs/GaInAs Avalanche Photodiode with Butt-joint CouplingStructure" Optical Fiber Communication Conference (OFC) 2022, paper W3D.2.https://doi.org/10.1364/0FC.2022.W3D.2). The spot-size converter comprises a core layer and an upper cladding layer on the core layer. The photodiode unit includes a light absorbing layer, an upper cladding layer, and a contact layer. The core layer of the spot-size converter is connected to the light absorbing layer of the photodiode unit.

SUMMARY OF INVENTION

A semiconductor optical device according to one aspect of the present disclosure includes a substrate having a main surface including a first region and a second region adjacent to the first region, a spot-size converter disposed in the first region, and an optical detector disposed in the second region. The spot-size converter includes a core layer and a first III-V compound semiconductor layer, the core layer is disposed between the substrate and the first III-V compound semiconductor layer, the optical detector includes a light absorbing layer, a second III-V compound semiconductor layer, and an insulating film, the light absorbing layer is disposed between the substrate and the second III-V compound semiconductor layer, the second III-V compound semiconductor layer is disposed between the light absorbing layer and the insulating film, the light absorbing layer is optically coupled to the core layer, the spot-size converter has a first end face connected to the optical detector and a second end face opposite to the first end face, and the first III-V compound semiconductor layer is connected to the second III-V compound semiconductor layer and the insulating film at the first end face.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a plan view schematically showing a semiconductor optical device according to an embodiment.

FIG. **2** is a cross-sectional view taken along line II-II of FIG. **1**.

FIG. **3** shows an end view of a semiconductor optical device in accordance with one embodiment.

FIG. **4** is a perspective view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

FIG. **5** is a perspective view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

FIG. **6** is a plan view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

FIG. **7** is a plan view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

FIG. **8** is a plan view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

FIG. **9** is a cross-sectional view taken along line IX-IX of FIG. **8**.

FIG. **10** is a cross-sectional view taken along line X-X of FIG. **8**.

FIG. **11** is a cross-sectional view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

FIG. **12** is a cross-sectional view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

FIG. **13** is a plan view showing one step of a method of manufacturing a semiconductor optical device according to one embodiment.

DESCRIPTION OF EMBODIMENTS

When a core layer of a spot-size converter is connected to a light absorbing layer of a photodiode unit, an upper cladding layer of the spot-size converter may be thicker than an upper cladding layer of the photodiode unit due to regrowth of semiconductor. In this case, a step is formed at an emission end face of the spot-size converter connected to the photodiode unit, and the upper cladding layer of the spot-size converter is exposed. This causes scattering of light from the upper cladding layer to the outside at the emission end face of the spot-size converter connected to the photodiode unit.

The present disclosure provides a semiconductor optical device capable of suppressing scattering of light between a spot-size converter and an optical detector.

DESCRIPTION OF EMBODIMENTS OF PRESENT DISCLOSURE

First, embodiments of the present disclosure will be listed and explained.

(1) A semiconductor optical device includes a substrate having a main surface including a first region and a second region adjacent to the first region, a spot-size converter disposed in the first region, and an optical detector disposed in the second region. The spot-size converter includes a core

layer and a first III-V compound semiconductor layer, the core layer is disposed between the substrate and the first III-V compound semiconductor layer, the optical detector includes a light absorbing layer, a second III-V compound semiconductor layer, and an insulating film, the light absorbing layer is disposed between the substrate and the second III-V compound semiconductor layer, the second III-V compound semiconductor layer is disposed between the light absorbing layer and the insulating film, the light absorbing layer is optically coupled to the core layer, the spot-size converter has a first end face connected to the optical detector and a second end face opposite to the first end face, and the first III-V compound semiconductor layer is connected to the second III-V compound semiconductor layer and the insulating film at the first end face.

According to the semiconductor optical device, scattering of light from the first III-V compound semiconductor layer at the first end face to the outside can be suppressed by the insulating film. Therefore, scattering of light between the spot-size converter and the optical detector can be suppressed.

(2) In the above (1), the first III-V compound semiconductor layer may have a top surface and a side surface at the second end face, the core layer may have a top surface and a side surface at the second end face, the first III-V compound semiconductor layer may cover the top surface and the side surface of the core layer, and $0.9 \leq XD/YD \leq 1.1$ may be satisfied, where YD represents a distance between the top surface of the core layer and the top surface of the first III-V compound semiconductor layer in a first direction orthogonal to the main surface, and XD represents a distance between the side surface of the core layer and the side surface of the first III-V compound semiconductor layer in a second direction orthogonal to the first direction. In this case, the polarization dependence of the spot-size converter can be reduced.

(3) In the above (1) or (2), the core layer may have a top surface and a side surface at the second end face, and $0.9 \leq XC/YC \leq 1.1$ may be satisfied, where XC represents a length of the top surface of the core layer and YC represents a length of the side surface of the core layer. In this case, the polarization dependence of the spot-size converter can be reduced.

(4) In any one of (1) to (3), the optical detector may have a third end face connected to the first end face, and a distance from the main surface to a top surface of the insulating film at the third end face may be larger than or equal to a distance from the main surface to a top surface of the first III-V compound semiconductor layer at the first end face. In this case, scattering of light from the first III-V compound semiconductor layer at the first end face to the outside can be further suppressed.

(5) In any one of (1) to (4), the semiconductor optical device may further include an electrode. The insulating film may have an opening, and the electrode may be connected to the second III-V compound semiconductor layer through the opening.

(6) In any one of (1) to (5), the insulating film may contain titanium oxide. In this case, the refractive index of the insulating film can be increased.

DETAILS OF EMBODIMENTS OF PRESENT DISCLOSURE

Hereinafter, embodiments of the present disclosure will be described in detail with reference to accompanying drawings. In the description of the drawings, the same reference numerals are used for the same or equivalent elements, and redundant description is omitted. In the drawings, an XYZ coordinates system is shown as necessary. The X-axis, the Y-axis, and the Z-axis cross each other (for example, are orthogonal to each other).

(Semiconductor Optical Device)

FIG. **1** is a plan view schematically showing a semiconductor optical device according to an embodiment. FIG. **2** is a cross-sectional view taken along line II-II of FIG. **1**. A semiconductor optical device **100** shown in FIGS. **1** and **2** includes a substrate **10**, a spot-size converter **20**, and an optical detector **30**.

Substrate **10** includes a main surface **10***a* including a first region R**1** and a second region R**2** adjacent to first region R**1**. First region R**1** and second region R**2** may be arranged along the Z-axis. Second region R**2** may be in contact with first region R**1**. Substrate **10** may be a III-V compound semiconductor substrate. Substrate **10** may be an indium phosphide (InP) substrate. Substrate **10** may include a semi-insulating III-V compound semiconductor substrate and a first conductivity-type III-V compound semiconductor layer disposed on the semi-insulating III-V compound semiconductor substrate. In this case, the first conductivity-type III-V compound semiconductor layer has main surface **10***a*. The first conductivity type is, for example, n-type. An electrode may be connected to the first conductivity-type III-V compound semiconductor layer.

Spot-size converter **20** is disposed on first region R**1**. Spot-size converter **20** may have a mesa structure. Spot-size converter **20** includes a core layer **21** and a first III-V compound semiconductor layer **22**. Core layer **21** is disposed between substrate **10** and first III-V compound semiconductor layer **22**. Core layer **21** and first III-V compound semiconductor layer **22** may be included in the mesa structure. Core layer **21** may be an i-type gallium indium arsenide phosphide (GaInAsP) layer. Core layer **21** may have a refractive index of 3.2 to 3.4 with respect to light having a wavelength of 1.31 μm or 1.55 μm. As the refractive index of core layer **21** increases, the optical confinement effect at spot-size converter **20** increases. Therefore, when the refractive index of core layer **21** is increased, optical coupling efficiency between core layer **21** and a light absorbing layer **32** can be increased by reducing lengths of the top surface and the side surface of core layer **21**.

First III-V compound semiconductor layer **22** may be a cladding layer. First III-V compound semiconductor layer **22** may include a first semiconductor layer **22***a* and a second semiconductor layer **22***b*. First semiconductor layer **22***a* may be an i-type InP layer. Second semiconductor layer **22***b* may be an i-type InP layer. First semiconductor layer **22***a* may have a constant thickness along the Z-axis. Second semiconductor layer **22***b* may have a thickness that gradually decreases from first region R**1** toward second region R**2** along the Z-axis. The Z axis may be parallel to the optical axis of core layer **21**. Second semiconductor layer **22***b* may cover the side surface of first semiconductor layer **22***a* and the side surface of core layer **21**.

Optical detector **30** is disposed on second region R**2**. Optical detector **30** may have a mesa structure. Optical detector **30** includes light absorbing layer **32**, a second III-V compound semiconductor layer **34**, and an insulating film **36**. Light absorbing layer **32** is disposed between substrate **10** and second III-V compound semiconductor layer **34**. Second III-V compound semiconductor layer **34** is disposed between light absorbing layer **32** and insulating film **36**. Light absorbing layer **32**, second III-V compound semiconductor layer **34**, and insulating film **36** may be included in the mesa structure. Light absorbing layer **32** is optically coupled to core layer **21**. Light absorbing layer **32** may be an i-type gallium indium arsenide (GaInAs) layer. The refractive index of core layer **21** may be adjusted to maximize the optical coupling efficiency between core layer **21** and light absorbing layer **32**.

Second III-V compound semiconductor layer **34** may include a cladding layer and a contact layer. The cladding layer is disposed between core layer **21** and the contact layer. Second III-V compound semiconductor layer **34** may include a second conductivity type InP layer and a second conductivity type GaInAs layer. The second conductivity type is, for example, p-type.

Insulating film **36** may have an opening **36***a*. A thickness of insulating film **36** may be 0.3 μm or more, or 0.6 μm or less. Insulating film **36** may include at least one selected from the group consisting of Titanium oxide (TiO_2), aluminum oxide (Al_2O_3), silicon nitride (Si_3N_4), silicon oxynitride (SiON), and silicon oxide (SiO_2). Insulating film **36** may have a refractive index of 1.4 or more with respect to light having a wavelength of 1.31 μm or 1.55 μm.

Optical detector **30** may include an embedded region **38** covering a side surface of light absorbing layer **32** and a side surface of second III-V compound semiconductor layer **34**. Embedded region **38** may include the same group III-V compound semiconductor as the group III-V compound semiconductor included in second semiconductor layer **22***b*.

Spot-size converter **20** includes a first end face E**1** connected to optical detector **30** and a second end face E**2** opposite to first end face E**1**. First end face E**1** may be a light emitting surface. Second end face E**2** may be a light incident surface. At first end face E**1**, first III-V compound semiconductor layer **22** is connected to second III-V compound semiconductor layer **34** and insulating film **36**. First semiconductor layer **22***a* may be connected to second III-V compound semiconductor layer **34**. Second semiconductor layer **22***b* may be connected to insulating film **36**. At first end face E**1**, a step may be formed by the end face of first III-V compound semiconductor layer **22** and the end face of second III-V compound semiconductor layer **34**, and insulating film **36** may be disposed on the step. At first end face E**1**, first III-V compound semiconductor layer **22** may contact second III-V compound semiconductor layer **34** and insulating film **36**. Semiconductor optical device **100** may include an antireflection film **40** disposed at second end face E**2**.

Optical detector **30** may include a third end face E**3** connected to first end face E**1**. Insulating film **36** may terminate at third end face E**3**. A distance H**2** from main surface **10***a* to a top surface **36***t* of insulating film **36** at third end face E**3** may be larger than or equal to a distance H**1** from main surface **10***a* to a top surface **22***bt* of first III-V compound semiconductor layer **22** at first end face E**1**. At first end face E**1**, first III-V compound semiconductor layer **22** may be covered with second III-V compound semiconductor layer **34** and insulating film **36**. The distance H**2** may be smaller than the distance H**1**.

Semiconductor optical device **100** may include a protective film **50** covering spot-size converter **20** and optical detector **30**. Semiconductor optical device **100** may further include an electrode **60**. Electrode **60** may be connected to second III-V compound semiconductor layer **34** penetrating through insulating film **36** and through opening **36***a* of insulating film **36**. Electrode **60** is disposed in opening **36***a*. Electrode **60** may be disposed to extend on protective film **50** along the Z-axis. Insulating film **36** and protective film **50** may be disposed between electrode **60** and second III-V compound semiconductor layer **34**.

Semiconductor optical device **100** may include a plurality of semiconductor terraces **70** provided on first region R**1**. Spot-size converter **20** may be disposed between the plurality of semiconductor terraces **70**. Each semiconductor terrace **70** may include a first layer including the same semiconductor material as the semiconductor material included in core layer **21** and a second layer including the same semiconductor material as the semiconductor material included in first semiconductor layer **22***a*.

Semiconductor optical device **100** may include a semiconductor stack **80** disposed in second region R**2**. Optical detector **30** may be disposed between semiconductor stack **80** and spot-size converter **20**. Semiconductor stack **80** may include a first layer **81** including the same semiconductor material as the semiconductor material included in core layer **21** and a second layer **82** including the same semiconductor material as the semiconductor material included in first semiconductor layer **22***a*.

According to semiconductor optical device **100**, scattering of light from first III-V compound semiconductor layer **22** at first end face E**1** to the outside can be suppressed by insulating film **36**. Therefore, scattering of light between spot-size converter **20** and optical detector **30** can be suppressed. Therefore, light receiving sensitivity of optical detector **30** can be improved.

When the distance H**2** is larger than or equal to the distance H**1**, the end surface of first III-V compound semiconductor layer **22** is covered with insulating film **36**. Therefore, scattering of light from first III-V compound semiconductor layer **22** at first end face E**1** to the outside can be further suppressed.

When insulating film **36** contains titanium oxide, the refractive index of insulating film **36** can be increased. As a result, the difference between the refractive index of the material included in first III-V compound semiconductor layer **22** and the refractive index of insulating film **36** can be reduced. Therefore, scattering of light from first III-V compound semiconductor layer **22** at first end face E**1** to the outside can be further suppressed.

FIG. **3** shows an end view of a semiconductor optical device in accordance with one embodiment. In FIG. **3**, antireflection film **40** and protective film **50** are omitted. In FIG. **3**, second end face E**2** of spot-size converter **20** is shown.

When viewed from second end surface E**2**, first III-V compound semiconductor layer **22** may have top surface **22***bt* and a side surface **22***bs* at second end surface E**2**. At second end face E**2**, core layer **21** may have a top surface **21***t* and a side surface **21***s* in the vicinity of second end surface E**2**. First III-V compound semiconductor layer **22** may cover top surface **21***t* and side surface **21***s* of core layer **21**. YD represents a distance between top surface **21***t* of core layer **21** and top surface **22***bt* of first III-V compound semiconductor layer **22** in the first direction (e.g., the positive direction of the Y-axis) orthogonal to main surface **10***a* of substrate **10**. XD represents a distance between side surface **21***s* of core layer **21** and side surface **22***bs* of first III-V compound semiconductor layer **22** in the second direction (e.g., the positive direction of the X-axis) orthogonal to the first direction. XD is measured along a straight line crossing the center of core layer **21** in the positive direction of the Y-axis. This measurement is performed by scanning electron microscope (SEM) observation of a cross-section. For example, S-8000 manufactured by Hitachi, Ltd. is used, and observation is performed under conditions of an acceleration voltage of 2.0 kV and an observation at 20,000× magnification. In this case, the following formula (1) may be satisfied.

$$0.9 \leq XD/YD \leq 1.1 \quad (1)$$

When the above formula (1) is satisfied, polarization dependence of spot-size converter **20** can be reduced.

XD may be 1 μm or more. YD may be 1.5 μm to 4.5 μm. XD may be equal to YD.

XC represents a length of top surface **21***t* of core layer **21**. YC represents a length of side surface **21***s* of core layer **21**. In this case, the following formula (2) may be satisfied.

$$0.9 \leq XC/YC \leq 1.1 \quad (2)$$

When the above formula (2) is satisfied, the polarization dependence of spot-size converter **20** can be reduced.

XC may be 0.1 μm to 1.0 μm. YC may be 0.2 μm to 0.6 μm. XC may be the same as YC. XC and YC may be adjusted according to the diameter of the light beam incident at second end face E**2** of spot-size converter **20**.

(Method of Manufacturing Semiconductor Optical Device)

Hereinafter, a method of manufacturing a semiconductor optical device according to an embodiment will be described with reference to FIGS. **4** to **13**. Semiconductor optical device **100** may be manufactured as follows.

First, as shown in FIG. **4**, light absorbing layer **32** and second III-V compound semiconductor layer **34** are formed in this order on substrate **10**. Substrate **10** may include a semi-insulating III-V compound semiconductor substrate **12** and a first conductivity-type III-V compound semiconductor layer **14** disposed on semi-insulating III-V compound semiconductor substrate **12**. The first conductivity type is, for example, n-type. Light absorbing layer **32** is formed on first conductivity-type III-V compound semiconductor layer **14**. Second III-V compound semiconductor layer **34** may include a cladding layer **34***a* and a contact layer **34***b* disposed on cladding layer **34***a*. Cladding layer **34***a* is formed on light absorbing layer **32**.

Next, a mask M**1** is formed on second III-V compound semiconductor layer **34**. Thereafter, light absorbing layer **32** and second III-V compound semiconductor layer **34** are etched. Mask M**1** may be an insulating mask.

Next, using mask M**1** as a mask, core layer **21** and first semiconductor layer **22***a* are butt-joint grown on substrate **10** in this order. A butt-joint interface is formed between first semiconductor layer **22***a* and second III-V compound semiconductor layer **34**. At the same time, first layer **81** and second layer **82** are formed in this order.

After mask M**1** is removed, insulating films **36** and **76** are formed on first semiconductor layer **22***a*, second III-V compound semiconductor layer **34**, and second layer **82**. Insulating film **36** and insulating film **76** are formed by a chemical vapor deposition (CVD) method and then by photolithography and etching. Next, first semiconductor layer **22***a*, core layer **21**, and first conductivity-type III-V compound semiconductor layer **14** are etched using insulating film **36** and insulating film **76** as a mask. Thus, as shown in FIG. **5**, a mesa structure for forming spot-size converter **20** and optical detector **30**, and a plurality of semiconductor terraces **70** are formed.

Insulating film **36** and insulating film **76** have the pattern shown in FIG. **6**. FIG. **5** shows a portion (half) of insulating film **36** and insulating film **76**.

Next, insulating film **36** on first semiconductor layer **22***a* and a part of insulating film **76** are removed by photolithography and etching. As shown in FIG. **7**, insulating film **76** after etching has, for example, a trapezoidal pattern in a plan view.

Next, as shown in FIG. **8**, embedded region **38** and second semiconductor layer **22***b* are grown. FIG. **9** is a cross-sectional view taken along line IX-IX of FIG. **8**. As shown in FIG. **9**, embedded region **38** covers the side surfaces of first conductivity-type III-V compound semiconductor layer **14**, light absorbing layer **32**, and second III-V compound semiconductor layer **34**. Thus, optical detector **30** is formed. FIG. **10** is a cross-sectional view taken along line X-X of FIG. **8**. As shown in FIG. **10**, second semiconductor layer **22***b* covers a top surface of first semiconductor layer **22***a* and side surfaces of first semiconductor layer **22***a*, core layer **21** and first conductivity-type III-V compound semiconductor layer **14**. A thickness of second semiconductor layer **22***b* gradually decreases from core layer **21** toward light absorbing layer **32** along the optical axis direction of core layer **21**. Thus, spot-size converter **20** is formed.

Next, protective film **50** is formed on insulating film **36** and embedded region **38**. Protective film **50** is also formed on second semiconductor layer **22***b* and semiconductor terrace **70** as shown in FIG. **12**. Thereafter, an opening is formed in protective film **50** on second III-V compound semiconductor layer **34** by photolithography and etching, and then opening **36***a* is formed in insulating film **36**. Thereafter, as shown in FIG. **11**, electrodes **60** are formed in the openings of protective film **50** and opening **36***a* of insulating film **36** by lift-off.

Next, substrate **10**, spot-size converter **20**, semiconductor terraces **70** and protective film **50** are cut along a cutting-plane line CT shown in FIG. **13**. The cutting may be cleavage. Thus, second end face E**2** of spot-size converter **20** is formed.

Next, as shown in FIGS. **1** and **2**, antireflection film **40** is formed at second end face E**2**.

Although embodiments of the present disclosure have been described in detail above, the present disclosure is not limited to the embodiments described above.

It should be understood that the embodiments disclosed herein are illustrative in all respects and are not restrictive. The scope of the present invention is defined by the appended claims rather than by the foregoing description, and is intended to include all modifications within the scope and meaning equivalent to the appended claims.

What is claimed is:

1. A semiconductor optical device comprising:

a substrate having a main surface including a first region and a second region adjacent to the first region;

a spot-size converter disposed in the first region; and

an optical detector disposed in the second region,

wherein the spot-size converter includes a core layer and a first III-V compound semiconductor layer,

wherein the core layer is disposed between the substrate and the first III-V compound semiconductor layer,

wherein the optical detector includes a light absorbing layer, a second III-V compound semiconductor layer, and an insulating film,

wherein the light absorbing layer is disposed between the substrate and the second III-V compound semiconductor layer,

wherein the second III-V compound semiconductor layer is disposed between the light absorbing layer and the insulating film,

wherein the light absorbing layer is optically coupled to the core layer, wherein the spot-size converter has a first end face connected to the optical detector and a second end face opposite to the first end face,

wherein the first III-V compound semiconductor layer is connected to the second III-V compound semiconductor layer and the insulating film at the first end face,

wherein the first III-V compound semiconductor layer has a top surface and a side surface,

wherein the core layer has a top surface and a side surface,

wherein the first III-V compound semiconductor layer covers the top surface and the side surface of the core layer, and

wherein $0.9 \leq XD/YD \leq 1.1$ is satisfied, where YD represents a distance between the top surface of the core layer and the top surface of the first III-V compound semiconductor layer in a first direction orthogonal to the main surface, and XD represents a distance between the side surface of the core layer and the side surface of the first III-V compound semiconductor layer in a second direction orthogonal to the first direction.

2. The semiconductor optical device according to claim **1**, wherein $0.9 \leq XC/YC \leq 1.1$ is satisfied, where XC represents a length of the top surface of the core layer and YC represents a length of the side surface of the core layer.

3. The semiconductor optical device according to claim **1**, wherein the optical detector has a third end face connected to the first end face, and

wherein a distance from the main surface to a top surface of the insulating film at the third end face is larger than or equal to a distance from the main surface to the top surface of the first III-V compound semiconductor layer at the first end face.

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

an electrode,

wherein the insulating film has an opening, and

wherein the electrode is connected to the second III-V compound semiconductor layer through the opening.

5. The semiconductor optical device according to claim **1**, wherein the insulating film contains titanium oxide.

6. A semiconductor optical device comprising:

a substrate having a main surface including a first region and a second region adjacent to the first region;

a spot-size converter disposed in the first region; and

an optical detector disposed in the second region,

wherein the spot-size converter includes a core layer and a first III-V compound semiconductor layer,

wherein the core layer is disposed between the substrate and the first III-V compound semiconductor layer,

wherein the optical detector includes a light absorbing layer, a second III-V compound semiconductor layer, and an insulating film,

wherein the light absorbing layer is disposed between the substrate and the second III-V compound semiconductor layer,

wherein the second III-V compound semiconductor layer is disposed between the light absorbing layer and the insulating film,

wherein the light absorbing layer is optically coupled to the core layer,

wherein the spot-size converter has a first end face connected to the optical detector and a second end face opposite to the first end face,

wherein the first III-V compound semiconductor layer is connected to the second III-V compound semiconductor layer and the insulating film at the first end face,

wherein the core layer has a top surface and a side surface, and

wherein $0.9 \leq XC/YC \leq 1.1$ is satisfied, where XC represents a length of the top surface of the core layer and YC represents a length of the side surface of the core layer.

7. The semiconductor optical device according to claim **6**, wherein the first III-V compound semiconductor layer has a top surface and a side surface,

wherein the first III-V compound semiconductor layer covers the top surface and the side surface of the core layer, and

wherein $0.9 \leq XD/YD \leq 1.1$ is satisfied, where YD represents a distance between the top surface of the core layer and the top surface of the first III-V compound semiconductor layer in a first direction orthogonal to the main surface, and XD represents a distance between the side surface of the core layer and the side surface of the first III-V compound semiconductor layer in a second direction orthogonal to the first direction.

8. The semiconductor optical device according to claim **6**, wherein the optical detector has a third end face connected to the first end face, and

wherein a distance from the main surface to a top surface of the insulating film at the third end face is larger than or equal to a distance from the main surface to a top surface of the first III-V compound semiconductor layer at the first end face.

9. The semiconductor optical device according to claim **6**, further comprising:

an electrode,

wherein the insulating film has an opening, and

wherein the electrode is connected to the second III-V compound semiconductor layer through the opening.

10. The semiconductor optical device according to claim **6**,

wherein the insulating film contains titanium oxide.

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