[CLAIMS]

[Claim 1]

An optical waveguide device comprising:

a substrate;

a lower cladding disposed on the substrate;

a rib waveguide including a slab disposed on the lower cladding and a single rib disposed on the slab contiguous to the slab; and

an upper cladding disposed on the rib waveguide,

wherein the rib waveguide includes a first doped region having a first electric conductivity exhibiting a P-type electric conductivity across the rib and the slab and a second doped region being contiguous to the first doped region and having a second electric conductivity exhibiting an N-type electric conductivity across the rib and the slab,

a boundary between the first doped region and the second doped region provides a PN junction formed in a direction perpendicular to a surface of the substrate and is disposed in a corrugated line in a propagating direction of guided light in the rib waveguide in a plan view of the substrate, and

the rib waveguide includes at least one of a first low conductive region being contiguous to an opposite side of the second doped region in the rib and exhibiting lower electric conductivity than the second doped region and a second low conductive region being contiguous to an opposite side of the first doped region in the rib and exhibiting lower electric conductivity than the first doped region.

[Claim 2]

The optical waveguide device according to Claim 1, wherein at least one of the first conductive region and the second low conductive region is an intrinsic region.

[Claim 3]

The optical waveguide device according to Claim 1 or 2,

wherein, in a case that the rib waveguide includes the first low conductive region, a third doped region being contiguous to the second doped region and the first low conductive region and having the second electric conductivity is disposed in a region immediately below the first low conductive region on the slab, a fourth doped region having the second electric conductivity is disposed contiguous to the third doped region in a part of the slab in which the rib is not present on the slab, a carrier density in the first low conductive region is lower than a carrier density in the third doped region, a carrier density in the third doped region is lower than a carrier density in the second doped region, and a carrier density in the fourth doped region is equal to or higher than

the carrier density in the second doped region, and
in a case that the rib waveguide includes the second low conductive region, a seventh doped region being contiguous to the first doped region and the first low conductive region and having the first electric conductivity is disposed in a region immediately below the second low conductive region of the slab, an eighth doped region having the first electric conductivity is disposed contiguous to the seventh doped region in a part of the slab in which the rib is not present on the slab, a carrier density in the first low conductive region is lower than a carrier density in the third doped region, a carrier density in the seventh doped region is lower than the carrier density in the first doped region, and a carrier density in the eighth doped region is equal to or higher than the carrier density in the first doped region.

[Claim 4]
The optical waveguide device according to any one of Claims 1 to 3,
wherein, in a case that the rib waveguide includes the first low conductive region, a width of the second doped region is substantially constant in a propagating direction of the guided light, and
in a case that the rib waveguide includes the second low conductive region, a width of the first doped region is substantially constant in the propagating direction of the guided light.

[Claim 5]
The optical waveguide device according to any one of Claims 1 to 4,
wherein, in a case that the rib waveguide does not include the second low conductive region, the first doped region is extended up to a part of the slab in which the rib is not present on the slab in the same side with the first doped region with respect to the boundary, and
in a case that the rib waveguide does not include the first low conductive region, the second doped region is extended up to a part of the slab in which the rib is not present on the slab in the same side with the second doped region with respect to the boundary.

[Claim 6]
The optical waveguide device according to any one of Claims 1 to 5, further comprising:
a first metal electrode disposed on the upper cladding,
wherein a fifth doped region having the second electric conductivity is disposed in the part of the slab in which the rib is not present on the slab in the same side with the second doped region with respect to the boundary, and the fifth doped region and the first metal electrode are connected to each other through a first through-hole via.

[Claim 7]
The optical waveguide device according to any one of Claims 1 to 6, further comprising:
a second metal electrode disposed on the upper cladding,
wherein a sixth doped region having the first electric conductivity disposed in the part of the slab in which the rib is not present on the slab in the same side with the first doped region with respect to the boundary, and the sixth doped region and the second metal electrode are connected to each other through a second through-hole via.
[Claim 8]
The optical waveguide device according to any one of Claims 1 to 7, comprising:
a first rib waveguide and a second rib waveguide both of which constitute the two rib waveguides disposed parallel along a width direction of the optical waveguide device.
[Claim 9]
The optical waveguide device according to Claim 8,
wherein a part of the slab in the first rib waveguide closer to the second rib waveguide than the rib in the first rib waveguide is connected to a third metal electrode disposed on the upper cladding through a third through-hole via, and
a part of the slab in the second rib waveguide closer to the first rib waveguide than the rib in the second rib waveguide are connected to a fourth metal electrode disposed on the upper cladding through a fourth through-hole via.
[Claim 10]
The optical waveguide device according to Claim 8,
wherein a part of the slab in the first rib waveguide closer to the second rib waveguide than the rib in the first rib waveguide and a part of the slab in the second rib waveguide closer to the first rib waveguide than the rib in the second rib waveguide are connected electrically to a common fifth metal electrode disposed on the upper cladding through the third through-hole via and the fourth through-hole via respectively.
[Claim 11]
A manufacturing method for the optical waveguide device according to any one of Claims 1 to 10 comprising:
a resist production step of, in a case that the rib waveguide includes the first low conductive region but does not include the second low conductive region, forming a first resist having a resist side wall disposed in a corrugated shape in the propagating direction of the guided light in the rib waveguide on a horizontal surface in a location serving as a boundary between the first low conductive region and the second doped region, covering a region serving as the second doped region, and exposing a region

serving as the first low conductive region,
in a case in which the rib waveguide includes the second low conductive region but does not include the first low conductive region, forming a second resist having a resist side wall disposed in a corrugated shape in the propagating direction of the guided light in the rib waveguide on a horizontal surface in a location serving as a boundary between the second low conductive region and the first doped region, covering a region serving as the first doped region, and exposing a region serving as the second low conductive region, and,
in a case in which the rib waveguide includes the first low conductive region and the second low conductive region, producing the first resist or the second resist; and
a resist trimming step of trimming the first resist or the second resist after the resist production step, thereby forming a resist having a resist side wall disposed in a corrugated shape in the propagating direction of the guided light in the rib waveguide on a horizontal surface in a location serving as the PN junction on a plan view of the substrate.

Claims

1. An optical waveguide device comprising:

a substrate;

a lower cladding disposed on the substrate;

a rib waveguide including a slab disposed on the lower cladding and a single rib disposed on the slab contiguous to the slab; and

an upper cladding disposed on the rib waveguide,

wherein the rib waveguide includes a first doped region having a first electric conductivity exhibiting a P-type electric conductivity across the rib and the slab and a second doped region being contiguous to the first doped region and having a second electric conductivity exhibiting an N-type electric conductivity across the rib and the slab,

a boundary between the first doped region and the second doped region provides a PN junction formed in a direction perpendicular to a surface of the substrate and is disposed in a corrugated line in a propagating direction of guided light in the rib waveguide in a plan view of the substrate,

the rib waveguide includes at least one of a first low conductive region being contiguous to an opposite side of the second doped region in the rib and exhibiting lower electric conductivity than the second doped region and a second low conductive region being contiguous to an opposite side of the first doped region in the rib and exhibiting lower electric conductivity than the first doped region,

in a case that the rib waveguide includes the first low conductive region, a width of the second doped region is substantially constant in a propagating direction of the guided light, and

in a case that the rib waveguide includes the second low conductive region, a width of the first doped region is substantially constant in the propagating direction of the guided light.

2. The optical waveguide device according to Claim 1, wherein at least one of the first conductive region and the second low conductive region is an intrinsic region.

3. The optical waveguide device according to Claim 1 or 2,

wherein, in a case that the rib waveguide includes the first low conductive region, a

third doped region being contiguous to the second doped region and the first low conductive region and having the second electric conductivity is disposed in a region immediately below the first low conductive region on the slab, a fourth doped region having the second electric conductivity is disposed contiguous to the third doped region in a part of the slab in which the rib is not present on the slab, a carrier density in the first low conductive region is lower than a carrier density in the third doped region, a carrier density in the third doped region is lower than a carrier density in the second doped region, and a carrier density in the fourth doped region is equal to or higher than the carrier density in the second doped region, and

in a case that the rib waveguide includes the second low conductive region, a seventh doped region being contiguous to the first doped region and the first low conductive region and having the first electric conductivity is disposed in a region immediately below the second low conductive region of the slab, an eighth doped region having the first electric conductivity is disposed contiguous to the seventh doped region in a part of the slab in which the rib is not present on the slab, a carrier density in the first low conductive region is lower than a carrier density in the third doped region, a carrier density in the seventh doped region is lower than the carrier density in the first doped region, and a carrier density in the eighth doped region is equal to or higher than the carrier density in the first doped region.

4. The optical waveguide device according to any one of Claims 1 to 3, wherein, in a case that the rib waveguide does not include the second low conductive region, the first doped region is extended up to a part of the slab in which the rib is not present on the slab in the same side with the first doped region with respect to the boundary, and

in a case that the rib waveguide does not include the first low conductive region, the second doped region is extended up to a part of the slab in which the rib is not present on the slab in the same side with the second doped region with respect to the boundary.

5. The optical waveguide device according to any one of Claims 1 to 4, further comprising:

a first metal electrode disposed on the upper cladding,

wherein a fifth doped region having the second electric conductivity is disposed in the part of the slab in which the rib is not present on the slab in the same side with the second

doped region with respect to the boundary, and the fifth doped region and the first metal electrode are connected to each other through a first through-hole via.

6. The optical waveguide device according to any one of Claims 1 to 5, further comprising:

a second metal electrode disposed on the upper cladding,

wherein a sixth doped region having the first electric conductivity disposed in the part of the slab in which the rib is not present on the slab in the same side with the first doped region with respect to the boundary, and the sixth doped region and the second metal electrode are connected to each other through a second through-hole via.

7. The optical waveguide device according to any one of Claims 1 to 6, comprising:

a first rib waveguide and a second rib waveguide both of which constitute the two rib waveguides disposed parallel along a width direction of the optical waveguide device.

8. The optical waveguide device according to Claim 7,

wherein a part of the slab in the first rib waveguide closer to the second rib waveguide than the rib in the first rib waveguide is connected to a third metal electrode disposed on the upper cladding through a third through-hole via, and

a part of the slab in the second rib waveguide closer to the first rib waveguide than the rib in the second rib waveguide are connected to a fourth metal electrode disposed on the upper cladding through a fourth through-hole via.

9. The optical waveguide device according to Claim 7,

wherein a part of the slab in the first rib waveguide closer to the second rib waveguide than the rib in the first rib waveguide and a part of the slab in the second rib waveguide closer to the first rib waveguide than the rib in the second rib waveguide are connected electrically to a common fifth metal electrode disposed on the upper cladding through the third through-hole via and the fourth through-hole via respectively.

10. A manufacturing method for the optical waveguide device according to any one of Claims 1 to 9 comprising:

a resist production step of, in a case that the rib waveguide includes the first low conductive region but does not include the second low conductive region, forming a first resist having a resist side wall disposed in a corrugated shape in the propagating direction of the guided light in the rib waveguide on a horizontal surface in a location serving as a boundary between the first low conductive region and the second doped region, covering a region serving as the second doped region, and exposing a region serving as the first low conductive region,

in a case in which the rib waveguide includes the second low conductive region but does not include the first low conductive region, forming a second resist having a resist side wall disposed in a corrugated shape in the propagating direction of the guided light in the rib waveguide on a horizontal surface in a location serving as a boundary between the second low conductive region and the first doped region, covering a region serving as the first doped region, and exposing a region serving as the second low conductive region, and,

in a case in which the rib waveguide includes the first low conductive region and the second low conductive region, producing the first resist or the second resist; and

a resist trimming step of trimming the first resist or the second resist after the resist production step, thereby forming a resist having a resist side wall disposed in a corrugated shape in the propagating direction of the guided light in the rib waveguide on a horizontal surface in a location serving as the PN junction on a plan view of the substrate.