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## Semiconductor laser and method of manufacturing semiconductor laser

### Abstract

A semiconductor laser including: a stacked body in which a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided between the first cladding layer and the second cladding layer are stacked on a semiconductor substrate; and a ridge part provided as a projection structure extending in one direction at a top surface in a stacking direction of the stacked body, in which the stacked body is provided to have both end surfaces in the extending direction of the ridge part that each have a shape including an arc in a plan view of the stacked body from the top surface.

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## Background/Summary

TECHNICAL FIELD
(1) The present disclosure relates to a semiconductor laser and a method of manufacturing a semiconductor laser.
BACKGROUND ART
(2) In recent years, semiconductor lasers have been utilized in a variety of fields. The semiconductor laser amplifies laser light by using an end surface of the semiconductor laser orthogonal to a direction of propagation of the laser light as a reflecting surface of a resonator.
(3) Such a semiconductor laser is manufactured by, for example, forming a plurality of laser structures on a semiconductor substrate and thereafter dividing the semiconductor substrate into individual laser structures. The semiconductor substrate is divided by, for example, cleaving the semiconductor substrate along a crystal plane derived from the crystal structure (see Patent Literature 1, for example).
CITATION LIST
Patent Literature
(4) Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2011-135016
SUMMARY OF THE INVENTION
(5) Here, for a semiconductor laser, it is desired that a characteristic of emitted laser light be improved by more appropriately performing amplification of the laser light with a resonator.
(6) It is desirable to provide a semiconductor laser that is able to emit laser light having a superior characteristic.
(7) A semiconductor laser according to one embodiment of the present disclosure includes: a stacked body in which a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided between the first cladding layer and the second cladding layer are stacked on a semiconductor substrate; and a ridge part provided as a projection structure extending in one direction at a top surface in a stacking direction of the stacked

body. The stacked body is provided to have both end surfaces in the extending direction of the ridge part that each have a shape including an arc in a plan view of the stacked body from the top surface.
(8) Further, a method of manufacturing a semiconductor laser according to one embodiment of the present disclosure includes: forming a stacked body by stacking a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided between the first cladding layer and the second cladding layer on a semiconductor substrate; forming a ridge part having a projection structure extending in one direction at a top surface in a stacking direction of the stacked body; forming a dividing groove from the top surface toward a depth direction, the dividing groove being curved; and subjecting the stacked body to singulation to allow both end parts in the extending direction of the ridge part to each have a shape including an arc in a plan view of the stacked body from the top surface.
(9) According to the semiconductor laser and the method of manufacturing a semiconductor laser of the respective embodiments of the present disclosure, in the stacked body in which the first cladding layer of the first conductivity type, the second cladding layer of the second conductivity type, and the light emission layer provided between the first cladding layer and the second cladding layer are stacked on the semiconductor substrate, it is possible to provide the end surfaces in the direction in which the ridge part extends at the top surface in the stacking direction of the stacked body to each have a shape including an arc in a plan view of the stacked body from the top surface. In the semiconductor laser, it is thereby possible to provide the end surfaces of the stacked body in the extending direction of the ridge part to be generally perpendicular to a waveguide region provided in a region corresponding to the ridge part, for example.

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## Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a schematic cross-sectional diagram illustrating a stacked structure of a semiconductor laser according to one embodiment of the present disclosure.
(2) FIG. **2** is an explanatory diagram illustrating a crystal structure of GaN.
(3) FIG. **3** is a plan diagram describing a planar structure of the semiconductor laser according to the embodiment.
(4) FIG. **4**A is a plan diagram illustrating an example of the planar structure of a semiconductor laser according to a modification example of the embodiment.
(5) FIG. **4**B is a plan diagram illustrating another example of the planar structure of a semiconductor laser according to a modification example of the embodiment.
(6) FIG. **5** is a flowchart diagram illustrating a flow of a method of manufacturing the semiconductor laser according to the embodiment.
(7) FIG. **6** is an explanatory diagram schematically illustrating an example of a cross-sectional shape of a dividing groove.
(8) FIG. **7** is an explanatory diagram schematically illustrating a method of dividing a stacked body by using the dividing groove.
(9) FIG. **8** is a cross-sectional view of the stacked body illustrating a specific example of the dividing groove.
(10) FIG. **9** is a plan view of a top surface in a stacking direction of the stacked body illustrating a specific example of the dividing groove.
(11) FIG. **10** is a plan view of a back surface opposite to the top surface of the stacked body illustrating a specific example of the dividing groove.
(12) FIG. **11** is a plan view of the top surface in the stacking direction of the stacked body illustrating a modification example of the dividing groove.

MODES FOR CARRYING OUT THE INVENTION

(13) In the following, description is given in detail of embodiments of the present disclosure with reference to the drawings. The embodiments described in the following are specific examples of the present disclosure, and the technology according to the present disclosure is not limited to the following modes. In addition, arrangements, dimensions, dimensional ratios, and the like of components in the present disclosure are not limited to the modes illustrated in the drawings.

(14) It is to be noted that the description is given in the following order. 1. Configuration of Semiconductor Laser 1.1. Stacked Structure 1.2. Planar structure 2. Method of Manufacturing Semiconductor Laser 2.1. Outline of Manufacturing Method 2.2. Specific Example of Dividing Groove 3. Conclusion

1. CONFIGURATION OF SEMICONDUCTOR LASER

1.1. Stacked Structure

(15) First, with reference to FIG. **1**, description is given of a stacked structure of a semiconductor laser according to an embodiment of the present disclosure. FIG. **1** is a schematic cross-sectional diagram illustrating the stacked structure of the semiconductor laser **100** according to the present embodiment. In FIG. **1**, a stacking direction of the semiconductor laser **100** is defined as a Z direction; of in-plane directions of the semiconductor laser **100**, a direction from a front side of a sheet plane to a rear side of the sheet plane is defined as a Y direction; and an in-plane direction of the semiconductor laser **100** orthogonal to the Y direction is defined as an X direction.

(16) It is to be noted that description will be given hereinafter with a first conductivity type as an n type and a second conductivity type as a p type.

(17) As illustrated in FIG. **1**, the semiconductor laser **100** includes, for example, a stacked body **10** in which an epitaxial layer **2** is stacked on one surface **1***a* (also referred to as a top surface **1***a*) of a semiconductor substrate **1**, an insulating layer **3** and a first electrode **4** provided on the epitaxial layer **2**, and a second electrode **5** provided on another surface **1***b* (also referred to as a back surface **1***b*) of the semiconductor substrate **1** opposite to the top surface **1***a*.

(18) The semiconductor substrate **1** includes, for example, a hexagonal group-III nitride semiconductor such as GaN, AlN, AlGaN, InGaN, or InAlGaN. Specifically, the semiconductor substrate **1** may be a GaN substrate of which carriers are of the n type. In the semiconductor laser **100** according to the present embodiment, the top surface **1***a* of the semiconductor substrate **1** on which the epitaxial layer **2**, the insulating layer **3**, and the first electrode **4** are stacked is a semipolar plane. The semipolar plane will be described later with reference to FIG. **2**.

(19) The epitaxial layer **2** is provided by, for example, epitaxially growing a buffer layer **11**, a first cladding layer **12**, a first light guide layer **13**, a light emission layer **14**, a second light guide layer **15**, a carrier blocking layer **16**, a second cladding layer **17**, and a contact layer **18** in order on the top surface Ta of the semiconductor substrate **1**.

(20) The buffer layer **11** is provided, for example, as a gallium-nitride-based semiconductor layer such as an n-type GaN layer. The first cladding layer **12** is provided, for example, as a gallium-nitride-based semiconductor layer such as an n-type AlGaN layer or an n-type InAlGaN layer. The first light guide layer **13** is provided, for example, as a gallium-nitride-based semiconductor layer such as an n-type GaN layer or an n-type InGaN layer.

(21) The light emission layer **14** includes, for example, a well layer (not illustrated) including a gallium-nitride-based semiconductor such as InGaN or InAlGaN, and a barrier layer (not illustrated) including a gallium-nitride-based semiconductor such as GaN, InGaN, or InAlGaN. Specifically, the light emission layer **14** may be provided in a multi-quantum well structure including a plurality of well layers and a plurality of barrier layers that are alternately stacked. The light emission layer **14** is alight emission region in the epitaxial layer **2**, and is able to emit light in a wavelength band of, for example, 480 nm to 550 nm.

(22) The second light guide layer **15** is provided as a gallium-nitride-based semiconductor layer such as a p-type GaN layer or a p-type InGaN layer. The carrier blocking layer **16** is an electron

blocking layer, and is provided, for example, as a gallium-nitride-based semiconductor layer such as a p-type AlGaN layer.
(23) The second cladding layer **17** is provided, for example, as a gallium-nitride-based semiconductor layer such as a p-type AlGaN layer or a p-type InAlGaN layer. A ridge part **17***a* is provided on a first-electrode-4 side of the second cladding layer **17**. The ridge part **17***a* is a projection structure extending in the Y direction from the front side of the sheet plane to the rear side of the sheet plane of FIG. **1**, and is provided by excavating a region of a surface of the second cladding layer **17** on the first-electrode-4 side other than a region corresponding to the ridge part **17***a* by etching or the like.
(24) The ridge part **17***a* is provided to extend from one end surface to another end surface opposite thereto of a single semiconductor laser **100**. Both end surfaces opposed to each other in the extending direction of the ridge part **17***a* function as reflecting surfaces of a laser resonator. In other words, a laser resonator is configured by both end surfaces provided in the extending direction of the ridge part **17***a* and an optical waveguide region in the epitaxial layer **2** corresponding to a plane region on which the ridge part **17***a* is provided. The semiconductor laser **100** is able to externally emit laser light by amplifying, with the laser resonator, light emitted from the light emission layer **14**.
(25) The contact layer **18** is provided, for example, as a gallium-nitride-based semiconductor layer such as a p-type GaN layer. The contact layer **18** is provided on the ridge part **17***a* of the second cladding layer **17**.
(26) The insulating layer **3** includes, for example, an insulating film such as a SiO.sub.2 film. The insulating layer **3** is provided on a region of the second cladding layer **17** other than the ridge part **17***a* and on side surfaces of the ridge part **17***a* and the contact layer **18**.
(27) The first electrode **4** includes, for example, an electrically conductive film such as a Pd film. The first electrode **4** is provided on the contact layer **18** and on an end surface of the insulating layer **3** on the contact-layer-18 side. It is to be noted that the semiconductor laser **100** may further be provided with an electrically conductive film for a pad electrode that electrically couples to the first electrode **4**. The electrically conductive film for the pad electrode may be provided to cover the insulating layer **3** and the first electrode **4**, for example.
(28) The second electrode **5** includes, for example, an electrically conductive film such as an Al film. The second electrode **5** is provided on the back surface **1***b* of the semiconductor substrate **1**.
(29) Here, with reference to FIG. **2**, description is given of a crystal structure of a hexagonal group-III nitride semiconductor such as GaN and the semipolar plane of the semiconductor substrate **1**. FIG. **2** is an explanatory diagram illustrating the crystal structure of GaN.
(30) GaN has a crystal structure called a hexagonal crystal as illustrated in FIG. **2**. In the hexagonal crystal structure, a first plane **201** perpendicular to a c-axis which is a growth axis is referred to as a polar plane, and a second plane **202** parallel to the c-axis is referred to as a nonpolar plane. Further, a third plane **203** to which a direction of the normal is an axial direction inclined at a predetermined angle with respect to the c-axis in an m-axis direction is a plane having a characteristic intermediate between the first plane **201** and the second plane **202**, and is therefore referred to as a semipolar plane.
(31) In the semiconductor laser **100**, the epitaxial layer **2** is epitaxially grown on a semipolar plane of the semiconductor substrate **1**. For example, the epitaxial layer **2** may be epitaxially grown on a semipolar plane, such as a {2, 0, −2, 1} plane, a {1, 0, −1, 1} plane, a {2, 0, −2, −1} plane, or a {1, 0, −1, −1} plane, of the semiconductor substrate **1**. In the semipolar plane, it is possible to reduce a piezoelectric field occurring in a c-axis direction while maintaining a crystal growth characteristic close to the polar plane. This makes it possible for the semiconductor laser **100** to achieve favorable crystal growth of the epitaxial layer **2** and to reduce the piezoelectric field that degrades light emission efficiency at the light emission layer **14**. Accordingly, it is possible to improve a light emission characteristic.

(32) Meanwhile, the semiconductor laser **100** is manufactured by cutting individual semiconductor lasers **100** out of a production substrate including a plurality of semiconductor lasers **100** arranged two-dimensionally. The cutting of the semiconductor lasers **100** out of the production substrate is performed by, for example, cleavage along a crystal plane of the crystal structure of each of the semiconductor substrate **1** and the epitaxial layer **2**. A surface resulting from the cleavage (also referred to as a cleavage surface) is relatively flat and smooth, and is therefore suitably usable as a reflecting surface of the laser resonator in the semiconductor laser **100**.
(33) However, in a case where the epitaxial layer **2** is stacked on the semipolar plane of the semiconductor substrate **1**, the cleavage surface at the time of cutting of the semiconductor lasers **100** is affected by the crystal plane of the first plane **201** (i.e., the {0, 0, 0, 1} plane). As a result, in some cases, the cleavage surface at the time of the cutting of the semiconductor lasers **100** can be the first plane **201**, thus not being a plane perpendicular to the light emission layer **14** (i.e., the third plane **203**) as illustrated in FIG. **2**. In such a case, the cleavage surface in an end surface of the light emission layer **14** is lower in function as a reflecting surface of the laser resonator, thus leading to a substantial decrease in reflectance, or an increase in guiding loss of the laser light. As a result, degradation in light emission characteristic of the laser light or an increase in characteristic variations from one element to another occurs in the semiconductor laser **100**.
(34) The technology according to the present disclosure has been conceived in view of the above circumstances. The technology according to the present disclosure is to provide an end surface functioning as a reflecting surface of the laser resonator in the semiconductor laser **100** in a shape including an arc. The technology according to the present disclosure makes it possible to improve perpendicularity of the cleavage surface and the extending direction of the optical waveguide region to each other.
1.2. Planar Structure
(35) In the following, description is given of details of the technology according to the present disclosure with reference to FIG. **3**. FIG. **3** is a plan diagram describing a planar structure of the semiconductor laser **100** according to the present embodiment. In FIG. **3**, a right-and-left direction when facing the drawing corresponds to the X direction, and an up-and-down direction when facing the drawing corresponds to the Y direction. Further, in FIG. **3**, a direction from the rear side of the sheet plane to the front side of the sheet plane corresponds to the Z direction.
(36) As illustrated in FIG. **3**, in the semiconductor laser **100**, the stacked body **10** is provided in a longitudinal shape that extends in the direction in which the ridge part **17***a* extends (the Y direction in FIG. **3**) in a plan view from a stacking direction in which the epitaxial layer **2** is stacked on the semiconductor substrate **1** (hereinafter, also referred to simply as the stacking direction). More specifically, the stacked body **10** is provided in a substantially rectangular shape that extends in the extending direction of the ridge part **17***a*.
(37) Further, the ridge part **17***a* is provided to extend from one end surface **6** to another end surface **6** of the stacked body **10** in substantially the middle in a lateral direction (the X direction in FIG. **3**) of the stacked body **10** in a plan view from the stacking direction. It is to be noted that the unillustrated first electrode **4** is provided on the ridge part **17***a*.
(38) The end surfaces **6** of the stacked body **10** in the direction in which the ridge part **17***a* extends are each provided to have a shape including an arc in a plan view from the stacking direction. Specifically, the end surfaces **6** may each be provided to form an arc that is concave with respect to the stacked body **10** from respective corners of the substantially rectangular shape of the stacked body **10** in a plan view from the stacking direction. With this configuration, in the ridge part **17***a* provided in substantially the middle in the lateral direction of the stacked body **10**, the arcs that the end surfaces **6** form are reduced in radius of curvature, and the end surfaces **6** thus become substantially flat. Accordingly, the end surfaces **6** of the stacked body **10** in the direction in which the ridge part **17***a* extends are each able to have the function as a reflecting surface of the laser resonator.

(39) For example, the end surfaces **6** may each be provided in an arc that has a radius of curvature of 5 mm or more and that is concave with respect to the stacked body **10** in a plan view from the stacking direction. In such a case, in the ridge part **17***a* provided in substantially the middle in the lateral direction of the stacked body **10**, the end surfaces **6** each become substantially perpendicular to the waveguide region, thus being able to have a more favorable shape as a reflecting surface of the laser resonator.
(40) The end surfaces **6** of the stacked body **10** described above are formed by providing a dividing groove for guiding, which is provided when cutting the semiconductor lasers **100** out of the production substrate including a plurality of semiconductor lasers **100** arranged two-dimensionally, to be curved in the extending direction of the ridge part **17***a*. Specifically, the dividing groove for guiding, which is provided in the stacked body **10** when dividing the production substrate into the semiconductor lasers **100**, is provided to be curved toward the stacked body **10** to thereby perform dividing. This makes it possible to form the end surfaces **6** that are not along the crystal plane of the first plane **201** in FIG. **2**. By virtue of this, in the semiconductor laser **100**, it is possible to form the end surfaces **6** that are not along the crystal plane of the first plane **201** in FIG. **2** by dividing. Accordingly, it is possible to improve the perpendicularity of the end surfaces **6** to the in-plane direction of the light emission layer **14**.
(41) Such dividing makes it possible for the end surfaces **6** to be formed as smooth divided surfaces with irregularities of a magnitude of 0.1 μm or smaller. Further, in a case of using the end surfaces **6** as reflecting surfaces of the laser resonator in the semiconductor laser **100**, irregularities of 0.02 μm or more are allowed and therefore the magnitude of irregularities of the end surfaces **6** may be greater than or equal to 0.02 μm and smaller than or equal to 0.1 μm. The end surfaces **6** having such irregularities are suitably usable as reflecting surfaces of the laser resonator in the semiconductor laser **100**.
(42) It is to be noted that the end surfaces **6** may each be provided in a shape including the arc described above in a region from the top surface at which the ridge part **17***a* is provided to at least a depth at which the light emission layer **14** is provided. For example, the end surfaces **6** may each be provided in a shape including the arc described above in a region from the top surface at which the ridge part **17***a* is provided to a depth of at least 2 μm. It is the end surfaces **6** of the stacked body **10** present in the in-plane direction of the light emission layer **14** that function as the reflecting surfaces of the laser resonator. Accordingly, it is preferable that the end surfaces **6** each have a shape including the arc described above in the region from the top surface at which the ridge part **17***a* is provided to at least the depth at which the light emission layer **14** is provided. Meanwhile, the end surfaces **6** of the first light guide layer **13**, the first cladding layer **12**, the buffer layer **11**, and the semiconductor substrate **1** below the light emission layer **14** in the stacked body **10** may be end surfaces resulting from dividing along the crystal plane of the first plane **201** in FIG. **2**.
(43) Furthermore, as illustrated in FIG. **3**, a groove section part **7** is provided at each of the corners of the substantially rectangular shape of the stacked body **10** in a plan view from the stacking direction.
(44) The groove section part **7** is a remaining portion of the dividing groove for guiding which is provided at the time of dividing the production substrate formed by two-dimensionally arranging a plurality of semiconductor lasers **100** into the individual semiconductor lasers **100**. Specifically, the groove section part **7** is a remaining portion of a sidewall face of the groove that is provided from the top surface of the stacked body **10**, at which the ridge part **17***a* is provided, toward the depth direction in such a manner as to be curved. For example, the groove section part **7** may be a sidewall face that is curved from the top surface of the stacked body **10** toward the extending direction of the ridge part **17***a*.
(45) The groove section part **7** may be provided at a distance from the ridge part **17***a*. For example, the groove section part **7** may be provided at a distance of 10 μm or more from the ridge part **17***a*. One reason for this is that the dividing groove for guiding including the groove section part **7** can

cause damage to the stacked body **10** therearound in a process of forming the dividing groove for guiding. By providing the groove section part **7** at a distance from the ridge part **17***a*, it is possible to prevent damage to a region contributing to light emission that is provided in the region corresponding to the ridge part **17***a*.

(46) It is to be noted that details of the dividing groove for guiding which is provided at the time of dividing the production substrate into the individual semiconductor lasers **100** will be described later in a section of a method of manufacturing the semiconductor laser **100**.

(47) Next, with reference to FIGS. **4**A and **4**B, description is given of modification examples of the semiconductor laser **100** according to the present embodiment. FIG. **4**A is a plan diagram illustrating an example of the planar structure of the semiconductor laser **100** according to a modification example. FIG. **4**B is a plan diagram illustrating another example of the planar structure of the semiconductor laser **100** according to a modification example. In FIGS. **4**A and **4**B, a configuration of the stacked body **10** in one of the extending directions of the ridge part **17***a* is extracted and illustrated.

(48) As illustrated in FIG. **4**A, in a semiconductor laser **100**A, an end surface **6**A in the direction in which the ridge part **17***a* extends is provided to have a shape including a plurality of arcs in a plan view from the stacking direction. Specifically, the end surface **6**A may have a shape in which a rectangular shape with rounded corners smaller than the substantially rectangular shape of the stacked body **10** is excavated into a concavity in a plan view from the stacking direction. According to the present modification example, the shape of the end surface **6**A in a plan view from the stacking direction may include only an arc, may include a plurality of arcs, or may include an arc and a straight line as long as the end surface **6**A becomes substantially flat in the region in which the ridge part **17***a* is provided.

(49) As illustrated in FIG. **4**B, in a semiconductor laser **100**B, an end surface **6**B of the stacked body **10** in the direction in which the ridge part **17***a* extends is provided to be convex with respect to the stacked body **10** in a plan view from the stacking direction. Specifically, the end surface **6**B may be provided to form an arc that is convex with respect to the stacked body **10** from the respective corners of the substantially rectangular shape of the stacked body **10** in a plan view from the stacking direction. It is possible to form such an end surface **6**B by providing the dividing groove for guiding, which is provided in the stacked body **10** at the time of dividing the production substrate into the semiconductor lasers **100**, to be curved away from the stacked body **10**. According to the present modification example, the shape of the end surface **6**B in a plan view from the stacking direction may be a concave shape with respect to the stacked body **10** or a convex shape with respect to the stacked body **10** as long as the end surface **6**B becomes substantially flat in the region in which the ridge part **17***a* is provided.

## 2. METHOD OF MANUFACTURING SEMICONDUCTOR LASER

### 2.1. Outline of Manufacturing Method

(50) Next, with reference to FIGS. **5** to **7**, description is given of a method of manufacturing the semiconductor laser **100** according to one embodiment of the present disclosure. FIG. **5** is a flowchart diagram illustrating a flow of the method of manufacturing the semiconductor laser **100** according to the present embodiment.

(51) As illustrated in FIG. **5**, first, the semiconductor substrate **1** for forming a plurality of semiconductor lasers **100** in a two-dimensional arrangement is prepared (S**100**). The semiconductor substrate **1** is a substrate including, for example, a hexagonal group-III nitride semiconductor, and having the top surface **1***a* serving as a semipolar plane. The semipolar plane of the prepared semiconductor substrate **1** is cleaned by thermal cleaning or the like.

(52) Next, the epitaxial layer **2** is formed (S**110**) by epitaxially growing various semiconductor layers in order on the semipolar plane of the semiconductor substrate **1** by means of, for example, an MOCVD (Metal Organic Chemical Vapor Deposition) method. Specifically, the buffer layer **11**, the first cladding layer **12**, the first light guide layer **13**, the light emission layer **14**, the second light

guide layer **15**, the carrier blocking layer **16**, the second cladding layer **17**, and the contact layer **18** are epitaxially grown in order on the top surface **1***a* of the semiconductor substrate **1**.
(53) Subsequently, within a surface region of the contact layer **18**, a mask is provided on a region in which the ridge part **17***a* is to be formed, and the ridge part **17***a* is formed (S**120**) in each of the semiconductor lasers **100** by etching the contact layer **18** and the second cladding layer **17** in a region other than the region on which the mask is provided. Thereafter, the mask is removed and the insulating layer **3** is formed on the surfaces of the contact layer **18** and the second cladding layer **17** by means of a vapor deposition method or a sputtering method.
(54) Next, the contact layer **18** is exposed by removing the insulating layer **3** on the ridge part **17***a* by means of a photolithography technique, following which the first electrode **4** is formed (S**130**) on the exposed contact layer **18** by means of a vapor deposition method or a sputtering method. Thereafter, the back surface **1***b* of the semiconductor substrate **1** is polished until the semiconductor substrate **1** achieves a desired thickness (for example, about 70 μm to about 80 μm), following which the second electrode **5** is formed on the back surface **1***b* of the semiconductor substrate **1** by means of a vapor deposition method or a sputtering method.
(55) Subsequently, at the top surface in the stacking direction of the stacked body **10** including the semiconductor substrate **1** and the epitaxial layer **2** that are stacked, the dividing groove (also referred to as a scribe line) is formed (S**140**) at each corner of formation regions of the semiconductor lasers **100** adjacent to each other in the extending direction of the ridge part **17***a*. Specifically, the dividing groove is provided at each corner of the formation regions of the semiconductor lasers **100** in the depth direction from the top surface in the stacking direction of the stacked body **10** in such a manner as to be curved.
(56) Here, a cross-sectional shape of the dividing groove will be described with reference to FIG. **6**. FIG. **6** is an explanatory diagram schematically illustrating an example of the cross-sectional shape of a dividing groove **300**.
(57) As illustrated in FIG. **6**, the dividing groove **300** is provided from the top surface in the stacking direction of the stacked body **10** toward the depth direction to allow an end thereof to be curved. Specifically, the dividing groove **300** may be provided to allow an angle θ of a straight line passing through a center of the dividing groove **300** to satisfy $0°<\theta<75°$, preferably $10°<\theta<45°$ in a cross section of the dividing groove **300** taken along a curving direction. Further, the curving direction of the dividing groove **300** may be, for example, the Y direction which is the extending direction of the ridge part **17***a* (that is, a direction toward the crystal plane of the first plane **201** in FIG. **2**).
(58) It is possible to form such a dividing groove **300** by, for example, laser ablation. Laser ablation is a technique of processing an object by causing the object at a laser-light-irradiation position to evaporate with heat when the object absorbs laser light applied thereto. For example, it is possible to perform laser ablation on the stacked body **10** by using a laser of a wavelength of 355 nm that a group-III nitride semiconductor is able to absorb.
(59) Specifically, laser light emitted from an oscillator is allowed to be incident on a principal surface of a quarter-wave plate with a plane of polarization inclined at **450** to thereby generate circularly polarized laser light. By condensing the generated circularly polarized laser light with a lens or the like and applying it to the stacked body **10**, it is possible to form the dividing groove **300** with an end thereof having a curved shape. A curve angle of the dividing groove **300** is changeable, for example, by a ratio between circularly polarized light and linearly polarized light that are included in the laser light used in the laser ablation.
(60) It is to be noted that as long as it is possible to form the dividing groove **300** having the curved shape, the dividing groove **300** may be formed by means of dry etching or the like, instead of laser ablation.
(61) Furthermore, in order for dividing of the stacked body **10** at a later stage to be performed more smoothly, a dividing groove of another shape may further be provided. For example, a dividing

groove that penetrates through the stacked body **10**, or a back-surface dividing groove that is excavated from the back surface of the stacked body **10** opposite to the top surface in the stacking direction may further be provided. Specific examples of the dividing grooves to be provided in the stacked body **10** will be described later with reference to FIGS. **8** to **10**.
(62) Next, the stacked body **10** including a plurality of semiconductor lasers **100** arranged two-dimensionally is divided (cleaved) by using the dividing groove, and the semiconductor lasers **100** adjacent to each other in the extending direction of the ridge part **17***a* are separated from each other, whereby the stacked body **10** is processed into a bar shape (S**150**). Specifically, it is possible to process the stacked body **10** into a bar shape by placing a blade onto the back surface of the stacked body **10** and dividing the stacked body **10** in such a manner as to open the stacked body **10** from the top surface in the stacking direction.
(63) Here, a method of dividing the stacked body **10** by using the dividing groove will be described with reference to FIG. **7**. FIG. **7** is an explanatory diagram schematically illustrating the method of dividing the stacked body **10** by using the dividing groove.
(64) As illustrated in FIG. **7**, it is possible to perform dividing of the stacked body **10**, through the use of a breaking apparatus, by supporting the stacked body **10** using two support blades **401** and **402** with the back surface facing upward, and by placing a blade **403** onto an intended dividing position from the back surface. The intended dividing position is, for example, a boundary between the formation regions of the semiconductor lasers **100** including each corner at which the dividing groove is provided. The top surface in the stacking direction (that is, the surface opposite to the back surface on which the blade **403** is placed) of the stacked body **10** is thereby so divided (cleaved) as to open, and the stacked body **10** is thus divided into a bar shape.
(65) The end surfaces **6** of the stacked body **10** in the extending direction of the ridge part **17***a* are thereby formed to be smooth and flat, thus becoming able to be used as reflecting surfaces of the laser resonator. Further, in the method of manufacturing the semiconductor laser **100** according to the present embodiment, the dividing groove is curved toward the crystal plane of the first plane **201** in the depth direction of the stacked body **10**. This makes it possible for the stacked body **10** to be so divided as not to be along the crystal plane of the first plane **201**. Accordingly, the end surfaces **6** of the stacked body **10** thus divided each have a shape including an arc, and therefore, in the region in which the ridge part **17***a* is provided, the end surfaces **6** become substantially flat surfaces orthogonal to the extending direction of the ridge part **17***a*. The method of manufacturing the semiconductor laser **100** according to the present embodiment therefore makes it possible to obtain end surfaces that are not inclined with respect to the waveguide region of the laser resonator.
(66) Subsequently, the semiconductor lasers **100** are subjected to singulation into individual chips (S**160**) by cutting the stacked body **10** that has been processed into a bar shape and separating the semiconductor lasers **100** from each other. Thereafter, the semiconductor laser **100** having undergone the singulation is assembled together with a control circuit, a power supply circuit, etc. and is thereby manufactured as a product (S**170**).
2.2. Specific Example of Dividing Groove
(67) Next, with reference to FIGS. **8** to **10**, description is given of specific examples of the dividing groove to be provided by the method of manufacturing the semiconductor laser **100** according to the present embodiment.
(68) Each of FIGS. **8** to **10** is a cross-sectional view or a plan view of the stacked body **10** illustrating a specific example of the dividing groove. FIG. **8** is a cross-sectional view of the stacked body **10** taken along the Z direction at a boundary between adjacent formation regions of the semiconductor lasers **100**. FIG. **9** is a plan view of the top surface in the stacking direction of the stacked body **10**, and FIG. **10** is a plan view of the back surface opposite to the top surface in the stacking direction of the stacked body **10**. For example, the cross-sectional view illustrated in FIG. **8** corresponds to a cross-sectional view taken along line A-AA in the plan view illustrated in each of FIGS. **9** and **10**. In FIGS. **8** to **10**, the stacking direction of the stacked body **10** is defined

as the Z direction, the extending direction of the ridge part **17***a* is defined as the Y direction, and the direction orthogonal to the Z direction and the Y direction is defined as the X direction.

(69) As illustrated in FIGS. **8** to **10**, at the boundary between the formation regions of the semiconductor lasers **100** adjacent to each other in the Y direction, the dividing groove **300** is formed by laser ablation or the like to divide (cleave) the stacked body **10** to obtain the reflecting surfaces of the laser resonators in the semiconductor lasers **100**. Specifically, the dividing groove **300** includes a curved dividing groove **301**, a through dividing groove **302**, and a back-surface dividing groove **303**.

(70) The curved dividing groove **301** is provided between adjacent semiconductor lasers **100** at the top surface of the stacked body **10** to have an end curved in the extending direction of the ridge part **17***a*. For example, the curved dividing groove **301** may be provided at the boundary between the formation regions of the semiconductor lasers **100** located at a distance of 10 μm or more in the X direction from the ridge part **17***a* to have a depth greater than or equal to 5 μm and smaller than or equal to 40 μm. In a case where the depth of the curved dividing groove **301** falls within the above-described range, it is possible to easily divide the stacked body **10** and to prevent excessive damage to the stacked body **10**. To suppress damage to the stacked body **10**, a width in the Y direction of the curved dividing groove **301** is preferably as small as possible, and is preferably smaller than or equal to 5 μm, for example. The curve angle of the curved dividing groove **301** may be, for example, greater than 0° and smaller than 75°, preferably greater than 100 and smaller than 45°. By providing the curved dividing groove **301**, the stacked body **10** is divided to allow the semiconductor lasers **100** resulting from the dividing to have end surfaces each including a desired arc.

(71) The through dividing groove **302** is provided through the stacked body **10** from the top surface to the back surface of the stacked body **10**. For example, the through dividing groove **302** may be provided at a point of intersection of the boundaries between the formation regions of the semiconductor lasers **100** to have a width in the X direction greater than or equal to 3 μm and smaller than or equal to 30 μm, and a width in the Y direction smaller than or equal to 10 μm. The through dividing groove **302** is a dividing groove that is more effective in allowing the end surfaces **6** of the stacked body **10** to each have a shape including an arc in a plan view from the stacking direction. By providing the through dividing groove **302**, the stacked body **10** is divided to allow the end surfaces **6** to each have a shape including an arc more easily.

(72) A plurality of back-surface dividing grooves **303** is provided at small intervals between adjacent semiconductor lasers **100** at the back surface of the stacked body **10**. For example, the back-surface dividing grooves **303** may be provided by forming grooves having a width in the X direction of about 8 μm and a depth of 35 μm in a dashed-line manner with a spacing of about 2 μ between adjacent grooves at the boundary between the formation regions of the semiconductor lasers **100** adjacent to each other in the Y direction. Providing the back-surface dividing grooves **303** results in more easy dividing of the stacked body **10**.

(73) It is to be noted that these dividing grooves **300** are formable by dry etching instead of laser ablation. A modification example of forming the dividing grooves **300** by dry etching will be described with reference to FIG. **11**. FIG. **11** is a plan view of the stacked body **10** illustrating the modification example of the dividing grooves **300**. FIG. **11** illustrates a plan view of the top surface in the stacking direction of the stacked body **10** in a case where dry etching is used. In FIG. **11**, the stacking direction of the stacked body **10** is defined as the Z direction, the extending direction of the ridge part **17***a* is defined as the Y direction, and the direction orthogonal to the Z direction and the Y direction is defined as the X direction.

(74) As illustrated in FIG. **11**, in the case where the dividing grooves **300** are formed by dry etching, the dividing grooves **300** include a guide dividing groove **304** instead of the curved dividing groove **301**.

(75) The guide dividing groove **304** is a groove having a plan shape that promotes dividing

(cleaving) to allow the end surfaces **6** of the semiconductor lasers **100** adjacent to each other in the Y direction to each have a shape including an arc. Specifically, the guide dividing groove **304** is provided at the boundary between the formation regions of the semiconductor lasers **100** located away from the ridge part **17***a* in the X direction, and is provided with an end part shaped to turn to obliquely intersect the ridge part **17***a*. For example, the guide dividing groove **304** may be provided in a linear shape with both end parts bifurcated with respect to the ridge part **17***a*. Providing the guide dividing groove **304** allows dividing of the end surfaces in the Y direction of the semiconductor laser **100** to be performed obliquely from the respective corners of the formation region of the semiconductor laser **100** toward the ridge part **17***a*. This makes it easier for the end surfaces in the Y direction of the semiconductor laser **100** to be each formed into a shape in which the corners of the formation region of the semiconductor laser **100** are connected by an arc. Accordingly, even in a case of using such a manufacturing method, it is possible to manufacture the semiconductor laser **100** according to the present embodiment.

3. CONCLUSION

(76) As has been described hereinabove, in the semiconductor laser **100** according to the present embodiment, each of the end surfaces **6** in the extending direction of the ridge part **17***a* is shaped to include an arc, and it is thereby possible to obtain a reflecting surface of the laser resonator that is not inclined with respect to the optical waveguide region. This makes it possible for the semiconductor laser **100** to achieve an improved light emission characteristic of laser light and to suppress characteristic variations. Specifically, it is possible for the semiconductor laser **100** to suppress threshold current value, slope efficiency, and variations of these characteristics. Further, it is possible for the semiconductor laser **100** to suppress an optical axis deviation of an FFP (Far Field Pattern) spectrum and variations of the characteristic.

(77) Further, with the semiconductor laser **100** according to the present embodiment, it is possible to suppress irregularities of the reflecting surface of the laser resonator. This makes it possible for the semiconductor laser **100** to be improved in resistance to electrostatic discharge (Electro Static Discharge: ESD), resistance to catastrophic optical damage (Catastrophic Optical Damage: COD), and long-term reliability.

(78) The technology according to the present disclosure has been described hereinabove with reference to the embodiments and the modification examples. However, the technology according to the present disclosure is not limited to the embodiments and the like described above, and may be modified in a variety of ways. For example, the technology according to the present disclosure is also applicable to a semiconductor laser that uses an AlGaAs/GaAs-based material.

(79) Furthermore, not all of the configurations and operations described in each of the embodiments are indispensable as the configurations and operations of the present disclosure. For example, among the components of each of the embodiments, any component that is not recited in an independent claim which represents the most generic concept of the present disclosure is to be understood as an optional component.

(80) Terms used throughout this specification and the appended claims should be construed as “non-limiting” terms. For example, the term “including” or “included” should be construed as “not limited to what is described as being included”. The term “having” should be construed as “not limited to what is described as being had”.

(81) The terms used herein are used merely for the convenience of description and include terms that are not used to limit the configuration and the operation. For example, the terms such as “right”, “left”, “up”, and “down” only indicate directions in the drawings being referred to. In addition, the terms “inside” and “outside” only indicate a direction toward the center of a component of interest and a direction away from the center of a component of interest, respectively. The same applies to terms similar to these and to terms with the similar purpose.

(82) It is to be noted that the technology according to the present disclosure may have the following configurations. The technology according to the present disclosure having the following

configurations makes it possible for the end surfaces of the stacked body in the extending direction of the ridge part to be non-inclined, substantially perpendicular end surfaces with respect to the optical waveguide region. This makes it possible for the laser resonator of the semiconductor laser to achieve a more favorable characteristic. Such a semiconductor laser makes it possible to improve the characteristic of laser light to be emitted and reduce characteristic variations. Effects attained by the technology according to the present disclosure are not necessarily limited to the effects described herein, but may include any of the effects described in the present disclosure.
(83) (1)
(84) A semiconductor laser including: a stacked body in which a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided between the first cladding layer and the second cladding layer are stacked on a semiconductor substrate; and a ridge part provided as a projection structure extending in one direction at a top surface in a stacking direction of the stacked body, in which the stacked body is provided to have both end surfaces in the extending direction of the ridge part that each have a shape including an arc in a plan view of the stacked body from the top surface.
(2)
(85) The semiconductor laser according to (1), in which a plan shape of the stacked body in the plan view from the top surface is a longitudinal shape that extends in the extending direction.
(86) (3)
(87) The semiconductor laser according to (2), in which the both end surfaces of the stacked body in the extending direction are provided to be convex or concave with respect to the stacked body.
(88) (4)
(89) The semiconductor laser according to (3), in which the both end surfaces are provided to be substantially flat in a region corresponding to the ridge part.
(90) (5)
(91) The semiconductor laser according to (4), in which, in the region corresponding to the ridge part, the both end surfaces are provided to be substantially flat to at least a depth at which the light emission layer is provided.
(92) (6)
(93) The semiconductor laser according to (4) or (5), in which, in the region in which the both end surfaces are substantially flat, the both end surfaces have irregularities of a magnitude greater than or equal to 0.02 μm and smaller than or equal to 0.1 μm.
(94) (7)
(95) The semiconductor laser according to any one of (2) to (6), in which a groove section part that is curved is provided at a corner of the longitudinal shape of the stacked body from the top surface of the stacked body toward a depth direction.
(96) (8)
(97) The semiconductor laser according to (7), in which the groove section part is curved toward the extending direction.
(98) (9)
(99) The semiconductor laser according to (7) or (8), in which the groove section part is provided at a distance from the ridge part.
(100) (10)
(101) The semiconductor laser according to any one of (7) to (9), in which the groove section part is provided through the stacked body.
(102) (11)
(103) The semiconductor laser according to any one of (1) to (10), in which a back-surface groove section part is further provided in the stacked body at a back surface opposed to the top surface.
(104) (12)
(105) The semiconductor laser according to any one of (1) to (11), in which the first cladding layer,

the second cladding layer, and the light emission layer are stacked on a semipolar principal surface of the semiconductor substrate.
(106) (13)
(107) The semiconductor laser according to any one of (1) to (12), in which the semiconductor substrate includes a hexagonal group-III nitride semiconductor.
(108) (14)
(109) A method of manufacturing a semiconductor laser, including: forming a stacked body by stacking a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided between the first cladding layer and the second cladding layer on a semiconductor substrate; forming a ridge part having a projection structure extending in one direction at a top surface in a stacking direction of the stacked body; forming a dividing groove from the top surface toward a depth direction, the dividing groove being curved; and subjecting the stacked body to singulation to allow both end parts in the extending direction of the ridge part to each have a shape including an arc in a plan view of the stacked body from the top surface.
(15)
(110) The method of manufacturing a semiconductor laser according to (14), in which the dividing groove is formed by laser ablation.
(111) (16)
(112) The method of manufacturing a semiconductor laser according to (15), in which the laser ablation is performed with a circularly polarized laser.
(113) (17)
(114) The method of manufacturing a semiconductor laser according to any one of (14) to (16), in which a curve angle of the dividing groove is greater than 0° and smaller than 75°.
(115) (18)
(116) The method of manufacturing a semiconductor laser according to any one of (14) to (17), in which the singulation of the stacked body is performed by cleaving the stacked body.
(117) This application claims the benefit of Japanese Priority Patent Application JP2019-210558 filed with the Japan Patent Office on Nov. 21, 2019, the entire contents of which are incorporated herein by reference.
(118) It should be understood by those skilled in the art that various modifications, combinations, sub-combinations, and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

## Claims

1. A semiconductor laser comprising: a stacked body in which a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided between the first cladding layer and the second cladding layer are stacked on a semiconductor substrate; and a ridge part provided as a projection structure extending in one direction at a top surface in a stacking direction of the stacked body, in which the stacked body is provided to have both end surfaces in the extending direction of the ridge part that each have a shape including an arc in a plan view of the stacked body from the top surface, a plan shape of the stacked body in the plan view from the top surface is a longitudinal shape that extends in the extending direction, the both end surfaces of the stacked body in the extending direction are provided to be convex or concave with respect to the stacked body, the both end surfaces are provided to be substantially flat in a region corresponding to the ridge part, and in the region in which the both end surfaces are substantially flat, the both end surfaces have irregularities of a magnitude greater than or equal to 0.02 μm and smaller than or equal to 0.1 μm.
2. The semiconductor laser according to claim 1, wherein, in the region corresponding to the ridge

part, the both end surfaces are provided to be substantially flat to at least a depth at which the light emission layer is provided.

3. The semiconductor laser according to claim 1, wherein a groove section part that is curved is provided at a corner of the longitudinal shape of the stacked body from the top surface of the stacked body toward a depth direction.

4. The semiconductor laser according to claim 3, wherein the groove section part is curved toward the extending direction.

5. The semiconductor laser according to claim 3, wherein the groove section part is provided at a distance from the ridge part.

6. The semiconductor laser according to claim 3, wherein the groove section part is provided through the stacked body.

7. The semiconductor laser according to claim 1, wherein a back-surface groove section part is further provided in the stacked body at a back surface opposed to the top surface.

8. The semiconductor laser according to claim 1, wherein the first cladding layer, the second cladding layer, and the light emission layer are stacked on a semipolar principal surface of the semiconductor substrate.

9. The semiconductor laser according to claim 1, wherein the semiconductor substrate includes a hexagonal group-III nitride semiconductor.

10. A method of manufacturing a semiconductor laser, comprising: forming a stacked body by stacking a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided between the first cladding layer and the second cladding layer on a semiconductor substrate; forming a ridge part having a projection structure extending in one direction at a top surface in a stacking direction of the stacked body; forming a dividing groove from the top surface toward a depth direction, the dividing groove being curved; and subjecting the stacked body to singulation to allow both end parts in the extending direction of the ridge part to each have a shape including an arc in a plan view of the stacked body from the top surface, wherein a plan shape of the stacked body in the plan view from the top surface is a longitudinal shape that extends in the extending direction, the both end surfaces of the stacked body in the extending direction are provided to be convex or concave with respect to the stacked body, the both end surfaces are provided to be substantially flat in a region corresponding to the ridge part, and in the region in which the both end surfaces are substantially flat, the both end surfaces have irregularities of a magnitude greater than or equal to 0.02 μm and smaller than or equal to 0.1 μm.

11. The method of manufacturing a semiconductor laser according to claim 10, wherein the dividing groove is formed by laser ablation.

12. The method of manufacturing a semiconductor laser according to claim 11, wherein the laser ablation is performed with a circularly polarized laser.

13. The method of manufacturing a semiconductor laser according to claim 10, wherein a curve angle of the dividing groove is greater than 0° and smaller than 75°.

14. The method of manufacturing a semiconductor laser according to claim 10, wherein the singulation of the stacked body is performed by cleaving the stacked body.

15. A semiconductor laser comprising: a stacked body in which a first cladding layer of a first conductivity type, a second cladding layer of a second conductivity type, and a light emission layer provided as a semipolar plane between the first cladding layer and the second cladding layer are stacked on a semiconductor substrate; and a ridge part provided as a projection structure extending in one direction at a top surface in a stacking direction of the stacked body, in which the stacked body is provided to have both end surfaces in the extending direction of the ridge part that each have a shape including an arc in a plan view of the stacked body from the top surface, a plan shape of the stacked body in the plan view from the top surface is a longitudinal shape that extends in the extending direction, the both end surfaces of the stacked body in the extending direction are

provided to be convex or concave with respect to the stacked body, the both end surfaces are provided to be substantially flat in a region corresponding to the ridge part, and in the region in which the both end surfaces are substantially flat, the both end surfaces have irregularities of a magnitude greater than or equal to 0.02 μm and smaller than or equal to 0.1 μm.