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VERTICAL CAVITY SURFACE EMITTING DEVICE

Abstract

A vertical cavity surface emitting device includes a substrate, a first multilayer film reflecting mirror formed on the substrate, a light-emitting structure layer formed on the first multilayer film reflecting mirror and including a light-emitting layer, and a second multilayer film reflecting mirror formed on the light-emitting structure layer. A resonator is constituted between the second multilayer film reflecting mirror and the first multilayer film reflecting mirror. The light-emitting structure layer includes a low resistance region and high resistance regions. The low resistance region is disposed in a ring shape between the first multilayer film reflecting mirror and the second multilayer film reflecting mirror. The high resistance regions are formed inside and outside the low resistance region and have electrical resistances higher than an electrical resistance of the low resistance region.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a Continuation Application of U.S. application Ser. No. 17/285,859, filed Apr. 15, 2021, which is a 371 of PCT/JP2019/039455, filed Oct. 7, 2019, which is based upon and claims the benefit of priority from Japanese Patent Application No. 2018-196393, filed Oct. 18, 2018, the entire contents of all of which are incorporated herein by reference.

TECHNICAL FIELD
[0002] The present invention relates to a vertical cavity surface emitting device, such as a vertical cavity surface emitting laser.
BACKGROUND ART
[0003] The vertical cavity surface emitting laser (hereinafter simply referred to as a surface emitting laser) is a semiconductor laser that includes reflecting mirrors formed of multilayer films stacked on a substrate and emits light in a direction perpendicular to a surface of the substrate. For example, Patent Document 1 discloses a surface emitting laser using a nitride semiconductor.
PRIOR ART DOCUMENTS
Patent Literature
[0004] Patent Document 1: Japanese Patent No. 5707742
SUMMARY OF THE INVENTION
Problems to be Solved by the Invention
[0005] For example, in the vertical cavity surface emitting device, such as the surface emitting laser, it is preferred that a light emission pattern is stable, for example, a far-field pattern is stable. Accordingly, for example, a resonator configured to generate light in a desired transverse mode is preferably configured in the vertical cavity surface emitting device. For example, generating a laser beam in a fundamental eigenmode allows obtaining a far-field pattern of unimodal laser beam having a low emission angle and a high-output power.
[0006] The present invention has been made in consideration of the above-described points and an object of which is to provide a vertical cavity surface emitting device that allows emitting light in a stable transverse mode.
Solutions to the Problems
[0007] A vertical cavity surface emitting device according to the present invention includes a substrate, a first multilayer film reflecting mirror, a light-emitting structure layer, and a second multilayer film reflecting mirror. The first multilayer film reflecting mirror is formed on the substrate. The light-emitting structure layer is formed on the first multilayer film reflecting mirror and includes a light-emitting layer. The second multilayer film reflecting mirror is formed on the light-emitting structure layer. A resonator is constituted between the second multilayer film reflecting mirror and the first multilayer film reflecting mirror. The light-emitting structure layer

includes a low resistance region and a high resistance region. The low resistance region is disposed in a ring shape between the first multilayer film reflecting mirror and the second multilayer film reflecting mirror. The high resistance region is formed inside the low resistance region and has an electrical resistance higher than an electrical resistance of the low resistance region.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0008] FIG. **1** is a cross-sectional view of a surface emitting laser according to Embodiment 1.
[0009] FIG. **2** is a schematic top view of the surface emitting laser according to Embodiment 1.
[0010] FIG. **3** is a drawing schematically illustrating a configuration of a resonator in the surface emitting laser according to Embodiment 1.
[0011] FIG. **4** is a drawing schematically illustrating current paths in the surface emitting laser according to Embodiment 1.
[0012] FIG. **5** is a drawing schematically illustrating light emitted from the surface emitting laser according to Embodiment 1.
[0013] FIG. **6**A is a drawing illustrating a relationship between a width of a current injected region and an eigenmode in the surface emitting laser according to Embodiment 1.
[0014] FIG. **6**B is a drawing illustrating an example of a far-field pattern of the light emitted from the surface emitting laser according to Embodiment 1.
[0015] FIG. **6**C is a drawing illustrating another example of the far-field pattern of the light emitted from the surface emitting laser according to Embodiment 1.
[0016] FIG. **7**A is a schematic top view of a surface emitting laser according to Modification 1 of Embodiment 1.
[0017] FIG. **7**B is a schematic top view of a surface emitting laser according to Modification 2 of Embodiment 1.
[0018] FIG. **7**C is a schematic top view of a surface emitting laser according to Modification 3 of Embodiment 1.
[0019] FIG. **8** is a cross-sectional view of a surface emitting laser according to Embodiment 2.
[0020] FIG. **9** is a cross-sectional view of a surface emitting laser according to Embodiment 3.
[0021] FIG. **10** is a cross-sectional view of a surface emitting laser according to Embodiment 4.
[0022] FIG. **11** is a cross-sectional view of a surface emitting laser according to Embodiment 5.
DESCRIPTION OF PREFERRED EMBODIMENTS
[0023] The following will describe embodiments of the present invention in detail. In the following embodiments, a case where the present invention is embodied as a surface emitting laser (semiconductor laser) will be described. However, the present invention is not limited to the surface emitting laser but applicable to various kinds of vertical cavity surface emitting devices, such as a vertical cavity surface emitting diode.
Embodiment 1
[0024] FIG. **1** is a cross-sectional view of a Vertical Cavity Surface Emitting Laser (hereinafter referred to as a surface emitting laser: VCSEL) according to Embodiment 1. FIG. **2** is a schematic top view of a surface emitting laser **10**. FIG. **1** is a cross-sectional view taken along the line V-V in FIG. **2**. The configuration of the surface emitting laser **10** will be described with reference to FIG. **1** and FIG. **2**.
[0025] The surface emitting laser **10** includes a substrate **11** and a first multilayer film reflecting mirror (hereinafter simply referred to as a first reflecting mirror) **12** formed on the substrate **11**. In this embodiment, the first reflecting mirror **12** is formed on the substrate **11** and has a structure in which first semiconductor films (hereinafter referred to as high refractive index semiconductor films) H**1** and second semiconductor films (hereinafter referred to as low refractive index

semiconductor films) L**1** having a refractive index lower than that of the high refractive index semiconductor film H**1** are stacked in alternation.
[0026] That is, in this embodiment, the first reflecting mirror **12** is a semiconductor multilayer film reflecting mirror constituting a Distributed Bragg Reflector (DBR) made of a semiconductor material.
[0027] In this embodiment, the substrate **11** has a composition of GaN. The substrate **11** is a substrate for growth used for crystal growth of the first reflecting mirror **12**. The high refractive index semiconductor film H**1** in the first reflecting mirror **12** has a composition of GaN, and the low refractive index semiconductor film L**1** has a composition of AlInN. In this embodiment, between the substrate **11** and the first reflecting mirror **12**, a buffer layer (not illustrated) having a composition of GaN is disposed.
[0028] The surface emitting laser **10** includes a light-emitting structure layer EM formed on the first reflecting mirror **12** and including a light-emitting layer **14**. In this embodiment, the light-emitting structure layer EM includes a plurality of semiconductor layers made of a nitride-based semiconductor. The light-emitting structure layer EM includes an n-type semiconductor layer (first semiconductor layer) **13** formed on the first reflecting mirror **12**, the light-emitting layer (active layer) **14** formed on the n-type semiconductor layer **13**, and a p-type semiconductor layer (second semiconductor layer) **15** formed on the light-emitting layer **14**.
[0029] In this embodiment, the n-type semiconductor layer **13** has a composition of GaN and contains Si as n-type impurities. The light-emitting layer **14** has a quantum well structure that includes a well layer having a composition of InGaN and a barrier layer having a composition of GaN. The p-type semiconductor layer **15** has a GaN-based composition and contains Mg as p-type impurities.
[0030] The configuration of the light-emitting structure layer EM is not limited to this. For example, the n-type semiconductor layer **13** may include a plurality of n-type semiconductor layers having mutually different compositions. The p-type semiconductor layer **15** may include a plurality of p-type semiconductor layers having mutually different compositions.
[0031] For example, the p-type semiconductor layer **15** may include, for example, an AlGaN layer as an electron-blocking layer (not illustrated) that reduces an overflow of electrons injected into the light-emitting layer **14** to the p-type semiconductor layer **15** at the interface with the light-emitting layer **14**. The p-type semiconductor layer **15** may include a contact layer (not illustrated) to form an ohmic contact with an electrode. In this case, for example, the p-type semiconductor layer **15** only needs to include a GaN layer as a cladding layer between the electron-blocking layer and the contact layer.
[0032] In this embodiment, the p-type semiconductor layer **15** includes an upper surface **15**A and a projection **15**B projected from the upper surface **15**A. When viewed in a direction perpendicular to the upper surface **15**A, the projection **15**B has a ring shape. In this embodiment, as illustrated in FIG. **2**, the projection **15**B is a surface region of the p-type semiconductor layer **15** projecting from the upper surface **15**A in a circular ring shape.
[0033] The surface emitting laser **10** includes an insulating layer (first insulating layer) **16** formed on the upper surface **15**A excluding the projection **15**B of the p-type semiconductor layer **15**. In this embodiment, the insulating layer **16** is in contact with the upper surface **15**A of the p-type semiconductor layer **15** and the side surface of the projection **15**B of the p-type semiconductor layer **15**. The insulating layer **16** has translucency to light emitted from the light-emitting layer **14** and is made of a material having a refractive index lower than that of the p-type semiconductor layer **15** (the projection **15**B), for example, an oxide, such as SiO.sub.2.
[0034] Additionally, the insulating layer **16** includes an inner insulating portion **16**A formed on a region surrounded by the projection **15**B in the upper surface **15**A of the p-type semiconductor layer **15**. In this embodiment, the surface on the side opposite to the light-emitting layer **14** of the p-type semiconductor layer **15** is exposed from the insulating layer **16** in the upper end surface of

the projection **15**B.

[0035] The surface emitting laser **10** includes a light-transmitting electrode layer **17** formed on the insulating layer **16** and connected to the p-type semiconductor layer **15** in the projection **15**B of the p-type semiconductor layer **15**. The light-transmitting electrode layer **17** is a conductive film having translucency to light emitted from the light-emitting layer **14**. The light-transmitting electrode layer **17** is in contact with the upper surface of the insulating layer **16** and the upper end surface of the projection **15**B of the p-type semiconductor layer **15**. For example, the light-transmitting electrode layer **17** is made of a metal oxide film, such as ITO or IZO.

[0036] The insulating layer **16** functions as a current confinement layer that confines a current injected into the light-emitting structure layer EM via the light-transmitting electrode layer **17**. First, the projection **15**B of the p-type semiconductor layer **15** is exposed from the insulating layer **16** and in contact with the light-transmitting electrode layer **17** (electrode) to function as a low resistance region LR in the light-emitting structure layer EM. The region where the projection **15**B of the p-type semiconductor layer **15** is disposed functions as a current injected region from which a current is injected into the light-emitting layer **14**.

[0037] The regions inside and outside the projection **15**B (the regions of the upper surface **15**A) in the p-type semiconductor layer **15** function as high resistance regions HR having an electrical resistance higher than that of the low resistance region LR by being covered with the insulating layer **16**. That is, the region where the upper surface **15**A is disposed of the p-type semiconductor layer **15** functions as a non-current injected region where the injection of the current into the light-emitting layer **14** is suppressed.

[0038] In other words, the light-emitting structure layer EM includes: the low resistance region LR disposed in the ring shape between the first and the second reflecting mirrors **12** and **19**, and the high resistance regions HR that is formed inside and outside the low resistance region LR and has the electrical resistances higher than that of the low resistance region LR.

[0039] The surface emitting laser **10** includes an insulating layer (second insulating layer) **18** formed on the light-transmitting electrode layer **17**. For example, the insulating layer **18** is made of a metal oxide, such as Ta_2O_5, Nb_2O_5, ZrO_2, TiO_2, and HfO_2. The insulating layer **18** has translucency to the light emitted from the light-emitting layer **14**.

[0040] The surface emitting laser **10** includes the second multilayer film reflecting mirror (hereinafter simply referred to as the second reflecting mirror) **19** formed on the insulating layer **18**. The second reflecting mirror **19** is disposed at a position facing the first reflecting mirror **12** via the light-emitting structure layer EM. A resonator OC having a direction perpendicular to the light-emitting structure layer EM (a direction perpendicular to the substrate **11**) as a resonator length direction is constituted between the second reflecting mirror **19** and the first reflecting mirror **12**.

[0041] In this embodiment, as illustrated in FIG. **2**, the second reflecting mirror **19** has a column shape. Therefore, in this embodiment, the surface emitting laser **10** includes the column-shaped resonator OC.

[0042] In this embodiment, the second reflecting mirror **19** has a structure in which first dielectric films (hereinafter referred to as high refractive index dielectric films) H**2** and second dielectric films (hereinafter referred to as low refractive index dielectric films) L**2** having a refractive index lower than that of the high refractive index dielectric films H**2** are stacked in alternation.

[0043] That is, in this embodiment, the second reflecting mirror **19** is a dielectric multilayer film reflecting mirror constituting a Distributed Bragg Reflector (DBR) made of a dielectric material. In this embodiment, the high refractive index dielectric film H**2** is formed of a Ta_2O_5 layer, and the low refractive index dielectric film L**2** is made of an Al_2O_3 layer.

[0044] The projection **15**B of the p-type semiconductor layer **15** in the light-emitting structure layer EM, namely, the low resistance region LR is disposed in the region between the first reflecting mirror **12** and the second reflecting mirror **19**. That is, in this embodiment, the resonator OC includes a ring-shaped region R**2** extending between the first and the second reflecting mirrors **12**

and **19** corresponding to the low resistance region LR in the light-emitting structure layer EM, a central region R**1** disposed corresponding to the high resistance region HR at the inside of the ring-shaped region R**2**, and an outer region R**3** disposed outside the ring-shaped region R**2**.
[0045] In this embodiment, the insulating layer **16** has a refractive index lower than that of the p-type semiconductor layer **15**. Therefore, the central region R**1** and the outer region R**3** in the resonator OC have an equivalent refractive index lower than that of the ring-shaped region R**2**. That is, the central region R**1** and the outer region R**3** function as low refractive index regions, and the ring-shaped region R**2** functions as a high refractive index region. In this embodiment, the central region R**1** has a column shape, and the ring-shaped region R**2** and the outer region R**3** each have a cylindrical shape.
[0046] The surface emitting laser **10** includes first and second electrodes E**1** and E**2** that apply electric current to the light-emitting structure layer EM. The first electrode E**1** is formed on the n-type semiconductor layer **13**. The second electrode E**2** is formed on the light-transmitting electrode layer **17**.
[0047] The application of a voltage between the first and the second electrodes E**1** and E**2** emits the light from the light-emitting layer **14** in the light-emitting structure layer EM. The light emitted from the light-emitting layer **14** repeats reflection between the first and the second reflecting mirrors **12** and **19**, thus entering a resonance state (performing laser oscillation).
[0048] In this embodiment, the first reflecting mirror **12** has reflectance slightly lower than that of the second reflecting mirror **19**. Therefore, a part of the light resonated between the first and the second reflecting mirrors **12** and **19** transmits through the first reflecting mirror **12** and the substrate **11** and is taken to the outside. Thus, the surface emitting laser **10** emits the light in the direction perpendicular to the substrate **11** and the light-emitting structure layer EM.
[0049] The projection **15**B of the p-type semiconductor layer **15** in the light-emitting structure layer EM defines a luminescence center in the light-emitting layer **14** and defines a center axis CA of the resonator OC. The center axis CA of the resonator OC passes through the center of the projection **15**B of the p-type semiconductor layer **15** and extends in the direction perpendicular to the p-type semiconductor layer **15** (light-emitting structure layer EM). In this embodiment, the center of the projection **15**B of the p-type semiconductor layer **15** is disposed at a position corresponding to the center of the inner insulating portion **16**A in the insulating layer **16**.
[0050] Here, an exemplary configuration of each layer in the surface emitting laser **10** will be described. In this embodiment, the first reflecting mirror **12** is formed of 44 pairs of GaN layers and AlInN layers. The n-type semiconductor layer **13** has a layer thickness of 650 nm. The light-emitting layer **14** is formed of an active layer having a multiple quantum well structure in which 4 nm of InGaN layers and 5 nm of GaN layers are stacked three times. The second reflecting mirror **19** is formed of 10 pairs of Ta2O5 layers and Al2O3 layers.
[0051] The p-type semiconductor layer **15** has a layer thickness T**1** of 50 nm in the region of the projection **15**B. The p-type semiconductor layer **15** has a layer thickness of 30 nm in the region of the upper surface **15**A. The projection **15**B has an inner diameter D**1** of 3.3 μm. The projection **15**B has an outer diameter of 10 μm. The projection **15**B has a width W**1** of 3.35 μm.
[0052] The insulating layer **16** has a layer thickness of 20 nm. The upper surface of the insulating layer **16** is formed to be flush with the upper end surface of the projection **15**B of the p-type semiconductor layer **15**. Note that these are merely one example.
[0053] FIG. **3** is a drawing schematically illustrating an optical property of the resonator OC in the surface emitting laser **10**. Although FIG. **3** is a cross-sectional view similar to FIG. **1**, FIG. **3** omits hatchings. In this embodiment, the insulating layer **16** has a refractive index lower than that of the p-type semiconductor layer **15** and is formed at a height same as the upper end surface of the projection **15**B of the p-type semiconductor layer **15**. The layer thicknesses of the other layers between the first and the second reflecting mirrors **12** and **19** are each constant.
[0054] Therefore, the equivalent refractive index (an optical distance between the first and the

second reflecting mirrors **12** and **19**, a resonator length) in the resonator OC differs among the central region R**1**, the ring-shaped region R**2**, and the outer region R**3** by a difference in refractive index between the p-type semiconductor layer **15** and the insulating layer **16**.

[0055] Specifically, as illustrated in FIG. **3**, when an optical distance between the first and the second reflecting mirrors **12** and **19** in the ring-shaped region R**2** is defined as an optical distance OL**1** and an optical distance between the first and the second reflecting mirrors **12** and **19** in the central region R**1** and the outer region R**3** is defined as an optical distance OL**2**, the optical distance OL**2** is smaller than the optical distance OL**1**. That is, the equivalent resonator length in the central region R**1** and the outer region R**3** is smaller than the equivalent resonator length in the ring-shaped region R**2**.

[0056] FIG. **4** is a drawing schematically illustrating an electrical property in the resonator OC (in the light-emitting structure layer EM) of the surface emitting laser **10**. FIG. **4** is a drawing schematically illustrating currents CR flowing through the inside of the light-emitting structure layer EM. Although FIG. **4** is a cross-sectional view similar to FIG. **1**, FIG. **4** omits hatchings. In this embodiment, the ring-shaped region R**2**, which is the region of the projection **15**B, functions as the low resistance region LR, and the central region R**1** and the outer region R**3**, which are the other regions, function as the high resistance regions HR.

[0057] Therefore, as illustrated in FIG. **4**, the current CR is injected into the light-emitting layer **14** only in the ring-shaped region R**2**, and the current is hardly injected into the light-emitting layer **14** in the central region R**1**. That is, while light is generated (a gain is generated) in the ring-shaped region R**2**, light is not generated in the central region R**1**.

[0058] FIG. **5** is a drawing schematically illustrating light emitted from the surface emitting laser **10**. In this embodiment, a standing wave in the surface emitting laser **10** is taken to the outside from the first reflecting mirror **12**. Here, as illustrated in FIG. **5**, light resonated in the surface emitting laser **10** is taken to the outside while being converged at the central region R**1**. FIG. **5** schematically illustrates a beam outer edge of a laser beam LB emitted from the surface emitting laser **10** by the dashed line.

[0059] Specifically, first, in this embodiment, the refractive index of the insulating layer **16** is smaller than the refractive index of the p-type semiconductor layer **15** (projection **15**B). Accordingly, the difference in equivalent refractive index is provided between the regions R**1** to R**3** in the resonator OC. In this embodiment, the equivalent refractive index of the resonator OC (laser medium) in the outer region R**3** is smaller than the equivalent refractive index of the resonator OC in the ring-shaped region R**2**.

[0060] This suppresses an optical loss due to divergence (emission) of the standing wave in the resonator OC from the ring-shaped region R**2** to the outside. That is, a large amount of light remains in the inside of the ring-shaped region R**2**, and the laser beam LB is taken to the outside in the state. Accordingly, a large amount of light concentrates on the ring-shaped region R**2** in the resonator OC, thereby ensuring generating and emitting the laser beam LB with high output power.

[0061] In this embodiment, by providing the difference in equivalent refractive index, an optical confinement structure in the resonator OC is formed. Therefore, almost all light serves as the laser beams LB without causing deterioration of intensity. This allows highly efficiently generating and emitting the laser beam LB with high output power.

[0062] Next, in this embodiment, the low resistance region LR, that is, the current injected region to the light-emitting layer **14** is restricted to only the ring-shaped region R**2**. That is, the current is not injected into the central region R**1**, but the current injected region is disposed surrounding the non-current injected region. This allows stabilizing an eigenmode of the laser beam LB.

[0063] Specifically, considering a wavelength of the light emitted from the light-emitting layer **14**, mainly adjusting the width W**1** (see FIG. **2**) of the low resistance region LR, namely, a current injection width, allows emitting the laser beam LB in the stable eigenmode. Thus, the stable, highly intensive far-field pattern can be obtained.

[0064] FIG. **6**A is a drawing illustrating a relationship between the current injection width W**1** and the eigenmode (also referred to as a super mode) of the laser beam LB. FIG. **6**A plots the width W**1** of the low resistance region LR (namely, the projection **15**B) on the horizontal axis and the number of eigenmodes of the laser beam LB on the vertical axis. Note that FIG. **6**A illustrates a change in eigenmode of the laser beam LB relative to the width W**1**.
[0065] As illustrated in FIG. **6**A, with the current injection width W**1** of 2.3 μm or less, the eighth eigenmode appears. In other words, there are eight beam spots in the ring-shaped region R**2**, and a mode in which a phase is inverted between the adjacent spots appears (an out-of-phase mode is attained). Therefore, in the far-field pattern, the multimodal laser beam LB is observed. FIG. **6**B is a drawing illustrating the far-field pattern of the laser beam LB with the current injection width W**1** of less than 2.3 μm.
[0066] Meanwhile, with the current injection width W**1** of 2.85 μm or more, the mode enters the fundamental eigenmode. Specifically, the eight beam spots are present in the ring-shaped region R**2**, and a mode in which all the spots become in the same phase appears (an in-phase mode is attained). Therefore, the unimodal laser beam LB is emitted. FIG. **6**C is a drawing illustrating the far-field pattern of the laser beam LB with the current injection width W**1** larger than 2.85 μm.
[0067] The inventor of this application has confirmed that the eigenmode changes between the in-phase mode and the out-of-phase mode depending on the applied current value in a range of the current injection width W**1** of from 2.3 to 2.85 μm.
[0068] Thus, disposing the low resistance region LR in the ring shape and adjusting the width W**1** ensure generating the laser beam LB in the stable eigenmode, thus forming the stable far-field pattern. However, considering generating the laser beam LB in the stable transverse mode, it is only necessary to dispose the ring-shaped low resistance region LR and the high resistance region HR inside the low resistance region LR in the resonator OC.
[0069] The current injection width W**1** can be adjusted according to mainly the wavelength of the laser beam LB (that is, the light emitted from the light-emitting layer **14**) and the equivalent refractive index of the resonator OC. For example, to adjust the width W**1** considering only the emission wavelength, when the wavelength of the light emitted from the light-emitting layer **14** is defined as a wavelength λ, the current injection width W**1** only needs to be set so as to meet the relationship W**1**≥2.85×(λ/0.445) [μm] considering obtaining the unimodal laser beam LB.
[0070] Additionally, adjusting the width W**1** considering both of the emission wavelength and the equivalent refractive index allows further stabilizing the eigenmode of the laser beam LB. For example, in a case where the wavelength of the light emitted from the light-emitting layer **14** is defined as the wavelength λ, the equivalent refractive index of the ring-shaped region R**2** relative to the wavelength λ is defined as a refractive index nλ, and the equivalent refractive index of the ring-shaped region R**2** relative to a wavelength at 445 nm is defined as a refractive index n.sub.445, considering obtaining the unimodal laser beam LB, the width W**1** of a current injected region CJ only needs to be set so as to meet the relationship W**1**≥2.85×(λ/0.445)×(nλ/n.sub.445) [μm].
[0071] The inventor of this application has confirmed that the current injection width W**1** of 5.5 μm or less is preferred to obtain the laser beam LB in the stable single eigenmode. This is because, with the width W**1** of larger than 5.5 μm, when a threshold of laser oscillation was exceeded, the laser beam LB was emitted in multimode in some cases. That is, considering obtaining the unimodal laser beam LB at the wavelength λ of 445 nm, the width W**1** only needs to meet the relationship 2.85≤W**1**≤5.5 [μm]. This range only needs to be adjusted according to the emission wavelength λ and the equivalent refractive index of the ring-shaped region R**2**.
[0072] The inner diameter D**1** (see FIG. **2**) of the low resistance region LR can be set to the preferred range considering a diffusion length of carriers (electrons or electron holes) in the light-emitting layer **14**. For example, the diffusion length of carriers in the light-emitting layer **14** corresponds to a distance that the carriers move in a direction (lateral direction) parallel to the light-emitting layer **14** in the light-emitting layer **14**.

[0073] For example, in this embodiment, the region of the light-emitting layer **14** into which a current is not injected is preferably formed inside the ring-shaped region R**2**. Accordingly, when viewed in the direction perpendicular to the light-emitting layer **14**, when the low resistance region LR has the inner diameter D**1** twice or more of the diffusion length of the carriers (the electrons in this embodiment) in the light-emitting layer **14**, the region into which a current is not injected is formed in at least a part of the region of the light-emitting layer **14** inside the ring-shaped region R**2**. Therefore, when viewed in the direction perpendicular to the light-emitting layer **14**, the low resistance region LR preferably has the inner diameter D**1** twice or more of the diffusion length of carriers in the light-emitting layer **14**. That is, the width of the high resistance region HR inside the low resistance region LR is preferably twice or more of the diffusion length of the carriers in the light-emitting layer **14**.
[0074] Similarly, a layer thickness T**1** (in this embodiment, a distance from the upper end surface of the projection **15**B to the interface with the light-emitting layer **14**, see FIG. **1**) of the p-type semiconductor layer **15** can also be set to a preferred range considering the diffusion length of carriers in the light-emitting layer **14**. The layer thickness T**1** of the p-type semiconductor layer **15** is preferably twice or less of the diffusion length of carriers in the light-emitting layer **14**. This allows forming the region of the light-emitting layer **14** where the carriers (electrons) do not reach, at the inside of the ring-shaped region R**2**.
[0075] In this embodiment, the ring-shaped region R**2** is the low resistance region LR and the high refractive index region. Therefore, not only the most injected current can be used to generate the laser beam LB, but also the loss of the laser beam LB in the central region R**1** or the outer region R**3** due to the difference in refractive index can be substantially suppressed. Therefore, the laser beam LB in the stable transverse mode with high output power can be generated at a low threshold and high efficiency. Additionally, since a current does not flow through the central region R**1**, heat generation in the central region R**1** can be suppressed, and an operation at a high temperature is possible.
[0076] In this embodiment, the case where the ring-shaped region R**2** is the high refractive index region and the central region R**1** and the outer region R**3** are the low refractive index regions has been described. That is, the case where the boundary between the low resistance region LR and the high resistance region HR is disposed at the position matched with the boundary between the high refractive index region and the low refractive index region has been described. However, configurations of the central region R**1**, the ring-shaped region R**2**, and the outer region R**3** are not limited to these.
[0077] Considering obtaining the laser beam LB in the stable transverse mode, it is only necessary to dispose the ring-shaped low resistance region LR and the high resistance region HR inside the low resistance region LR between the first and the second reflecting mirrors **12** and **19**. For example, the boundary between the high refractive index region and the low refractive index region may be disposed at a position different from the boundary between the central region R**1** and the ring-shaped region R**2**.
[0078] In this embodiment, the case where the p-type semiconductor layer **15** includes the projection **15**B and the projection **15**B contacts the light-transmitting electrode layer **17** to function as the low resistance region LR has been described. However, it is only necessary that the light-emitting structure layer EM includes the ring-shaped low resistance region LR. For example, the n-type semiconductor layer **13** may include a projection similar to the projection **15**B. That is, the low resistance region LR and the high resistance region HR may be disposed in the n-type semiconductor layer **13**.
[0079] Additionally, in this embodiment, the case where the low resistance region LR, namely, the projection **15**B of the p-type semiconductor layer **15** is formed in the circular ring shape has been described. However, the configuration of the low resistance region LR is not limited to this.
[0080] FIG. **7**A is a schematic top view of a surface emitting laser **10**A according to Modification 1

of this embodiment. Except for a configuration of a light-emitting structure layer EMA, the surface emitting laser **10**A has a configuration similar to that of the surface emitting laser **10**. Except for a configuration of a p-type semiconductor layer **15**M**1**, the light-emitting structure layer EMA has a configuration similar to that of the light-emitting structure layer EM.

[0081] In the light-emitting structure layer EMA, the p-type semiconductor layer **15**M**1** includes a projection **15**B**1** having an ellipsoidal ring shape (track shape). That is, in this modification, the ring-shaped region R**2** having the ellipsoidal ring shape (the low resistance region LR and the high refractive index region) is formed. In the case where the ring-shaped region R**2** is thus formed as well, for example, by adjusting the width of the projection **15**B**1**, the eigenmode of the laser beam LB is stabilized. Therefore, for example, the far-field pattern of the unimodal laser beam LB can be obtained. The laser beam LB having a low emission angle and a high intensity can be obtained.

[0082] FIG. **7**B is a schematic top view of a surface emitting laser **10**B according to Modification 2 of this embodiment. Except for a configuration of a light-emitting structure layer EMB, the surface emitting laser **10**B has a configuration similar to that of the surface emitting laser **10**. Except for a configuration of a p-type semiconductor layer **15**M**2**, the light-emitting structure layer EMB has a configuration similar to that of the light-emitting structure layer EM.

[0083] In the light-emitting structure layer EMB, the p-type semiconductor layer **15**M**2** includes a projection **15**B**2** having a rectangular ring shape. That is, in this modification, the ring-shaped region R**2** (the low resistance region LR and the high refractive index region) having the rectangular ring shape is formed. In the case where the ring-shaped region R**2** is thus formed as well, for example, by adjusting the width of the projection **15**B**2**, the eigenmode of the laser beam LB is stabilized. Therefore, for example, the far-field pattern of the unimodal laser beam LB having the low emission angle and high intensity can be obtained.

[0084] FIG. **7**C is a schematic top view of a surface emitting laser **10**C according to Modification 3 of this embodiment. Except for a configuration of a light-emitting structure layer EMC, the surface emitting laser **10**C has a configuration similar to that of the surface emitting laser **10**. Except for a configuration of a p-type semiconductor layer **15**M**3**, the light-emitting structure layer EMC has a configuration similar to that of the light-emitting structure layer EM.

[0085] In the light-emitting structure layer EMC, the p-type semiconductor layer **15**M**3** includes a ring-shaped projection **15**B**3** so as to surround a cross. That is, in this modification, the ring-shaped region R**2** (the low resistance regions LR and the high refractive index region) surrounding the cross is formed. In the case where the ring-shaped region R**2** is thus formed as well, for example, by adjusting the width of the projection **15**B**3**, the eigenmode of the laser beam LB is stabilized. Therefore, for example, the far-field pattern of the unimodal laser beam LB having the low emission angle and high intensity can be obtained.

[0086] Thus, in this embodiment, disposing the ring-shaped low resistance region LR in the resonator OC stabilizes the eigenmode of the light that appears in the ring-shaped region R**2**. Accordingly, for example, the laser beam LB in the single eigenmode (for example, see FIG. **6**C) is obtained, and the laser beam LB as a collection of lights in a plurality of eigenmodes (for example, see FIG. **6**B) is obtained. Accordingly, for example, as illustrated in FIG. **7**A to FIG. **7**C, the low resistance region LR can have various kinds of configurations.

[0087] In this embodiment, the case where the low resistance region LR is formed in the light-emitting structure layer EM with the p-type semiconductor layer **15** and the insulating layer **16** has been described. However, the configuration of the low resistance region LR is not limited to this. For example, the regions other than the ring-shaped region may be set in the high resistance on the upper surface of the p-type semiconductor layer **15** to form the low resistance region LR.

[0088] As described above, in this embodiment, the surface emitting laser **10** includes the substrate **11**, the first reflecting mirror **12** formed on the substrate **11**, the light-emitting structure layer EM formed on the first reflecting mirror **12** and including the light-emitting layer **14**, and the second reflecting mirror **19** formed on the light-emitting structure layer EM. The resonator OC is constituted between the second reflecting mirror **19** and the first reflecting mirror **12**. Additionally, the light-emitting structure layer EM includes: the low resistance region LR formed in the ring shape between the first and the second reflecting mirrors **12** and **19**, and the high resistance region HR that is disposed inside the low resistance region LR and has the electrical resistance higher than that of the low resistance region LR. This allows providing the surface emitting laser **10** configured to emit the light in the stable transverse mode.

Embodiment 2

[0089] FIG. **8** is a cross-sectional view of a surface emitting laser **20** according to Embodiment 2. Except for configurations of a light-emitting structure layer EM**1** and the low resistance region LR, the surface emitting laser **20** has a configuration similar to that of the surface emitting laser **10**.

[0090] The light-emitting structure layer EM**1** includes a p-type semiconductor layer (second semiconductor layer) **21** including an ion implanted region **21**A into which ions have been implanted with the ring-shaped region left. For example, the ion implanted region **21**A is a region of the upper surface of the p-type semiconductor layer **21** into which B ions, Al ions, or oxygen ions have been implanted.

[0091] In the ion implanted region **21**A, p-type impurities are inactivated. That is, the ion implanted region **21**A functions as the high resistance region HR. In the ion implanted region **21**A, implantation of ions changes the refractive index.

[0092] In this embodiment, a region **21**B of the p-type semiconductor layer **21** other than the ion implanted region **21**A is a non-ion implanted region formed in a ring shape where ion implantation is not performed. Therefore, in this embodiment, the non-ion implanted region **21**B functions as the low resistance region LR and forms the ring-shaped region R**2**.

[0093] As in this embodiment, differences can be provided in electrical resistance and refractive index by whether to perform ion implantation. Therefore, the low resistance region LR can be disposed in the light-emitting structure layer EM. This allows providing the surface emitting laser **20** configured to emit the light in the stable transverse mode.

Embodiment 3

[0094] FIG. **9** is a cross-sectional view of a surface emitting laser **30** according to Embodiment 3. Except that the surface emitting laser **30** includes an insulating layer (second insulating layer) **31** formed between the light-emitting structure layer EM**1** and the second reflecting mirror **19** and having different refractive indexes between regions, the surface emitting laser **30** has a configuration similar to that of the surface emitting laser **20**.

[0095] In the surface emitting laser **30**, the insulating layer **31** includes a high refractive index insulating layer **32** formed on the light-transmitting electrode layer **17** and including a projection **32**A on a non-ion implanted region **21**B, and a low refractive index insulating layer **33** formed on the high refractive index insulating layer **32** while exposing the projection **32**A and having a refractive index lower than that of the high refractive index insulating layer **32**. For example, the high refractive index insulating layer **32** is made of Nb.sub.2O.sub.5. For example, the low refractive index insulating layer **33** is made of SiO.sub.2.

[0096] In this embodiment, in addition to the inside of the light-emitting structure layer EM**1**, the insulating layer **31**, which is formed outside the light-emitting structure layer EM**1**, provides the difference in refractive index between the central region R**1**, the ring-shaped region R**2**, and the outer region R**3**. Accordingly, for example, the low resistance region LR and the high resistance region HR can be preferentially and reliably defined by the light-emitting structure layer EM**1**, and the low refractive index region and the high refractive index region can be defined and reinforced by the insulating layer **31**. This allows providing the surface emitting laser **30** configured to emit the light in the stable transverse mode.

Embodiment 4

[0097] FIG. **10** is a cross-sectional view of a surface emitting laser **40** according to Embodiment 4. Except for configurations of a light-emitting structure layer EM**2** and the low resistance region LR, the surface emitting laser **40** has a configuration similar to that of the surface emitting laser **10**.

[0098] In the surface emitting laser **40**, the light-emitting structure layer EM**2** includes a p-type semiconductor layer **41** including etched portion **41**A on which dry etching was performed with a ring-shaped region left. The ring-shaped upper surface region on which etching is not performed in the p-type semiconductor layer **41** becomes a projection **41**B.

[0099] A surface of the semiconductor, such as the p-type semiconductor layer **41**, containing impurities is roughened by dry etching. This inactivates the p-type impurities in the etched portion **41**A. That is, the p-type semiconductor layer **41** includes inactivated region **41**C where the p-type impurities are inactivated in the regions of the etched portion **41**A. Therefore, the inactivated region **41**C functions as the high resistance regions HR.

[0100] In this embodiment, in the etched portion **41**A, the p-type semiconductor layer **41** is partially removed. Therefore, the region other than the etched portion **41**A becomes the projection **41**B projected from the etched portion **41**A. In the etched portion **41**A, a contact layer, which is generally disposed at an interface with a metal in a semiconductor layer, is removed. Therefore, for example, even when the insulating layer **16** is not disposed as in Embodiment 1, the etched portion **41**A is sufficiently set in the high resistance.

[0101] Accordingly, first, a current is injected into the light-emitting structure layer EM**2** only from the projection **41**B. The layer thickness of the p-type semiconductor layer **41** differs between the etched portion **41**A and the projection **41**B. This allows providing a difference in the equivalent refractive index of the resonator OC, that is, the optical distance in the resonator OC.

[0102] Note that, considering disposing the low resistance region LR, the p-type semiconductor layer **41** only needs to selectively include the inactivated regions **41**C. Therefore, the p-type semiconductor layer **41** is not limited to the case of including the etched portions **41**A on which dry etching was performed. For example, the inactivated regions **41**C may be formed by ion implantation, or the inactivated regions **41**C may be formed by an ashing process.

[0103] In this embodiment, the p-type semiconductor layer (second semiconductor layer) **41** in the light-emitting structure layer EM**2** includes the inactivated regions **41**C where the p-type impurities are inactivated with the ring-shaped region left. Then, the projection **41**B of the p-type semiconductor layer **41** where impurities are not inactivated functions as the low resistance region LR.

[0104] Thus, for example, selectively performing etching to partially inactivate the p-type semiconductor layer **41** also allows providing the differences in electrical resistance and refractive index. This allows providing the low resistance region LR in the light-emitting structure layer EM. This allows providing the surface emitting laser **40** configured to emit the light in the stable transverse mode.

Embodiment 5

[0105] FIG. **11** is a cross-sectional view of a surface emitting laser **50** according to Embodiment 5. Except for configurations of a light-emitting structure layer EM**3** and the low resistance region LR, the surface emitting laser **50** has a configuration similar to that of the surface emitting laser **10**.

[0106] In the surface emitting laser **50**, the light-emitting structure layer EM**3** includes a tunnel junction layer **51** disposed in a ring shape on the projection **15**B of the p-type semiconductor layer **15** and an n-type semiconductor layer (a second n-type semiconductor layer or a third semiconductor layer) **52** disposed on the tunnel junction layer **51**. The light-emitting structure layer EM**3** includes an n-type semiconductor layer (a third n-type semiconductor layer or a fourth semiconductor layer) **53** that surrounds the side surfaces of the tunnel junction layer **51** and the n-type semiconductor layer **52** and has a refractive index lower than those of the tunnel junction layer **51** and the n-type semiconductor layer **52**.

[0107] The tunnel junction layer **51** includes a high-doped p-type semiconductor layer (not illustrated) formed on the p-type semiconductor layer **15** and having an impurity concentration higher than that of the p-type semiconductor layer (second semiconductor layer) **15** and a high-

doped n-type semiconductor layer (not illustrated) formed on the high-doped p-type semiconductor layer and having an impurity concentration higher than that of the n-type semiconductor layer (the first n-type semiconductor layer or the first semiconductor layer) **13**.
[0108] In this embodiment, the n-type semiconductor layer **53** contains Ge as n-type impurities. Accordingly, the n-type semiconductor layer **53** has a refractive index lower than the average refractive index of the n-type semiconductor layer **52**, the tunnel junction layer **51**, and the projection **15**B of the p-type semiconductor layer **15**.
[0109] Therefore, in this embodiment, the tunnel junction layer **51** functions as the low resistance region LR. In this embodiment, namely, the light-emitting structure layer EM**3** includes the tunnel junction layer **51** formed in the ring shape on the p-type semiconductor layer **15** (second semiconductor layer) and functioning as the low resistance region LR. The n-type semiconductor layer **53** defines the central region R**1** and the outer region R**3**.
[0110] As in this embodiment, current confinement is performed by tunnel junction or the region is disposed in the ring shape to ensure forming the low resistance region LR in the light-emitting structure layer EM**3**. Decreasing the refractive index at the regions other than the low resistance region LR allows defining the central region R**1**, the ring-shaped region R**2**, and the outer region R**3**. This allows providing the surface emitting laser **50** configured to emit the light in the stable transverse mode.
[0111] The above-described embodiments are merely one example. For example, the above-described various kinds of embodiments can be combined. For example, the surface emitting laser **10** may include the insulating layer **31** similar to that of the surface emitting laser **30**. For example, the surface emitting laser **40** may include the insulating layer **16** on the inactivated region **41**C.
[0112] As described above, for example, in the surface emitting laser **10**, the light-emitting structure layer EM includes the low resistance region (current injected region CJ) disposed in the ring shape between the first and the second reflecting mirrors **12** and **19**. This allows providing the surface emitting laser **10** (vertical cavity surface emitting device) configured to emit the light in the stable transverse mode.
DESCRIPTION OF REFERENCE SIGNS
[0113] **10**, **10**A, **10**B, **10**C, **20**, **30**, **40**, **50** Surface emitting laser (vertical cavity surface emitting device) [0114] EM, EMA, EMB, EMC, EM**1**, EM**2**, EM**3** Light-emitting structure layer [0115] **14** Light-emitting layer [0116] LR Low resistance region

Claims

1. A vertical cavity surface emitting device comprising: a substrate; a first multilayer film reflecting mirror formed on the substrate; a light-emitting structure layer that is formed on the first multilayer film reflecting mirror and that includes a first semiconductor layer, a light-emitting layer, and a second semiconductor layer, the first semiconductor layer being formed on the first multilayer film reflecting mirror, the light-emitting layer being formed on the first semiconductor layer, and the second semiconductor layer being formed on the light-emitting layer and having a conductivity type opposite to a conductivity type of the first semiconductor layer; and a second multilayer film reflecting mirror formed on the light-emitting structure layer, a resonator being constituted between the second multilayer film reflecting mirror and the first multilayer film reflecting mirror, wherein: the second semiconductor layer includes an upper surface and a projection, the projection projecting from the upper surface in a ring shape, the light-emitting structure layer includes a low resistance region and high resistance regions, the low resistance region being formed corresponding to the projection, and the high resistance regions being formed inside and outside the low resistance region and having electrical resistances higher than an electrical resistance of the low resistance region, the resonator includes a ring-shaped region, a central region, and an outer region, the ring-shaped region corresponding to the low resistance region of the light-emitting structure layer and extending between the first and the second multilayer film reflecting mirrors, the central region being disposed corresponding to the high resistance region inside the ring-shaped region, and the outer region being disposed outside the ring-shaped region, the central region and the outer region have equivalent refractive indexes lower than an equivalent refractive index of the ring-shaped region, and a width of the low resistance region corresponding to the projection is set such that a far-field pattern of a laser beam emitted from the vertical cavity surface emitting device is unimodal.

2. The vertical cavity surface emitting device according to claim 1, wherein the light-emitting structure layer includes a plurality of semiconductor layers made of nitride semiconductor.

3. The vertical cavity surface emitting device according to claim 1, further comprising an insulating layer having a refractive index lower than a refractive index of the second semiconductor layer, the insulating layer being formed on the upper surface of the second semiconductor layer inside and outside the low resistance region.
