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(54) **MANUFACTURING METHOD FOR VERTICAL CAVITY SURFACE EMITTING LASER**

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(52) **U.S. Cl.**

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(57) **ABSTRACT**

A manufacturing method for a vertical cavity surface emitting laser includes steps of forming, on a substrate, a multilayer body including first and second Distributed Bragg Reflector layers, an active layer, and a to-be-oxidized layer becoming a current constriction structure, processing the multilayer body such that a lateral surface of at least the to-be-oxidized layer is exposed, and forming a current constriction structure by oxidizing the to-be-oxidized layer from the lateral surface thereof after the multilayer body has been processed. The step of forming the current constriction structure includes steps of holding the substrate to be positioned along a uniformly-heated plate that is placed on a heat conduction member, and to be spaced from the uniformly-heated plate, and heating the substrate by radiant heat from the uniformly-heated plate by heating the heat conduction member.

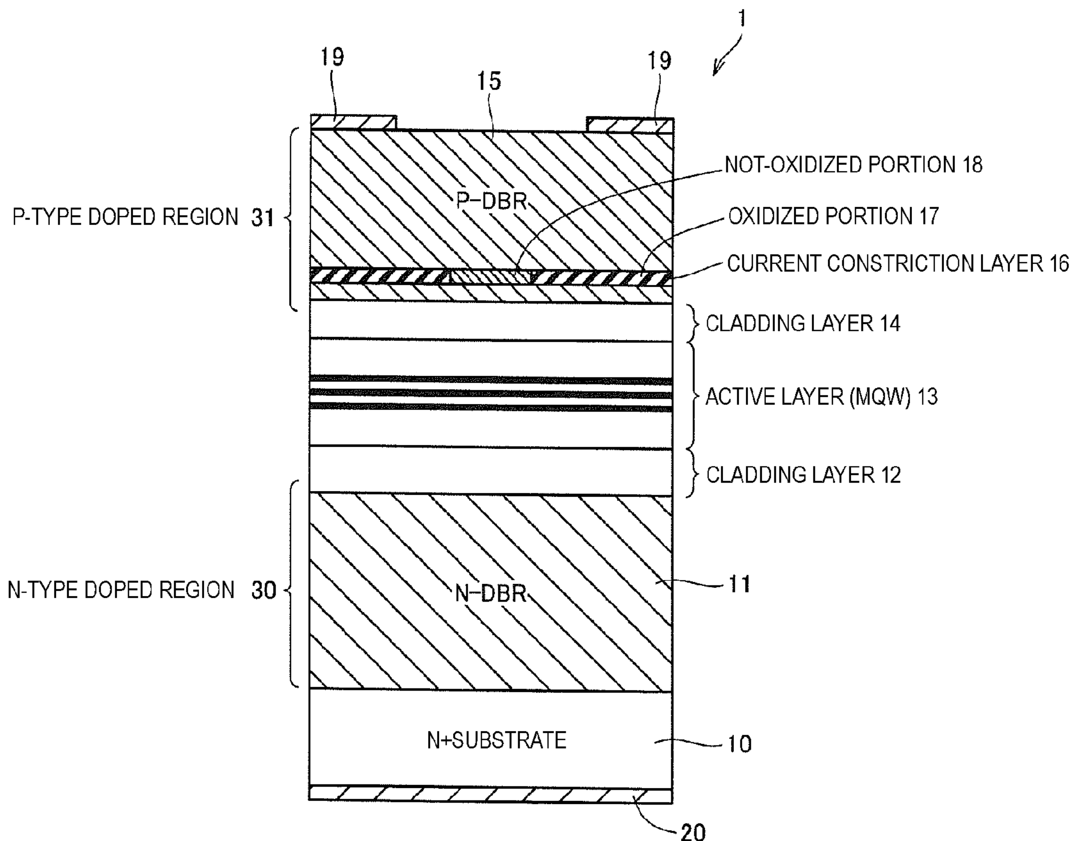
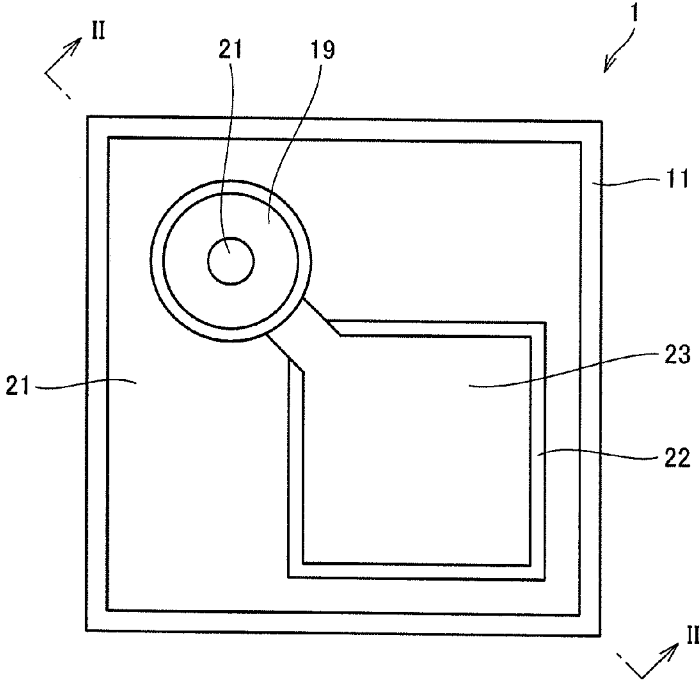


FIG.1



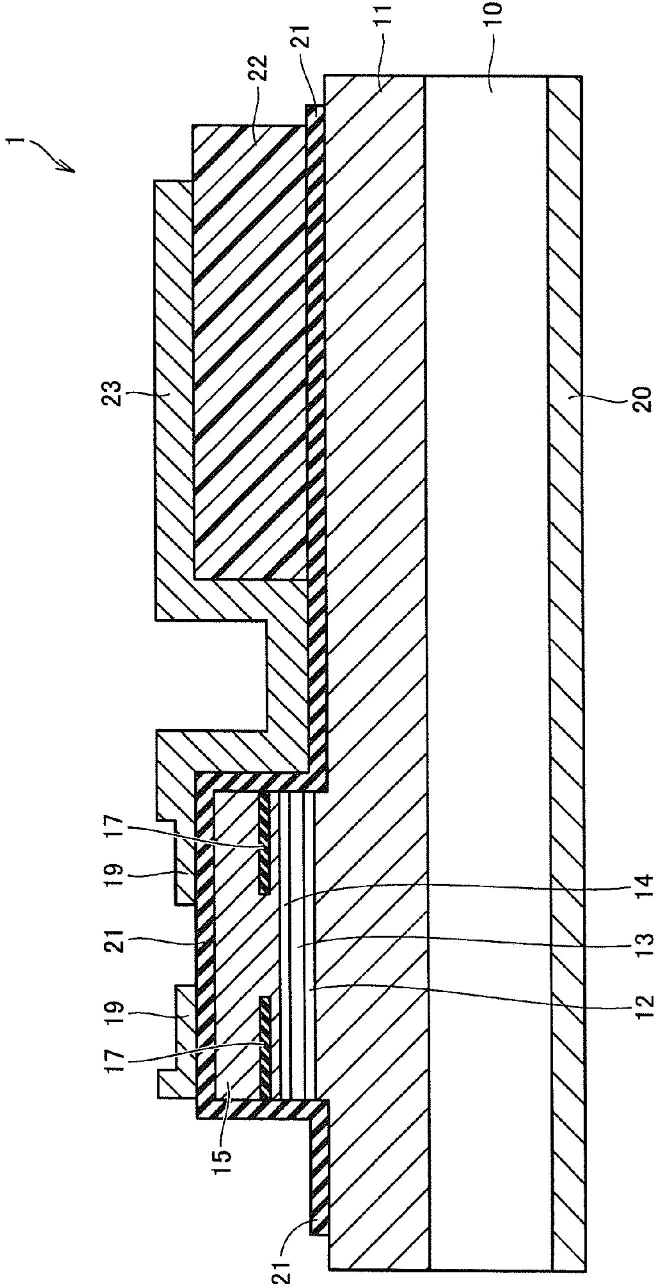


FIG.2

FIG.3

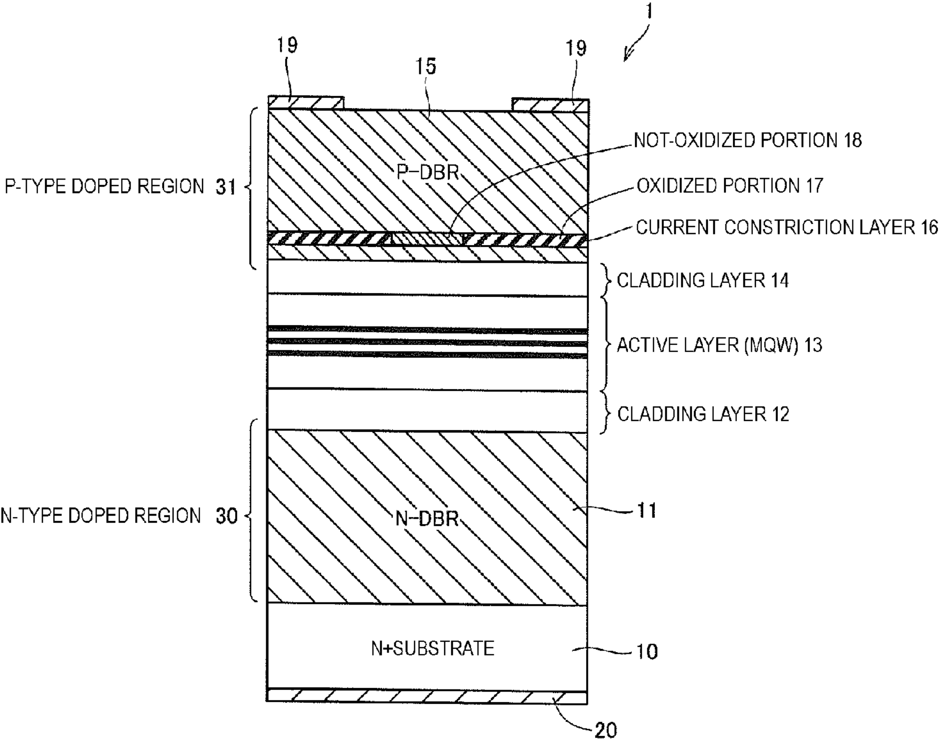


FIG.4

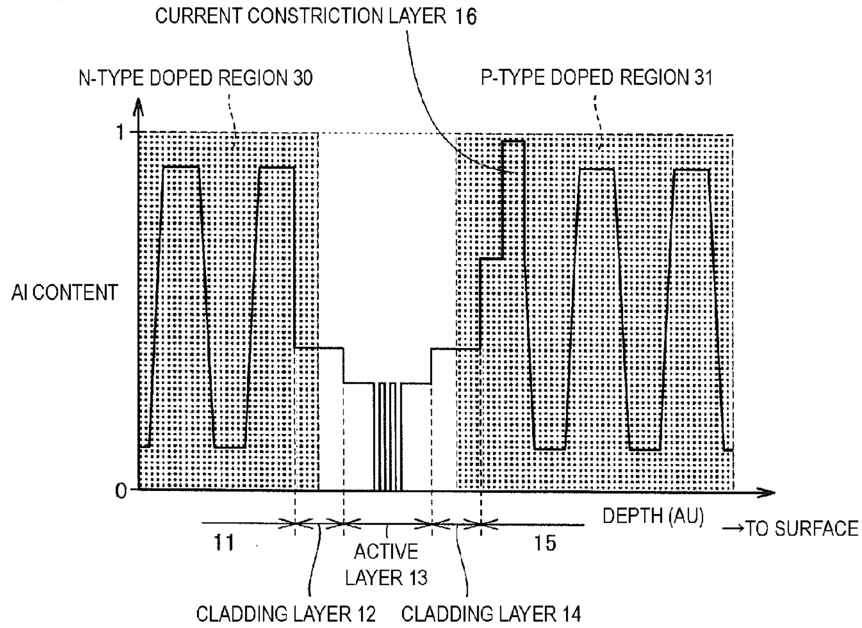


FIG.5

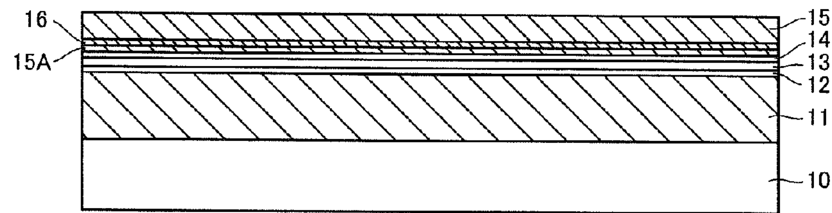


FIG.6

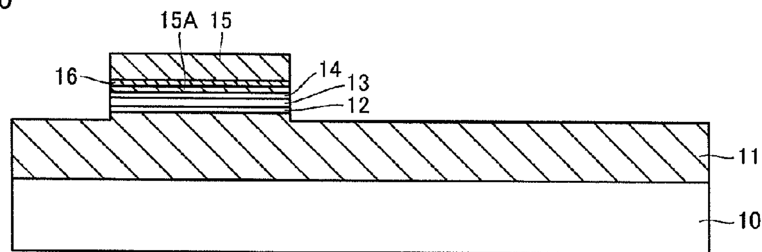


FIG.7

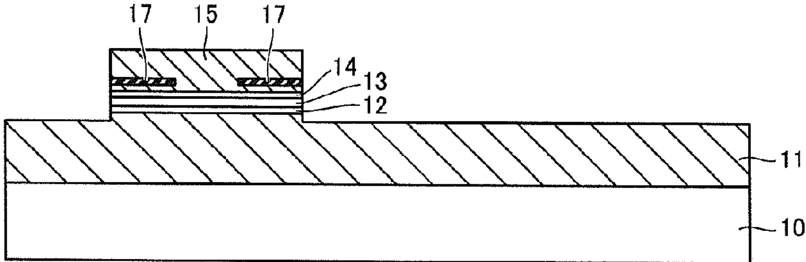


FIG.8

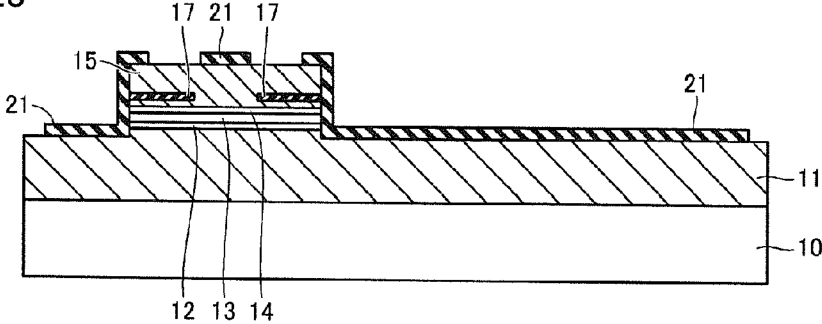


FIG.9

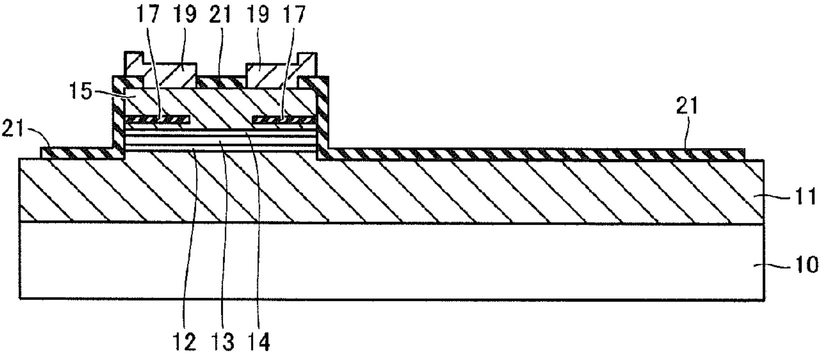


FIG.10

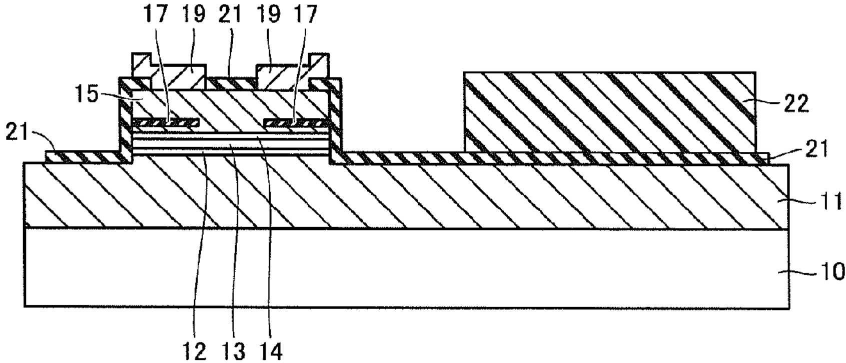
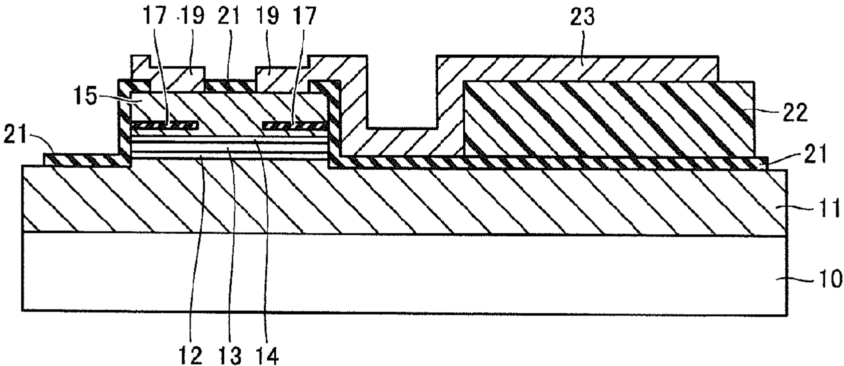


FIG.11



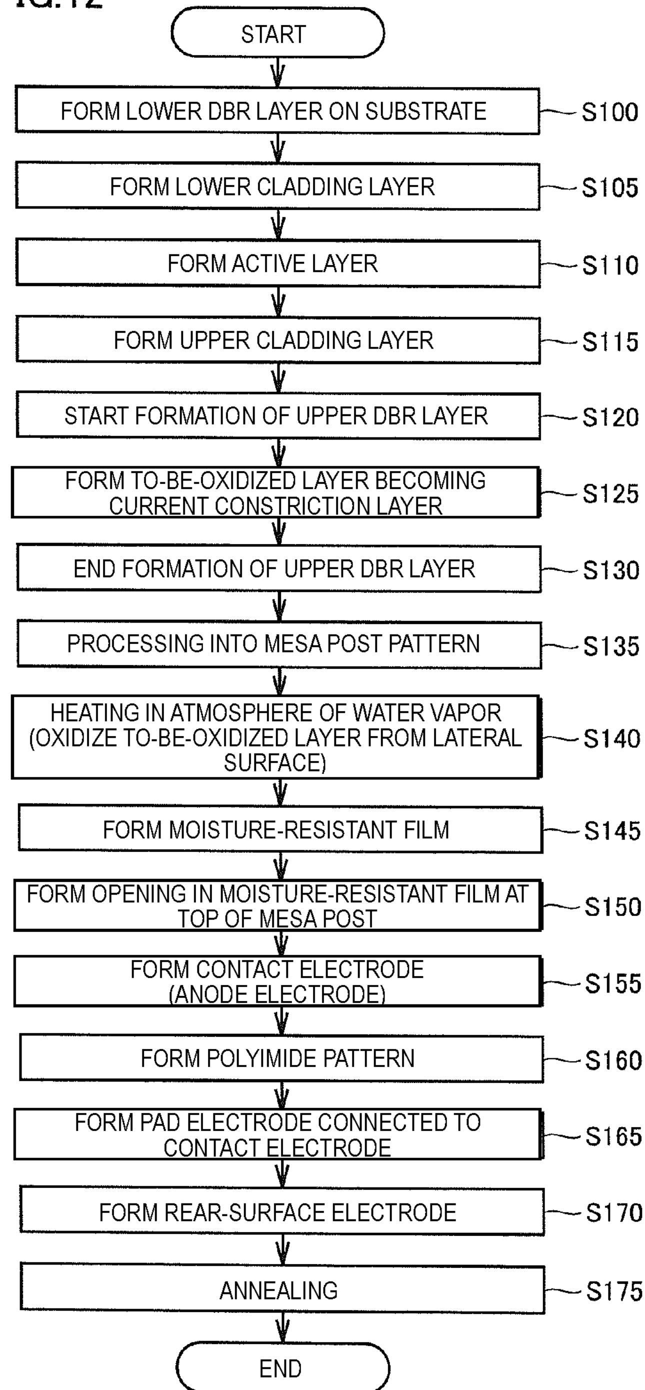


FIG.12
START
FORM LOWER DBR LAYER ON SUBSTRATE
S100
FORM LOWER CLADDING LAYER
S105
FORM ACTIVE LAYER
S110
FORM UPPER CLADDING LAYER
S115
START FORMATION OF UPPER DBR LAYER
S120
FORM TO-BE-OXIDIZED LAYER BECOMING CURRENT CONSTRICTION LAYER
S125
END FORMATION OF UPPER DBR LAYER
S130
PROCESSING INTO MESA POST PATTERN
S135
HEATING IN ATMOSPHERE OF WATER VAPOR (OXIDIZE TO-BE-OXIDIZED LAYER FROM LATERAL SURFACE)
S140
FORM MOISTURE-RESISTANT FILM
S145
FORM OPENING IN MOISTURE-RESISTANT FILM AT TOP OF MESA POST
S150
FORM CONTACT ELECTRODE (ANODE ELECTRODE)
S155
FORM POLYIMIDE PATTERN
S160
FORM PAD ELECTRODE CONNECTED TO CONTACT ELECTRODE
S165
FORM REAR-SURFACE ELECTRODE
S170
ANNEALING
S175
END

FIG.13

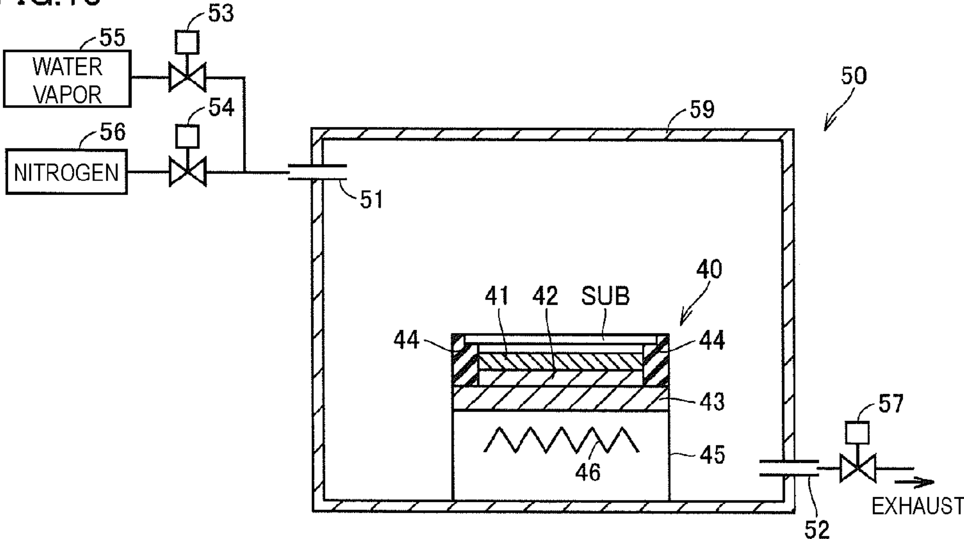


FIG.14

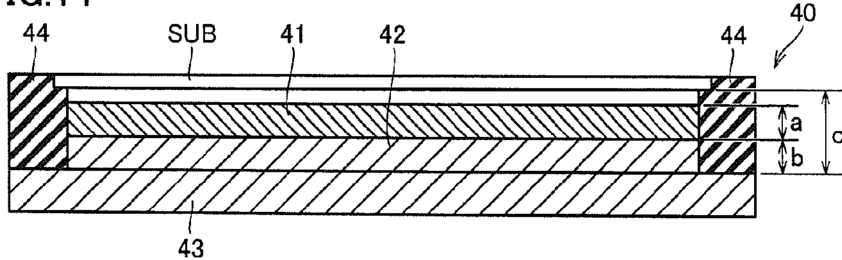
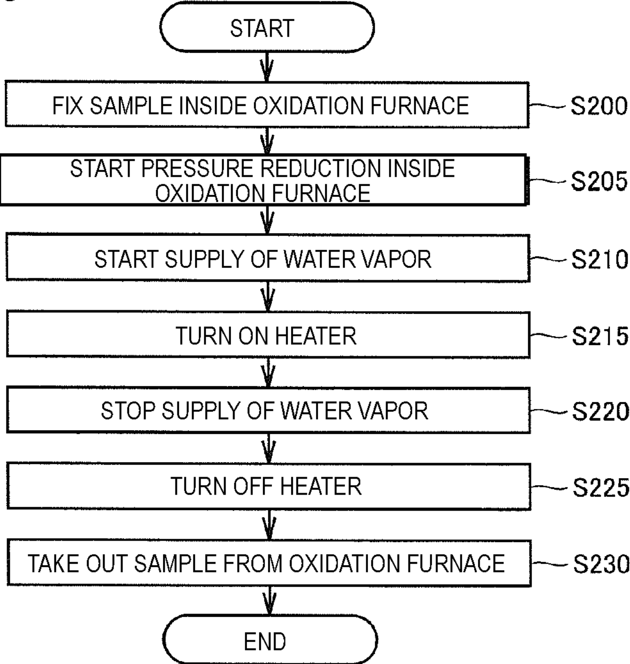


FIG.15



MANUFACTURING METHOD FOR VERTICAL CAVITY SURFACE EMITTING LASER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of priority to Japanese Patent Application 2013-191860 filed Sep. 17, 2013, and to International Patent Application No. PCT/JP2014/066114 filed Jun. 18, 2014, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to a manufacturing method for a vertical cavity surface emitting laser.

BACKGROUND

[0003] A vertical cavity surface emitting laser (VCSEL) is a laser device in which an optical resonator is formed in a direction vertical to a substrate surface and a laser beam is output in the direction vertical to the substrate surface. Usually, a current constriction structure is formed in the VCSEL to concentrate a current to a light emitting region.

[0004] In many cases, a cavity structure formed by oxidizing the outer peripheral side of an AlAs (aluminum arsenic) layer is utilized as the current constriction structure. More specifically, the AlAs layer is oxidized by holding, in water vapor heated to 400 to 500° C., a substrate on which a multilayer body (oxidation object) processed into a mesa-like shape such that the AlAs layer is exposed at a lateral surface of the multilayer body. In that case, a temperature distribution inside the substrate is desirably within ±1° C.

[0005] A method disclosed in Japanese Unexamined Patent Application Publication No. 2011-18876 is known as a process for making the temperature distribution inside the substrate more uniform. According to the method disclosed in Japanese Unexamined Patent Application Publication No. 2011-18876, an upper surface of a radiation plate on which the substrate is placed is processed into a spherical shape corresponding to a warp of the substrate on which the oxidation object is formed, the warp being caused during thermal oxidation.

SUMMARY

Technical Problem

[0006] The method disclosed in Japanese Unexamined Patent Application Publication No. 2011-18876 has the following problem. Because a warp amount of the substrate is different depending on the substrate temperature, it is difficult to accurately grasp the warp amount during the thermal oxidation. Because the warp amount of the substrate is further different depending on the structure and the growth conditions of an epitaxial film that is formed on the substrate, the warp amount takes a different value per product type (model number). Therefore, the radiation plate having an upper surface with a different curvature needs to be prepared per product type in order to implement the method disclosed in Japanese Unexamined Patent Application Publication No. 2011-18876. Thus, the disclosed method is not easy to put it into practice.

[0007] Inherently, the warp amount of the substrate is about 20 μm. Accordingly, when the substrate is heated by radiant heat in a state where a space of about several hundred microns is held between the radiation plate and the substrate, the warp amount of the substrate is substantially a negligible value, and there is no need of processing the upper surface of the radiation plate into a spherical surface.

[0008] The inventors of the present disclosure have found that the problem with the case of heating the substrate by radiant heat from the radiation plate with the space held between the radiation plate and the substrate is a temperature distribution of the radiation plate because a temperature distribution of the substrate directly reflects the temperature distribution of the radiation plate. In other words, the radiation plate is usually heated by electrically-heated wires that are disposed inside a heater device, and an appreciable temperature distribution is generated in the radiation plate depending on the layout of the electrically-heated wires. However, the temperature distribution of the radiation plate is not at all taken into consideration in Japanese Unexamined Patent Application Publication No. 2011-18876.

[0009] The present disclosure has been made in consideration of the above-described problem, and an object of the present disclosure is to make a temperature distribution inside a substrate more uniform than in prior art when a current constriction layer is formed by a thermal oxidation method in manufacturing a vertical cavity surface emitting laser.

Solution to Problem

[0010] According to one aspect of the present disclosure, there is provided a manufacturing method for a vertical cavity surface emitting laser, the method including steps of forming, on a substrate, a multilayer body including first and second Distributed Bragg Reflector layers, an active layer, and a to-be-oxidized layer becoming a current constriction structure, processing the multilayer body into a mesa shape such that a lateral surface of at least the to-be-oxidized layer is exposed, and forming the current constriction structure by oxidizing the to-be-oxidized layer from the lateral surface thereof after the multilayer body has been processed into the mesa shape. The step of forming the current constriction structure includes steps of holding the substrate to be positioned along a uniformly-heated plate that is placed on a heat conduction member, and to be spaced from the uniformly-heated plate, and heating the substrate by radiant heat from the uniformly-heated plate by heating the heat conduction member.

[0011] With the manufacturing method described above, a temperature distribution of the heat conduction member is made more uniform by the uniformly-heated plate, the oxidation can be performed in a state where temperature of the substrate in a planar direction has higher uniformity.

[0012] Preferably, the uniformly-heated plate is made of an anisotropic material having a larger thermal conductivity in a planar direction than in a vertical direction. By employing the uniformly-heated plate made of the above-mentioned anisotropic material, a non-uniform temperature distribution within the uniformly-heated plate can be effectively suppressed even when a non-uniform temperature distribution occurs within the heat conduction member.

[0013] Preferably, a material of the uniformly-heated plate is Pyrolytic Graphite. The Pyrolytic Graphite has the above-mentioned anisotropy in thermal conductivity.

[0014] Preferably, the step of holding the substrate includes a step of supporting a peripheral edge portion of the substrate by a spacer that is attached to the heat conduction member. In

this case, preferably, a thermal conductivity of the spacer is smaller than the thermal conductivity of the uniformly-heated plate in the vertical direction. With that feature, the substrate can be suppressed from being heated through thermal conduction via the spacer.

[0015] Preferably, the heat conduction member and the uniformly-heated plate are disposed within an oxidation furnace. The step of heating the substrate is executed in a state that pressure in the oxidation furnace is reduced. By heating the substrate under the reduced pressure, the substrate can be suppressed from being heated through thermal conduction via gas, and the substrate is mainly heated by radiant heat from the uniformly-heated plate. As a result, uniformity of the substrate temperature can be further increased.

Advantageous Effects of Disclosure

[0016] According to the present disclosure, when the current constriction layer is formed by a thermal oxidation method in manufacturing the vertical cavity surface emitting laser, a temperature distribution inside the substrate can be made more uniform than in prior art.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** is a plan view schematically illustrating a configuration of a VCSEL.

[0018] FIG. **2** schematically illustrates a sectional structure taken along a line II-II in FIG. **1**.

[0019] FIG. **3** is an enlarged view of a part of FIG. **2**.

[0020] FIG. **4** is a graph depicting a distribution of Al compositions in individual layers of FIG. **3**.

[0021] FIG. **5** is a sectional view schematically illustrating a multilayer epitaxial film in a process of fabricating the VCSEL.

[0022] FIG. **6** is a sectional view schematically illustrating formation of a mesa post structure in the process of fabricating the VCSEL.

[0023] FIG. **7** is a sectional view schematically illustrating oxidation of an outer peripheral portion of a current constriction layer in the process of fabricating the VCSEL.

[0024] FIG. **8** is a sectional view schematically illustrating formation of a moisture resistant film in the process of fabricating the VCSEL.

[0025] FIG. **9** is a sectional view schematically illustrating formation of a contact electrode in the process of fabricating the VCSEL.

[0026] FIG. **10** is a sectional view schematically illustrating formation of a polyimide pattern in the process of fabricating the VCSEL.

[0027] FIG. **11** is a sectional view schematically illustrating formation of a pad electrode in the process of fabricating the VCSEL.

[0028] FIG. **12** is a flowchart representing the process of fabricating the VCSEL.

[0029] FIG. **13** is a sectional view schematically illustrating a configuration of an oxidation furnace.

[0030] FIG. **14** is an enlarged sectional view schematically illustrating a principal part of a substrate heating mechanism **40** illustrated in FIG. **13**.

[0031] FIG. **15** is a flowchart representing procedures of a heated water-vapor oxidation step (step S**140** in FIG. **12**).

DETAILED DESCRIPTION

[0032] An embodiment will be described in detail below with reference to the drawings. In the following, a configuration of a VCSEL and a method of manufacturing the VCSEL are first described, and a method of heating a substrate, i.e., a feature of the present disclosure, is then described in detail. It is to be noted that the same or corresponding components are denoted by the same reference signs, and that description of those components is not repeated in some cases.

Configuration of VCSEL

[0033] FIG. **1** is a plan view schematically illustrating a configuration of a VCSEL. FIG. **2** schematically illustrates a sectional structure taken along a line II-II in FIG. **1**. FIG. **3** is an enlarged view of a part of FIG. **2**. It is to be noted that FIGS. **2** and **3** are schematic sectional views, and that thicknesses of individual layers in the drawings are not in proportion to those of the corresponding layers in an actual device.

[0034] Referring to FIGS. **1** to **3**, the VCSEL **1** includes a substrate **10**, Distributed Bragg Reflector (DBR) layers **11** and **15**, cladding layers **12** and **14**, an active layer **13**, and a current constriction layer **16** disposed within the DBR layer **15**, an anode electrode layer **19**, and a cathode electrode layer **20**.

[0035] In this embodiment, a GaAs (gallium arsenic) semiconductor substrate exhibiting the conductivity type N is used as the substrate **10**. The cathode electrode layer (rear surface electrode layer) **20** is formed on a rear surface of the substrate **10**. Unlike the case illustrated in FIGS. **1** to **3**, a non-doped GaAs substrate exhibiting a semi-insulating property may also be used as the substrate **10**. In such a case, the cathode electrode layer **20** is formed on a surface of the DBR layer **11**.

[0036] The Distributed Bragg Reflector (DBR) layer **11** constituted by a compound semiconductor exhibiting the conductivity type N is formed on the substrate **10**. The DBR layer **11** includes a structure formed by alternately laminating, e.g., $Al_{0.15}Ga_{0.85}As$ and $Al_{0.9}Ga_{0.1}As$ in an optical film thickness of $\lambda/4$ (X denotes a wavelength) per layer. The DBR layer **11** is doped with Si (silicon) to exhibit the conductivity type N, and a concentration of the doped Si is, e.g., 2 to 3×10^{18} cm^{-3}. Si tends to be coordinated at a Ga (Al) site and to become a donor.

[0037] $Al_xGa_{(1-x)}As$ (aluminum gallium arsenic) is a mixed crystal semiconductor of GaAs and AlAs, and it exhibits a wider energy gap and a lower refractive index as an Al composition (X) increases. Because the lattice constant hardly changes depending on the Al composition (X), an $Al_xGa_{(1-x)}As$ film having any Al composition (X) can be epitaxially grown on a GaAs substrate. In this Description, $Al_xGa_{(1-x)}As$ is simply expressed by AlGaAs in some cases when the Al composition (X) is not needed to be specified.

[0038] An active region generating a laser beam is formed on the DBR layer **11**. The active region is constituted by the cladding layers **12** and **14**, and the active layer **13** that is sandwiched between the cladding layers **12** and **14**, and that provides an optical gain. A Multiple Quantum Well (MQW) is formed in the active layer **13** by multiply-laminating a quantum well layer and a barrier layer. The active layer **13** is a non-doped region where impurities are not doped.

[0039] The cladding layers **12** and **14** may be non-doped or partly doped depending on design of a device resistance value. In this embodiment, the cladding layers **12** and **14**

contacting the N-type and P-type DBR layers **11** and **15** are partly doped with impurities having the same conductivity types as the DBR layers **11** and **15** adjacent thereto.

[0040] The DBR layer **15** being on the upper side and constituted by a compound semiconductor exhibiting the conductivity type P is formed on the active region. The DBR layer **15** on the upper side constitutes an optical resonator in cooperation with the DBR layer **11** on the lower side. The DBR layer **15** except for the current constriction layer **16** includes a structure formed by alternately laminating, e.g., $Al_{0.15}Ga_{0.85}As$ and $Al_{0.9}Ga_{0.1}As$ in an optical film thickness of λ/4 per layer, as in the DBR layer **11** on the lower side (substrate side). The DBR layer **15** is doped with C (carbon) to exhibit the conductivity type P, and a concentration of the doped C is, e.g., 2 to 3×10^{18} cm^{-3}. C tends to be coordinated at an As site and to become an acceptor.

[0041] The conductivity types may be reversed to those described above such that the substrate **10** is constituted by a P-type semiconductor substrate, the conductivity type of the lower DBR layer **11** is set to the P-type, and the conductivity type of the upper DBR layer **15** is set to the N-type. It is to be noted that when expressions "first and second conductivity types" are used in this Description, one of the first and second conductivity types is the P-type and the other is the N-type.

[0042] The current constriction layer **16** is formed in a part of the upper DBR layer **15** for the purpose of efficiently injecting a current into the active region and developing a lens effect. As illustrated in FIG. **3**, the current constriction layer **16** includes a non-oxidized portion **18** in a central portion, and an oxidized portion **17** that is present around the non-oxidized portion **18** and that is made of substantially an insulator. Such a structure is obtained by forming a to-be-oxidized layer, which becomes the current constriction layer **16**, with $Al_xGa_{(1-x)}As$ on condition of $0.95\leq X\leq 1$ (including the case of X=1, i.e., AlAs), processing a multilayer epitaxial film, which includes the to-be-oxidized layer, into a mesa post shape, and then selectively oxidizing the to-be-oxidized layer from the surroundings in an atmosphere of heated water vapor. Since only the non-oxidized portion **18** in the central portion serves as a current path, the current can be efficiently injected into the active region.

[0043] As illustrated in FIGS. **1** and **2**, an insulating film **21** for moisture resistance (also called a moisture-resistant film) is formed on the multilayer epitaxial film having a mesa post structure. An opening is formed in the insulating film **21** positioned on the mesa post structure to make a surface of the DBR layer **15** exposed. An anode electrode layer **19** (ring electrode layer) is connected to the exposed surface of the DBR layer **15**. A pad electrode **23** for bonding is connected to the anode electrode layer **19**. A polyimide pattern **22** is disposed between the pad electrode **23** and the DBR layer **11** to reduce parasitic capacitance.

Distribution of Al Composition

[0044] FIG. **4** is a graph depicting a distribution of Al compositions in individual layers of FIG. **3**. A vertical axis of FIG. **4** represents an Al content (X) of $Al_xGa_{(1-x)}As$, and a horizontal axis represents a depth direction of the VCSEL in an arbitrary unit (AU). The case of X=0 implies GaAs, and the case of X=1 implies AlAs.

[0045] Referring to FIG. **4**, in each of the DBR layers **11** and **15**, a low refractive-index layer having a large Al content and a high refractive-index layer having a small Al content are alternately laminated. In the DBR layers **11** and **15**, respective regions adjacent to the cladding layers **12** and **14** each correspond to the first low refractive-index layer. In the case of FIG. **4**, the current constriction layer **16** is formed at a position within the first low refractive-index layer of the DBR layer **15**, the position being most spaced from the active layer **13**. The current constriction layer **16** may be arranged within the first low refractive-index layer at the lower side than the case of FIG. **4** (e.g., at a position adjacent to the cladding layer **14**). A P-type doped region **31** extends over the DBR layer **15** and reaches the inside of the cladding layer **14** partly.

[0046] While, in FIG. **4**, the current constriction layer **16** is formed within the first low refractive-index layer that constitutes the DBR layer **15**, it may be arranged at a position closer to the active layer **13**, e.g., at a position within the cladding layer **14**. Stated in a more general way, the current constriction layer **16** is arranged within the DBR layer **15** or between the DBR layer **15** and the active layer **13**. As an alternative, the current constriction layer **16** may be arranged at the side closer to the substrate **10** than the active layer **13**. Thus, the current constriction layer **16** may be arranged within the DBR layer **11** or between the DBR layer **11** and the active layer **13**.

Process of Fabricating VCSEL

[0047] FIGS. **5** to **11** are sectional views schematically illustrating a process of fabricating the VCSEL. FIG. **12** is a flowchart representing the process of fabricating the VCSEL. A method of fabricating the VCSEL **1** illustrated in FIGS. **1** to **4** will be described below with reference to FIGS. **5** to **12**.

[0048] Referring to FIG. **5**, the epitaxial films **11** to **16** are formed in a multilayer form on the semiconductor substrate **10** (N-type GaAs substrate in this embodiment). MOCVD (Metal Organic Chemical Vapor Deposition) or MBE (Molecular Beam Epitaxy) is suitably used as a method to form the epitaxial films.

[0049] More specifically, the DBR layer **11** exhibiting the conductivity type N is first formed on the GaAs substrate **10** (step S**100** in FIG. **12**). The DBR layer **11** is formed in a structure of 30 to 40 paired layers, each pair including a high refractive-index region and a low refractive-index region in an optical film thickness of λ/4 per layer. $Al_xGa_{(1-x)}As$ with X=about 0.1 can be utilized as a high refractive-index material, and $Al_xGa_{(1-x)}As$ with X=about 0.9 can be utilized as a low refractive-index material. The DBR layer **11** is doped with Si as impurities at about 2×10^{18} cm^{-3} to exhibit the conductivity type N.

[0050] Next, the active layer **13** including a Quantum Well (QW) is formed on the N-type DBR layer **11** in a state sandwiched between the cladding layers **12** and **14** (steps S**105** to S**115** in FIG. **12**). Respective film thicknesses and materials of the active layer **13** and the cladding layers **12** and **14** can be adjusted as appropriate depending on an oscillation wavelength. For example, the adjustment can be made to obtain the oscillation wavelength of 850 nm in the case of utilizing GaAs as the material of the active layer **13**.

[0051] Next, the P-type DBR layers **15** and **15**A are formed on the cladding layer **14** (i.e., steps S**120** to S**130** in FIG. **12**). As in the N-type DBR layer **11**, the P-type DBR layers **15** and **15**A are each formed in a structure of about 20 paired layers, each pair including a high refractive-index region and a low refractive-index region in an optical film thickness of λ/4 per layer. $Al_xGa_{(1-x)}As$ with X=about 0.1 can be utilized as a high refractive-index material, and $Al_xGa_{(1-x)}As$ with X=about 0.9 can be utilized as a low refractive-index material. The DBR

layer **15** and **15**A are each doped with C as impurities at about 2×10^{18} cm^{-3} to exhibit the conductivity type P.

[0052] In the structure illustrated in FIGS. **1** to **4**, the to-be-oxidized layer becoming the current constriction layer **16** is formed in the first low refractive-index layer contacting the cladding layer **14**. More specifically, for example, the $Al_xGa_{(1-x)}As$ layer **15**A (X=0.65) is formed on the cladding layer **14** while C (carbon) is doped at about 2 to 3×10^{18} cm^{-3} (steps S**120** in FIG. **12**). Then, the Al composition X is increased to 0.95 or more and the $Al_xGa_{(1-x)}As$ layer ($0.95\leq X\leq 1$) is formed as the to-be-oxidized layer while C (carbon) is doped at about 2 to 3×10^{18} cm^{-3} (steps S**125** in FIG. **12**).

[0053] Because the to-be-oxidized layer becoming the current constriction layer **16** generates distortion due to volume shrinkage caused during an oxidation process, its thickness is desirably set to 40 nm or less to suppress the influence of the distortion. As described above in connection with FIG. **4**, the to-be-oxidized layer may be formed within the first low refractive-index layer at a position closer to the overlying layer or underlying layer.

[0054] Referring to FIG. **6**, a multilayer epitaxial film (multilayer body), which has been formed on the substrate **10** as described above, is processed into a mesa post pattern with a diameter ϕ of, e.g., 30 μm in order to form a current constriction structure (step S**135** in FIG. **12**). The mesa post pattern is formed by methods of photolithography and dry etching. The dry etching needs to be performed at least until a lateral surface of the to-be-oxidized layer becoming the current constriction layer **16** is exposed. In FIG. **6**, the dry etching is performed until reaching a depth at which the surface of the lower DBR layer **11** is exposed.

[0055] Referring to FIG. **7**, the oxidized portion **17** is then formed by heating the substrate including the multilayer epitaxial film, which has been processed into the mesa post pattern, to 450° C. or higher in an atmosphere of water vapor, thus causing oxidation of the to-be-oxidized film becoming the current constriction layer **16** to progress selectively from an outer peripheral portion thereof (step S**140** in FIG. **12**). An oxidation time is adjusted such that the non-oxidized portion **18** in a central portion has a diameter ϕ of 10 μm.

[0056] Referring to FIG. **8**, a silicon nitride film or a silicon oxide film is then formed as the moisture-resistant film **21** (step S**145** in FIG. **12**). For example, CVD or sputtering can be used as a method to form the moisture-resistant film **21**. An opening adapted for a contact electrode layer is formed at a top of the mesa post is formed by methods of photolithography and dry etching (step S**150** in FIG. **12**).

[0057] Referring to FIG. **9**, the P-type contact electrode layer (anode electrode layer) **19** is formed in the opening at the top of the mesa post by, e.g., photolithography and vapor deposition (steps S**155** in FIG. **12**). A multilayer film made of Ti (titanium), Pt (platinum), and Au (gold), for example, can be utilized as the P-type contact electrode layer **19**.

[0058] Referring to FIG. **10**, the polyimide pattern **22** is then formed for the purpose of reducing capacitance under the pad electrode **23** (step S**160** in FIG. **12**). Referring to FIG. **11**, the pad electrode **23** connected to the P-type contact electrode layer is then formed by a film forming method including, e.g., photolithography and sputtering (steps S**165** in FIG. **12**).

[0059] Then, as illustrated in FIGS. **1** to **3**, the rear-surface electrode layer **20** is formed after adjusting the thickness of the substrate **10** (step S**170** in FIG. **12**). A multilayer film made of Au, Ge and Ni, for example, can be used as the rear-surface electrode layer **20**. An annealing process is further performed (step S**175** in FIG. **12**) to establish ohmic contact between each of the electrode layers **19** and **20** and the semiconductor layer. The VCSEL **1** is thus completed.

Details of Method of Forming Current Constriction Structure

[0060] A method of forming the current constriction layer with oxidation using heated water vapor (step S**140** in FIG. **12**), which is the feature of the present disclosure, will be described below.

[0061] FIG. **13** is a sectional view schematically illustrating a configuration of an oxidation furnace. Referring to FIG. **13**, the oxidation furnace **50** includes a chamber **59**, a substrate heating mechanism **40** disposed inside the chamber **59**, and pipes **51** and **52** penetrating through a wall of the chamber **59**.

[0062] The pipe **51** is connected to a water vapor supply source through a valve **53**, and to a nitrogen supply source **56** through a valve **54**. With such an arrangement, a gas mixture of water vapor and nitrogen can be supplied to the chamber **59**.

[0063] The pipe **52** is used as an exhaust port, and gas within the chamber is exhausted through a valve **57**. When pressure in the chamber **59** is to be reduced, the pipe **52** may be connected to an evacuation apparatus (e.g., a vacuum pump) through the valve **57**.

[0064] FIG. **14** is an enlarged sectional view schematically illustrating a principal part of the substrate heating mechanism illustrated in FIG. **13**. Referring to FIGS. **13** and **14**, the substrate heating mechanism **40** includes heat conduction members **42** and **43**, a uniformly-heated plate **41** placed on the heat conduction member **42**, a spacer **44** attached to the conduction member **42**, and a heater device **45** for heating the heat conduction member **43**.

[0065] The heat conduction members **42** and **43** are each made of a material having an isotropic thermal conductivity, e.g., an isotropic carbon material. The thermal conductivity of the isotropic carbon material is, e.g., 110 W/(K·m). While FIG. **14** illustrates a structure in which the heat conduction members **42** and **43** in the form of two plates are laid one above the other, they may be formed as one structure.

[0066] A lower surface of the heat conduction member **43** (on the side oppositely away from a substrate SUB as a heating object) is heated by the heater device **45**. The heater device **45** may be a hot plate including an electrically-heated wire **46** embedded therein, or a lamp heater.

[0067] The uniformly-heated plate **41** is placed on an upper flat surface of the heat conduction member **42**. The uniformly-heated plate **41** is made of an anisotropic material having a larger thermal conductivity in a planar direction larger than in a vertical direction. For example, Pyrolytic Graphite (PG) can be used as the material of the uniformly-heated plate **41**. The thermal conductivity of the PG is, e.g., 350 W/(K·m) in the planar direction, and 2 W/(K·m) in the vertical direction. In this case, a ratio of the thermal conductivity in the planar direction to the thermal conductivity in the vertical direction is 175:1. Furthermore, it is desirable that the thermal conductivity of the uniformly-heated plate **41** in the planar direction is larger than the thermal conductivity of the heat conduction member **42**, and that the thermal conductivity of the uniformly-heated plate **41** in the vertical direction is fairly smaller than the thermal conductivity of the heat conduction member **42**.

[0068] The spacer **44** is attached to the heat conduction member **42**, and it supports a peripheral edge portion of the

substrate SUB. In order to suppress heating of the substrate SUB through thermal conduction via the spacer **44**, the thermal conductivity of the spacer **44** is desirably isotropic and is smaller than that of the uniformly-heated plate **41** in the vertical direction. For example, a ceramic material having the thermal conductivity of 1.6 W/(K·m) can be used as the spacer **44**.

[0069] Thicknesses of individual components of the substrate heating mechanism **40** can be set, by way of example, such that a thickness b of the heat conduction member **42** is 2.7 mm, and a thickness a of the uniformly-heated plate **41** is 2 mm. In such a case, by setting a distance c from an upper surface of the heat conduction member **43** to a lower surface of the substrate SUB (i.e., a height of the spacer) to 5 mm, a space of 0.3 mm can be formed between the uniformly-heated plate **41** and the substrate SUB. Thus, the substrate SUB is heated by radiant heat from the uniformly-heated plate **41**.

[0070] FIG. **15** is a flowchart representing procedures of a heated water-vapor oxidation step (step S**140** in FIG. **12**). Referring to FIGS. **13** and **15**, a sample (i.e., a substrate including a multilayer body processed into a mesa post shape) is first fixed to a predetermined position of the substrate heating mechanism **40** inside the chamber **59** of the oxidation furnace (i.e., onto the spacer **44** in FIG. **14**) (step S**200**).

[0071] Next, when the oxidation using heated water vapor is to be performed under reduced pressure, reduction of pressure within the chamber **59** of the oxidation furnace is started (step S**205**). Thereafter, supply of a gas mixture of water vapor and nitrogen to the chamber **59** is started (step S**210**). The pressure within the chamber **59** is determined depending on balance between a supply amount and an exhaust amount of the gas mixture of water vapor and nitrogen. By heating under the reduced pressure, the heating of the substrate through thermal conduction via gas is suppressed, and the substrate is mainly heated by heat radiation from the uniformly-heated plate **41**. Accordingly, uniformity in the temperature of the substrate can be further increased.

[0072] On the other hand, when the oxidation using heated water vapor is to be performed under the atmospheric pressure, the step S**205** is not executed. In such a case, the supply of the gas mixture of water vapor and nitrogen to the chamber **59** is started (step S**210**) in a state where the valve in the pipe **51** is opened.

[0073] When the atmosphere of water vapor is formed inside the chamber **59** and when the pressure in the chamber reaches a predetermined value in the case of the oxidation under the reduced pressure, heating of the heat conduction member **43** is started by the heater device **45**. An amount of heat applied to the heat conduction member **43** from the heater device **45** (more specifically, an amount of current flowing through the electrically-heated wire **46**) is feedback-controlled depending on a temperature value detected at a particular position of the substrate (sample). In practice, the temperature at the particular position (e.g., a central position) of the substrate is controlled to be held at a predetermined setting temperature between 450° C. and 500° C.

[0074] After a predetermined oxidation time has elapsed from heater-on, the supply of water vapor is stopped (step S**220**), and the heating by the heater device **45** is turned off (step S**225**). Thereafter, the sample is cooled down to near the room temperature and is then taken out from the chamber **59** of the oxidation furnace.

Result of Comparison Experiment

[0075] To confirm the effect of the uniformly-heated plate **41**, an experiment for comparing in-plane distributions of the substrate temperature was conducted between the case where the uniformly-heated plate **41** was disposed in the substrate heating mechanism **40** constituted as illustrated in FIG. **14** (Condition 1) and the case where the uniformly-heated plate **41** was not so disposed (Condition 2). The substrate temperature was measured at plural positions within a diameter ϕ of 40 mm from the center of substrate. When an output of the heater device **45** was set such that an average value of the substrate temperature was equal under both the Condition 1 and Condition 2, a standard deviation σ in the case where the uniformly-heated plate **41** was disposed (Condition 1) was 1.2° C., whereas a standard deviation σ in the case where the uniformly-heated plate **41** was not so disposed (Condition 2) was 3.9° C. In other words, the standard deviation σ was reduced to about ⅓ as a result of disposing the uniformly-heated plate **41**, and the effect of making the substrate temperature more uniform by the uniformly-heated plate **41** was confirmed.

ADVANTAGEOUS EFFECT

[0076] According to the embodiment described above, with the uniformly-heated plate **41** placed on the upper surface of the heat conduction member **42**, heat conducted from the heater device **45** through thermal conduction via the heat conduction members **42** and **43** is uniformized within the uniformly-heated plate **41**. Since the substrate SUS is then heated by radiant heat from the uniformly-heated plate **41**, the substrate temperature in the planar direction can be made more uniform. As a result, the oxidation rate of the to-be-oxidized layer ($Al_xGa_{(1-x)}As$ layer where $0.95 \leq X \leq 1$) becoming the current constriction layer **16** can be held constant in a plane, and in-plane variations in respective sizes of the non-oxidized portion **18** and the oxidized portion **17** illustrated in FIG. **3** can be suppressed.

Modification

[0077] In the embodiment described above, the multilayer body including the DBR layers **11** and **15**, the cladding layers **12** and **14**, the active layer **13**, and the to-be-oxidized layer becoming the current constriction layer **16** is processed into the mesa post shape. However, the multilayer body may be processed into a recessed structure instead of the mesa post shape. Also in the recessed structure, oxidation is progressed from the lateral surface of the to-be-oxidized layer becoming the current constriction layer **16**, whereby the oxidized portion is formed in a state surrounding the non-oxidized portion.

[0078] The embodiment disclosed here should be construed to be not restrictive, but illustrative in all respects. The scope of the present disclosure is defined in not the foregoing description, but in Claims, and is intended to involve all modifications that are equivalent to Claims in terms of meaning and scope.

1. A manufacturing method for a vertical cavity surface emitting laser, the method comprising steps of:

forming, on a substrate, a multilayer body including first and second Distributed Bragg Reflector layers, an active layer, and a to-be-oxidized layer becoming a current constriction structure;

processing the multilayer body such that a lateral surface of at least the to-be-oxidized layer is exposed; and

forming the current constriction structure by oxidizing the to-be-oxidized layer from the lateral surface thereof after the multilayer body has been processed,

wherein the step of forming the current constriction structure includes steps of:

holding the substrate to be positioned along a uniformly-heated plate that is placed on a heat conduction member, and to be spaced from the uniformly-heated plate; and

heating the substrate by radiant heat from the uniformly-heated plate by heating the heat conduction member.

2. The manufacturing method for the vertical cavity surface emitting laser according to claim **1**, wherein the uniformly-heated plate is made of an anisotropic material having a larger thermal conductivity in a planar direction than in a vertical direction.

3. The manufacturing method for the vertical cavity surface emitting laser according to claim **2**, wherein a material of the uniformly-heated plate is Pyrolytic Graphite.

4. The manufacturing method for the vertical cavity surface emitting laser according to claim **2**, wherein the step of holding the substrate includes a step of supporting a peripheral edge portion of the substrate by a spacer that is attached to the heat conduction member, and a thermal conductivity of the spacer is smaller than the thermal conductivity of the uniformly-heated plate in the vertical direction.

5. The manufacturing method for the vertical cavity surface emitting laser according to claim **1**, wherein the heat conduction member and the uniformly-heated plate are disposed within an oxidation furnace, and

the step of heating the substrate is executed in a state that pressure in the oxidation furnace is reduced.

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