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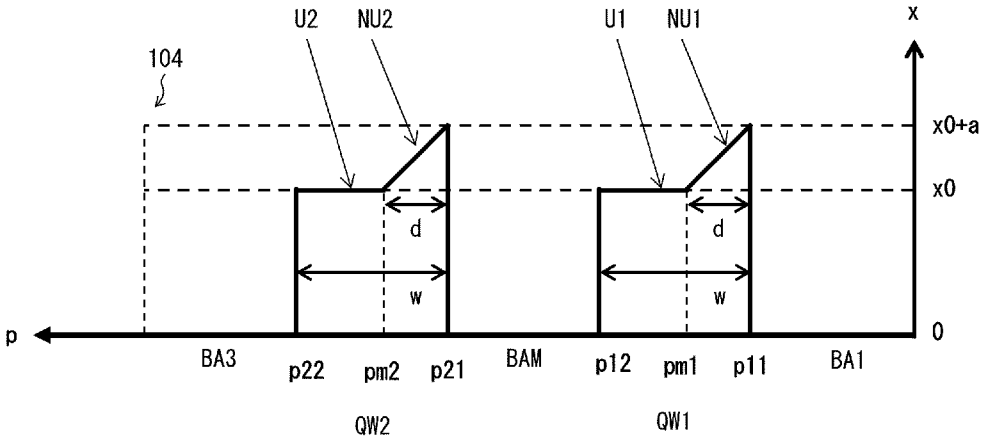
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(54) **Title:** LIGHT EMITTING ELEMENT

FIG. 3



(57) **Abstract:** At least one QW layer (QW1, QW2) in an active region (104) of a light emitting element is composed of $In_xGa_{1-x}N$. The profile of a distribution of x in the thickness direction of the at least one QW layer is represented as a continuous function of a position in the thickness direction. The at least one QW layer includes (i) a QW layer's uniform portion (U1, U2) in which the value of x is constantly equal to x0 at every position in the thickness direction and (ii) a QW layer's non-uniform portion (NU1, NU2) in which the value of x changes with a change in position in the thickness direction. The value of x is equal to or greater than x0 at every position in the QW layer's non-uniform portion.

Description

Title of Invention: LIGHT EMITTING ELEMENT

Technical Field

[0001] One aspect of the present invention relates to a light emitting element that includes a quantum well (QW) layer composed of an InGaN material.

Background Art

[0002] There are various techniques proposed concerning a semiconductor light emitting element (e.g., laser diode). For example, Patent Literature 1 and Non-patent Literature 1 each disclose a light emitting element that includes a QW layer composed of an InGaN material.

Citation List

Patent Literature

[0003] PTL 1: U.S. Patent No. US 7,345,324 B2

Non Patent Literature

[0004] NPL 1: "Approaches for high internal quantum efficiency green InGaN light-emitting diodes with large overlap quantum wells", Hongping Zhao, Guangyu Liu, Jing Zhang, Jonathan D. Poplawsky, Volkmar Dierolf, and Nelson Tansu, Optics Express Vol. 19, Issue S4, pp. A991-A1007 (2011).

Summary of Invention

Technical Problem

[0005] It is an object of one aspect of the present invention to improve the performance of a light emitting element that includes a QW layer composed of an InGaN material.

Solution to Problem

[0006] In order to attain the above object, a light emitting element in accordance with one aspect of the present invention includes: an n-type semiconductor layer; a p-type semiconductor layer; and an active region lying between the n-type semiconductor layer and the p-type semiconductor layer, the active region including a first quantum barrier (QB) layer that is nearest the n-type semiconductor layer, a second QB layer that is nearest the p-type semiconductor layer, and at least one quantum well (QW) layer lying between the first QB layer and the second QB layer, wherein an indium content of each of the layers included in the active region is represented as x with the proviso that $0 \leqq x < 1$, the at least one QW layer is composed of $In_xGa_{1-x}N$, a profile of a distribution of x in a thickness direction of the at least one QW layer is represented as a continuous function of a position in the thickness direction, and the at least one QW layer includes a QW layer's uniform portion in which a value of x is constantly equal

to x0 at every position in the thickness direction, and a QW layer's non-uniform portion in which the value of x changes with a change in position in the thickness direction, the value of x being equal to or greater than x0 at every position of the QW layer's non-uniform portion.

Advantageous Effects of Invention

[0007] According to one aspect of the present invention, it is possible to improve the performance of a light emitting element that includes a QW layer composed of $In_xGa_{1-x}N$.

Brief Description of Drawings

[0008] [fig.1]FIG. 1 illustrates a general configuration of a light emitting element of Embodiment 1.

[fig.2]FIG. 2 illustrates a configuration of an active region of the light emitting element in FIG. 1.

[fig.3]FIG. 3 is a graph showing one example of an indium composition profile for the active region in FIG. 2.

[fig.4](a) and (b) of FIG. 4 are illustrations for explaining effects provided by an active region having the indium composition profile shown in FIG. 3.

[fig.5]FIG. 5 is a graph showing one example of an indium composition profile for an active region of Embodiment 2.

[fig.6](a) and (b) of FIG. 6 are illustrations for explaining effects provided by an active region having the indium composition profile shown in FIG. 5.

[fig.7]FIG. 7 is a graph showing one example of an indium composition profile for an active region of Embodiment 3.

[fig.8]FIG. 8 is a graph showing an indium composition profile for an active region in accordance with one example of numerical simulations.

[fig.9]FIG. 9 is a graph showing one example of simulation results.

[fig.10]FIG. 10 is a graph showing another example of the simulation results.

Description of Embodiments

Embodiment 1

[0009] The following description will discuss a light emitting element 100 (semiconductor light emitting element) of Embodiment 1. For convenience, members having functions identical to those described in Embodiment 1 are assigned identical referential numerals and their descriptions are omitted in the subsequent embodiments.

[0010] (General configuration of light emitting element 100)

FIG. 1 illustrates a general configuration of the light emitting element 100. In Embodiment 1, the light emitting element 100 is a semiconductor laser element (e.g., laser diode). Each semiconductor layer included in the light emitting element 100 may be produced by a known growth method. FIG. 1 shows the growth direction of each semi-

conductor layer in the growth method. The growth direction may be hereinafter referred to as the upward direction. The growth direction can also be expressed as the thickness direction of each layer described below.

[0011] Examples of a growth method include metal organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE). The growth method can be any method, provided that a semiconductor layer with a superior crystal quality can be produced.

[0012] The layers constituting the light emitting element 100 are stacked together on a substrate 110. The substrate 110 serves as a support member that supports the layers constituting the light emitting element 100. A preferred material for the substrate 110 is, for example, but not limited to, GaN, Si, SiC, or sapphire.

[0013] The light emitting element 100 includes a cladding layer 101 (lower cladding layer), a guide layer 102 (lower guide layer), a guide layer 103 (middle guide layer), an active region 104, a guide layer 105 (upper guide layer), a carrier blocking layer 106, a cladding layer 107 (upper cladding layer), a contact layer 108, and a metal electrode layer 109a (upper metal electrode layer) in the order named from the substrate 110 in the upward direction. The light emitting element 100 includes a metal electrode layer 109b (lower metal electrode layer) below the substrate 110. The light emitting element 100 includes an insulating layer 111 lying between the cladding layer 107 and the metal electrode layer 109a.

[0014] The cladding layer 101 and the guide layers 102 and 103 may be collectively referred to as an n-type semiconductor layer 112. The guide layer 105, the carrier blocking layer 106, and the cladding layer 107 may be collectively referred to as a p-type semiconductor layer 113. As illustrated in FIG. 1, the active region 104 lies between the n-type semiconductor layer 112 and the p-type semiconductor layer 113. The active region 104 will be described later as to its specific configuration.

[0015] The light emitting element 100 is a group III nitride-based semiconductor light emitting element. Therefore, the n-type semiconductor layer 112 is an n-type group III nitride-based semiconductor layer, and the p-type semiconductor layer 113 is a p-type group III nitride-based semiconductor layer. The n-type semiconductor layer 112 and the p-type semiconductor layer 113 are fabricated in (Al, In, Ga)N material system. The active region 104 is also a group III nitride-based active region. The active region 104 is also fabricated in (Al, In, Ga)N material system.

[0016] A preferred dopant for the n-type semiconductor layer 112 is, for example, but not limited to, Si, Ge, O, S, or Se. A preferred dopant for the p-type semiconductor layer 113 is, for example, but not limited to, Be, Cd, or Mg.

[0017] The active region 104 includes at least one QW layer and a plurality of barrier layers, as will be described later. The active region 104 is surrounded by the n-type semi-

conductor layer 112 and the p-type semiconductor layer 113. It is particularly preferable to provide the active region 104 in this manner for localizing recombination of carriers.

[0018] The active region 104 (more specifically, QW layer(s)) emits light (hereinafter referred to as light L) by electroluminescence (EL). The wavelength (hereinafter referred to as λ) of the light L is determined by the energy of the photon released when an electron (more accurately, free electron) and hole (positive hole) recombine by a radiative process. It is therefore possible to obtain longer wavelength λ, that is, it is possible to produce light L with longer wavelength, by reducing the energy difference between the electron and hole which recombine. The light L is, for example, blue light or green light.

[0019] For the light emitting element 100 to achieve lasing operation, the structure described above requires confinement of the carrier (electron and hole) and emitted photons (in other words, emitted light L) to the active region 104. The confinement of the emitted light L in the thickness direction of the active region 104 is achieved by arranging the guide layers 102 and 103 below the active region 104 and the guide layer 105 above the active region 104. Specifically, for the confinement of the light L, each of the guide layers 102, 103, and 105 is configured such that its refractive index is higher than the effective index of the guided light.

[0020] For stronger confinement of the light L in the thickness direction of the active region 104, the cladding layer 101 is provided below the active region 104, and the cladding layer 107 is provided above the active region 104. Specifically, for the confinement of the light L, each of the cladding layers 101 and 107 is configured such that its refractive index is lower than the effective index of the guided light.

[0021] The refractive index of InN is comparatively higher than the refractive index of GaN. It follows that the refractive index of an InGaN material will increase with increasing indium (In) composition by a relationship which may or may not be linear. It is known that, at wavelengths longer than 450 nm, the refractive indices of GaN and InN both decrease with increasing wavelength of light. It follows that the refractive index contrast between GaN and InN is reduced at longer wavelength of light. As such, the refractive index contrast between GaN and InGaN, for a chosen indium composition, is reduced at longer wavelength of light.

[0022] The refractive index of AlN is comparatively lower than the refractive index of GaN. It follows that the refractive index of an AlGaN material will decrease with increasing Al composition by a relationship which may or may not be linear. At wavelengths longer than 450 nm, the refractive index of AlN increases with increasing wavelength of light. It follows that the refractive index contrast between GaN and AlN is reduced at longer wavelength of light. As such, the refractive index contrast between GaN and

AlGaN, for a chosen Al composition, is reduced at longer wavelength.

[0023] The carrier blocking layer 106 lies between the guide layer 105 and the cladding layer 107. The carrier blocking layer 106 has a higher band gap (more accurately, band gap energy) than the guide layer 105 and the cladding layer 107. The carrier blocking layer 106 effectively reduces transport of electrons from the guide layer 105 to the cladding layer 107, but does not strongly impact transport of holes from the cladding layer 107 to the guide layer 105.

[0024] The cladding layer 107 has a shaped upper surface, formed by some post-growth processing. In a typical layout, the shaped upper surface is a ridge formed in the plane of growth. The upper surface of the cladding layer 107 may also be referred to as a ridge. As such, the cladding layer 107 has a protrusion. The ridge confines light propagation to the direction of the longest dimension of the ridge (i.e., a direction perpendicular to the growth direction).

[0025] The contact layer 108 is formed on top of the cladding layer 107 prior to post-growth processing on the cladding layer 107. The contact layer 108 may be composed of p-type GaN, p-type InGaN, or p-type AlGaN. The contact layer 108 is provided to aid electrical contact to the light emitting element 100.

[0026] The metal electrode layer 109a is in contact with the contact layer 108. The metal electrode layer 109a enables electrical contact to the contact layer 108. The metal electrode layer 109a is shaped complementary to the cladding layer 107. The metal electrode layer 109b is in contact with the substrate 110. The metal electrode layer 109b enables electrical contact to the substrate 110. As such, the metal electrode layers 109a and 109b allow the light emitting element 100 to be electrically activated.

[0027] The insulating layer 111 lies between the cladding layer 107 and the metal electrode layer 109a. A preferred material for the insulating layer 111 is, for example, but not limited to, SiO_2, SiN_x, or Al_2O_3. The insulating layer 111 allows the injection of holes to the light emitting element 100 to occur only in the area defined by the contact layer 108 (p-type GaN) (this area coincides with the top face of the ridge).

[0028] For convenience of description, the growth direction in FIG. 1 (vertical direction of the page on which FIG. 1 is printed) is hereinafter also referred to as a p direction. On the other hand, the horizontal direction of FIG. 1 (lateral direction of the page on which FIG. 1 is printed) is hereinafter also referred to as a q direction. The q direction is perpendicular to the p direction. Furthermore, a direction perpendicular both to the p direction and the q direction is referred to as an r direction. The r direction is orthogonal to the plane occupied by the page on which FIG. 1 is printed.

[0029] The light emitting element 100 has two mirror surfaces (not illustrated), which may be provided by cleavage of the semiconductor layer perpendicular (i) to the longest dimension of the ridge and (ii) to the active region. That is, the mirror surfaces may be

provided so as to extend along the r direction. Alternatively, the mirror surfaces may be provided by some other method. The mirror surfaces confine the light in the direction parallel to the active region. The two mirror surfaces together define an optical cavity.

[0030] The mirror surfaces may be treated, for example, by deposition of an additional material (e.g., SiO_2, SiN_x, or Al_2O_3). This treatment alters the refractive index property of the mirror surfaces. This makes it possible to change the mirror reflectivity of the mirror surfaces to the laser light resulting from oscillation (e.g., the foregoing light L). The light L partially passes through the mirror surfaces and goes out of the light emitting element 100. In this arrangement, the light emitting element 100 is said to be edge emitting. Each edge extends perpendicular to (i) the active region and to (ii) the longest dimension of the ridge. That is, the edge may be provided so as to extend along the r direction.

[0031] The optical cavity of the light emitting element 100 may also be defined parallel to the active region. This results in a vertically emitting light emitting element 100. The vertically emitting light emitting element 100 emits the light L in the p direction.

[0032] (Active region 104)

FIG. 2 illustrates a configuration of the active region 104. The active region 104 includes a barrier layer 114 (lower barrier layer, first QB layer), a first QW layer 115 (lower QW layer), a barrier layer 116 (middle barrier layer, third QB layer), a second QW layer 117 (upper QW layer), and a barrier layer 118 (upper barrier layer, second QB layer) in the order named from the substrate 110 in the upward direction. As such, the active region 104 includes one or more QW structures (e.g., two QW structures).

[0033] The active region 104 includes two QW layers: the first QW layer 115 and the second QW layer 117. The first QW layer 115 and the second QW layer 117 may be hereinafter collectively referred to as QW layers for short. The QW layers are each composed of an InGaN material represented by the compositional formula $In_xGa_{1-x}N$, where x represents the indium content of a QW layer and $0<x<1$. That is, the first QW layer 115 and the second QW layer 117 both contain indium. The first QW layer 115 is closer to the n-type semiconductor layer 112 than the second QW layer 117 is to the n-type semiconductor layer 112, whereas the second QW layer 117 is closer to the p-type semiconductor layer 113 than the first QW layer 115 is to the p-type semiconductor layer 113.

[0034] It should be noted that, in a case where the active region 104 includes only one QW layer, the barrier layer 116 is not necessary. For example, the active region 104 may be constituted by the barrier layer 114, the first QW layer 115, and the barrier layer 118.

[0035] Hereinafter, the indium content of the first QW layer 115 is represented as x1, and the indium content of the second QW layer 117 is represented as x2, for distinction

purposes. That is, the first QW layer 115 is composed of $In_{x1}Ga_{1-x1}N$, whereas the second QW layer 117 is composed of $In_{x2}Ga_{1-x2}N$. It should be noted that $0<x1<1$ and $0<x2<1$. The values of x1 and the x2 may be the same or different, as will be described later. That is, the first QW layer 115 and the second QW layer 117 may be made of materials of the same composition or different compositions. The first QW layer 115 and the second QW layer 117 may have the same thickness (defined as "w", described later) or different thicknesses.

[0036] The active region 104 includes three barrier layers: the barrier layers 114, 116, and 118. The barrier layers 114, 116, and 118 are each composed of an InGaN material, substantially in the same manner as the first QW layer 115 and the second QW layer 117. Specifically, each of the barrier layers is a quantum barrier (QB) layer.

[0037] The barrier layer 116 lies between the first QW layer 115 and the second QW layer 117. The barrier layer 116 is composed of an InGaN material represented by the compositional formula $In_yGa_{1-y}N$, where y satisfies (i) $0\leqq y<1$ and (ii) $y<x1$ and $y<x2$. The barrier layer 116 preferably contains no indium. That is, it is preferable that $y=0$. This improves crystal quality of the barrier layer 116. Furthermore, since this provides a barrier layer 116 with a smooth surface, it becomes easy to form a high-quality second QW layer 117 (which is to be formed subsequently to the barrier layer 116). That is, it is possible to improve growth quality of the second QW layer 117.

[0038] The barrier layer 114 lies between the first QW layer 115 and the n-type semiconductor layer 112. That is, the barrier layer 114 is closer to the n-type semiconductor layer 112 than any other layer in the active region 104. The first QW layer 115 lies between the barrier layer 114 and the barrier layer 116. The barrier layer 114, the first QW layer 115, and the barrier layer 116 may be collectively referred to as a first QW structure.

[0039] On the other hand, the barrier layer 118 lies between the second QW layer 117 and the p-type semiconductor layer 113. That is, the barrier layer 118 is closer to the p-type semiconductor layer 113 than any other layer in the active region 104. The second QW layer 117 lies between the barrier layer 118 and the barrier layer 116. The barrier layer 118, the second QW layer 117, and the barrier layer 116 may be collectively referred to as a second QW structure.

[0040] The barrier layers 114 and 118 are each composed of an InGaN material represented by the compositional formula $In_zGa_{1-z}N$, where z satisfies (i) $0\leqq z<1$ and (ii) $z<x1$ and $z<x2$. The barrier layers 114 and 118 preferably contain no indium. That is, it is preferable that $z=0$. This improves crystal quality of the barrier layers 114 and 118. Furthermore, since this provides a barrier layer 114 with a smooth surface, it is possible to improve growth quality of the first QW layer 115 (which is to be formed subsequently to the barrier layer 114). Likewise, since this provides a barrier layer 118

with a smooth surface, it is possible to improve growth quality of a layer to be formed subsequently to the barrier layer 118 (e.g., guide layer 105).

[0041] The active region 104 (more specifically, each of the layers constituting the active region 104) may be doped by a dopant. The introduction of dopants, however, can reduce the crystal quality of the active region 104, which would then impact the performance of the light emitting element 100. Thus, the active region 104 is preferably non-doped by a dopant to improve crystal quality.

[0042] However, if the active region 104 was not doped by a dopant, the injection of carriers to the first QW layer 115 and the second QW layer 117 would decrease, and the threshold current of the light emitting element 100 would increase. Accordingly, in terms of reducing threshold current, one or more of the layers constituting the active region 104 may be doped by a dopant. The dopant is, for example, but not limited to, one or more dopants selected from Si, Ge, O, S, Se, Be, Cd, and Mg. Note that Si and Mg are typical dopants commonly used in the (Al, In, Ga)N material system.

[0043] (Impact of indium contained in QW layer)

In a light emitting element that includes a QW layer composed of an InGaN material, the wavelength (λ) of light L is dependent on the concentration of indium in the QW layer. Specifically, as the foregoing indium content x becomes greater, the wavelength λ becomes longer. Therefore, in order to achieve a light emitting element with long wavelength emission, it is necessary to increase the indium content of the QW layer.

[0044] Note, however, that increased indium content of the QW layer may have the following disadvantages, for example.

[0045] (Disadvantage 1) Defects are caused in the QW layer by indium segregation. This reduces the yield for mass produced light emitting elements.

[0046] (Disadvantage 2) The crystal quality (crystallinity) of the QW layer lowers due to strain resulting from the above defects.

[0047] (Disadvantage 3) The electrical resistivity of the active region becomes high.

[0048] In consideration of these disadvantages, the inventors of the present invention (hereinafter referred to as the inventors) arrived at a novel configuration which enhances the wavelength λ for a given increase in indium in a QW layer. That is, in order to overcome the above disadvantages, the inventors arrived at the following novel structure of the active region 104.

[0049] (One example of indium composition profile for active region)

FIG. 3 is a graph showing one example of an indium composition profile for the active region 104. The indium composition profile means a spatial distribution (more specifically, a distribution viewed in the growth direction) of the indium content of each layer in the active region 104.

[0050] In FIG. 3, the following abbreviated names are used for the respective layers, for

convenience.

BA1: Barrier layer 114 (lower barrier layer)

QW1: First QW layer 115 (lower QW layer)

BAM: Barrier layer 116 (middle barrier layer)

QW2: Second QW layer117 (upper QW layer)

BA3: Barrier layer 118 (upper barrier layer)

The horizontal axis (p) of the graph in FIG. 3 indicates growth direction. The vertical axis (x) of the graph in FIG. 3 indicates indium content of each layer in the active region 104. In regard to the BA1 and BA3, x may be read as z, as described earlier. In regard to the BAM, x may be read as y, as described earlier. Thus, x falls within the range of $0 \leqq x < 1$ in the following description.

[0051] The BA1, BAM, and BA3 shown in FIG. 3 each contain no indium. That is, the BA1, BAM, and BA3 are each composed of GaN. As such, $x=0$ in all the regions of the BA1, BAM, and BA3. That is, the BA1, BAM, and BA3 each have a uniform band gap.

[0052] The QW1 in FIG. 3 is a region of the range $p11 \leqq p \leqq p12$. The "p11" (the lower limit of the range for p) indicates the position of the lower surface of the QW1, whereas the "p12" (the upper limit of the range for p) indicates the position of the upper surface of the QW1. The same applies to other layers which will be described later. The indium composition profile for the QW1 is hereinafter referred to as PQ1. The PQ1 may also be written as PQ1(p), which is a function of p. The PQ1 is a continuous function of p throughout the range of $p11 \leqq p \leqq p12$.

[0053] As illustrated in FIG. 3, the indium content of the QW1 at p11 is x0+a. That is, $PQ1(p11)=x0+a$. On the other hand, the indium content of the QW1 at p12 is x0. That is, $PQ1(p12)=x0$. In the above equations, x0 is the indium content of U1 (described later), and "a" is a positive number. The "a" represents the peak indium content difference (greatest difference) between U1 and NU1 (described later). Thus, the peak value of x in NU1 is $PQ1(p11)=x0+a$. As such, the peak value of x in NU1 exists at an extremity along the p direction (thickness direction), more specifically, at an extremity closer to the n-type semiconductor layer 112.

[0054] The QW1 includes (i) a portion that has a uniform (constant) indium content (this portion is U1, such a portion is hereinafter referred to as a uniform portion) and (ii) a portion that has a non-uniform (not constant) indium content (this portion is NU1, such a portion is hereinafter referred to as a non-uniform portion). In particular, U1 is referred to as a "QW layer's uniform portion" (uniform portion of QW layer) for distinction from a QB layer's uniform portion (described later). Similarly, NU1 is referred to as a "QW layer's non-uniform portion" (non-uniform portion of QW layer) for distinction from a QB layer's non-uniform portion (described later). More specifically, the

QW1 consists of U1 and NU1. The pm1 indicates the boundary between U1 and NU1. In the example shown in FIG. 3, the pm1 may take any value, provided that p11<pm1<p12 is satisfied. Since the PQ1 is a continuous function, PQ1(pm1)=x0. In the example shown in FIG. 3, the thickness of the QW1 is defined as w, whereas the thickness of NU1 is defined as d. The thickness of U1 is w-d. The pm1 may also be represented as pm1=p11+d. In the QW1, d may take any value, provided that 0<d<w is satisfied.

[0055] In NU1, the value of x changes linearly within the region of p11≦p≦pm1. More specifically, in NU1, the value of x linearly decreases as the value of p increases. On the other hand, in U1 (the remaining portion of the QW1 other than NU1), x=x0 in the region of pm1≦p≦p12 regardless of the value of p.

[0056] As described above, the PQ1 is represented by a combination of (i) an indium composition profile whose value changes linearly (this profile is the indium composition profile for NU1) and (ii) an indium composition profile whose value is constant (this profile is the indium composition profile for U1).

[0057] Furthermore, the inventors employed a configuration in which the value of x is equal to or greater than x0 at every position in NU1. As a result, the inventors succeeded in overcoming the foregoing disadvantages 1 to 3 (described later). In contrast, conventional techniques (e.g., techniques disclosed by Patent Literature 1 and Non-patent Literature 1) do not disclose any specific configuration to overcome the disadvantages 1 to 3.

[0058] Assume that the average of the indium contents in the QW1 (hereinafter referred to as the average indium content) is defined as x_{ave}. The x_{ave} is represented by the following equation.

$$x_{ave} = \frac{1}{w}\int_{p11}^{p12} PQ1(p)\,dp$$

For example, in the case of FIG. 3, the x_{ave} is represented by $x_{ave}=x0+(d\times a)/(2\times w)$.

As described earlier, the value of x is equal to or greater than x0 at every position in NU1. Thus, the value of x is greater than x0 in a part of NU1. Therefore, by providing NU1 in the QW1, it is possible to allow the QW1 as a whole to have a greater average indium content than a QW layer consisting only of U1 (e.g., such a layer is QWr, which is described later).

[0059] The QW2 in FIG. 3 is a region of the range p21≦p≦p22. The indium composition profile for the QW2 is referred to as PQ2. The QW2 consists of a QW layer's uniform portion (U2) and a QW layer's non-uniform portion (NU2), as with the QW1. The pm2 in FIG. 3 indicates the boundary between U2 and NU2.

[0060] In the example shown in FIG. 3, the PQ2 has the same profile as the PQ1. Therefore, the indium composition profile for U2 is the same as the indium composition profile for U1. The indium composition profile for NU2 is also the same as the indium composition profile for NU1. Thus, the average indium content of the QW2 is also represented as x_{ave}, as with the QW1.

[0061] (Advantageous effects)

FIG. 4 shows illustrations for explaining effects provided by the active region 104. (a) of FIG. 4 is a band diagram (energy band diagram) for a QW layer (e.g., QW1) of Embodiment 1. (b) of FIG. 4 is a band diagram as a comparative example (Comparative Example 1) for comparison with (a) of FIG. 4. The QWr in (b) of FIG. 4 is a comparative example for comparison with the QW1. In the QWr, x=x0 (constant) throughout the region of $p11 \leqq p \leqq p12$. That is, the QWr is different from the QW1 in that d=0.

[0062] In (b) of FIG. 4, the conduction band is represented as Ecr, and the valence band is represented as Evr. The profiles of the Ecr and Evr each correspond to the indium composition profile for the QWr. Thus, the band gap of the QWr is constant throughout the region of $p11 \leqq p \leqq p12$.

[0063] In (b) of FIG. 4, the Eer indicates the energy of electrons confined in the QWr, and the Ehr indicates the energy of holes confined in the QWr. The transition energy ΔEr in the QWr is represented by $\Delta Er=Eer-Ehr$. In a case of a recombination of electrons and holes in the QWr, light of energy equal to ΔEr is emitted. Assuming that the frequency of the light is ν and the Planck's constant is h, the transition energy ΔEr is represented as $\Delta Er=h\times\nu$. Assuming that the speed of light is c, the frequency ν of the light is represented as $\nu=c/\lambda$, and therefore the wavelength λ is represented as $\lambda=(h\times c)/\Delta Er$.

[0064] On the other hand, in (a) of FIG. 4, the conduction band is represented as Ec, and the valence band is represented as Ev. In (a) of FIG. 4, the Ee indicates the energy of electrons confined in the QW1, and the Eh indicates the energy of holes confined in the QW1. The transition energy ΔE in the QW1 is represented as $\Delta E=Ee-Eh$. The wavelength λ for the QW1 is represented as $\lambda=(h\times c)/\Delta E$.

[0065] The profiles of the Ec and Ev each correspond to the indium composition profile for the QW1. Thus, the band gap of NU1 ($p11 \leqq p \leqq pm1$) is smaller than that of U1 ($pm1 \leqq p \leqq p12$). As such, the band gap of the QW1 is non-uniform in the region of NU1. It follows that $Ee<Eer$ and $Eh>Ehr$. Thus, the relationship $\Delta E<\Delta Er$ holds.

[0066] As has been described, the QW1 has a lower transition energy than the QWr. That is, the QW1 provides a longer wavelength λ than the QWr. In other words, according to the QW1, the indium content required to achieve a chosen wavelength λ is reduced as compared to the QWr. As such, the QW1, which includes NU1, makes it possible to

achieve a longer wavelength λ while reducing the average indium content, as compared to conventional techniques.

[0067] Accordingly, the light emitting element 100 makes it possible to achieve the following advantages, for example. That is, according to the light emitting element 100, it is possible to overcome the foregoing disadvantages, and thus possible to provide a light emitting element with better performance than conventional devices.

[0068] (Advantage 1) Defects caused by indium segregation can be reduced, and thus the yield for mass produced light emitting elements can be improved.

[0069] (Advantage 2) Strain can be lowered, and thus higher crystal quality of QW layers can be obtained.

[0070] (Advantage 3) Electrical resistivity of the active region can be reduced.

[0071] Furthermore, since a QW layer includes U1, the structure of the QW layer during crystal growth is easy to control. In addition, since the QW layer has a continuous indium composition profile, the structure is easier to control. Furthermore, since there is no interface between U1 and NU1 which makes the indium composition non-continuous, crystal quality further improves.

Embodiment 2

[0072] FIG. 5 is a graph showing one example of an indium composition profile for an active region 204 of Embodiment 2. The active region 204 is different from the active region 104 in that the lower barrier layer and middle barrier layer of the active region 204 each include a QB layer's uniform portion (uniform portion of QB layer) and a QB layer's non-uniform portion (non-uniform portion of QB layer). In this manner, at least one of the barrier layers may include a QB layer's uniform portion and a QB layer's non-uniform portion.

[0073] The active region 204 is constituted by the following layers.

BA1v: Lower barrier layer

QW1: Lower QW layer

BAMv: Middle barrier layer

QW2: Upper QW layer

BA3: Upper barrier layer.

[0074] The BA1v in FIG. 5 is a region of the range $0 \leqq p \leqq p11$. The BA1v consists of a QB layer's uniform portion (UA) ($0 \leqq p \leqq pa$) and a QB layer's non-uniform portion (NUA) ($pa \leqq p \leqq p11$). The pa indicates the boundary between UA and NUA. The pa is set to satisfy $pa=p11-d$. In UA of the BA1v and UB (described later) of the BAMv, $x=0$. As such, in the QB layer's uniform portion, the value of x is constantly equal to 0 at every position in the p direction.

[0075] In NUA, the value of x changes linearly in the region of $pa \leqq p \leqq p11$. More specifically, in NUA, the value of x linearly increases as the value of p increases. As

such, the value of x in the QB layer's non-uniform portion is equal to or greater than 0 at every position in the QB layer's non-uniform portion. Thus, the value of x is greater than 0 in a part of the QB layer's non-uniform portion. The indium composition profile in NUA has its peak value at p11. The active region 204 is configured such that the peak value is "a". As such, the peak value of x in NUA exists at an extremity along the p direction (thickness direction), more specifically, at an extremity closer to the p-type semiconductor layer 113. As such, NUA is configured such that its indium composition profile is a counterpart of that of NU1 (the QW layer's non-uniform portion on top of the BA1v). Furthermore, NUA is positioned closer to the n-type semiconductor layer 112 than NU1 is to the n-type semiconductor layer 112.

[0076] The BAMv in FIG. 5 is a region of the range $p12 \leqq p \leqq p21$. The BAMv also consists of a QB layer's uniform portion (UB) and a QB layer's non-uniform portion (NUB), as with the BA1v. The pb in FIG. 5 indicates the boundary between UB and NUB. The pb is set to satisfy pb=p21-d. The indium composition profile for NUB is the same as the indium composition profile for NUA. That is, NUB is configured such that its indium composition profile is a counterpart of that of NU2 (the QW layer's non-uniform portion on top of the BAMv).

[0077] FIG. 6 shows illustrations for explaining effects provided by the active region 204. (a) of FIG. 6 is a band diagram for the QW1 and NUA. (b) of FIG. 6 is a band diagram as a comparative example (Comparative Example 2) for comparison with (a) of FIG. 6. The NUAr in (b) of FIG. 6 is a comparative example for comparison with NUA. In NUAr, x=x0 (constant) throughout the region of $pa \leqq p \leqq p11$. That is, NUAr is the different from NUA in that d=0. The QW layer in Comparative Example 2 is the QWr, which is the same as that of Comparative Example 1.

[0078] The profiles of the Ecr and Evr in NUAr each correspond to the indium composition profile for NUAr. Thus, the band gap in NUAr is constant. As such, the Ehr and Eer are the same as those of Comparative Example 1. It follows that the ΔEr is also the same as that of Comparative Example 1.

[0079] On the other hand, in (a) of FIG. 6, the profiles of the Ec and Ev in NUA each correspond to the indium composition profile for NUA. It follows that the Ee is lower than that in the case of the active region 104. In contrast, the Eh is higher than that in the case of the active region 104.

[0080] As such, by providing NUA that has a non-uniform band gap, it is possible to reduce the ΔE to a greater extent than the case of the active region 104. Accordingly, the indium content of the QW layer required to achieve a chosen wavelength λ is reduced to a greater extent than the case of the active region 104. As such, it is possible to achieve a light emitting element with longer wavelength emission.

Embodiment 3

[0081] FIG. 7 is a graph showing one example of an indium composition profile for an active region 304 of Embodiment 3. The active region 304 is different from the active region 204 in that, among the barrier layers, only the middle barrier layer includes both a QB layer's uniform portion and a QB layer's non-uniform portion, and that, among the two QW layers, only one QW layer (e.g., QW2) includes both a QW layer's uniform portion and a QW layer's non-uniform portion.

[0082] The active region 304 is constituted by the following layers.

BA1: Lower barrier layer

QW1v: Lower QW layer

BAMv: Middle barrier layer

QW2: Upper QW layer

BA3: Upper barrier layer

The QW1v is a region of the range $p11 \leqq p \leqq p12$, in which x=x0 (constant). The QW1v corresponds to the foregoing QWr.

[0083] As such, the lower and upper QW layers may have different values of d. Therefore, the lower and upper QW layers may have different values of a. In the QW1v, d=0, and thus a=0. By changing the indium composition profile for each QW layer, it is possible to control the emission wavelengths of the respective QW layers independently of each other. This arrangement is suitable for cases where light emission is desired mainly in a certain QW layer (e.g., QW2) of a plurality of QW layers.

[0084] In this arrangement, light emission may be unnecessary in the other QW layer(s) (e.g., QW1v). In view of this, the QW1v is configured such that the x_{ave} (average indium content) of the QW1v is less than the x_{ave} of the QW2. Specifically, the QW1v is configured such that its indium composition profile is uniform. In the QW1v, d=0, and thus $x_{ave}=x0$. As such, the QW1v has a smaller indium content than the QW2.

[0085] According to this arrangement, it is possible to make the electrical resistance of the QW1v (a QW layer that does not need to contribute to emission of light L) smaller than the electrical resistance of the QW2 (a QW layer that contributes to emission of light L). This makes it possible to achieve a light emitting element with long wavelength emission while reducing the electrical resistance of the active region 304 to a greater extent.

Experiment examples

[0086] The inventors performed numerical simulations to verify the effectiveness of the light emitting element 100. The following description will discuss some examples of the simulation results.

[0087] (Example 1)

FIG. 8 is a graph showing an indium composition profile for an active region 404 (hereinafter referred to as active region A1) in accordance with Example 1. The active

region A1 is constituted by the following layers.

BA1: Lower barrier layer

QW1v: Lower QW layer

BAM: Middle barrier layer

QW2: Upper QW layer

BA3: Upper barrier layer

The active region A1 is the same as the active region 304 except that the active region A1 has BAM in place of BAMv.

[0088] First of all, the inventors set the following simulation conditions for Example 1.

Thickness of n-type semiconductor layer 112: 1000 nm to 4000 nm

Thickness of p-type semiconductor layer 113: 600 nm to 1200 nm

w=3 nm, x0=0.24 (for both lower QW layer and upper QW layer)

Lower QW layer: d=0 nm, a=0

Upper QW layer: d=1 nm, a=0.12

Other simulations were performed also under the same conditions as above, unless otherwise specified. Under the above simulation conditions, the x_{ave} of the QW2 was $x_{ave}=0.26$. As a result of the simulation, it was found that $\lambda=529.2$ nm.

[0089] The inventors then designed a comparative example for comparison with the active region A1. Specifically, the inventors set an active region serving as a comparative example, by replacing the QW2 of the active region A1 by another upper QW layer (hereinafter referred to as QWRU). The active region serving as a comparative example is hereinafter referred to as active region RU1. The QWRU is set such that its indium composition profile is uniform. Thus, in the active region RU1, both the upper QW layer (QWRU) and the lower QW layer (QW1v) have a uniform indium composition profile.

[0090] The inventors performed a simulation on the active region RU1 for comparison with the active region A1. The simulation was performed under the conditions set such that the x_{ave} of the QWRU was $x_{ave}=0.26$. That is, the simulation was performed under the conditions in which x in the QWRU was x=0.26. As a result of the simulation, it was found that $\lambda=525.6$ nm.

[0091] The inventors then designed another comparative example for comparison with the active region A1. Specifically, the inventors set an active region serving as another comparative example, by replacing the QW2 of the active region A1 by still another upper QW layer (hereinafter referred to as QWRL). The active region serving as another comparative example is hereinafter referred to as active region RL1. The QWRL is set such that the value of its indium composition profile continues to change linearly over the entire region of the QWRL.

[0092] The inventors performed a simulation also on the active region RL1 for further

comparison with the active region A1. The simulation was performed under the conditions set such that the x_{ave} of the QWRL was x_{ave}=0.26. As a result of the simulation, it was found that λ=527.79 nm.

[0093] As has been described, the simulations were performed to verify that, according to a QW layer (e.g., QW2 of the active region A1) in accordance with one aspect of the present invention, it is possible to achieve a longer wavelength λ (achieve a light emitting element with longer wavelength emission) while reducing the average indium content as compared to conventional techniques.

[0094] The inventors performed additional simulations with varying values of x_{ave} on the active regions A1, RU1, and RL1. FIG. 9 is a graph showing one example of the simulation results. In FIG. 9, the horizontal axis indicates x_{ave}, and the vertical axis indicates wavelength λ. The result shown in FIG. 9 demonstrated that the active region A1 tends to provide longer wavelengths λ than each of the active regions RU1 and RL1, for the same x_{ave}. It was verified also from FIG. 9 that the active region A1 is superior to the active regions RU1 and RL1.

[0095] (Example 2)

Next, the inventors performed a simulation on the foregoing active region 304 (hereinafter referred to as active region A2) illustrated in FIG. 7. For the middle barrier layer (BAMv) of the active region A2, d was set to satisfy d=1 nm and a was set to satisfy a=0.12. As a result of the simulation, it was found that λ=535.4 nm.

[0096] For comparison, the inventors designed a comparative example for comparison with the active region A2. Specifically, the inventors set an active region serving as a comparative example, by replacing the QW2 of the active region A2 by the foregoing QWRU (foregoing another upper QW layer). This active region serving as a comparative example is hereinafter referred to as active region RU2.

[0097] The inventors designed another comparative example for comparison with the active region A2. Specifically, the inventors set an active region serving as another comparative example, by replacing the QW2 of the active region A2 by the foregoing QWRL (foregoing still another upper QW layer). This active region serving as another comparative example is hereinafter referred to as active region RL2.

[0098] The inventors performed simulations with varying values of x_{ave} on the active regions A2, RU2, and RL2. FIG. 10 is a graph showing one example of the simulation results. The result shown in FIG. 10 demonstrated that the active region A2 has the same tendency as that shown in FIG. 9. That is, it was verified that the active region A2 is superior to the active regions RU2 and RL2.

[0099] (Examples of values)

The inventors found from the simulation results that the following numerical ranges are preferred in regard to a QW layer (e.g., QW2) in accordance with one aspect of the

present invention.

[0100] It is preferable that the x_{ave} of the QW layer satisfies $x_{ave}>x0+0.01$. With this arrangement, the effect of increasing the value of λ (the effect of achieving longer wavelength of light L emitted from the QW layer) becomes apparent. For example, in the examples shown in Figs. 9 and 10, the QW layer is configured such that x0=0.24. It was verified that, for this value of x0, suitably longer emission wavelengths of light L were obtained when the x_{ave} was in the range of $x_{ave}>0.25$.

[0101] It is particularly preferable that $x_{ave}>x0+0.015$, in order to obtain longer emission wavelength of light L more effectively. For example, in the example shown in FIG. 9, the value of λ for the active region A1 is less than as least one of the values λ of the active regions RU1 and RL1 at the point where $x_{ave}\fallingdotseq0.25$. On the other hand, in cases where $x_{ave}>0.255$, the value of λ for the active region A1 is greater than the value of λ for each of the active regions RU1 and RL1.

[0102] It is preferable that d of the QW layer satisfies $d\geqq1$ nm. With this arrangement, the effect of achieving longer emission wavelength of light L becomes more apparent. The arrangement also makes it possible to unfailingly control the composition of a QW layer's non-uniform portion.

[0103] It is preferable that a of the QW layer satisfies $a>0.05$. With this arrangement, the effect of achieving longer emission wavelength of light L becomes apparent.

[0104] It is preferable that w of the QW layer satisfies $2\text{ nm}<w<10\text{ nm}$. With this arrangement, the effect of achieving longer emission wavelength of light L becomes apparent.

[0105] It is preferable that the value of λ for the QW layer satisfies $\lambda>450$ nm. According to this QW layer, longer emission wavelength of light L, even within the wavelength range ($\lambda>450$ nm) that it was difficult for conventional techniques to achieve, is suitably obtained. As such, it is possible to provide high-quality light L (e.g., blue laser light).

[0106] It is more preferable that the value of λ for the QW layer satisfies $\lambda>500$ nm. According to this QW layer, longer emission wavelength of light L, even within the wavelength range ($\lambda>500$ nm) that it was especially difficult for conventional techniques to achieve, is suitable obtained. As such, it is possible to provide high-quality light L (e.g., green laser light).

Recap

[0107] A light emitting element in accordance with one aspect of the present invention includes: an n-type semiconductor layer; a p-type semiconductor layer; and an active region lying between the n-type semiconductor layer and the p-type semiconductor layer, the active region including a first quantum barrier (QB) layer that is nearest the n-type semiconductor layer, a second QB layer that is nearest the p-type semiconductor

layer, and at least one quantum well (QW) layer lying between the first QB layer and the second QB layer, wherein an indium content of each of the layers included in the active region is represented as x with the proviso that $0 \leqq x < 1$, the at least one QW layer is composed of $In_xGa_{1-x}N$, a profile of a distribution of x in a thickness direction of the at least one QW layer is represented as a continuous function of a position in the thickness direction, and the at least one QW layer includes a QW layer's uniform portion in which a value of x is constantly equal to x0 at every position in the thickness direction, and a QW layer's non-uniform portion in which the value of x changes with a change in position in the thickness direction, the value of x being equal to or greater than x0 at every position in the QW layer's non-uniform portion.

[0108] The light emitting element is configured such that the QW layer's non-uniform portion is such that the value of x linearly decreases with decreasing distance in the thickness direction to the QW layer's uniform portion.

[0109] The light emitting element is configured such that an average indium content of the at least one QW layer is greater than x0+0.01.

[0110] The light emitting element is configured such that the QW layer's non-uniform portion has a thickness of 1 nm or greater.

[0111] The light emitting element is configured such that a peak value of x in the QW layer's non-uniform portion is x0+a, a value of a being greater than 0.05.

[0112] The light emitting element is configured such that a peak value of x in the QW layer's non-uniform portion exists at an extremity along the thickness direction.

[0113] The light emitting element is configured such that a peak value of x in the QW layer's non-uniform portion exists at an extremity closer to the n-type semiconductor layer along the thickness direction.

[0114] The light emitting element is configured such that the at least one QW layer has a thickness greater than 2 nm and less than 10 nm.

[0115] The light emitting element is configured such that the at least one QW layer emits light with a wavelength λ by electroluminescence, a value of λ being greater than 450 nm.

[0116] The light emitting element is configured such that: the at least one QW layer included in the active region is two QW layers which are a first QW layer and a second QW layer; the active region further includes a third QB layer lying between the first QB layer and the second QB layer; the first QW layer lies between the first QB layer and the third QB layer; the second QW layer lies between the second QB layer and the third QB layer; and the first QW layer and the second QW layer each include the QW layer's uniform portion and the QW layer's non-uniform portion.

[0117] The light emitting element is configured such that: the at least one QW layer included in the active region is two QW layers which are a first QW layer and a second

QW layer; the active region further includes a third QB layer lying between the first QB layer and the second QB layer; the first QW layer lies between the first QB layer and the third QB layer; the second QW layer lies between the second QB layer and the third QB layer; one of the first QW layer and the second QW layer includes the QW layer's uniform portion and the QW layer's non-uniform portion; and the other of the first QW layer and the second QW layer includes the QW layer's uniform portion but does not include the QW layer's non-uniform portion.

[0118] The light emitting element is configured such that: the at least one QW layer included in the active region is two QW layers which are a first QW layer and a second QW layer; the active region further includes a third QB layer lying between the first QB layer and the second QB layer; the first QW layer lies between the first QB layer and the third QB layer; the second QW layer lies between the second QB layer and the third QB layer; the first QB layer, the second QB layer, and the third QB layer are each composed of $In_xGa_{1-x}N$; and at least one of the first QB layer, the second QB layer, and the third QB layer includes a QB layer's uniform portion in which the value of x is constantly equal to 0 at every position in the thickness direction, and a QB layer's non-uniform portion in which the value of x changes with a change in position in the thickness direction, the value of x being equal to or greater than 0 at every position in the QB layer's non-uniform portion, the QB layer's non-uniform portion being positioned closer to the n-type semiconductor layer than the QW layer's non-uniform portion is to the n-type semiconductor layer.

[0119] The light emitting element is configured such that a peak value of x in the QB layer's non-uniform portion exists at an extremity along the thickness direction.

[0120] The light emitting element is configured such that a peak value of x in the QB layer's non-uniform portion exists at an extremity closer to the p-type semiconductor layer along the thickness direction.

Note

[0121] One aspect of the present invention is not limited to the foregoing embodiments, but can be altered by a skilled person in the art within the scope of the claims. One aspect of the present invention also encompasses, in its technical scope, any embodiment derived by combining technical means disclosed in differing embodiments. Furthermore, technical means disclosed in differing embodiments may be combined to provide a new technical feature.

Reference Signs List

[0122] 100 Light emitting element
104, 204, 304, 404 Active region
112 n-type semiconductor layer

113 p-type semiconductor layer

114, BA1, BA1v Barrier layer (first QB layer)

115, QW1, QW1v First QW layer (QW layer)

116, BAM, BAMv Barrier layer (third QB layer)

117, QW2, Second QW layer (QW layer)

118, BA3 Barrier layer (second QB layer)

NU1, NU2 Non-uniform portion of QW layer (QW layer's non-uniform portion)

U1, U2 Uniform portion of QW layer (QW layer's uniform portion)

NUA, NUB Non-uniform portion of QB layer (QB layer's non-uniform portion)

UA, UB Uniform portion of QB layer (QB layer's uniform portion)

Claims

[Claim 1] A light emitting element comprising:
an n-type semiconductor layer;
a p-type semiconductor layer; and
an active region lying between the n-type semiconductor layer and the p-type semiconductor layer,
the active region including
a first quantum barrier (QB) layer that is nearest the n-type semiconductor layer,
a second QB layer that is nearest the p-type semiconductor layer, and
at least one quantum well (QW) layer lying between the first QB layer and the second QB layer,
wherein
an indium content of each of the layers included in the active region is represented as x with the proviso that $0 \leqq x < 1$,
the at least one QW layer is composed of $In_xGa_{1-x}N$,
a profile of a distribution of x in a thickness direction of the at least one QW layer is represented as a continuous function of a position in the thickness direction, and
the at least one QW layer includes
a QW layer's uniform portion in which a value of x is constantly equal to x0 at every position in the thickness direction, and
a QW layer's non-uniform portion in which the value of x changes with a change in position in the thickness direction,
the value of x being equal to or greater than x0 at every position in the QW layer's non-uniform portion.

[Claim 2] The light emitting element according to claim 1, wherein the QW layer's non-uniform portion is such that the value of x linearly decreases with decreasing distance in the thickness direction to the QW layer's uniform portion.

[Claim 3] The light emitting element according to claim 1 or 2, wherein an average indium content of the at least one QW layer is greater than x0+0.01.

[Claim 4] The light emitting element according to any one of claims 1 to 3, wherein the QW layer's non-uniform portion has a thickness of 1 nm or greater.

[Claim 5] The light emitting element according to any one of claims 1 to 4,

wherein a peak value of x in the QW layer's non-uniform portion is x0+a, a value of a being greater than 0.05.

[Claim 6] The light emitting element according to any one of claims 1 to 5, wherein a peak value of x in the QW layer's non-uniform portion exists at an extremity along the thickness direction.

[Claim 7] The light emitting element according to any one of claims 1 to 6, wherein a peak value of x in the QW layer's non-uniform portion exists at an extremity closer to the n-type semiconductor layer along the thickness direction.

[Claim 8] The light emitting element according to any one of claims 1 to 7, wherein the at least one QW layer has a thickness greater than 2 nm and less than 10 nm.

[Claim 9] The light emitting element according to any one of claims 1 to 8, wherein the at least one QW layer emits light with a wavelength λ by electroluminescence, a value of λ being greater than 450 nm.

[Claim 10] The light emitting element according to any one of claims 1 to 9, wherein:
the at least one QW layer included in the active region is two QW layers which are a first QW layer and a second QW layer;
the active region further includes a third QB layer lying between the first QB layer and the second QB layer;
the first QW layer lies between the first QB layer and the third QB layer;
the second QW layer lies between the second QB layer and the third QB layer; and
the first QW layer and the second QW layer each include the QW layer's uniform portion and the QW layer's non-uniform portion.

[Claim 11] The light emitting element according to any one of claims 1 to 9, wherein:
the at least one QW layer included in the active region is two QW layers which are a first QW layer and a second QW layer;
the active region further includes a third QB layer lying between the first QB layer and the second QB layer;
the first QW layer lies between the first QB layer and the third QB layer;
the second QW layer lies between the second QB layer and the third QB layer;
one of the first QW layer and the second QW layer includes the QW

layer's uniform portion and the QW layer's non-uniform portion; and the other of the first QW layer and the second QW layer includes the QW layer's uniform portion but does not include the QW layer's non-uniform portion.

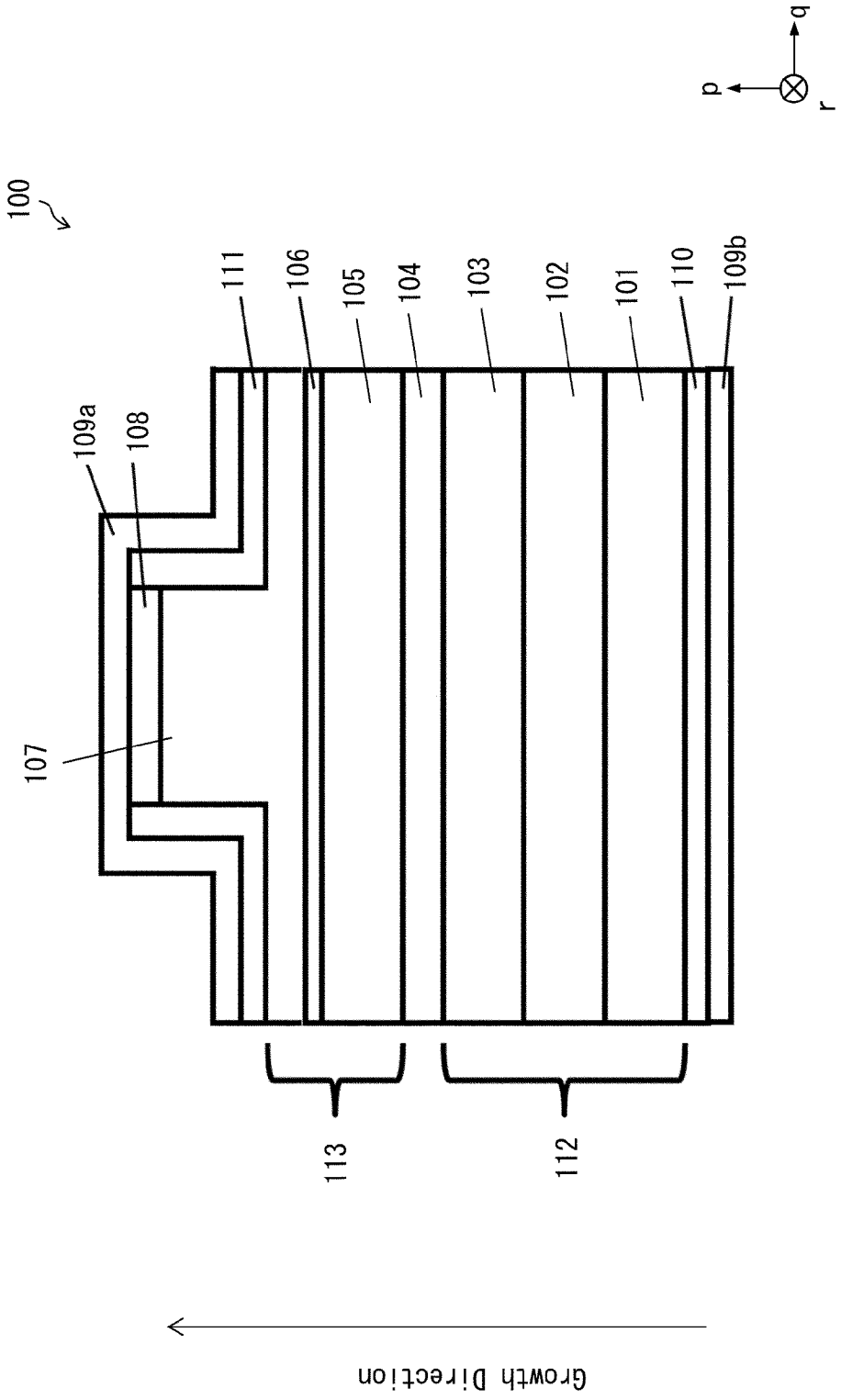
[Claim 12] The light emitting element according to any one of claims 1 to 11, wherein:
the at least one QW layer included in the active region is two QW layers which are a first QW layer and a second QW layer;
the active region further includes a third QB layer lying between the first QB layer and the second QB layer;
the first QW layer lies between the first QB layer and the third QB layer;
the second QW layer lies between the second QB layer and the third QB layer;
the first QB layer, the second QB layer, and the third QB layer are each composed of $In_xGa_{1-x}N$; and
at least one of the first QB layer, the second QB layer, and the third QB layer includes
a QB layer's uniform portion in which the value of x is constantly equal to 0 at every position in the thickness direction, and
a QB layer's non-uniform portion in which the value of x changes with a change in position in the thickness direction,
the value of x being equal to or greater than 0 at every position in the QB layer's non-uniform portion,
the QB layer's non-uniform portion being positioned closer to the n-type semiconductor layer than the QW layer's non-uniform portion is to the n-type semiconductor layer.

[Claim 13] The light emitting element according to claim 12, wherein a peak value of x in the QB layer's non-uniform portion exists at an extremity along the thickness direction.

[Claim 14] The light emitting element according to claim 13, wherein a peak value of x in the QB layer's non-uniform portion exists at an extremity closer to the p-type semiconductor layer along the thickness direction.

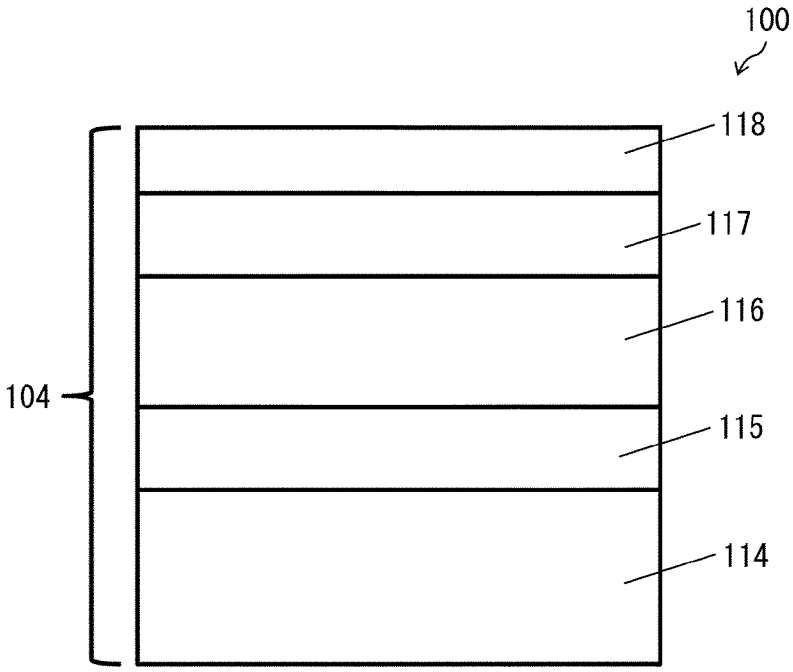
[Fig. 1]

FIG. 1


q
p
r
100
111
106
105
104
103
102
101
110
109b
109a
108
107
113
112
Growth Direction

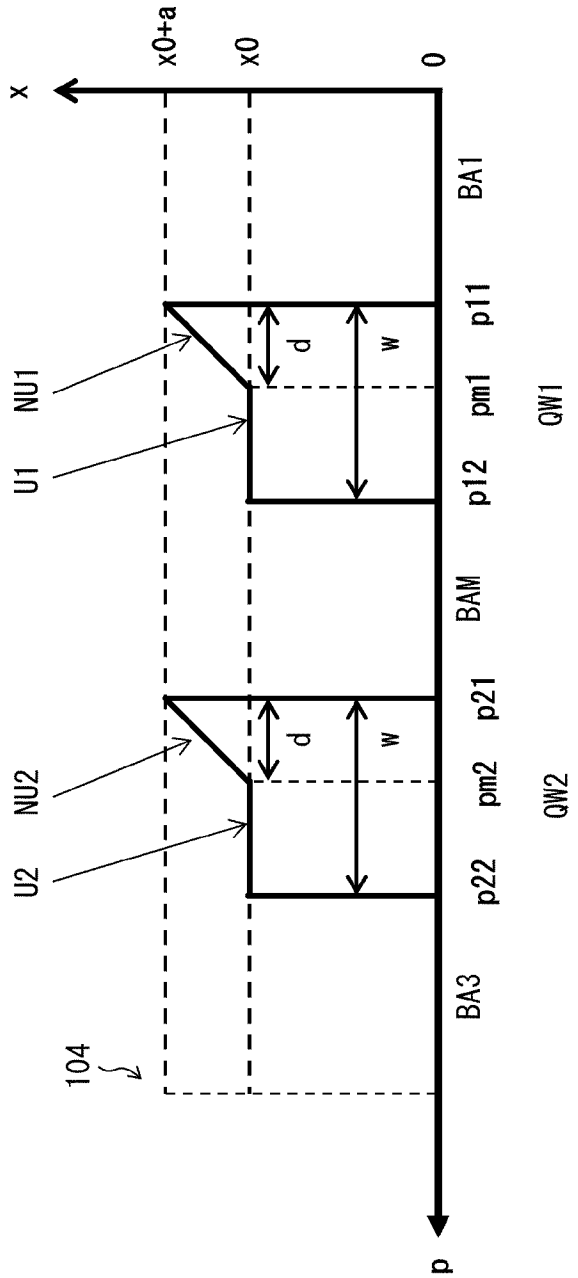
[Fig. 2]

FIG. 2



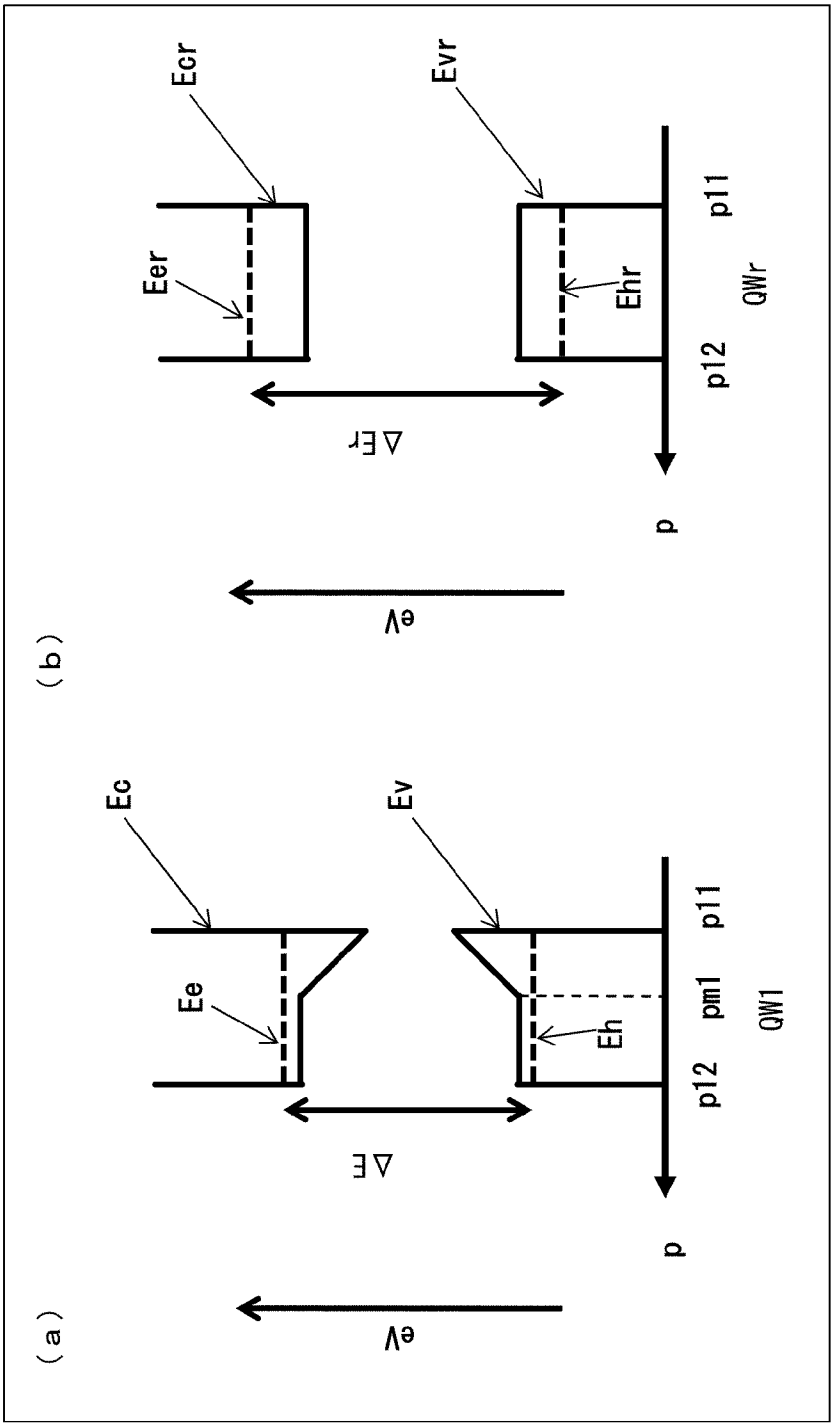
[Fig. 3]

FIG. 3


x0+a
x0
0
x
BA1
p11
d
w
NU1
U1
pm1
QW1
p12
BAM
p21
d
w
NU2
U2
pm2
QW2
p22
BA3
104
p

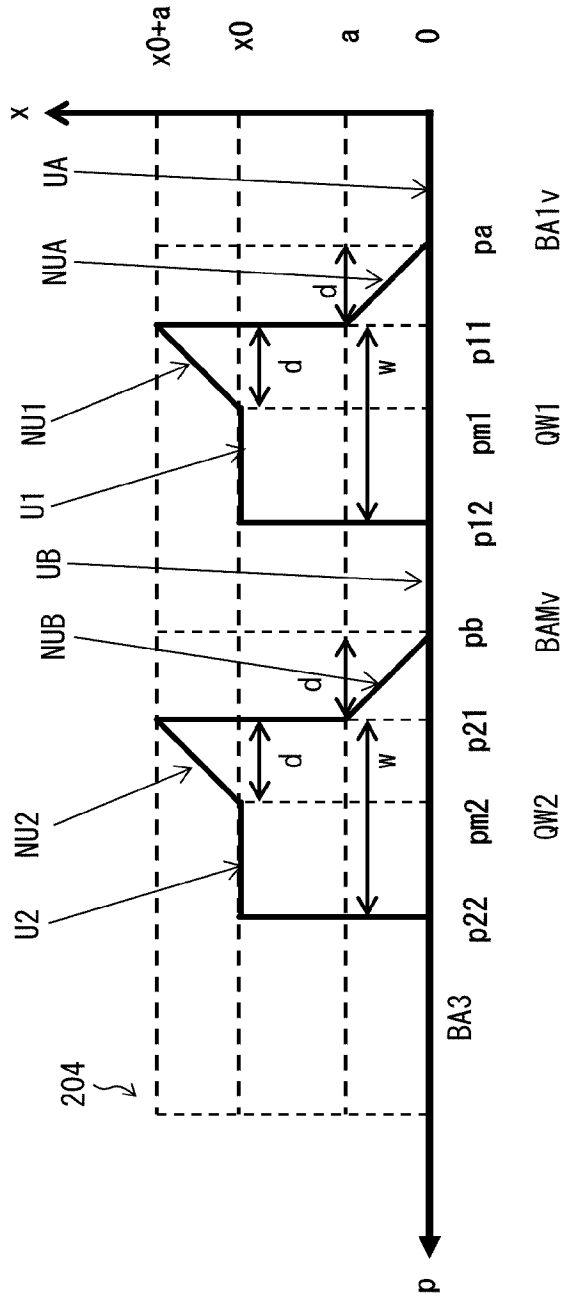
[Fig. 4]

FIG. 4


Ecr
Evr
Eer
Ehr
p11
QWr
p12
ΔEr
p
eV
(b)
Ec
Ev
Ee
Eh
p11
pm1
QW1
p12
ΔE
p
eV
(a)

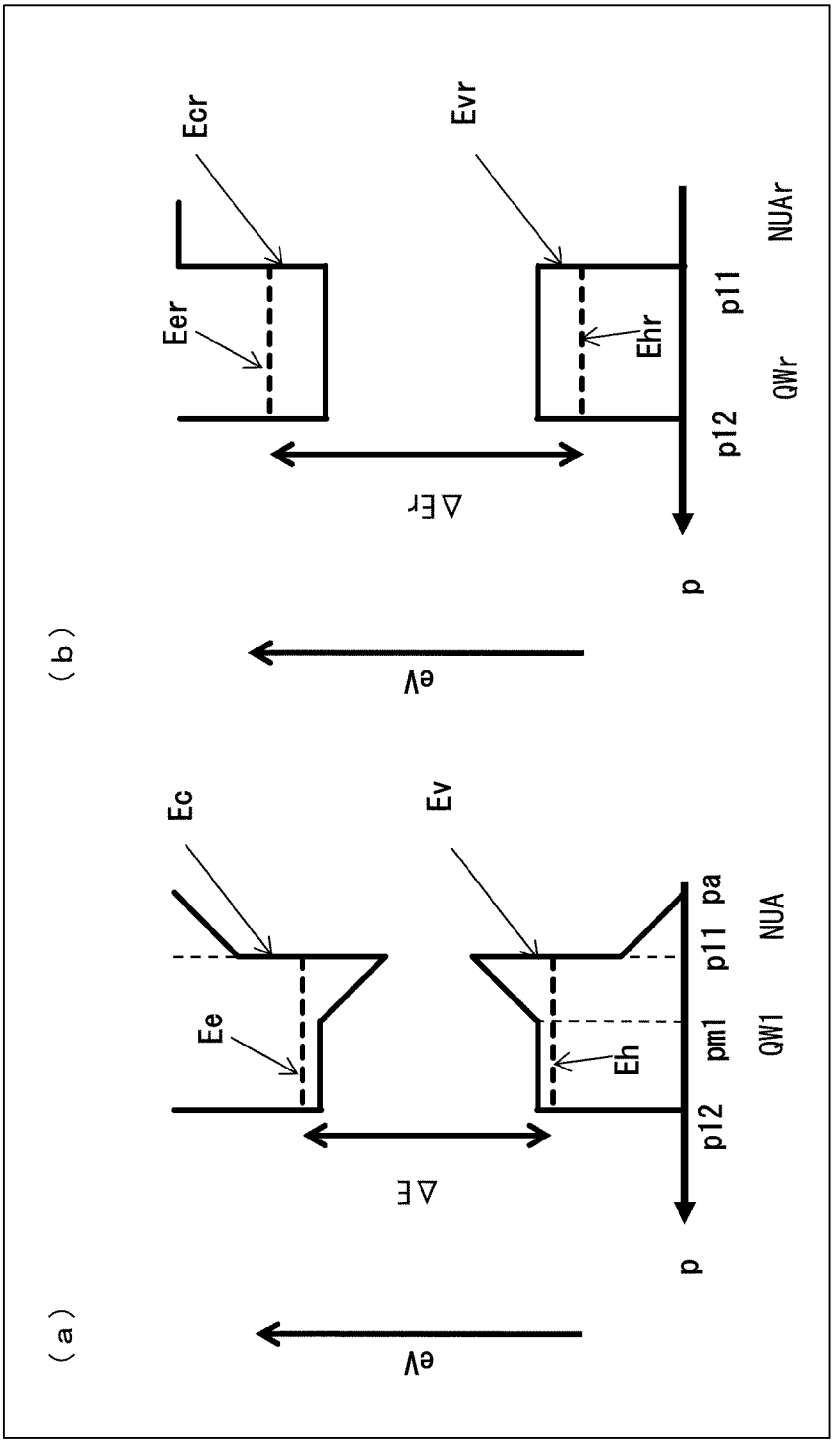
[Fig. 5]

FIG. 5


x0+a
x0
a
0
x
UA
NUA
NU1
U1
UB
NUB
NU2
U2
204
d
w
pa
p11
pm1
p12
pb
p21
pm2
p22
BA3
BA1v
QW1
BAMv
QW2
p

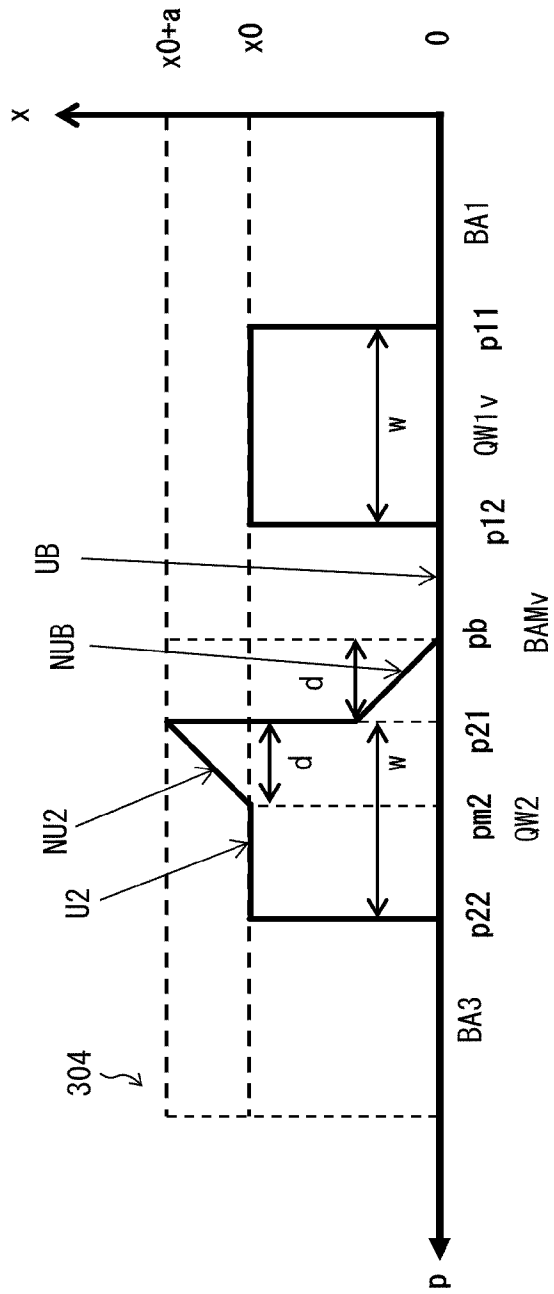
[Fig. 6]

FIG. 6


(a)
eV
ΔE
Ec
Ev
Ee
Eh
p12
pm1
p11
pa
QW1
NUA
p
(b)
eV
ΔEr
Ecr
Evr
Eer
Ehr
p12
p11
QWr
NUAr
p

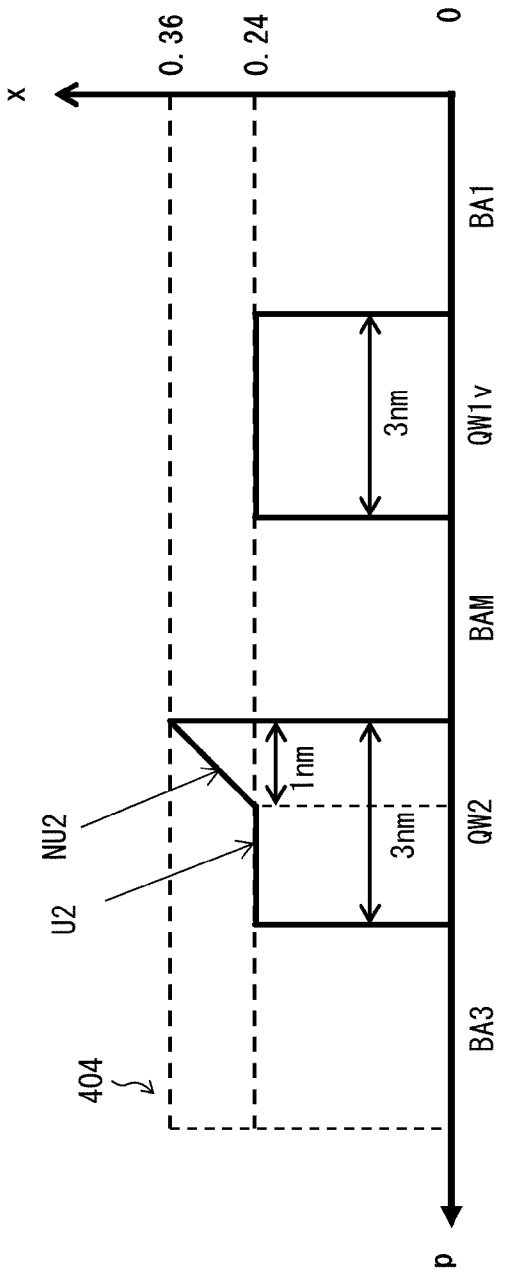
[Fig. 7]

FIG. 7


x0+a
x0
0
x
BA1
p11
QW1v
w
p12
UB
NUB
pb
BAMv
d
p21
d
w
NU2
pm2
QW2
U2
p22
BA3
304
p

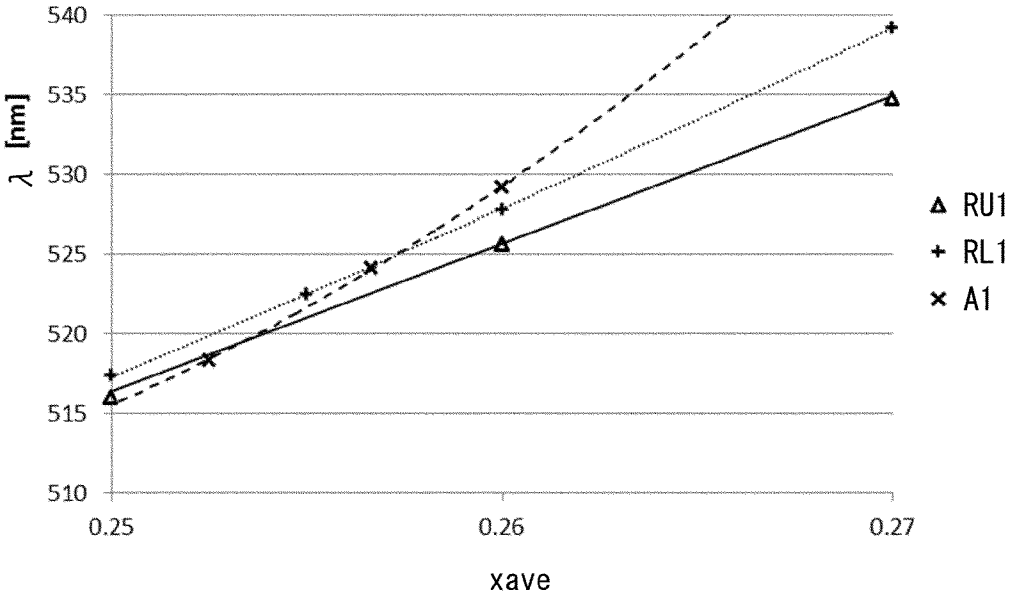
[Fig. 8]

FIG. 8



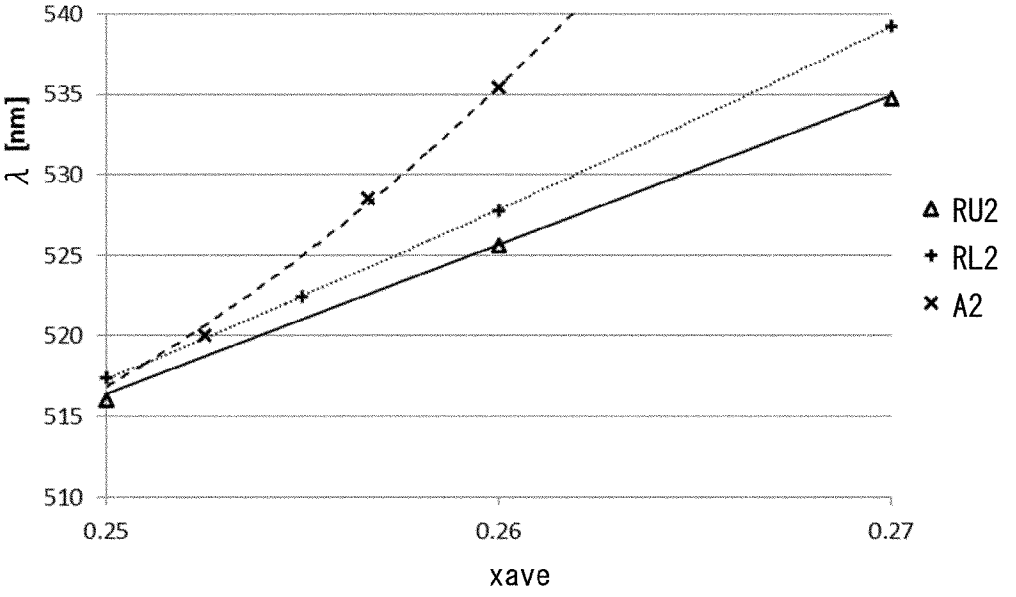
[Fig. 9]

FIG. 9



[Fig. 10]

FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/018789

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H01L33/32(2010.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H01L33/00-33/64, H01S5/00-5/50

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2018
Registered utility model specifications of Japan 1996-2018
Published registered utility model applications of Japan 1994-2018

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Science Direct

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 2012/0138890 A1 (KABUSHIKI KAISHA TOSHIBA) 2012.06.07, Paragraphs [0166], [0169], [0173] - [0175], Figures 4-5, 7, 11B & JP 2012-119560 A Paragraphs [0116], [0118], [0122] - [0124], Figures 4-5, 7, 11B	1-5, 8-10 11 6-7, 12-14
Y	WO 2017/119365 A1 (SONY CORPORATION) 2017.07.13, Paragraph [0058], Figure 12 (No Family)	11
A	US 2009/0256494 A1 (SONY CORPORATION) 2009.10.15, Paragraphs [0065], [0121], Figure 2 & JP 2009-259885 A Paragraphs [0064], [0087], Figure 2 & CN 101562226 A	1-14

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Date of the actual completion of the international search	Date of mailing of the international search report
07.08.2018	14.08.2018

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/018789

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2003-234545 A (SANYO ELECTRIC CO., LTD.) 2003.08.22, Figures 14-15, 24-25 (No Family)	1-14
A	US 2015/0053917 A1 (NICHIA CORPORATION) 2015.02.26, Paragraphs [0033] - [0045], Figures 1-5 & JP 2015-43352 A Paragraphs [0014] - [0025], Figures 1-5	1-14
A	JP 2014-116542 A (STANLEY ELECTRIC CO., LTD.) 2014.06.26, Figure 3 (No Family)	1-14
A	JP 63-60571 A (NEC CORPORATION) 1988.03.16, Figure 3(a) (No Family)	1-14
A	US 8729578 B2 (KABUSHIKI KAISHA TOSHIBA) 2014.05.20, Figure 10 & JP 2014-33029 A Figure 10 & EP 2693499 A1 & CN 103579427 A & KR 10-2014-0017443 A	1-14