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(54) SEMICONDUCTOR LIGHT-EMITTING DEVICE

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(57) ABSTRACT

There is provided a semiconductor light-emitting device including a substrate having a first refractive index, a nitride semiconductor layer formed on the substrate and having a second refractive index that is different from the first refractive index, a light-emitting structure formed on the nitride semiconductor layer and including a first conductive semiconductor layer, an active layer, and a second conductive semiconductor layer, and an optical extraction film disposed between the substrate and the nitride semiconductor layer and having a refractive index between the first refractive index and the second refractive index.

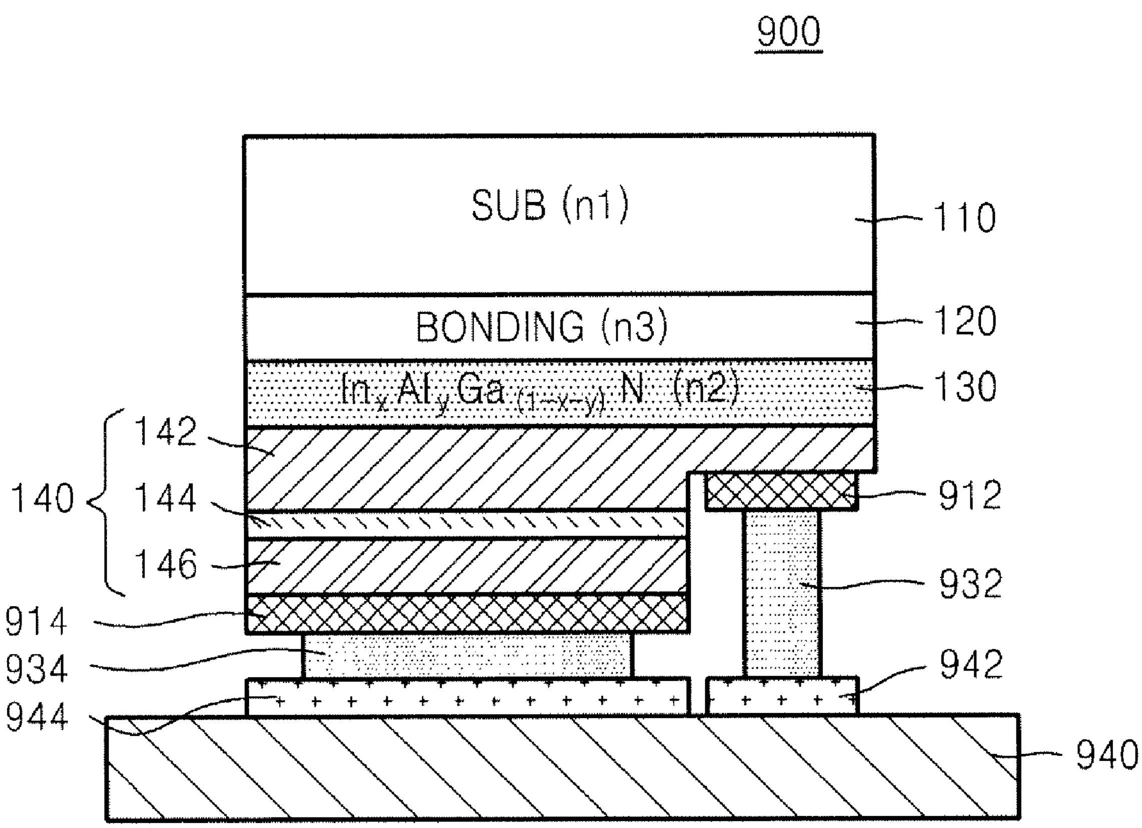


FIG. 1

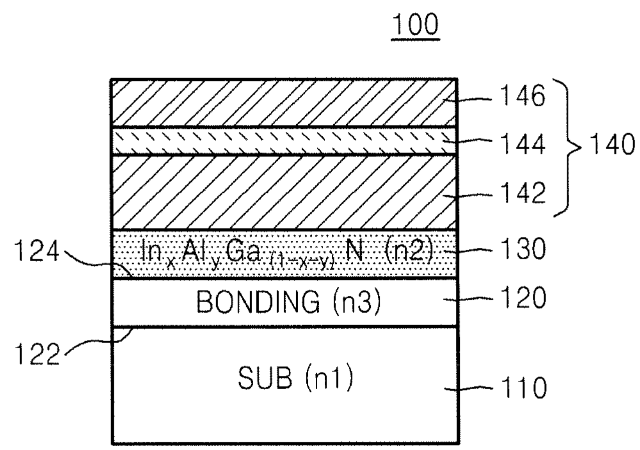


FIG. 2A

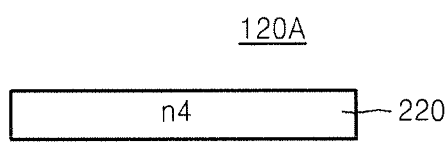


FIG. 2B

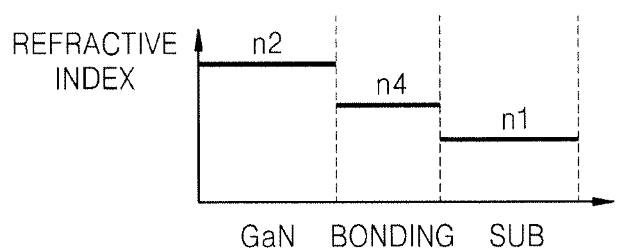


FIG. 2C

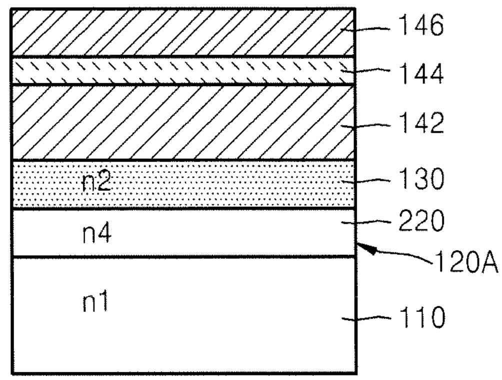


FIG. 3A

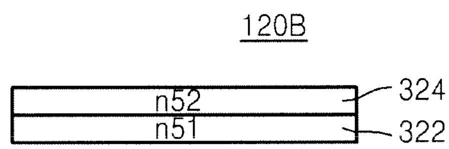


FIG. 3B

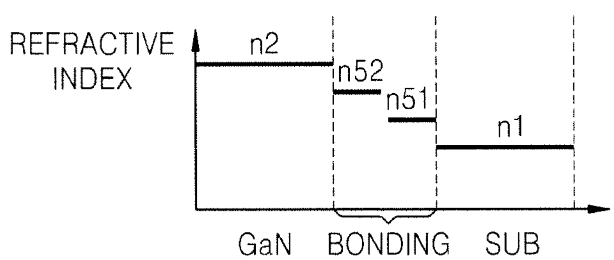


FIG. 3C

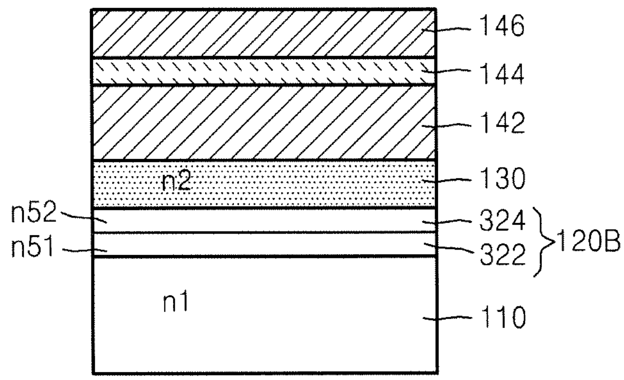


FIG. 4A

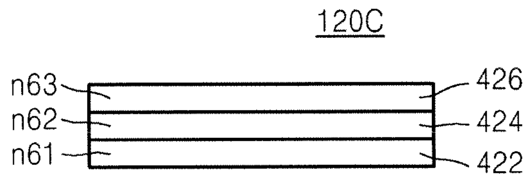


FIG. 4B

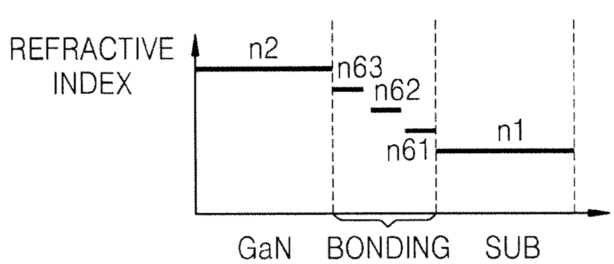


FIG. 5A

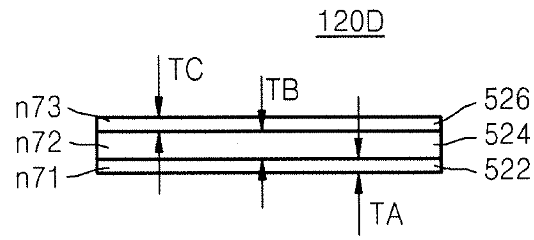


FIG. 5B

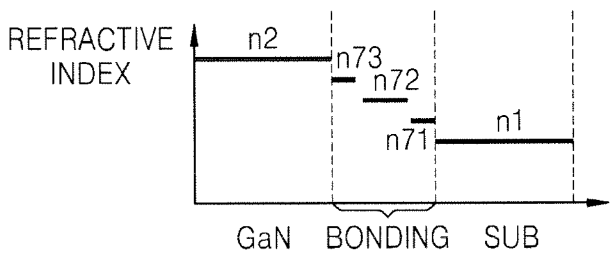


FIG. 6A

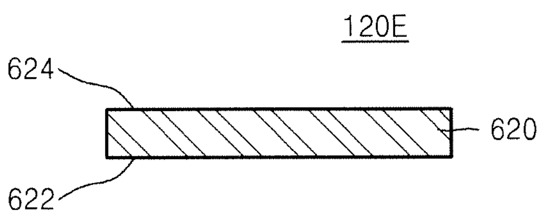


FIG. 6B

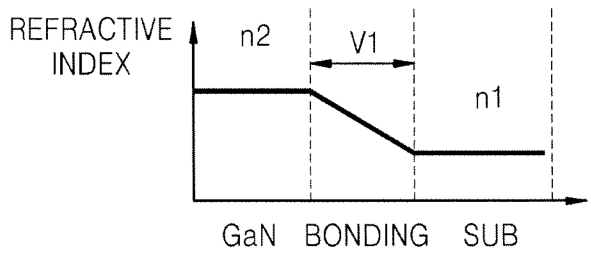


FIG. 6C

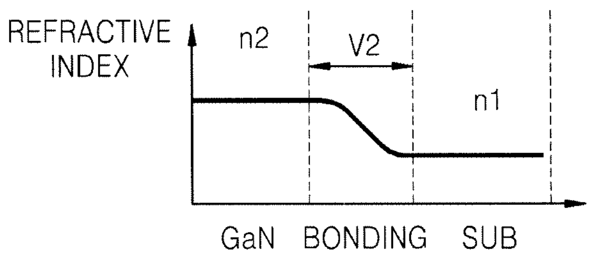


FIG. 6D

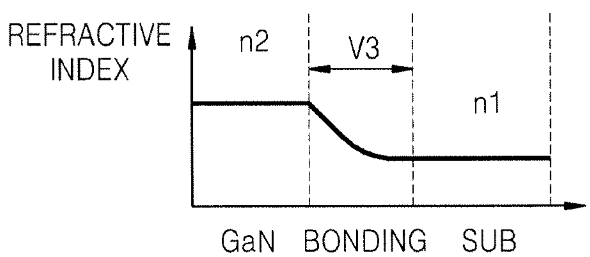


FIG. 6E

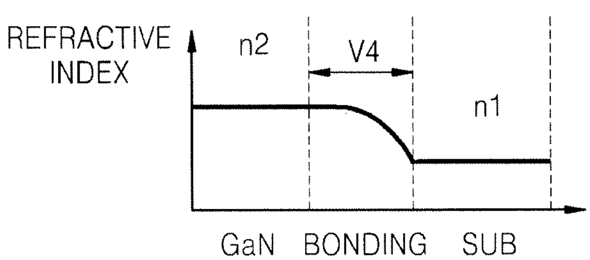


FIG. 7

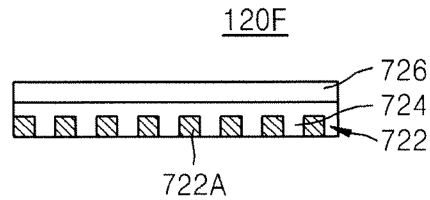


FIG. 8

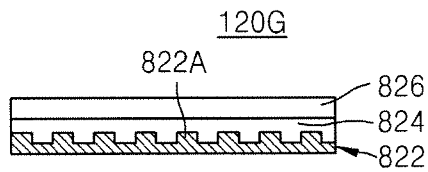


FIG. 9

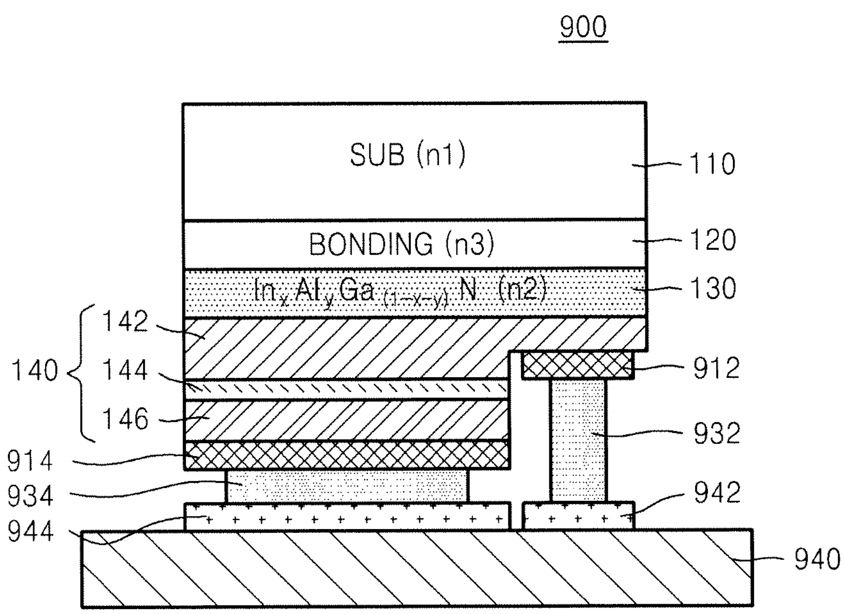


FIG. 10A

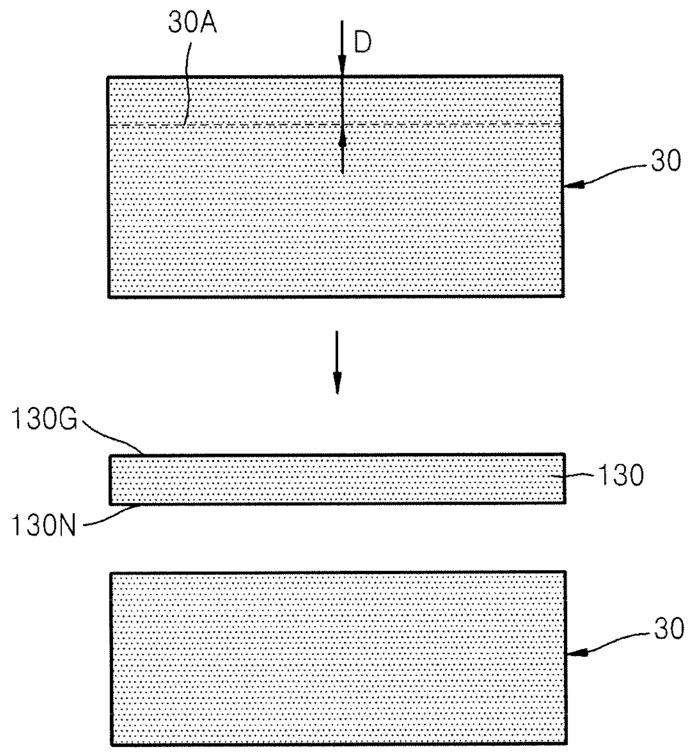


FIG. 10B

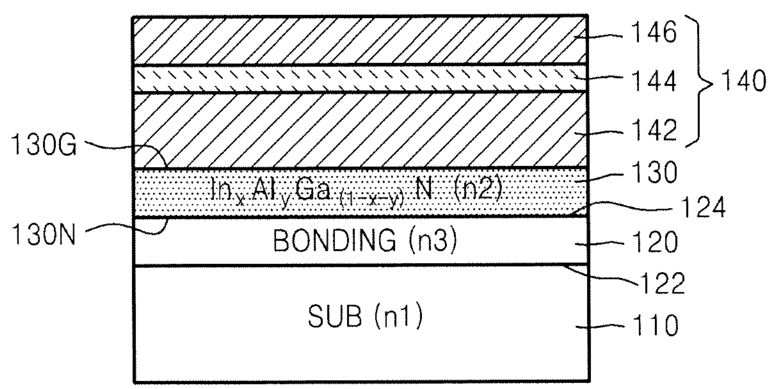


FIG. 10C

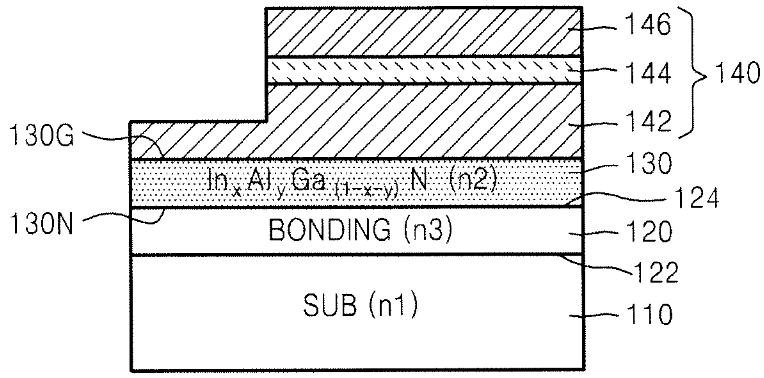


FIG. 10D

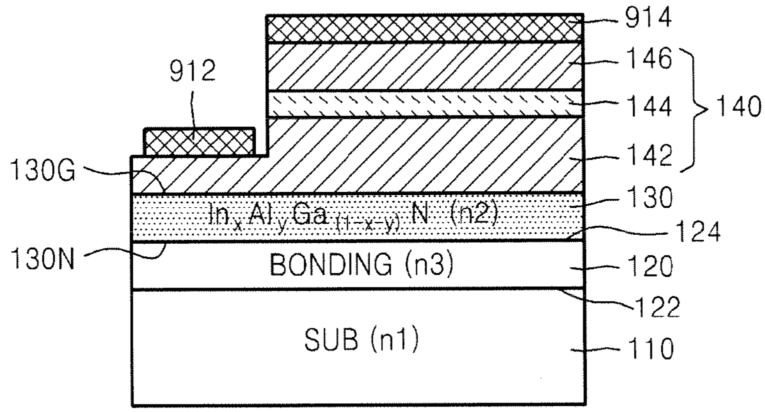
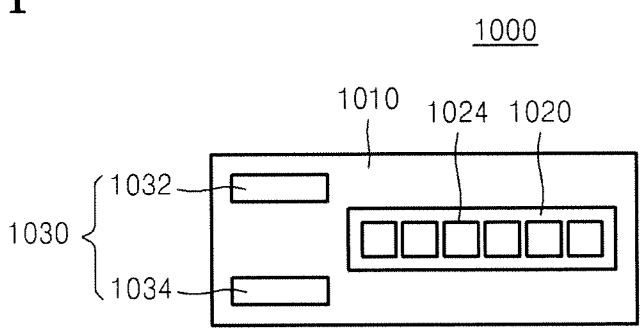


FIG. 11



SEMICONDUCTOR LIGHT-EMITTING DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit to Korean Patent Application No. 10-2013-0001788, filed on Jan. 7, 2013, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein in its entirety by reference.

TECHNICAL FIELD

[0002] One or more embodiments of the present inventive concept relates to a semiconductor light-emitting device, and in particular, a semiconductor light-emitting device including a nitride semiconductor thin film bonded onto a heterogeneous substrate.

BACKGROUND

[0003] Light-emitting diodes using nitride semiconductor (nitride semiconductor light-emitting devices) are widely used in various light sources used for back light, illuminations, signal devices, and large-scale displays. To form a light-emitting device including an InGaAlN-based active layer, a nitride semiconductor thin film is bonded to a heterogeneous substrate, such as a sapphire substrate or a silicon substrate, and then, films for forming a light-emitting device on the nitride semiconductor thin film are grown thereon. However, in techniques disclosed, due to a difference in refractive indexes of a bonding layer for bonding the nitride semiconductor thin film to the heterogeneous substrate and the nitride semiconductor thin film, optical extraction efficiency decreases.

SUMMARY

[0004] The inventive concept provides a semiconductor light-emitting device having such a structure that a decrease in optical extraction efficiency due to a bonding portion between a heterogeneous substrate and a nitride semiconductor thin film is prevented.

[0005] According to an aspect of the inventive concept, there is provided a semiconductor light-emitting device including: a substrate having a first refractive index, a nitride semiconductor layer disposed on the substrate and having a second refractive index that is different from the first refractive index, a light-emitting structure disposed on the nitride semiconductor layer and including a first conductive semiconductor layer, an active layer, and a second conductive semiconductor layer, and an optical extraction film disposed between the substrate and the nitride semiconductor layer and having a refractive index between the first refractive index and the second refractive index.

[0006] The optical extraction film may include a plurality of bonding layers having different refractive indexes included in a range from the first refractive index to the second refractive index, and the bonding layers are stacked from the substrate to the nitride semiconductor layer in such a sequence that a bonding layer with a larger refractive index is disposed closer to the nitride semiconductor layer.

[0007] The first refractive index is smaller than the second refractive index, the optical extraction film includes a plurality of bonding layers with different refractive indexes, and the bonding layers are stacked from the substrate to the nitride semiconductor layer in such a sequence that a bonding layer with a larger refractive index is disposed closer to the nitride semiconductor layer. The bonding layers of the optical extraction film are stacked in such a way that a refractive index increases in the form of a step structure in a thickness direction of the optical extraction film from the substrate to the nitride semiconductor layer.

[0008] The optical extraction film includes a plurality of bonding layers with different refractive indexes, and the plurality of bonding layers includes a bottom surface bonding layer having the smallest refractive index among the plurality of bonding layers and contacts the substrate, a top surface bonding layer having the largest refractive index among the plurality of bonding layers and being in contact with the nitride semiconductor layer, and a middle bonding layer having a refractive index between a refractive index of the bottom surface bonding layer and a refractive index of the top surface bonding layer and being disposed between the bottom surface bonding layer and the top surface bonding layer.

[0009] The bottom surface bonding layer, the top surface bonding layer, and the middle bonding layer have identical thicknesses. The bottom surface bonding layer, the top surface bonding layer, and the middle bonding layer have different thicknesses. From among the bottom surface bonding layer, the top surface bonding layer, and the middle bonding layer, the middle bonding layer has the largest thickness.

[0010] The extraction film includes a plurality of bonding layers with different refractive indexes, and at least one bonding layer of the plurality of bonding layers includes a plurality of island patterns that are spaced apart from each other.

[0011] The optical extraction film includes a plurality of bonding layers with different refractive indexes, and at least a portion of at least one bonding layer of the plurality of bonding layers has an uneven pattern.

[0012] The optical extraction film includes has a graded refractive index (GRI) bonding layer with a GRI. The GRI bonding layer comprises a $Ti_xSi_{1-x}O_y$ film ($0.05 \le x \le 0.95$ and $0.2 \le y \le 2$), a TiO_x film ($0.2 \le x \le 2$), a SiO_x film ($0.2 \le x \le 2$), or a combination thereof.

[0013] According to an aspect of the inventive concept, there is provided a semiconductor light-emitting device including: a substrate, an optical extraction film being in contact with a surface of the substrate and including at least one bonding layer having a refractive index that is larger than a refractive index of the substrate, a nitride semiconductor layer being in contact with a surface of the optical extraction film and having a refractive index that is equal to or larger than a refractive index of a portion of the optical extraction film of which refractive index is the largest from among all the portions of the optical extraction film, and a light-emitting structure formed on the nitride semiconductor layer and including a first conductive semiconductor layer, an active layer, and a second conductive semiconductor layer.

[0014] The optical extraction film includes a plurality of bonding layers with different refractive indexes included in a range that is larger than the refractive index of the substrate and is equal to or smaller than the refractive index of the nitride semiconductor layer, and the plurality of bonding layers are stacked from the substrate to the nitride semiconductor layer in such a sequence that a bonding layer with a larger refractive index is disposed closer to the nitride semiconductor layer.

[0015] Additional advantages and novel features will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following and the accompanying drawings or may be learned by production or operation of the examples. The advantages of the present teachings may be realized and attained by practice or use of various aspects of the methodologies, instrumentalities and combinations set forth in the detailed examples discussed below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Exemplary embodiments of the inventive concept will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings in which:

[0017] FIG. **1** is a cross-sectional view of essential parts of a semiconductor light-emitting device according to some embodiments of the present inventive concept;

[0018] FIG. **2**A is a cross-sectional view of an optical extraction film according to some embodiments of the present inventive concept that is employable as an optical extraction film of the semiconductor light-emitting device of FIG. **1**;

[0019] FIG. **2**B shows a graph showing a refractive index difference in an exemplary structure including a substrate, the optical extraction film of FIG. **2**A, and a nitride semiconductor thin film;

[0020] FIG. **2**C is a cross-sectional view of the semiconductor light-emitting device of FIG. **1** including the optical extraction film of FIG. **2**A as an optical extraction film;

[0021] FIG. **3**A is a cross-sectional view of an optical extraction film according to some embodiments of the present inventive concept that is employable as an optical extraction film of the semiconductor light-emitting device of FIG. **1**;

[0022] FIG. **3**B shows a graph showing a refractive index difference in an exemplary structure including a substrate, the optical extraction film of FIG. **3**A, and a nitride semiconductor thin film;

[0023] FIG. **3**C is a cross-sectional view of the semiconductor light-emitting device of FIG. **1** including the optical extraction film of FIG. **3**A as an optical extraction film;

[0024] FIG. **4**A is a cross-sectional view of an optical extraction film according to some embodiments of the present inventive concept that is employable as an optical extraction film of the semiconductor light-emitting device of FIG. **1**;

[0025] FIG. **4**B shows a graph showing a refractive index difference in an exemplary structure including a substrate, the optical extraction film of FIG. **4**A, and a nitride semiconductor thin film;

[0026] FIG. **5**A is a cross-sectional view of an optical extraction film according to some embodiments of the present inventive concept that is employable as an optical extraction film of the semiconductor light-emitting device of FIG. **1**;

[0027] FIG. **5**B shows a graph showing a refractive index difference in an exemplary structure including a substrate, the optical extraction film of FIG. **5**A, and a nitride semiconductor thin film;

[0028] FIG. **6**A is a cross-sectional view of an optical extraction film according to some embodiments of the present inventive concept that is employable as an optical extraction film of the semiconductor light-emitting device of FIG. **1**;

[0029] FIGS. **6**B to **6**E show graphs illustrating refractive index distributions in a GRI bonding layer illustrated in FIG. **6**A;

[0030] FIG. **7** is a cross-sectional view of an optical extraction film according to some embodiments of the present inventive concept that is employable as an optical extraction film of the semiconductor light-emitting device of FIG. **1**;

[0031] FIG. **8** is a cross-sectional view of an optical extraction film according to some embodiments of the present inventive concept that is employable as an optical extraction film of the semiconductor light-emitting device of FIG. **1**;

[0032] FIG. **9** is a cross-sectional view of a semiconductor light-emitting device according to some embodiments of the present inventive concept;

[0033] FIGS. **10**A to **10**D are cross-sectional views for explaining a process for forming the semiconductor light-emitting device of FIG. **9**, according to some embodiments of the present inventive concept; and

[0034] FIG. **11** is a diagram illustrating a dimming system including a nitride semiconductor light-emitting device according to some embodiments of the present inventive concept.

DETAILED DESCRIPTION

[0035] In the following detailed description, numerous specific details are set forth by way of examples in order to provide a thorough understanding of the relevant teachings. However, it should be apparent to those skilled in the art that the present teachings may be practiced without such details. In other instances, well known methods, procedures, components, and/or circuitry have been described at a relatively high-level, without detail, in order to avoid unnecessarily obscuring aspects of the present teachings.

[0036] The inventive concept will now be described more fully with reference to the accompanying drawings, in which exemplary embodiments of the inventive concept are shown. The same elements in the drawings are denoted by the same reference numerals and a repeated explanation thereof will be omitted.

[0037] The inventive concept now will be described more fully hereinafter with reference to the accompanying drawings, in which elements of the inventive concept are shown. The inventive concept may, however, be embodied in many different forms and should not be construed as limited to the exemplary embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the inventive concept to one of ordinary skill in the art.

[0038] It will be understood that, although the terms first, second, third, etc., may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the inventive concept. For example, a first element may be named a second element and similarly a second element may be named a first element without departing from the scope of the inventive concept.

[0039] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this inventive concept belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0040] In other embodiments, a specific order of processes may be changed. For example, two processes which are continuously explained may be substantially simultaneously performed and may be performed in an order opposite to that explained.

[0041] Variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, exemplary embodiments should not be construed as limited to the particular shapes of regions illustrated herein but may be to include deviations in shapes that result, for example, from manufacturing.

[0042] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0043] FIG. **1** is a cross-sectional view of essential parts of a semiconductor light-emitting device **100** according to some embodiments of the present inventive concept.

[0044] Referring to FIG. **1**, the semiconductor light-emitting device **100** includes a substrate **110**, an optical extraction film **120** contacting a surface of the substrate **110**, a nitride semiconductor thin film **130** contacting a surface of the optical extraction film **120**, and a light-emitting structure **140** formed on the nitride semiconductor thin film **130**.

[0045] The substrate **110** may be a transparent substrate having a first refractive index n1. For example, the substrate **110** may be formed of sapphire (Al_2O_3), gallium oxide (Ga_2O_3), lithium gallium oxide ($LiGaO_2$), lithium aluminum oxide ($LiAlO_2$), or magnesium aluminum oxide ($MgAl_2O_4$).

[0046] The nitride semiconductor thin film **130** may have a second refractive index n2 that is different from the first refractive index n1. In some embodiments, the second refractive index n2 of the nitride semiconductor thin film **130** may be larger than the first refractive index n1.

[0047] The nitride semiconductor thin film **130** may be formed of a gallium nitride-based compound semiconductor represented by $In_xAl_yGa_{(1-x-y)}N$($0\leq x\leq 1$, $0\leq y\leq 1$, and $0\leq x+y\leq 1$). In some embodiments, the nitride semiconductor thin film **130** may be formed of a GaN monocrystal.

[0048] The optical extraction film **120** interposed between the substrate **110** and the nitride semiconductor thin film **130** may have a bottom surface **122** contacting the substrate **110** and a top surface **124** contacting the nitride semiconductor thin film **130**. The optical extraction film **120** may include at least one bonding layer having a third refractive index n3 between the first refractive index n1 and the second refractive index n2.

[0049] The optical extraction film **120** is disposed between the substrate **110** and the nitride semiconductor thin film **130** to attach the substrate **110** and the nitride semiconductor thin film **130** to each other. The optical extraction film **120** has a refractive index between a refractive index of the substrate **110** and a refractive index of the nitride semiconductor thin film **130**, thereby preventing optical loss caused by a reflective light occurring when there is a large difference in a refractive index between the nitride semiconductor thin film **130** and a film disposed on an optical pathway to the substrate **110**.

[0050] The light-emitting structure **140** formed on the nitride semiconductor thin film **130** may include a first conductive semiconductor layer **142**, an active layer **144**, and a second conductive semiconductor layer **146**, each formed of a gallium nitride-based compound semiconductor represented by $In_xAl_yGa_{(1-x-y)}N$($0\leq x\leq 1$, $0\leq y\leq 1$, and $0\leq x+y\leq 1$). In some embodiments, the first conductive semiconductor layer **142** may include an n-type GaN layer, and the second conductive semiconductor layer **146** may include a p-type GaN layer. The n-type impurity included in the n-type GaN layer may be Si, Ge, Sn, or the like. The p-type impurity included in the p-type GaN layer may be Mg, Zn, Be, or the like. The active layer **144** may emit light with a predetermined intensity of energy due to the recombination of electrons and holes. The active layer **144** may have at least one alternate structure of a quantum well layer and a quantum barrier layer. The quantum well layer may have a single quantum well structure or a multi-quantum well structure. In some embodiments, the active layer **144** may be formed of u-AlGaN. In other embodiments, the active layer **144** may have a multi-quantum well structure of GaN/AlGaN, InAlGaN/InAlGaN, or InGaN/AlGaN. To improve light-emitting efficiency of the active layer **144**, the depth of the quantum well, the stack number of pairs of quantum well layers and quantum barrier layers, and thicknesses of the quantum well layer and the quantum barrier layer in the active layer **144** may be varied.

[0051] In some embodiments, the light-emitting structure **140** may be formed by metal-organic chemical vapor deposition (MOCVD), hydride vapor phase epitaxy (HVPE), or molecular beam epitaxy (MBE).

[0052] FIG. **2**A is a cross-sectional view of an optical extraction film **120**A according to some embodiments of the present inventive concept that is employable as the optical extraction film **120** of the semiconductor light-emitting device **100** of FIG. **1**.

[0053] The optical extraction film **120**A may comprise a bonding layer **220** with a refractive index n4 that is larger than the first refractive index n1 of the substrate **110** illustrated in FIG. **1** and the second refractive index n2 of the nitride semiconductor thin film **130** illustrated in FIG. **1**.

[0054] FIG. **2**B shows a graph showing a refractive index difference in an exemplary structure including the substrate **110**, the optical extraction film **120**A, and the nitride semiconductor thin film **130**.

[0055] As illustrated in FIG. **2**B, in the semiconductor light-emitting device **100** of FIG. **1**, the nitride semiconductor thin film **130** may include a GaN monocrystalline layer and the optical extraction film **120** may be the optical extraction film **120**A illustrated in FIG. **2**A. The nitride semiconductor thin film **130** including a GaN monocrystalline layer may have a refractive index of about 2.48692 at a wavelength of 450 nm. When the substrate **110** is formed of sapphire, the substrate **110** may have a refractive index of about 1.77937 at a wavelength of 450 nm. The bonding layer **220** that constitutes the optical extraction film **120**A may have a refractive index that is larger than the refractive index of sapphire and is smaller than the refractive index of the GaN monocrystalline layer. For example, the bonding layer **220** may include a SiO_2, Ta_2O_5, HfO_2, ZnO, ZrO_2, or SiO_xN_y film ($x+y\leq 2$, $x>0$, and $y>0$). At a wavelength of 450 nm, a SiO_2 film may have a refractive index of about 1.55248, a Ta_2O_5 film may have a refractive index of about 1.83236, a HfO_2 film may have a refractive index of about 1.9597, a ZnO film may have a refractive index of about 2.1054, and ZrO_2 film may have a refractive index of about 2.23884. A SiO_xN_y film may have a refractive index of about 1.49 to about 1.92 at a wavelength of 450 nm according to a nitrogen (N) content, and the larger refractive index, the larger N content.

[0056] The bonding layer **220** may be formed by chemical vapor deposition (CVD), plasma-enhanced CVD (PECVD), high density plasma-enhanced chemical vapor deposition (HD-PECVD), atomic layer deposition (ALD), plasma-enhanced atomic layer deposition (PEALD), or physical vapor deposition (PVD). In some embodiments, during a deposition process for the bonding layer **220**, a refractive index of the bonding layer **220** may be controlled by adjusting power of a radio frequency (RF) and a deposition temperature.

[0057] FIG. **2**C is a cross-sectional view of the semiconductor light-emitting device **100** of FIG. **1** that includes the optical extraction film **120**A of FIG. **2**A as the optical extraction film **120**.

[0058] When light generated in the active layer **144** progresses from the nitride semiconductor thin film **130** having a relatively large refractive index to the substrate **110** with a refractive index that is smaller than the refractive index of the nitride semiconductor thin film **130**, even when a difference in the refractive indexes of the nitride semiconductor thin film **130** and the substrate **110** is large, due to the presence of the optical extraction film **120**A including the bonding layer **220** with a refractive index between the refractive index n1 of the substrate **110** and the refractive index n2 of the nitride semiconductor thin film **130**, it is highly likely that an incident angle of light generated in the active layer **144** progressing from the nitride semiconductor thin film **130** to the substrate **110** through the optical extraction film **120**A may be smaller than a critical angle that is an angle at which total reflection occurs. Accordingly, the most of light progressing from the active layer **144** to the nitride semiconductor thin film **130** is refracted into the optical extraction film **120**A without reflection and is extracted toward the outside the substrate **110**. Accordingly, when light from the active layer **144** arrives the substrate **110** from the nitride semiconductor thin film **130** through the optical extraction film **120**A, a pathway of light that is extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110** may be reduced, optical loss may be suppressed, and optical extraction efficiency may improve.

[0059] FIG. **2**A illustrates the optical extraction film **120**A including the single bonding layer **220** as the optical extraction film **120** of FIG. **1**. However, embodiments of the present inventive concept are not limited thereto. The optical extraction film **120** may have a multi-layer structure including a plurality of bonding layers.

[0060] FIG. **3**A is a cross-sectional view of an optical extraction film **120**B according to some embodiments of the present inventive concept that is employable as the optical extraction film **120** of the semiconductor light-emitting device **100** of FIG. **1**.

[0061] The optical extraction film **120**B may include a first bonding layer **322** and a second bonding layer **324**, which have different refractive indexes.

[0062] The first bonding layer **322** and the second bonding layer **324** respectively have refractive indexes n51 and n52 that are larger than the first refractive index n1 of the substrate **110** illustrated in FIG. **1**, and smaller than the second refractive index n2 of the nitride semiconductor thin film **130**. The refractive index n51 of the first bonding layer **322** may be different from the refractive index n52 of the second bonding layer **324**.

[0063] FIG. **3**B shows a graph showing a refractive index difference in an exemplary structure including the substrate **110**, the optical extraction film **120**B, and the nitride semiconductor thin film **130**.

[0064] As illustrated in FIG. **3**B, in the semiconductor light-emitting device **100** of FIG. **1**, the substrate **110** may be formed of sapphire, the nitride semiconductor thin film **130** may include a GaN monocrystalline layer, and the optical extraction film **120** may be the optical extraction film **120**B illustrated in FIG. **3**A. The first bonding layer **322** and the second bonding layer **324** that constitute the optical extraction film **120**B may have a refractive index that is larger than the refractive index of sapphire and is smaller than the refractive index of the GaN monocrystalline layer. The first bonding layer **322** and the second bonding layer **324** may be sequentially stacked in a direction from the substrate **110** to the nitride semiconductor thin film **130** in such a way that a bonding layer closer to the nitride semiconductor thin film **130** has a larger refractive index.

[0065] For example, the first bonding layer **322** and the second bonding layer **324** may each be formed of different materials selected from a SiO_2, Ta_2O_5, HfO_2, ZnO, ZrO_2, and SiO_xN_y film ($x+y\leq2$, $x>0$, and $y>0$).

[0066] FIG. **3**C is a cross-sectional view of the semiconductor light-emitting device **100** of FIG. **1** that includes the optical extraction film **120**C of FIG. **3**A as the optical extraction film **120**.

[0067] When light generated in the active layer **144** progresses from the nitride semiconductor thin film **130** having a relatively large refractive index to the substrate **110** with a refractive index that is smaller than the refractive index of the nitride semiconductor thin film **130**, even when a difference in the refractive indexes of the nitride semiconductor thin film **130** and the substrate **110** is large, due to the presence of the optical extraction film **120**B including the first bonding layer **322** and the second bonding layer **324** having the refractive indexes n51 and n52 between the refractive index n1 of the substrate **110** and the refractive index n2 of the nitride semiconductor thin film **130**, it is highly likely that an incident angle of light generated in the active layer **144** progressing from the nitride semiconductor thin film **130** to the substrate **110** through the optical extraction film **120**B may be smaller than a critical angle that is an angle at which total reflection occurs. Accordingly, the most of light progressing from the active layer **144** to the nitride semiconductor thin film **130** is refracted into the optical extraction film **120** without reflection and is extracted toward the outside the substrate **110**. Accordingly, when light from the active layer **144** arrives the substrate **110** from the nitride semiconductor thin film **130** through the optical extraction film **120**B, a pathway of light that is extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110** may be reduced, optical loss may be suppressed, and optical extraction efficiency may improve.

[0068] FIG. **4**A is a cross-sectional view of an optical extraction film **120**C according to some embodiments of the present inventive concept that is employable as the optical extraction film **120** of the semiconductor light-emitting device **100** of FIG. **1**.

[0069] The optical extraction film **120**C may include a first bonding layer **422**, a second bonding layer **424**, and a third bonding layer **426**, which have different refractive indexes.

[0070] The first bonding layer **422**, the second bonding layer **424**, and the third bonding layer **426** respectively have refractive indexes n61, n62, n63 that are larger than the first refractive index n1 of the substrate **110** illustrated in FIG. **1** and smaller than the second refractive index n2 of the nitride semiconductor thin film **130**. The refractive indexes n61, n62, n63 of the first bonding layer **422**, the second bonding layer **424**, and the third bonding layer **426** may be different from each other. In some embodiments, the first bonding layer **422**, the second bonding layer **424**, and the third bonding layer **426** may have a substantially identical thickness, but are not limited thereto.

[0071] FIG. **4**B shows a graph showing a refractive index difference in an exemplary structure including the substrate **110**, the optical extraction film **120**C, and the nitride semiconductor thin film **130**.

[0072] As illustrated in FIG. **4**B, in the semiconductor light-emitting device **100** of FIG. **1**, the substrate **110** may be formed of sapphire, the nitride semiconductor thin film **130** may include a GaN monocrystalline layer, and the optical extraction film **120** may be the optical extraction film **120**C illustrated in FIG. **4**A. The first bonding layer **422**, the second bonding layer **424**, and the third bonding layer **426** that constitute the optical extraction film **120**C may have a refractive index that is larger than the refractive index of sapphire and is smaller than the refractive index of the GaN monocrystalline layer. The first bonding layer **422**, the second bonding layer **424**, and the third bonding layer **426** may be sequentially stacked in a direction from the substrate **110** to the nitride semiconductor thin film **130** in such a way that a bonding layer closer to the nitride semiconductor thin film **130** has a larger refractive index.

[0073] For example, the first bonding layer **422**, the second bonding layer **424**, and the third bonding layer **426** may each be formed of different materials selected from a SiO_2, Ta_2O_5, HfO_2, ZnO, ZrO_2, or SiO_xN_y film ($x+y\leq 2$, $x>0$, and $y>0$).

[0074] When the optical extraction film **120**C of FIG. **4**A is used, as described in connection with FIGS. **2**C and **3**C, when light from the active layer **144** arrives the substrate **110** from the nitride semiconductor thin film **130** through the optical extraction film **120**C, a pathway of light that is extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110** may be reduced, optical loss may be suppressed, and optical extraction efficiency may improve.

[0075] FIG. **5**A is a cross-sectional view of an optical extraction film **120**D according to some embodiments of the present inventive concept that is employable as the optical extraction film **120** of the semiconductor light-emitting device **100** of FIG. **1**.

[0076] The optical extraction film **120**C may include a first bonding layer **522**, a second bonding layer **524**, and a third bonding layer **526**, which have different refractive indexes.

[0077] The first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526** respectively have refractive indexes n71, n72, and n73 that are larger than the first refractive index n1 of the substrate **110** illustrated in FIG. **1** and smaller than the second refractive index n2 of the nitride semiconductor thin film **130**. The refractive indexes n71, n72, and n73 of the first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526** may be different from each other. In some embodiments, the first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526** may have different thicknesses TA, TB, and TC. In other embodiments, from among the first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526**, the second bonding layer **524** disposed between the first bonding layer **522** and the third bonding layer **526** may have the largest thickness. Also, a thickness TA of the first bonding layer **522** and a thickness TC of the third bonding layer **526** may be smaller than the thickness TB of the second bonding layer **524**. In other embodiments, the thickness TA of the first bonding layer **522** may be the same as the thickness TC of the third bonding layer **526**. However, the present inventive concept is not limited to the exemplary structures, the first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526** may have various thicknesses.

[0078] FIG. **5**B shows a graph showing a refractive index difference in an exemplary structure including the substrate **110**, the optical extraction film **120**D, and the nitride semiconductor thin film **130**.

[0079] As illustrated in FIG. **5**B, in the semiconductor light-emitting device **100** of FIG. **1**, the substrate **110** may be formed of sapphire, the nitride semiconductor thin film **130** may include a GaN monocrystalline layer, and the optical extraction film **120** may be the optical extraction film **120**C illustrated in FIG. **5**A. The first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526** that constitute the optical extraction film **120**D may have a refractive index that is larger than the refractive index of sapphire and is smaller than the refractive index of the GaN monocrystalline layer. The first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526** may be sequentially stacked in a direction from the substrate **110** to the nitride semiconductor thin film **130** in such a way that a bonding layer closer to the nitride semiconductor thin film **130** has a larger refractive index.

[0080] For example, the first bonding layer **522**, the second bonding layer **524**, and the third bonding layer **526** may each be formed of different materials selected from a SiO_2, Ta_2O_5, HfO_2, ZnO, ZrO_2, or SiO_xN_y film ($x+y\leq 2$, $x>0$, and $y>0$).

[0081] When the optical extraction film **120**D of FIG. **5**A is used, like described in connection with FIGS. **2**C and **3**C, when light from the active layer **144** arrives the substrate **110** from the nitride semiconductor thin film **130** through the optical extraction film **120**D, a pathway of light that is extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110** may be reduced, optical loss may be suppressed, and optical extraction efficiency may improve.

[0082] Bonding layers that constitute the optical extraction films **120**B, **120**C, and **120**D of FIGS. **3**A, **4**A and **5**A have refractive indexes that increase in the form of a step structure in the direction from the substrate **110** to the nitride semiconductor thin film **130** illustrated in FIG. **1**. However, the present inventive concept is not limited thereto. According to an embodiment of the present inventive concept, the optical extraction film **120** illustrated in FIG. **1** may include a GRI bonding layer having a graded refractive index (GRI).

[0083] FIG. **6**A is a cross-sectional view of an optical extraction film **120**E according to some embodiments of the present inventive concept that is employable as the optical extraction film **120** of the semiconductor light-emitting device **100** of FIG. **1**.

[0084] The optical extraction film **120**E may include a GRI bonding layer **620** with a refractive index that continuously changes between the first refractive index n1 of the substrate **110** illustrated in FIG. **1** and the second refractive index n2 of the nitride semiconductor thin film **130** illustrated in FIG. **1**.

[0085] The GRI bonding layer **620** may be formed of a $Ti_xSi_{1-x}O_y$ film ($0.05 \le x \le 0.95$, $0.2 \le y \le 2$), a TiO_x film ($0.2 \le x \le 2$), a SiO_x film ($0.2 \le x \le 2$), or a combination thereof.

[0086] When the GRI bonding layer **620** includes a $Ti_xSi_{1-x}O_y$ film, the larger Ti content in the $Ti_xSi_{1-x}O_y$ film, the $Ti_xSi_{1-x}O_y$ film may have the larger refractive index. Accordingly, in the GRI bonding layer **620**, a portion of the GRI bonding layer **620** closer to a bottom surface **622** of the GRI bonding layer **620** may have a lower Ti content in the $Ti_xSi_{1-x}O_y$ film, and a portion of the GRI bonding layer **620** closer to a top surface **624** of the GRI bonding layer **620** may have a larger Ti content in the $Ti_xSi_{1-x}O_y$ film.

[0087] In some embodiments, a $Ti_xSi_{1-x}O_y$ film that constitutes the GRI bonding layer **620** may be formed by plasma-enhanced atomic layer deposition (PEALD). For example, a first atomic layer depostion (ALD) cycle for forming atom layers of TiO_2 having a relatively great refractive index, and a second ALD cycle for forming atom layers of SiO_2 having a relatively low refractive index are alternately performed, and the refractive index and thickness of the GRI bonding layer **620** may be controlled by adjusting a ratio of the number of first ALD cycles to the number of the second ALD cycles. When the number of second ALD cycles is larger than the number of first ALD cycles, the Si content increases and thus, the refractive index may be relatively small. On the other hand, when the number of first ALD cycles is larger than the number of second ALD cycles, the Ti content increases and thus, the refractive index may be relatively great.

[0088] In some embodiments, the GRI bonding layer **620** may have a stack structure including a SiO_x film, a $Ti_xSi_{1-x}O_y$ film, and a TiO_x film, which are sequentially stacked. In this regard, a SiO_x film is first formed to constitute the bottom surface **622** of the GRI bonding layer **620**, and then, a $Ti_xSi_{1-x}O_y$ film and a TiO_x film are sequentially formed thereon. By doing so, the GRI bonding layer **620** may have an increasing refractive index in a thickness direction thereof from the bottom surface **622** to the top surface **624** of the GRI bonding layer **620**.

[0089] In other embodiments, the $Ti_xSi_{1-x}O_y$ film of the GRI bonding layer **620** may be formed by sputtering. For example, in a sputtering chamber containing a $Ti_xSi_{1-x}O_y$ target, the GRI bonding layer **620** may be formed in the presence of a reactive gas comprising argon (Ar) gas, oxygen (O_2) gas, nitrogen (N_2) gas, or a combination thereof. An atom ratio or weight ratio of Ti to Si in the $Ti_xSi_{1-x}O_y$ target may be controlled by changing x value of the $Ti_xSi_{1-x}O_y$ target. When the x value of the $Ti_xSi_{1-x}O_y$ target decreases, the Si content increases and thus, the refractive index may relatively decrease, and when the x value increases, the Ti content increases and thus, the refractive index may relatively increase.

[0090] When the GRI bonding layer **620** includes a SiO_xN_y film, the larger N content in the SiO_xN_y film, the SiO_xN_y film may have a larger refractive index. Accordingly, in the GRI bonding layer **620**, a portion of the GRI bonding layer **620** closer to a bottom surface **622** of the GRI bonding layer **620** may have a lower N content in the SiO_xN_y film, and a portion of the GRI bonding layer **620** closer to a top surface **624** of the GRI bonding layer **620** may have a larger N content in the $Ti_xSi_{1-x}O_y$ film.

[0091] FIGS. **6**B to **6**E show graphs illustrating refractive index distributions in the GRI bonding layer **620** illustrated in FIG. **6**A.

[0092] Referring to FIG. **6**B, in the semiconductor light-emitting device **100** of FIG. **1**, the nitride semiconductor thin film **130** may include a GaN monocrystalline layer and the optical extraction film **120** may be the optical extraction film **120**E illustrated in FIG. **6**A. The GRI bonding layer **620** that constitutes the optical extraction film **120**E may have, as in section "V1", a variable refractive index that continuously changes at a constant variation rate from the first refractive index n1 to the second refractive index n2, from the bottom surface **622** of the GRI bonding layer **620** contacting the substrate **110** to the top surface **624** of the GRI bonding layer **620** contacting the nitride semiconductor thin film **130** in the thickness direction of the GRI bonding layer **620**.

[0093] Referring to FIG. **6**C, the GRI bonding layer **620** that constitutes the optical extraction film **120**E may have the same structure as described in connection with FIG. **6**B, except that as in section "V2", although the GRI bonding layer **620** has a variable refractive index from the first refractive index n1 to the second refractive index n2, from the bottom surface **622** contacting the substrate **110** to the top surface **624** contacting the nitride semiconductor thin film **130** in the thickness direction of the GRI bonding layer **620**, portions of the GRI bonding layer **620** near the bottom surface **622** and the top surface **624** may undergo a relatively small refractive index change, and a central portion of GRI bonding layer **620** may undergo a relatively large refractive index change.

[0094] Referring to FIG. **6**D, the GRI bonding layer **620** that constitutes the optical extraction film **120**E may have the same structure as described in connection with FIG. **6**B, except that as in section "V3", although the GRI bonding layer **620** has variable a refractive index from the first refractive index n1 to the second refractive index n2, from the bottom surface **622** contacting the substrate **110** to the top surface **624** contacting the nitride semiconductor thin film **130** in the thickness direction of the GRI bonding layer **620**, a portion of the GRI bonding layer **620** near the bottom surface **622** may undergo a relatively small refractive index change, and a central portion of GRI bonding layer **620** and a portion of the GRI bonding layer **620** near the top surface **624** thereof may undergo a relatively large refractive index change.

[0095] Referring to FIG. **6**E, the GRI bonding layer **620** that constitutes the optical extraction film **120**E may have the same structure as described in connection with FIG. **6**B, except that as in section "V4", although the GRI bonding layer **620** has a variable refractive index from the first refractive index n1 to the second refractive index n2, from the bottom surface **622** contacting the substrate **110** to the top surface **624** contacting the nitride semiconductor thin film **130** in the thickness direction of the GRI bonding layer **620**, a portion of the GRI bonding layer **620** near the bottom surface **622** may undergo a relatively large refractive index change, and a central portion of GRI bonding layer **620** and a portion of the GRI bonding layer **620** near the top surface **624** thereof may undergo a relatively small refractive index change.

[0096] When the optical extraction film **120**E of FIG. **6**A is used, like described in connection with FIGS. **2**C and **3**C, when light from the active layer **144** arrives the substrate **110** from the nitride semiconductor thin film **130** through the optical extraction film **120**E, a pathway of light that is extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110** may be reduced, optical loss may be suppressed, and optical extraction efficiency may be improved.

[0097] FIG. **7** is a cross-sectional view of an optical extraction film **120**F according to some embodiments of the present inventive concept that is employable as the optical extraction film **120** of the semiconductor light-emitting device **100** of FIG. **1**.

[0098] The optical extraction film **120**F may include a first bonding layer **722**, a second bonding layer **724**, and a third bonding layer **726**, which have different refractive indexes.

[0099] The first bonding layer **722**, the second bonding layer **724**, and the third bonding layer **726** respectively have refractive indexes that are larger than the first refractive index n1 of the substrate **110** illustrated in FIG. **1** and smaller than the second refractive index n2 of the nitride semiconductor thin film **130**. The refractive indexes of the first bonding layer **722**, the second bonding layer **724**, and the third bonding layer **726** may be different from each other.

[0100] The first bonding layer **722** may include a plurality of island patterns **722**A that are spaced from each other. However, the present inventive concept is not limited to the exemplary structure. According to the present inventive concept, at least one bonding layer of the first bonding layer **722**, the second bonding layer **724**, and the third bonding layer **726** may include a plurality of island patterns that are spaced from each other. For example, the second bonding layer **724** or the third bonding layer **726** may include a plurality of island patterns that are spaced from each other. Also, although the island patterns **722**A of the first bonding layer **722** illustrated in FIG. **7** have the same shape and the same size, the present inventive concept is not limited thereto. The island pattern **722**A may have various other shapes and sizes.

[0101] In some embodiments, the first bonding layer **722**, the second bonding layer **724**, and the third bonding layer **726** may each be formed of different materials selected from a SiO_2, Ta_2O_5, HfO_2, ZnO, ZrO_2, and SiO_xN_y film ($x+y\leq2$, $x>0$, and $y>0$).

[0102] In some embodiments, the first bonding layer **722** formed of the island pattern **722**A is formed as follows: first, a continuous film-type preliminary first bonding layer (not shown) is formed, and then, the preliminary first bonding layer is patterned by dry etching or wet etching.

[0103] When the optical extraction film **120**F of FIG. **7** is used, like described in connection with FIGS. **2**C and **3**C, when light from the active layer **144** arrives the substrate **110** from the nitride semiconductor thin film **130** through the optical extraction film **120**F, a pathway of light that is extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110** may be reduced, optical loss may be suppressed, and optical extraction efficiency may improve. Also, since the optical extraction film **120**F includes the first bonding layer **722** including the island pattern **722**A, a critical angle may increase due to the island pattern **722**A and thus, even when light generated in the active layer **144** enters the optical extraction film **120**F at an angle that is larger than a critical angle, which is an angle at which total reflection may occur, light may transmit through the optical extraction film **120**F without total reflection due to the island patterns **722**A, entering the substrate **110**. Accordingly, an optical extraction efficiency may be further improved.

[0104] FIG. **8** is a cross-sectional view of an optical extraction film **120**G according to some embodiments of the present inventive concept that is employable as the optical extraction film **120** of the semiconductor light-emitting device **100** of FIG. **1**.

[0105] The optical extraction film **120**G may include a first bonding layer **822**, a second bonding layer **824**, and a third bonding layer **826**, which have different refractive indexes.

[0106] The first bonding layer **822**, the second bonding layer **824**, and the third bonding layer **826** respectively have refractive indexes that are larger than the first refractive index n1 of the substrate **110** illustrated in FIG. **1** and smaller than the second refractive index n2 of the nitride semiconductor thin film **130**. The refractive indexes of the first bonding layer **822**, the second bonding layer **824**, and the third bonding layer **826** may be different from each other. In some embodiments, at least a portion of at least one bonding layer of the first bonding layer **822**, the second bonding layer **824**, and the third bonding layer **826** may have an uneven structure. In FIG. **8**, uneven patterns **822**A are formed only in the first bonding layer **822**. However, the present inventive concept is not limited thereto. For example, at least one of the second bonding layer **824** and the third bonding layer **826** may also have an uneven pattern. Also, although the uneven patterns **822**A of the first bonding layer **822** illustrated in FIG. **8** have the same shape and the same size, the present inventive concept is not limited thereto. The uneven patterns **822**A may have various other shapes and sizes.

[0107] In some embodiments, the first bonding layer **822**, the second bonding layer **824**, and the third bonding layer **826** may each be formed of different materials selected from a SiO_2, Ta_2O_5, HfO_2, ZnO, ZrO_2, and SiO_xN_y film ($x+y\leq2$, $x>0$, and $y>0$).

[0108] In some embodiments, the first bonding layer **822** comprising the uneven patterns **822**A is formed as follows: first, a continuous film-type preliminary first bonding layer (not shown) is formed, and then, the preliminary first bonding layer is etched by dry etching or wet etching in such a way that only a part of a total thickness is removed.

[0109] When the optical extraction film **120**G of FIG. **8** is used, like described in connection with FIGS. **2**C and **3**C, when light from the active layer **144** arrives the substrate **110** from the nitride semiconductor thin film **130** through the optical extraction film **120**G, a pathway of light that is extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110** may be reduced, optical loss may be suppressed, and optical extraction efficiency may be improved. Also, since the optical extraction film **120**G includes the first bonding layer **822** comprising the uneven patterns **822**A, a critical angle may increase due to the uneven patterns **822**A and thus, even when light generated in the active layer **144** enters the optical extraction film **120**G at an angle that is larger than a critical angle, which is an angle at which total reflection may occur, light may transmit through the optical extraction film **120**G to the substrate **110** without total reflection by virtue of the uneven patterns **822**A. Accordingly, an optical extraction efficiency may be further improved.

[0110] FIG. **9** is a cross-sectional view of a semiconductor light-emitting device **900** according to some embodiments of the present inventive concept.

[0111] The semiconductor light-emitting device **900** illustrated in FIG. **9** has a flip-chip mounted vertical structure. In FIG. **9**, the same reference numerals denote the same elements as those shown in FIG. **1**, and the detailed description thereof are omitted herein to simplify the description.

[0112] Referring to FIG. **9**, the semiconductor light-emitting device **900** includes an n-type electrode **912** formed on a first conductive semiconductor layer **142**, and a p-type electrode **914** formed on a second conductive semiconductor layer **146**. The n-type electrode **912** and the p-type electrode **914** are respectively connected to a first conductive pattern **942** and a second conductive pattern **944** formed on a top surface of the submount **940** through conductive adhesion layers **932** and **934**.

[0113] The submount **940** may be formed of a material with excellent thermal conductivity. In some embodiments, the submount **940** may be formed of Si. However, a material for forming the submount **940** is not limited thereto.

[0114] The conductive adhesion layers **932** and **934** may be formed of a thin film or a stud bump. In some embodiments, the conductive adhesion layers **932** and **934** may be formed of Au, Sn, Ag, Cu, or a combination thereof. However, a material for forming the conductive adhesion layers **932** and **934** is not limited thereto.

[0115] In the semiconductor light-emitting device **900**, light generated in the active layer **144** may be emitted without having constant directivity, and light emitted toward the substrate **110** may be extracted from the substrate **110** through the optical extraction film **120**. As described in connection with FIGS. **2**A to **8**, the optical extraction film **120** may include at least one bonding layer having a refractive index between a refractive index of the substrate **110** and a refractive index of the nitride semiconductor thin film **130**. In particular, from the nitride semiconductor thin film **130** to the substrate **110** through the optical extraction film **120**, a refractive index difference between neighboring films is relatively small, and also, from the nitride semiconductor thin film **130** to the substrate **110**, a refractive index sequentially changes. Accordingly, when light generated in the active layer **144** progresses from the nitride semiconductor thin film **130** to the substrate **110** through the optical extraction film **120**, there is little possibility of the reflection of the light by total reflection caused by the refractive index difference. And, by reducing a pathway of light extracted from the nitride semiconductor thin film **130** to the outside through the substrate **110**, optical loss may be suppressed and optical extraction efficiency may be improved.

[0116] FIGS. **10**A to **10**D are cross-sectional views for explaining a process for forming the semiconductor light-emitting device **900**, according to some embodiments of the present inventive concept. In FIGS. **10**A to **10**D, the same reference numerals denote the same elements as those shown in FIGS. **1** and **9**, and accordingly, detailed description thereof will be omitted.

[0117] Referring to FIG. **10**A, a nitride semiconductor monocrystalline bulk **30** is grown by hydride vapor phase epitaxy (HVPE), metal-organic chemical vapor deposition (MOCVD), or molecular beam epitaxy (MBE), and then, a portion of the nitride semiconductor monocrystalline bulk **30** is cut along a cut line **30**A to separate into two partions, and the cut line **30**A is polished to form a nitride semiconductor thin film **130** having a predetermined thickness.

[0118] The nitride semiconductor thin film **130** may have a thickness D of about 0.1 to 100 μm

[0119] In some embodiments, the nitride semiconductor monocrystalline bulk **30** may be formed of a GaN monocrystalline bulk. The nitride semiconductor thin film **130** formed of GaN may have an N surface (nitrogen atom surface) **130**N, and a Ga surface (gallium atom surface) **130**G that is opposite to the N surface **130**N.

[0120] Referring to FIG. **10**B, the substrate **110** that is a heterogeneous substrate having a chemical composition different from that in the nitride semiconductor thin film **130**, and then, the optical extraction film **120** that includes at least one bonding layer with a refractive index n3 that is different from a refractive index of the nitride semiconductor thin film **130** is formed on the substrate **110**, and the nitride semiconductor thin film **130** obtained by using the method explained in connection with FIG. **10**A is bonded to the substrate **110** by using the optical extraction film **120** as an adhesive layer.

[0121] When the nitride semiconductor thin film **130** is formed of GaN, the nitride semiconductor thin film **130** is bonded to the optical extraction film **120** in such a way that the N surface **130**N of the nitride semiconductor thin film **130** faces the top surface **124** of the optical extraction film **120**.

[0122] Thereafter, the first conductive semiconductor layer **142**, the active layer **144**, and the second conductive semiconductor layer **146** are sequentially grown from the Ga surface **130**G of the nitride semiconductor thin film **130** to form a light-emitting structure **140**.

[0123] In some embodiments, the light-emitting structure **140** may be formed by MOCVD, HVPE, or MBE.

[0124] Referring to FIG. **10**C, the light-emitting structure **140** is mesa-etched to expose a portion of the first conductive semiconductor layer **142**.

[0125] Referring to FIG. **10**D, the n-type electrode **912** is formed on the exposed portion of the first conductive semiconductor layer **142**, and then, the p-type electrode **914** is formed on the second conductive semiconductor layer **146**.

[0126] Thereafter, the n-type electrode **912** and the p-type electrode **914** are respectively connected to the first conductive pattern **942** and second conductive pattern **944** formed on the top surface of the submount **940** through the conductive adhesion layers **932** and **934**, thereby obtaining the semiconductor light-emitting device **900** of FIG. **9**.

[0127] FIG. **11** is a diagram illustrating a dimming system **1000** including a nitride semiconductor light-emitting device according to some embodiments of the present inventive concept.

[0128] Referring to FIG. **11**, the dimming system **1000** includes a light-emitting module **1020** and a power supplier **1030** which are disposed on a structure **1010**.

[0129] The light-emitting module **1020** includes a plurality of light-emitting device packages **1024**. Each of the light-emitting device package **1024** may include at least one of the semiconductor light-emitting devices **100**, **200**, **300**, and **400** which have been explained in connection with FIGS. **1** to **4**.

[0130] The power supplier **1030** may include an interface **1032** through which power is input, and a power controller **1034** that controls power supplied to the light-emitting module **1020**. The interface **1032** may include a fuse for blocking excess current and an electromagnetic wave shielding filter for shielding an electromagnetic wave glitch. The power controller **1034** may include a rectifying section and a soothing section that convert an alternate current input as power into a direct current, and a constant voltage controller for converting into a voltage appropriate for the light-emitting module **1020**. The power supplier **1030** may include a feedback circuit apparatus that compares an intensity of light from the plurality of light-emitting device packages **1024** and an intensity of light that is set in advance, and a memory apparatus for storing information about, for example, target brightness or color rendering.

[0131] The dimming system **1000** may be used as an interior illumination, such as a backlight unit, a lamp, or a flat panel illumination used in a display apparatus, such as a liquid crystal display apparatus including an image panel, and an exterior illumination, such as street light, a sign, or a notice plane. Also, the dimming system **1000** may be used as an illumination device for various transportation means, for example, an illumination for vehicles, ships, or airplanes, and may be household appliances, such as TV, a refrigerator, or the like, or a medical device.

[0132] While the foregoing has described what are considered to be the best mode and/or other examples, it is understood that various modifications may be made therein and that the subject matter disclosed herein may be implemented in various forms and examples, and that the teachings may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all applications, modifications and variations that fall within the true scope of the present teachings.

What is claimed is:

1. A semiconductor light-emitting device comprising:

a substrate having a first refractive index;

a nitride semiconductor layer disposed on the substrate and having a second refractive index that is different from the first refractive index;

a light-emitting structure disposed on the nitride semiconductor layer and including a first conductive semiconductor layer, an active layer, and a second conductive semiconductor layer; and

an optical extraction film disposed between the substrate and the nitride semiconductor layer and having a refractive index between the first refractive index and the second refractive index.

2. The semiconductor light-emitting device of claim **1**, wherein:

the optical extraction film includes a plurality of bonding layers having different refractive indexes included in a range from the first refractive index to the second refractive index, and

the bonding layers are stacked from the substrate to the nitride semiconductor layer in such a sequence that a bonding layer with a larger refractive index is disposed closer to the nitride semiconductor layer.

3. The semiconductor light-emitting device of claim **1**, wherein:

the first refractive index is smaller than the second refractive index,

the optical extraction film includes a plurality of bonding layers with different refractive indexes, and

the bonding layers are stacked from the substrate to the nitride semiconductor layer in such a sequence that a bonding layer with a larger refractive index is disposed closer to the nitride semiconductor layer.

4. The semiconductor light-emitting device of claim **3**, wherein:

the bonding layers of the optical extraction film are stacked in such a way that a refractive index increases in the form of a step structure in a thickness direction of the optical extraction film from the substrate to the nitride semiconductor layer.

5. The semiconductor light-emitting device of claim **1**, wherein:

the optical extraction film includes a plurality of bonding layers with different refractive indexes, and

the plurality of bonding layers includes:

a bottom surface bonding layer having the smallest refractive index among the plurality of bonding layers and contacts the substrate,

a top surface bonding layer having the largest refractive index among the plurality of bonding layers and being in contact with the nitride semiconductor layer, and

a middle bonding layer having a refractive index between a refractive index of the bottom surface bonding layer and a refractive index of the top surface bonding layer and being disposed between the bottom surface bonding layer and the top surface bonding layer.

6. The semiconductor light-emitting device of claim **5**, wherein:

the bottom surface bonding layer, the top surface bonding layer, and the middle bonding layer have identical thicknesses.

7. The semiconductor light-emitting device of claim **5**, wherein:

the bottom surface bonding layer, the top surface bonding layer, and the middle bonding layer have different thicknesses.

8. The semiconductor light-emitting device of claim **5**, wherein:

from among the bottom surface bonding layer, the top surface bonding layer, and the middle bonding layer, the middle bonding layer has the largest thickness.

9. The semiconductor light-emitting device of claim **1**, wherein:

the optical extraction film includes a plurality of bonding layers with different refractive indexes, and

at least one bonding layer of the plurality of bonding layers includes a plurality of island patterns that are spaced apart from each other.

10. The semiconductor light-emitting device of claim **1**, wherein:

the optical extraction film includes a plurality of bonding layers with different refractive indexes, and

at least a portion of at least one of the bonding layers has an uneven pattern.

11. The semiconductor light-emitting device of claim **1**, wherein:

the optical extraction film includes has a graded refractive index (GRI) bonding layer with a GRI.

12. The semiconductor light-emitting device of claim **11**, wherein the GRI bonding layer comprises:

a $Ti_xSi_{1-x}O_y$ film ($0.05 \leq x \leq 0.95$ and $0.2 \leq y \leq 2$), a TiO_x film ($0.2 \leq x \leq 2$), a SiO_x film ($0.2 \leq x \leq 2$), or a combination thereof.

13. A semiconductor light-emitting device comprising:

a substrate;

an optical extraction film in contact with a surface of the substrate and including at least one bonding layer having a refractive index that is larger than a refractive index of the substrate;

a nitride semiconductor layer in contact with a surface of the optical extraction film and having a refractive index that is equal to or larger than a refractive index of a portion of the optical extraction film of which refractive index is the largest from among all the portions of the optical extraction film; and

a light-emitting structure disposed on the nitride semiconductor layer and including a first conductive semiconductor layer, an active layer, and a second conductive semiconductor layer.

14. The semiconductor light-emitting device of claim **13**, wherein:

the optical extraction film includes a plurality of bonding layers with different refractive indexes included in a range that is larger than the refractive index of the substrate and is equal to or smaller than the refractive index of the nitride semiconductor layer, and

the plurality of bonding layers are stacked from the substrate to the nitride semiconductor layer in such a sequence that a bonding layer with a larger refractive index is disposed closer to the nitride semiconductor layer.

15. The semiconductor light-emitting device of claim **13**, wherein:

the optical extraction film includes a graded refractive index (GRI) bonding layer with a GRI.

16. A dimming system comprising a semiconductor light-emitting device, the semiconductor light-emitting device including:

a substrate;

an optical extraction film being in contact with a surface of the substrate and including at least one bonding layer having a refractive index that is greater larger than a refractive index of the substrate;

a nitride semiconductor layer being in contact with a surface of the optical extraction film and having a refractive index that is equal to or greater larger than a refractive index of a portion of the optical extraction film of which refractive index is the largest from among all the portions of the optical extraction film; and

a light-emitting structure disposed on the nitride semiconductor layer and including a first conductive semiconductor layer, an active layer, and a second conductive semiconductor layer.

17. The system of claim **16**, wherein the optical extraction film comprises a GRI bonding layer including:

a $Ti_xSi_{1-x}O_y$ film ($0.05 \le x \le 0.95$ and $0.2 \le y \le 2$), a TiO_x film ($0.2 \le x \le 2$), a SiO_x film ($0.2 \le x \le 2$), or a combination thereof.

18. The system of claim **16**, wherein:

the optical extraction film includes a plurality of bonding layers with different refractive indexes, and

at least a portion of at least one of the bonding layers has an uneven pattern.

19. The system of claim **16**, wherein:

the optical extraction film includes a plurality of bonding layers with different refractive indexes, and

at least one bonding layer of the plurality of bonding layers includes a plurality of island patterns that are spaced apart from each other.

20. The system of claim **18**, wherein:

the plurality of bonding layers are stacked from the substrate to the nitride semiconductor layer in such a sequence that a bonding layer with a larger refractive index is disposed closer to the nitride semiconductor layer.

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