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(54) **METHOD OF MANUFACTURING AN LED**

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H01L 21/20 (2006.01)

(52) **U.S. Cl.** **438/141**; 438/91; 438/602; 257/E21.053; 257/E21.126; 257/E21.127; 257/E21.352

(58) **Field of Classification Search** 438/91, 438/141, 513, 602, 603, 604, 606, 608, 650, 438/686

See application file for complete search history.

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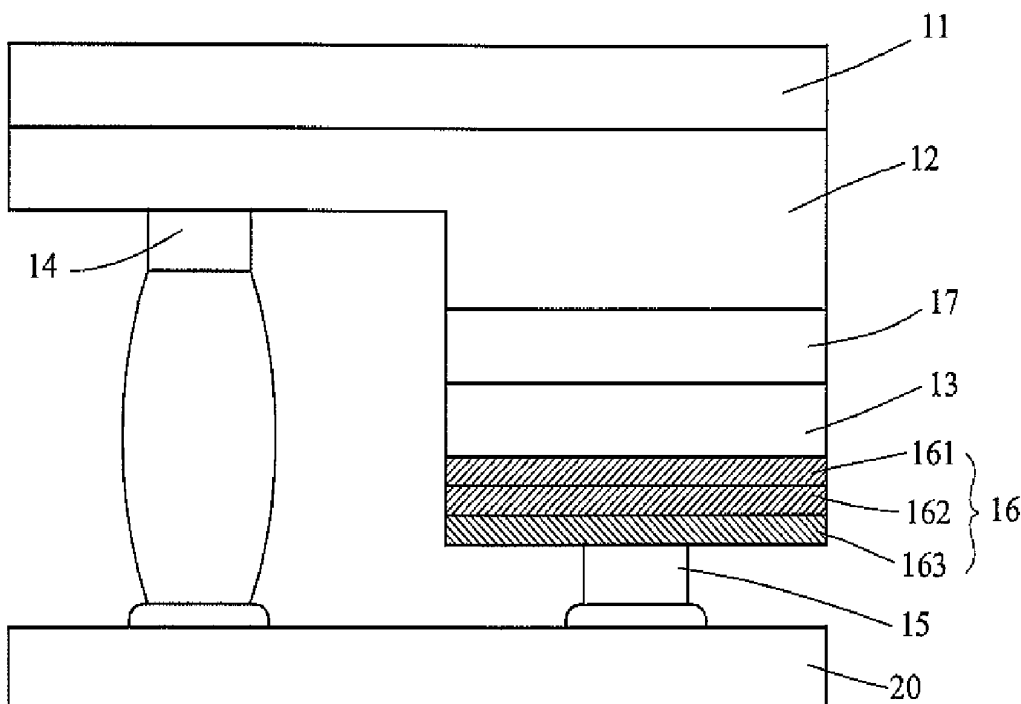
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(57) **ABSTRACT**

A method of manufacturing an LED of high reflectivity includes forming a substrate; depositing an n-type GaN layer on the substrate; depositing an active layer on a first portion of the n-type GaN layer; attaching an n-type metal electrode to a second portion of the n-type GaN layer; depositing a p-type GaN layer on the active layer; forming a metal reflector on the p-type GaN layer; attaching a p-type metal electrode to the metal reflector; and attaching the p-type metal electrode and the n-type metal electrode to an epitaxial layer respectively. The metal reflector includes a transparent layer, an Ag layer, and an Au layer. The transparent layer and the Ag layer are formed by annealing in a furnace, and the Au layer is subsequently coated on the Ag layer.

7 Claims, 10 Drawing Sheets



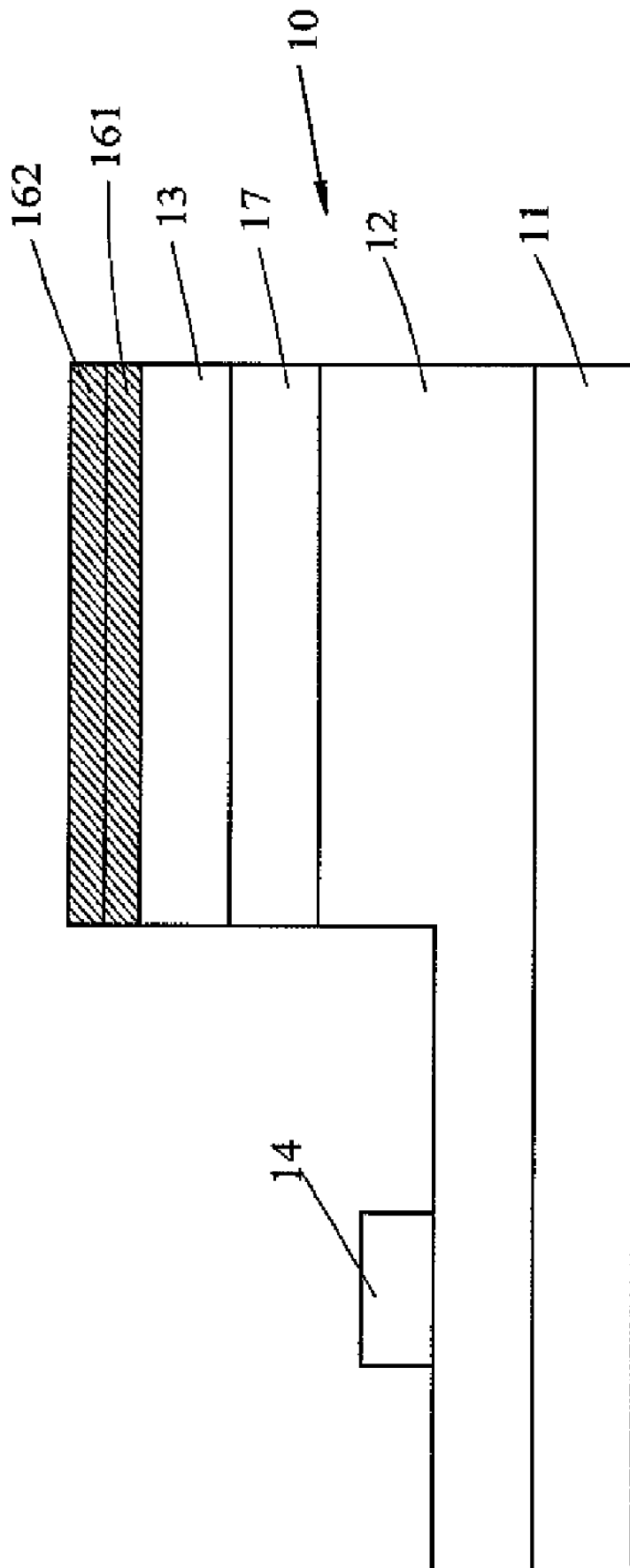


FIG. 1

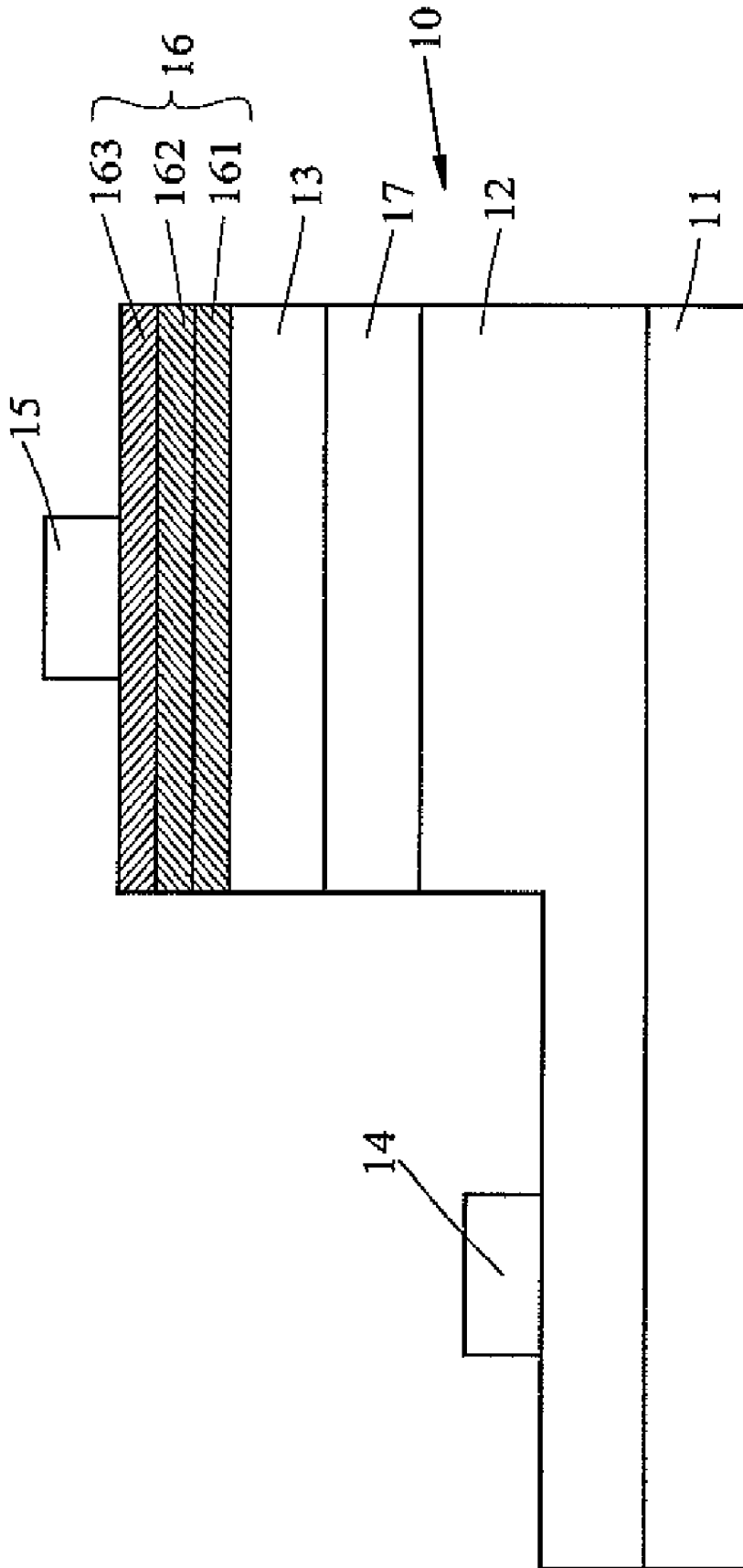


FIG. 2

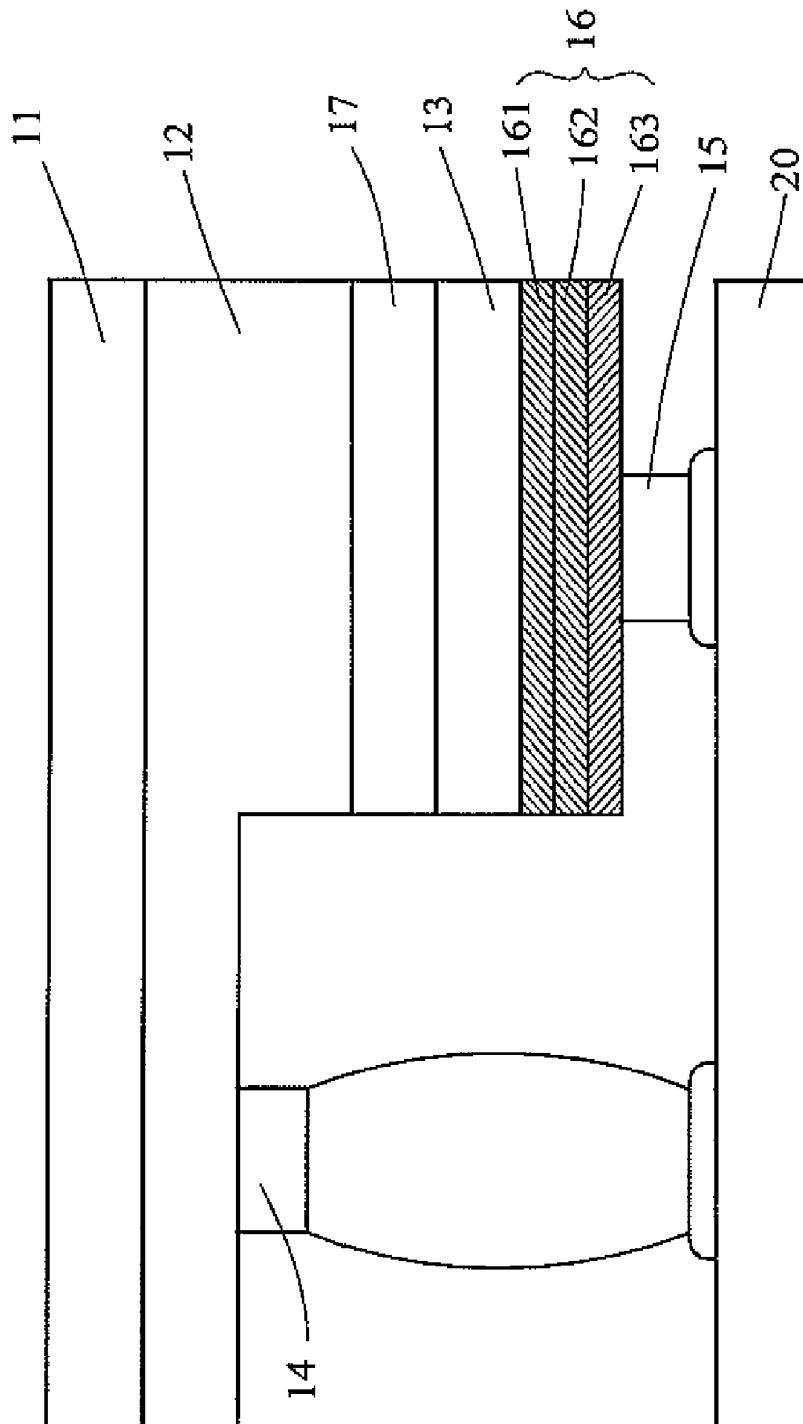


FIG. 3

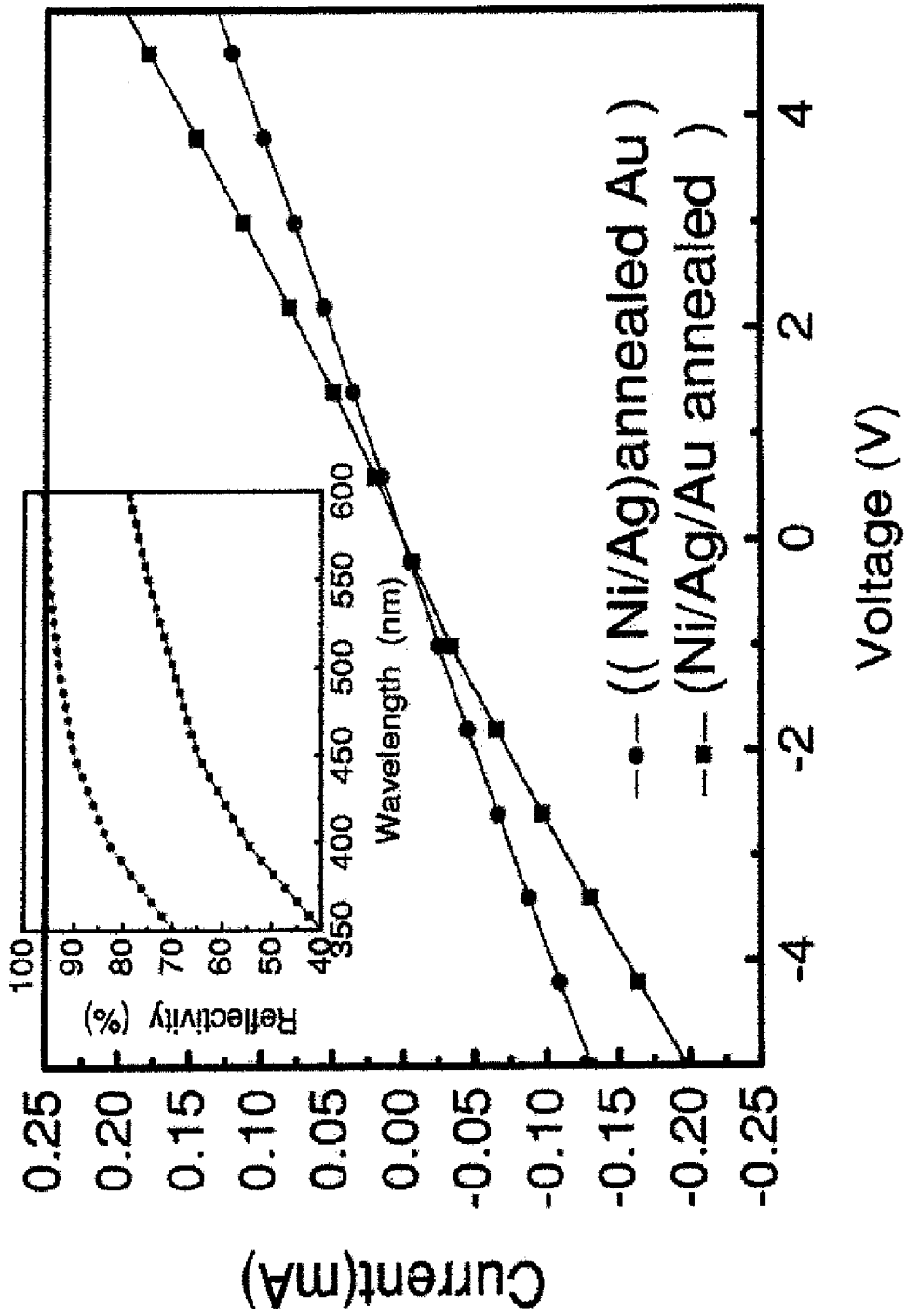
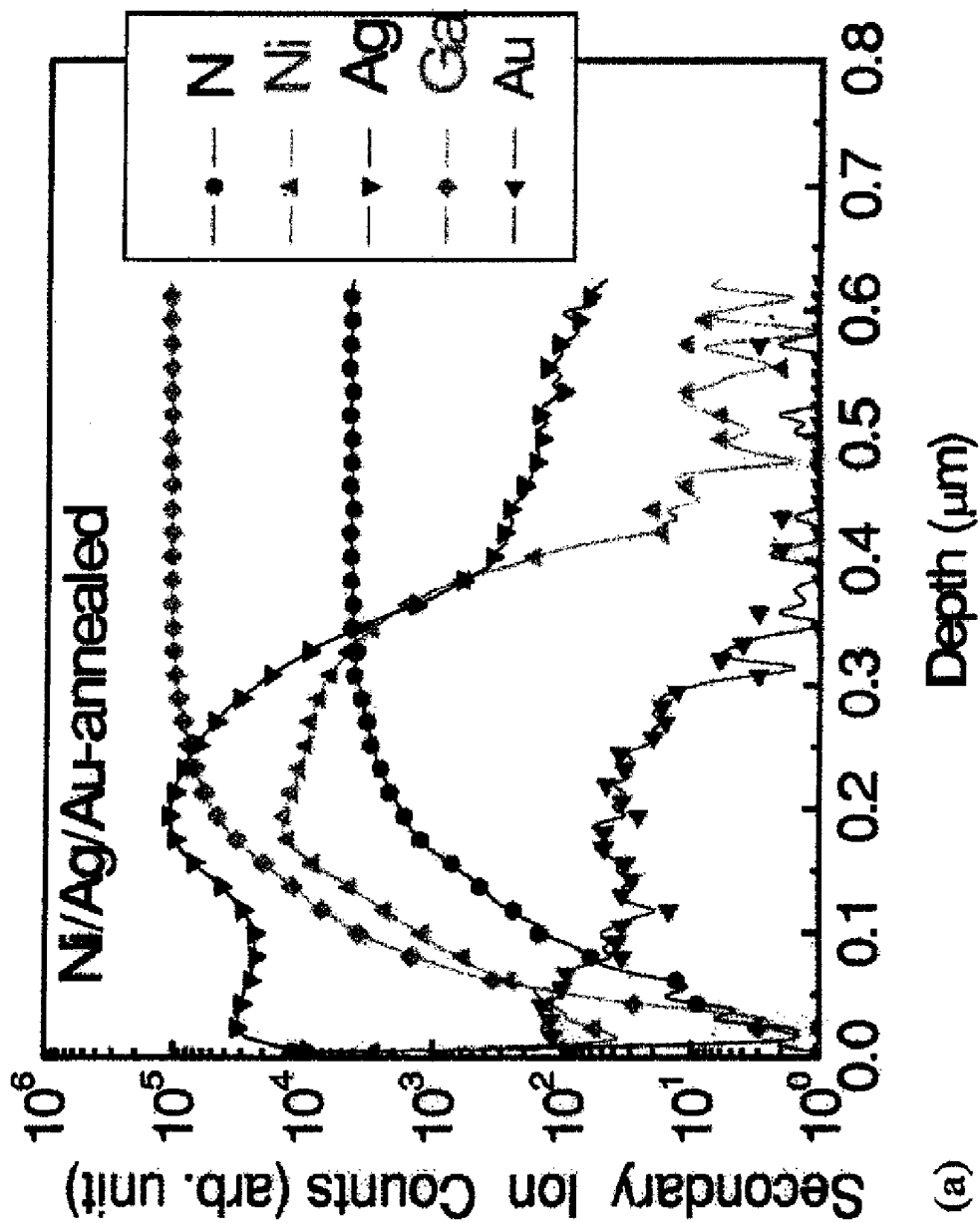


FIG.4



(a)

FIG.5a

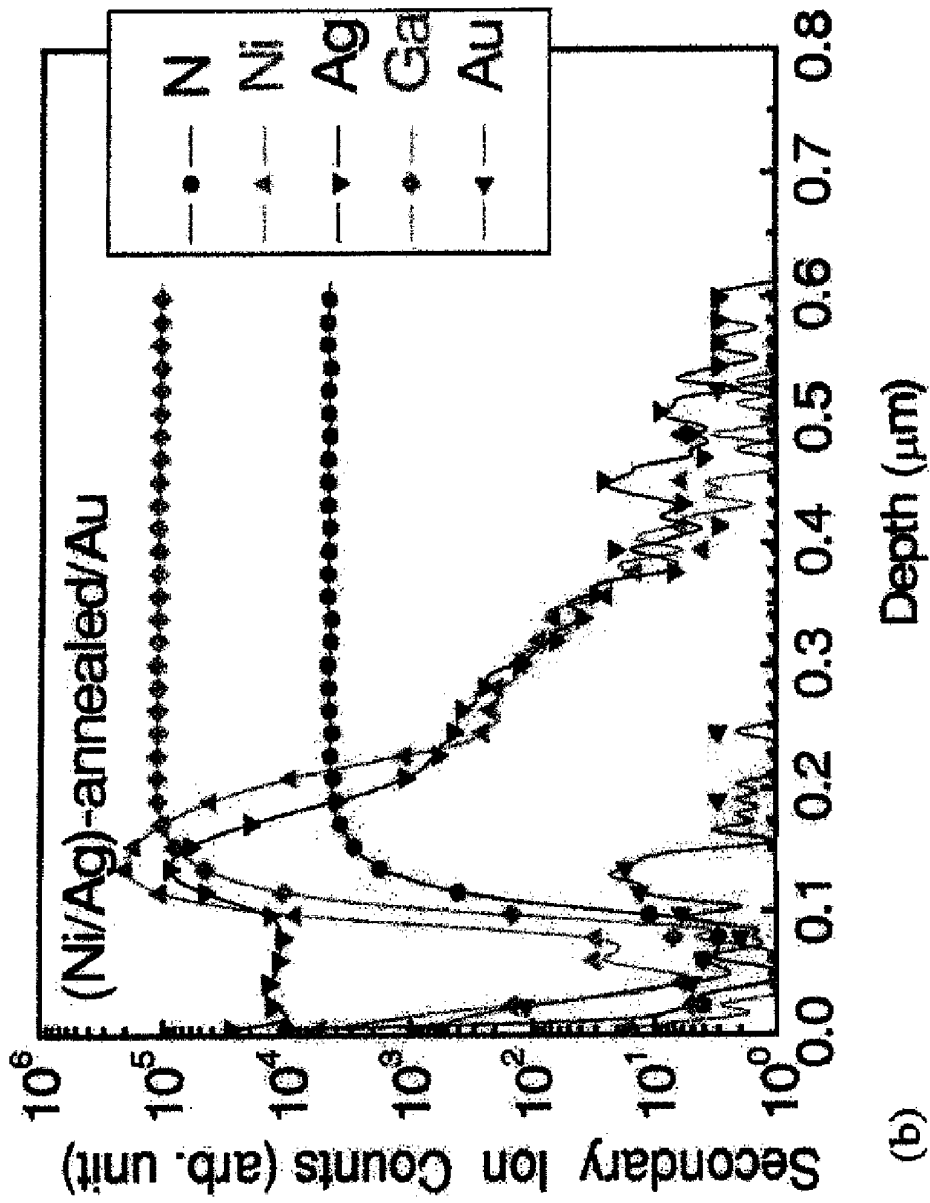


FIG. 5b

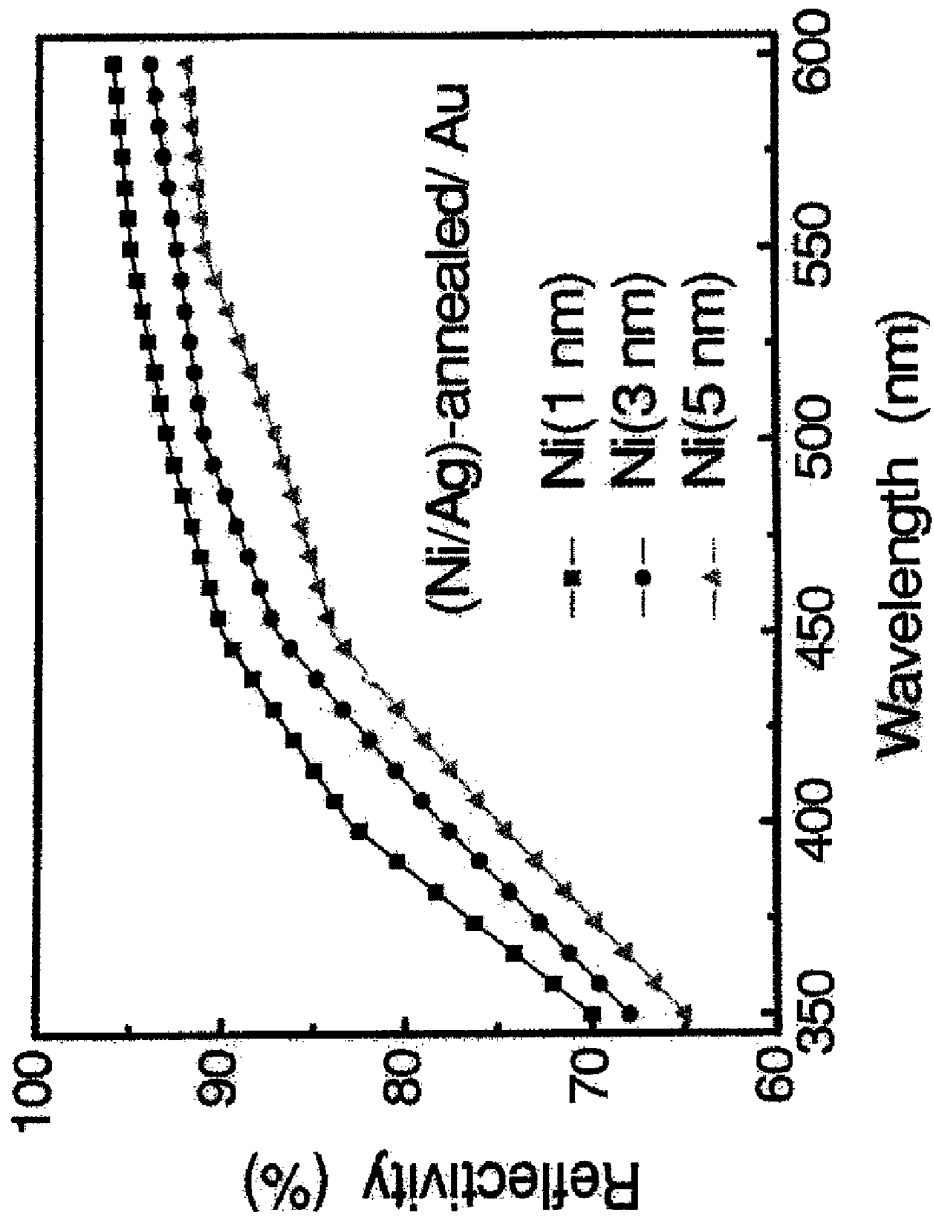


FIG.6

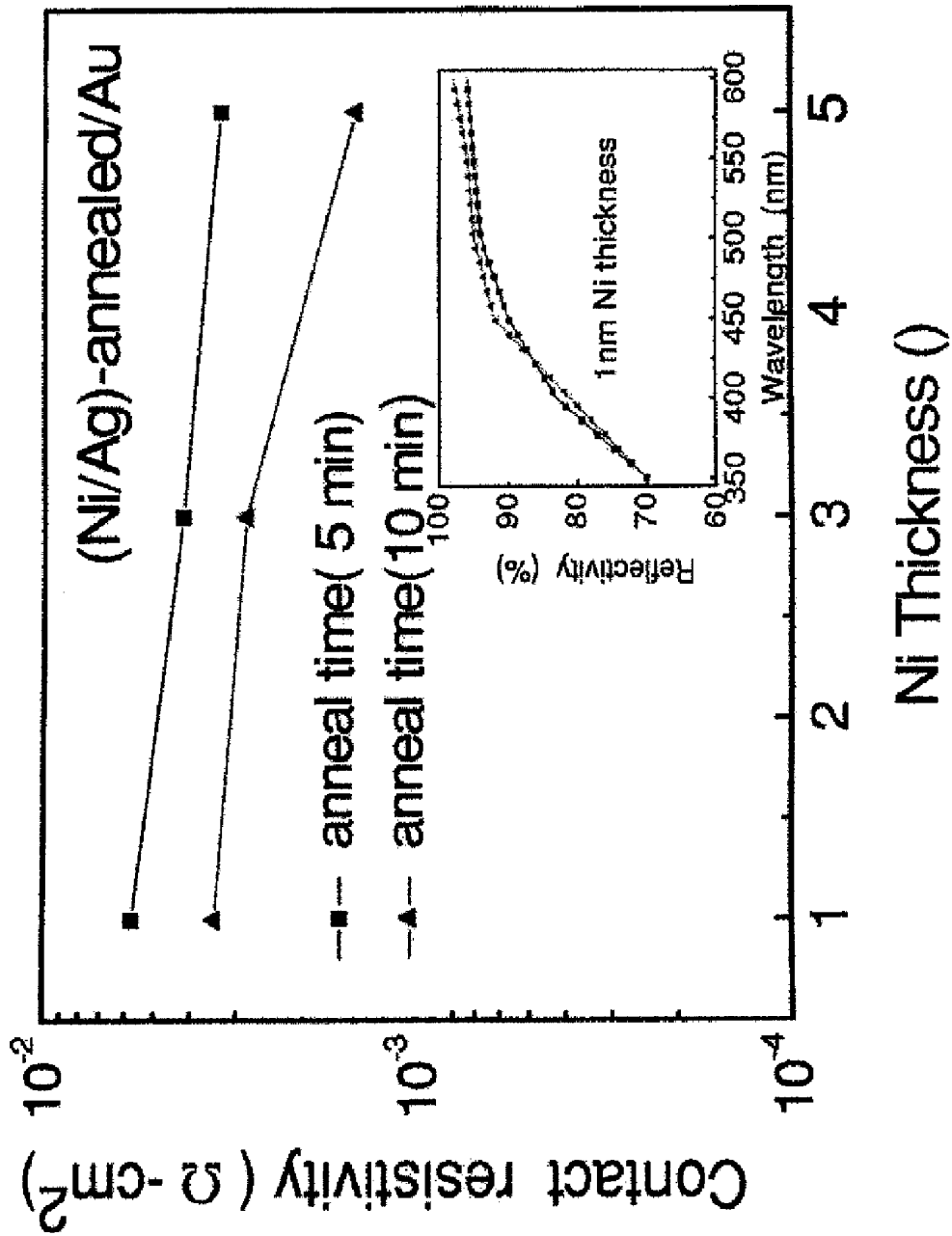


FIG.7

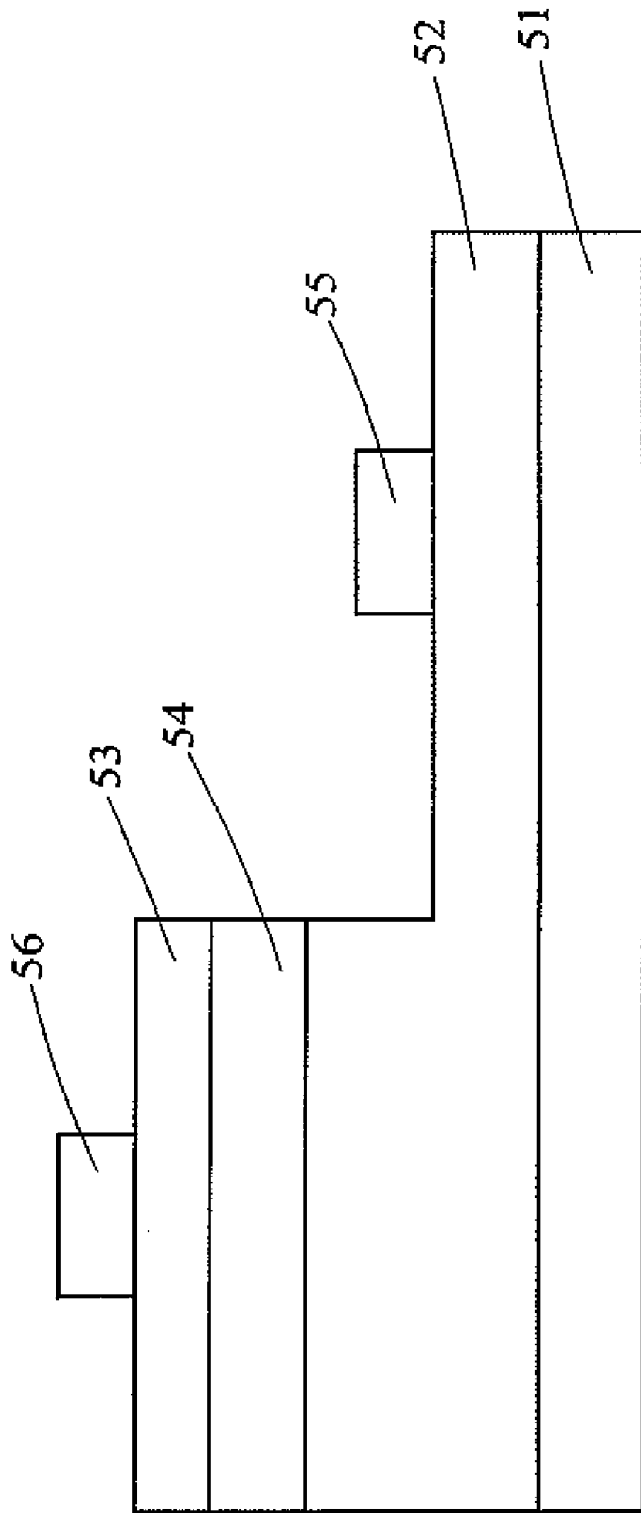


FIG. 8
PRIOR ART

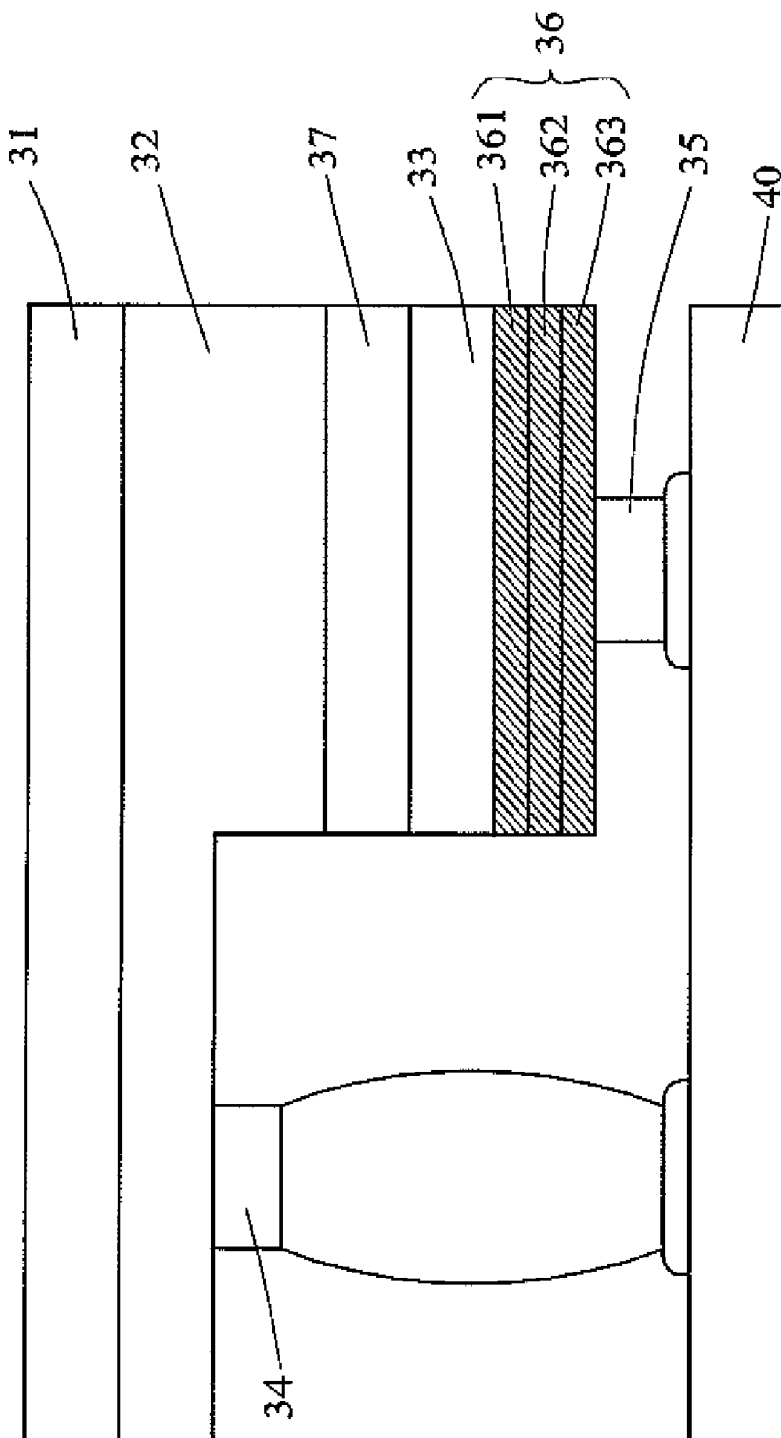


FIG. 9
PRIOR ART

METHOD OF MANUFACTURING AN LED

BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates to LED (light-emitting diode) manufacturing, particularly, to a method of manufacturing an LED of high reflectivity, and, more particularly, to a method of manufacturing an LED having a metal reflector including an Au layer coated on an Ag layer thereof after annealing.

2. Description of Related Art

A conventional LED is schematically shown in FIG. 8. The LED comprises a substrate **51**, an n-type GaN (gallium nitride) layer **52** deposited on the substrate **51**, an active layer **54** deposited on a portion of the n-type GaN layer **52**, an n-type metal electrode **55** on another portion of the n-type GaN layer **52**, a p-type GaN layer **53** deposited on the active layer **54**, and a p-type metal electrode **56** on the p-type GaN layer **53**.

The above conventional LED has a low light emission efficiency.

Another conventional method of manufacturing an LED is schematically shown in FIG. 9. A produced LED is formed on an n-GaN based epitaxial layer **40**. The LED comprises a metal reflector **36** including an upper Ni (nickel) layer **361**, an intermediate Ag (silver) layer **362**, and a lower Au (gold) layer **363** stacked together in which the upper Ni layer **361** functions as an adhesive and the Ag layer **362** acts for reflecting light. A p-type metal electrode **35** electrically interconnects the Au layer **363** and the n-GaN based epitaxial layer **40**. A p-type GaN layer **33** is deposited on the metal reflector **36** to be electrically connected to the p-type metal electrode **35** through the Au layer **363**. An active layer **37** is deposited on the p-type GaN layer **33**. An n-type GaN layer **32** is deposited on the active layer **37**. An n-type metal electrode **34** electrically interconnects the n-type GaN layer **32** and the n-GaN based epitaxial layer **40**. A substrate **31** is deposited on the n-type GaN layer **32**.

The Ni, Ag, and Au layers **361**, **362**, and **363** are annealed in a furnace to form the metal reflector **36** which is adhered to the p-type GaN layer **33**.

Light emitted from the active layer **37** impinges on the metal reflector **36** prior to reflecting to the active layer **37**. Thus, the metal reflector **36** of high reflectivity can increase the light emission efficiency of the LED.

However, the Au layer **363** tends to melt and, thus, permeates the Ag layer **362** in the annealing process. This can decrease reflectivity of the Ag layer **362**, resulting in a decrease of the light emission efficiency of the LED.

In addition, there have been numerous suggestions in prior patents for the manufacturing of an LED. For example, U.S. Pat. No. 7,279,347 discloses a method for manufacturing a light-emitting structure of a light-emitting device (LED).

Thus, it is desirable to provide a novel method of manufacturing an LED in order to overcome the inadequacies of the prior art.

SUMMARY OF THE INVENTION

It is therefore one object of the invention to provide a method of manufacturing an LED of high reflectivity.

To achieve the above and other objects, the invention provides a method of manufacturing an LED including forming a substrate; depositing an n-type GaN layer on the substrate; depositing an active layer on a first portion of the n-type GaN layer; attaching an n-type metal electrode to a second portion of the n-type GaN layer; depositing a p-type GaN layer on the

active layer; forming a metal reflector on the p-type GaN layer; attaching a p-type metal electrode to the metal reflector; and attaching the p-type metal electrode and the n-type metal electrode to an epitaxial layer respectively. The metal reflector comprises a transparent layer, an Ag layer, and an Au layer, the transparent layer and the Ag layer are formed by annealing in a furnace, and the Au layer is subsequently coated on the Ag layer.

The above and other objects, features and advantages of the invention will become apparent from the following detailed description taken with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic sectional view of an LED being manufactured in a first step of a method according to the invention where a transparent layer and an Ag layer are formed;

FIG. 2 is a view similar to FIG. 1 where an Au layer is formed on the Ag layer and a p-type metal electrode is attached onto the Au layer in a second step of the method;

FIG. 3 is a schematic sectional view of the LED formed with an epitaxial layer in a third step of the method;

FIG. 4 is a diagram of Current-voltage (I-V) characteristics of (Ni/Ag)-annealed/Au and Ni/Ag/Au-annealed contacts at an annealing temperature of 500° C. for 10 minutes in O₂ ambient, wherein the inset shows the reflectivity of (Ni/Ag)-annealed/Au and Ni/Ag/Au-annealed contacts;

FIG. 5a is a diagram of SIMS depth profiles of (Ni/Ag)-annealed/Au;

FIG. 5b is a diagram of SIMS depth profiles of (Ni/Ag/Au)-annealed contacts;

FIG. 6 is a diagram of Reflectivity of Ni/Ag)-annealed/Au contacts annealed at 500° C. for 10 minutes in an O₂ ambient;

FIG. 7 is a diagram of Resistivity of (Ni/Ag)-annealed/Au contacts annealed at 500° C. for (a) 5 minutes, and (b) 10 minutes, wherein the inset shows the reflectivity of (Ni/Ag)-annealed/Au contacts;

FIG. 8 is a schematic sectional view of a conventional LED; and

FIG. 9 is a schematic sectional view of another conventional LED formed with an epitaxial layer.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIGS. 1 to 3, a method of manufacturing an LED **10** in accordance with a preferred embodiment of the invention is illustrated.

In a first step as illustrated in FIG. 1, a substrate **11** is formed. Next, an n-type GaN layer **12** is deposited on the substrate **11**. Next, an active layer **17** is deposited on a portion of the n-type GaN layer **12**, and an n-type metal electrode **14** is attached to another portion of the n-type GaN layer **12** respectively. The n-type metal electrode **14** is electrically connected to the n-type GaN layer **12**. Next, a p-type GaN layer **13** is deposited on the active layer **17**. Next, a transparent layer **161** is formed on the p-type GaN layer **13**. Finally, an Ag layer **162** is formed on the transparent layer **161**.

It is noted that the transparent layer **161** and the Ag layer **162** are annealed in a furnace. Next, the stacked transparent layer **161** and the Ag layer **162** are adhered on the p-type GaN layer **13**.

In a second step as illustrated in FIG. 2, an Au layer **163** is coated on the Ag layer **162**, and, thus, a metal reflector **16** is formed. Finally, a p-type metal electrode **15** is attached to the Au layer **163** and electrically connected thereto.

The transparent layer **161** is formed of nickel, tin oxide, indium tin oxide, zinc oxide, or zinc aluminum oxide. The transparent layer **161** has a thickness more than 1 μm . The annealing process is conducted in a temperature greater than 500° C. so as to form the transparent layer **161**. Alternatively, the annealing process is conducted in a temperature less than 450° C. so as to form the transparent layer **161**. Also, thickness of the Au layer **163** should be sufficiently large. Otherwise, the Au layer **163** may peel off when electrically connecting to another component.

In a third step as illustrated in FIG. 3, the produced LED is attached onto an epitaxial layer **20**. The n-type metal electrode **14** is further electrically connected to the epitaxial layer **20**, and the p-type metal electrode **15** is further electrically connected to the epitaxial layer **20**, respectively.

As a result, light emitted from the active layer **17** passes through the transparent layer **161** and, then, impinges on the Ag layer **162**. Finally, light is reflected from the Ag layer **162** to the active layer **17**. Au is prevented from permeating the Ag layer **162**, because only the transparent layer **161** and the Ag layer **162** are placed in the furnace in the annealing process. Hence, light reflection of the Ag layer **162** is not lowered adversely. As such, reflectivity of the metal reflector **16** is greatly increased. As a result, the produced LED has an increased light emission efficiency.

FIG. 4 shows the current-voltage (I-V) characteristics of both (Ni/Ag)-annealed/Au samples at an annealing temperature of 500° C. for 10 minutes in O₂ ambient. The contact resistance of Ni/Ag/Au-annealed samples with a value of $4.35 \times 10^{-4} \Omega\text{cm}^2$ is one order less than that of the (Ni/Ag)-annealed/Au contacts ($3.44 \times 10^{-3} \Omega\text{cm}^2$). However, as shown in the inset of FIG. 6, reduced light reflectance (63%) of Ni/Ag/Au-annealed samples at a 465 nm wavelength is found to be 29% less compared to that of (Ni/Ag)-annealed/Au contacts (92%). It is known that Ag is an excellent material for metallic reflectors due to its high reflectivity in the visual light wavelength region. However, the strong interdiffusion of Ohmic metals and GaN in the Ni/Ag/Au-annealed samples resulted in poor reflectance. On the other hand, the (Ni/Ag)-annealed/Au samples have a slightly larger contact resistivity when compared to the Ni/Ag/Au-annealed contacts but exhibit higher reflectivity for the usage of FCLED.

FIGS. 5a and 5b show the secondary ion mass spectrometry (SIMS) depth profiles of (Ni/Ag)-annealed/Au and Ni/Ag/Au-annealed contacts, respectively. It is observed that a strong interdiffusion of Ohmic metals and GaN occurs in the Ni/Ag/Au-annealed contacts but not in the (Ni/Ag)-annealed/Au contacts. Thus, the low reflectivity of the Ni/Ag/Au-annealed contacts can be attributed to the intermixing of Ni, Ag, Au metals.

FIG. 6 shows the reflectivity of (Ni/Ag)-annealed/Au contacts annealed at 500° C. for 10 minutes in an O₂ ambient. Three different thicknesses of Ni, 1, 3, 5 nm, are examined. As shown in FIG. 6, the thicker the Ni thickness is, the lower the

reflectance is. In addition, the resistivity of the proposed (Ni/Ag)-annealed/Au contacts is shown in FIG. 7, in which the (Ni/Ag) double layers with three different thickness of Ni, i.e., 1, 3, 5 nm, were annealed at an annealing temperature of 500° C. for both 5 and 10 minutes. The reflectivity of the Ohmic contact with 1 nm thickness of Ni is shown in the inset. The samples annealed for 10 minutes produced better Ni oxide/p-GaN contacts and resulted in lower resistivity than the samples annealed for 5 minutes.

In order to prepare these p-GaN FCLED reflective Ohmic contacts with the highest level of reflectivity and the lowest resistivity, it is suggested that the correspondent two step (Ni/Ag)-annealed/Au metallization process should have a thin Ni thickness (of 1 nm) and a proper Ni/Ag annealing time (of 10 min).

While the invention herein disclosed has been described by means of specific embodiments, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope and spirit of the invention set forth in the claims.

What is claimed is:

1. A method of manufacturing an LED comprising:

forming a substrate;

depositing an n-type GaN layer on the substrate;

depositing an active layer on a first portion of the n-type GaN layer;

attaching an n-type metal electrode to a second portion of the n-type GaN layer;

depositing a p-type GaN layer on the active layer;

forming a metal reflector on the p-type GaN layer;

attaching a p-type metal electrode to the metal reflector; and

attaching the p-type metal electrode and the n-type metal electrode to an epitaxial layer respectively,

wherein the metal reflector comprises a transparent layer, an Ag layer, and an Au layer, and wherein the transparent layer and the Ag layer are formed by annealing in a furnace, and the Au layer is subsequently coated on the Ag layer, wherein the transparent layer and the Ag layer are annealed at an annealing temperature of 500° C. for 10 minutes in O₂ ambient.

2. The method of claim 1, wherein the transparent layer is formed of nickel.

3. The method of claim 2, wherein the transparent layer has a thickness of 1 nm.

4. The method of claim 1, wherein the transparent layer is formed of zinc oxide.

5. The method of claim 1, wherein the transparent layer is formed of zinc aluminum oxide.

6. The method of claim 1, wherein the transparent layer is formed of tin oxide.

7. The method of claim 1, wherein the transparent layer is formed of indium tin oxide.

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