US00RE42636E

(19) **United States**
(12) **Reissued Patent**
Chen et al.

(10) **Patent Number: US RE42,636 E**
(45) **Date of Reissued Patent: Aug. 23, 2011**

(54) **WINDOW FOR GALLIUM NITRIDE LIGHT EMITTING DIODE**

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(21) Appl. No.: **12/662,196**

(22) Filed: **Apr. 5, 2010**

Related U.S. Patent Documents

Reissue of:
(64) Patent No.: **6,420,736**
Issued: **Jul. 16, 2002**
Appl. No.: **09/626,445**
Filed: **Jul. 26, 2000**

(51) **Int. Cl.**
H01L 33/00 (2010.01)

(52) **U.S. Cl.** **257/99**; 257/94; 257/96; 257/103; 257/E33.07

(58) **Field of Classification Search** 257/99, 257/94, 96, 103, E33.07
See application file for complete search history.

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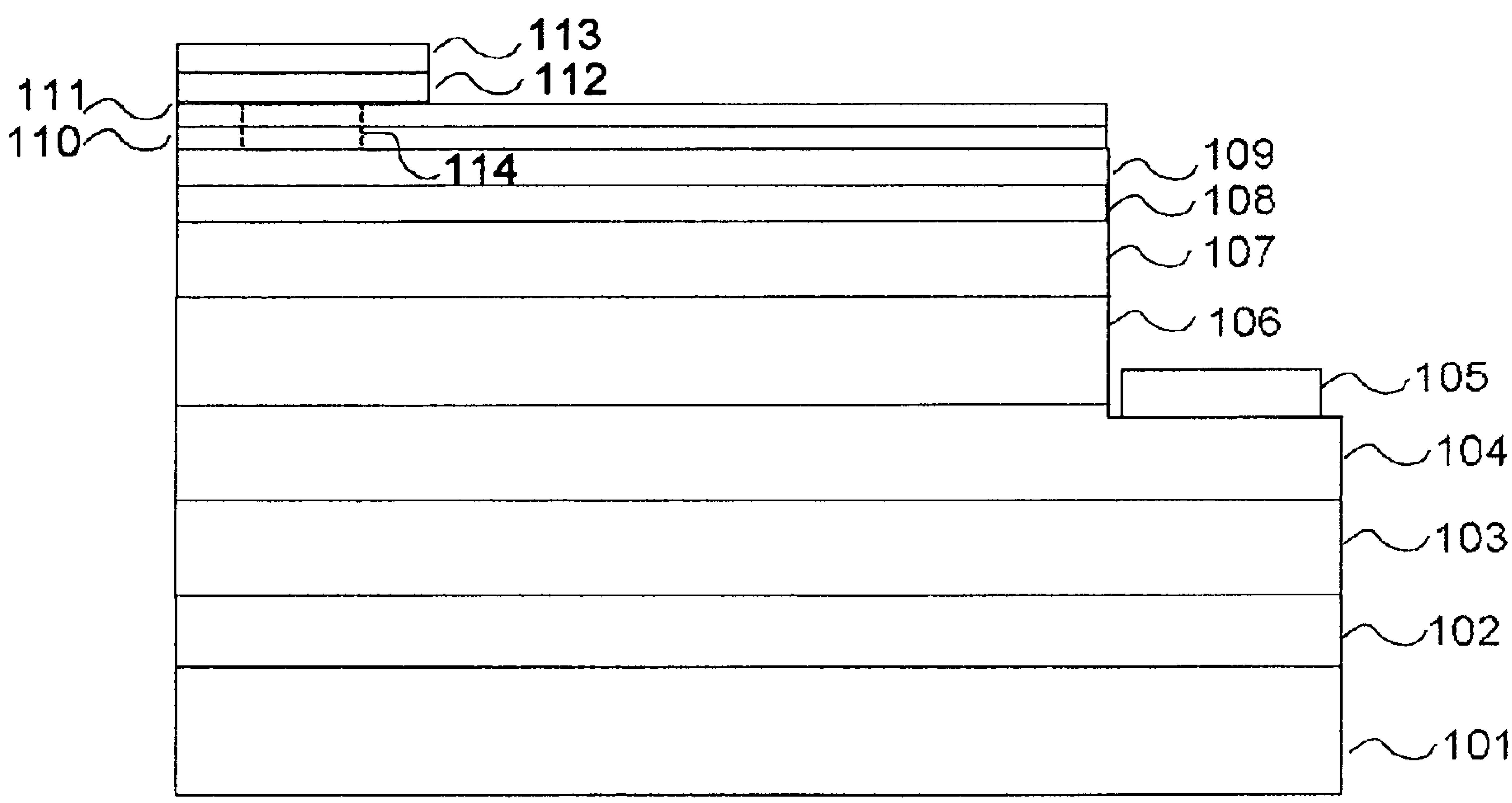
(57) **ABSTRACT**

A window structure for a gallium nitride (GaN)-based light emitting diode (LED) includes a Mg+ doped p window layer of a GaN compound; a thin, semi-transparent metal contact layer; and an amorphous current spreading layer formed on the contact layer. The contact layer is formed of NiO_x/Au and the current spreading layer is formed of Indium Tin Oxide. The p electrode of the diode includes a titanium adhesion layer which forms an ohmic connection with the current spreading layer and a Schottky diode connection with the Mg+ doped window layer.

6 Claims, 1 Drawing Sheet



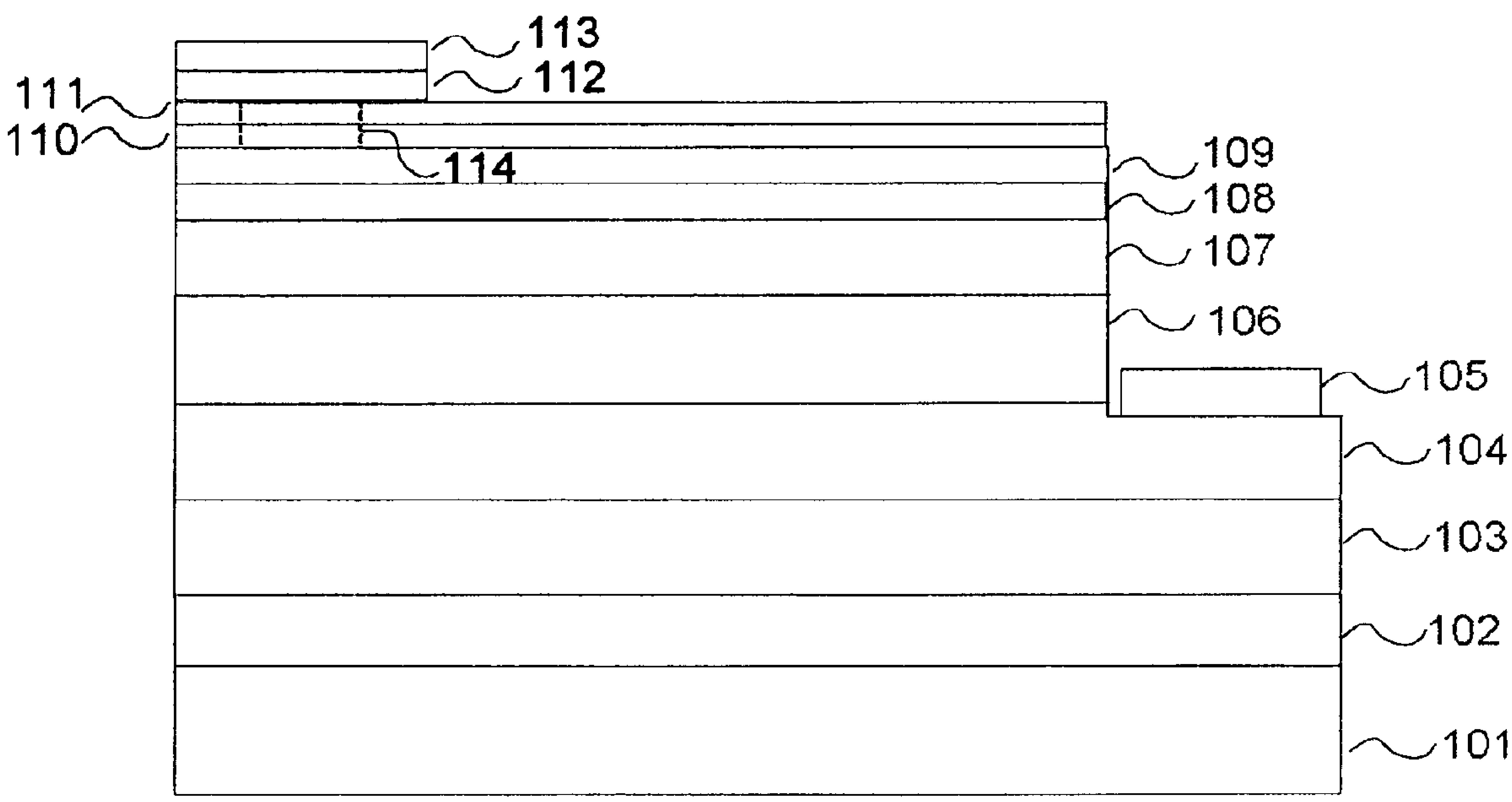


Fig. 1

WINDOW FOR GALLIUM NITRIDE LIGHT EMITTING DIODE

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

The present invention relates to an improved window for a gallium nitride (GaN)-based light-emitting diode (LED).

BACKGROUND OF THE INVENTION

A semiconductor light-emitting diode (LED) includes a substrate, a light emitting region, a window structure, and a pair of electrodes for powering the diode. The substrate may be opaque or transparent. Light-emitting diodes which are based on gallium nitride (GaN) compounds generally include a transparent, insulating substrate, i.e., a sapphire substrate. With a transparent substrate, light may be utilized from either the substrate or from the opposite end of the LED which is termed the "window".

The amount of light generated by an LED is dependent on the distribution of the energizing current across the face of the light emitting region. It is well known in semiconductor technology that the current flowing between the electrodes tends to concentrate in a favored path directly under the electrode. This current flow tends to activate corresponding favored portions of the light-emitting region to the exclusion of portions which fall outside the favored path. Further since such favored paths fall under the opaque electrode, the generated light reaching the electrode is lost. Prior art GaN LEDs have employed conductive current spreading layers formed of nickel/gold (Ni/Au), and have a gold (Au) window bond pad mounted on such layers. In such arrangements, the Ni/Au layer and/or the Au bond pad tend to peel during the wire bonding operation to the pad.

SUMMARY OF THE INVENTION

In one embodiment consistent with the present invention, light is utilized at the output of the window structure, which includes a very thin, semi-transparent nickel oxide/gold (NiO_x/Au) contact layer formed on a p-doped nitride compound window layer; a semi-transparent amorphous conducting top window layer; and a p electrode structure formed of a titanium layer with a covering Au bond pad. The amorphous top layer, by way of example, may be formed of indium tin oxide (ITO), tin oxide (TO), or zinc oxide (ZnO). Layers of other amorphous, conductive, and semi-transparent oxide compounds also may be suitable for construction of the top window layer.

Advantageously, the thin NiO_x/Au layer provides an excellent ohmic connection to both the amorphous current spreading conducting layer and to the magnesium (Mg)-doped GaN window layer. The highly conductive amorphous layer efficiently spreads current flowing between the electrodes across the light-emitting region to improve the efficiency of the device.

Additionally, the titanium electrode passes through both the amorphous conducting layer and the underlying Ni/Au to: (a) form an ohmic contact with those layers; (b) contact the p-doped top widow layer and form a Schottky diode connection therewith; and (c) provide good adhesion between the titanium (Ti) and the magnesiusm (Mg)-doped window layer.

The Schottky diode connection forces current from the electrode into the amorphous conducting layer and eliminates the tendency of the prior art structures to concentrate current in a path directly under the electrode.

BRIEF DESCRIPTION OF THE DRAWING

The FIGURE is a schematic depicting a cross-sectional view of an LED according to one embodiment consistent with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The Figure depicts an LED according to one embodiment consistent with the present invention, as a GaN-based device in which light exits through window **109**.

The LED of the Figure includes a sapphire substrate **101**, buffer region **102**, GaN substitute substrate layer **103**, n cladding layer **104**, active region **106**, p cladding layer **107**, **[**window layers **108**, **109**,**]** n electrode **105**, and a window structure which includes *window layers 108, 109,* a thin NiO_x/Au semi-transparent layer **110**, a semi-transparent amorphous conducting layer **111**, a titanium electrode **112**, and a bond pad **113**.

Layers **101** through **104**, and layers **106** through **109**, are grown in a Metal Organic Chemical Vapor Deposition (MOCVD) reactor. The details of MOCVD growth of the stated layers are well known in the semiconductor industry and will not be discussed herein.

The remaining components of the illustrative LED, namely, layers NiO_x/Au layer **110**, amorphous conducting layer **111**, n electrode **105**, p electrode **112**, and bond pad **113**, are formed by evaporation in an apparatus other than a MOCVD reactor. Such processes are well known in the semiconductor industry and are not described herein.

The Light-emitting Structure

The illustrative light-emitting structure of the Figure includes an n cladding layer **104**, active region **106**, and p cladding layer **107**.

The n cladding layer **104** is formed of silicon-doped GaN.

In the illustrative example depicted by the Figure, active region **106** is a silicon-doped n-type gallium indium nitridie/gallium nitride (GaInN/GaN) multi-quantum well (MQW) structure. However, other forms of active regions may be utilized with the illustrative window structure.

The p cladding layer **107** is formed of Mg-doped aluminum gallium nitride (AlGaN).

The Window Layers

The first window layer **108** is formed of Mg-doped GaN. The window layer **108** has a nominal thickness of 300 nm.

The second window layer **109** is similarly formed of Mg-doped GaN. However, window layer **109** is more highly doped to permit an ohmic contact between layer **109** and the very thin NiO_x/Au layer **110**.

Completion of the MOCVD Growth Process

Growth of the p-type GaN layers is achieved with the introduction of gaseous flows of TMG with hydrogen (H_2) as a carrier gas, NH_3 as a group V material, and Mg as a dopant. In the absence of an appropriate cool down protocol, hydrogen passivation of the Mg may occur, in which case, the conductivity of the Mg-doped layer is reduced.

In order to avoid hydrogen passivation of the Mg-doped layers **107**, **108**, and **109**, the following described cool-down protocol has been adopted upon completion of the MOCVD growth.

1. The ambient gas of the reactor is switched from H_2 to nitrogen (N_2) immediately after completion of the LED structure;
2. The reactor temperature is ramped down from the growth temperature to about 900 degrees C. in about 2 minutes;
3. The flow of NH_3 is terminated;
4. The reactor temperature is further ramped down to about 750 degrees C. in about 2 minutes;
5. A temperature of about 750 degrees C. is held for about 20 minutes;
6. The heater of the reactor is shut off and the reactor is allowed to complete cool-down naturally. Experience shows that cool-down to 120 degrees C. occurs in about 30 minutes after heater shut off.

The resulting product exhibits the expected desired physical and electrical characteristics.

Formation of the Electrode Structures

The embodiment consistent with the present invention as depicted by the Figure, illustrates the locations of both p electrode layers **111**, **112** and n electrode **105**.

Layer **110** is a very thin, semi-transparent contact layer of NiO_x/Au which is deposited over the entire exposed face of window layer **109**. Opening **114** is formed in layers **110** and **111** to permit the deposit of a titanium adhesion layer **112** to contact window layer **109**. Titanium forms a strong physical bond with layer **109** and thus tends to eliminate peeling during wire bonding. In addition to reaching through to layer **109**, titanium structure **112** is deposited through and on top of amorphous layer **111**. Titanium electrode **112** forms ohmic contacts with layers **110** and **111**, and forms a Schottky diode contact with window layer **109**. The Schottky diode connection to window layer **109** eliminates the current path directly under the electrode and forces current flowing between the electrodes into conducting layer **111**.

The p electrode Au bond pad **113** is deposited on top of titanium layer **112** to form an ohmic contact.

Since the Mg-doped layers do not suffer from hydrogen passivation, it is not necessary to heat treat the structure to activate the Mg doping in those layers. However, Ni/Au layer [**111**] *110* and the Ti and Au contact structures are heated in an atmosphere of molecular nitrogen and air. Thus, the Ni is converted to a form of nickel oxide. The described heat treatment improves the quality of the contact structures.

The invention has been described with particular attention to its preferred embodiment. However, it should be understood that variations and modifications within the spirit and scope of the invention may occur to those skilled in the art to which the invention pertains.

What is claimed is:

1. A light emitting diode comprising:
a substrate;
a light emitting region;
a window structure[; and
first and second electrodes;
wherein said window structure comprises] *comprising:*
an Mg+ doped window layer;
a semi-transparent [metal] *NiO_x/Au* contact layer[,] *disposed on said Mg+ doped window layer;* and
a semi-transparent, conductive amorphous current spreading layer formed directly on an exposed face of said contact layer; [and
wherein an opening is formed through said contact layer and said current spreading layer and said first electrode comprises a layer of titanium formed on said current spreading layer and through said opening to contact an upper surface of said Mg+ doped window layer.]

a first electrode having a layer of titanium and formed on said current spreading layer and forming an ohmic connection with said current-spreading layer;
a second electrode; and
an opening formed through said contact layer and said current spreading layer, such that said layer of titanium of said first electrode contacts an upper surface of said Mg+ doped window layer.

[**2**. The light emitting diode in accordance with claim **1**, wherein said contact layer is a NiO_x/Au layer.]

3. The light emitting diode in accordance with claim **1**, wherein said amorphous current spreading layer is formed of Indium Tin Oxide.

[**4**. The light emitting diode diode in accordance with claim **2**, wherein said amorphous current spreading layer is formed of Indium Tin Oxide.]

5. The light emitting diode in accordance with claim **1**, wherein said window structure comprises:
a [Mg+ doped] *further* window layer[; and
wherein said Ni/Au contact layer is formed on said Mg+ doped window layer and said first electrode forms an ohmic connection with said current spreading layer].

6. The light emitting diode in accordance with claim **5**, wherein said first electrode forms a Schottky diode connection with said Mg+ doped window layer.

[**7**. The light emitting diode in accordance with claim **2**, wherein after heat treatment, said contact layer comprises a Ni oxide/Au layer.]

8. A light emitting diode comprising:
a substrate;
a light emitting region;
a window structure; and
first and second electrodes;
wherein said window structure comprises:
an Mg+ doped window layer;
a semi-transparent NiO_x/Au contact layer formed on said Mg+ doped window layer; and
a semi-transparent, conductive amorphous current spreading layer formed of indium tin oxide directly on an exposed face of said contact layer;
wherein said first electrode forms an ohmic connection with said current spreading layer[;], and forms a Schottky diode connection with said Mg+ doped window layer;
wherein an opening is formed through said contact layer and said current spreading layer; and
wherein said first electrode comprises a layer of titanium formed on said current spreading layer and through said opening to contact an upper surface of said Mg+ doped window layer.

9. A light emitting diode comprising:
a substrate;
a buffer region;
a GaN substitute substrate layer;
an n cladding layer;
an active region;
a p cladding layer;
[a double window layer structure;]
an n electrode;
a window structure comprising:
a double window layer structure;
a semi-transparent metal contact layer[,]*;* and
a semi-transparent, conductive amorphous current spreading layer formed directly on an exposed face of said contact layer;
a titanium electrode; and

a bond pad;

wherein an opening is formed through said contact layer and said current spreading layer to said double window layer structure [for said titanium electrode], *such that said titanium electrode contacts an upper surface of said double window layer structure*.

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