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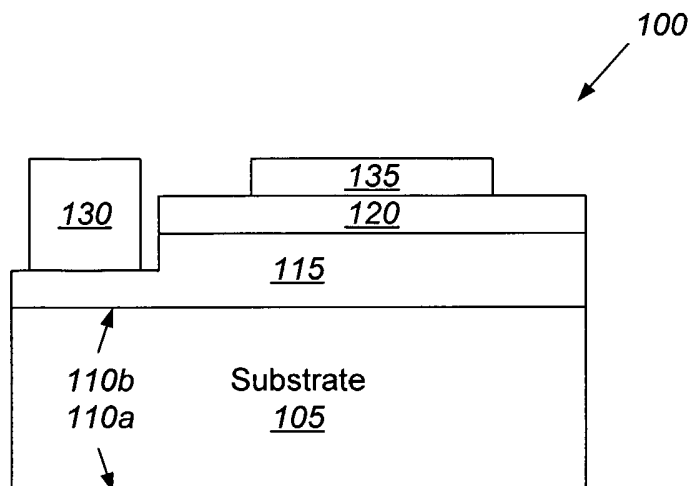
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(54) Title: LIGHT-EMITTING DEVICES HAVING COPLANAR ELECTRICAL CONTACTS ADJACENT TO A SUBSTRATE SURFACE OPPOSITE AN ACTIVE REGION AND METHODS OF FORMING THE SAME



(57) Abstract: A light-emitting device includes a substrate having first and second opposing surfaces. An active region is on the first surface and first and second electrical contacts are adjacent to the second surface and are conductively coupled to the active region. In other embodiments, a light-emitting device includes a substrate having first and second opposing surfaces. An active region is on the first surface and includes a first active layer having a first conductivity type on the first surface and a second active layer having a second conductivity type on the first active layer. A first electrical contact is adjacent to the second surface. A contact plug extends through the substrate and the active region and couples the first electrical contact to the second active layer. A second electrical contact is coupled to the substrate at the second surface.

LIGHT-EMITTING DEVICES HAVING COPLANAR ELECTRICAL CONTACTS
ADJACENT TO A SUBSTRATE SURFACE OPPOSITE AN ACTIVE REGION
AND METHODS OF FORMING THE SAME

Related Application

This application claims the benefit of and priority to U. S. Provisional Patent Application No. 60/466,635, filed April 30, 2003, the disclosure of which is hereby incorporated herein by reference as if set forth in its entirety.

5

Background of the Invention

The present invention relates generally to microelectronic devices and fabrication methods therefor, and, more particularly, to light-emitting devices and fabrication methods therefor.

Light-emitting diodes (LEDs) are widely used in consumer and commercial
10 applications. As is well known to those skilled in the art, a light-emitting diode generally includes a diode region on a microelectronic substrate. The microelectronic substrate may comprise, for example, gallium arsenide, gallium phosphide, alloys thereof, silicon carbide, and/or sapphire. Continued developments in LEDs have resulted in highly efficient and mechanically robust light sources that can cover the
15 visible spectrum and beyond. These attributes, coupled with the potentially long service life of solid state devices, may enable a variety of new display applications, and may place LEDs in a position to compete with well entrenched incandescent and fluorescent lamps.

Referring now to **FIG. 1**, a conventional GaN-based LED **100** comprises a
20 substrate **105**, such as sapphire (Al_2O_3) or SiC, that has first and second opposing surfaces **110a** and **110b**, respectively, and may be at least partially transparent to

optical radiation. A diode region, comprising an n-type layer **115** and a p-type layer **120** is disposed on the second surface **110b** and is configured to emit optical radiation upon application of a voltage across the diode region, for example across ohmic contacts **130** and **135**.

5 The diode region including the n-type layer **115** and/or the p-type layer **125** may comprise gallium nitride-based semiconductor layers, including alloys thereof, such as indium gallium nitride and/or aluminum indium gallium nitride. The fabrication of gallium nitride on SiC is known to those skilled in the art, and is described, for example, in U. S. Patent No. 6,177,688, the disclosure of which is
10 hereby incorporated herein by reference. It will also be understood that a buffer layer or layers comprising aluminum nitride, for example, may be provided between the n-type gallium nitride layer **115** and the substrate **105**, as described in U.S. Patents 5,393,993, 5,523,589, 6,177,688, and Application Serial No. 09/154,363 entitled *Vertical Geometry InGaN Light Emitting Diode*, the disclosures of which are hereby
15 incorporated herein by reference. The n-type gallium nitride layer **115** may comprise silicon-doped gallium nitride, while the p-type gallium nitride layer **120** may comprise magnesium-doped gallium nitride.

 In some LEDs, the ohmic contact **135** for the p-type gallium nitride layer **120** comprises platinum, nickel and/or titanium/gold. In other LEDs, a reflective ohmic
20 contact comprising, for example, aluminum and/or silver, may be used. The ohmic contact **130** to the n-type gallium nitride layer **115** may comprise aluminum and/or titanium. Other suitable materials that form ohmic contacts to p-type gallium nitride and n-type gallium nitride may be used for ohmic contacts **135** and **130**, respectively. Examples of ohmic contacts to n-type gallium nitride layers and p-type gallium nitride
25 layers are described, for example, in U.S. Patent 5,767,581, the disclosure of which is hereby incorporated herein by reference.

 Unfortunately, LED devices that have coplanar electrical contacts on the active side (*i.e.*, the diode region side) may use thicker diode regions than other vertical designed LEDs to reduce current crowding (*i.e.*, forcing electrons to make sharp
30 turns).

Summary of the Invention

According to some embodiments of the present invention, a light-emitting device comprises a substrate having first and second opposing surfaces. An active region is on the first surface and first and second electrical contacts are adjacent to the second surface and are conductively coupled to the active region. Advantageously, such configurations may allow electrical contacts to be coplanar on a non-active side of a substrate, which may obviate the need to use relatively thick active regions to reduce current crowding when electrical contacts are made coplanar on the active side of the substrate. As a result, more active devices may be formed on a single wafer.

In other embodiments of the present invention, a light-emitting device comprises a substrate having first and second opposing surfaces. An active region is on the first surface and comprises a first active layer having a first conductivity type on the first surface and a second active layer having a second conductivity type on the first active layer. A first electrical contact is adjacent to the second surface. A contact plug extends through the substrate and the active region and couples the first electrical contact to the second active layer. A second electrical contact is coupled to the substrate at the second surface.

In still further embodiments, a dielectric spacer is disposed between the contact plug and the substrate and between the contact plug and the first active layer. The dielectric spacer may comprise a material, such as spin-on-glass, a polyimide, silicon-dioxide, and/or silicon-nitride.

In still further embodiments, an ohmic contact layer is on the second active layer and the contact plug extends through the second active layer to contact the ohmic contact layer. The ohmic contact layer may comprise at least one of the following materials: TiN, platinum, nickel/gold, nickel oxide/gold, nickel oxide/platinum, Ti, and titanium/gold. The ohmic contact layer may also have a thickness between about 10 Å and about 100 Å and may be at least partially transparent.

In other embodiments, a buffer layer, which may comprise aluminum nitride, may be disposed between the active region and the substrate, such that the contact plug extends through the buffer layer.

In further embodiments, the substrate comprises a conductive material, such as SiC, and the contact plug comprises a conductive material, such as gold, silver, gold

alloys, and/or silver alloys. The first electrical contact may comprise platinum, nickel, and/or titanium/gold. The second electrical contact may comprise aluminum and/or titanium.

Although described above primarily with respect to apparatus aspects of the present invention, methods of forming light-emitting devices are also described herein.

Brief Description of the Drawings

Other features of the present invention will be more readily understood from the following detailed description of specific embodiments thereof when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a cross-sectional diagram that illustrates a conventional GaN-based light-emitting diode (LED); and

FIGS. 2A - 2K are cross sectional diagrams that illustrate light-emitting devices and methods of forming same in accordance with various embodiments of the present invention.

Detailed Description of Preferred Embodiments

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular forms disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims. Like numbers refer to like elements throughout the description of the figures. In the figures, the dimensions of layers and regions are exaggerated for clarity. Each embodiment described herein also includes its complementary conductivity type embodiment.

It will be understood that when an element such as a layer, region or substrate is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. It will be understood that if part of an element, such as a surface, is referred to as "inner," it is farther from the outside of the device than other parts of the element. Furthermore, relative terms such as "beneath" or "overlies" may be used herein to describe a relationship of one layer or region to

another layer or region relative to a substrate or base layer as illustrated in the figures. It will be understood that these terms are intended to encompass different orientations of the device in addition to the orientation depicted in the figures. Finally, the term "directly" means that there are no intervening elements. As used herein, the term
5 "and/or" includes any and all combinations of one or more of the associated listed items.

It will be understood that, although the terms first, second, 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
10 terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first region, layer or section discussed below could be termed a second region, layer or section, and, similarly, a second without departing from the teachings of the present invention.

Embodiments of the present invention will now be described, generally, with
15 reference to GaN-based light-emitting diodes (LEDs) on SiC-based substrates. The present invention, however, is not limited to such structures. Embodiments of the invention may use other substrates including combinations, such as an AlGaInP diode on a GaP substrate, a GaN diode on a SiC substrate, an SiC diode on an SiC substrate, and/or a nitride-based diode on a gallium nitride, silicon carbide, aluminum nitride,
20 zinc oxide and/or other substrate. Moreover, the present invention is not limited to the use of a diode region as an active region. Other types of active regions may also be used in accordance with some embodiments of the present invention.

Examples of light-emitting devices that may be used in embodiments of the present invention include, but are not limited to, the devices described in the
25 following U. S. Patent Nos.: 6,201,262, 6,187,606, 6,120,600, 5,912,477, 5,739,554, 5,631,190, 5,604,135, 5,523,589, 5,416,342, 5,393,993, 5,338,944, 5,210,051, 5,027,168, 5,027,168, 4,966,862 and/or 4,918,497, the disclosures of which are incorporated herein by reference. Other suitable LEDs and/or lasers are described in United States Patent Application Serial No. 10/140,796, entitled "GROUP III
30 NITRIDE BASED LIGHT EMITTING DIODE STRUCTURES WITH A QUANTUM WELL AND SUPERLATTICE, GROUP III NITRIDE BASED QUANTUM WELL STRUCTURES AND GROUP III NITRIDE BASED SUPERLATTICE STRUCTURES", filed May 7, 2002, as well as United States

Patent Application Serial No. 10/057,821, filed January 25, 2002 entitled "LIGHT
EMITTING DIODES INCLUDING SUBSTRATE MODIFICATIONS FOR LIGHT
EXTRACTION AND MANUFACTURING METHODS THEREFOR" the
disclosures of which are incorporated herein as if set forth fully. Furthermore,
5 phosphor coated LEDs, such as those described in United States Patent Application
Serial No. 10/659,241 entitled "PHOSPHOR-COATED LIGHT EMITTING DIODES
INCLUDING TAPERED SIDEWALLS, AND FABRICATION METHODS
THEREFOR," filed September 9, 2003, the disclosure of which is incorporated by
reference herein as if set forth full, may also be suitable for use in embodiments of the
10 present invention.

The LEDs and/or lasers may be configured to operate in a "flip-chip"
configuration such that light emission occurs through the substrate. In such
embodiments, the substrate may be patterned so as to enhance light output of the
devices as is described, for example, in United States Patent Application Serial No.
15 10/057,821, filed January 25, 2002 entitled "LIGHT EMITTING DIODES
INCLUDING SUBSTRATE MODIFICATIONS FOR LIGHT EXTRACTION AND
MANUFACTURING METHODS THEREFOR" the disclosure of which is
incorporated herein by reference as if set forth fully herein.

Referring now to **FIGS. 2A - 2H**, light-emitting devices and methods of
20 forming same, in accordance with some embodiments of the present invention, will
now be described. As shown in **FIG. 2A**, a substrate **205**, such as, for example, a SiC
substrate, is provided. The substrate **205** has a first surface **210a** and a second surface
210b and may be at least partially transparent to optical radiation. A buffer layer or
layers **220** comprising, for example, aluminum nitride may be formed on the first
25 surface **210a** of the substrate **205** as described in the above-incorporated U.S. Patents
5,393,993, 5,523,589, 6,177,688, and Application Serial No. 09/154,363 entitled
Vertical Geometry InGaN Light Emitting Diode.

Referring now to **FIGS. 2B** and **2C**, an active region, such as, for example, a
diode region comprising an n-type layer **225** and a p-type layer **230** may be epitaxially
30 grown on the buffer layer **220**. The diode region, including the n-type layer **225**
and/or the p-type layer **230** may comprise gallium nitride-based semiconductor layers,
including alloys thereof, such as indium gallium nitride, aluminum gallium nitride,
and/or aluminum indium gallium nitride. The fabrication of gallium nitride layers is

described, for example, in the above-incorporated U.S. Patent 6,177,688. The n-type gallium nitride layer **225** may comprise silicon-doped gallium nitride, while the p-type gallium nitride layer **230** may comprise magnesium-doped gallium nitride.

Referring now to **FIG. 2D**, an ohmic contact layer **235** may be formed on the p-type gallium nitride layer **230**. In accordance with various embodiments of the present invention, the ohmic contact layer **235** may comprise TiN, platinum, nickel/gold, nickel oxide/gold, nickel oxide/platinum, Ti, titanium/gold and/or alloys thereof. The ohmic contact layer **235** may have a thickness between about 10 Å and about 100 Å and may be at least partially transparent to optical radiation in accordance with some embodiments of the present invention.

Referring now to **FIG. 2E**, a via is formed through the substrate **205**, the buffer layer **220**, and the diode region **225**, **230**. In some embodiments, the via may be formed by etching the substrate **205**, the buffer layer **220**, and the diode region **225**, **230** using the ohmic contact layer **235** as an etch stop layer. Various etching techniques may be used in accordance with different embodiments of the present invention, including, but not limited to, wet etching, dry etching, and micro-machining.

Referring now to **FIGS. 2F - 2H**, exemplary operations for forming a dielectric spacer on sides of the via will now be described. As shown in **FIG. 2F**, the via is at least partially filled with a dielectric material **240**. By using, for example, sol-gel technology, spin-on-glass, a polyimide material, silicon dioxide and/or silicon nitride the dielectric material **240** may be formed in the via in the liquid state and later etched after curing to a solid. A mask **245** is formed on the second surface **210b** of the substrate **205** and patterned so as to expose a portion of the dielectric material **240** as shown in **FIG. 2G**. Referring now to **FIG. 2H**, the dielectric material **240** is etched through the mask **245** so as to leave a dielectric spacer **240a** and **240b** on sides of the via. Various etching techniques may be used in accordance with different embodiments of the present invention, including, but not limited to, wet etching, dry etching, and micro-machining.

Referring now to **FIG. 2I**, a contact plug **250** is formed in the via by, for example, plating the via with a conductive material, such as gold, silver, gold alloys, and/or silver alloys, in accordance with some embodiments of the present invention.

Referring now to **FIG. 2J**, a first electrical contact **255** is formed adjacent to the second surface **210b** such that the contact plug **250** couples the first electrical contact **255** to the p-type gallium nitride layer **230** via the ohmic contact layer **235**. Advantageously, because the ohmic contact layer **235** contacts the p-type gallium nitride layer **230** across a relatively broad surface area, improved current spreading may be provided. The first electrical contact **255** for the p-type gallium nitride layer **230** may comprise platinum, nickel, titanium/gold and/or alloys thereof. In other embodiments, a reflective ohmic contact comprising, for example, aluminum and/or silver, may be used to implement the first electrical contact **255**.

As shown in **FIG. 2J**, one or more second electrical contact(s) **260** are formed on the second surface **210b** of the substrate **205**. The second electrical contact(s) **260** for the n-type gallium nitride layer **225** may comprise aluminum, titanium and/or alloys thereof. Other suitable materials that form ohmic contact to n-type gallium nitride may be used for the second electrical contact(s) **260**. Examples of ohmic contacts to n-type gallium nitride layers and p-type gallium nitride layers are described, for example, in the above-incorporated U.S. Patent 5,767,581. **FIG. 2K** shows the structure of **FIG. 2J** inverted with the diode region on top of the substrate **205**.

Advantageously, light-emitting devices, according to some embodiments of the present invention, may allow electrical contacts to be coplanar on a non-active side of a substrate, which may obviate the need to use relatively thick diode regions to reduce current crowding when electrical contacts are made coplanar on the active side of the substrate. As a result, more active devices may be formed on a single wafer.

Embodiments of the invention have been described above in which a diode is shown as an example of an active region. It should be understood, however, that an active region may include, but is not limited to, quantum wells, heterojunctions, homojunctions, multiple layers, combinations of the foregoing, or the like, in accordance with some embodiments of the present invention. For example, layers **225** and **230** may be embodied as described in the above-referenced patents and/or applications. Moreover, additional layers, such as lattice strain layers, may also be incorporated in light-emitting devices in accordance with further embodiments of the present invention.

In concluding the detailed description, it should be noted that many variations and modifications can be made to the preferred embodiments without substantially departing from the principles of the present invention. All such variations and modifications are intended to be included herein within the scope of the present
5 invention, as set forth in the following claims.

Claims

That which is claimed:

1. A light-emitting device, comprising:
a substrate having first and second opposing surfaces;
5 an active region comprising a first active layer having a first conductivity type on the first surface and a second active layer having a second conductivity type on the first active layer;
a first electrical contact adjacent to the second surface;
a contact plug extending through the substrate and the active region that
10 couples the first electrical contact to the second active layer; and
a second electrical contact that is coupled to the substrate at the second surface.
2. The light-emitting device of Claim 1, further comprising:
15 a dielectric spacer on sides of the contact plug that separate the contact plug from the substrate and the first active layer.
3. The light-emitting device of Claim 2, wherein the dielectric spacer comprises spin-on-glass, a polyimide, silicon dioxide and/or silicon nitride.
20
4. The light-emitting device of Claim 1, further comprising:
an ohmic contact layer on the second active layer, the contact plug extending through the second active layer to contact the ohmic contact layer.
- 25 5. The light-emitting device of Claim 4, wherein the ohmic contact layer comprises at least one of TiN, platinum, nickel/gold, nickel oxide/gold, nickel oxide/platinum, Ti, and titanium/gold.
6. The light-emitting device of Claim 5, wherein the ohmic contact layer
30 has a thickness between about 10 Å and about 100 Å.
7. The light-emitting device of Claim 4, wherein the ohmic contact layer is at least partially transparent.

8. The light-emitting device of Claim 1, further comprising:
a buffer layer between the active region and the substrate, the contact plug
extending through the buffer layer.

5

9. The light-emitting device of Claim 8, wherein the buffer layer
comprises aluminum nitride.

10. The light-emitting device of Claim 1, wherein the substrate comprises
SiC.

11. The light-emitting device of Claim 1, wherein the contact plug
comprises gold, silver, a gold alloy, and/or a silver alloy.

12. The light-emitting device of Claim 1, wherein the first conductivity
type is n-type, and wherein the second electrical contact comprises at least one of
aluminum and titanium.

13. The light-emitting device of Claim 1, wherein the second conductivity
type is p-type, and wherein the first electrical contact comprises at least one of
platinum, nickel, and titanium/gold.

14. The light-emitting device of Claim 1, wherein the first active layer
comprises GaN.

25

15. The light-emitting device of Claim 1, wherein the second active layer
comprises GaN.

16. A light-emitting device, comprising:
a substrate having first and second opposing surfaces;
an active region on the first surface;
first and second electrical contacts adjacent to the second surface that are
conductively coupled to the active region.

30

17. The light-emitting device of Claim 16, wherein the active region comprises:

5 a first active layer having a first conductivity type on the first surface; and
a second active layer having a second conductivity type on the first active layer.

18. The light-emitting device of Claim 17, further comprising:
a contact plug extending through the substrate and the active region that
10 couples the first electrical contact to the second active layer.

19. The light-emitting device of Claim 18, further comprising:
a dielectric spacer on sides of the contact plug that separate the contact plug
from the substrate and the first active layer.

15 20. The light-emitting device of Claim 19, wherein the dielectric spacer
comprises spin-on-glass, a polyimide, silicon dioxide, and/or silicon nitride.

21. The light-emitting device of Claim 18, further comprising:
20 an ohmic contact layer on the second active layer, the contact plug extending
through the second active layer to contact the ohmic contact layer.

22. The light-emitting device of Claim 21, wherein the ohmic contact layer
comprises at least one of TiN, platinum, nickel/gold, nickel oxide/gold, nickel
25 oxide/platinum, Ti, and titanium/gold.

23. The light-emitting device of Claim 22, wherein the ohmic contact layer
has a thickness between about 10Å and about 100 Å.

30 24. The light-emitting device of Claim 21, wherein the ohmic contact layer
is at least partially transparent.

25. The light-emitting device of Claim 18, further comprising:

a buffer layer between the active region and the substrate, the contact plug extending through the buffer layer.

26. The light-emitting device of Claim 25, wherein the buffer layer
5 comprises aluminum nitride.

27. The light-emitting device of Claim 18, wherein the contact plug comprises gold, silver, a gold alloy, and/or a silver alloy.

10 28. The light-emitting device of Claim 17, wherein the first conductivity type is n-type, and wherein the second electrical contact comprises at least one of aluminum and titanium.

29. The light-emitting device of Claim 17, wherein the second conductivity
15 type is p-type, and wherein the first electrical contact comprises at least one of platinum, nickel, and titanium/gold.

30. The light-emitting device of Claim 17, wherein the first active layer comprises GaN.
20

31. The light-emitting device of Claim 17, wherein the second active layer comprises GaN.

32. The light-emitting device of Claim 16, wherein the substrate comprises
25 SiC.

33. A method of forming a light-emitting device, comprising:
forming a first active layer having a first conductivity type on a first surface a
substrate having first and second opposing surfaces;
30 forming a second active layer having a second conductivity type on the first active layer, the first and second active layers comprising an active region;
forming a via through the substrate and the active region;
forming a contact plug in the via;

forming a first electrical contact adjacent to the second surface, the contact plug coupling the first electrical contact to the second active layer; and

forming a second electrical contact that is coupled to the substrate at the second surface.

5

34. The method of Claim 33, further comprising:

forming a dielectric spacer on sides of the contact plug that separate the contact plug from the substrate and the first active layer.

10

35. The method of Claim 34, wherein forming the dielectric spacer comprises:

filling at least a portion of the via with a dielectric material;

forming a mask on the second surface; and

etching the dielectric material through the mask.

15

36. The method of Claim 33, further comprising:

forming an ohmic contact layer on the second active layer, the contact plug extending through the second active layer to contact the ohmic contact layer.

20

37. The method of Claim 33, wherein forming the via comprises:

etching the substrate using the ohmic contact layer as an etch stop.

38. The method of Claim 37, wherein etching the substrate is performed

using at least one of the following etching techniques: wet etching, dry etching, and

25

micro-machining.

39. The method of Claim 33, further comprising:

forming a buffer layer between the active region and the substrate, the contact plug extending through the buffer layer.

30

40. The method of Claim 33, wherein forming the contact plug comprises:

plating the via with gold, silver, a gold alloy, and/or a silver alloy.

41. A method of forming a light-emitting device, comprising:
forming an active region on a first surface of a substrate having first and
second opposing surfaces;
forming first and second electrical contacts adjacent to the second surface that
5 are conductively coupled to the active region.

42. The method of Claim 41, wherein forming the active region comprises:
forming a first active layer having a first conductivity type on the first surface;
and
10 forming a second active layer having a second conductivity type on the first
active layer.

43. The method of Claim 42, further comprising:
forming a contact plug extending through the substrate and the active region
15 that couples the first electrical contact to the second active layer.

44. The method of Claim 43, further comprising:
forming a dielectric spacer on sides of the contact plug that separate the
contact plug from the substrate and the first active layer.

20 45. The method of Claim 43, further comprising:
forming an ohmic contact layer on the second active layer, the contact plug
extending through the second active layer to contact the ohmic contact layer.

25 46. The method of Claim 43, further comprising:
forming a buffer layer between the active region and the substrate, the contact
plug extending through the buffer layer.

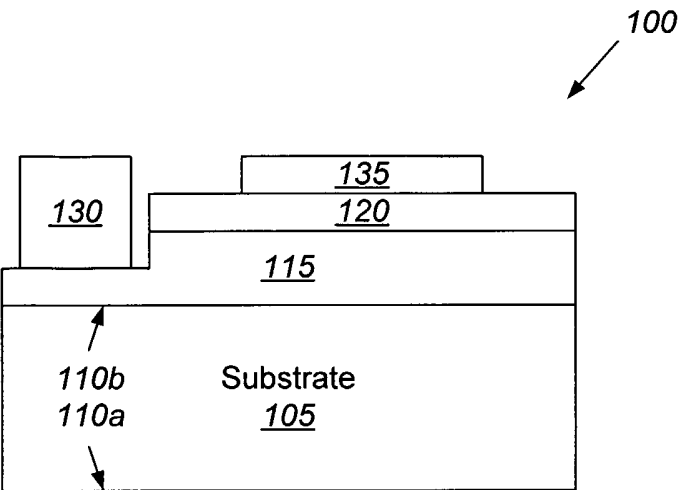


FIG. 1
(PRIOR ART)

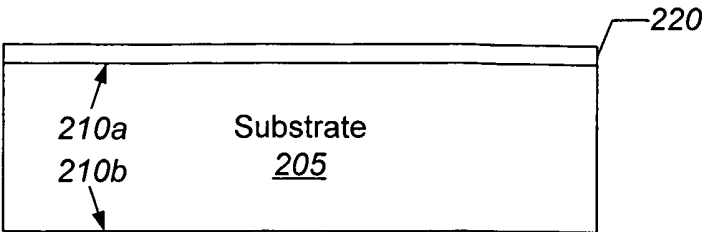


FIG. 2A

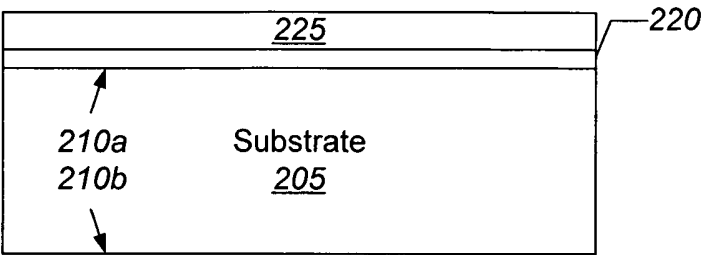


FIG. 2B

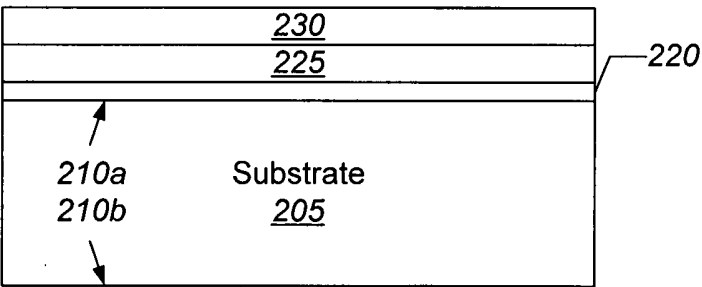


FIG. 2C

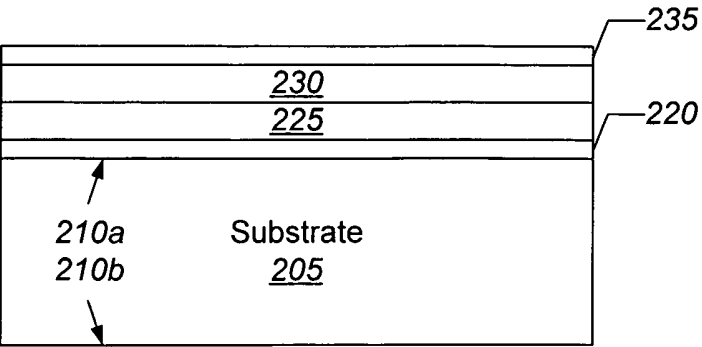


FIG. 2D

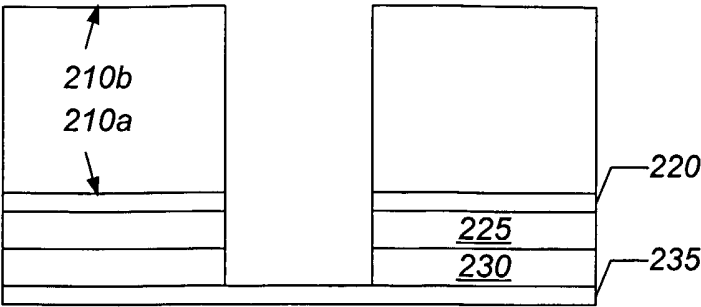


FIG. 2E

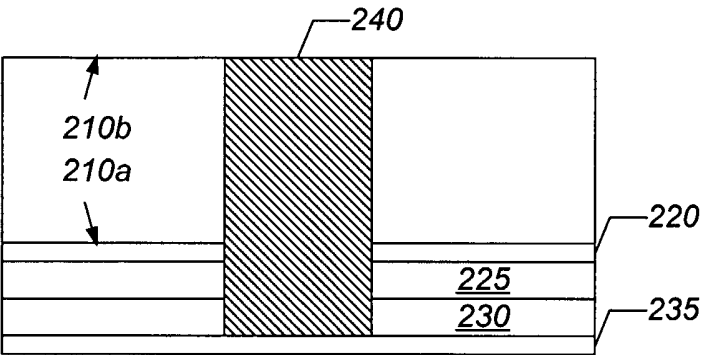


FIG. 2F

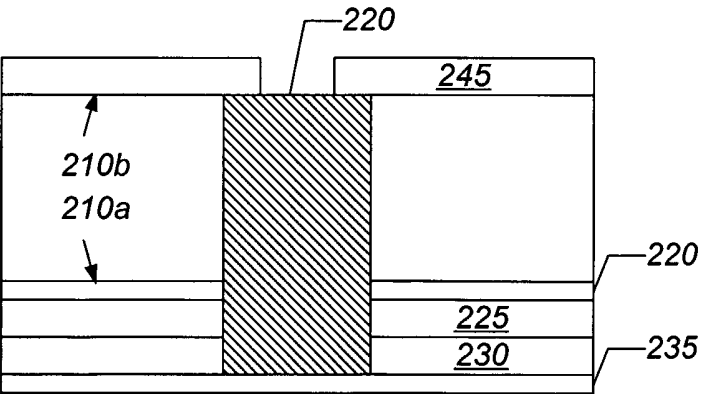


FIG. 2G

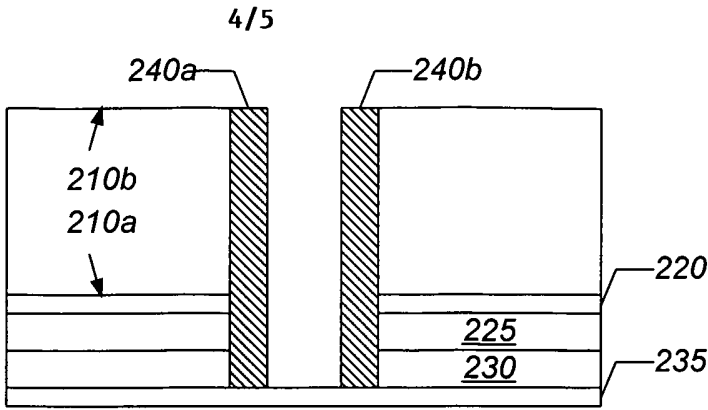


FIG. 2H

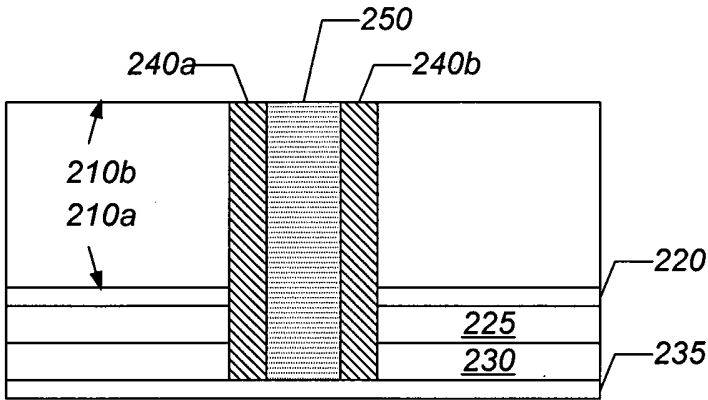


FIG. 2I

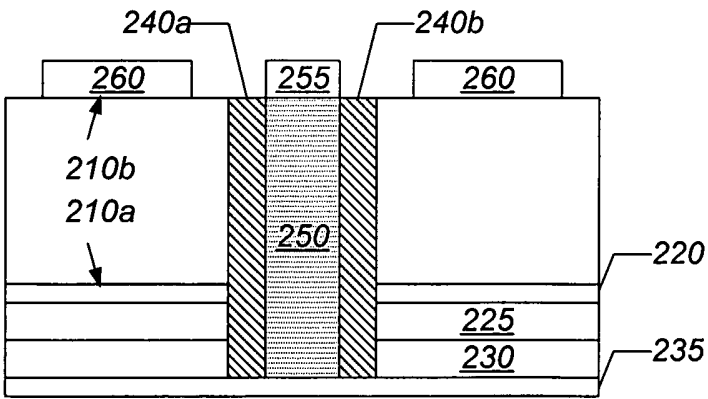
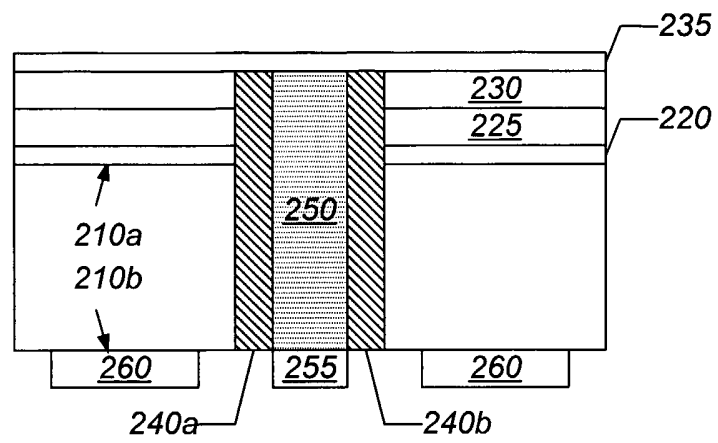


FIG. 2J

**FIG. 2K**