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(54) **LIGHT EMITTER DEVICE**

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(58) **Field of Classification Search** 257/79–99; 438/22, 48–55
See application file for complete search history.

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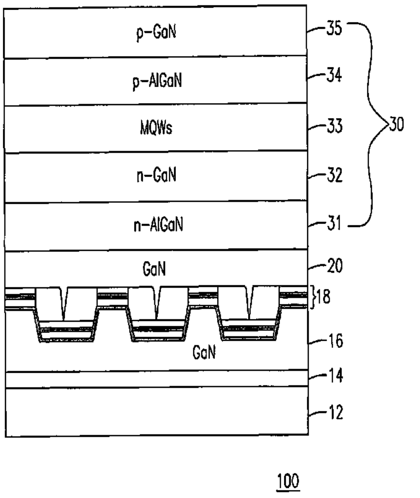
(57) **ABSTRACT**

A light emitting device (LED) structure formed on a Group IV-based semiconductor substrate is provided. The LED structure includes a Group IV-based substrate, an AlN nucleation layer formed on the Group IV-based substrate, a GaN epitaxial layer formed on the AlN nucleation layer, a distributed Bragg reflector (DBR) multi-layer structure formed on the epitaxial layer, and an LED active layer formed on the DBR multi-layer structure.

16 Claims, 5 Drawing Sheets



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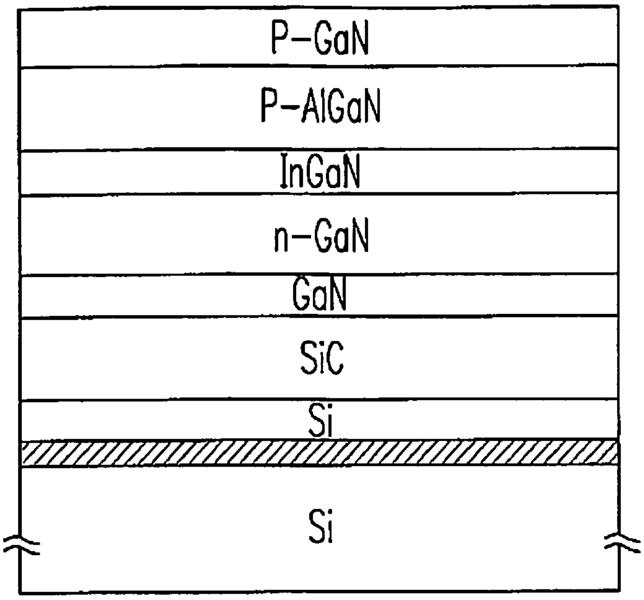
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P-AlGaN
InGaN
n-GaN
GaN
SiC
Si
Si

Fig. 1(A)

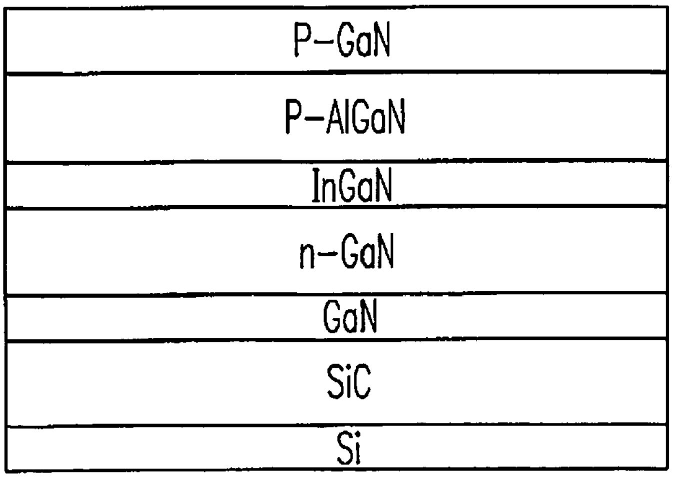
P-GaN
P-AlGaN
InGaN
n-GaN
GaN
SiC
Si

Fig. 1(B)

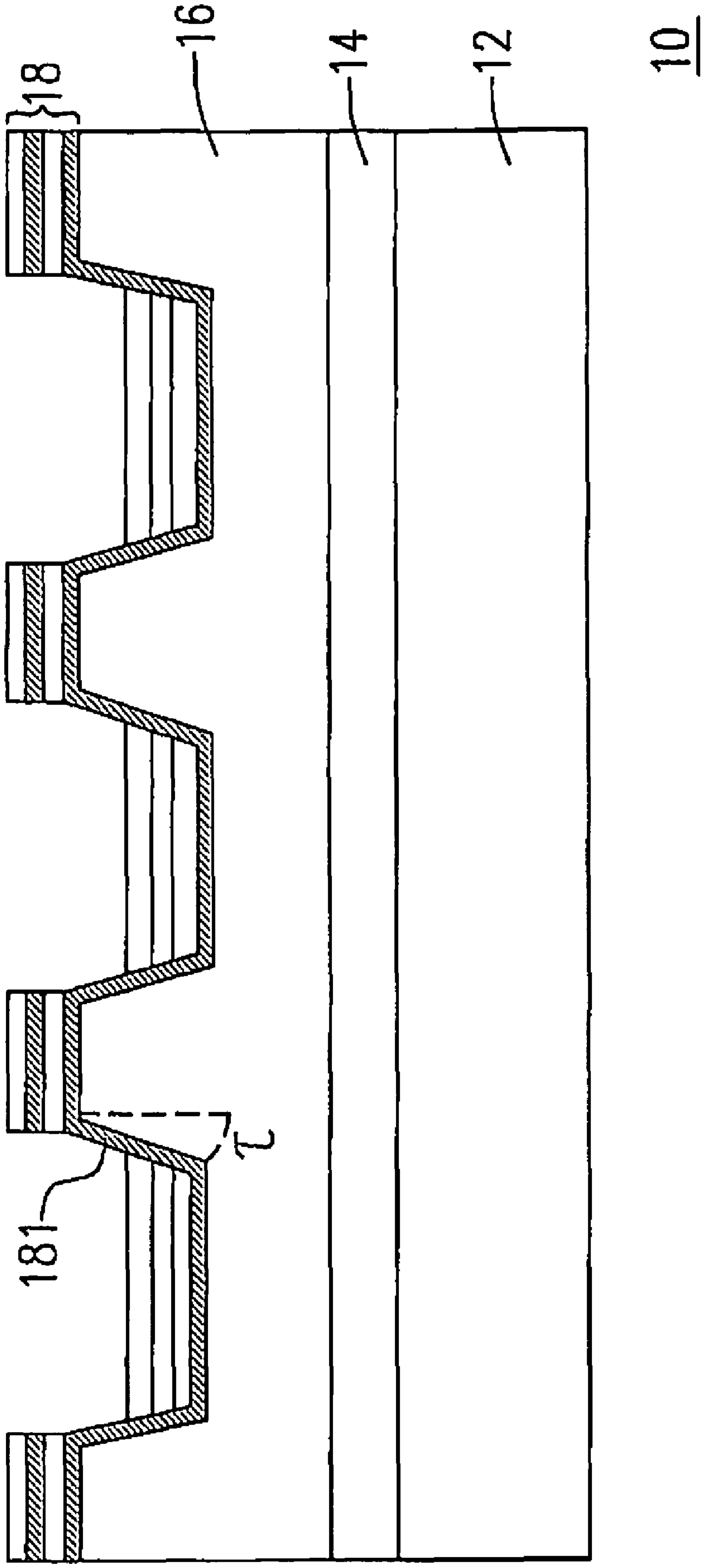

Fig. 2

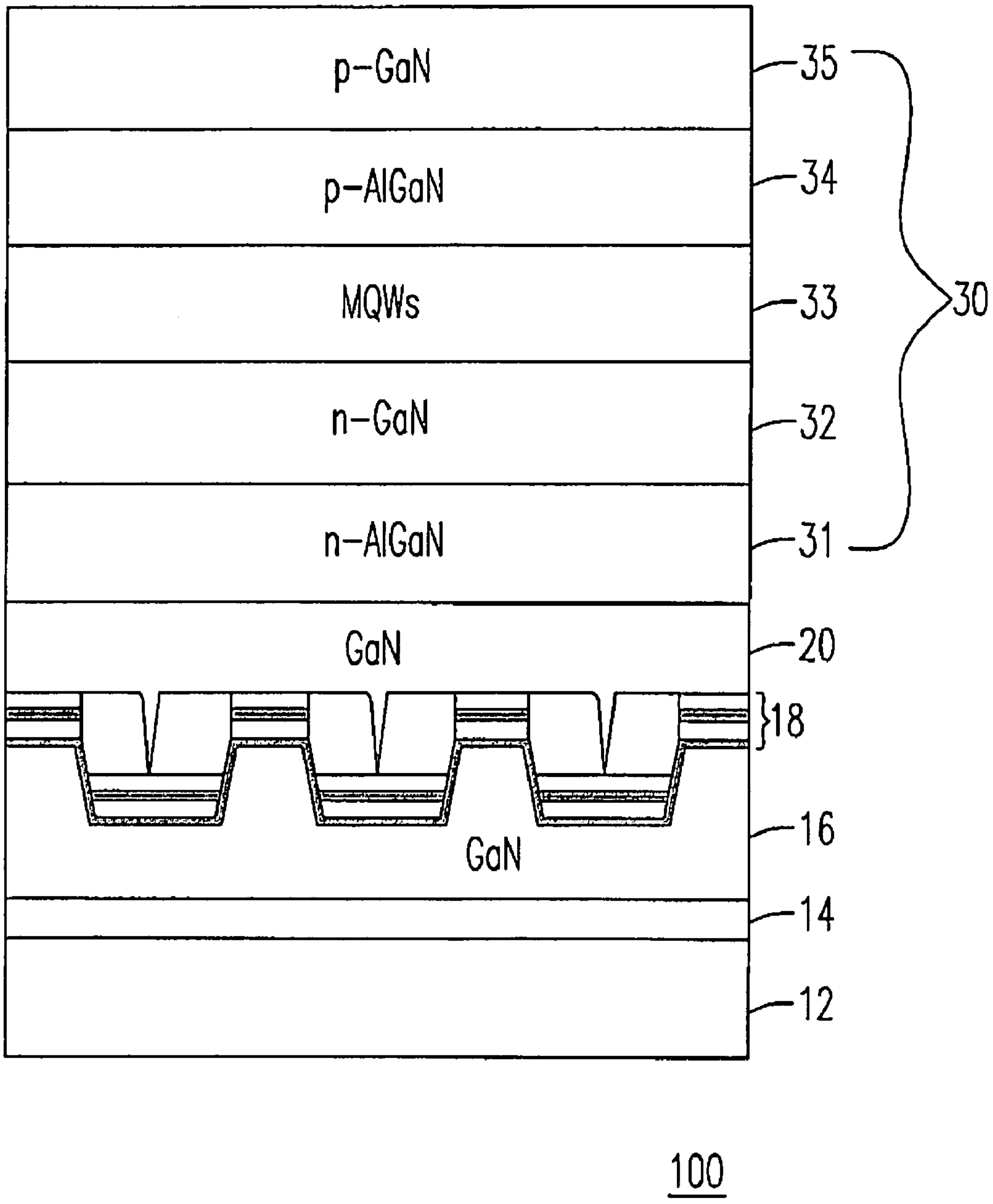
p-GaN
35
p-AlGaN
34
MQWs
33
30
n-GaN
32
n-AlGaN
31
GaN
20
18
16
GaN
14
12
100

Fig. 3

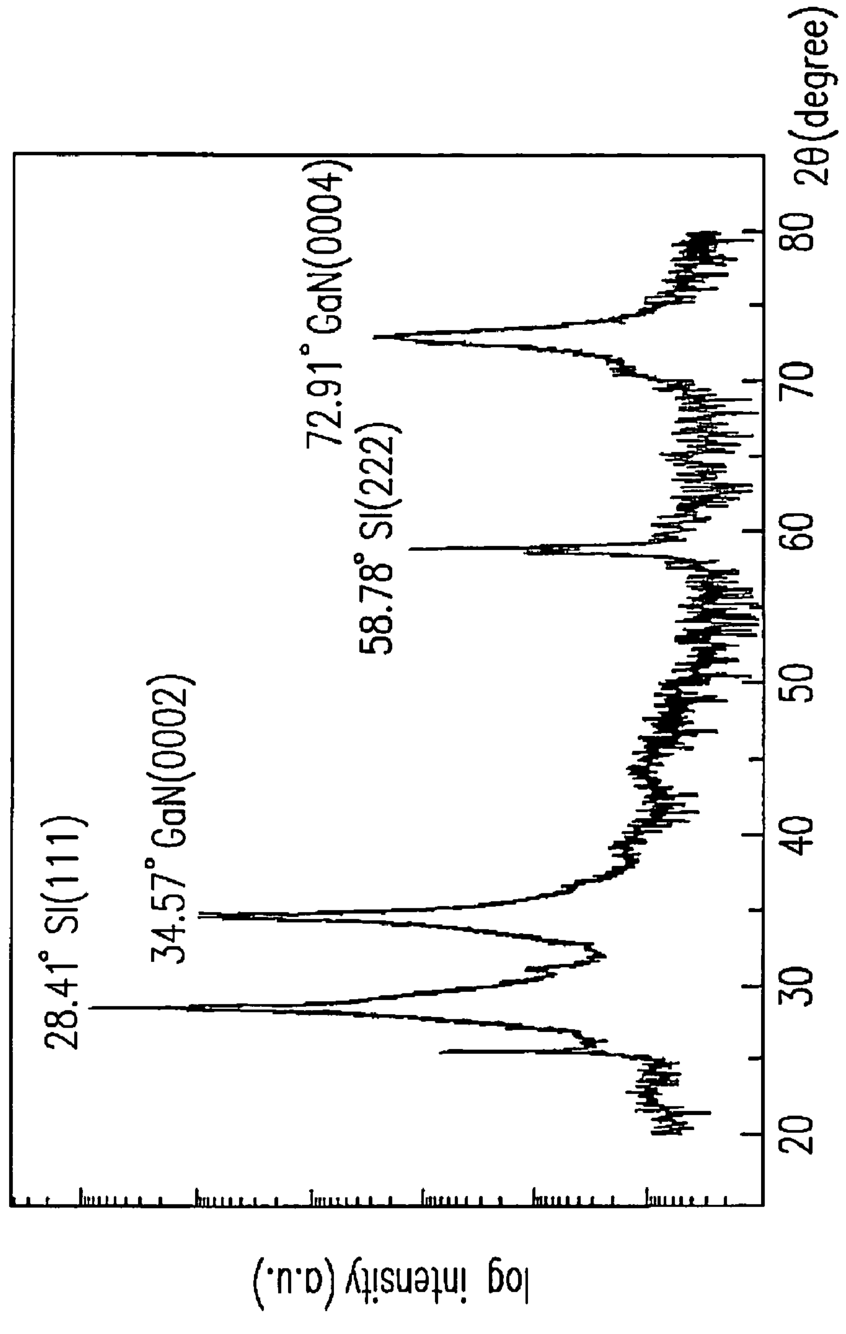
28.41° SI(111)
34.57° GaN(0002)
58.78° SI(222)
72.91° GaN(0004)
log intensity (a.u.)
2θ(degree)
20
30
40
50
60
70
80

Fig. 4

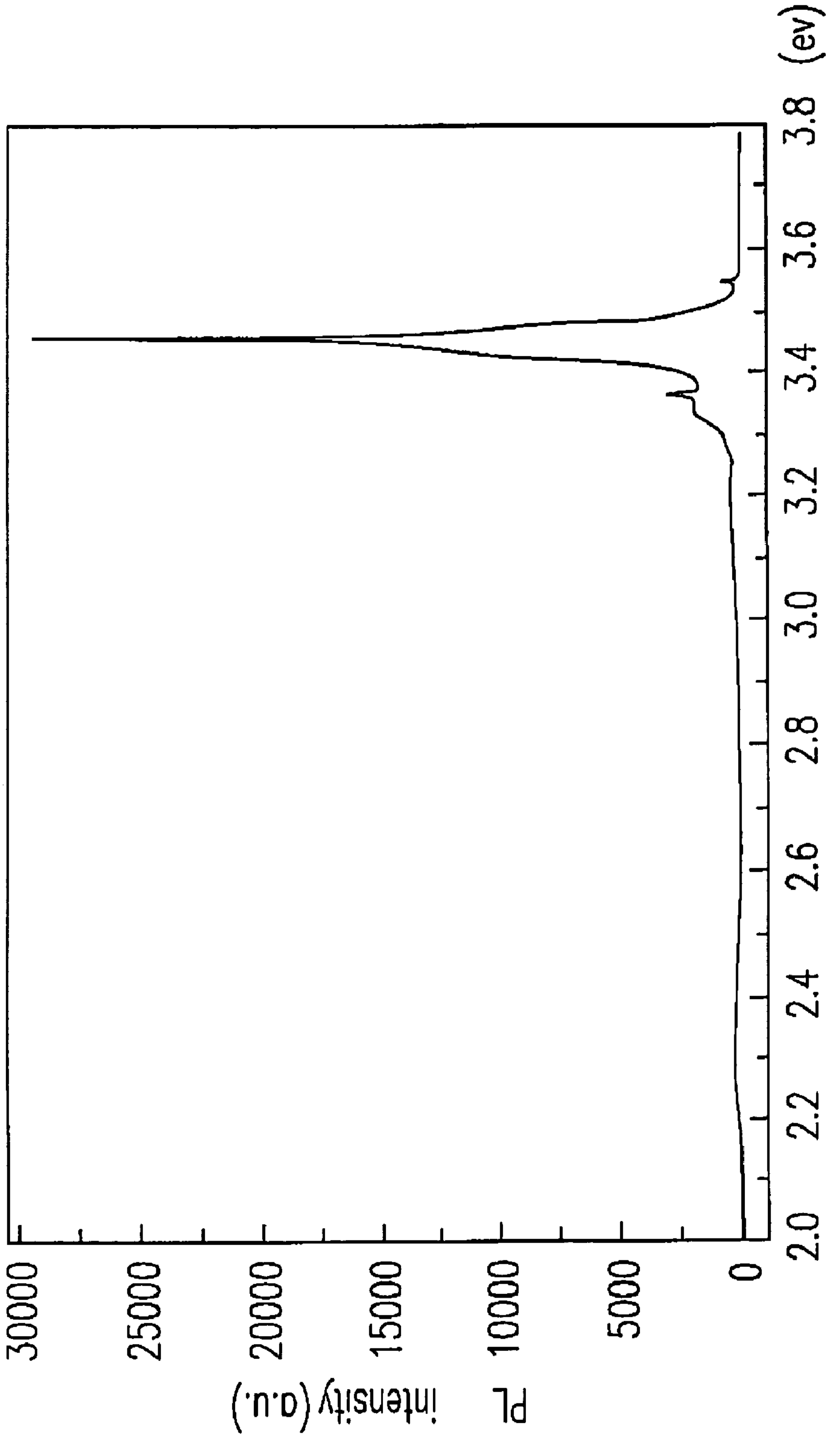
PL intensity (a.u.)
30000
25000
20000
15000
10000
5000
0
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
(ev)

Fig. 5

LIGHT EMITTER DEVICE

FIELD OF THE INVENTION

The present invention relates to a light emitting device, and in particular to a light emitting device formed on a Group IV-based semiconductor substrate.

BACKGROUND OF THE INVENTION

Recently, more and more researches are focus on forming a Group III-nitride based light emitting device (LED) structure on a Group IV-based semiconductor substrate. This is because the Group IV-based semiconductor substrate is much cheaper than that of the typical LED substrates, such as sapphire substrate or the silicon carbide (SiC) substrate. The LED structure formed on the Group IV-based semiconductor substrate is also much easier to be integrated on the integration circuits formed on the Group IV-based semiconductor substrate, or could be easily compatible with the fabrication process of the integration circuits on the Group IV-based semiconductor substrate. Nevertheless, the hetero-junction structure existing between the Group III-nitride based LED structure and the Group IV-based substrate usually brings some structural problems due to the mismatch of two different crystalline lattices and/or the difference of coefficient of thermal expansion (CTE) between these two materials in the hetero-junction structure. The mismatch of the hetero-junction structure always causes bad epitaxy quality of LED structure, which might greatly affect the optical property of the light emitting device.

There are many references relating to the fabrication of the Group III-nitride based LED structure on the Group IV-based substrate. C. A. Tran disclosed in Applied Physics Letters (1999) a method for growing an InGaN/GaN multiple quantum well (MQW) blue light emitting diodes (435 nm) on a silicon (111) substrate by the metalorganic vapor phase epitaxiy (MOVPE) process, where the LED is operable in 4 volts. However, the epitaxial film of such LED would be cracked due to the stress existing between the epitaxial film and the silicon substrate.

B. J. Zhang et al. also disclosed in Phys. Stat. Sol. (a) (2001) an InGaN multiple quantum well (MQW) light emitting diodes (LED) structure formed on a silicon (111) substrate. The MQW LED is fabricated by the steps of forming an n-type AlN/AlGaN (120/380 nm) buffer layer in the temperature of 1130° C. by the MOCVD, forming an n-type GaN layer of 0.2 μm, forming an $In_{0.13}Ga_{0.87}N$ quantum well of 3 nm, forming an $In_{0.01}Ga_{0.99}N$ barrier layer of 5 nm, forming a p-doped layer of $Al_{0.15}Ga_{0.85}N$ of 20 nm and forming a p-type GaN cover layer of 0.2 μm. Although the crack does not occur in the LED structure disclosed by B. J. Zhang et al., it is clear that the formation of the n-type AlN/AlGaN buffer layer in the temperature of 1130° C. could likely result in the formation of the AlSi alloy since the eutectic point thereof is about 577° C. Thus, the epitaxy quality of the LED structure could be affected by the formation of the AlSi alloy.

A. Dadgar et al. also disclosed in Phys. Stat. Sol. (a) (2001) a crack free InGaN/GaN LED structure on a silicon (111) substrate. Such LED structure is fabricated by the steps of forming a patterned silicon nitride on a silicon substrate by a sputtering process, and then forming a silicon-doped AlN layer, 15 pairs of AlGaN/GaN multiplayer structure, GaN:Si structure of 300 nm and three-layered InGaN/GaN quantum well on the pre-deposited aluminum layer. Although such LED structure is crack free, the formation of the patterned silicon nitride will occupy many areas of the silicon substrate, which results in the decrease of the effective area of the LED.

In addition, please refer to FIG. **1**(A) and FIG. **1**(B), which respective show a conventional nitride LED structure formed on a SiC/Si substrate and on a SOI (silicon on insulator) substrate according to the U.S. Pat. No. 5,786,606 by Johji Nishio et al. The conventional LED structure is mainly focused on forming a silicon layer on a Si or SiC substrate having thereon a silicon oxide (SiO_2) layer, and then forming the LED active layer on the silicon layer. After the formation of the LED active layer, the silicon oxide layer is removed by a wet etching process, so as to form the LED structure shown in the respective FIG. **1**(A) and FIG. **1**(B). Nevertheless, it is clear that the fabrication processes for the LED structures in the respective FIG. **1**(A) and FIG. **1**(B) are much complicated, time consuming and costly.

In order to overcome the above-mentioned issues, a novel light emitting device (LED) structure on a Group IV-based semiconductor substrate and the fabrication method therefore are provided. In such a light emitting device (LED) structure and the fabrication method, the epitaxy quality and the optical property of the LED structure on a Group IV-based semiconductor substrate will be greatly improved.

SUMMARY OF THE INVENTION

It is a first aspect of the present invention to provide a light emitting device (LED) structure formed on a Group IV-based semiconductor substrate. The LED structure includes a Group IV-based substrate, an AlN nucleation layer formed on the Group IV-based substrate, a GaN epitaxial layer formed on the AlN nucleation layer, a distributed Bragg reflector (DBR) multi-layer structure formed on the epitaxial layer, and an LED active layer formed on the DBR multi-layer structure.

Preferably, the LED structure further includes a GaN buffer layer formed between the LED active layer and the DBR multi-layer structure.

Preferably, the DBR multi-layer structure is made of a nitride including a Group III element.

Preferably, the GaN epitaxial layer is a patterned epitaxial layer.

Preferably, the DBR multi-layer structure is a patterned multi-layer structure.

Preferably, LED active layer further includes an n-type AlGaN layer, an n-type GaN layer formed on the n-type AlGaN layer, a multiple quantum wells (MQWs) active layer formed on the n-type GaN layer, a p-type AlGaN layer formed on the MQWs active layer, and a p-type GaN layer formed on the p-type AlGaN layer.

Preferably, the DBR multi-layer structure has a reflective surface having a tilt angle ranged from 5 to 75 degree with respect to a vertical line.

Preferably, the reflective surface has a tilt angle of 64 degree with respect to a vertical line.

It is a second aspect of the present invention to provide a light emitting device (LED) structure formed on a Group IV-based semiconductor substrate. The LED structure includes a substrate having a distributed Bragg reflector (DBR) multi-layer structure, a GaN buffer layer formed on the substrate, and an LED active layer formed on the GaN buffer layer.

Preferably, the substrate further includes a Group IV-based substrate, a nucleation layer formed on the Group IV-based substrate, an epitaxial layer formed on the nucleation layer, and a patterned distributed Bragg reflector (DBR) multi-layer structure formed on the epitaxial layer.

Preferably, the DBR multi-layer structure is made of a nitride including a Group III element.

Preferably, the nucleation layer is an AlN diffusion barrier layer.

Preferably, the epitaxial layer is a patterned GaN epitaxial layer.

Preferably, the LED active layer further includes an n-type AlGaN layer formed on the GaN buffer layer, an n-type GaN layer formed on the n-type AlGaN layer, a multiple quantum wells (MQWs) active layer formed on the n-type GaN layer, a p-type AlGaN layer formed on the MQWs active layer, and a p-type GaN layer formed on the p-type AlGaN layer;

Preferably, the DBR multi-layer structure has a reflective surface having a tilt angle ranged from 5 to 75 degree with respect to a vertical line.

Preferably, the reflective surface has a tilt angle of 64 degree with respect to a vertical line.

It is a third aspect of the present invention to provide a fabrication method for a light emitting device. The fabrication method includes the steps of providing a substrate having a distributed Bragg reflector (DBR) multi-layer structure, forming a GaN buffer layer on the substrate, and forming an LED active layer on the GaN buffer layer, wherein the GaN buffer layer is formed on the substrate by a lateral growth process.

Preferably, the step for providing the substrate having a DBR multi-layer structure further includes the step of providing a Group IV-based substrate, forming an AlN diffusion barrier layer on the Group IV-based substrate by a relatively low temperature growth process, forming a patterned GaN epitaxial layer on the AlN diffusion barrier layer, and forming a patterned DBR multi-layer structure formed on the patterned GaN epitaxial layer.

The above objects and advantages of the present invention will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed descriptions and accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**(A) and FIG. **1**(B) are diagrams schematically illustrating the conventional nitride LED structure formed on a SiC/Si substrate and on a SOI substrate according to the prior arts;

FIG. **2** is a diagram schematically illustrating a group IV-based substrate having a patterned Group III nitride distributed Bragg reflector (DBR) multi-layer structure according to the present invention;

FIG. **3** is a diagram schematically illustrating a Group III nitride LED structure formed on a group IV-based substrate according to an preferred embodiment of the present invention;

FIG. **4** is an XRD diffraction diagram of the LED structure according to FIG. **3**; and

FIG. **5** is a Photoluminescence (PL) intensity diagram of the LED structure according to FIG. **3** at the temperature of 13 K.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will now be described more specifically with reference to the following embodiments. It is to be noted that the following descriptions of preferred embodiments of this invention are presented herein for purpose of illustration and description only; it is not intended to be exhaustive or to be limited to the precise form disclosed.

Please refer to FIG. **2**, which schematically shows a substrate structure having a patterned Group III nitride distributed Bragg reflector (DBR) multi-layer structure according to the present invention. As shown in FIG. **2**, the substrate structure **10** including a group IV-based substrate **12**, a nucleation layer **14**, an epitaxial layer **16** and a patterned distributed Bragg reflector (DBR) multi-layer structure **18**. Typically, the nucleation layer **14** is an AlN diffusion barrier layer formed on the group IV-based substrate **12** by a relatively low temperature growth process. Since the growth process is implemented in the relatively low temperature, the possible eutectic reaction between the Al element of the AlN diffusion barrier layer and the group IV element, such as silicon element, of the group IV-based substrate **12** could be avoidable. Further, the nucleation layer **14** could also be used as a diffusion barrier layer barrier layer for preventing the silicon of the group IV-based substrate **12** from further being diffused. After the formation of the AlN nucleation layer (or diffusion barrier layer) **14**, a patterned GaN epitaxial layer **16** is formed on the nucleation layer **14**, and then a distributed Bragg reflector (DBR) multi-layer structure **18**, which is made of the Group III nitride and has a pattern corresponding to the patterned GaN epitaxial layer, is formed on the epitaxial layer **16**.

Please further refer to FIG. **3**, after the formation of the substrate structure **10** having a patterned Group III nitride DBR multi-layer structure, as shown in FIG. **2**, an GaN buffer layer **20** is formed on the substrate structure **10** through a lateral growth process. Then, an LED active layer **30** is formed on the GaN buffer layer **20**, so that a light emitting device (LED) structure **100** formed on the Group IV-based substrate structure **10** having a distributed Bragg reflector (DBR) multi-layer structure is provided.

As mentioned above, the distributed Bragg reflector (DBR) multi-layer structure **18** of the present invention is preferably made of a material including a nitride of Group III material. The DBR multi-layer structure **18** is not only used for reflecting the light emitting from the LED active layer **30**, but also used as a barrier layer preventing the defect of epitaxial layer **16** from being diffused upwardly. Accordingly, the DBR multi-layer structure **18** could not only improve the optical property of the LED structure but also increase the light extraction efficiency of the LED structure. In a preferred embodiment of the present invention, the DBR multi-layer structure **18** further has a reflective surface **181** (as shown in FIG. **2**) having a tilt angle τ with respect to a vertical. Typically, the light extraction efficiency of the LED structure could be affected by the tilt angle τ. Preferably, the tilt angle τ of the reflective surface **181** is ranged from 5 to 75 degree. In a preferred embodiment of the present invention, the light extraction efficiency of the LED structure **100** is optimal in a tilt angle τ of 64 degree with respect to a vertical line.

On the other hand, in a preferred embodiment of the present invention, the LED active layer **30** of the LED structure **100** according to the present invention could include an n-type AlGaN layer **31** formed on the GaN buffer layer **20**, an n-type GaN layer **32** formed on the n-type AlGaN layer **31**, a multiple quantum wells (MQWs) active layer **33** formed on the n-type GaN layer **32**, a p-type AlGaN layer **34** formed on the MQWs active layer **33**, and a p-type GaN layer **35** formed on the p-type AlGaN layer **34**.

On the other hand, since the GaN buffer layer **20** disposed between the LED active layer **30** and the Group IV-based substrate structure **10** having a distributed Bragg reflector (DBR) multi-layer structure **18** is formed by a lateral growth process, there could be few stress accumulated within the GaN buffer layer **20**. Accordingly, a better epitaxiy quality for the LED structure **100** could be obtained. Please refer to FIG.

4, which shows an XRD diffraction diagram of the LED structure according to FIG. 3. As shown in FIG. 4, the peak value of the GaN buffer layer 20 occur at 34.57°, which means the stress within the GaN buffer layer 20 is released.

Further, please refer to FIG. 5, which further shows a Photoluminescence (PL) intensity diagram of the LED structure according to FIG. 3 at the temperature of 13 K. As shown in FIG. 5, both the high peak value of the PL intensity and the smaller width of the full-width-half-maximum (FWHM) of the PL spectrum imply that a better epitaxy quality of the LED structure **100** is obtained.

While the invention has been described in terms of what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention needs not be limited to the disclosed embodiments. On the contrary, it is intended to cover various modifications and similar arrangements included within the spirit and scope of the appended claims, which are to be accorded with the broadest interpretation so as to encompass all such modifications and similar structures.

What is claimed is:

1. A light emitting device (LED), comprising:
a Group IV-based substrate;
an AlN nucleation layer formed on the Group IV-based substrate;
a GaN epitaxial layer formed on the AlN nucleation layer;
a distributed Bragg reflector (DBR) multi-layer structure formed on the epitaxial layer, wherein the DBR multi-layer structure has a reflective surface having a tilt angle ranged from 5 to 75 degree with respect to a vertical line; and
an LED active layer formed on the DBR multi-layer structure.

2. A light emitting device according to claim **1**, further comprising a GaN buffer layer formed between the LED active layer and the DBR multi-layer structure.

3. A light emitting device according to claim **1**, wherein the DBR multi-layer structure is made of a nitride comprising a Group III element.

4. A light emitting device according to claim **1**, wherein the GaN epitaxial layer is a patterned epitaxial layer.

5. A light emitting device according to claim **1**, wherein the DBR multi-layer structure is a patterned multi-layer structure.

6. A light emitting device according to claim **1**, wherein the LED active layer further comprises:
an n-type AlGaN layer;
an n-type GaN layer formed on the n-type AlGaN layer;
a multiple quantum wells (MQWs) active layer formed on the n-type GaN layer;
a p-type AlGaN layer formed on the MQWs active layer; and
a p-type GaN layer formed on the p-type AlGaN layer.

7. A light emitting device according to claim **1**, wherein the reflective surface has a tilt angle of 64 degree with respect to a vertical line.

8. A light emitting device (LED), comprising:
a substrate having a distributed Bragg reflector (DBR) multi-layer structure, wherein the DBR multi-layer structure has a reflective surface having a tilt angle ranged from 5 to 75 degree with respect to a vertical line;
a GaN buffer layer formed on the substrate; and
an LED active layer formed on the GaN buffer layer.

9. A light emitting device according to claim **8**, wherein the substrate further comprises:
a Group IV-based substrate;
a nucleation layer formed on the Group IV-based substrate;
an epitaxial layer formed on the nucleation layer; and
a patterned distributed Bragg reflector (DBR) multi-layer structure formed on the epitaxial layer.

10. A light emitting device according to claim **9**, wherein the DBR multi-layer structure is made of a nitride comprising a Group III element.

11. A light emitting device according to claim **9**, wherein the nucleation layer is an AlN diffusion barrier layer.

12. A light emitting device according to claim **9**, wherein the epitaxial layer is a patterned GaN epitaxial layer.

13. A light emitting device according to claim **8**, wherein the LED active layer further comprises:
an n-type AlGaN layer formed on the GaN buffer layer;
an n-type GaN layer formed on the n-type AlGaN layer;
a multiple quantum wells (MQWs) active layer formed on the n-type GaN layer;
a p-type AlGaN layer formed on the MQWs active layer; and
a p-type GaN layer formed on the p-type AlGaN layer.

14. A light emitting device (LED), comprising:
a substrate having a distributed Bragg reflector (DBR) multi-layer structure, and the substrate further comprising:
  a Group IV-based substrate;
  a nucleation layer formed on the Group IV-based substrate;
  an epitaxial layer formed on the nucleation layer; and
  a patterned distributed Bragg reflector (DBR) multi-layer structure formed on the epitaxial layer, wherein the DBR multi-layer structure has a reflective surface having a tilt angle ranged from 5 to 75 degree with respect to a vertical line;
a GaN buffer layer formed on the substrate; and
an LED active layer formed on the GaN buffer layer.

15. A light emitting device according to claim **14**, wherein the reflective surface has a tilt angle of 64 degree with respect to a vertical line.

16. A light emitting device according to claim **8**, wherein the reflective surface has a tilt angle of 64 degree with respect to a vertical line.

* * * * *