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(54) **NITRIDE SEMICONDUCTOR SUBSTRATE, METHOD FOR FORMING A NITRIDE SEMICONDUCTOR LAYER AND METHOD FOR SEPARATING THE NITRIDE SEMICONDUCTOR LAYER FROM THE SUBSTRATE**

(75) Inventors: **Yih-Der Guo**, Hsinchu City (TW); **Chih-Ming Lai**, Pingtung County (TW); **Jenq-Dar Tsay**, Kaohsiung City (TW); **Po-Chun Liu**, Taichung County (TW)

Correspondence Address:
JIANQ CHYUN INTELLECTUAL PROPERTY OFFICE
7 FLOOR-1, NO. 100, ROOSEVELT ROAD, SECTION 2
TAIPEI 100

(73) Assignee: **INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE**, Hsinchu (TW)

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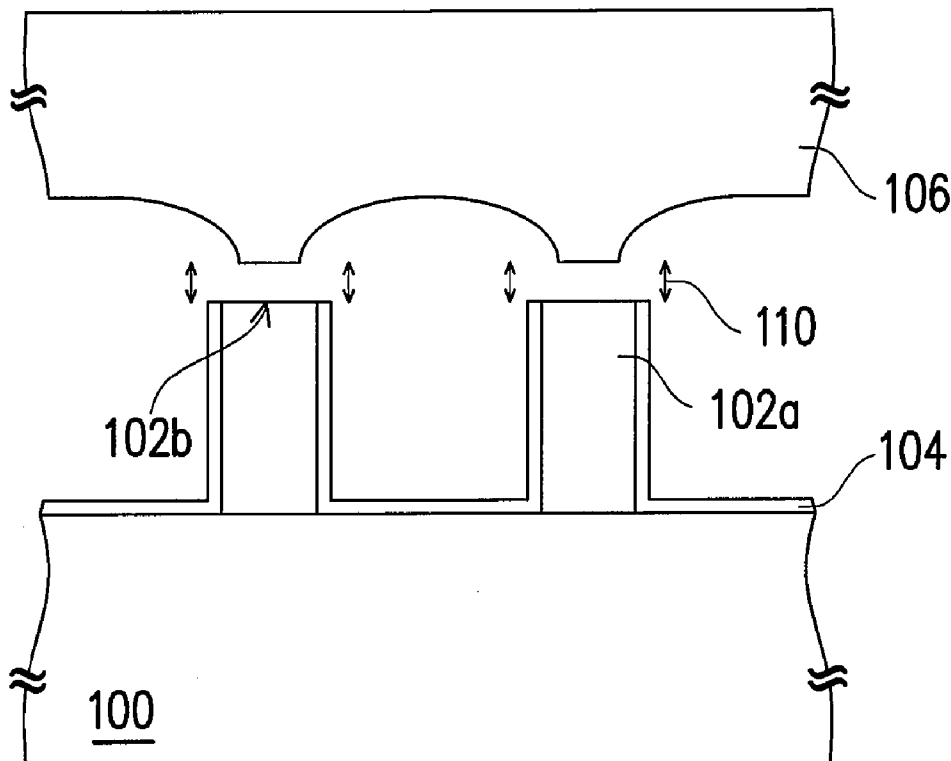
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(57) **ABSTRACT**

There is provided a method of forming a nitride semiconductor layer, including the steps of firstly providing a substrate on which a patterned epitaxy layer with a pier structure is formed. A protective layer is then formed on the patterned epitaxy layer, exposing a top surface of the pier structure. Next, a nitride semiconductor layer is formed over the patterned epitaxy layer connected to the nitride semiconductor layer through the pier structure, wherein the nitride semiconductor layer, the pier structure, and the patterned epitaxy layer together form a space exposing a bottom surface of the nitride semiconductor layer. Thereafter, a weakening process is performed to remove a portion of the bottom surface of the nitride semiconductor layer and to weaken a connection point between the top surface of the pier structure and the nitride semiconductor layer. Finally, the substrate is separated from the nitride semiconductor layer through the connection point.



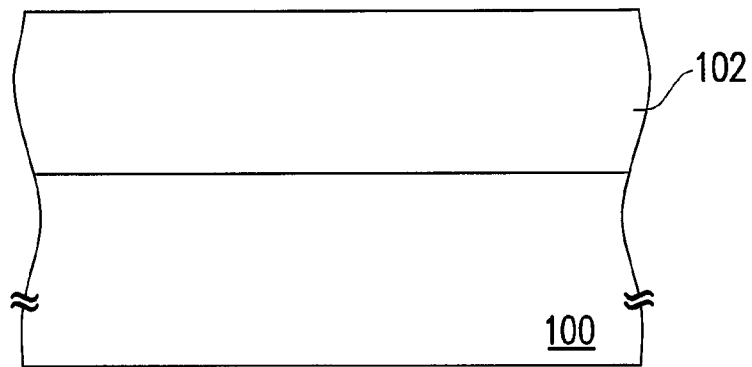


FIG. 1A

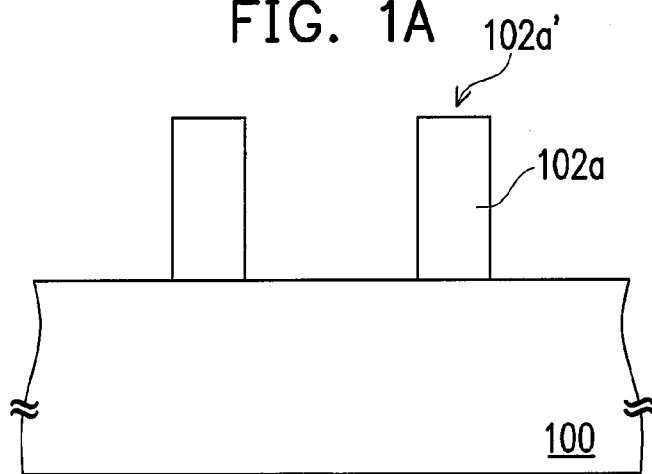


FIG. 1B

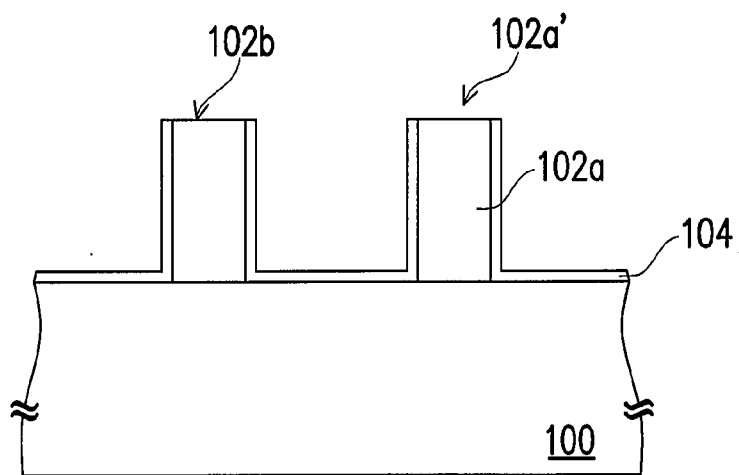


FIG. 1C

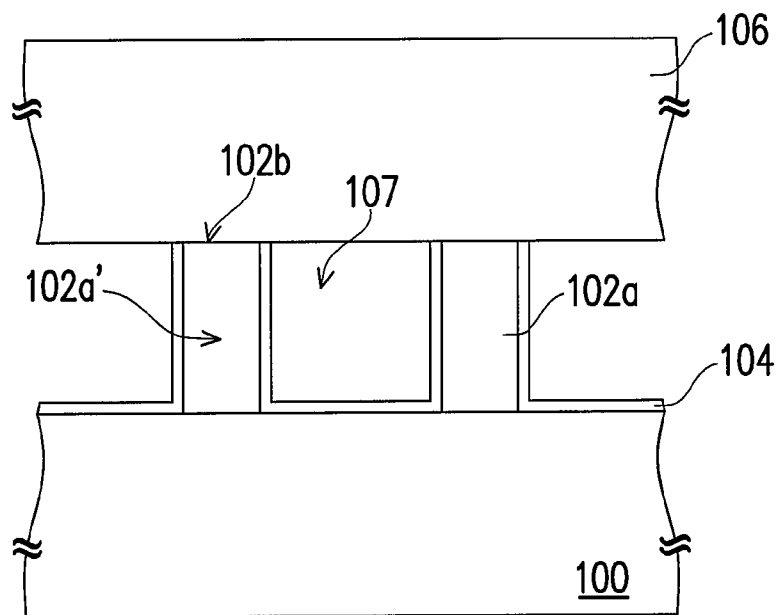


FIG. 1D

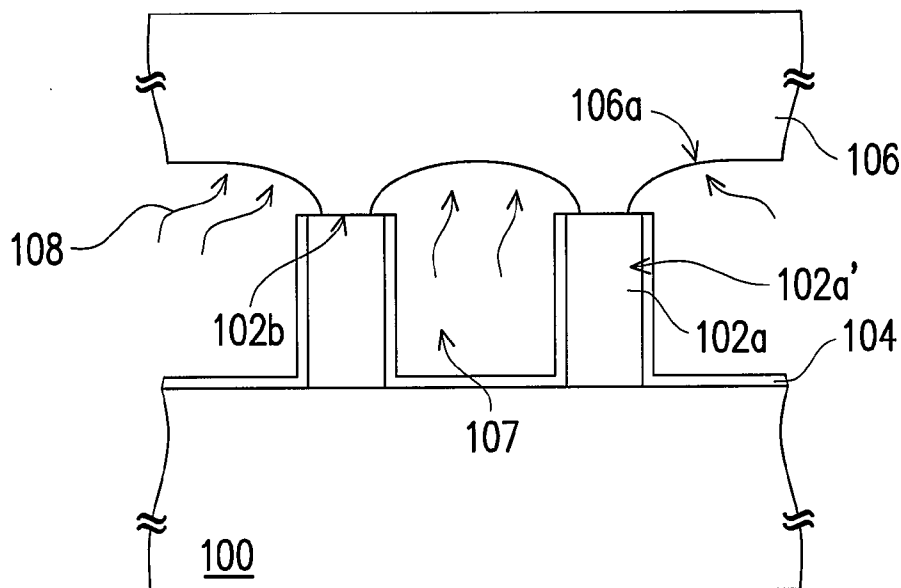


FIG. 1E

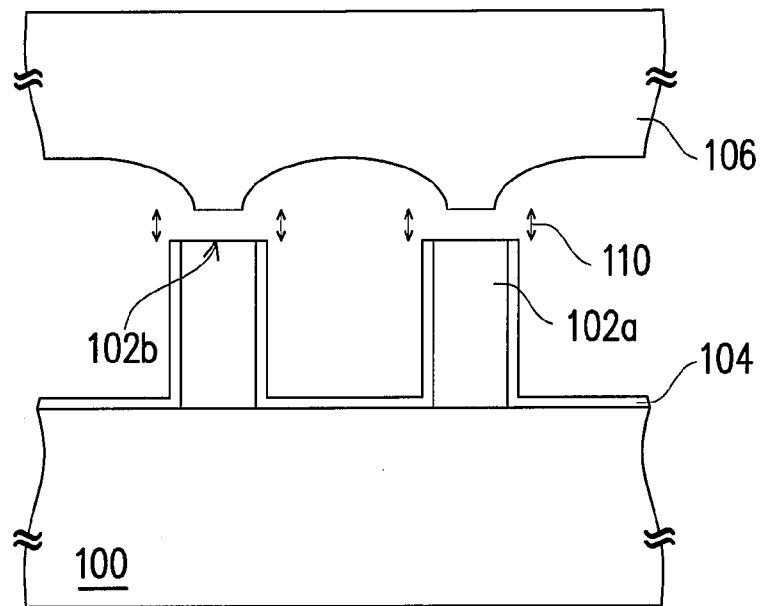


FIG. 1F

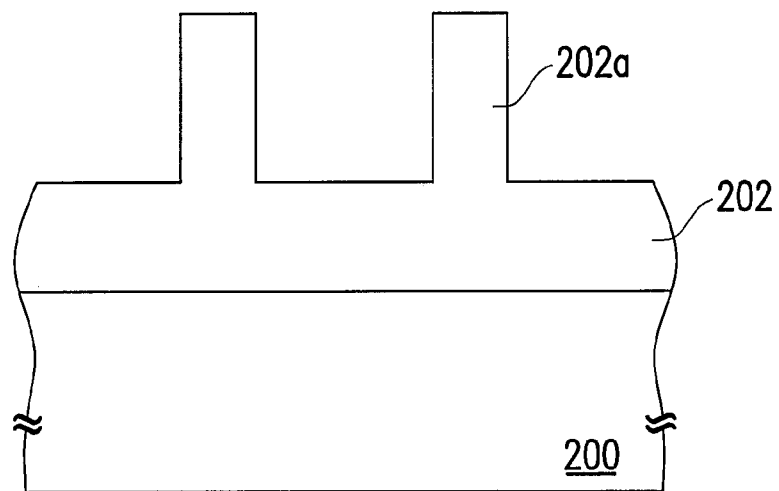


FIG. 2

**NITRIDE SEMICONDUCTOR SUBSTRATE,
METHOD FOR FORMING A NITRIDE
SEMICONDUCTOR LAYER AND METHOD
FOR SEPARATING THE NITRIDE
SEMICONDUCTOR LAYER FROM THE
SUBSTRATE**

**CROSS-REFERENCE TO RELATED
APPLICATION**

[0001] This application claims the priority benefit of Taiwan application serial no. 95132153, filed Aug. 31, 2006. All disclosure of the Taiwan application is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a method of forming a group III/V semiconductor layer, and in particular to a method of forming a nitride semiconductor layer and separating the same from a substrate.

[0004] 2. Description of Related Art

[0005] In the recent years, light emitting diodes (LED) and laser diodes (LD) are now prevailing in commercial use. For example, a mixture of blue and yellow phosphors made of gallium nitride (GaN) is capable of generating white light, which leads to a high luminance and substantially low power consumption over a conventional light bulb. In addition, the LED has a lifetime of more than tens of thousand hours, longer than that of the conventional light bulb.

[0006] In the process of manufacturing a GaN semiconductor LED, due to mismatched lattice constants and differential coefficients of thermal expansion between a GaN semiconductor layer and a hetero-substrate, the GaN semiconductor easily encounters the problems caused by threading dislocation and thermal stress during an epitaxy process, which drastically deteriorates luminance efficiency of the LED.

[0007] According to the prior art, a method of separating the GaN semiconductor layer from the hetero-substrate includes applying an irradiating method whereby laser beams pass through a substrate and illuminate an interlayer between the substrate and the GaN semiconductor layer. Thus, the GaN semiconductor layer and the hetero-substrate are separated. Moreover, a wet etching method can also be performed to directly remove a barrier structure between the substrate and the GaN semiconductor layer so as to weaken a connection structure therebetween and to further separate the GaN semiconductor layer from the hetero-substrate. In addition, a vapor phase etching process can be performed at a high temperature to directly remove the interlayer between the GaN semiconductor layer and the hetero-substrate. Thus, the GaN semiconductor layer and the hetero-substrate are separated.

[0008] Nevertheless, said methods are not capable of mitigating the loss in luminance efficiency of the GaN semiconductor layer due to the defects of threading dislocation and thermal stress in the epitaxy process.

SUMMARY OF THE INVENTION

[0009] The present invention provides a method of forming a nitride semiconductor layer. Thereby, a gallium nitride

(GaN) semiconductor layer with a roughened surface is formed to enhance the irradiating effect of the GaN semiconductor layer.

[0010] The present invention further provide a method of separating the GaN semiconductor layer from a substrate by weakening a structure therebetween.

[0011] Still another object of the present invention is to provide a nitride semiconductor substrate. A patterned epitaxy layer of the substrate comprises a pier structure whereby a timing of separating the nitride semiconductor layer from the substrate can be measured.

[0012] The present invention provides a nitride semiconductor substrate whose patterned epitaxy layer comprises the pier structure. The structural strength thereof can be enhanced by adjusting an aspect ratio and a distribution density of the pier structure, so that a light emitting device (LED) layer can be further formed on the nitride semiconductor layer over the patterned epitaxy layer.

[0013] The present invention provides a method of forming a nitride semiconductor layer, comprising the steps of providing a substrate at first. Next, a patterned epitaxy layer is formed on the substrate, wherein the patterned epitaxy layer comprises a pier structure. A protective layer is then formed on the patterned epitaxy layer and exposes a top surface of the pier structure. After that, a nitride semiconductor layer is formed over the patterned epitaxy layer connected to the nitride semiconductor layer through the pier structure, wherein the nitride semiconductor layer, the pier structure, and the patterned epitaxy layer together form a space exposing a bottom surface of the nitride semiconductor layer. Thereafter, a weakening process is performed to remove a portion of the bottom surface of the nitride semiconductor layer and to weaken a connection point between the top surface of the pier structure and the nitride semiconductor layer. Finally, the substrate is separated from the nitride semiconductor layer through the connection point.

[0014] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the weakening process comprises a step of using an electrolytic solution.

[0015] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the electrolytic solution comprises a potassium hydroxide (KOH) solution.

[0016] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the weakening process further comprises a step of applying an irradiating method to facilitate the weakening process.

[0017] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the concentration of the electrolytic solution is approximately 0.5~15M.

[0018] The method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention comprises a hydride vapor-phase epitaxy method and a metal organic chemical vapor-phase epitaxy method.

[0019] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the material of the substrate is selected from a group consisting of silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

[0020] The present invention further provides a separating method. Said method comprises the steps of providing a substrate having a nitride semiconductor layer disposed thereon and connected thereto through a pier structure. The nitride semiconductor layer, the pier structure, and the patterned epitaxy layer together form a space exposing a bottom surface of the nitride semiconductor layer. Next, an electrolytic solution is used within the space to remove a portion of the bottom surface of the nitride semiconductor layer and to weaken a connection point between the pier structure and the nitride semiconductor layer. Finally, the substrate is separated from the nitride semiconductor layer.

[0021] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the electrolytic solution comprises a potassium hydroxide (KOH) solution.

[0022] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, an irradiating method is used to expeditiously remove a portion of the nitride semiconductor layer.

[0023] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the concentration of the electrolytic solution is approximately 0.5~15M.

[0024] The method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention comprises a hydride vapor-phase epitaxy method and a metal organic chemical vapor-phase epitaxy method.

[0025] According to the method of forming the nitride semiconductor layer illustrated in a preferred embodiment of the present invention, the material of the substrate is selected from a group consisting of silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

[0026] The present invention further provides a nitride semiconductor substrate. The nitride semiconductor substrate comprises a substrate, a patterned epitaxy layer, and a protective layer. The patterned epitaxy layer is disposed on the substrate, wherein the patterned epitaxy layer comprises a pier structure. The protective layer is disposed over the substrate and covers a portion of the patterned epitaxy layer to expose a top surface of the pier structure.

[0027] The material of the nitride semiconductor substrate illustrated in a preferred embodiment of the present invention is selected from a group consisting of silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

[0028] According to the nitride semiconductor substrate illustrated in a preferred embodiment of the present invention, the material of the protective layer comprises dielectric material.

[0029] The present invention further provides a nitride semiconductor substrate. The nitride semiconductor substrate comprises a substrate, a patterned epitaxy layer, a protective layer, and a gallium nitride (GaN) semiconductor layer. The patterned epitaxy layer is disposed on the substrate, wherein the patterned epitaxy layer comprises a pier structure. The protective layer is disposed over the substrate and covers a portion of the patterned epitaxy layer to expose a top surface of the pier structure. The GaN semiconductor layer is disposed over the substrate and connected thereto through the exposed top surface of the pier structure, wherein the GaN semiconductor layer, the pier structure, and

the substrate together form a space exposing a bottom surface of the GaN semiconductor layer.

[0030] The material of the nitride semiconductor substrate illustrated in a preferred embodiment of the present invention is selected from a group consisting of silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

[0031] According to the nitride semiconductor substrate illustrated in a preferred embodiment of the present invention, the material of the protective layer comprises dielectric material.

[0032] In the present invention, a patterned epitaxy layer is disposed between the nitride semiconductor layer and the substrate. The epitaxy layer comprises a pier structure. The pier structure and the nitride semiconductor layer together form a space exposing the bottom surface of the GaN semiconductor layer. Accordingly, the weakening process is performed within the space exposing a portion of the bottom surface to weaken the connection point between the GaN semiconductor layer and the pier structure. Thereby, the weakened connection point which is no longer capable of withstanding the stress breaks and consequently separates the GaN semiconductor from the substrate. Furthermore, during the weakening process, a portion of the bottom surface of the GaN semiconductor layer is roughened to form several pyramidal protrusions. Thereby, the irradiating effect can be enhanced when the GaN semiconductor layer having a roughened surface is successively used as an LED.

[0033] In order to make aforementioned and other objects, features and advantages of the present invention comprehensible, a preferred embodiment accompanied with figures are described in detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

[0035] FIGS. 1A through 1F depict a method of forming a nitride semiconductor layer according to one preferred embodiment of the present invention.

[0036] FIG. 2 depicts a simplified sectional view of a patterned epitaxy layer according to another preferred embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

[0037] Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

[0038] FIGS. 1A through 1F illustrate a method of forming a nitride semiconductor layer according to a preferred embodiment of the present invention. Firstly, referring to FIG. 1A, a substrate **100** is provided. The material of the substrate **100** is selected from a group consisting of silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide. Then, an epitaxy layer **102** is formed on the substrate **100**. The material of the epitaxy layer **102** comprises an indium-containing nitride semicon-

ductor, an aluminum-containing nitride semiconductor, or a gallium-containing nitride semiconductor.

[0039] Referring to FIG. 1B, a patterning process is performed to pattern the epitaxy layer 102, so that a patterned epitaxy layer 102a having a pier structure 102a' is formed. In the present embodiment, the patterned epitaxy layer 102a exposes a portion of a top surface of the substrate 100. However, the present invention is not limited to this embodiment. FIG. 2 depicts a simplified sectional view of a patterned epitaxy layer according to another preferred embodiment of the present invention. Referring to FIG. 2, in another embodiment, the patterned epitaxy layer 202 having a pier structure 202a does not expose a top surface of a substrate 200. Namely, the epitaxy layer is partially patterned so as to form the patterned epitaxy layer 202. Moreover, the pier structure 102a'/202a has a point-like or a bar-like cross-sectional profile.

[0040] Referring to FIG. 1C, a protective layer 104 is formed over the substrate 100. The protective layer 104 covers a portion of the patterned epitaxy layer 102 and exposes a top surface 102b of the pier structure 102a'. Wherein, the protective layer 104 is made of dielectric material, for example.

[0041] Referring to FIG. 1D, an epitaxy process is performed to form a nitride semiconductor layer, e.g. a gallium nitride (GaN) semiconductor layer 106 over the substrate 100. The method of forming the GaN semiconductor layer 106 is, for example, a hydride vapor-phase epitaxy method and a metal organic chemical vapor-phase epitaxy method. It should be noted that the nitride semiconductor layer 106 is connected to the patterned epitaxy layer 102a through the pier structure 102a'. That is to say, during the epitaxy process, the exposed top surface 102b of the pier structure 102a' provides an epitaxial environment, i.e. a nucleus surface, resulting in an upward and lateral growth of the GaN semiconductor layer 106 on the top surface 102b. And the nitride semiconductor layer 106, the pier structure 102a', and the patterned epitaxy layer 102a together form a space 107 exposing a bottom surface of the nitride semiconductor layer 106.

[0042] Referring to FIG. 1E, a weakening process 108 is then performed within the space 107 exposing the bottom surface of the GaN semiconductor layer 106 to remove a portion of the bottom surface of the nitride semiconductor layer 106 and weaken a connection point between the top surface 102b of the pier structure 102a' and the nitride semiconductor layer. Wherein, the weakening process 108 includes a step of using an electrolytic solution. The electrolytic solution preferably comprises a potassium hydroxide (KOH) solution, and the concentration of the electrolytic solution is approximately 0.5~15M. Moreover, the weakening process 108 further comprises a step of using an irradiating method to facilitate the weakening process 108, so that the electrolytic solution can expeditiously react with the bottom surface of the GaN semiconductor layer 106.

[0043] Note that when the weakening process 108 is performed to remove the partially exposed bottom surface of the GaN semiconductor layer 106, the bottom surface is simultaneously roughened and several hexagonal pyramidal protrusions are then formed thereon. Thereby, the irradiating effect can be enhanced when the GaN semiconductor layer 106 is successively used as an LED.

[0044] During the weakening process 108, the connection point between the GaN semiconductor layer 106 and the pier

structure 102a' can withstand less and less stress arisen from hetero materials. Hence, when the weakened connection point between the GaN semiconductor layer 106 and the pier structure 102a' can no longer withstand any stress, the GaN semiconductor layer 106 is then separated from the substrate 100 due to the disconnection 110 between the GaN semiconductor layer 106 and the connection point of the pier structure 102a', as is shown in FIG. 1F.

[0045] Furthermore, the method of separating the nitride semiconductor layer, i.e. said GaN semiconductor layer, from the substrate can be further applied through a cooling step during the epitaxy process. Namely, through the cooling step, the differential coefficients of thermal expansion between the nitride semiconductor layer and the substrate result in the disconnection between the GaN semiconductor layer and the connection point of the pier structure 102a'.

[0046] In addition, when the patterned epitaxy layer 102a having the pier structure 102a' is formed, an aspect ratio and a distribution density of the pier structure 102a' can be adjusted, so that the structural strength of the pier structure surpasses the stress between the nitride semiconductor layer and the substrate. Thereby, after the nitride semiconductor layer is formed, a light emitting device (LED) layer can be formed on the nitride semiconductor layer prior to separating the nitride semiconductor layer from the substrate. And the method of forming the LED layer on the nitride semiconductor layer is, for example, a hydride vapor-phase epitaxy method and a metal organic chemical vapor-phase epitaxy method. Besides, through adjustment of the aspect ratio and the distribution density of the pier structure 102a' and enhancement of the structural strength of the pier structure 102a', not only can the LED layer be formed on the nitride semiconductor layer before the nitride semiconductor layer is separated from the substrate, but also a P-type or an N-type electrode photolithographic process can be performed on the LED layer.

[0047] In view of the foregoing, the present invention discloses a patterned epitaxy layer disposed between the nitride semiconductor layer and the substrate. The epitaxy layer comprises a pier structure. The pier structure and the nitride semiconductor layer together form a space exposing the bottom surface of the GaN semiconductor layer. Accordingly, the weakening process is performed within the space exposing a portion of the bottom surface to weaken the connection point between the GaN semiconductor layer and the pier structure. Thereby, the weakened connection point which is no longer capable of withstanding the stress breaks and consequently separates the GaN semiconductor from the substrate. Furthermore, during the weakening process, a portion of the bottom surface of the GaN semiconductor layer is roughened to form several pyramidal protrusions. Thereby, the irradiating effect can be enhanced when the GaN semiconductor layer having a roughened surface is successively used as an LED.

[0048] It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A method of forming a nitride semiconductor layer, comprising the following steps:

providing a substrate;
 forming a patterned epitaxy layer on the substrate, wherein the patterned epitaxy layer comprises a pier structure;
 forming a protective layer on the patterned epitaxy layer, wherein the protective layer exposes a top surface of the pier structure;
 forming a nitride semiconductor layer over the patterned epitaxy layer connected to the nitride semiconductor layer through the pier structure, wherein the nitride semiconductor layer, the pier structure, and the patterned epitaxy layer together form a space exposing a bottom surface of the nitride semiconductor layer;
 performing a weakening process to remove a portion of the bottom surface of the nitride semiconductor layer and to weaken a connection point between the top surface of the pier structure and the nitride semiconductor layer; and
 separating the nitride semiconductor layer from the substrate through the connection point.

2. The method of forming the nitride semiconductor layer according to claim 1, wherein the weakening process comprises a step of using an electrolytic solution.

3. The method of forming the nitride semiconductor layer according to claim 2, wherein the electrolytic solution comprises a potassium hydroxide (KOH) solution.

4. The method of forming the nitride semiconductor layer according to claim 3, wherein the weakening process further comprises performing an irradiating process to facilitate the weakening process.

5. The method of forming the nitride semiconductor layer according to claim 2, wherein the concentration of the electrolytic solution is approximately 0.5~15M.

6. The method of forming the nitride semiconductor layer according to claim 1, wherein the forming method of the nitride semiconductor layer comprising a hydride vapor-phase epitaxy method and a metal organic chemical vapor-phase epitaxy method.

7. The method of forming the nitride semiconductor layer according to claim 1, wherein the material of the substrate comprises silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

8. A separating method, comprising:
 providing a substrate having a nitride semiconductor layer disposed thereon and connected thereto through a pier structure, wherein the nitride semiconductor layer, the pier structure, and a patterned epitaxy layer together form a space exposing a bottom surface of the nitride semiconductor layer;
 using an electrolytic solution within the space to remove a portion of the bottom surface of the nitride semiconductor layer and to weaken a connection point between the pier structure and the nitride semiconductor layer; and

separating the nitride semiconductor layer from the substrate.

9. The method of claim 8, wherein the electrolytic solution comprises a potassium hydroxide (KOH) solution.

10. The method of claim 9, wherein an irradiating method is used to expeditiously remove a portion of the nitride semiconductor layer.

11. The method of claim 8, wherein the concentration of the electrolytic solution is approximately 0.5~15M.

12. The method of claim 8, wherein the forming method of the nitride semiconductor layer comprising a hydride vapor-phase epitaxy method and a metal organic chemical vapor-phase epitaxy method.

13. The method of claim 8, wherein the material of the substrate comprises silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

14. A nitride semiconductor substrate, comprising:
 a substrate;
 a patterned epitaxy layer disposed on the substrate, wherein the patterned epitaxy layer comprises a pier structure; and
 a protective layer disposed over the substrate, wherein the protective layer covers a portion of the patterned epitaxy layer to expose a top surface of the pier structure.

15. The nitride semiconductor substrate of claim 14, wherein the material of the substrate comprises silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

16. The nitride semiconductor substrate of claim 14, wherein the material of the protective layer comprises dielectric material.

17. A nitride semiconductor substrate, comprising:
 a substrate;
 a patterned epitaxy layer disposed on the substrate, wherein the patterned epitaxy layer comprises a pier structure;
 a protective layer disposed over the substrate, wherein the protective layer covers a portion of the patterned epitaxy layer to expose a top surface of the pier structure; and
 a gallium nitride (GaN) semiconductor layer disposed over the substrate and connected thereto through the exposed top surface of the pier structure, wherein the GaN semiconductor layer, the pier structure, and the substrate together form a space exposing a bottom surface of the GaN semiconductor layer.

18. The nitride semiconductor substrate of claim 17, wherein the material of the substrate comprises silicon, silicon carbide, sapphire, arsenide, phosphide, zinc oxide (ZnO), and magnesium oxide.

19. The nitride semiconductor substrate of claim 17, wherein the material of the protective layer comprises dielectric material.

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