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Kim et al.(10) **Pub. No.: US 2013/0207149 A1**(43) **Pub. Date: Aug. 15, 2013**(54) **SEMICONDUCTOR LIGHT-EMITTING
DEVICE HAVING A PHOTONIC CRYSTAL
PATTERN FORMED THEREON, AND
METHOD FOR MANUFACTURING SAME**(75) Inventors: **Taegeun Kim**, Seongnam-si (KR);
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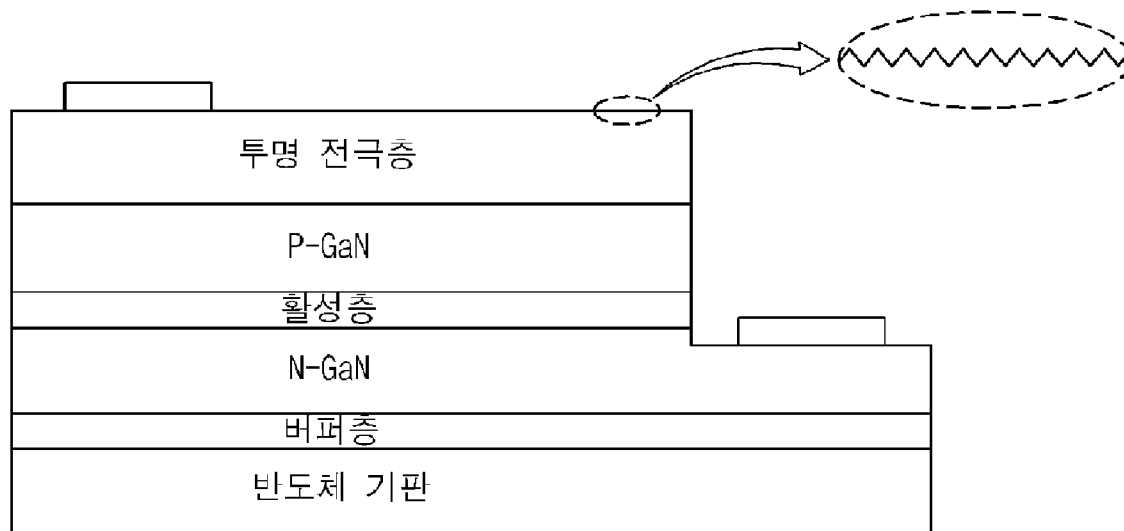
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(2013.01)USPC **257/98**; 438/32

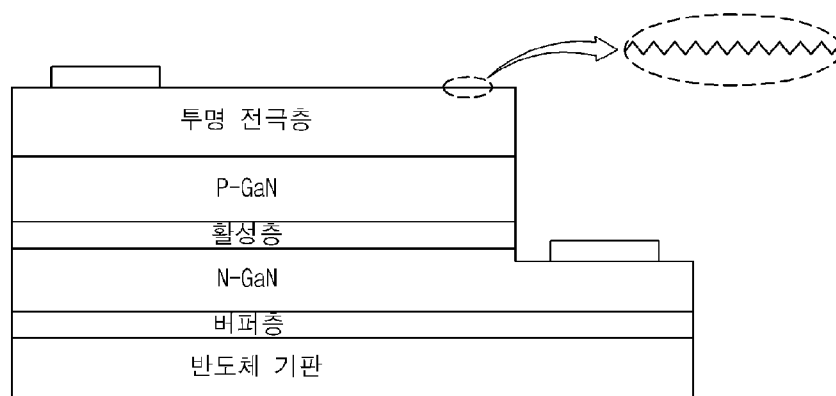
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ABSTRACT

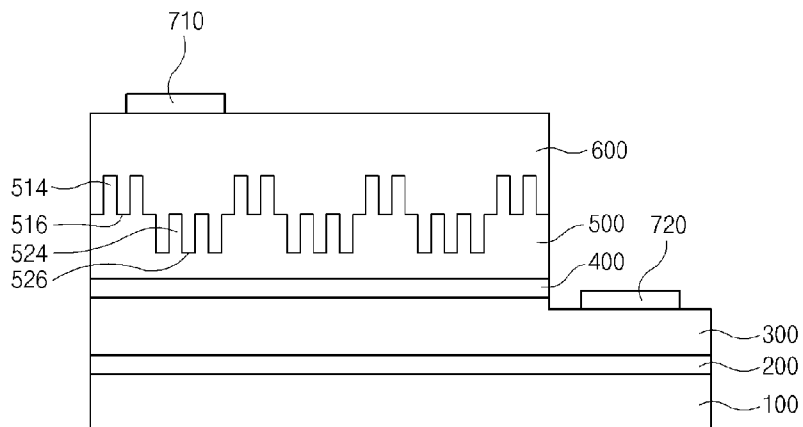
The present invention relates to a semiconductor light-emitting device having a two-stage photonic crystal pattern formed thereon, and to a method for manufacturing same. According to the present invention, a second photonic crystal pattern is formed inside a first photonic crystal pattern formed on a semiconductor layer or transparent electrode layer, in order to improve light extraction efficiency. Also, according to the present invention, in order to form a second fine nanoscale photonic crystal pattern in the first photonic crystal pattern, a nanosphere lithography process employing polymer beads is used, and a trapping layer made of a thermoplastic resin was used to conveniently form polymer beads in a single layer so as to eliminate the inconvenience of having to calculate and change process variables according to polymer bead sizes in traditional nanosphere lithography processes.



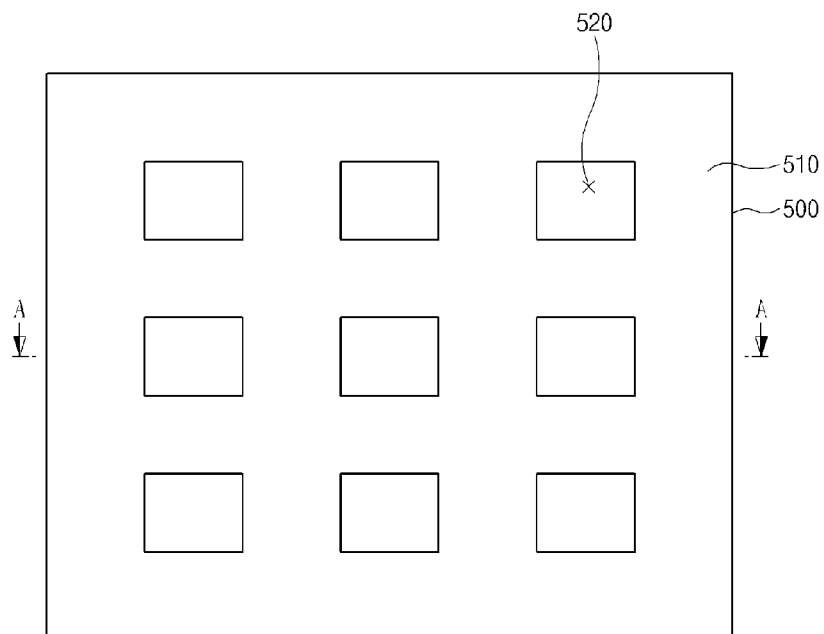
[Fig. 1]



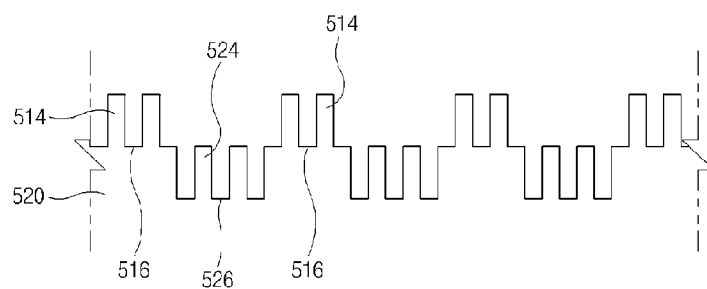
[Fig. 2]



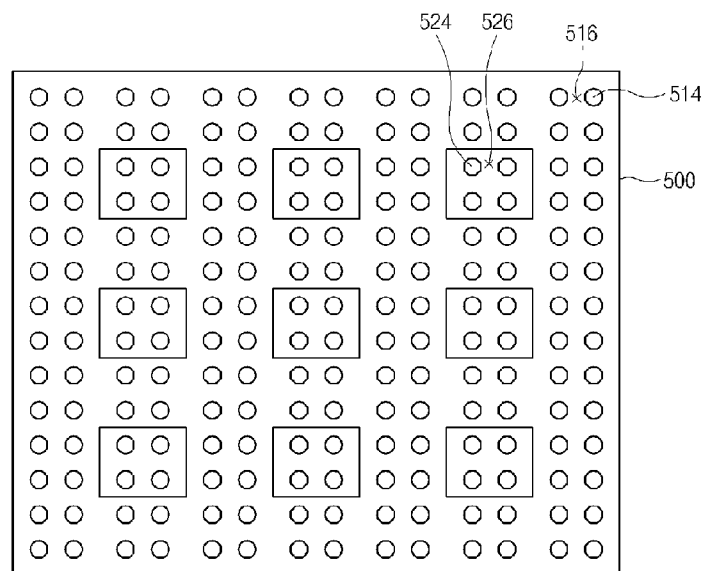
[Fig. 3a]



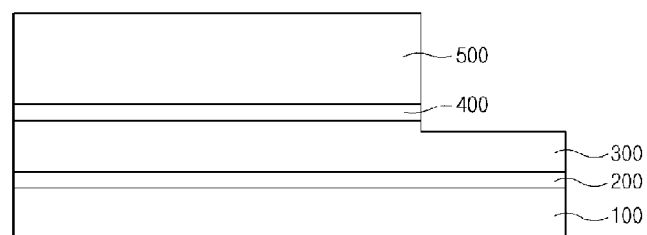
[Fig. 3b]



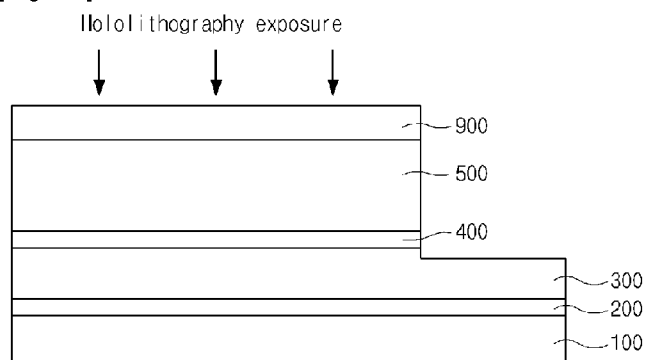
[Fig. 3c]



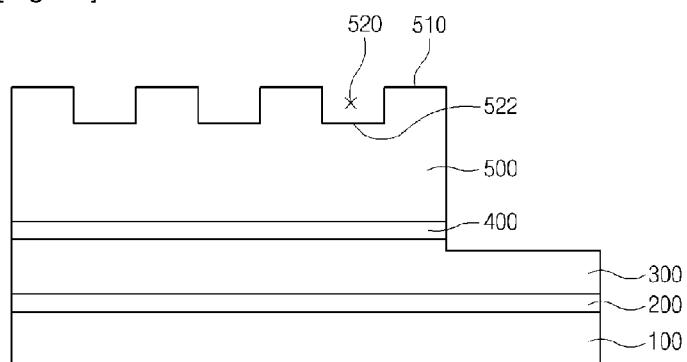
[Fig. 4a]



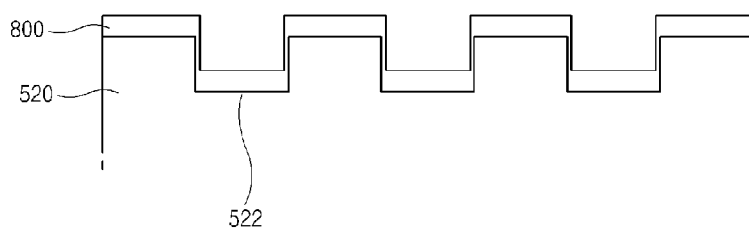
[Fig. 4b]



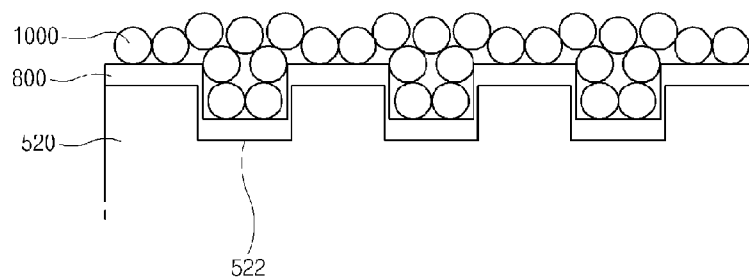
[Fig. 4c]



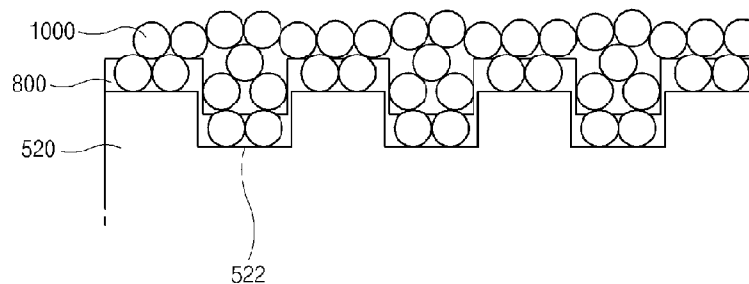
[Fig. 4d]



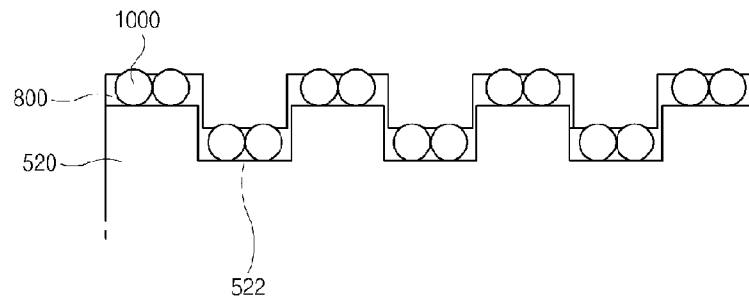
[Fig. 4e]



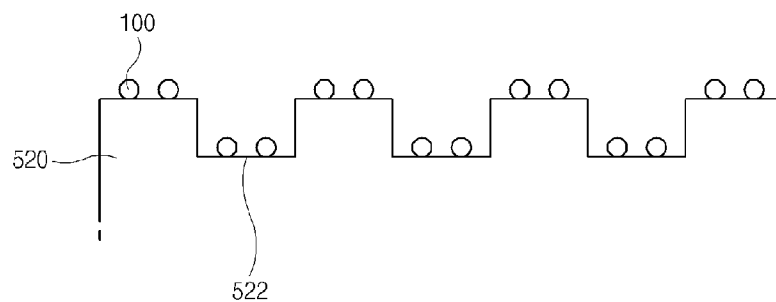
[Fig. 4f]



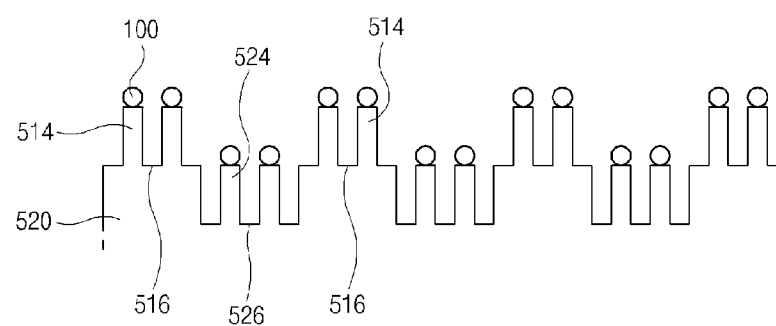
[Fig. 4g]



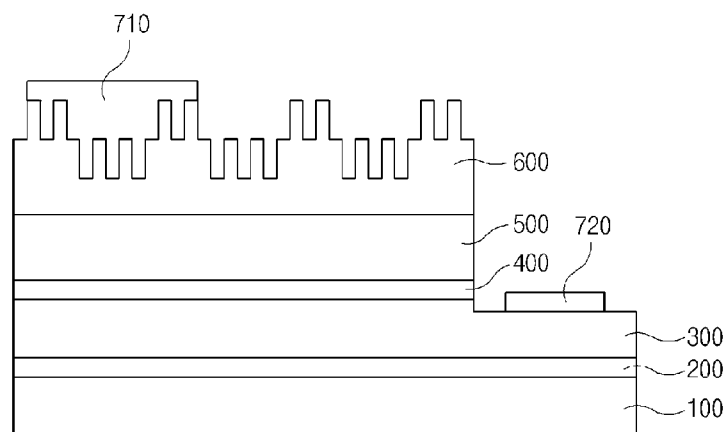
[Fig. 4h]



[Fig. 4i]



[Fig. 5]



**SEMICONDUCTOR LIGHT-EMITTING
DEVICE HAVING A PHOTONIC CRYSTAL
PATTERN FORMED THEREON, AND
METHOD FOR MANUFACTURING SAME**

TECHNICAL FIELD

[0001] The present invention relates to a semiconductor light-emitting device, and more particularly, to a semiconductor light-emitting device having a two-stage photonic crystal pattern formed thereon, so as to improve light extraction efficiency.

BACKGROUND ART

[0002] The conventional gallium nitride-based light emitting diode (LED) has very low light extraction efficiency, because only about 4% of light proceeding to an air layer from the gallium nitride-based LED is extracted due to Fresnel reflection resulting from a refraction difference between a semiconductor and an air layer, and due to a total reflectivity by the law of refraction known as Snell's law.

[0003] In order to improve the low light extraction efficiency, research is being actively ongoing. As a representative method, a concavo-convex structure or a fine pattern is formed on the surface of the gallium nitride-based LED, thereby improving light extraction efficiency through a surface scattering effect or a two-dimensional (2D) photonic crystal effect. FIG. 1 is a view illustrating an example that a fine pattern is formed on the surface of a transparent electrode layer so as to improve light extraction efficiency of an LED in accordance with the conventional art.

[0004] Recent LED processes are being performed as fine nanoscale processes. As a lithography method for forming a fine pattern applicable to the fine nanoscale processes, mainly used are a holographic lithography, an electron-beam lithography, and a nanosphere lithography (NSL). However, in case of the hololithography, it is difficult to form a nanoscale pattern having a size of several tens of nanometers. And, the electron-beam lithography has a limitation in being applicable to patterning for a large area.

[0005] When compared with the hololithography and electron-beam lithography techniques, the nanosphere lithography has an advantage that the number of processes including PR coating, exposure, development, etc. can be reduced, because it does not require an additional mask when forming a nanoscale pattern. Further, polymer or silica-based beads used in the nanosphere lithography have various sizes of 30 nm~200 μ m. This can implement various patterns of various sizes including a fine nanoscale pattern.

[0006] However, the nanosphere lithography also has the following problems. Among lithography processes using such nano-sized beads, the most important process is to coat beads in a monolayer. In order to coat polymer beads in a monolayer, various process variables such as a bead weight (wt %), a spin speed, and a surfactant amount for contact with a substrate, should be calculated and changed according to the size of the polymer beads.

DISCLOSURE OF THE INVENTION

[0007] Therefore, an object of the present invention is to provide a semiconductor light-emitting device capable of improving light extraction efficiency by forming a two-stage

photonic crystal pattern on a semiconductor layer or a transparent electrode layer, and a method for manufacturing the same.

[0008] Another object of the present invention is to provide a semiconductor light-emitting device capable of effectively extracting light by forming a second fine nanoscale photonic crystal pattern in a first photonic crystal pattern, sequentially using a hololithography and a nanosphere lithography when forming a two-stage photonic crystal pattern, and a method for manufacturing the same.

[0009] Still another object of the present invention is to provide a semiconductor light-emitting device capable of simply performing a reproductive monolayer coating despite change of polymer beads, using a trapping layer when applying a nanosphere lithography, and a method for manufacturing the same.

[0010] To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described herein, there is provided a semiconductor light-emitting device, comprising: a semiconductor substrate; a first semiconductor layer formed on the semiconductor substrate; an active layer formed on the first semiconductor layer, and configured to generate light; a second semiconductor layer formed on the active layer, having a first photonic crystal pattern formed thereon, and having a second photonic crystal pattern formed in the first photonic crystal pattern; and a transparent electrode layer formed on the second semiconductor layer.

[0011] According to another aspect of the present invention, there is provided a semiconductor light-emitting device, comprising: a semiconductor substrate; a first semiconductor layer formed on the semiconductor substrate; an active layer formed on the first semiconductor layer, and configured to generate light; a second semiconductor layer formed on the active layer; and a transparent electrode layer formed on the second semiconductor layer, having a first photonic crystal pattern formed thereon, and having a second photonic crystal pattern formed in the first photonic crystal pattern.

[0012] In the semiconductor light-emitting device, the first photonic crystal pattern may have a concavo-convex section configured as an upper surface and a concaved portion, and the second photonic crystal pattern may have a concavo-convex section and may be formed on the upper surface and a lower surface of the concaved portion, respectively.

[0013] The second photonic crystal pattern may have a concavo-convex section, by a plurality of protrusions having a cylindrical shape and bottom surfaces, each bottom surface formed between the protrusions.

[0014] The concaved portion of the first photonic crystal pattern may have a quadrangular plane.

[0015] To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described herein, there is also provided a method for manufacturing a semiconductor light-emitting device, comprising: (a) sequentially forming, on a semiconductor substrate, a first semiconductor layer, an active layer and a second semiconductor layer; (b) forming, on the surface of the second semiconductor layer, a first photonic crystal pattern so as to have a concavo-convex section, and forming a second photonic crystal pattern in the first photonic crystal pattern; and (c) forming a transparent electrode layer on the second semiconductor layer.

[0016] The step (b) may include (b1) forming a plurality of concave portions on the surface of the second semiconductor

layer, thereby forming the first photonic crystal pattern; and (b2) forming a second photonic crystal pattern having a concavo-convex section on an upper surface of the second semiconductor layer between the concaved portions, and on a lower surface between the concaved portions, respectively.

[0017] In step (b2), polymer beads may be arranged in a single layer, on the upper surface of the second semiconductor layer where the first photonic crystal pattern has been formed, and on the lower surface of the concaved portions. Then, the size of the polymer beads may be controlled. Then, the second semiconductor layer may be etched using the polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

[0018] The step (b2) may include (b2-1) forming a trapping layer, on the surface of the second semiconductor layer where the first photonic crystal pattern has been formed; (b2-2) arranging the polymer beads on the trapping layer; (b2-3) melting the trapping layer by applying heat to the semiconductor substrate, and immersing the polymer beads positioned on the trapping layer into the melted trapping layer; (b2-4) cooling the semiconductor substrate thereby solidifying the trapping layer in a state where the polymer beads have been immersed in the trapping layer, and removing the polymer beads positioned on the trapping layer, thereby arranging the polymer beads on the second semiconductor layer in a single layer; and (b2-5) removing the trapping layer, controlling the size of the polymer beads, and etching the second semiconductor layer using the size-controlled polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

[0019] According to another aspect of the present invention, there is provided a method for manufacturing a semiconductor light-emitting device, comprising: (a) sequentially forming, on a semiconductor substrate, a first semiconductor layer, an active layer, a second semiconductor layer, and a transparent electrode layer; and (b) forming, on the surface of the transparent electrode layer, a first photonic crystal pattern so as to have a concavo-convex section, and forming a second photonic crystal pattern in the first photonic crystal pattern.

[0020] The step (b) may include (b1) forming a plurality of concaved portions on the surface of the transparent electrode layer, thereby forming the first photonic crystal pattern; and (b2) forming a second photonic crystal pattern having a concavo-convex section on an upper surface of the transparent electrode layer between the concaved portions, and on a lower surface of the concaved portions, respectively.

[0021] In step (b2), polymer beads may be arranged in a single layer, on the upper surface of the transparent electrode layer where the first photonic crystal pattern has been formed, and on the lower surface of the concaved portions. Then, the size of the polymer beads may be controlled. Then, the transparent electrode layer may be etched using the polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

[0022] The step (b2) may include (b2-1) forming a trapping layer, on the surface of the transparent electrode layer where the first photonic crystal pattern has been formed; (b2-2) arranging the polymer beads on the trapping layer; (b2-3) melting the trapping layer by applying heat to the semiconductor substrate, and immersing the polymer beads positioned on the trapping layer into the melted trapping layer; (b2-4) cooling the semiconductor substrate thereby solidifying the trapping layer in a state where the polymer beads have been immersed in the trapping layer, and removing the poly-

mer beads positioned on the trapping layer, thereby arranging the polymer beads on the transparent electrode layer in a single layer; and (b2-5) removing the trapping layer, controlling the size of the polymer beads, and etching the transparent electrode layer using the size-controlled polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

[0023] The trapping layer may be formed of a thermoplastic resin.

[0024] In step (b2-1), the trapping layer may be preferably formed such that the thickness thereof is smaller than the diameter of the polymer beads.

[0025] The present invention may have the following advantages.

[0026] Firstly, the second photonic crystal pattern is formed inside the first photonic crystal pattern formed on the semiconductor layer or the transparent electrode layer, in order to improve light extraction efficiency.

[0027] Secondly, in order to form the second fine nanoscale photonic crystal pattern in the first photonic crystal pattern, a nanosphere lithography process employing polymer beads is used, and the trapping layer made of a thermoplastic resin was used to conveniently form polymer beads in a single layer so as to eliminate the inconvenience of having to calculate and change process variables according to polymer bead sizes in conventional nanosphere lithography processes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is a view showing an example to form a fine pattern on the surface of a transparent electrode layer, in order to enhance light extraction efficiency of a light emitting diode (LED) in accordance with the conventional art;

[0029] FIG. 2 is a view showing a light-emitting device according to a preferred embodiment of the present invention;

[0030] FIGS. 3A to 3C are views showing a structure of a photonic crystal pattern according to an embodiment of the present invention;

[0031] FIGS. 4A to 4I are views showing manufacturing processes of a semiconductor light-emitting device having a two-stage photonic crystal pattern formed thereon, according to an embodiment of the present invention; and

[0032] FIG. 5 is a view showing a structure of a semiconductor light-emitting device according to a modification embodiment of the present invention.

MODES FOR CARRYING OUT THE PREFERRED EMBODIMENTS

[0033] Reference will now be made in detail to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings. It will also be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

[0034] FIG. 2 is a view showing a semiconductor light-emitting device according to a preferred embodiment of the present invention. FIG. 2 illustrates a horizontal type light-emitting device. However, the present invention may be also applicable to a vertical type light-emitting device.

[0035] Referring to FIG. 2, like the conventional semiconductor light-emitting device, the semiconductor light-emitting

ting device according to a preferred embodiment of the present invention includes a semiconductor substrate **100**, a buffer layer **200**, a first semiconductor layer **300**, an active layer **400**, a second semiconductor layer **500**, and a transparent electrode layer **600** formed on the semiconductor substrate **100**, sequentially. A two-stage photonic pattern is formed on an upper surface **510** of the semiconductor layer **500** contacting the transparent electrode layer **600**.

[0036] In an embodiment of the present invention, the first semiconductor layer **300** is implemented as an 'n'-type semiconductor layer, and the second semiconductor layer **500** is implemented as a 'p'-type semiconductor layer. However, the first semiconductor layer **300** may be formed as a 'p'-type semiconductor layer, and the second semiconductor layer **500** may be formed as an 'n'-type semiconductor layer.

[0037] The semiconductor substrate **100**, the buffer layer **200**, the first semiconductor layer **300**, the active layer **400**, and the second semiconductor layer **500** may have the same configurations as those of a general horizontal type light-emitting device, and thus detailed explanations thereof will be omitted. Rather, only the feature of the present invention, a photonic crystal pattern will be explained.

[0038] FIGS. 3A to 3C are views showing a structure of a photonic crystal pattern according to an embodiment of the present invention. FIG. 3A is a planar view of the second semiconductor layer **500** having a first photonic crystal pattern formed thereon. FIG. 3B is a sectional view of the second semiconductor layer **500** having first and second photonic crystal patterns formed thereon. And, FIG. 3C is a planar view of the second semiconductor layer **500** having first and second photonic crystal patterns formed thereon.

[0039] Referring to FIG. 3a, a plurality of concaved portions **520** are formed on the surface of the second semiconductor layer **500**, so that a first photonic crystal pattern having a concavo-convex section (A-A') is formed on the surface of the second semiconductor layer **500**. The width of the concaved portions **520** of the first photonic crystal pattern is formed in several micrometer size. And, the number and the size of the concaved portions **520** formed on the second semiconductor layer **500** may be controllable. Hereinafter, the surface of the second semiconductor layer **500** will be called an 'upper surface' **510**, and the bottom surface of the concaved portions **520** formed toward the inside of the second semiconductor layer **500** from the upper surface **510** will be called a 'lower surface' **522**.

[0040] In FIG. 3A, the concaved portions **520** has a quadrangular planar shape. However, the concaved portions **520** may have various planar shapes. Further, it should be noted that only a first photonic crystal pattern rather than a second photonic crystal pattern was illustrated in FIG. 3A for convenience.

[0041] Referring to FIGS. 3B and 3C, a second photonic crystal pattern consisting of protrusion **514** and **524** and bottom surfaces **516** and **526** lower than the protrusions **514** and **524**, are formed on the upper surface **510** and the lower surface **522** of the second semiconductor layer **500**, respectively. Since the second photonic crystal pattern having a concavo-convex section is respectively formed on the upper surface **510** and the lower surface **522** of the second semiconductor layer **500**, the second semiconductor layer **500** entirely has a two-stage photonic crystal pattern. The width of the protrusions **514** and **524** formed on the upper surface **510** and

the lower surface **522**, respectively has a nanometer size, and the interval between the protrusions **514** and **524** also has a nanometer size.

[0042] As the two-stage photonic crystal pattern is formed on the second semiconductor layer **500**, light extraction efficiency can be more improved than in the conventional art.

[0043] In the aforementioned embodiment, the two-stage photonic crystal pattern was formed on the second semiconductor layer **500**. However, in a modification embodiment of the present invention, the two-stage photonic crystal pattern was formed on a transparent electrode layer **600**.

[0044] FIGS. 4A to 4I are views showing manufacturing processes of a semiconductor light-emitting device having a two-stage photonic crystal pattern formed thereon, according to an embodiment of the present invention. Hereinafter, with reference to FIGS. 4A to 4I, will be explained a method for manufacturing a semiconductor light-emitting device having a two-stage photonic crystal pattern formed thereon, according to an embodiment of the present invention.

[0045] As shown in FIG. 4A, a buffer layer **200**, a first semiconductor layer **300**, an active layer **400**, and a second semiconductor layer **500** are sequentially formed on a semiconductor substrate **100**, in the same manner as the conventional art.

[0046] As shown in FIG. 4B, a photoresist **900** is formed on the second semiconductor layer **500**, and then exposed to be developed by a hololithography exposure technique, thereby being prepared as a photolithography mask. As shown in FIG. 4C, the second semiconductor layer **500** is etched using the remaining photoresist **900** as an etching mask, thereby forming a plurality of concaved portions **520** on the second semiconductor layer **500**. Then, the remaining photoresist **900** is removed to form a first photonic crystal pattern on the second semiconductor layer **500**.

[0047] As shown in FIG. 4D, a trapping layer **800** formed of a polymer-based thermoplastic material well-melted by applied heat, is formed on the second semiconductor layer **500**. Here, the thickness of the trapping layer should be smaller than the diameter of polymer beads **1000**. Preferably, the thickness of the trapping layer should be designed so that the melted trapping layer **800** cannot exceed the polymer beads **1000**, when the polymer beads **1000** are immersed in the melted trapping layer **800** by sequent processes.

[0048] After the trapping layer **800** is formed, as shown in FIG. 4E, the polymer beads **1000** are coated on the second semiconductor layer **500** having the trapping layer **800** formed thereon. Here, the polymer beads **1000** may be coated in various manners. For instance, a solution containing the polymer beads **1000** is coated, by a sol-gel method, onto the second semiconductor layer **500** having the trapping layer **800** formed thereon. Then, a solvent is evaporated to coat the polymer beads **1000** in multi layers.

[0049] After the second semiconductor layer **500** is coated with the polymer beads **1000**, heat having a proper temperature where the trapping layer **800** can be melted (about 100°C in the preferred embodiment of the present invention) is applied to the semiconductor substrate **100**. As a result, as shown in FIG. 4F, the polymer beads **1000** positioned on the trapping layer **800** start to be immersed into the trapping layer **800** while the trapping layer **800** is melted. If the semiconductor substrate **100** is cooled, the melted trapping layer **800**

is solidified. As a result, the polymer beads **1000** immersed in the trapping layer **800** are accommodated in the trapping layer **800**.

[0050] As shown in FIG. 4G, if the polymer beads **1000** not accommodated in the trapping layer **800** are removed by performing a rinsing process using ultra pure de-ionized water (at a temperature of about 40° for about 15 minutes), the polymer beads **1000** are arranged in a single layer, on the upper surface **510** of the second semiconductor layer **500** and on the lower surface **522** of the concaved portions **520**, the upper surface **510** and the lower surface **522** which constitute a first photonic crystal pattern.

[0051] Once the single layer of the polymer beads **1000** is disposed on the second semiconductor layer **500**, as shown in FIG. 4H, the trapping layer **800** is removed by an O₂ RIE (Reactive Ion Etching) process. Then, the polymer beads **1000** are etched by a CF₄ RIE process, to thus have a reduced size. Then, the polymer beads **1000** having a reduced size are used as an etching mask, thereby determining the size (width) of the protrusions **514** and **524** of the second photonic crystal pattern formed in the first photonic crystal pattern, and the interval between the protrusions **514** and **524**.

[0052] After the polymer beads **1000** are etched in correspondence to the second photonic crystal pattern, as shown in FIG. 4I, the second semiconductor layer **500** is etched by a deep RIE (Reactive Ion Etching) process, using the polymer beads **1000** as an etching mask. Upon completion of the etching, the second photonic crystal pattern having a concavo-convex section is respectively formed on the upper surface **510** of the first photonic crystal pattern having a concavo-convex section, and on the lower surface **522** of the concaved portions **520**. The polymer beads **1000** used to form the second photonic crystal pattern are spherical. Accordingly, once the second photonic crystal pattern is formed, the protrusions **514** and **524** having a cylindrical shape are formed on the upper surface **510** of the second semiconductor layer **500** and in the concaved portions **520**.

[0053] Once the second photonic crystal pattern is formed on the second semiconductor layer **500**, the polymer beads **1000** are removed, and then a transparent electrode layer **600** is formed on the second semiconductor layer **500**. Then, electrode pads **710** and **720** are formed on the transparent electrode layer **600** and the first semiconductor layer, thereby completing the semiconductor light-emitting device of FIG. 2.

[0054] So far, explained were the semiconductor light-emitting device having a two-stage photonic crystal pattern formed thereon, and a method for manufacturing the same according to an embodiment of the present invention. In the aforementioned embodiment, a two-stage photonic crystal pattern was formed on the second semiconductor layer **500**. However, in a modification embodiment, as shown in FIG. 5, the transparent electrode layer **600** is formed on the second semiconductor layer **500**, and a two-stage photonic crystal pattern is formed on the transparent electrode layer **600**. Then, an electrode pad **710** which fills the photonic crystal pattern is formed on a partial region of the transparent electrode layer **600**. In the modification embodiment, the processes for forming the two-stage photonic crystal pattern are the same as those in the aforementioned embodiment, except that the two-stage photonic crystal pattern is formed on the transparent electrode layer **600**. Therefore, detailed explanations thereof will be omitted.

1-15. (canceled)

16. A semiconductor light-emitting device, comprising:
a semiconductor substrate;
a first semiconductor layer formed on the semiconductor substrate;
an activation layer formed on the first semiconductor layer, and configured to generate light;
a second semiconductor layer formed on the activation layer, having a first photonic crystal pattern formed thereon, and having a second photonic crystal pattern formed in the first photonic crystal pattern; and
a transparent electrode layer formed on the second semiconductor layer.

17. The semiconductor light-emitting device of claim **16**, wherein the first photonic crystal pattern has a concavo-convex section configured as an upper surface and a concaved portion, and

wherein the second photonic crystal pattern is respectively formed on the upper surface and on a lower surface of the concaved portion, and has a concavo-convex section.

18. The semiconductor light-emitting device of claim **17**, wherein the second photonic crystal pattern has a concavo-convex section, by a plurality of protrusions having a cylindrical shape and bottom surfaces, each bottom surface formed between the protrusions.

19. The semiconductor light-emitting device of claim **17**, wherein the concaved portion of the first photonic crystal pattern has a quadrangular plane.

20. A semiconductor light-emitting device, comprising:
a semiconductor substrate;
a first semiconductor layer formed on the semiconductor substrate;
an activation layer formed on the first semiconductor layer, and configured to generate light;
a second semiconductor layer formed on the activation layer; and
a transparent electrode layer formed on the second semiconductor layer, having a first photonic crystal pattern formed thereon, and having a second photonic crystal pattern formed in the first photonic crystal pattern.

21. The semiconductor light-emitting device of claim **20**, wherein the first photonic crystal pattern has a concavo-convex section configured as an upper surface and a concaved portion, and

wherein the second photonic crystal pattern is respectively formed on the upper surface and on a lower surface of the concaved portion, and has a concavo-convex section.

22. The semiconductor light-emitting device of claim **21**, wherein the second photonic crystal pattern has a concavo-convex section, by a plurality of protrusions having a cylindrical shape and bottom surfaces, each bottom surface formed between the protrusions.

23. The semiconductor light-emitting device of claim **21**, wherein the concaved portion of the first photonic crystal pattern has a quadrangular plane.

24. A method for manufacturing a semiconductor light-emitting device, comprising:

- (a) sequentially forming, on a semiconductor substrate, a first semiconductor layer, an activation layer and a second semiconductor layer;
- (b) forming, on the surface of the second semiconductor layer, a first photonic crystal pattern so as to have a

concavo-convex section, and forming a second photonic crystal pattern in the first photonic crystal pattern; and
(c) forming a transparent electrode layer on the second semiconductor layer.

25. The method of claim **24**, wherein the step (b) includes:

(b1) forming a plurality of concave portions on the surface of the second semiconductor layer, thereby forming the first photonic crystal pattern; and

(b2) forming a second photonic crystal pattern having a concavo-convex section, on an upper surface of the second semiconductor layer between the concaved portions, and on a lower surface of the concaved portions, respectively.

26. The method of claim **25**, wherein in step (b2), polymer beads are arranged in a single layer, on the upper surface of the semiconductor layer where the first photonic crystal pattern has been formed, and on the lower surface of the concaved portions, then the size of the polymer beads is controlled, and then the second semiconductor layer is etched using the polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

27. The method of claim **26**, wherein the step (b2) includes:

(b2-1) forming a trapping layer, on the surface of the second semiconductor layer where the first photonic crystal pattern has been formed;

(b2-2) arranging the polymer beads on the trapping layer;

(b2-3) melting the trapping layer by applying heat to the semiconductor substrate, and immersing the polymer beads positioned on the trapping layer into the melted trapping layer;

(b2-4) cooling the semiconductor substrate thereby solidifying the trapping layer in a state where the polymer beads have been immersed in the trapping layer, and removing the polymer beads positioned on the trapping layer, thereby arranging the polymer beads on the second semiconductor layer in a single layer; and

(b2-5) removing the trapping layer, controlling the size of the polymer beads, and etching the second semiconductor layer using the size-controlled polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

28. The method of claim **27**, wherein the trapping layer is formed of a thermoplastic resin.

29. The method of claim **27**, wherein in step (b2-1), the trapping layer is formed such that the thickness thereof is smaller than the diameter of the polymer beads.

30. A method for manufacturing a semiconductor light-emitting device, comprising:

(a) sequentially forming, on a semiconductor substrate, a first semiconductor layer, an activation layer, a second semiconductor layer, and a transparent electrode layer; and

(b) forming, on the surface of the transparent electrode layer, a first photonic crystal pattern so as to have a concavo-convex section, and forming a second photonic crystal pattern in the first photonic crystal pattern.

31. The method of claim **30**, wherein the step (b) includes:

(b1) forming a plurality of concaved portions on the surface of the transparent electrode layer, thereby forming the first photonic crystal pattern; and

(b2) forming a second photonic crystal pattern having a concavo-convex section on an upper surface of the transparent electrode layer between the concaved portions, and on a lower surface of the concaved portions, respectively.

32. The method of claim **31**, wherein in step (b2), polymer beads are arranged in a single layer, on the upper surface of the transparent electrode layer where the first photonic crystal pattern has been formed, and on the lower surface of the concaved portions, then the size of the polymer beads is controlled, and then the transparent electrode layer is etched using the polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

33. The method of claim **32**, wherein the step (b2) includes:

(b2-1) forming a trapping layer, on the surface of the transparent electrode layer where the first photonic crystal pattern has been formed;

(b2-2) arranging the polymer beads on the trapping layer;

(b2-3) melting the trapping layer by applying heat to the semiconductor substrate, and immersing the polymer beads positioned on the trapping layer into the melted trapping layer;

(b2-4) cooling the semiconductor substrate thereby solidifying the trapping layer in a state where the polymer beads have been immersed in the trapping layer, and removing the polymer beads positioned on the trapping layer, thereby arranging the polymer beads on the transparent electrode layer in a single layer; and

(b2-5) removing the trapping layer, controlling the size of the polymer beads, and etching the transparent electrode layer using the size-controlled polymer beads as an etching mask, thereby forming the second photonic crystal pattern.

34. The method of claim **33**, wherein the trapping layer is formed of a thermoplastic resin.

35. The method of claim **33**, wherein in step (b2-1), the trapping layer is formed such that the thickness thereof is smaller than the diameter of the polymer beads.

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