Claims

1. A method of forming a monolithic LED array precursor, the method comprising:

(i) providing a substrate having a surface;

(ii) forming a continuous first semiconductor layer on the surface of the substrate;

(iii) selectively masking the first semiconductor layer, by depositing a masking layer, which comprises a plurality of apertures, on the first semiconductor layer;

(iv) growing a second semiconductor layer on unmasked portions of the first semiconductor layer, through the apertures of the masking layer to form a plurality of columns each having a regular trapezoidal cross-section normal to the substrate with sloped sides and a substantially flat upper surface portion;

(v) forming a third semiconductor layer covering the second semiconductor layer, wherein the third semiconductor layer comprises one or more quantum well sub-layers and has sloped sides and a substantially flat upper surface portion;

(vi) forming a fourth semiconductor layer covering the third semiconductor layer, whereby the fourth semiconductor layer has sloped sides and a substantially flat upper surface portion;

(vii) forming primary electrical contacts on the substantially flat upper surface portion of the fourth semiconductor layer; and wherein the first to fourth semiconductor layers comprise Group III-nitrides;

(viii) forming electrically insulating, optically transparent spacers on the sloped sides of the fourth semiconductor layer, the spacers having an internal surface facing the sloped sides of the fourth semiconductor layer and an opposing external surface, wherein the external surface of the spacers has a pseudo parabolic or parabolic profile; and

(ix) depositing a reflecting, electrically conducting layer over the external surface of the spacers.

2. The method according to claim 1, wherein step (iii) comprises:
(a) depositing a continuous masking layer, and (b) selectively removing a plurality of portions of said mask layer to provide a plurality of apertures, optionally wherein selectively removing a plurality of portions of said masking layer includes selectively removing a plurality of corresponding portions of the first semiconductor layer.

3. A method of forming a monolithic LED array precursor, the method comprising:

(i) providing a substrate having a surface;

(ii) forming a continuous first semiconductor layer on the surface of the substrate;

(iii) selectively treating the first semiconductor layer to form an amorphous surface pattern, wherein the amorphous surface pattern defines a plurality of untreated portions of the first semiconductor layer;

(iv) growing a second semiconductor layer on the untreated portions of the first semiconductor layer to form a plurality of columns each having a regular trapezoidal cross-section normal to the substrate with sloped sides and a substantially flat upper surface portion;

(v) forming a third semiconductor layer covering the second semiconductor layer, wherein the third semiconductor layer comprises one or more quantum well sub-layers and has sloped sides and a substantially flat upper surface portion;

(vi) forming a fourth semiconductor layer covering the third semiconductor layer, whereby the fourth semiconductor layer has sloped sides and a substantially flat upper surface portion;

(vii) forming primary electrical contacts on the substantially flat upper surface portion of the fourth semiconductor layer wherein the first to fourth semiconductor layers comprise Group III-nitrides;

(viii) forming electrically insulating, optically transparent spacers on the sloped sides of the fourth semiconductor layer, the spacers having an internal surface facing the sloped sides of the fourth semiconductor layer and an opposing external surface, wherein the external surface of the spacers has a pseudo parabolic or parabolic profile; and

(ix) depositing a reflecting, electrically conducting layer over the external surface of the spacers.

4. A method according to any of the preceding claims, wherein forming the primary electrical contacts comprises depositing a transparent conducting oxide having an internal surface in contact with the substantial flat upper surface portion of the fourth semiconductor layer, and convex external surface.

5. A method according to claim 4 further comprising depositing a reflective, electrically conducting layer over the convex external surface of the transparent conducting oxide.

~~6. A method according to any of the preceding claims, wherein the external surface of the spacers has a pseudo parabolic or parabolic profile, and/or wherein the profile of the external face of the spacers approximates a Bézier curve having two control points with a Bézier coefficient of 0.5.~~

~~7. A method according to any of the preceding claims, wherein the spacers are formed of a transparent conducting oxide and an insulating layer is provided between the transparent conducting oxide spacers and the underlying first semiconductor layer.~~

6~~8~~. A method according to any of claims 1-5~~6~~, wherein the spacers are formed of any one of silicon dioxide, silicon nitride or titanium oxide.

7~~9~~. A method according to any of the preceding claims, wherein the internal surface of the spacers is formed of a first material and the external surface of the spacers is formed of a second material, and wherein the first material has a higher index of refraction than the second material.

8~~10~~. A method according to any of the preceding claims, the method further comprising forming one or more secondary electrical contacts in electrical communication with the primary electrical contacts across the quantum well sublayers to form a monolithic LED array~~, preferably wherein the one or more secondary electrical contacts are formed on the first semiconductor layer~~.

9~~11~~. A method according to any of the preceding claims, further comprising a step of at least partially removing the substrate, and at least partially removing the first semiconductor layer to form a plurality of dome or lens structures corresponding to and aligned with each of the plurality of columns of the second semiconductor layer.

10~~12~~. A method according to any of the preceding claims, wherein the substrate is selectively removed to form a plurality of collimating channels, each of the collimating channels aligned with a primary contact formed on the substantially flat upper surface portion of the fourth semiconductor layer.

~~13. A monolithic LED array precursor or LED array obtainable by the method of any of the preceding claims.~~

11~~14~~. A monolithic LED array precursor comprising:
a plurality of LED structures sharing a first semiconductor layer, wherein the first semiconductor layer defines a plane of the LED array precursor, each LED structure comprising:

(i) a second semiconductor layer on the first semiconductor layer, having an upper surface portion parallel to the plane of the LED array precursor, the second semiconductor

layer having a regular trapezoidal cross-section normal to the upper surface portion, such that the second semiconductor layer has sloped sides;

(ii) a third semiconductor layer on the second semiconductor layer, having an upper surface portion parallel to the plane of the LED array precursor, the third semiconductor layer having a regular trapezoidal cross-section normal to the upper surface portion, such that the third semiconductor layer has sloped sides parallel to the sloped sides of the second semiconductor layer;

(iii) a fourth semiconductor layer on the third semiconductor layer, having an upper surface portion parallel to the plane of the LED array precursor, the fourth semiconductor layer having a regular trapezoidal cross-section normal to the upper surface portion, such that the fourth semiconductor layer has sloped sides parallel to the sloped sides of the third semiconductor layer;

(iv) a primary electrical contact on the fourth semiconductor layer, wherein the contact is only on the upper surface portion of the fourth semiconductor layer which is parallel to the plane of the LED array precursor;

(v) electrically insulating, optically transparent spacers on the sloped sides of the fourth semiconductor layer, the spacers having an internal surface facing the sloped sides of the fourth semiconductor layer and an opposing external surface, wherein the external surface of the spacers has a pseudo parabolic or parabolic profile; and

(vi) a reflecting layer, electrically conducting extending over the external surface of the spacers;

wherein the third semiconductor layer comprises a plurality of quantum well sub-layers, the quantum well sub-layers having a greater thickness on a portion parallel to the plane of the LED array precursor and a reduced thickness on a portion which is not parallel to the plane of the LED array precursor.

12~~15~~. The monolithic LED array precursor of claim 11~~14~~, wherein the primary electrical contact comprises a transparent conducting oxide having an internal surface in contact with the substantial flat upper surface portion of the fourth semiconductor layer, and convex external surface.

13~~16~~. The monolithic LED array precursor of any of claims 11~~14~~ and 12~~15~~ wherein the reflective, electrically conducting layer extends over the convex external surface of the transparent conducting oxide.

~~17. The monolithic LED array precursor of any of claims 14 to 16 wherein the external surface of the spacers has a pseudo parabolic or parabolic profile and/or wherein the profile~~

~~of the external face of the spacers approximates a Bézier curve having two control points with a Bézier coefficient of 0.5.~~

~~18. The monolithic LED array precursor of any of claims 14 to 17, wherein the spacers are formed of a transparent conducting oxide and an insulating layer is provided between the transparent conducting oxide spacers and the underlying first semiconductor layer.~~

14~~19~~. The monolithic LED array precursor of any of claims 11~~14~~ to 13~~17~~, wherein the spacers are formed of any one of silicon dioxide, silicon nitride or titanium oxide.

15~~20~~. The monolithic LED array precursor of any of claims 11~~14~~ to 14~~19~~, wherein the internal surface of the spacers is formed of a first material and the external surface of the spacers is formed of a second material, and wherein the first material has a higher index of refraction than the second material.

16~~21~~. The monolithic LED array precursor of any of claims 11~~14~~ to 15~~20~~, wherein a spacing of the sloped sides of the third semiconductor layer from the sloped sides of the second semiconductor layer is less than a spacing of the upper surface portion of the third semiconductor layer from the upper surface portion of the second semiconductor layer, and/or wherein a spacing of the sloped sides of the fourth semiconductor layer from the sloped sides of the third semiconductor layer is less than a spacing of the upper surface portion of the fourth semiconductor layer from the upper surface portion of the third semiconductor layer.

17~~22~~. The monolithic LED array precursor of any of claims 11~~14~~ to 16~~21~~, wherein the first semiconductor layer comprises a plurality of lens structures corresponding to and aligned with the plurality of LED structures.

18~~23~~. A monolithic LED array comprising the monolithic LED array precursor of any of claims 11~~14~~ to 17~~22~~ and further comprising one or more secondary electrical contacts in electrical communication with the primary electrical contacts across the quantum well sub-layers.

19~~24~~. The monolithic LED array of claim 18~~23~~ wherein the secondary electrical contacts are provided by a transparent conducting oxide layer in contact with the first semiconductor layer.

20~~25~~. A display device comprising the monolithic LED array according to any of claims 11~~14~~ to 19~~24~~.