

CLAIMS:

1. A method of forming a Light Emitting Diode (LED) precursor comprising:
forming a LED stack comprising a plurality of Group III-nitride layers on a substrate,
5 the LED stack comprising a LED stack surface formed on an opposite side of the LED
stack to the substrate;
masking a first portion of the LED stack surface, leaving a second portion of the
LED stack surface exposed,
subjecting the second portion of the LED stack surface to a poisoning process such
10 that a second region of the LED stack below the second portion of the LED stack surface
comprising at least one of the Group III-nitride layers of the LED stack has a relatively
higher resistivity than a resistivity of the respective Group-III nitride layer in a first region of
the LED stack below the first portion of the LED stack surface.
- 15 2. A method of forming a Light Emitting Diode (LED) precursor according to claim 1,
wherein
masking the first portion of the LED stack surface comprises selectively forming a
contact layer on the first portion of the LED stack surface.
- 20 3. A method of forming a LED precursor according to claim 1 or claim 2, wherein
forming the LED stack comprises:
forming a first semiconducting layer comprising a Group III-nitride on
the substrate;
forming an active layer comprising a Group III-nitride on the first
25 semiconducting layer; and
forming a p-type semiconducting layer comprising a Group III-nitride
on the active layer, wherein a major surface of the p-type semiconducting
layer on an opposite side of the p-type semiconducting layer to the active
layer provides an LED stack surface of the LED stack;
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4. A method according to claim 3, wherein
the second region of the LED stack includes a second region of the p-type
semiconducting layer, and
the first region of the LED stack includes a first region of the p-type semiconducting
35 layer.

5. A method according to claim 3 or claim 4, wherein
the second region of the LED stack includes a second region of the active layer;
and
the first region of the LED stack includes a first region of the active layer.
- 5 6. A method according to any of claims 3 to 5, wherein
the second region of the LED stack includes a second region of the first
semiconducting layer; and
the first region of the LED stack includes a first region of the first semiconducting
10 layer.
7. A method according to any preceding claim, wherein the second portion of the LED
stack surface encircles the first portion of the LED stack surface.
- 15 8. A method according to any preceding claim, wherein masking the first portion of the
LED stack surface comprises masking a plurality of first portions in order to define a
plurality of second portions of the LED stack surface, wherein optionally the plurality of
second portions of the LED stack surface are arranged in an annular or chequerboard
pattern.
- 20 9. A method according to any preceding claim, wherein a first portion of the LED stack
surface is masked with a contact layer and a third portion of the LED stack surface is
masked with a masking layer such that the first and third portions of the LED stack surface
are covered and the second portion of the LED stack surface is exposed.
- 25 10. A method according to claim 9, wherein
the masking layer and the contact layer are formed on the LED stack surface in
order to define one or more second portions of the LED stack surface having an annular or
chequerboard pattern.
- 30 11. A method according to any preceding claim, wherein
the poisoning process comprises exposing the second portion of the LED stack
surface to a plasma comprising hydrogen ions.
- 35 12. A method according to any preceding claim, wherein

the LED stack formed comprises a column having a regular trapezoidal cross-section in a plane normal to the substrate surface.

13. A method according to claim 12, wherein forming the LED stack comprises:
- 5 forming the first semiconducting layer on a substrate surface of the substrate, the first semiconducting layer having a growth surface on an opposite side of the first semiconducting layer to the substrate;
- selectively removing a portion of the first semiconducting layer to form a mesa structure such that the growth surface of the first semiconducting layer comprises a mesa
- 10 surface and a bulk semiconducting surface,
- monolithically forming a second semiconducting layer comprising a Group III-nitride on the growth surface of the first semiconducting layer such that the second semiconducting layer covers the mesa surface and the bulk semiconducting surface.
- wherein the active layer and the p-type semiconducting layer are formed on the
- 15 second semiconducting layer.
14. A method according to claim 13, wherein
- the second region of the LED stack includes a second region of the second semiconducting layer; and
- 20 the first region of the LED stack includes a first region of the second semiconducting layer.
15. A method according to claim 14, wherein
- the second semiconducting layer is formed on the growth surface of the first
- 25 semiconducting layer to provide an inclined sidewall portion extending between a first portion of the second semiconducting layer on the mesa surface of the first semiconducting layer and a second portion of the second semiconducting layer on the bulk semiconducting surface of the first semiconducting layer
- 30 16. A method according to any one of claims 14 or 15, wherein
- forming the first semiconducting layer on the substrate comprises:
- forming a first semiconducting sublayer comprising a Group III-nitride on the substrate surface;
- forming a dielectric sublayer on the first semiconducting sublayer, the dielectric
- 35 sublayer defining an aperture through a thickness of the dielectric sublayer; and

forming a second semiconducting sublayer comprising a Group III-nitride on the dielectric sublayer, and

wherein selectively removing a portion of the first semiconducting layer to form a mesa structure comprises selectively removing a portion of the second semiconducting sublayer to form a mesa structure which is aligned with the aperture of the dielectric sublayer.

17. A method according to any of claims 3 to 16, wherein the active layer of the LED stack comprises a plurality of quantum well layers configured to output visible light.

18. A method according to any preceding claim, wherein the LED precursor is a micro LED precursor wherein the LED stack has a surface area on the substrate of no greater than $100\text{ }\mu\text{m} \times 100\text{ }\mu\text{m}$, or no greater than $10\text{ }\mu\text{m} \times 10\text{ }\mu\text{m}$.

19. A light emitting diode (LED) precursor comprising: a LED stack comprising a plurality of Group III-nitride layers, the LED stack comprising a LED stack surface formed on an opposite side of the LED stack to a light emitting surface of the LED stack;

wherein a first portion of the LED stack surface defines a first region of at least one of the plurality of layers of the LED stack below the LED stack surface having a first resistivity; and

a second portion of the LED stack surface defines a second region of the LED stack below the LED stack surface in which a resistivity of the respective layer of the LED stack is increased relative to the first region of the LED stack.

20. A LED precursor according to claim 19, further comprising a contact layer formed on the first portion of the LED stack surface.

21. A LED precursor according to claim 19 or claim 20, wherein the LED stack comprises:

a first semiconducting layer comprising a Group III-nitride providing the light emitting surface of the LED stack;

an active layer comprising a Group III-nitride and provided on the first semiconducting layer; and

5 a p-type semiconducting layer comprising a Group III-nitride and provided on the active layer, wherein a major surface of the p-type semiconducting layer on an opposite side of the p-type semiconducting layer to the active layer provides an LED stack surface of the LED stack.

22. A LED precursor according to claim 21, wherein
the second region of the LED stack includes a second region of the p-type
10 semiconducting layer, and
the first region of the LED stack includes a first region of the p-type semiconducting layer.

23. A LED precursor according to claim 21 or claim 22, wherein
15 the second region of the LED stack includes a second region of the active layer;
and
the first region of the LED stack includes a first region of the active layer.

24. A LED precursor according to any of claims 21 to 23, wherein
20 the second region of the LED stack includes a second region of the first semiconducting layer; and
the first region of the LED stack includes a first region of the first semiconducting layer.

25. A LED precursor according to any of claims 19 to 24, wherein the second portion of the LED stack surface encircles the first portion of the LED stack surface.

26. A LED precursor according to any of claims 19 to 25, wherein the LED stack surface comprises a plurality of first portions and a plurality of second portions of the LED
30 stack surface, wherein optionally the plurality of first and second portions of the LED stack surface are arranged in an annular or chequerboard pattern.

27. A LED precursor according to any of claims 19 to 26, wherein a contact layer is provided on the first portion of the LED stack surface and a mask layer is provided on a
35 third portion of the LED stack surface.

28. A LED precursor according to claim 27, wherein
the masking layer and the contact layer are provided on the LED stack surface in
order to define one or more second portions of the LED stack surface having an annular or
chequerboard pattern.
29. A LED precursor according to any of claims 19 to 28, wherein
the LED stack comprises a column having a regular trapezoidal cross-section in a
plane normal to the substrate surface.
30. A LED precursor according to any of claims 19 to 29, wherein:
the first semiconducting layer has a growth surface and the light emitting surface of
the LED stack on opposite sides of the first semiconducting layer;
the first semiconducting layer includes a mesa structure such that the growth
surface of the first semiconducting layer comprises a mesa surface and a bulk
semiconducting surface,
a second semiconducting layer is provided on the growth surface of the first
semiconducting layer such that the second semiconducting layer covers the mesa surface
and the bulk semiconducting surface.
- wherein the active layer and the p-type semiconducting layer are formed on the
second semiconducting layer.
31. A LED precursor according to claim 30, wherein
the second region of the LED stack includes a second region of the second
semiconducting layer; and
the first region of the LED stack includes a first region of the second
semiconducting layer.
32. A LED precursor according to claim 30 or claim 31, wherein
the second semiconducting layer is formed on the growth surface of the first
semiconducting layer to provide an inclined sidewall portion extending between a first
portion of the second semiconducting layer on the mesa surface of the first semiconducting
layer and a second portion of the second semiconducting layer on the bulk semiconducting
surface of the first semiconducting layer

33. A LED precursor according to any one of claims 29 to 32, wherein
the first semiconducting layer comprises:
a first semiconducting sublayer comprising a Group III-nitride provided on the
substrate surface;
5 an insulating sublayer provided on the first semiconducting sublayer, the insulating
layer defining an aperture through a thickness of the insulating sublayer; and
a second semiconducting sublayer comprising a Group III-nitride provided on the
insulating layer and within the aperture of the insulating sublayer,
wherein the mesa structure is provided by a portion of the second semiconducting
10 sublayer and the mesa structure which is aligned with the aperture of the insulating layer.
34. A LED precursor according to any of claims 19 to 33, wherein
the active layer of the LED stack comprises a plurality of quantum well layers
configured to output visible light.
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35. A LED precursor according to any of claims 19 to 34, wherein
the LED precursor is a micro LED wherein the LED stack has a surface area on the
substrate of no greater than 100 μm x 100 μm .
- 20 36. A LED comprising:
a LED layer configured to emit pump light having a pump light wavelength from a
light emitting surface, the LED layer comprising a LED precursor according to any of claims
19 to 35;
a container layer provided on the light emitting surface of the LED layer, the
25 container layer having a container surface on an opposite side of the container layer to the
light emitting surface, the container surface including an opening defining a container
volume through the container layer to the light emitting surface of the LED layer;
a colour converting layer provided in the container volume, the colour converting
layer configured to absorb pump light and emit converted light of a converted light
30 wavelength longer than the pump light wavelength; and
a lens provided on the container surface over the opening, the lens having a convex
surface on an opposite side of the lens to the colour converting layer.