

CLAIMS:

1. A light emitting diode comprising:
- 5 a LED layer configured to emit pump light having a pump light wavelength from a light emitting surface, the LED layer comprising a plurality of Group III-nitride layers
- a container layer provided on the light emitting surface of the LED layer, the 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;
- 10 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 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;
- 15 a pump light reflector laminate provided over the convex surface of the lens the pump light reflector laminate having a stop-band configured to reflect the pump light centred on a first wavelength comprising:
- a first interface layer provided on the convex surface of the lens; the first interface layer having a first thickness and a first refractive index, wherein a
- 20 product of the first refractive index and first thickness is one eighth of the first wavelength;
- a plurality of layers alternating between:
- a low reflectance layer having a second refractive index and a
- 25 second thickness, wherein the second refractive index is lower than the first refractive index; and
- a high reflectance layer having a third thickness and a third refractive index which is higher than the second refractive index,
- wherein a product of the second refractive index and the
- 30 second thickness for each of the low reflectance layers is one quarter of the first wavelength, and a product of the third refractive index and the third thickness for each of the high reflectance layers is one quarter of the first wavelength;
- a second interface layer provided on a low reflectance layer of the plurality of layers, the second interface layer having a fourth refractive index and a
- 35 fourth thickness, wherein a product of the fourth refractive index and the

fourth thickness is one eighth of the first wavelength, and the fourth refractive index larger than the second refractive index.

2. A light emitting diode according to claim 1, wherein the container layer comprises
5 an inner sidewall defining the container volume, wherein the inner sidewall defining the container volume is sloped at an acute angle relative to the light emitting surface of the LED layer and comprises a reflective material.
3. A light emitting diode according to claim 1 or claim 2, further comprising a converted
10 light reflector laminate provided between the LED layer and the colour converting layer, the converted light reflector laminate having a stop-band configured to reflect the converted light centred on a second wavelength comprising:
- a third interface layer provided on the light emitting surface of the LED layer;
the third interface layer having a fifth thickness and a fifth refractive index, wherein
15 a product of the fifth thickness and fifth refractive index is one eighth of the second wavelength;
- a plurality of layers alternating between:
- a converted light high reflectance layer having a sixth
thickness and a sixth refractive index which is higher than the fifth
20 refractive index,
- a converted light low reflectance layer having a seventh
refractive index and a seventh thickness, wherein the seventh
refractive index is lower than the sixth refractive index; and
wherein a product of the sixth refractive index and the sixth thickness
25 for each of the converted light high reflectance layers is one quarter of the second wavelength, and a product of the seventh refractive index and the seventh thickness for each of the converted light low reflectance layers is one quarter of the second wavelength;
- a fourth interface layer provided on a converted light high reflectance layer
30 of the plurality of layers, the fourth interface layer having an eighth refractive index and an eighth thickness, wherein a product of the eighth refractive index and the eighth thickness is one eighth of the second wavelength, and the eighth refractive index is lower than the sixth refractive index.

4. A LED according to any preceding claim further comprising a reflection enhancement layer provided on the inner sidewall of the container layer, the reflection enhancement layer comprising a dielectric.
- 5 5. A LED according to any preceding claim, further comprising an antireflection layer provided over the pump light reflector laminate, the antireflection layer configured to reduce reflection of light of the converted light wavelength.
6. A LED according to any preceding claim, wherein a lens interface layer is provided
10 on the pump light reflector laminate on an opposite side to the lens.
7. A LED according to any preceding claim, wherein the colour converting layer comprises quantum dots or a phosphor.
- 15 8. A LED according to any preceding claim, wherein the inner sidewall forms an angle relative to the light emitting surface of the LED layer of at least 45°; and/or
the inner sidewall forms an angle relative to the light emitting surface of the LED layer of no greater than 85°.
- 20 9. A LED according to any preceding claim, wherein the pump light wavelength may be at least 440 nm and/or no greater than 480 nm; and/or
the converted light wavelength may be at least 500 nm and/or no greater than 650 nm.
- 25 10. A LED according to any preceding claim, wherein the first, third and/or fourth refractive index is at least 2; and/or
wherein the second refractive index is no greater than 1.8.
11. A LED according to any preceding claim, wherein the container layer defines an
30 opening having a surface area of no greater than 10^{-8} m².
12. A LED according to any preceding claim wherein, the first refractive index of the first interface layer, the third refractive index of the high reflectance layer, and the fourth refractive index of the second interface layer are the same; and/or

the fifth refractive index of the third interface layer, the seventh refractive index of the converted light low reflectance layer, and the eighth refractive index of the fourth interface layer are the same.

- 5 13. A LED according to any preceding claim, wherein the first wavelength (λ_0), the second refractive index (n_L) and the third refractive index (n_H) of the pump light reflector laminate provide an upper stop-band wavelength (λ_e) of the pump light reflector laminate which is longer than the pump light wavelength, where:

$$\lambda_e = \frac{\lambda_0}{1 - \frac{2}{\pi} \sin^{-1} \left(\frac{(n_H - n_L)}{(n_H + n_L)} \right)}$$

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14. A LED according to any preceding claim, wherein the pump light reflector and/or the converted light reflector comprises layers of TiO_2 and SiO_2 .

15. A light emitting diode array comprising:

- 15 a LED layer comprising a plurality of LEDs, each LED configured to emit pump light of a pump light wavelength from a light emitting surface and each LED comprising a plurality of Group III-nitride layers;

a container layer provided on the light emitting surface of the LED layer, the container layer having a container surface on an opposite side of the container layer to the light emitting surface, the container surface including a plurality of openings each defining a container volume through the container layer to the light emitting surface of the LED layer, each opening and container volume aligned with a respective LED of the LED layer,

- 25 a colour converting layer selectively provided in a container volume, the colour converting layer configured to absorb pump light and emit first converted light of a first converted light wavelength longer than the pump light wavelength;

a lens provided on the container surface over the opening to the container volume containing a colour converting material, the lens having a convex surface on an opposite side of the lens to the colour converting layer;

- 30 a pump light reflector laminate provided over the convex surface of the lens, the pump light reflector laminate having a stop-band configured to reflect the pump light centred on a first wavelength comprising:

a first interface layer provided on the convex surface of the lens; the first interface layer having a first thickness and a first refractive index, wherein a product of the first refractive index and first thickness is one eighth of the first wavelength;

5 a plurality of layers alternating between:

a low reflectance layer having a second refractive index and a second thickness, wherein the second refractive index is lower than the first refractive index; and

10 a high reflectance layer having a third thickness and a third refractive index which is higher than the second refractive index, wherein a product of the second refractive index and the second thickness for each of the low reflectance layers is one quarter of the first wavelength, and a product of the third refractive index and the third thickness for each of the high reflectance layers is one
15 quarter of the first wavelength;

a second interface layer provided on a low reflectance layer of the plurality of layers, the second interface layer having a fourth refractive index and a fourth thickness, wherein a product of the fourth refractive index and the fourth thickness is one eighth of the first wavelength, and the fourth refractive index is longer than
20 the second refractive index.

16. A light emitting diode array according to claim 15, wherein

a further colour converting layer is provided in a further container volume of the plurality of container volumes, the further colour converting layer configured to absorb
25 pump light and emit second converted light of a second converted light wavelength longer than the first converted light wavelength,

a lens is provided over the further container volume, and a pump light reflector laminate is provided on the lens.

30 17. A light emitting diode array according to claim 15 or claim 16, further comprising: at least one converted light reflector laminate provided between the colour converting layer and the light emitting surface of the corresponding LED of the LED layer, the converted light reflector laminate the converted light reflector laminate having a stop-band configured to reflect the first and/or second converted light centred on a second
35 wavelength comprising:

a third interface layer provided on the light emitting surface of the LED layer; the third interface layer having a fifth thickness and a fifth refractive index, wherein a product of the fifth thickness and fifth refractive index is one eighth of the second wavelength;

5 a plurality of layers alternating between:

a converted light high reflectance layer having a sixth thickness and a sixth refractive index which is higher than the fifth refractive index,

10 a converted light low reflectance layer having a seventh refractive index and a seventh thickness, wherein the seventh refractive index is lower than the sixth refractive index; and wherein a product of the sixth refractive index and the sixth thickness for each of the converted light high reflectance layers is one quarter of the second wavelength, and a product of the seventh refractive index and the seventh thickness for each of the converted light low reflectance layers is one quarter of the second wavelength;

15 a fourth interface layer provided on a converted light high reflectance layer of the plurality of layers, the fourth interface layer having an eighth refractive index and an eighth thickness, wherein a product of the eighth refractive index and the eighth thickness is one eighth of the second wavelength, and the eighth refractive index is lower than the sixth refractive index.

18. A LED array according to any of claims 15-17, wherein the container layer comprises a plurality of inner sidewalls defining the container volumes, wherein the inner
25 sidewalls defining the container volumes are sloped at an acute angle relative to the light emitting surface of the LED layer and comprise a reflective material.

19. A LED array according to claim 18, further comprising a reflection enhancement layer provided on the inner sidewalls of the container layer, the reflection enhancement
30 layer comprising a dielectric.

20. A LED array according to any of claims 15-19, further comprising an antireflection layer provided over each pump light reflector laminate, the antireflection layer configured to reduce reflection of light of the first converted light wavelength and/or the second converted
35 light wavelength.

21. A LED array according to any of claims 15-20, wherein each colour converting layer comprises a quantum dots or a phosphor.
- 5 22. A LED array according to any of claims 15-21, wherein the inner sidewalls form an angle relative to the light emitting surface of the LED layer of at least 30°; and/or
the inner sidewalls form an angle relative to the light emitting surface of the LED layer of no greater than 85°.
- 10 23. A LED array according to any of claims 15-22, wherein the pump light wavelength may be at least 440 nm and/or no greater than 480 nm; and/or
the first converted light wavelength may be at least 500 nm and/or no greater than 650 nm; and/or
the second converted light wavelength may be at least 600 nm and/or no greater
15 than 650 nm.
24. A LED array according to any of claims 15-23, wherein the pump light reflector laminate comprises layers of SiO₂ and TiO₂
- 20 25. A LED array according to any of claims 15-23, wherein the pump light reflector laminate comprises a plurality of layers comprising oxygen, and a plurality of layers comprising fluorine.