

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization

International Bureau



(10) International Publication Number

WO 2014/167455 A2

(43) International Publication Date
16 October 2014 (16.10.2014)

(51) International Patent Classification:
H01L 33/20 (2010.01)

(21) International Application Number:
PCT/IB2014/060310

(22) International Filing Date:
31 March 2014 (31.03.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/810,833 11 April 2013 (11.04.2013) US
61/900,466 6 November 2013 (06.11.2013) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- without international search report and to be republished upon receipt of that report (Rule 48.2(g))

WO 2014/167455 A2

(54) Title: TOP EMITTING SEMICONDUCTOR LIGHT EMITTING DEVICE

(57) Abstract: Embodiments of the invention include a semiconductor structure including a light emitting layer sandwiched between an n-type region and a p-type region. A growth substrate is attached to the semiconductor structure. The growth substrate has at least one angled sidewall. A reflective layer is disposed on the angled sidewall. A majority of light extracted from the semiconductor structure and the growth substrate is extracted through a first surface of the growth substrate.

Top emitting semiconductor light emitting device

Field of the invention

The present invention relates to top-emitting, wavelength-converted semiconductor light emitting devices.

Background

5 Semiconductor light-emitting devices including light emitting diodes (LEDs), resonant cavity light emitting diodes (RCLEDs), vertical cavity laser diodes (VCSELs), and edge emitting lasers are among the most efficient light sources currently available. Materials systems currently of interest in the manufacture of high-brightness light emitting devices capable of operation across the visible spectrum include Group III-V semiconductors, 10 particularly binary, ternary, and quaternary alloys of gallium, aluminum, indium, and nitrogen, also referred to as III-nitride materials. Typically, III-nitride light emitting devices are fabricated by epitaxially growing a stack of semiconductor layers of different compositions and dopant concentrations on a sapphire, silicon carbide, III-nitride, or other suitable substrate by metal-organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), or other epitaxial techniques. The stack often includes one or more n-type 15 layers doped with, for example, Si, formed over the substrate, one or more light emitting layers in an active region formed over the n-type layer or layers, and one or more p-type layers doped with, for example, Mg, formed over the active region. Electrical contacts are formed on the n- and p-type regions.

20 LEDs that emit light only from a surface that is commonly referred to as the “top” surface (i.e. devices where light emission from the side surfaces of the LED is substantially reduced or eliminated) are often formed by growing an LED semiconductor structure on a growth substrate, attaching the semiconductor structure to a mount, then removing the growth substrate.

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Summary

It is an object of the invention to provide a device that emits a majority of light from the top surface of the device, without requiring removal of the growth substrate.

Embodiments of the invention include a semiconductor structure including a light emitting layer sandwiched between an n-type region and a p-type region. A growth substrate is attached to the semiconductor structure. The growth substrate has at least one angled sidewall. A reflective layer is disposed on the angled sidewall. A majority of light extracted from the semiconductor structure and the growth substrate is extracted through a top surface of the growth substrate.

Embodiments of the invention include a semiconductor structure including a light emitting layer sandwiched between an n-type region and a p-type region. A growth substrate having a thickness less than 150 microns is attached to the semiconductor structure. A reflective layer is disposed on a sidewall of the growth substrate and a sidewall of the semiconductor structure. A majority of light extracted from the semiconductor structure and the growth substrate is extracted through a top surface of the growth substrate.

A method according to embodiments of the invention includes attaching a plurality of semiconductor light emitting devices to a carrier. A reflective material is disposed in areas between the semiconductor light emitting devices. Two neighboring semiconductor light emitting devices are separated. Separating includes cutting the reflective material.

Brief description of the drawings

Fig. 1 illustrates one example of a III-nitride LED.

Fig. 2 illustrates a wafer of LEDs attached to a temporary carrier.

5 Fig. 3 illustrates the structure of Fig. 2 after forming slots in the growth substrate.

Fig. 4 illustrates the structure of Fig. 3 after attaching wavelength converting members to the LEDs.

10 Fig. 5 illustrates the structure of Fig. 4 after filling the areas between the LEDs with reflective material.

Fig. 6 illustrates the structure of Fig. 5 after separating the LEDs.

Fig. 7 illustrates LEDs attached to a temporary carrier.

15 Fig. 8 illustrates the structure of Fig. 7 after attaching wavelength converting members to the LEDs.

Fig. 9 illustrates the structure of Fig. 8 after filling the areas between the LEDs with reflective material.

Fig. 10 illustrates the structure of Fig. 7 after filling the areas between the LEDs with reflective material.

Fig. 11 illustrates the structure of Fig. 10 after forming a wavelength converting layer over the LEDs.

Fig. 12 illustrates wavelength converting members attached to a temporary carrier.

5 Fig. 13 illustrates the structure of Fig. 12 after attaching LEDs to the wavelength converting members.

Fig. 14 illustrates the structure of Fig. 13 after filling the areas between the LEDs with reflective material.

10 Fig. 15 illustrates LEDs with a substantially conformal wavelength converting layer attached to a temporary carrier.

Fig. 16 illustrates the structure of Fig. 15 after filling the areas between the LEDs with reflective material.

Fig. 17 illustrates LEDs with a mask layer formed over the tops of the LEDs attached to a temporary carrier.

15 Fig. 18 illustrates the structure of Fig. 17 after forming a reflective layer.

Fig. 19 illustrates the structure of Fig. 18 after removing the mask layer.

Fig. 20 illustrates the structure of Fig. 19 after forming a wavelength converting layer over the structure.

20 Detailed description

In embodiments of the invention, wafers of semiconductor LEDs grown on a growth substrate are processed into individual devices or groups of devices where a majority of light is extracted through a top surface of each LED. A reflective material is disposed on the sides of the device to prevent light from escaping from the sides of the device, or to 25 reduce the amount of light extracted from the sides of the device. The reflective material may also increase the amount of light extracted through the top surface of the LED.

Though in the examples below the semiconductor light emitting devices are III-nitride LEDs that emit blue or UV light, semiconductor light emitting devices besides LEDs such as laser diodes and semiconductor light emitting devices made from other 30 materials systems such as other III-V materials, III-phosphide, III-arsenide, II-VI materials, ZnO, or Si-based materials may be used.

Fig. 1 illustrates a III-nitride LED that may be used in embodiments of the present invention. Any suitable semiconductor light emitting device may be used and embodiments of the invention are not limited to the device illustrated in Fig. 1. The device of

Fig. 1 is formed by growing a III-nitride semiconductor structure 12 on a growth substrate 10 as is known in the art. The growth substrate is often sapphire but may be any suitable substrate such as, for example, SiC, Si, GaN, or a composite substrate. A surface of the growth substrate on which the III-nitride semiconductor structure is grown may be patterned, 5 roughened, or textured before growth, which may improve light extraction from the device. A surface of the growth substrate opposite the growth surface (i.e. the surface through which a majority of light is extracted in a flip chip configuration) may be patterned, roughened or textured before or after growth, which may improve light extraction from the device.

The semiconductor structure includes a light emitting or active region 10 sandwiched between n- and p-type regions. An n-type region 16 may be grown first and may include multiple layers of different compositions and dopant concentration including, for example, preparation layers such as buffer layers or nucleation layers, which may be n-type or not intentionally doped, and n- or even p-type device layers designed for particular optical, material, or electrical properties desirable for the light emitting region to efficiently emit light. 15 A light emitting or active region 18 is grown over the n-type region. Examples of suitable light emitting regions include a single thick or thin light emitting layer, or a multiple quantum well light emitting region including multiple thin or thick light emitting layers separated by barrier layers. A p-type region 20 may then be grown over the light emitting region. Like the n-type region, the p-type region may include multiple layers of different composition, 20 thickness, and dopant concentration, including layers that are not intentionally doped, or n-type layers.

After growth, a p-contact is formed on the surface of the p-type region. The p-contact 21 often includes multiple conductive layers such as a reflective metal and a guard metal which may prevent or reduce electromigration of the reflective metal. The reflective 25 metal is often silver but any suitable material or materials may be used. After forming the p-contact 21, a portion of the p-contact 21, the p-type region 20, and the active region 18 is removed to expose a portion of the n-type region 16 on which an n-contact 22 is formed. The n- and p-contacts 22 and 21 are electrically isolated from each other by a gap 25 which may be filled with a dielectric such as an oxide of silicon or any other suitable material. Multiple 30 n-contact vias may be formed; the n- and p-contacts 22 and 21 are not limited to the arrangement illustrated in Fig. 1. The n- and p-contacts may be redistributed to form bond pads with a dielectric/metal stack, as is known in the art.

In order to form electrical connections to the LED, one or more interconnects 26 and 28 are formed on or electrically connected to the n- and p-contacts 22 and 21.

Interconnect 26 is electrically connected to n-contact 22 in Fig. 1. Interconnect 28 is electrically connected to p-contact 21. Interconnects 26 and 28 are electrically isolated from the n- and p-contacts 22 and 21 and from each other by dielectric layer 24 and gap 27. Interconnects 26 and 28 may be, for example, solder, stud bumps, gold layers, or any other 5 suitable structure. Many individual LEDs are formed on a single wafer then diced from the wafer of devices. The semiconductor structure and the n- and p-contacts 22 and 21 of a wafer of LEDs are represented in the following figures by block 12. The interconnects 26 and 28 of a wafer of LEDs are represented by block 14.

The substrate 10 may be thinned after growth of the semiconductor structure 10 or after forming the individual devices as described above in reference to Fig. 1. After thinning, the substrate may be at least 50 μm thick in some embodiments, no more than 150 μm thick in some embodiments, at least 80 μm thick in some embodiments and no more than 120 μm thick in some embodiments.

Figs. 2, 3, 4, 5, and 6 illustrate forming a device according to embodiments of 15 the invention.

In Fig. 2, before the wafer of LEDs is diced into individual LEDs or groups of LEDs, the wafer is attached to a temporary carrier 30 through the interconnects 14. The temporary carrier 30 stabilizes the wafer for the following processing steps. Temporary carrier 30 may be any suitable material such as, for example, wafer handling tape.

In Fig. 3, slots 32 are formed in the growth substrate 10. Slots 32 are no more 20 than 50 μm wide (for example, at the top of a slot with an angled sidewall as illustrated in Fig. 3) in some embodiments. The slots are disposed in the region between LEDs where the structure will be cut, as described below, to separate the wafer into individual LEDs or groups of LEDs. The slots may be formed by any suitable technique including, for example, wet or dry etching, laser scribing, or mechanical cutting such as sawing with a diamond blade. The slots 32 may extend through the entire thickness of substrate 10, though they need not. 25 The slots 32 may have angled sidewalls, as illustrated in Fig. 3, though angled sidewalls are not required.

In Fig. 4, wavelength converting members 34 are attached to the top of 30 substrate 10, such that the wavelength converting members are aligned with individual LEDs or groups of LEDs. Wavelength converting members 34 are generally wavelength converting structures that are formed separately from the wafer of LEDs, then attached to the substrate 10. As such, wavelength converting members 34 are self-supporting structures, not structures that are formed in situ on the substrate 10. Examples of suitable wavelength converting

members 34 include phosphor that is formed into ceramic platelets, for example by sintering, and/or a phosphor or other wavelength converting material disposed in a transparent material, such as glass, silicone, or epoxy, that is cast or otherwise formed into a sheet, then cut into individual wavelength converting members 34.

5 The wavelength converting material in wavelength converting members 34 may be, for example, conventional phosphors, organic phosphors, quantum dots, organic semiconductors, II-VI or III-V semiconductors, II-VI or III-V semiconductor quantum dots or nanocrystals, dyes, polymers, or other materials that luminesce. The wavelength converting material absorbs light emitted by the LED and emits light of one or more different 10 wavelengths. Unconverted light emitted by the LED is often part of the final spectrum of light extracted from the structure, though it need not be. Examples of common combinations include a blue-emitting LED combined with a yellow-emitting wavelength converting material, a blue-emitting LED combined with green- and red-emitting wavelength converting materials, a UV-emitting LED combined with blue- and yellow-emitting wavelength 15 converting materials, and a UV-emitting LED combined with blue-, green-, and red-emitting wavelength converting materials. Wavelength converting materials emitting other colors of light may be added to tailor the spectrum of light emitted from the structure.

Wavelength converting member 34 may be attached to substrate 10 by, for example, gluing with a material such as silicone or any other suitable adhesive, direct 20 bonding, or any other suitable technique.

In Fig. 5, a reflective material 36 is disposed in the slots 32 formed in Fig. 3. Reflective material may be, for example, reflective or other particles disposed in a transparent material. The particles and transparent material may be selected to have substantially different indices of refraction in order to cause optical scattering. In some 25 embodiments, the transparent material has a low index (for example, silicone may have an index of refraction of 1.4 or less) and the particles have a higher index (for example, TiO₂ has an index of refraction of 2.6). Any suitable reflective particle may be used, including, for example, TiO₂, ZnO, or Al₂O₃. Examples of suitable transparent materials include silicone molding compound, liquid silicone, epoxy, and glass. In some embodiments, the reflective 30 particles, the transparent material, and/or the combination of reflective particles and transparent material has a higher thermal conductivity than common silicone materials. Common silicone materials typically have a thermal conductivity around 0.1-0.2W/mK.

Reflective material 36 may be disposed in the slots 32 by any suitable technique such as, for example, dispensing or molding. Reflective material 36 may

completely fill slots 32, as illustrated in Fig. 5, such that the top of the reflective material 36 is coplanar with the tops of wavelength converting members 34 in some embodiments. Reflective material 36 does not completely fill slots 32 in some embodiments. In some embodiments, excessive reflective material 36 is removed after disposing the reflective 5 material 36 in the slots. For example, reflective material that extends above the tops of slots 32, or that covers the LEDs, may be removed by any suitable technique, such as mechanical abrasion, grinding, or microbead blasting.

In Fig. 6, individual LEDs are separated from the wafer by cutting through the reflective material 36 and the LED wafer in the regions 38 between LEDs. Individual LEDs 10 may be cut from the wafer by any suitable technique including, for example, diamond sawing, laser cutting, or scribing and breaking. The kerf formed by cutting may be, for example, no more than 20 μm wide. The necessary thickness of reflective material 36 remaining on the sides of the LEDs in Fig. 6 after cutting, for proper functioning of the reflective material, may depend on the type of reflective material. For reflective metal films, no more than 1 μm 15 is required in some embodiments. For diffuse reflectors such as TiO_2 in silicone, the reflectivity may depend on the thickness. For example, a diffuse reflector that is at least 90% reflective may be 20 μm thick or less in some embodiments and a diffuse reflector that is at least 95% reflective may be 50 μm thick or less in some embodiments.

After cutting, the finished LEDs are removed from the temporary carrier 30 by 20 any suitable technique such as, for example, thermal release, transfer to a different carrier, or direct picking.

One disadvantage of the method and resulting device illustrated in Figs. 2-6 is that the available area for wavelength converting member 34 and reflective material 36 is limited by the original pitch of the LEDs on the growth substrate wafer 10. The area between 25 neighboring LEDs is limited, for example for cost reasons, which limits the size of wavelength converting member 34 and the thickness of reflective material 36. Figs. 7, 8, and 9 illustrate an alternative embodiment, where individual LEDs are first separated from a wafer, then rearranged with larger pitch on a temporary carrier.

In Fig. 7, individual LEDs are placed on a carrier 30, which may be a 30 temporary carrier such as those described above in reference to Fig. 2. The LEDs may be spaced at least 100 μm apart in some embodiments, no more than 800 μm apart in some embodiments, at least 400 μm apart in some embodiments, and no more than 600 μm apart in some embodiments. The growth substrate 10 on each LED may have substantially vertical sidewalls, rather than the angled sidewalls illustrated in the embodiment described in Figs. 2-

6, though vertical sidewalls are not required and the shape of the sidewall may depend on the technique used to separate the LEDs.

In Fig. 8, wavelength converting elements 34 are attached to the growth substrate 10 of each LED, as described above in reference to Fig. 4.

5 In Fig. 9, reflective material 36 is disposed in the gaps between the LEDs, as described above in reference to Fig. 5. The individual devices may be separated by cutting the reflective material, as described above in reference to Fig. 6, then removed from the temporary carrier, as described above in reference to Fig. 6.

10 Figs. 10 and 11 illustrate an alternative embodiment where individual LEDs are first separated from a growth wafer, then disposed on a temporary carrier. In Fig. 10, individual LEDs are placed on a carrier 30 (as illustrated in Fig. 7), which may be a temporary carrier such as those described above in reference to Fig. 2. Reflective material 36 is disposed in the regions between the LEDs, as described above in reference to Fig. 5.

15 In Fig. 11, a wavelength converting layer 40 is formed over the LEDs and the reflective material 36. Wavelength converting layer 40 may be, for example, a phosphor disposed in a transparent material such as silicone. Wavelength converting layer 40 may be formed by any suitable technique including, for example, lamination, molding, dispensing, spray coating, or spin coating. The LEDs are then separated by cutting through the structure, for example in regions 38 between neighboring LEDs, as described above in reference to Fig. 20 6. The LEDs are then removed from the temporary carrier 30, as described above in reference to Fig. 6.

25 Figs. 12, 13, and 14 illustrate an alternative embodiment. In Fig. 12, individual wavelength converting elements 34 are placed on a carrier 30, which may be a temporary carrier such as those described above in reference to Fig. 2. The wavelength converting elements 34 are described above in reference to Fig. 4.

In Fig. 13, LEDs are attached to the wavelength converting elements 34. The LEDs may be attached using the methods and materials described above in reference to Fig. 4.

30 In Fig. 14, a reflective material 36 is disposed in the regions between the LEDs, as described above in reference to Fig. 5. The LEDs are then separated by cutting through the structure, for example in regions 38 between neighboring LEDs, as described above in reference to Fig. 6. The LEDs are then removed from the temporary carrier 30, as described above in reference to Fig. 6.

Figs. 15 and 16 illustrate an alternative embodiment. In Fig. 15, LEDs are attached to a temporary carrier 30, which may be a temporary carrier such as those described

above in reference to Fig. 2. Before or after attaching the LEDs to the temporary carrier 30, the tops of the LEDs in some embodiments, and the tops and sides of the LEDs in some embodiments, are covered with a wavelength converting layer 42. The wavelength converting layer 42 may be, for example, a wavelength converting material mixed with a 5 transparent material, and may be formed by any suitable technique, including, for example, lamination, molding, or electrophoretic deposition.

In Fig. 16, a reflective material 36 is disposed in the regions between the LEDs, as described above in reference to Fig. 5. The reflective material 36 may be formed by a technique that limits damage to the substantially conformal wavelength converting layer 42. 10 One example of a suitable technique is dispensing reflective particles mixed with liquid silicone in the areas between the LEDs, then curing the liquid silicone. The LEDs are then separated by cutting through the structure, for example in regions 38 between neighboring LEDs, as described above in reference to Fig. 6. The LEDs are then removed from the temporary carrier 30, as described above in reference to Fig. 6.

15 Figs. 17, 18, 19, and 20 illustrate an alternative embodiment. In Fig. 17, LEDs are attached to a temporary carrier 30, which may be a temporary carrier such as those described above in reference to Fig. 2. Before or after attaching the LEDs to the temporary carrier, the tops of the LEDs are covered with a masking layer 44. In some embodiments, the masking layer is applied to the growth substrate of a wafer of LEDs, before singulating the 20 LEDs by cutting the growth substrate. The masking layer 44 may be, for example, photoresist, dielectric material, or any other suitable material. Masking layer 44 may be formed by any suitable technique, including, for example, spin-coating, roller-coating, dip-coating, lamination, spray-coating, evaporation, sputtering, and direct pick and place of a piece part such as a piece of glass. In some embodiments, the masking layer 44 is patterned, for 25 example, by photolithography, shadow masking, and/or wet or dry chemical etching.

In Fig. 18, a reflective coating 46 is disposed over the structure illustrated in Fig. 17. The reflective coating 46 may be any suitable material including, for example, a dichroic mirror, a distributed Bragg reflector (DBR), metallic film, or other suitable dielectric stack. The reflective coating 46 may be formed by any suitable technique including, for 30 example, physical vapor deposition, CVD, sputtering, evaporation, and spray-coating. The reflective coating 46 may substantially conformally coat the structure, as illustrated in Fig. 18, though this is not required.

In Fig. 19, the masking layer 44 and the reflective coating 46 over the tops of the LEDs are removed by any suitable process such as, for example, a lift-off process. After

removing the masking layer 44, reflective coating 46 remains on the sidewalls of the LEDs and the regions between the LEDs.

In Fig. 20, a wavelength converting layer 48 is formed over the structure illustrated in Fig. 19. Wavelength converting layer 48 may be, for example, a wavelength 5 converting material mixed with a transparent material, and may be formed by any suitable technique including, for example, lamination, molding, spray coating, or spin coating. Wavelength converting layer 48 may fill the regions between the LEDs, as illustrated in Fig. 20, or wavelength converting layer 48 may be a substantially conformal layer. The LEDs are then separated by cutting through the structure, for example in regions 38 between 10 neighboring LEDs, as described above in reference to Fig. 6. The LEDs are then removed from the temporary carrier 30, as described above in reference to Fig. 6.

In some embodiments, a lens or other optical element is formed over the finished LED, which may be any of the devices described above. In any of the devices described above, in some embodiments, the sidewalls of the growth substrate may be angled.

Having described the invention in detail, those skilled in the art will appreciate 15 that, given the present disclosure, modifications may be made to the invention without departing from the spirit of the inventive concept described herein. Therefore, it is not intended that the scope of the invention be limited to the specific embodiments illustrated and described.

CLAIMS:

1. A device comprising:

a semiconductor structure comprising a light emitting layer sandwiched between an n-type region and a p-type region;

a growth substrate attached to the semiconductor structure, the growth substrate having at least one angled sidewall; and

a reflective layer disposed on the angled sidewall;

wherein the reflective layer is arranged such that a majority of light extracted from the semiconductor structure and the growth substrate is extracted through a first surface of the growth substrate.

2. The device of claim 1 further comprising a wavelength converting layer disposed over the first surface of the growth substrate.

3. The device of claim 1 wherein the growth substrate has a thickness less than 150 microns.

4. A device comprising:

a semiconductor structure comprising a light emitting layer sandwiched between an n-type region and a p-type region;

a growth substrate attached to the semiconductor structure, the growth substrate having a thickness less than 150 microns; and

a reflective layer disposed on a sidewall of the growth substrate and a sidewall of the semiconductor structure;

wherein the reflective layer is arranged such that a majority of light extracted from the semiconductor structure and the growth substrate is extracted through a first surface of the growth substrate.

5. The device of claim 4 further comprising a wavelength converting layer disposed over the first surface of the growth substrate.

6. The device of claim 5 wherein the wavelength converting layer is formed separately from the semiconductor structure and attached to the growth substrate.

7. The device of claim 6 wherein the reflective layer is disposed on a sidewall of the wavelength converting layer.

8. A method comprising:

attaching a plurality of semiconductor light emitting devices to a carrier;

disposing a reflective material in areas between the semiconductor light emitting devices;

separating two neighboring semiconductor light emitting devices, wherein separating comprises cutting the reflective material; and

after separating two neighboring semiconductor light emitting devices, removing the carrier.

9. The method of claim 8 wherein attaching a plurality of semiconductor light emitting devices to a carrier comprises attaching a growth substrate wafer on which a plurality of semiconductor light emitting devices are formed to a carrier, the method further comprising forming slots in the growth substrate wafer in areas between the semiconductor light emitting devices, wherein disposing a reflective material in areas between the semiconductor light emitting devices comprises disposing a reflective material in the slots.

10. The method of claim 8 further comprising attaching a wavelength converting member to each of the plurality of semiconductor light emitting devices prior to disposing a reflective material in areas between the semiconductor light emitting devices, wherein the wavelength converting member is formed separately from the semiconductor light emitting device.

11. The method of claim 8 further comprising forming a wavelength converting layer over the plurality of semiconductor light emitting devices after disposing a reflective material in areas between the semiconductor light emitting devices.

12. The method of claim 8 wherein attaching a plurality of semiconductor light emitting devices to a carrier comprises attaching a plurality of wavelength converting members to a carrier; and attaching a semiconductor light emitting device to each of the wavelength converting members.

13. The method of claim 8 further comprising disposing a wavelength converting layer on each of the plurality of semiconductor light emitting devices prior to attaching the plurality of semiconductor light emitting devices to a carrier.

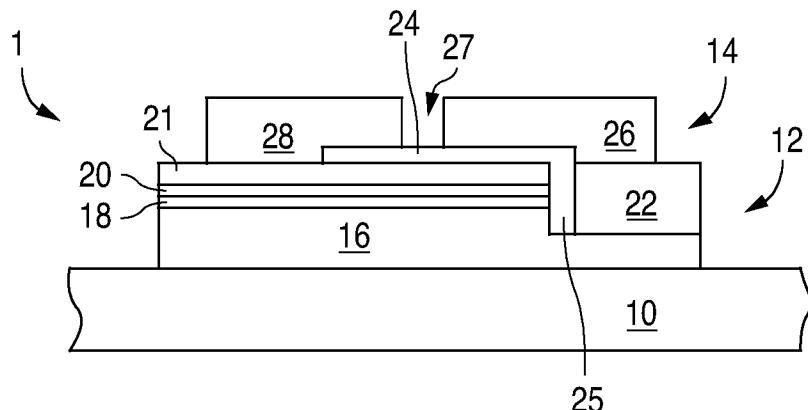
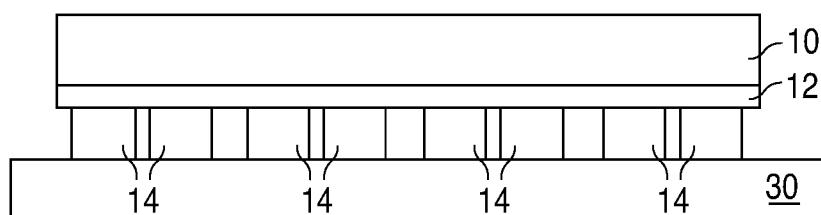
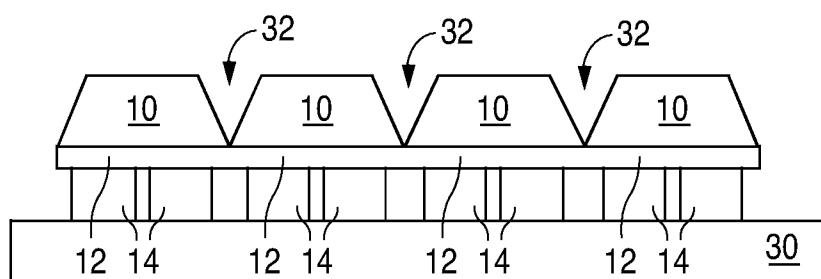
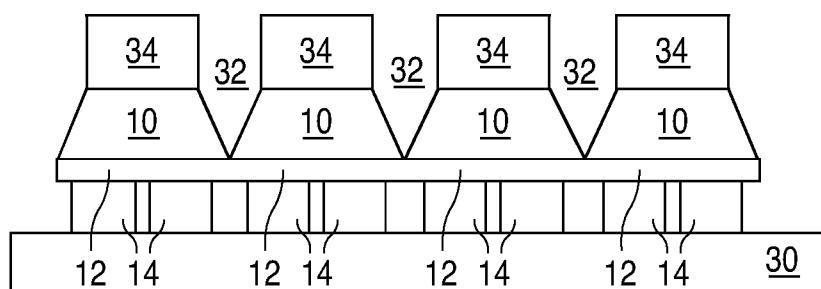
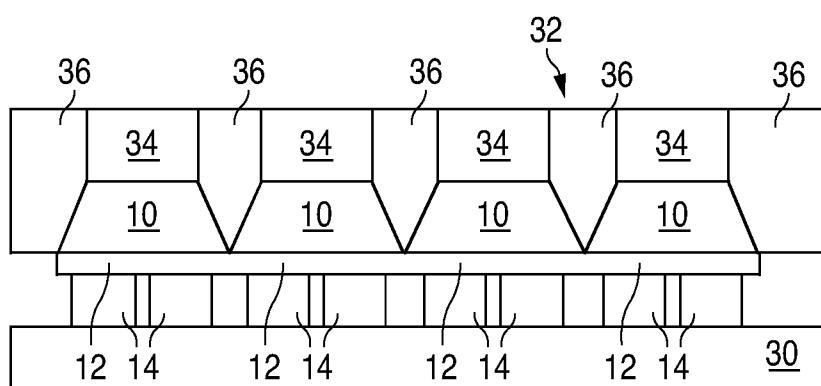
14. The method of claim 8 wherein disposing a reflective material in areas between the semiconductor light emitting devices comprises:

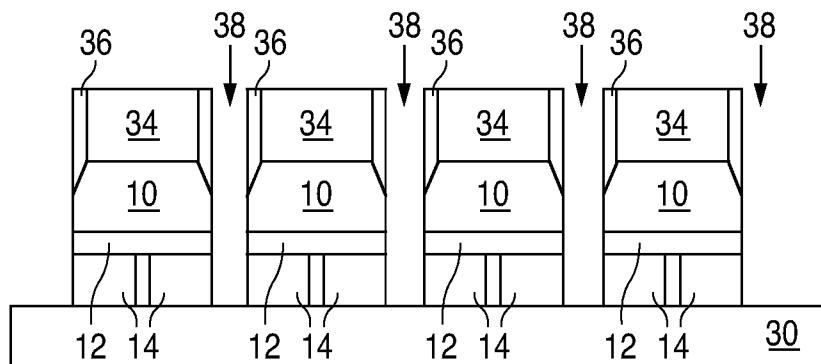
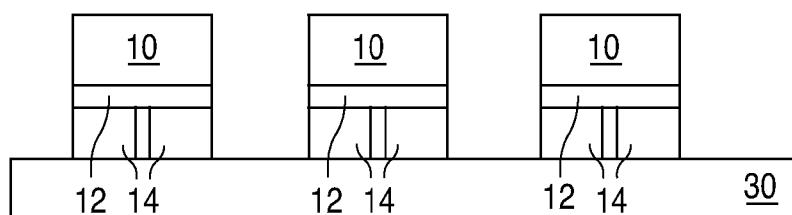
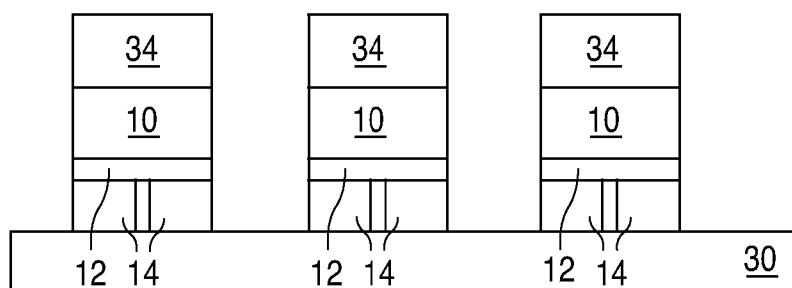
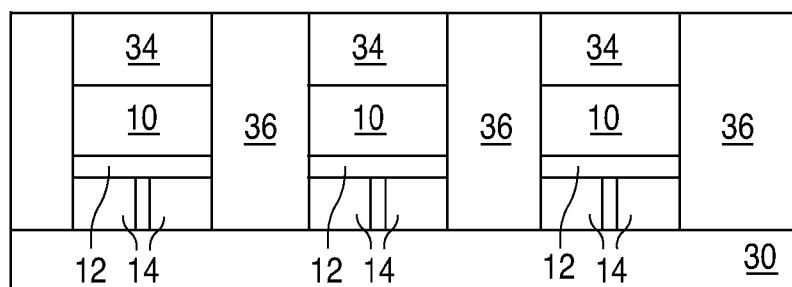
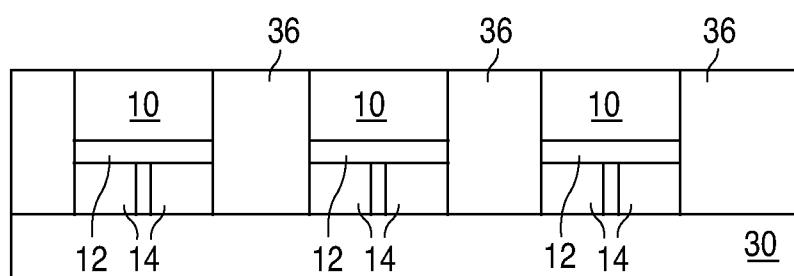
forming a mask layer on first surfaces of the semiconductor light emitting devices;

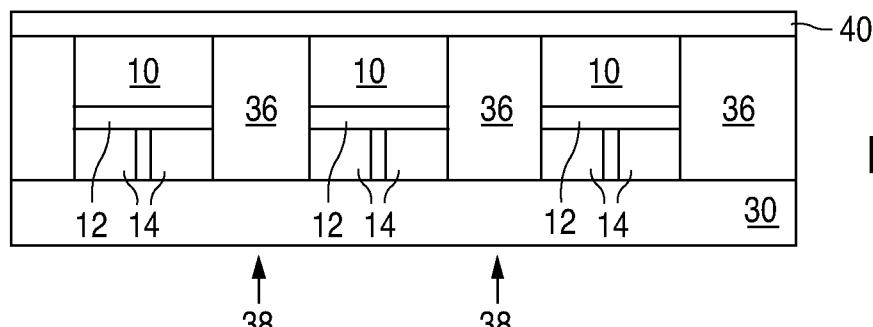
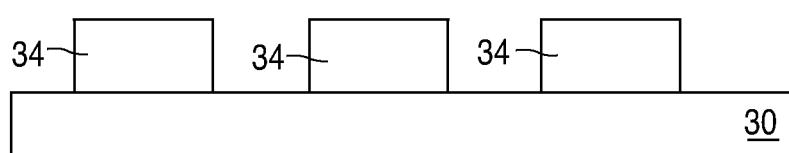
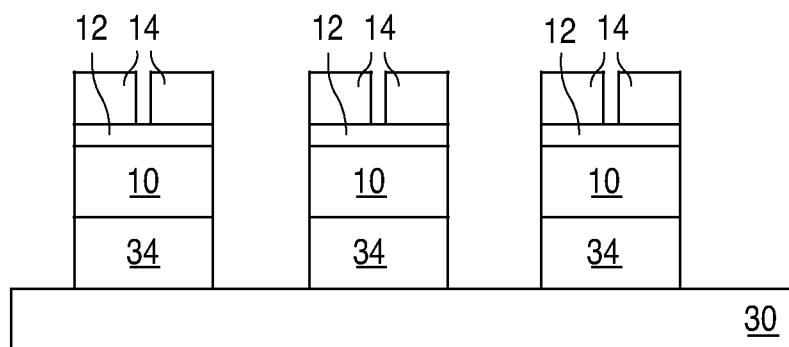
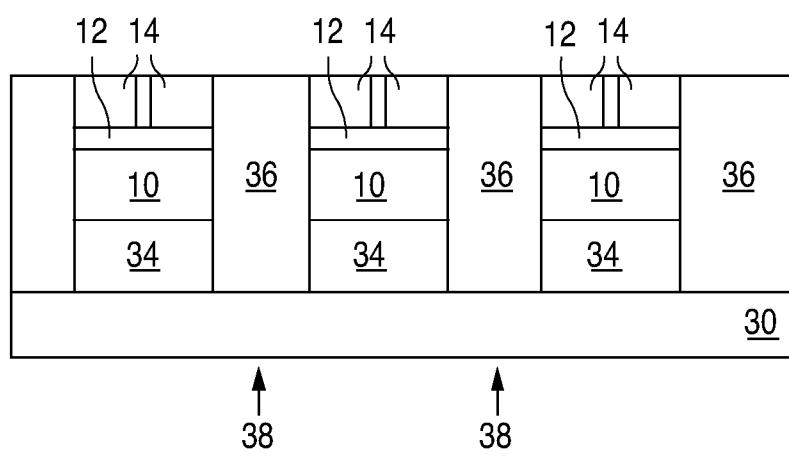
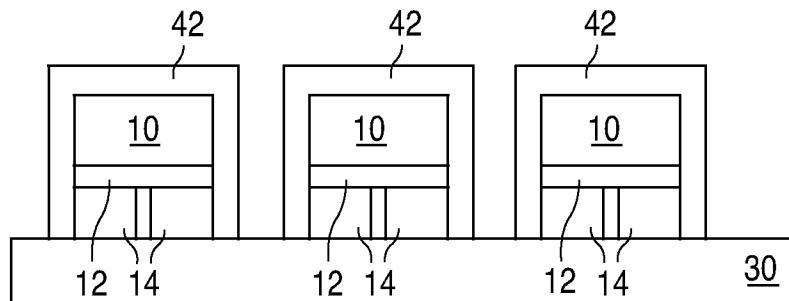
forming a reflective layer over the mask layer and sidewalls of the plurality of semiconductor light emitting devices; and

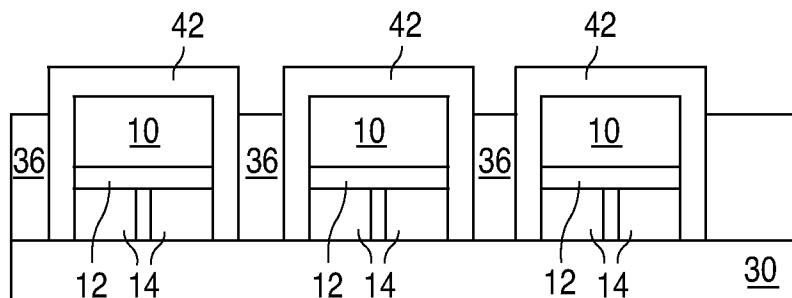
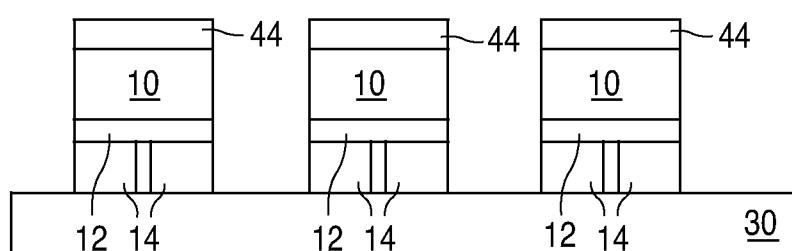
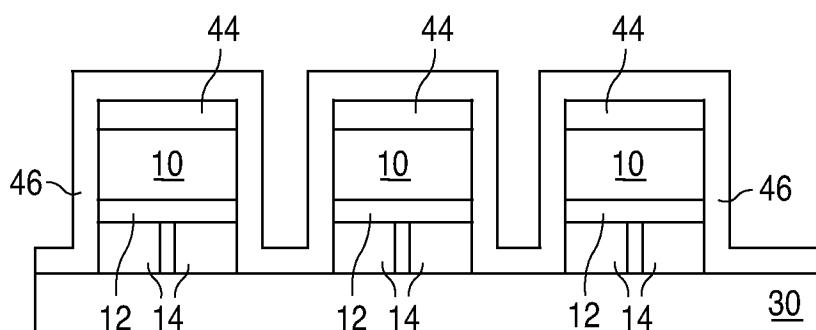
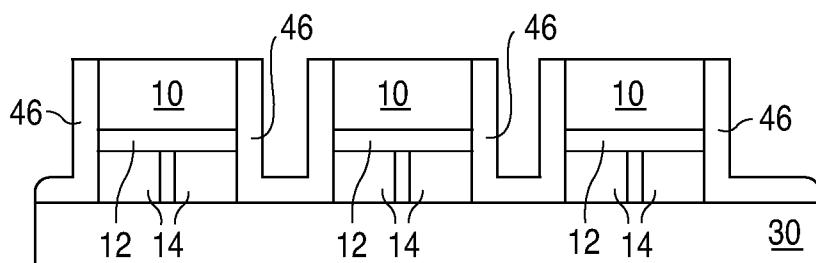
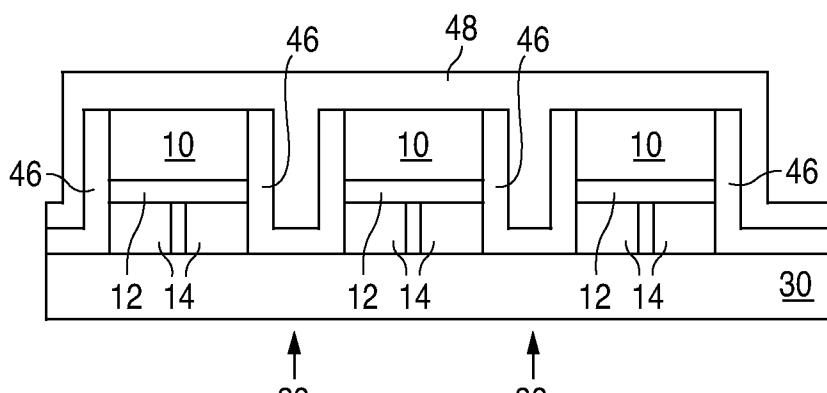
removing the mask layer;

the method further comprising forming a wavelength converting layer over the first surfaces of the semiconductor light emitting devices after removing the mask layer.

**FIG. 1****FIG. 2****FIG. 3****FIG. 4****FIG. 5**

**FIG. 6****FIG. 7****FIG. 8****FIG. 9****FIG. 10**

**FIG. 11****FIG. 12****FIG. 13****FIG. 14****FIG. 15**

**FIG. 16****FIG. 17****FIG. 18****FIG. 19****FIG. 20**