# LIGHT EMITTING DIODES AND METHODS FOR MANUFACTURING LIGHT EMITTING DIODES

## TECHNICAL FIELD

**[0001]** The present disclosure is directed generally to light emitting diodes and methods for manufacturing light emitting diodes.

## BACKGROUND

**[0002]** Light emitting diodes (LEDs) are an efficient source of bright light for computer monitors, televisions, cellphones, digital cameras, and a variety of other electronic devices and applications. White light LEDs can also be used in general lighting, architectural, outdoor, commercial, and/or residential illumination. True white light LEDs, however, are not available because LEDs typically only emit at one particular wavelength. For human eyes to perceive the color white, a mixture of wavelengths is needed.

**[0003]** One conventional technique for emulating white light with LEDs includes depositing a light conversion material (e.g., a phosphor) on a base material (e.g., indium gallium nitride (InGaN)). In operation, the InGaN base material emits a blue light that stimulates the light conversion material to emit a yellow light. Because yellow light stimulates the red and green receptors of a human eye, the resulting mix of blue and yellow light gives the appearance of white to the eye if the base material and light conversion material are matched appropriately. If not matched appropriately, however, the combined emissions appear off white and may reduce color fidelity of electronic devices.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0004]** Figure 1A is a partially schematic illustration of a representative microelectronic workpiece carrying microelectronic devices configured in accordance with embodiments of the technology.

**[0005]** Figure 1B is a schematic illustration of a microelectronic device singulated from the workpiece shown in Figure 1A.

[0006] Figures 2A-6 illustrate various stages of a method for selectively applying light conversion materials onto LEDs in accordance with embodiments of the technology.

[0007] Figure 7 is a partially schematic, top view of a portion of a microelectronic workpiece after selectively applying light conversion materials onto an LED in accordance with another embodiment of the technology.

[0008] Figure 8 is a partially schematic, top view of a portion of a microelectronic workpiece after selectively applying light conversion materials onto an LED in accordance with still another embodiment of the technology.

## DETAILED DESCRIPTION

[0009] Various embodiments of microelectronic workpieces having LEDs formed thereon and methods for manufacturing such LEDs are described below. The term "microelectronic workpiece" is used throughout to include substrates upon which and/or in which microelectronic devices, micromechanical devices, data storage elements, read/write components, and other features are fabricated. Substrates can be, for example, semiconductive pieces (e.g., silicon wafers, gallium arsenide wafers, or other semiconductor wafers), nonconductive pieces (e.g., various ceramic substrates), or conductive pieces. Well-known structures, systems, and methods often associated with such systems have not been shown or described in detail to avoid unnecessarily obscuring the description of the various embodiments of the technology. A person of ordinary skill in the relevant art will accordingly understand that the technology may have additional embodiments and that the technology may be practiced without several of the elements shown and described below with reference to Figures 1A-8.

[0010] Figure 1A is a microelectronic workpiece 100 in the form of a semiconductor wafer 110 that includes multiple microelectronic devices or components 120. At least some of the processes described below may be conducted on the microelectronic workpiece 100 at the wafer level, and other processes may be conducted on the individual microelectronic devices 120 of the microelectronic workpiece 100 after the devices 120 have been singulated from the larger wafer 110. Accordingly, unless otherwise noted, structures and methods described below in the context of a microelectronic workpiece can apply to the wafer 110, the devices 120 that are formed from the wafer 110, and/or an assembly of one or more devices 120 attached to a support member. Figure 1B is a schematic illustration of an individual device 120 after it has been singulated from the wafer 110 shown in Figure 1A. The device 120 can include operable

microelectronic structures, optionally encased within a protective encapsulant. For example, the device 120 can include an InGaN and/or other types of LEDs, transistors, capacitors, color filters, mirrors, and/or other types of electrical/mechanical/optical components. The device 120 can be electrically connected to external structural devices by pins, bond pads, solder balls, redistribution structures, and/or other conductive structures.

**[0011]** Figures 2A-6 illustrate various stages of a method for selectively applying light conversion materials onto LEDs in accordance with embodiments of the technology. As described in greater detail below, one or more light conversion materials or converter materials (e.g., phosphor) can be applied onto discrete areas of each LED on a workpiece or wafer. The term "phosphor" generally refers to a material that can sustain glowing after exposure to energized particles (e.g., electrons and/or photons). The light conversion material(s) can be patterned or selectively applied onto each LED to help compensate for color variances across the wafer. Further, the color(s) of the individual components on the wafer can be precisely tuned or controlled using the methods described herein.

**[0012]** Figure 2A is a partially schematic, top plan view of a portion of a microelectronic workpiece 200 at an initial processing stage before any light conversion material has been applied onto the workpiece 200. Figure 2B is a partially schematic, side cross-sectional view taken substantially along line 2B-2B of Figure 2A. Referring to Figures 2A and 2B together, the microelectronic workpiece 200 includes a semiconductor substrate 202 having a front or active side 204 (Figure 2B) and an LED 210 (e.g., an InGaN LED) formed at the front side 204 (Figure 2B). Although only a single LED 210 is shown, it will be appreciated that the methods described herein with reference to Figures 2A-6 may be performed on multiple devices simultaneously or approximately simultaneously across the workpiece 200.

**[0013]** The workpiece 200 can include several features generally similar to the workpiece 100 described above with reference to Figures 1A and 1B. The substrate 202, for example, can be a semiconductor wafer with a plurality of microelectronic devices or components (e.g., LEDs 210) arranged in a die pattern on the wafer. Individual LEDs 210 also include terminals 212 (e.g., bond pads as shown in Figure 2A) and circuitry (not shown) electrically coupled to the terminals 212. One technique for forming the InGaN LEDs can include sequentially applying N-doped GaN, InGaN, and P-doped GaN materials on a sapphire ($Al_2O_3$) and/or silicon (Si) substrate via epitaxial growth in a metal organic chemical vapor deposition (MOCVD) process. In other embodiments, however, other suitable techniques may be used to form the LED 210.

**[0014]** Light conversion materials can be selectively applied to the LED 210 using a variety of different methods. In the illustrated embodiment, for example, a first mask or reticle 220 is positioned over the LED 210. The first mask 220 includes a plurality of apertures or openings 222 corresponding to a desired pattern for a first light conversion material (not shown—described in detail below with reference to Figures 3A and 3B) on the LED 210. The first mask 220 can be a discrete component spaced apart from an upper surface of the LED 210, or the mask 220 may be composed of a photoresist material or other suitable mask material applied on the upper surface of the LED 210 (as shown in broken lines in Figure 2B) and patterned using photolithography and/or other suitable techniques. The terminals 212 can also be masked off to prevent shorting or contamination during processing.

**[0015]** Referring to Figures 3A and 3B, a first light conversion material or first converter material 224 (e.g., yellow phosphor) is applied in a desired pattern on the LED 210. The first light conversion material 224 can be applied using a screen printing process and/or other suitable methods. As mentioned above, the first mask 220 is configured to exclude certain contact areas such that the first light conversion material 224 is selectively applied onto only desired regions of the LED 210. In the illustrated embodiment, the first light conversion material 224 comprises a plurality of blocks or "islands" arranged in a selected pattern on the LED 210. The individual portions of the first light conversion material 224 are separated from each other by a plurality of first gaps or channels 225. The pattern shown in Figures 3A and 3B is merely representative of one particular pattern for the first light conversion material 224. The first light conversion material 224 can be applied onto the LED 210 in a wide variety of different patterns or arrangements.

**[0016]** The first light conversion material 224 can have a composition that emits at a desired wavelength when stimulated. For example, in one embodiment, the first light conversion material 224 can include a phosphor containing Cerium(III)-doped Yttrium Aluminum Garnet (Ce:YAG or YAG:Ce) at a particular concentration. Such a material can emit a broad range of colors from green to yellow and to red under photoluminescence. In other embodiments, the first light conversion material 224 can include Neodymium-doped YAG, Neodymium-Chromium double-doped YAG, Erbium-doped YAG, Ytterbium-doped YAG, Neodymium-cerium double-doped YAG, Holmium-chromium-thulium triple-doped YAG, Thulium-doped YAG, Chromium(IV)-doped YAG, Dysprosium-doped YAG, Samarium-doped YAG, Terbium-doped YAG, and/or other suitable phosphor compositions. In yet other

embodiments, the first light conversion material 224 can include Europium phosphors (e.g., CaS:Eu, $CaAlSiN_3$:Eu, $Sr_2Si_5N_8$:Eu, SrS:Eu, $Ba_2Si_5N_8$:Eu, $Sr_2SiO_4$:Eu, $SrSi_2N_2O_2$:Eu, $SrGa_2S_4$:Eu, $SrAl_2O_4$:Eu, $Ba_2SiO_4$:Eu, $Sr_4Al_{14}O_{25}$:Eu, $SrSiAl_2O_3N$:Eu, $BaMgAl_{10}O_{17}$:Eu, $Sr_2P_2O_7$:Eu, $BaSO_4$:Eu, and/or $SrB_4O_7$:Eu). The foregoing list of light conversion materials is not exhaustive. The phosphor material may also be mixed in a suitable carrier material (epoxy, silicone, etc.).

**[0017]** As mentioned above, the first light conversion material (and any subsequent light conversion materials) can be selectively applied to the LED 210 using a number of different methods. For example, in another suitable method for selectively applying the first light conversion material 224 on the LED 210, a phosphor material (e.g., Ce:YAG) is mixed with a photosensitive material (e.g., PVA and ammonium dichromate) and a layer of the composition is applied onto the LED 210. A photolithographic procedure can be used to selectively expose portions of the composition such that the exposed portions are "fixed" at desired locations on the LED 210 to form the first light conversion material 224. This apply/expose/develop process can be repeated any number of times to selectively apply additional light conversion materials onto the LED 210.

**[0018]** Still another suitable technique for selectively applying the first light conversion material 224 comprises spinning a photoresist material onto the LED 210 and patterning the material to form openings over desired areas or regions of the LED 210. The first light conversion material 224 can be applied into the openings and onto the LED 210 using electrophoresis or another suitable process. After applying the first light conversion material 224, the photoresist can be removed. In an alternative embodiment, rather than using a photosensitive material, some other suitable material may be applied onto the LED 210 and the openings can be selectively formed using excimer laser ablation or another suitable process. In yet other embodiments, other suitable techniques may be used to selectively apply the first light conversion material 224 (and any subsequent light conversion materials) onto the LED 210.

**[0019]** Referring to Figures 4A and 4B, a second mask or reticle 230 is positioned over the LED 210. The second mask 230 includes a plurality of apertures or openings 232 corresponding to a desired pattern for a second light conversion material (not shown—described in detail below with reference to Figures 5A and 5B) on the LED 210. As with the first mask 220, the second mask 230 can be a discrete component spaced apart from an upper surface of the LED 210, or the second mask 230 may be composed of a photoresist material or other suitable

mask material applied on the upper surface of the LED 210 and patterned using photolithography and/or other suitable techniques.

**[0020]** Referring next to Figures 5A and 5B, a second light conversion material 234 (e.g., red phosphor) is selectively applied in a desired pattern on the LED 210. In the illustrated embodiment, for example, the second light conversion material 234 comprises a plurality of blocks or "islands" arranged in a selected pattern on the LED 210 in which the second light conversion material 234 may or may not contact adjacent portions of the first light conversion material 224. The individual portions of the second light conversion material 234, for example, can be separated from each other and the first light conversion material 224 by a plurality of second gaps or channels 235. The pattern shown in Figures 5A and 5B is merely representative of one particular pattern for the second light conversion material 234. The second light conversion material 234 can be applied onto the LED 210 in a wide variety of different patterns or arrangements.

**[0021]** The second light conversion material 234 can be composed of materials similar to those of the first light conversion material (e.g., Ce:YAG, etc.) described above with reference to Figures 3A and 3B. In addition, the second light conversion material 234 may be applied onto the LED 210 using processes similar to those used to apply the first light conversion material 224 described above with reference to Figures 3A and 3B. In other embodiments, however, the second light conversional material 234 may be composed of different materials and/or may be applied onto the LED 210 using different techniques.

**[0022]** Figure 6 is a partially schematic, top plan view of the workpiece 200 after the first and second light conversion materials 224 and 234 have been selectively applied on desired portions of the LED 210 and the second mask 230 (Figures 5A and 5B) has been removed. The LED 210 includes a plurality of uncoated or uncovered portions 240 that do not contain any light conversion materials and allow blue light to pass through. The LED 210 is accordingly configured to produce a desired color of light based on the arrangement of and contributions from the uncoated portions 240, the portions of first light conversion material 224, and the portions of second light conversion material 234. It will be appreciated that the selection of particular compositions for the first and second light conversion materials 224 and 234 and the precise placement of the first and second light conversion materials 224 and 234 on the LED 210 allow the LED 210 to produce any desired color of light (e.g., white light). Moreover, although only two light conversion materials are described herein, in other embodiments only a

single light conversion material or more than two light conversion materials may be applied onto the LED 210.

**[0023]** As mentioned previously, although only a single LED 210 is shown above with reference to Figures 2A-6, the methods described herein may be performed simultaneously or approximately simultaneously on multiple LEDs 210 across the workpiece 200. In one embodiment, for example, each LED 210 on the workpiece 200 may be processed using an identical or generally identical pattern of light conversion materials. In other embodiments, however, the pattern of light conversion material(s) on the individual LEDs 210 may vary across the workpiece 200. For example, one challenge of manufacturing microelectronic devices at the wafer level is accounting for variances in the individual microelectronic devices. It has been recognized, for example, that processing variances in epitaxial growth, chemical-mechanical polishing, wet etching, and/or other operations during formation of the microelectronic devices on the same microelectronic workpiece may cause the LEDs in one region of the workpiece 200 to emit light at different wavelengths than another region. As a result, if each LED across the workpiece 200 includes the same pattern of selectively applied light conversion materials, the emission from at least some of the LEDs may be inconsistent or off white (e.g., tinted to red, blue, and/or green). Embodiments of the methods described above with reference to Figures 2A-6 can address the foregoing emission variations in the LEDs across the workpiece 200 by specifically tailoring the composition of and/or arrangement of the first and second light conversion materials 224 and 234 for individual LEDs 210.

**[0024]** In other embodiments, however, rather than customizing the pattern for each LED 210, a pattern of selectively applied light conversion materials can be used for multiple LEDs in a particular region on the workpiece 200. For example, an operator may measure the emission characteristics of selected LEDs 210 on the workpiece 200 as representative for a region of individual LEDs 210. In further embodiments, measured emission characteristics may be averaged, filtered, and/or otherwise manipulated to derive a value as representative for a region of the individual LEDs 210. In still other embodiments, workpieces to be processed may be sorted beforehand so that a first batch of workpieces having similar emission characteristics can be processed together using a first selected pattern of light conversion materials for device on the individual workpieces, a second batch of workpieces can be processed together using a second pattern of light conversion materials for devices on the individual workpieces, and so on.

**[0025]** Figures 7 and 8 illustrate two additional embodiments of methods for selectively applying light conversion materials onto microelectronic workpieces as described above with respect to Figures 2A-6. In each of Figures 7 and 8, several of the features may be the same as those discussed above in connection with the workpiece 200 of Figures 2A-6. Accordingly, like reference numbers refer to like components in Figure 2A-6 and Figures 7 and 8.

**[0026]** Figure 7, for example, is a partially schematic, top plan view of a workpiece 300 having light conversion materials applied on the LED 210 in accordance with another embodiment of the technology. More specifically, the workpiece 300 differs from the workpiece 200 shown in Figures 2A-6 in that a first light conversion material 324 and a second light conversion material 334 have been selectively applied onto the LED 210 in a different pattern than the first and second light conversion materials 224 and 234 of Figure 6. In this embodiment, for example, the first light conversion material 324 includes a plurality of generally concentric circles across the LED 210. Other shapes, e.g., triangular, hexagonal, etc., are also contemplated. The individual circular portions of the first light conversion material 324 are separated by channels or gaps 325. A portion of these channels or gaps 325 comprise uncoated regions 340 that allow blue light from the LED 210 to pass through.

**[0027]** Figure 8 is a partially schematic, top plan view of a workpiece 400 having light conversion materials applied onto the LED 210 in accordance with still another embodiment of the technology. The workpiece 400 differs from the workpieces 200 and 300 described above with reference to Figures 2A-7 in that a first light conversion material 424 has been applied onto the LED 210 in a plurality of individual rectilinear portions across the LED 210. The individual rectilinear portions of the first light conversion material 424 are separated by channels or gaps 425. Individual portions of a second light conversion material 434 are applied onto the LED 210 in a pattern generally corresponding to the arrangement of the rectilinear portions of the first light conversion materials 424. In still other embodiments, portions of the first and/or second light conversion materials can be selectively applied onto the LED 210 in other shapes (e.g., polygonal) or suitable patterns.

**[0028]** From the foregoing, it will be appreciated that specific embodiments of the technology have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the technology. For example, structures and/or processes described in the context of particular embodiments may be combined or eliminated in other embodiments. In particular, the arrangement of the first and/or

second light conversion materials described above with reference to particular embodiments can include one or more additional light conversion materials selectively applied onto selected LEDs across the wafer, or one or more of the light conversion materials described above can be omitted. Moreover, while advantages associated with certain embodiments of the technology have been described in the context of these embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages to fall within the scope of the technology. Accordingly, embodiments of the technology are not limited except as by the appended claims

CLAIMS

I/We claim:

1. A method for manufacturing a light emitting diode (LED), the method comprising:

applying a first light conversion material to a first region on the LED; and

applying a second light conversion material to a second, different region on the LED, wherein the first light conversion material is spaced apart from the second light conversion material by a gap, and wherein at least a portion of the LED is accessible in the gap after applying the first and second light conversion materials,

wherein during operation of the LED, at least a portion of a light emitted by the LED passes through the gap.

2. The method of claim 1 wherein the LED is one of a plurality of LEDs on a workpiece, and wherein the method further comprises:

applying the first light conversion material to the first region on multiple LEDs on the workpiece; and

applying the second light conversion material to the second region on multiple LEDs on the workpiece.

3. The method of claim 2 wherein:

the first light conversion material is applied to two or more LEDs on the workpiece simultaneously or approximately simultaneously; and

the second light conversion material is applied to two or more LEDs on the workpiece simultaneously or approximately simultaneously.

4. The method of claim 2 wherein each LED on the workpiece includes the same arrangement of first and second light conversion materials.

5. The method of claim 2 wherein each LED on the workpiece includes a different arrangement of first and second light conversion materials.

6. The method of claim 2 wherein the workpiece includes a first set of LEDs having a first emission characteristic and a second set of LEDs having a second emission characteristic different than the first emission characteristic, and wherein:

the first and second light conversion materials have a first arrangement relative to each other on each LED in the first set of LEDs; and

the first and second light conversion materials have a second arrangement relative to each other on each LED in the second set of LEDs, and wherein the second arrangement is different than the first arrangement.

7. The method of claim 1 applying a second light conversion material to a second, different region on the LED comprising applying the second light conversion material such that the first light conversion material is spaced apart from the second light conversion material.

8. The method of claim 1 wherein:

applying the first light conversion material to the first region comprises applying the first light conversion material in a plurality of individual first rectilinear blocks on the LED with first gaps separating the individual first blocks from each other; and

applying the second light conversion material to the second region comprises applying the second light conversion material in a plurality of individual second rectilinear blocks on the LED with second gaps separating the individual second blocks from each other and from the first blocks.

9. The method of claim 1, further comprising:

selecting the first light conversion material before applying the first light conversion material, wherein selecting the first light conversion material comprises selecting at least one of a composition, a concentration, and a quantity of a first phosphor such that the first phosphor has a desired first emission wavelength; and

selecting the second light conversion material before applying the second light conversion material, wherein selecting the second light conversion material comprises selecting at least one of a composition, a concentration, and a quantity

of a second phosphor such that the second phosphor has a desired second emission wavelength.

10. The method of claim 1 wherein:

the first light conversion material comprises a yellow or yellowish phosphor, and

the second light conversion material comprises a red phosphor.

11. The method of claim 1 wherein applying the first light conversion material and applying the second light conversion material comprises screen printing the first and second light conversion materials onto the LED.

12. The method of claim 1 wherein:

applying the first light conversion material comprises applying the first light conversion material using a first photolithographic process; and

applying the second light conversion material comprises applying the second light conversion material using a second photolithographic process.

13. The method of claim 1 wherein the first light conversion material comprises a first phosphor and the second light conversion material comprises a second phosphor, and wherein:

applying the first light conversion material comprises–

applying and patterning a first photoresist material on the LED; and

depositing the first phosphor into openings in the first photoresist material using electrophoresis; and

applying the second light conversion material comprises–

removing the first photoresist material;

applying and patterning a second photoresist material on the LED;

depositing the second phosphor into openings in the second photoresist material using electrophoresis; and

removing the second photoresist material.

14. The method of claim 1 wherein the LED is one of a plurality of LEDs on a workpiece, and wherein the method further comprises measuring an emission characteristic of a plurality of LEDs on the workpiece before applying the first light conversion material.

15. The method of claim 1, further comprising selecting a first pattern for the first light conversion material on the LED and a second pattern for the second light conversion material on the LED based, at least in part, on a measured emission characteristic of the LED such that a combined emission from the LED and the first and second light conversion materials at least approximates a white light.

16. The method of claim 1, further comprising selecting a composition for the first light conversion material and a composition for the second light conversion material based, at least in part, on a measured emission characteristic of the LED such that a combined emission from the LED and the first and second light conversion materials at least approximates a white light.

17. The method of claim 1 wherein at least a portion of the light emitted by the LED does not pass through any intervening light conversion materials disposed on the LED.