Sealed Device Comprising Quantum Dots and Methods for Making the Same

Abstract: Disclosed herein are sealed devices comprising an array of cavities containing at least one quantum dot and at least one LED in contact with each other. The sealed devices can comprise first and second substrates sealed together to form the cavities, the seal extending around one or more cavities. Backlights, display devices, luminaires, and solid-state lighting devices comprising such sealed devices are also disclosed herein, as well as methods for making such sealed devices.
SEALED DEVICE COMPRISING QUANTUM DOTS
AND METHODS FOR MAKING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/185118 filed on June 26, 2015, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The disclosure relates generally to sealed devices comprising quantum dots and display devices comprising such sealed devices, and more particularly to devices having sealed cavities comprising quantum dots in contact with LED components.

BACKGROUND

[0003] Liquid crystal displays (LCDs) are commonly used in various electronics, such as cell phones, laptops, electronic tablets, televisions, and computer monitors. Conventional LCD backlights typically comprise a light emitting diode (LED) and a phosphor color converter, such as an yttrium aluminum garnet (YAG) phosphor. However, such LCDs can be limited, as compared to other display devices, in terms of brightness, contrast ratio, efficiency, and/or viewing angle. For instance, to compete with organic light emitting diode (OLED) technology, there is a demand for higher contrast ratio, color gamut, and brightness in conventional LCDs while also balancing product cost and power requirements, e.g., in the case of handheld devices.

[0004] Quantum dots have emerged as an alternative to phosphors and can, in some instances, provide improved precision and/or narrower emission lines, which can improve LCD color gamut. LCD displays utilizing quantum dots as color converters can comprise, for example, a glass tube, capillary, or sheet containing quantum dots, e.g., a quantum dot enhancement film (QDEF), which can be placed between the LCD panel and the light guide. Such films or devices can be filled with quantum dots, such as green and red emitting quantum dots, and can be sealed at both ends and/or around the periphery. However, such sealed devices can result in
significant material waste and/or can be complex to produce. These devices may also lack a good path for dissipating heat generated by color conversion.

[0005] LEDs used in backlights comprising phosphor color-converting elements often employ a conformal coating in which the phosphor is suspended in silicone and placed in contact with the LED die. In such configurations, heat can escape out of the LED package via the LED die itself. However, quantum dots are more temperature sensitive than phosphors and, to date, backlights using quantum dot material avoid direct contact between the quantum dot material and the LED die for this reason. In the case of quantum dots in sealed capillaries or sheets, a heat escape path via the LED die is not available because the quantum dots are not in contact with the LED die. Such sealed packages of quantum dots may thus complicate heat extraction and/or dissipation such that the heat generated by the quantum dots can limit the brightness of the backlight.

[0006] Accordingly, it would be advantageous to provide sealed devices for displays which can reduce material waste, thereby lowering the cost of such devices, and/or which can more efficiently dissipate heat generated by the quantum dots.

SUMMARY

[0007] The disclosure relates, in various embodiments, to sealed devices comprising a first substrate having a first surface, the first surface comprising an array of cavities; a second substrate; and at least one seal between the first substrate and the second substrate, the seal extending around at least one cavity in the array of cavities, wherein the at least one cavity comprises at least one quantum dot in contact with at least one LED component. Backlights and display devices comprising such sealed devices are also disclosed herein. Sealed lighting devices are also disclosed herein, the devices comprising a first substrate having a first surface comprising at least one cavity; a second substrate; and at least one seal between the first and second substrates, wherein the at least one cavity comprises at least one quantum dot in contact with at least one LED component.

[0008] In certain embodiments, at least one of the first or second substrates can be chosen from glass and alumina substrates. For example, the first substrate can comprise a glass substrate or an alumina substrate and the second substrate can comprise a glass substrate, optionally with a metallized pattern. The seal between the first substrate and the second substrate can comprise a laser weld
or laser frit seal. The sealed device can, in some embodiments, further comprise at least one heat sink.

[0009] Methods for making such sealed devices are also disclosed, the methods comprising placing at least one quantum dot in at least one cavity in an array of cavities on a first surface of a first substrate; contacting the at least one quantum dot with at least one LED component; bringing a second surface of a second substrate into contact with the first surface of the first substrate; and forming a seal between the first substrate and the second substrate, the seal extending around at least one cavity containing at least one quantum dot in contact with at least one LED component.

[0010] According to various embodiments, contacting the at least one quantum dot with the at least one LED can comprise, e.g., aligning the at least one cavity on the first surface of the first substrate with at least one LED component on a second surface of the second substrate and bringing the first and second surfaces into contact. Contacting the at least one quantum dot with the at least one LED can also comprise, for instance, introducing the at least one quantum dot into a cavity comprising an LED component, e.g., a cavity comprising a metallized via in contact with and/or attached to the LED component.

[0011] Additional features and advantages of the disclosure will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the methods as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0012] It is to be understood that both the foregoing general description and the following detailed description present various embodiments of the disclosure, and are intended to provide an overview or framework for understanding the nature and character of the claims. The accompanying drawings are included to provide a further understanding of the disclosure, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure and, together with the description, serve to explain the principles and operations of the disclosure.
BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The following detailed description can be further understood when read in conjunction with the following drawings in which, where possible, like numerals are used to refer to like elements, and:

[0014] FIG. 1 illustrates a cross-sectional view of a sealed device according to various embodiments of the disclosure;

[0015] FIG. 2 illustrates a cross-sectional view of a sealed device according to additional embodiments of the disclosure;

[0016] FIG. 3 illustrates a cross-sectional view of a sealed device according to further embodiments of the disclosure;

[0017] FIGS. 4A-C illustrate various stages of a method for making a sealed device according to embodiments of the disclosure;

[0018] FIGS. 5A-F illustrate various stages of a method for making a sealed device according to further embodiments of the disclosure; and

[0019] FIGS. 6A-B illustrate front and back exploded views of a sealed device according to various embodiments of the disclosure.

DETAILED DESCRIPTION

[0020] Various embodiments of the disclosure will be discussed with reference to FIGS. 1-6, which illustrate exemplary sealed devices and methods for making sealed devices. The following general description is intended to provide an overview of the claimed devices and methods, and various aspects will be more specifically discussed throughout the disclosure with reference to the non-limiting embodiments, these embodiments being interchangeable with one another within the context of the disclosure.

Devices

[0021] Disclosed herein are sealed devices comprising a first substrate having a first surface, the first surface comprising an array of cavities; a second substrate; and at least one seal between the first substrate and the second substrate, the seal extending around at least one cavity in the array of cavities, wherein the at least one cavity comprises at least one quantum dot in contact with at least one LED component. Backlights and display devices comprising such sealed devices are also disclosed herein.
[0022] A cross-sectional view of a first embodiment of a sealed device 100 is illustrated in FIG. 1. The sealed device 100 comprises a first substrate 101 comprising an array of cavities 105, and a second substrate 103. The at least one cavity 105 can contain at least one quantum dot 107. The at least one cavity can also contain at least one LED component, e.g., die 109, in contact with the at least one quantum dot 107. As used herein the term “contact” is intended to denote direct physical contact or interaction between two listed elements, e.g., the quantum dot and LED component are able to physically interact with one another within the cavity. By way of comparison, quantum dots in separate sealed capillaries or sheets, e.g., QDEFs, are not able to directly interact with the LED die.

[0023] According to various embodiments, the first and/or second substrates 101, 103, can be glass substrates. The first and second glass substrates may comprise any glass known in the art for use in a backlit display, such as an LCD, including, but not limited to, soda-lime silicate, aluminosilicate, alkali-alumino-silicate, borosilicate, alkali-borosilicate, aluminoborosilicate, alkali-aluminoborosilicate, and other suitable glasses. These substrates may, in various embodiments, be chemically strengthened and/or thermally tempered. Non-limiting examples of suitable commercially available substrates include EAGLE XG®, Lotus™, Iris™, Willow®, and Gorilla® glasses from Corning Incorporated, to name a few. Glasses that have been chemically strengthened by ion exchange may be suitable as substrates according to some non-limiting embodiments.

[0024] During the ion exchange process, ions within a glass sheet at or near the surface of the glass sheet may be exchanged for larger metal ions, for example, from a salt bath. The incorporation of the larger ions into the glass can strengthen the sheet by creating a compressive stress in a near surface region. A corresponding tensile stress can be induced within a central region of the glass sheet to balance the compressive stress.

[0025] Ion exchange may be carried out, for example, by immersing the glass in a molten salt bath for a predetermined period of time. Exemplary salt baths include, but are not limited to, KNO₃, LiNO₃, NaNO₃, RbNO₃, and combinations thereof. The temperature of the molten salt bath and treatment time period can vary. It is within the ability of one skilled in the art to determine the time and temperature according to the desired application. By way of a non-limiting example, the temperature of the molten salt bath may range from about 400°C to about 800°C,
such as from about 400°C to about 500°C, and the predetermined time period may range from about 4 to about 24 hours, such as from about 4 hours to about 10 hours, although other temperature and time combinations are envisioned. By way of a non-limiting example, the glass can be submerged in a KNO₃ bath, for example, at about 450°C for about 6 hours to obtain a K-enriched layer which imparts a surface compressive stress.

[0026] According to various embodiments, the first and/or second glass substrates may have a compressive stress greater than about 100 MPa and a depth of layer of compressive stress (DOL) greater than about 10 microns. In further embodiments, the first and/or second glass substrates may have a compressive stress greater than about 500 MPa and a DOL greater than about 20 microns, or a compressive stress greater than about 700 MPa and a DOL greater than about 40 microns. In non-limiting embodiments, the first and/or second substrates can have a thickness of less than or equal to about 3 mm, for example, ranging from about 0.1 mm to about 2.5 mm, from about 0.3 mm to about 2 mm, from about 0.5 mm to about 1.5 mm, or from about 0.7 mm to about 1 mm, including all ranges and subranges therebetween.

[0027] The first and/or second substrate can, in various embodiments, be transparent or substantially transparent. As used herein, the term “transparent” is intended to denote that the substrate, at a thickness of approximately 1 mm, has a transmission of greater than about 80% in the visible region of the spectrum (420-700 nm). For instance, an exemplary transparent substrate may have greater than about 85% transmittance in the visible light range, such as greater than about 90%, or greater than about 95%, including all ranges and subranges therebetween. In certain embodiments, an exemplary glass substrate may have a transmittance of greater than about 50% in the ultraviolet (UV) region (200-410 nm), such as greater than about 55%, greater than about 60%, greater than about 65%, greater than about 70%, greater than about 75%, greater than about 80%, greater than about 85%, greater than about 90%, greater than about 95%, or greater than about 99% transmittance, including all ranges and subranges therebetween.

[0028] According to various embodiments, e.g., in the case of transparent first and/or second substrates, at least a portion of the first and/or second transparent substrate may be painted, for instance, in one or more regions surrounding the cavity. The substrates can be painted, in some embodiments, with
white or otherwise reflective ink around one or more cavities such that when in use in a display device, light may propagate only through the cavity portions of the sealed device (e.g., the portions comprising quantum dots) and reflect off the surrounding painted areas. In certain embodiments, the first surface of the first substrate may be painted around the cavity openings prior to sealing with the second substrate. Alternatively, a reflective film can be positioned on the first surface, such as in between the first and second substrates or, in the case of a multi-layer first substrate (discussed in more detail below), the reflective film can also be positioned between two layers of the first substrate. Reflective films can include any metal disclosed herein, such as aluminum, copper, gold, and silver, to name a few.

[0029] While FIG. 1 depicts the cavities 105 as having a substantially rounded and concave cross-section, it is to be understood that the cavities can have any given shape or size, as desired for a given application. For example, the cavities can have a square, rectangular, semi-circular, or semi-elliptical cross-section, or an irregular cross-section, to name a few. Moreover, while the cavities 105 are depicted as spaced apart in a substantially even fashion, it is to be understood that the spacing between the cavities can be irregular or in any pattern which can be chosen to match any desired LED array pattern or circuitry pattern on a printed circuit board (PCB).

[0030] For example, a typical LED array for a backlit device can have a length and/or width ranging from about 5 mm to about 100 mm, such as from about 10 mm to about 90 mm, from about 15 mm to about 80 mm; from about 20 mm to about 75 mm, from about 25 mm to about 70 mm, from about 30 mm to about 65 mm, from about 35 mm to about 60 mm, from about 40 mm to about 55 mm, or from about 45 mm to about 50 mm, including all ranges and subranges therebetween. The LEDs can be spaced apart by a distance ranging from about 1 mm to about 20 mm, such as from about 2 mm to about 15 mm, from about 3 mm to about 12 mm, from about 4 mm to about 10 mm, from about 5 mm to about 8 mm, or from about 6 mm to about 7 mm, including all ranges and subranges therebetween. Of course, the size and spacing of the LED array can vary depending, e.g., on the brightness and/or total power of the display. Accordingly, the size and spacing of the cavities can likewise vary to produce any LED array with the desired size and/or spacing.
[0031] The cavities 105 on the first surface 111 of the first substrate 101 can have any given depth, which can be chosen as appropriate, e.g., for the type and/or amount of quantum dot to be placed in the cavities. By way of non-limiting embodiment, the cavities on the first surface can extend to a depth of less than about 1 mm, such as less than about 0.5 mm, less than about 0.4 mm, less than about 0.3 mm, less than about 0.2 mm, less than about 0.1 mm, less than about 0.05 mm, less than about 0.02 mm, or less than about 0.01 mm, including all ranges and subranges therebetween, such as ranging from about 0.01 mm to about 1 mm. It is envisioned that the array of cavities can comprise cavities having the same or different depths, the same or different shapes, and/or the same or different sizes.

[0032] At least one cavity 105 in the array of cavities can comprise at least one quantum dot. Quantum dots can have varying shapes and/or sizes depending on the desired wavelength of emitted light. For example, the frequency of emitted light may increase as the size of the quantum dot decreases, e.g., the color of the emitted light can shift from red to blue as the size of the quantum dot decreases. When irradiated with blue, UV, or near-UV light, a quantum dot may convert the light into longer red, yellow, green, or blue wavelengths. According to various embodiments, the quantum dot can be chosen from red and green quantum dots, emitting in the red and green wavelengths when irradiated with blue, UV, or near-UV light. For instance, the LED component can emit blue light (approximately 420-490 nm), UV light (approximately 200-410 nm), or near-UV light (approximately 300-410 nm).

[0033] A first surface 111 of the first substrate 101 and a second surface 113 of the second substrate 103 can be joined by a seal or weld 115. The seal 115 can extend around at least one of the cavities 105, thereby separating the at least one cavity from the other cavities and creating one or more discrete sealed regions or pockets. According to various embodiments, the seal or weld 115 can have a width ranging from about 1 micron to about 100 microns, such as from about 5 microns to about 90 microns, from about 10 microns to about 80 microns, from about 20 microns to about 70 microns, from about 30 microns to about 60 microns, or from about 40 microns to about 50 microns, including all ranges and subranges therebetween. For instance, a laser frit seal can have a width ranging from about 5 microns to about 20 microns, such as from about 10 microns to about 15 microns, and a laser weld can have a width of less than about 5 microns, such as from about
0.1 microns to about 3 microns, from about 0.5 microns to about 2 microns, or from about 1 micron to about 1.5 microns, including all ranges and subranges therebetween.

[0034] The seal 115 can be directly formed, in some embodiments, between the first surface 111 and the second surface 113. For instance, the first and second surfaces can be brought into contact to create a sealing interface (not labeled). A laser beam operating at a given wavelength can then be directed at the sealing interface, e.g., onto the sealing interface, below the sealing interface, or above the sealing interface, to form a seal between the two substrates. Exemplary laser sealing methods are described in co-pending U.S. Application No. 14/271,797 filed May 7, 2014, the entirety of which is incorporated herein by reference.

[0035] In various non-limiting embodiments, the device can comprise a sealing material or layer disposed between and connecting the first and second substrates (not illustrated). In these embodiments, the sealing material or layer can contact the first surface of the first substrate and a second surface of the second substrate. The sealing layer can be chosen, for example, from glass compositions having an absorption of greater than about 10% at the laser’s operating wavelength and/or a relatively low glass transition temperature ($T_g$). The glass compositions can include, for instance, glass frits, glass powders, and/or glass pastes. According to various embodiments, the sealing layer can be chosen from borate glasses, phosphate glasses tellurite glasses, and chalcogenide glasses, for instance, tin phosphates, tin fluorophosphates, and tin fluoro borates. Suitable sealing glasses are disclosed, for instance, in U.S. Patent Application Publication No. 2014/0151742, which is incorporated herein by reference in its entirety.

[0036] In general, suitable sealing layer materials can include low $T_g$ glasses and suitably reactive oxides of copper or tin. By way of non-limiting example, the sealing layer can comprise a glass with a $T_g$ of less than or equal to about 400°C, such as less than or equal to about 350°C, about 300°C, about 250°C, or about 200°C, including all ranges and subranges therebetween, such as ranging from about 200°C to about 400°C. The glass can have, in various embodiments, an absorption at the laser’s operating wavelength (at room temperature) of greater than about 10%, greater than about 15%, greater than about 20%, greater than about 25%, greater than about 30%, greater than about 35%, greater than about 40%, greater than about 45%, or greater than about 50%, including all ranges and
subranges therebetween, such as from about 10% to about 50%. The thickness of
the sealing layer can vary depending on the application and, in certain embodiments,
can range from about 0.1 microns to about 10 microns, such as less than about 5
microns, less than about 3 microns, less than about 2 microns, less than about 1
micron, less than about 0.5 microns, or less than about 0.2 microns, including all
ranges and subranges therebetween.

[0037] When the device comprises a sealing layer, the seal can be formed
between the first and second substrates by way of the sealing layer. For instance, a
laser beam operating at a given wavelength can be directed at the sealing layer (or
sealing interface) to form a seal or weld between the two substrates. Without
wishing to be bound by theory, it is believed that absorption of light from the laser
beam by the sealing layer and induced transient absorption by the first and/or
second substrates can cause localized heating and melting of both the sealing layer
and the substrates. In some embodiments the first and second substrates can be
glass substrates, thus forming a glass-to-glass weld between the two substrates.
Exemplary glass welds can be formed as described in pending and co-owned U.S.
Application No. 14/271,797 filed on May 7, 2014, the entirety of which is incorporated
herein by reference.

[0038] In the non-limiting embodiment depicted in FIG. 1, the first surface
111 of the first substrate 101 can comprise an array of cavities 105, while the second
surface 113 of the second substrate 103 can comprise a metallized pattern including
an array of metal elements 117, such that the second surface comprises metallized
and non-metallized portions (not labeled). The LED die 109 can, in some
embodiments, be attached to the second surface 113 of the second substrate 103
via the metal elements 117, e.g., by wire bonds 119. The metal elements 117 can
comprise any metal suitable for use in a display device, for example, aluminum,
copper, gold, and silver, to name a few.

[0039] While FIG. 1 depicts an embodiment in which each cavity 105
comprises quantum dots and an LED component, it is to be understood that this
depiction is not limiting. Embodiments in which one or more cavities do not comprise
quantum dots and/or LED components are also envisioned. Moreover, it is not
required that each cavity comprise the same number or amount of quantum dots, it
being possible for this amount to vary from cavity to cavity and for some cavities to
comprise no quantum dots. Furthermore, while the embodiment depicted in FIG. 1
depicts a seal 115 between each of the depicted cavities 105, it is to be understood that one or more cavities may not be sealed, as desired, for example, in the case of a cavity devoid of quantum dots. Thus, it is to be understood that various cavities can be empty or otherwise free of quantum dots, these empty cavities thus being sealed or unsealed as appropriate or desired. In some embodiments, the seal can extend around a single cavity or around a group of cavities in the array, such as two, three, four, five, ten, or more cavities, and so forth. Alternatively, the seal can extend around the entire array of cavities.

[0040] Additionally, it is possible that each cavity in the array of cavities can comprise the same or different types of quantum dots, e.g., quantum dots emitting different wavelengths. For example, in some embodiments each cavity can comprise quantum dots emitting both green and red wavelengths, to produce a red-green-blue (RGB) spectrum in each cavity. However, according to other embodiments, it is possible for each individual cavity to comprise only quantum dots emitting the same wavelength, such as a cavity comprising only green quantum dots or a cavity comprising only red quantum dots. For instance, for a given array, approximately one-third of the cavities may be filled with green quantum dots and approximately one-third of the cavities may be filled with red quantum dots, while approximately one-third of the cavities may remain empty (so as to emit blue light). Using such a configuration, the entire array can produce the RGB spectrum, while also providing dynamic dimming for each individual color. For instance, for a portion of an image containing no green color, the green cavities directly behind that portion of the image could be shut off such that they do not emit any light, thus removing green from that portion of the image. In the case of RGB cavities containing both green and red phosphors, the cavity behind the image would still emit green light, and the display device would likely have to rely on liquid crystal switching to eliminate green from the image.

[0041] Of course it is to be understood that any ratio of cavities containing any type, color, or amount of quantum dots is possible and envisioned as falling within the scope of the disclosure. It is within the ability of one skilled in the art to choose the configuration of cavities and the types and amounts of quantum dots to place in each cavity to achieve a desired display effect. Moreover, although the devices herein are discussed in terms of red and green quantum dots for display devices, it is to be understood that any type of quantum dot can be used, which can
emit any wavelength of light including, but not limited to, red, orange, yellow, green, blue, or any other color in the visible spectrum (e.g., 400-700nm).

[0042] As discussed in more detail with reference to the methods disclosed herein, the sealed device 100 can be further equipped with one or more heat sinks attached to the device (not illustrated in FIG. 1). As used herein, the term “heat sink” is intended to denote any component capable of extracting or redirecting heat from the at least one cavity comprising the quantum dot and LED component. Heat sinks can be constructed, e.g., from metals, but can also be constructed of any material more thermally conductive than the first and/or second substrate. For example, metal strips or rods can be positioned between the first and second substrates. These heat sinks can be placed in contact with at least one metal element or lead, and can function to dissipate heat from the sealed cavities. Exemplary heat sinks can be chosen from metals including, for example, aluminum, copper, gold, or silver, to name a few.

[0043] A cross-sectional view of a second embodiment of a sealed device 200 is illustrated in FIG. 2. The sealed device 200 comprises a first substrate 201 comprising an array of cavities 205, and a second substrate 203. The at least one cavity 205 can contain at least one quantum dot 207. The at least one cavity can also contain at least one LED die 209 in contact with the at least one quantum dot 207. According to various embodiments, the first substrate 201 can be an alumina substrate, such as white fused alumina. The second substrate 203 can, for example, comprise glass, which can have the same composition and/or properties of the glass substrates discussed above with respect to first and/or second substrates 101, 103.

[0044] White fused alumina substrates may present certain advantages over glass substrates, such as higher thermal conductivity (e.g., 25 W/m-K as compared to 1 W/m-K) and/or reflective surface properties (e.g., no painting step as compared to transparent glass substrates). The color of white fused alumina can be controlled, for example, by varying the amount or type of contaminants and/or the firing conditions. White alumina may therefore have an added cost advantage as compared to standard alumina. According to various embodiments, the first substrate can comprise one or more layers of alumina. For example, alumina may be tape cast to a first thickness and multiple layers can be stacked and fired to create an alumina substrate with a second thickness (greater than the first thickness). In some embodiments, a single layer of alumina can have a thickness
ranging from about 0.05 mm to about 0.3 mm, such as from about 0.1 mm to about 0.2 mm, including all ranges and subranges therebetween. An alumina substrate can have an overall thickness of about 0.1 mm to about 3 mm, such as from about 0.2 mm to about 2.5 mm, from about 0.3 mm to about 2 mm, from about 0.4 mm to about 1.5 mm, from about 0.5 mm to about 1 mm, from about 0.6 mm to about 0.9 mm, or from about 0.7 mm to about 0.8 mm, including all ranges and subranges therebetween. In some embodiments, the alumina substrate can comprise or be constructed from two or more layers, such as 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more layers.

[0045] The first substrate 201, e.g., constructed from alumina, can comprise a plurality of cavities 205, which can be cut, punched, or otherwise provided in the alumina substrate. For example, holes may be punched in one or more alumina layers and the layers comprising holes stacked with a bottom layer to create a substrate comprising one or more cavities. As illustrated in FIG. 2, the first substrate 201 can comprise three top layers 201a of alumina punched with holes corresponding to the side walls of the cavities 205 and one bottom layer 201b of alumina corresponding to the bottom of the cavities 205. The cavities 205 can comprise metallized vias 221, which can be provided, for example, in the bottom layer 201b, as discussed in more detail below with respect to the methods disclosed herein.

[0046] While FIG. 2 depicts the cavities 205 as having a substantially square or rectangular cross-section, it is to be understood that the cavities can have any given shape or size, as desired for a given application. For example, the cavities can have a square, rounded, convex, concave, semi-circular, or semi-elliptical cross-section, or an irregular cross-section, to name a few. Moreover, while the cavities 205 are depicted as spaced apart in a substantially even fashion, it is to be understood that the spacing between the cavities can be irregular or in any pattern which can be chosen to match any desired LED array pattern or circuitry pattern on a printed circuit board (PCB) 231.

[0047] The cavities 205 in the first substrate 201 can have any given depth, which can be chosen as appropriate, e.g., for the type and/or amount of quantum dot to be placed in the cavities. By way of non-limiting embodiment, the cavities on the first surface can extend to a depth of less than about 1 mm, such as less than about 0.5 mm, less than about 0.4 mm, less than about 0.3 mm, less than
about 0.2 mm, less than about 0.1 mm, less than about 0.05 mm, less than about 0.02 mm, or less than about 0.01 mm, including all ranges and subranges therebetween, such as from about 0.01 mm to about 1 mm. It is envisioned that the array of cavities can comprise cavities having the same or different depths, the same or different shapes, and/or the same or different sizes.

[0048] At least one cavity 205 in the array of cavities can comprise at least one quantum dot 207 and at least one LED die 209, as discussed with respect to FIG. 1. The LED die 209 can be bonded, e.g., by metal wires 219, to the metal vias 221. The first and second substrates 201, 203 can be joined by a seal or weld (not illustrated). The seal can extend around at least one of the cavities 205, thereby creating one or more discrete sealed regions or pockets. The seal can be formed in a manner similar to those described above with respect to FIG. 1 and can have similar properties, such as seal width and/or type (e.g., laser weld or laser frit seal).

[0049] In the non-limiting embodiment depicted in FIG. 2, the first surface substrate 201 can comprise an array of cavities 205, while the second substrate 203 can have one or more surfaces free of cavities or patterns, e.g., planar or smooth surfaces. In some embodiments, the second substrate can comprise a glass substrate, which can be similar to the glass substrates discussed above with respect to FIG. 1. While FIG. 2 depicts an embodiment in which each cavity 205 comprises quantum dots and an LED die, it is to be understood that this depiction is not limiting. Embodiments in which one or more cavities do not comprise quantum dots and/or LED components are also envisioned. Moreover, it is not required that each cavity comprise the same number or amount of quantum dots, it being possible for this amount to vary from cavity to cavity and for some cavities to comprise no quantum dots. Furthermore, it is to be understood that one or more cavities may not be sealed, as desired, for example, in the case of a cavity devoid of quantum dots. Thus, various cavities can be empty or otherwise free of quantum dots, these empty cavities being sealed or unsealed as appropriate or desired. In some embodiments, the seal can extend around a single cavity or around a group of cavities in the array, such as two, three, four, five, ten, or more cavities, and so forth. Alternatively, the seal can extend around the entire array of cavities.

[0050] As discussed in more detail with reference to the methods disclosed herein, the sealed device 200 can be further equipped with one or more heat sinks attached to the device. For example, as illustrated in FIG. 2, a heat sink 225 can be
positioned on a second surface (not labeled) of the first substrate 201 and attached, for instance, via an adhesive layer 223. The heat sink 225 can comprise, in various embodiments, a metal suitable for dissipating heat from a display device such as, for example, aluminum, copper, silver, or gold, to name a few. The adhesive layer can be heat conducting and can be chosen, for example, from conductive epoxies.

[0051] In some embodiments, the heat sink 225 can comprise one or more holes 227. The holes 227 can be aligned with cavities 205 and elastomeric ("zebra") connectors 229 can be passed through the holes and connected to the LED components 209, e.g., via the metallized vias 221. The connectors 229 can, for example, serve as a means to control each LED individually to achieve high resolution local dimming so as to improve image contrast. The LEDs 209 can be interconnected to a printed circuit board (PCB) 231, including circuitry for connecting each LED to an LED controller (not illustrated), which in turn can be driven by a display controller (not illustrated). Of course, it is not required that each cavity 205 in the sealed device 200 have a corresponding hole 227, for example, in the case of one or more cavities devoid of quantum dots and/or LED components.

[0052] A cross-sectional view of a third embodiment of a sealed device 300 is illustrated in FIG. 3. The sealed device 300 comprises a first substrate 301 comprising an array of cavities 305 (one shown), and a second substrate 303. The at least one cavity 305 can contain at least one quantum dot 307. The at least one cavity can also contain at least one LED die 309 in contact with the at least one quantum dot 307. According to various embodiments, the first and second substrates 301, 303 can comprise glass and can have the same composition and/or properties of the glass substrates discussed above with respect to first and/or second substrates 101, 103. In certain embodiments, the first substrate 301 (not illustrated) can comprise a single layer having a plurality of cavities containing at least one quantum dot 307.

[0053] Alternatively, as illustrated in FIG. 3, the first substrate 301 can comprise two or more layers, such as a top layer 301a and a bottom layer 301b. The bottom layer 301b can, in some embodiments, comprise glass. The top layer 301a can comprise, for example, glass or another material such as a plastic or ceramic material. The top layer 301a can comprise, for example, a well plate comprising a plurality of holes. In the case of a first substrate 301 comprising two or more layers, the top layer 301a can comprise a plurality of holes and the layer(s)
comprising holes can be stacked with the bottom layer 301b to create a first substrate 301 comprising one or more cavities.

[0054] As illustrated in FIG. 3, the first substrate 301 can comprise one top layer 301a comprising plastic punched or cut with holes corresponding to the side walls of the cavities 305 and one bottom layer 301b comprising glass corresponding to the bottom of the cavities 305. Of course, different numbers, arrangements, and materials for the top and bottom layers can be used as desired. According to some embodiments, the first substrate 301 can comprise one or more layers comprising a glass sheet with a well plate nested in a cutout provided therein, wherein the well plate has substantially the same thickness as the glass sheet (see FIGS. 6A-B).

[0055] In some embodiments, it can be advantageous to include a white plastic top layer 301a (or nested well plate) to increase the amount of light propagated from the sealed device toward the viewer and/or to avoid cross-talk between the cavities. Cross-talk can occur when quantum dots in one cavity are excited to produce light having one wavelength and such converted light is subsequently converted by adjacent quantum dots to light having another longer wavelength (e.g., light emitted from a green quantum dot can be converted to longer wavelengths by an adjacent red quantum dot). Transparent first substrates 301, including transparent top and bottom layers 301a, 301b can also be used in some embodiments. In such instances, the substrate or one or more layers of the substrate may be painted (e.g., with white or reflective ink) around the cavities and/or a reflective layer may be included in the sealed device.

[0056] The first substrate 301 can comprise a plurality of metallized vias 321, which can be provided, for example, in the bottom layer 301b adjacent each LED die 309, as discussed in more detail below with respect to the methods disclosed herein. Metallized vias 321 can have any desired diameter and can be spaced apart at any given pitch. For example, the diameter of a single metallized via can range from about 20 microns to about 200 microns, such as from about 40 microns to about 180 microns, from about 60 microns to about 160 microns, from about 80 microns to about 140 microns, or from about 100 microns to about 120 microns, including all ranges and subranges therebetween. The plurality of metallized vias 321 can, in some embodiments, comprise one or more discrete groups of vias (one group illustrated) positioned adjacent an LED die 309. Each discrete group can comprise, for example, two or more vias, such as 2 to 40 vias, 5
to 30 vias, 10 to 25 vias, or 15 to 20 vias, including all ranges and subranges therebetween.

[0057]  The pitch between metallized vias 321 in a group can range, for example, from about 40 microns to about 300 microns, from about 75 microns to about 250 microns, from about 100 microns to about 200 microns, or from about 120 microns to about 150 microns, including all ranges and subranges therebetween. Each group of metallized vias can be spaced apart by a distance corresponding to the LED die spacing of the device, e.g., ranging from about 1 mm to about 20 mm, such as from about 2 mm to about 15 mm, from about 3 mm to about 12 mm, from about 4 mm to about 10 mm, from about 5 mm to about 8 mm, or from about 6 mm to about 7 mm, including all ranges and subranges therebetween. Of course, the size and spacing of the metallized vias can vary to match any desired LED array.

[0058]  The LED die 309 can be bonded to the first substrate 301, e.g., by a conductive epoxy. In some embodiments, a conductive film 333 can be provided on the first substrate 301. As illustrated in FIG. 3, a reflective film 333 can be provided on a surface of the first substrate 301, such as on the surface of the bottom layer 301b in contact with the top layer 301a. The reflective film can be chosen from any metal as disclosed herein, such as aluminum, copper, silver, gold, and the like. The first and second substrates 301, 303 can be joined by a seal or weld (not illustrated). The LED die 309 can be bonded to the first substrate 301 by metal wires 319. The seal can extend around at least one of the cavities 305, thereby creating one or more discrete sealed regions or pockets. In some embodiments, the seal can extend around a group of cavities in the array, such as two or more cavities, three or more cavities, four or more cavities, five or more cavities, ten or more cavities, and so forth. Alternatively, the seal can extend around the entire array of cavities. The seal can be formed in a manner similar to those described above with respect to FIG. 1 and can have similar properties, such as seal width and/or type (e.g., laser weld or laser frit seal).

[0059]  While FIG. 3 depicts a cavity 305 comprising quantum dots and an LED die, it is to be understood that this depiction is not limiting. Embodiments in which one or more cavities do not comprise quantum dots and/or LED components are also envisioned. Moreover, it is not required that each cavity comprise the same number or amount of quantum dots, it being possible for this amount to vary from cavity to cavity and for some cavities to comprise no quantum dots. Furthermore, it
is to be understood that one or more cavities may not be sealed, as desired, for example, in the case of a cavity devoid of quantum dots. Thus, various cavities can be empty or otherwise free of quantum dots, these empty cavities being sealed or unsealed as appropriate or desired.

[0060] As discussed in more detail with reference to the methods disclosed herein, the sealed device 300 can be further equipped with one or more heat sinks attached to the device. For example, as illustrated in FIG. 3, a heat sink 325 can be positioned on a second surface (not labeled) of the first substrate 301 and attached, for instance, via an adhesive layer 323. The heat sink 325 can comprise, in various embodiments, a metal suitable for dissipating heat from a display device such as, for example, aluminum, copper, silver, or gold, to name a few. The adhesive layer 323 can be heat conducting and can be chosen, for example, from conductive epoxies. The heat sink can further comprise one or more features 335, such as fins, which can enhance the dissipation of thermal energy, e.g., via surrounding air flow (indicated by arrows A). As in the previously disclosed embodiments, the sealed device 300 can also be connected, e.g., by the heat sink 325, to a printed circuitry board (PCB) 331. Printed circuitry (not illustrated) can be provided on the second surface of the first substrate to connect each LED to an LED controller (not illustrated), which in turn can be driven by a display controller (not illustrated).

[0061] The first and second substrates can, in various embodiments be sealed together as disclosed herein, to produce a seal or weld around one or more of the cavities. In certain embodiments, the seal or weld may be a hermetic seal, e.g., forming one or more air-tight and/or waterproof pockets in the device. For example, at least one cavity containing at least one quantum dot can be hermetically sealed such that the cavity is impervious or substantially impervious to water, moisture, air, and/or other contaminants. By way of non-limiting example, a hermetic seal can be configured to limit the transpiration (diffusion) of oxygen to less than about $10^{-2}$ cm$^3$/m$^2$/day (e.g., less than about $10^{-3}$/cm$^3$/m$^2$/day), and limit transpiration of water to about $10^{-2}$ g/m$^2$/day (e.g., less than about $10^{-3}$, $10^{-4}$, $10^{-5}$, or $10^{-6}$ g/m$^2$/day). In various embodiments, a hermetic seal can substantially prevent water, moisture, and/or air from contacting the components protected by the hermetic seal.

[0062] In certain embodiments, the first and second substrates may be chosen such that the coefficient of thermal expansion (CTE) of the substrates is substantially similar. For example, the CTE of the second substrate can be within
about 20% of the CTE of the first substrate, such as within about 15%, within about 10%, within about 5%, within about 4%, within about 3%, within about 2%, or within about 1% of the CTE of the first substrate. According to various embodiments the CTE of the first substrate is substantially equal to the CTE of the second substrate.

[0063] By way of a non-limiting example, the CTE of the first and/or second substrate can range, for example, from about 0.5 x 10^-6/°C to about 15 x 10^-6/°C, such as from about 1 x 10^-6/°C to about 14 x 10^-6/°C, from about 2 x 10^-6/°C to about 13 x 10^-6/°C, from about 3 x 10^-6/°C to about 12 x 10^-6/°C, from about 4 x 10^-6/°C to about 11 x 10^-6/°C, from about 5 x 10^-6/°C to about 10 x 10^-6/°C, from about 6 x 10^-6/°C to about 9 x 10^-6/°C, or from about 7 x 10^-6/°C to about 8 x 10^-6/°C, including all ranges and subranges therebetween. In certain embodiments, the first and/or second substrate can comprise glass having a CTE ranging from about 8 x 10^-6/°C to about 10 x 10^-6/°C, for instance, ranging from about 8.5 x 10^-6/°C to about 9.5 x 10^-6/°C, including all ranges and subranges therebetween. According to non-limiting embodiments, the glass substrate can be Corning® Gorilla® glass having a CTE ranging from about 7.5 to about 8.5 x 10^-6/°C, or Corning® EAGLE XG®, Lotus™, or Willow® glasses having a CTE ranging from about 3 to about 4 x 10^-6/°C. In other embodiments, the first and/or second substrate can comprise alumina having a CTE ranging from about 0.5 x 10^-6/°C to about 3 x 10^-6/°C, such as from about 1 x 10^-6/°C to about 2.5 x 10^-6/°C, or from about 1.5 x 10^-6/°C to about 2 x 10^-6/°C, including all ranges and subranges therebetween.

[0064] The sealed devices disclosed herein can comprise an array of sealed cavities which can be spaced apart as desired, at least a portion of which can comprise at least one quantum dot. This configuration can make it possible to provide an optical component for a backlit device, such as an LCD device, which can provide quantum dots and LEDs in discrete, desired locations, without material waste of the quantum dots in areas not adjacent or proximate LED components. The configurations disclosed herein can also provide high dynamic range, high contrast (from local dimming), high color gamut (from quantum dot color conversion), and/or high brightness (from provision of a heat dissipation path from the color converter through the LED die to a heat sink).

[0065] According to certain aspects, the total thickness of the sealed device can be less than about 6 mm, such as less than about 5 mm, less than about 4 mm, less than about 3 mm, less than about 2 mm, less than about 1.5 mm, less
than about 1 mm, or less than about 0.5 mm, including all ranges and subrange
therebetween. For example, the thickness of the sealed device can range from
about 0.3 mm to about 3 mm, such as from about 0.5 mm to about 2.5 mm, or from
about 1 mm to about 2 mm, including all ranges and subrange therebetween.

[0066] While the embodiments depicted in FIGS. 1-3 contemplate a one-
dimensional (e.g., single row) of cavities and LEDs, it is to be understood that the
sealed device disclosed herein can also be used for two-dimensional arrays (e.g.,
more than one row and/or extending in more than one direction). The height and
length dimensions of the sealed device can therefore vary as desired to suit the
chosen display. For instance, one or more sealed devices can be arranged or
positioned together in one or more directions to accommodate any size display, for
example, having a length and/or width ranging from about 5 mm to about 1.5 m,
such as from about 1 cm to about 1 m, from about 10 cm to about 500 cm, from
about 25 cm to about 250 cm, or from about 50 cm to about 100 cm, including all
ranges and subrange therebetween. In certain embodiments, two or more sealed
devices can be arranged together to create a larger LED array, such as 3, 4, 5, 6, 7,
8, 9, 10, 12, 14, 16, 18, 20, or more devices in one or both directions to create an
LED array having a desired size.

[0067] The sealed devices disclosed herein may be used in various display
devices or display components including, but not limited to backlights or backlit
displays such as LCDs, which can comprise various additional components.
Exemplary LCD devices may further comprise various conventional components,
such as a reflector, a light guide, a diffuser, one or more prism films, a reflecting
polarizer, one or more linear polarizers, a thin-film-transistor (TFT) array, printed
circuit board (PCB), a liquid crystal layer, and/or a color filter.

[0068] The sealed devices disclosed herein can also be used as
illuminating devices, such as luminaires and solid state lighting applications. For
example, a sealed device comprising quantum dots in contact with at least one LED
die can be used for general illumination, e.g. mimicking the broadband output of the
sun. Such lighting devices can comprise, for example, quantum dots of various
sizes emitting at various wavelengths, such as wavelengths ranging from 400-
700nm. In certain embodiments, the sealed lighting devices can comprise at least
two different quantum dots of different sizes (e.g., emitting at different wavelengths),
such as at least three, at least four, at least five, or more different quantum dots.
According to various embodiments, the sealed device can comprise a mixture of quantum dots emitting colors broadly spanning the visible spectrum, such as red, orange, yellow, green, and blue wavelengths. The sealed lighting device can comprise a single cavity or an array of cavities (similar to the aforementioned sealed devices). In the case of multiple cavities, each cavity can contain the same or different quantum dots, e.g., each cavity can contain the same mixture of quantum dots, or the cavities can contain different mixtures of quantum dots, or each cavity can contain only one type of quantum dot.

**Methods**

[0069] Disclosed herein are methods for making sealed devices, the methods comprising placing at least one quantum dot in at least one cavity in an array of cavities on a first surface of a first substrate; contacting the at least one quantum dot with at least one LED component; bringing a second surface of a second substrate into contact with the first surface of the first substrate; and forming a seal between the first substrate and the second substrate, the seal extending around the at least cavity containing the at least one quantum dot in contact with the at least one LED component.

[0070] FIGS. 4A-C illustrate various stages of a method for making a sealed device according to certain embodiments of the disclosure, such as the sealed device depicted in FIG. 1. For instance, FIG. 4A depicts a top view of a first substrate 401 comprising an array of cavities 405. As discussed above, the depicted cavity array is not intended to be limiting on the claims, either by cavity number, arrangement, type, size, or the like. While FIG. 4A depicts the cavities 405 as having a substantially circular surface area, it is to be understood that the cavities can have any given shape or size, as desired for a given application. For example, the cavities can have a square, rectangular, or oval surface area, or an irregular surface area, to name a few.

[0071] Sealing material 437a, such as glass frit or paste, can optionally be deposited around each cavity. At least one quantum dot 407 can be placed in at least one cavity 405 in the array. FIG. 4A depicts quantum dots 407 dispersed among various exemplary cavities; however, it is to be understood that all cavities or different cavities can be filled with varying amounts of quantum dots, as desired for a particular application. According to various embodiments, the quantum dot material
407 can be deposited in the cavities 405 in an inert environment. Suitable methods for depositing the quantum dots 407 can include, for example, ink jet printing, screen printing, and microprinting methods, such as micro-contact printing.

[0072] According to various embodiments, the first substrate 401 can comprise a uniform piece or multiple assembled or attached pieces. For instance, as illustrated in FIG. 4A, the first substrate can comprise a fixture sheet 401a, which can be substantially planar or which can have an array of cavities (not labeled). Singulated (individual) substrates 401b comprising individual cavities 405 can be placed on a surface or in the cavities of the fixture sheet 401a to form a desired pattern of cavities. In such embodiments, the cavities 405 can be placed at substantially the same pitch as the LED dies. Singulated substrates 401b can be prepared, for example, by providing cavities in a substrate sheet (e.g., glass sheet), such as by pressing or any other suitable method. Individual substrates 401b can then be cut from the sheet to produce any desired shape and/or dimension. The substrates 401b, optionally comprising sealing material 437a around the cavities 405, can be fired as a sheet before cutting, after cutting, and/or after being placed in the cavities of the fixture sheet 401a.

[0073] In various embodiments, portions of the first substrate 401 can be painted in areas proximate the cavities, e.g., around the periphery of the cavities. For instance, in the case of a transparent first substrate 401 (such as a glass substrate), various portions of the substrate can be painted with a white or otherwise reflective ink. In the case of singulated substrates 401b, the sides of each substrate can be painted. Painting can be carried out, for example, to increase the amount of light propagated from the sealed device toward the LCD panel (e.g., toward the viewer) and/or to avoid cross-talk between the cavities.

[0074] FIG. 4B depicts a top view of an exemplary second substrate 403. The second surface 413 can comprise, for example, a metallized pattern. LED dies 409 can be attached to metal elements 417, such as by wirebonding, to form an array. Of course, while FIG. 4B illustrates a specific exemplary embodiment, it is to be understood that any metallized pattern can be provided on the second surface 413 of the second substrate 403. Moreover, any number of LED dies 409 can be provided on the second surface 403, in any desired pattern.

[0075] As depicted in FIG. 4C, first and second substrates (not labeled) can be brought into contact such that the first substrate (e.g. singulated substrates
comprising an array of cavities 405 contacts the second surface (not labeled) comprising the array of LED dies 409. In certain embodiments, the substrates can be aligned such that at least one cavity 405 comprises at least one quantum dot 407 and at least one LED die 409. The substrates thus contacted can be sealed, e.g., around at least one cavity 405 comprising the at least one quantum dot 407 and the at least one LED die 409. For instance, in the case of singulated substrates 401b, each substrate can be sealed to the second substrate to form an array of sealed cavities. Sealing can be carried out, for instance, by laser welding or laser frit sealing, as discussed above, to form a sealed device 400. For example, a laser can be directed at or on a sealing interface comprising sealing material to bond the first and second substrates together, or a laser weld can be formed in the absence of sealing material. The seal 437b can thus comprise a laser weld, or a laser frit seal. In the case of a frit seal, the seal 437b can correspond to the pattern of the sealing material 437a (see FIG. 4A). In some embodiments, the sealing method may be chosen depending on the CTE of the substrates, e.g., laser welding can be used for substrates having higher CTEs (such as greater than about 3 x 10^-6/°C), whereas laser frit sealing may be suitable for substrates with lower CTEs (such as less than about 3 x 10^-6/°C), although any combination of substrates and seals is possible and envisioned.

According to various embodiments, sealing the substrate can comprise scanning or translating a laser beam along the substrates (or the substrates can be translated relative to the laser) using any predetermined path to produce any pattern, such as a square, rectangular, circular, oval, or any other suitable pattern or shape, for example, to hermetically seal one or more cavities in the device. The translation speed at which the laser beam (or substrate) moves along the interface may vary by application and may depend, for example, upon the composition of the first and second substrates and/or the focal configuration and/or the laser power, frequency, and/or wavelength. In certain embodiments, the laser may have a translation speed ranging from about 1 mm/s to about 1000 mm/s, for example, from about 10 mm/s to about 500 mm/s, or from about 50 mm/s to about 700 mm/s, such as greater than about 100 mm/s, greater than about 200 mm/s, greater than about 300 mm/s, greater than about 400 mm/s, greater than about 500 mm/s, or greater than about 600 mm/s, including all ranges and subranges therebetween.
[0077] According to various embodiments disclosed herein, the laser wavelength, pulse duration, repetition rate, average power, focusing conditions, and other relevant parameters may be varied so as to produce an energy sufficient to weld the first and second substrates together, either directly or by way of a sealing material. It is within the ability of one skilled in the art to vary these parameters as necessary for a desired application. In various embodiments, the laser fluence (or intensity) is below the damage threshold of the first and/or second substrate, e.g., the laser operates under conditions intense enough to weld the substrates together, but not so intense as to damage the substrates. In certain embodiments, the laser beam may operate at a translation speed that is less than or equal to the product of the diameter of the laser beam at the sealing interface and the repetition rate of the laser beam.

[0078] The methods disclosed herein can further comprise attaching one or more heat sinks 425 to the sealed device 400. For example, metal strips can be placed in contact with one or more of the metal elements 417 such that heat can be dissipated from the sealed cavities 405. As depicted in FIG. 4C, the seal 437b can extend around the cavity 405 comprising the at least one quantum dot 407 and the at least one LED die 409. The metal element 417 can, in some embodiments, extend at least partially under the seal 437b, such that it is present both inside and outside the sealed cavity 405. In various embodiments, the metal element 417 can comprise one or more holes 439 (five illustrated) along the sealing interface to provide an integrated seal over the metal element 417. Of course, in other embodiments, the metal elements 417 can comprise more or less holes, or no holes 439.

[0079] FIGS. 5A-D illustrate various stages of a method for making a sealed device according to additional embodiments of the disclosure, such as the sealed device depicted in FIG. 2. For instance, FIG. 5A depicts a top view of a bottom layer 501b of a first substrate comprising via holes 521. FIG. 5B depicts a top view of a top layer 501a, punched with a plurality of holes 541. One or more top layers 501a can be stacked on the bottom layer 501b and assembled to form the first substrate 501 comprising a plurality of cavities 505, as depicted in FIG. 5C. The layers 501a and 501b thus assembled can be fired, e.g., to produce first substrate 501. In some embodiments, via holes 521 can be filled with conductive paste (not illustrated) prior to firing.
[0080] At least one LED component 509 can be secured in the cavity 505, for example, by die attaching to the bottom layer 501b and wire bonding to one or more of the metallized vias 521. As discussed above, the depicted cavity array is not intended to be limiting on the claims, either by cavity number, arrangement, type, size, or the like. While FIGS. 5C-E depict the cavities 505 as having a substantially square surface area, it is to be understood that the cavities can have any given shape or size, as desired for a given application. For example, the cavities can have a rectangular, circular, or oval surface area, or an irregular surface area, to name a few. At least one quantum dot 507 can be placed in at least one cavity 505 in the array. FIG. 5D depicts quantum dots 507 dispersed among various exemplary cavities; however, it is to be understood that all cavities or different cavities can be filled with quantum dots, as desired for a particular application.

[0081] FIG. 5E illustrates a top view of a sealed substrate 500 viewed with the second substrate 503 on top. In the depicted embodiment, the second substrate 503 is substantially transparent (e.g., a glass substrate), such that the first substrate 501 is visible from this view. FIG. 5F illustrates a reversed view of the sealed substrate 500, viewed with the second substrate (not labeled) on bottom. In the depicted embodiment, a metal substrate 525 (heat sink) is provided on a second surface (not labeled) of the first substrate 501. The first substrate 501 and metallized vias 521 are visible through the holes 527 in the metal substrate 525. As illustrated in the non-limiting embodiment, the first substrate 501 is not transparent (e.g., white alumina substrate), such that the second substrate 503 is not visible from this view.

[0082] FIGS. 6A-B illustrate front and rear exploded views of a sealed device according to certain embodiments of the disclosure, e.g., the sealed device depicted in FIG. 3. A first substrate 601 can be constructed from a top layer 601a and a bottom layer 601b. The top layer 601a can comprise a nested well plate 651, whereas the bottom layer 601b can comprise a reflective coating 653 on a surface in contact with the top layer 601a. Quantum dots (not illustrated) can be placed in at least one cavity 605 and placed in contact with at least one LED die 609 on the bottom layer 601b. Sealing material 637a, such as glass frit or paste, can optionally be deposited around each cavity. Sealing can be carried out, for instance, by laser welding or laser frit sealing, as discussed above, to form a sealed device 600. As illustrated in FIGS. 6A-B, the seal can extend, in some embodiments, around the
entire array of cavities. Of course, it is to be understood that other seal patterns can be utilized, such as various seals around groups of cavities or individual seals around individual cavities, and so forth.

[0083] Zebra connectors (or any other suitable connectors) 629 can be placed in contact with the LED dies 609 and can serve as a means to control each LED individually to achieve high resolution local dimming so as to improve image contrast. A heat sink 625 can be attached to the sealed device 600 by way of an adhesive layer (not illustrated). Furthermore, a PCB 631 can be provided to which the LED dies 609 are interconnected by way of printed circuitry 655. The printed circuitry can be constructed or deposited using any material known in the art, such as copper paste or any other conductive material.

[0084] It will be appreciated that the various disclosed embodiments may involve particular features, elements or steps that are described in connection with that particular embodiment. It will also be appreciated that a particular feature, element or step, although described in relation to one particular embodiment, may be interchanged or combined with alternate embodiments in various non-illustrated combinations or permutations.

[0085] It is also to be understood that, as used herein the terms “the,” “a,” or “an,” mean “at least one,” and should not be limited to “only one” unless explicitly indicated to the contrary. Thus, for example, reference to “a cavity” includes examples having one such “cavity” or two or more such “cavities” unless the context clearly indicates otherwise. Similarly, a “plurality” or an “array” is intended to denote two or more, such that an "array of cavities" or a “plurality of cavities” denotes two or more such cavities.

[0086] Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, examples include from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0087] All numerical values expressed herein are to be interpreted as including “about,” whether or not so stated, unless expressly indicated otherwise. It is further understood, however, that each numerical value recited is precisely
contemplated as well, regardless of whether it is expressed as "about" that value. Thus, "a dimension less than 10 mm" and "a dimension less than about 10 mm" both include embodiments of "a dimension less than about 10 mm" as well as "a dimension less than 10 mm."

[0088] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that any particular order be inferred.

[0089] While various features, elements or steps of particular embodiments may be disclosed using the transitional phrase "comprising," it is to be understood that alternative embodiments, including those that may be described using the transitional phrases "consisting" or "consisting essentially of," are implied. Thus, for example, implied alternative embodiments to a method comprising A+B+C include embodiments where a method consists of A+B+C, and embodiments where a method consists essentially of A+B+C.

[0090] It will be apparent to those skilled in the art that various modifications and variations can be made to the present disclosure without departing from the spirit and scope of the disclosure. Since modifications combinations, sub-combinations and variations of the disclosed embodiments incorporating the spirit and substance of the disclosure may occur to persons skilled in the art, the disclosure should be construed to include everything within the scope of the appended claims and their equivalents.
WHAT IS CLAIMED IS:

1. A sealed device comprising:
   a first substrate having a first surface, the first surface comprising an array of cavities;
   a second substrate; and
   at least one seal between the first substrate and the second substrate, the seal extending around at least one cavity in the array of cavities;
   wherein the at least one cavity comprises at least one quantum dot in contact with at least one LED component.

2. The sealed device of claim 1, wherein at least one of the first or second substrate comprises glass.

3. The sealed device of claim 2, wherein the second substrate is a glass substrate comprising a metallized pattern.

4. The sealed device of claim 3, wherein the at least one LED component is attached to the metallized pattern.

5. The sealed device of claim 1, wherein the first substrate comprises at least one layer of alumina or glass.

6. The sealed device of claim 5, wherein the at least one cavity comprises at least one metallized via.

7. The sealed device of claim 6, wherein the at least one LED component is attached to the at least one metallized via.

8. The sealed device of claim 1, wherein the at least one seal is chosen from laser weld and laser frit seals.
9. The sealed device of claim 1, wherein the at least one seal extends around a single cavity in the array of cavities, a group of two or more cavities in the array of cavities, or around the entire array of cavities.

10. The sealed device of claim 1, further comprising at least one heat sink.

11. The sealed device of claim 10, wherein the at least one heat sink is attached to the first or second substrate by a thermally conductive adhesive.

12. The sealed device of claim 10, wherein the at least one heat sink comprises at least one metal strip positioned on the first surface of the first substrate.

13. The sealed device of claim 10, wherein the at least one heat sink comprises a metal substrate positioned on a second surface of the first substrate, the metal substrate optionally comprising one or more holes.

14. A backlight comprising the sealed device of claim 1.

15. A display device comprising the sealed device of claim 1.

16. A sealed device comprising:
   a first substrate having a first surface comprising at least one cavity;
   a second substrate; and
   at least one seal between the first substrate and the second substrate, the seal extending around the at least one cavity;
   wherein the at least one cavity comprises at least one quantum dot in contact with at least one LED component.

17. The sealed device of claim 16, wherein the at least one quantum dot emits light at wavelengths ranging from about 400 nm to about 700 nm.

18. The sealed device of claim 16, wherein the at least one cavity comprises two or more quantum dots of different sizes.
19. The sealed device of claim 16, wherein the first surface comprises a single cavity or an array of cavities.

20. The sealed device of claim 16, wherein the at least one seal extends around a single cavity, a group of two or more cavities, or around an array of cavities.

21. A solid-state lighting device comprising the sealed device of claim 16.

22. A method for making a sealed device, the method comprising:
   placing at least one quantum dot in at least one cavity in an array of cavities on a first surface of a first substrate;
   contacting the at least one quantum dot with at least one LED component;
   bringing a second surface of a second substrate into contact with the first surface of the first substrate; and
   forming a seal between the first substrate and the second substrate, the seal extending around the at least one cavity containing the at least one quantum dot in contact with the at least one LED component.

23. The method of claim 22, wherein the at least one LED component is attached to the second surface of the second substrate, and wherein the first and second surfaces are brought into contact such that the at least one cavity containing the at least one quantum dot and the at least one LED component are aligned.

24. The method of claim 22, wherein the at least one LED component is positioned in at least one cavity in the array of cavities on the first surface of the first substrate, and wherein the at least one quantum dot is placed in the at least one cavity comprising the at least one LED component.

25. The method of claim 22, wherein at least one of the first or second substrates is a glass substrate and wherein forming a seal between the first and second substrates comprises laser welding or laser frit sealing.
26. The method of claim 22, wherein the at least one seal extends around a single cavity in the array of cavities, a group of two or more cavities in the array of cavities, or the entire array of cavities.

27. The method of claim 22, further comprising attaching at least one heat sink to the first surface or a second surface of the first substrate.
FIGURE 3
INTERNATIONAL SEARCH REPORT

INTERNATIONAL APPLICATION NO
PCT/US2016/038655

A. CLASSIFICATION OF SUBJECT MATTER
H01L 33/50(2010.01)i, H01L 33/48(2010.01)i, H01L 33/52(2010.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L 33/50; H01L 23/52; H01L 23/02; H01L 33/48; H01L 33/52; H01L 33/62

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: substrate, seal, cavity, glass, quantum dot

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>See paragraphs 27-37, 61, claim 1 and figures 1-4.</td>
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<td>See paragraphs 20-25, 66-70, claim 1 and figures 1, 9a-11.</td>
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<td>See paragraphs 10-22, claims 1-2 and figures 4-5.</td>
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☐ Further documents are listed in the continuation of Box C.  ☒ See patent family annex.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
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Date of the actual completion of the international search
05 October 2016 (05.10.2016)

Date of mailing of the international search report
05 October 2016 (05.10.2016)

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