The contents of U.S. Patent Pub. No. 20100001648, entitled "LED lighting that has continuous and adjustable color temperature (CT), while maintaining a high CRI," published on January 7, 2010 is based in part on the technical description and drawings provided herein by InventionWriter LLC.

OPTIMIZED LIGHT-EMITTING DIODE (LED) DEVICES THAT HAVE A HIGH COLOR RENDERING INDEX (CRI) FOR LIGHTING APPLICATIONS

FIELD OF THE INVENTION:

[0001] The present invention generally relates to the field of light-emitting diodes. In particular, the present invention is directed to light-emitting diode (LED) devices for use as white light sources in functional lighting applications.

BACKGROUND:

[0002] The use of LED-based white light sources in functional lighting applications is an emerging industry. A useful way to express the quality of a light source is its color rendering index (CRI). CRI is a method of describing the effect of a light source on the color appearance of objects, compared with a reference light source of the same color temperature. CRI values may be used as a quality distinction between light sources emitting light of the same color. The highest CRI attainable is 100. Additionally, color temperature (CT) is a way to express the spectral properties of a light source. For example, low CT implies warmer (more yellow/red) light, while high CT implies a colder (more blue) light. The standard unit for color temperature is Kelvin (K). For example, daylight has a rather low CT near dawn (approximately 3200K) and a higher CT around noon (approximately 5500K).

[0003] Typical white fluorescent lamps have a CRI of less than 82 at a CT of between 3200K and 5000K; halogen lamps have a CRI of 95 and above at a CT of <3200K; and ultra-high performance (UHP) lamps, such as high pressure mercury discharge lamps, have a CRI of less than 82 at a CT of >5000K. Unfortunately, a drawback to existing white light sources, such as fluorescent or halogen lamps, is that their CT value is fixed. Further, a drawback to utilizing LED devices for illumination purposes is that today's LED devices are "point" light sources and, thus, have limited usefulness in functional lighting applications, such as providing overhead lighting in a room or outdoor area lighting, wherein surface-emitting light sources are more suited. For these reasons, a need exists for improved LED devices for use as white light sources for functional lighting applications.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0004] For the purpose of illustrating the invention, the drawings show aspects of one or more embodiments of the invention. However, it should be understood that the present invention is not limited to the precise arrangements and instrumentalities shown in the drawings, wherein:

Figure 1 illustrates a chromaticity diagram (for reference only);

Figure 2A illustrates a schematic diagram of an example of a 3-in-1 LED device, according to one embodiment of the invention;

Figure 2B illustrates a top view of an example of the 3-in-1 LED device of Figure 2A packaged in a 6-pin device;

Figure 2C illustrates a cross-sectional view of the 3-in-1 LED device, taken along line AA of Figure 2B;

Figure 3A illustrates a schematic diagram of an example of a 4-in-1 LED device, according to another embodiment of the invention;

Figure 3B illustrates a top view of an example of the 4-in-1 LED device of Figure 3A packaged in an 8-pin device; and

Figure 3C illustrates a cross-sectional view of the 4-in-1 LED device, taken along line BB of Figure 3B.

DETAILED DESCRIPTION:

[0005] The present invention is optimized LED devices that have high CRI values for lighting applications, such as, but not limited to, overhead lighting in a room and outdoor area lighting. The LED devices of the invention provide a continuous, uniform, and adjustable CT range, while maintaining a high CRI. The LED devices of the invention may be implemented as *n*-in-1 LED devices, where *n* is the number of individual LEDs in the device. In one example, the LED device of the invention may be a 3-in-1 LED device. In another example, the LED device of the invention may be a 4-in-1 LED device.

[0006] Because a light source that is emitting radiant energy that is relatively balanced in all visible wavelengths will appear white to the eye, the LED devices of the invention provide multiple LEDs (e.g., red, green and blue) in one package, which allows color mixing in order to provide an appropriate white light source for illumination purposes that, additionally, has the capability to provide CT tracking. In particular, the LED devices of the invention may utilize at least one blue LED in combination with phosphor material for producing white light. Additionally, the phosphor material provides a mechanism for diffusing the light emitted by the LED, which renders the LED a surface-emitter rather than a point-emitter device and is, thus, more suited for general illumination purposes. Furthermore, the LED devices of the invention have a high CRI (e.g., >90) over a substantially continuous, uniform, and adjustable CT range of, for example, 3200 K to 9500 K.

[0007] Figure 1 illustrates a chromaticity diagram 100, which is provided for reference only for with regard to the LED devices of the invention. As is well known, a chromaticity diagram, such as chromaticity diagram 100, is a triangular-shaped line that connects the chromaticities of the spectrum of colors. In the case of chromaticity diagram 100, this line defines a color triangle 110. The curved line within color triangle 110 of chromaticity diagram 100 shows where the color of the spectrum lie and is called the spectral locus. In particular, a black body curve 112 is the spectral locus for white light. Combinations of colors, such as shades of blue, green, yellow, orange, and red, along black body curve 112 mix and produce white light. The wavelengths along black body curve 112 are indicated in nanometers. Furthermore, Figure 1 shows the range of CTs along the length of black body curve 112. For example, the end of black body curve 112 that is near the blue area indicates a CT of 10000K (cool light) and approaches infinity. By contrast, the end of black body curve 112 that is near the red area indicates a CT of 2500K (warm light) and approaches zero. Additionally, those skilled in the art will understand that the more colors of the spectrum that are present with sufficiently high energy levels within a white light source, the higher the CRI of the white light source and, thus, the higher the quality of the white light.

[0008] Figure 2A illustrates a schematic diagram of an example of a 3-in-1 LED device 200, according to one embodiment of the invention. 3-in-1 LED device 200 is one example of an *n*-in-1 LED device of the invention. 3-in-1 LED device 200 includes a device body 210 within which is arranged three LEDs, such as an LED 212, an LED 214, and an LED 216. 3-in-1 LED device 200 further includes a plurality of leads 220 that are arranged on the perimeter of device body 210. The cathode and anode of LED 212 is electrically connected to a first pair of leads 220. The cathode and anode of LED 214 is electrically connected to a second pair of leads 220. The cathode and anode of LED 216 is electrically connected to a third pair of leads 220.

[0009] Figure 2B illustrates a top view (not to scale) of an example of 3-in-1 LED device 200 of Figure 2A packaged in a 6-pin device. Figure 2C illustrates a cross-sectional view (not to scale) of 3-in-1 LED device 200, taken along line AA of Figure 2B. Figures 2B and 2C show that LEDs 212, 214, and 216 of 3-in-1 LED device 200 are physically arranged in a cavity formed by the sidewalls and floor of device body 210. For example, LEDs 212, 214, and 216 are mounted on respective pedestals 222 that are arranged within device body 210, as shown in Figures 2B and 2C. Additionally, a filler material 224 is used to encapsulate LEDs 212, 214, and 216 within device body 210 of 3-in-1 LED device 200. Filler material 224 may be formed, for example, of a blend of an epoxy 226, which is substantially transparent, and a quantity of yttrium-aluminum-garnet phosphor (YAG-phosphor) 228, as shown in Figure 2C.

[0010] In this example, 3-in-1 LED device 200 is formed by a 1x3 array of LEDs. Device body 210 may be formed of any suitably rigid, lightweight, thermally-conductive, and electrically non-conductive material, such as, but not limited to, molded plastic and ceramic. Device body 210 provides a cavity within which LEDs 212, 214, and 216 are mounted. The cavity is formed by a set of sidewalls and a floor, as shown in Figures 2B and 2C. The dimensions of device body 210 may vary. In one example, the length may be about 5.5 millimeters (mm), the width may be about 5.5 mm, and the height may be about 2.5 mm. Leads 220 may be formed of electrically conductive material, such as, but not limited to, a gold plated copper alloy. Leads 220 may be any standard lead structure, such as surface-mount type leads. On any given side of device body 210, the on-center spacing of leads 220 may be, for example, about 1.78 mm.

[0011] LEDs 212, 214, and 216 are standard LED die devices of various application- or user-defined color combinations that produce white light. In particular, the combination of the individual colors emitted by LEDs 212, 214, and 216 may mix to produce white light and, thereby, render 3-in-1 LED device 200 a white illumination device. In a preferred embodiment, at least one LED is a blue LED, while the color of the remaining two LEDs may vary (e.g., various combinations of red, green, blue, yellow, orange, cyan, and/or magenta). The placement of the blue LED within the physical 1x3 array formed by LEDs 212, 214, and 216 is inconsequential. In one example, LED 212 is a red LED, LED 214 is a blue LED, and LED 216 is a green LED. In another example, LED 212 is a yellow LED, LED 214 is a blue LED, and LED 216 is a cyan LED.

3-in-1 LED device 200 is not limited to the examples cited above, other color combinations are possible.

[0012] LED 212, LED 214, and LED 216 are each mounted on respective pedestals 222, which reside within the cavity formed by device body 210. Each pedestal 222 may be formed of an electrically conductive material, such as, but not limited to, copper, aluminum, silver, and gold. At each pedestal 222, electrically conductive wires (not shown) are bonded between the anode and cathode of each LED and its respective pair of leads 220 and, thus, an electrical connection is formed therebetween, as shown in Figure 2A. In one example, pedestals 222 and, thus, LEDs 212, 214, and 216 may be placed on a pitch of about 0.95 mm.

[0013] LEDs 212, 214, and 216 are encapsulated within device body 210 by use of filler material 224. In one example, filler material 224 may be a blend of transparent epoxy (e.g., epoxy 226) and a quantity of phosphor material (e.g., YAG-phosphor 228). Epoxy 226 may be, for example, a substantially transparent epoxy resin. Additionally, the percent by volume of YAG-phosphor 228 that is mixed within epoxy 226 may be, for example, from about 0% to about 5%.

[0014] The combination of phosphor material with a blue LED produces a high-brightness white light source. One example manufacturer of high-brightness LEDs that uses YAG-phosphor in combination with a blue LED is Nichia Corporation (Japan). YAG is commonly used as the down-conversion phosphor in white LEDs, as YAG phosphor can be excited by the radiation from blue LEDs, which produces white light. An example supplier of powder phosphors consisting of micron- or submicron-size particles is Nitto Denko Technical Corporation (Carlsbad, CA). Another benefit of the presence of the phosphor material (e.g., YAG-phosphor 228) within epoxy 226 is that the phosphor material acts to diffuse the light that is emitted by LEDs 212, 214, and 216. As a result, 3-in-1 LED device 200 is converted from a point-emitting light source to a surface-emitting light source, which is more suited for functional lighting applications.

[0015] Referring again to Figures 2A, 2B, and 2C, various combinations of colored LEDs within 3-in-1 LED device 200 for producing a white light source that is suitable for functional lighting applications are disclosed, e.g., red (R), green (G), blue (B), yellow (Y), orange (O), cyan (C), purple (P) and/or magenta (M). In each case, 3-in-1 LED device 200 may include at least one blue LED that reacts with the YAG (i.e., B+YAG) to produce white light. In the case in which 3-in-1 LED device 200 includes R, G, and B+YAG, this combination provides the mechanism by which the CT (see Figure 1) may be determined and adjusted, as compared with standard light sources. The addition of R and G provides a shift along black body curve 112 of chromaticity diagram 100 of Figure 1 further toward the blue area, as compared with an LED with B+YAG alone. Furthermore, by varying the electrical current that is supplied to LEDs 212, 214, and 216, the colors of the LEDs may change slightly, which has a positive effect on producing a higher CRI.

[0016] In another example configuration, 3-in-1 LED device 200 may include Y, P, and B+YAG to produce white light and to provide yet a further shift along black body curve 112 toward the blue area, as compared with B+YAG alone or R, G, and B+YAG. In yet another example configuration, 3-in-1 LED device 200 may include Y, C, and B+YAG to produce a device with a yet higher CRI because this combination adds even more spectra to the light.

[0017] In all instances of 3-in-1 LED device 200, adding two colors, such as R and G, to B+YAG adds more light spectra, which increases the CRI and, thus, increases the light quality.

[0018] Figure 3A illustrates a schematic diagram of an example of a 4-in-1 LED device 300, according to another embodiment of the invention. 4-in-1 LED device 300 is another example of an *n*-in-1 LED device of the invention. 4-in-1 LED device 300 is substantially the same as 3-in-1 LED device 200 of Figures 2A, 2B, and 2C, except that it includes four LEDs instead of three LEDs. For example, in addition to LEDs 212, 214, and 216, 4-in-1 LED device 300 includes an LED 218, along with its associated leads 220 and pedestal 222.

[0019] Figure 3B illustrates a top view (not to scale) of an example of 4-in-1 LED device 300 of Figure 3A packaged in an 8-pin device. Figure 3C illustrates a cross-sectional view (not to scale) of 4-in-1 LED device 300, taken along line BB of Figure 3B. Figures 3B and 3C show LEDs 212, 214, 216, and 218 encapsulated within device body 210 of 4-in-1 LED device 300 by filler material 224, which is, for example, the blend of epoxy 226 and a quantity of YAG-phosphor 228, as described with reference to Figures 2A, 2B, and 2C.

[0020] In one example, 4-in-1 LED device 300 may be formed by a 1x4 array of LEDs. In another example, 4-in-1 LED device 300 may be formed by a 2x2 array of LEDs. The dimensions of device body 210 may vary. In one example, the length may be about 6.5 mm, the width may be about 5.5 mm, and the height may be about 2.5 mm. Again, on any given side of device body 210, the on-center spacing of leads 220 may be, for example, about 1.78 mm.

[0021] The combination of the individual colors emitted by LED 212, LED 214, LED 216, and LED 218 may mix to produce white light and, thereby, render 4-in-1 LED device 300 a white illumination device. In a preferred embodiment, at least two of LEDs are blue LEDs, while the color of the remaining two LEDs may vary (e.g., various combinations of red, green, blue, yellow, orange, cyan, and/or magenta). The placement of the two blue LEDs within the physical 1x4 or 2x2 array formed by LEDs 212, 214, 216, and 218 is inconsequential. In one example, LED 212 is a red LED, LED 214 is a blue LED, LED 216 is a blue LED, and LED 218 is a green LED. In another example, LED 212 is a yellow LED, LED 214 is a blue LED, LED 216 is a blue LED, and LED 218 is a cyan LED. 4-in-1 LED device 300 is not limited to the examples cited above, other color combinations are possible.

[0022] Because blue LEDs tend to have a shorter lifetime than red and green LEDs, the presence of two blue LEDs in the package allows the user to activate the first blue LED alone and then activate the second blue LED only when the first blue LED begins to fail. Additionally, both blue LEDs may be activated simultaneously, but at a reduced power level, which prolongs their lifetime. In both cases, a technique is provided for prolonging the overall lifetime of the device due to failure of the blue LED. An additional benefit of including two blue LEDs is that in the event that the epoxy discolors (browns) over time, activating the second blue LED can help overcome the losses due to the epoxy.

[0023] In the case wherein 4-in-1 LED device 300 includes R, G, B+YAG, and B+YAG, this combination provides the mechanism by which the CT may be determined and adjusted, as compared with standard light sources. Furthermore, by varying the current that is supplied to LEDs 212, 214, 216, and 218, the colors of the LEDs may change slightly, which has a positive effect on producing a higher CRI. Additionally, 4-in-1 LED device 300 provides a yet further expanded (multi-spectra) device as compared with 3-in-1 LED device 200, which results in a yet higher CRI.

[0024] In another example, 4-in-1 LED device 300 includes R, G, O and B+YAG, which provides a yet further expanded (multi-spectra) device for achieving a yet higher CRI. For Because all three LEDs of 3-in-1 LED device 200 and all four LEDs of 4-in-1 LED device 300 are activated simultaneously, their power rating may be reduced for a certain illumination as compared with one white LED only producing the same amount of illumination. Therefore, the thermal management system (not shown) associated with 3-in-1 LED device 200 and 4-in-1 LED device 300 may be simplified as compared with high-power LEDs. Additionally, the combination of multiple (e.g., three or four) LEDs in a single package produces a surface-emitter device, instead of a point-emitter device.

[0025] Separate leads for each LED of 3-in-1 LED device 200 and 4-in-1 LED device 300 allows individual control of forward bias voltage (e.g., R=2 volts, B and G=4 volts). However, the invention is not limited to separate leads. Additionally, 3-in-1 LED device 200 and 4-in-1 LED device 300 may include a common lead to drive multiple LEDs when operating, for example, in a common anode or common cathode configuration.

[0026] Because the human eye is sensitive to variations in white light, combining R and G with B+YAG provides a mechanism for CT tracking (compensation). B+YAG alone provides a broad range of about 65% CT tracking, but adding R and G to B+YAG allows, for example, the device to be adjusted to 6900K and held constant. Adding R and G to B+YAG allows compensation to move light along the CT curve (see Figure 1). The result is that the *n*-in-1 LED devices of the invention provide a white light illumination device that has a CT in the range of 3200K to 9500K and a CRI of 90 and above.

[0027] Furthermore, the present invention is not limited to 3-in-1 and 4-in-1 devices, other *n*-in-1 devices are possible. For example, a 6-in-1 device may be formed by use of R, G, B+YAG and Y, C, B+YAG. R, G, B+YAG allows of CT shift toward red only, whereas Y, C, B+YAG further allows a CT shift toward blue (see Figure 1). In this example, further adjustability is provided. In the examples of 3-in-1 LED device 200, 4-in-1 LED device 300, and any other *n*-in-1 devices, adding two or more colors, such as R and G, to B+YAG adds more light spectra, which increases the CRI and, thus, increases the light quality.

[0028] Furthermore, in the examples of 3-in-1 LED device 200, 4-in-1 LED device 300, and any other *n*-in-1 devices, the epoxy may be replaced with silicon, as the use of silicon may increase the lifetime of the device. Additionally, in the examples of 3-in-1 LED device 200, 4-in-1 LED device 300, and any other *n*-in-1 devices, the LEDs may be replaced with organic LED (OLED) devices to produce a white light source that is suitable for functional lighting applications.

Optimized light-emitting diode (LED) devices that have a high color rendering index (CRI) for lighting applications

ABSTRACT OF THE DISCLOSURE:

Embodiments of optimized light-emitting diode (LED) devices that have high color rendering index (CRI) values for lighting applications are disclosed. LED devices of the invention provide multiple LEDs (e.g., red, green and blue) in one package (i.e., *n*-in-1 devices), which allows color mixing in order to provide an appropriate white light source for illumination purposes that, additionally, has the capability to provide color temperature (CT) tracking. For example, the LED devices of the invention may utilize at least one blue LED in combination with phosphor material, i.e., yttrium-aluminum-garnet phosphor (YAG-phosphor), for producing white light. The LED devices of the invention include two or more colors, such as red and green, plus blue-plus-YAG in order to add more light spectra, which increases the CRI and, thus, increases the light quality.

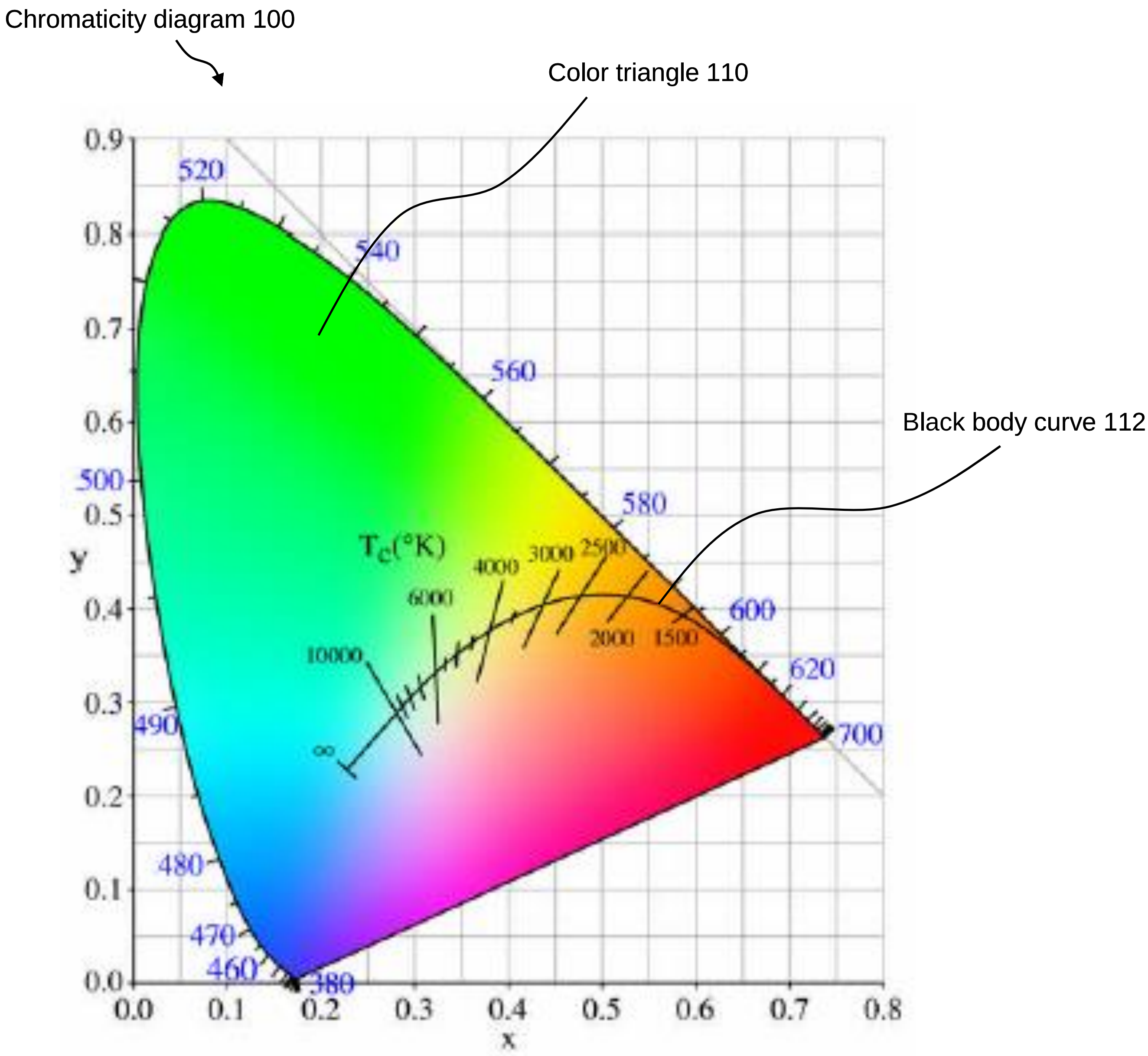
Chromaticity diagram 100
Color triangle 110
Black body curve 112
520
540
560
580
600
620
700
500
490
480
470
460
380
Tc(°K)
10000
6000
4000
3000
2500
2000
1500
∞
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x
y

FIG. 1

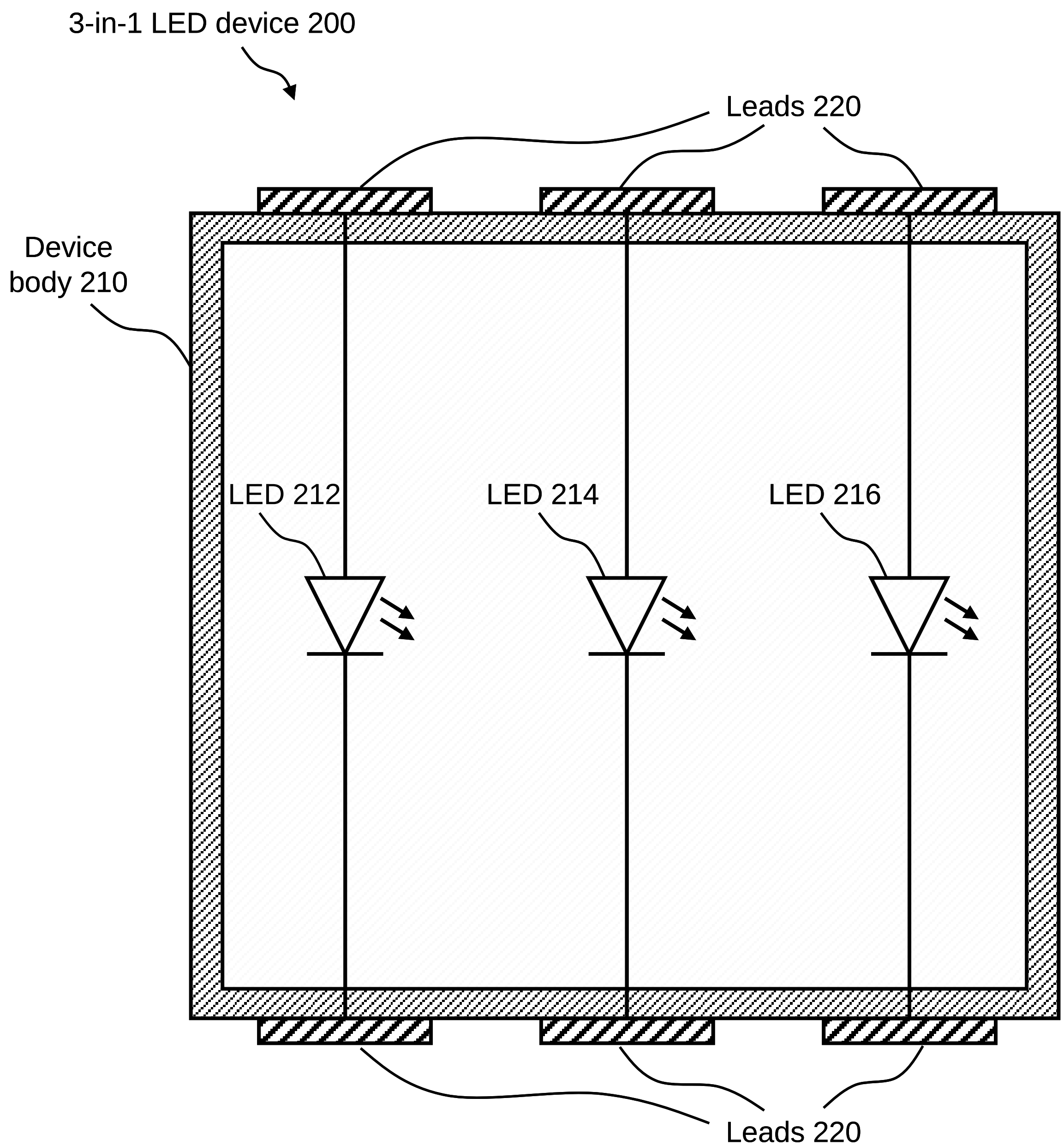
3-in-1 LED device 200
Leads 220
Device body 210
LED 212
LED 214
LED 216
Leads 220

FIG. 2A

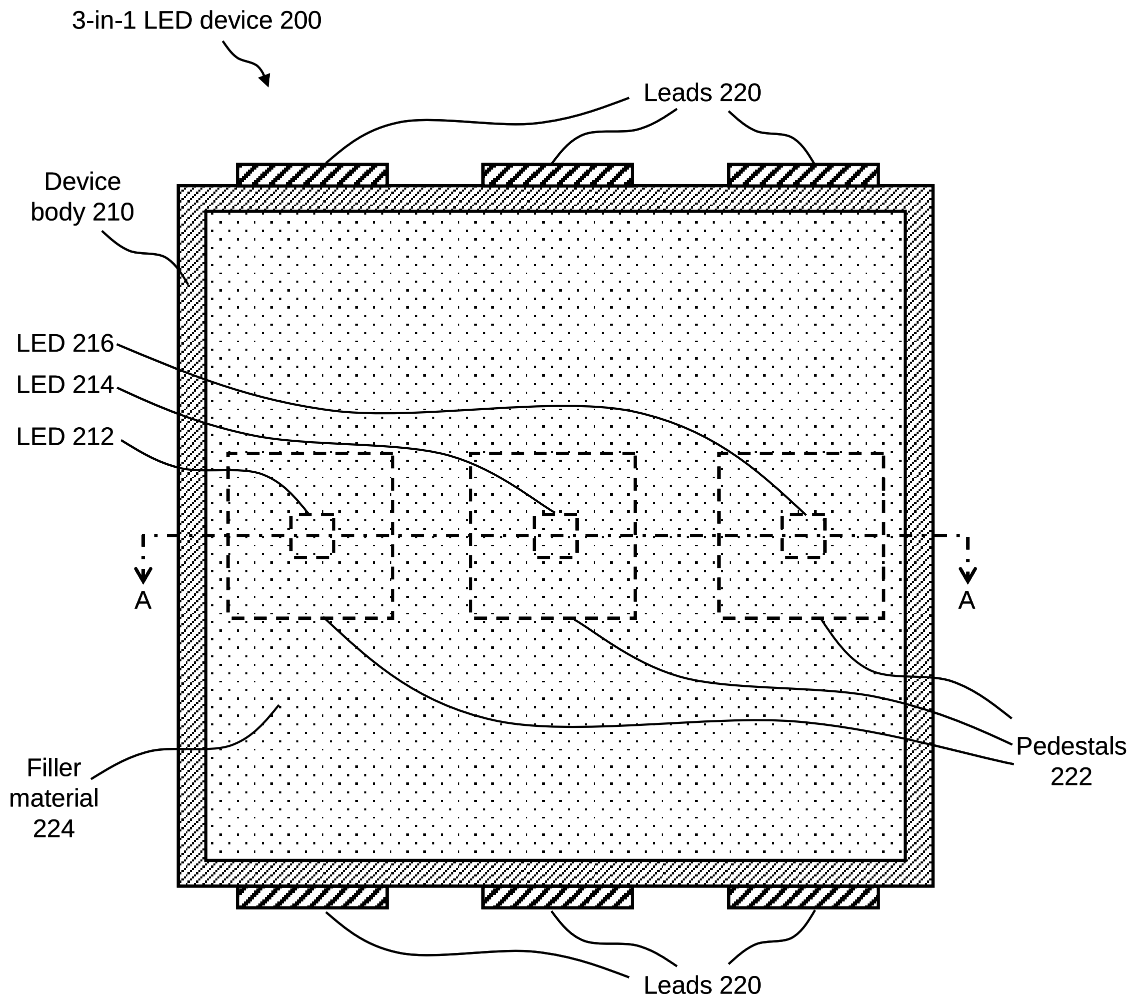
3-in-1 LED device 200
Leads 220
Device body 210
LED 216
LED 214
LED 212
A
A
Filler material 224
Pedestals 222
Leads 220

FIG. 2B

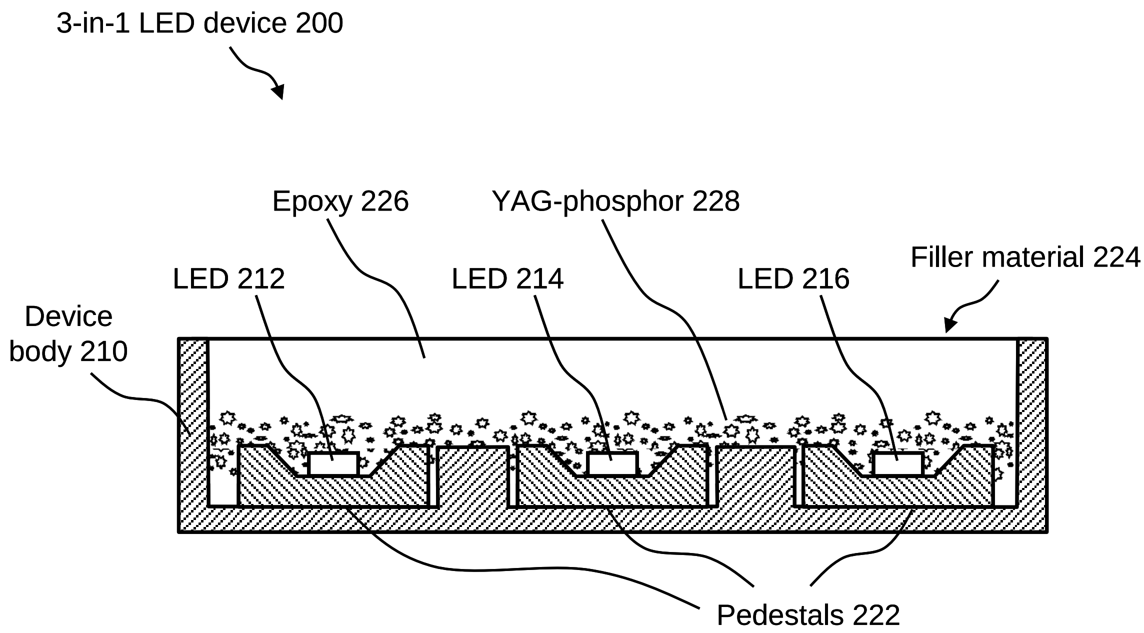
3-in-1 LED device 200
Epoxy 226
YAG-phosphor 228
Filler material 224
LED 212
LED 214
LED 216
Device body 210
Pedestals 222

FIG. 2C

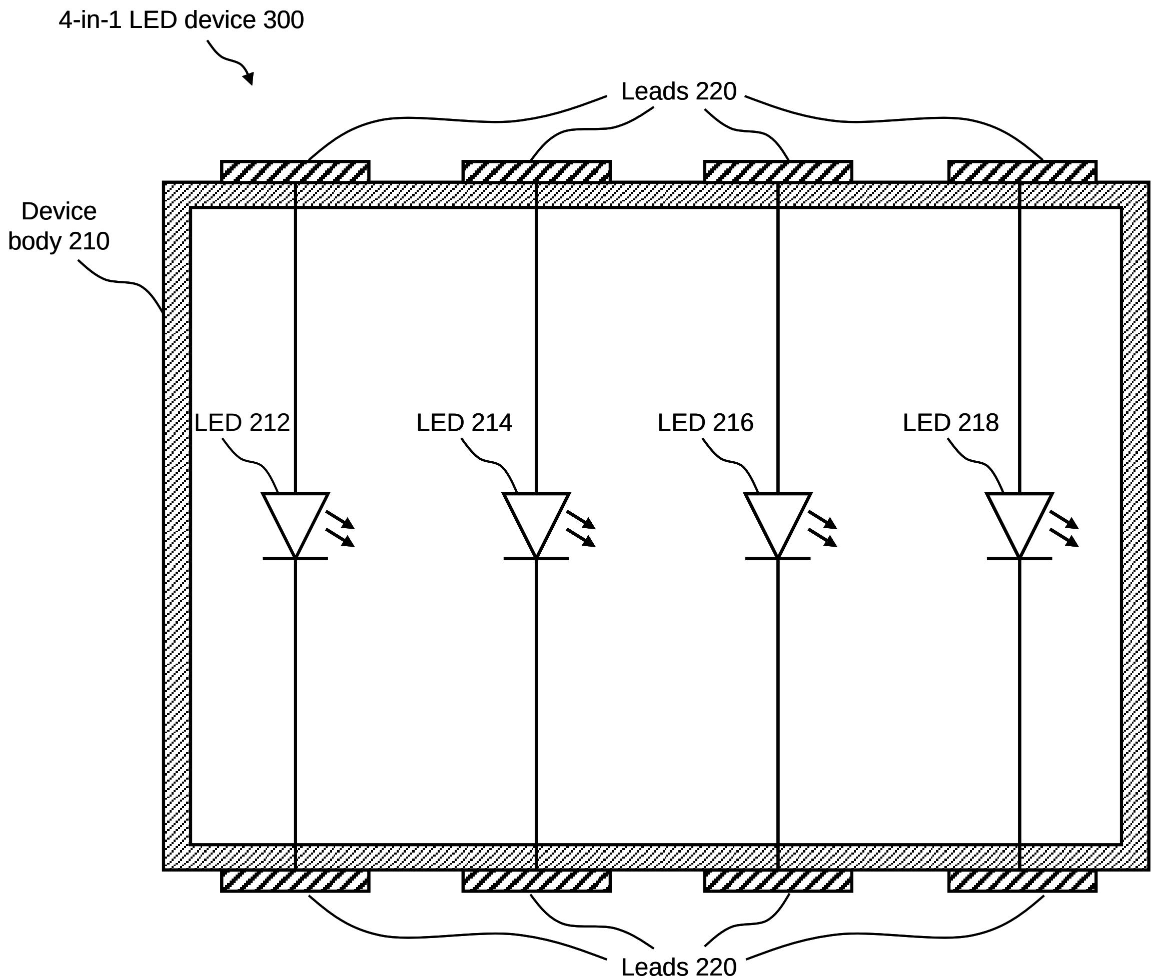
4-in-1 LED device 300
Leads 220
Device
body 210
LED 212
LED 214
LED 216
LED 218
Leads 220

FIG. 3A

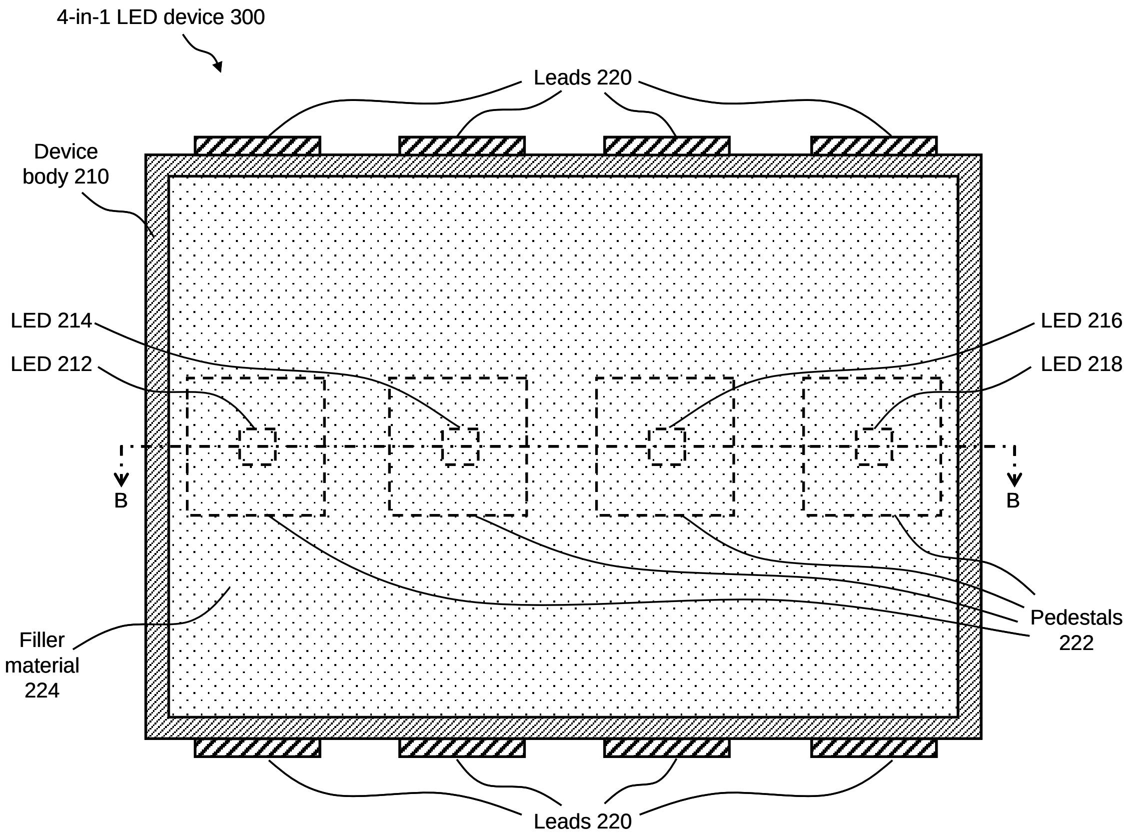
4-in-1 LED device 300
Leads 220
Device body 210
LED 214
LED 212
LED 216
LED 218
B
B
Filler material 224
Pedestals 222
Leads 220

FIG. 3B

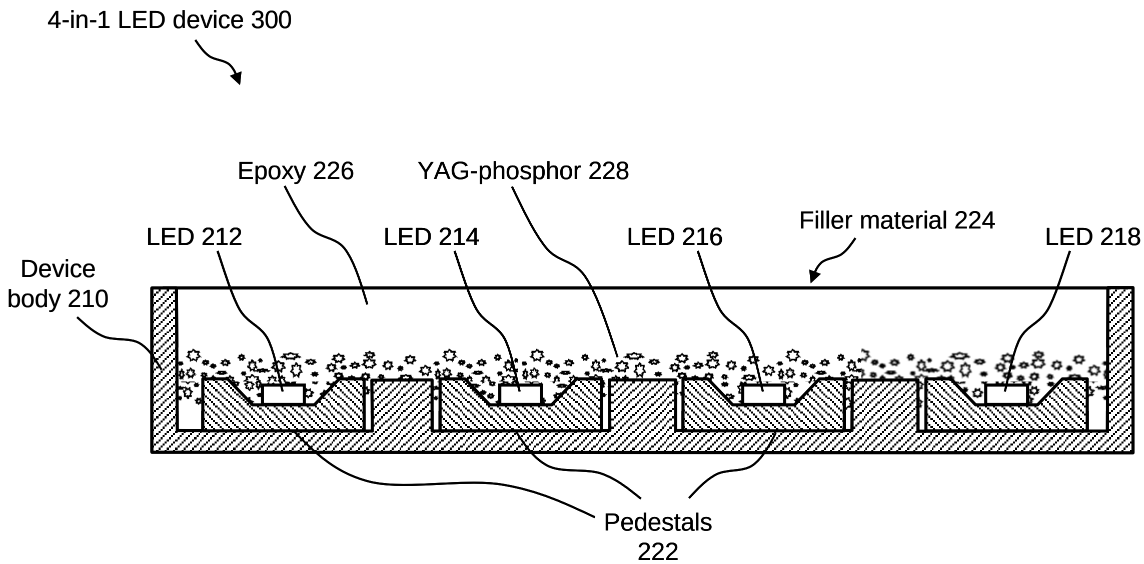
4-in-1 LED device 300
Epoxy 226
YAG-phosphor 228
Filler material 224
LED 212
LED 214
LED 216
LED 218
Device body 210
Pedestals 222

FIG. 3C

