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Polymer dispensing and embossing technology for the lens type LED packaging

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Abstract
This study presents a ring-type micro-structure design on the substrate and its corresponding micro fabrication processes for a lens-type light-emitting diode (LED) package. The dome-type or crater-type silicone lenses are achieved by a dispensing and embossing process rather than a molding process. Silicone with a high viscosity and thixotropy index is used as the encapsulant material. The ring-type micro structure is adopted to confine the dispensed silicone encapsulant so as to form the packaged lens. With the architecture and process described, this LED package technology herein has three merits: (1) the flexibility of lens-type LED package designs is enhanced; (2) a dome-type package design is used to enhance the intensity; (3) a crater-type package design is used to enhance the view angle. Measurement results show the ratio between the lens height and lens radius can vary from 0.4 to 1 by changing the volume of dispensed silicone. The view angles of dome-type and crater-type packages can reach $155^\circ \pm 5^\circ$ and $175^\circ \pm 5^\circ$, respectively. As compared with the commercial plastic leaded chip carrier-type package, the luminous flux of a monochromatic blue light LED is improved by 15% by the dome-type package (improved by 7% by the crater-type package) and the luminous flux of a white light LED is improved by 25% by the dome-type package (improved by 13% by the crater-type package). The luminous flux of monochromatic blue light LED and white light LED are respectively improved by 8% and 12% by the dome-type package as compare with the crater-type package.

(Some figures may appear in colour only in the online journal)

1. Introduction

Semiconductor based solid-state lighting (SSL), until recently associated mainly with simple indicator lamps in electronics and toys, has become as bright and efficient as incandescent bulbs at nearly all visible wavelengths. SSL has successful penetrated into the applications of liquid crystal display backlight source, traffic lights, street lights, display, automotive, and architectural directed-area lighting [1]. As one of the options for SSL, the light-emitting diode (LED) has advantages such as low energy consumption, long operation life, non-toxic ingredients and a fast response time [2, 3], as compared with the traditional incandescent light bulb and fluorescent light tube. Thus, the LED has recently experienced a rapid growth in technological development, market and applications.

Packaging is a critical issue for LEDs. They are frequently packaged and further integrated with a lens for the purposes of efficiency enhancement, view-angle modification and light-pattern adjustment [4]. In general, there are two approaches for the integration of lenses and LEDs. The first approach is to add an external secondary optics lens onto the packaged LED [5]. However, the use of a secondary optics lens will lower the brightness by more than 10% [6], and will also lead to a bulky

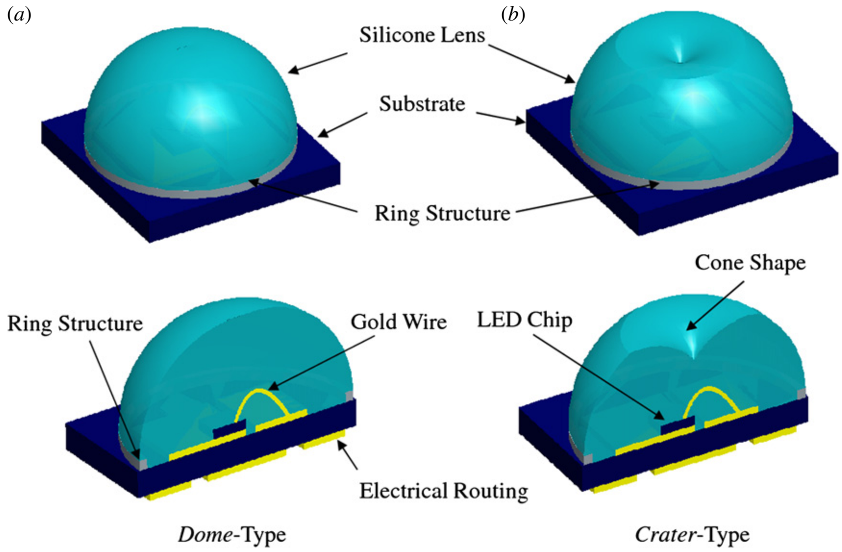

Figure 1. Design concept of the LED package and their cross sectional views: (*a*) dome-type design and (*b*) crater-type design.

system. Moreover, there are several issues caused by the lens assembly that need to be considered, such as the lens cost and yield loss. The second approach is the formation of a lens-type LED package [7]. In this design, the LED is encapsulated by silicone to protect the chip and its electrical connections. Meanwhile, the silicone has a lens-shaped surface for optical purposes. As reported in [8], the silicone molding system was widely adopted during the fabrication of high-power LEDs. However, the silicone molding system has a relatively high cost. The formation of dome-shape lenses uses a UV-curable epoxy confined by deep trenches and phosphor applied by a screen printing process [9, 10]. Thus, the lens formation and the LED package are achieved simultaneously. These are promising and cost-effective approaches for LED packages.

This study extends the concept in [9] to present a mold-less lens-type LED packaging technology [11]. Liquid silicone with a high viscosity and thixotropy index is dispensed to encapsulate the LED chip and also form the dome-type lens. Meanwhile, the ring-type micro structures bonded on the Al2O3 substrate surface are exploited to confine the bottom radius of the dome-type lens. The rings can also be employed to define the locations and pitches of the dome-type lenses. Thus, the materials for the substrate and ring are not limited to the fabrication processes. By adopting the ring structure and the high-viscosity/-thixotropy silicone, dome-type lenses could be formed on any type of substrate without a mold. Moreover, this study also adds an embossing process to define additional patterns on a dome-type lens. For instance, a crater-type lens is achieved after the embossing of a stamp with cone shapes on the dome-type silicone lens. Thus, the lens shape can be further modulated using the approach presented to change the emitting characteristics of the packaged LED.

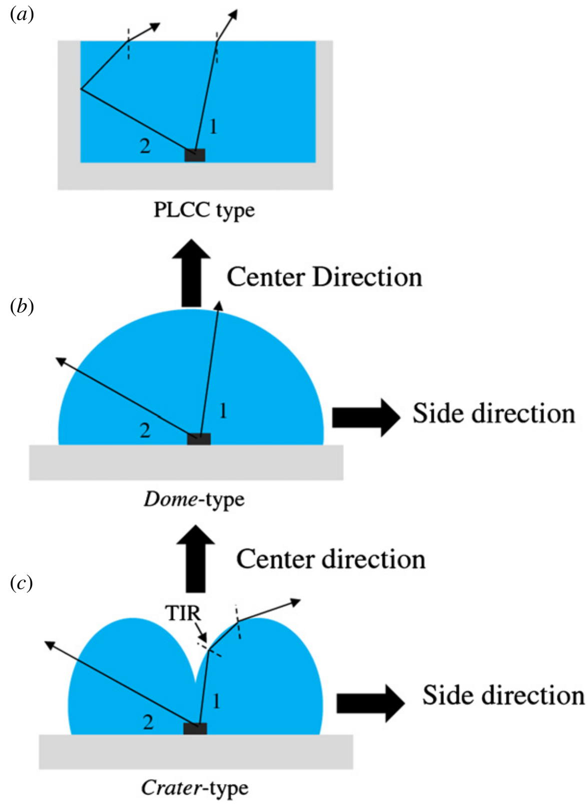

Figure 2. Light progressing in three types of package structures: (*a*) PLCC type, (*b*) dome- type, and (*c*) crater-type.

2. Concept and design

Figure 1 illustrates the proposed dome-type and crater-type package designs and their cross-sectional views. The packaged device consists of five major components including a ring-type micro structure, ceramic substrate (with electrical routings), LED chip, gold wire, and silicone lens (dome-type or crater-type lens). The ceramic substrate works as a main structure to support the LED chip. The metal wire acts as the electrical connection after the die bonding. The ring which is on the substrate and surrounds the LED chip

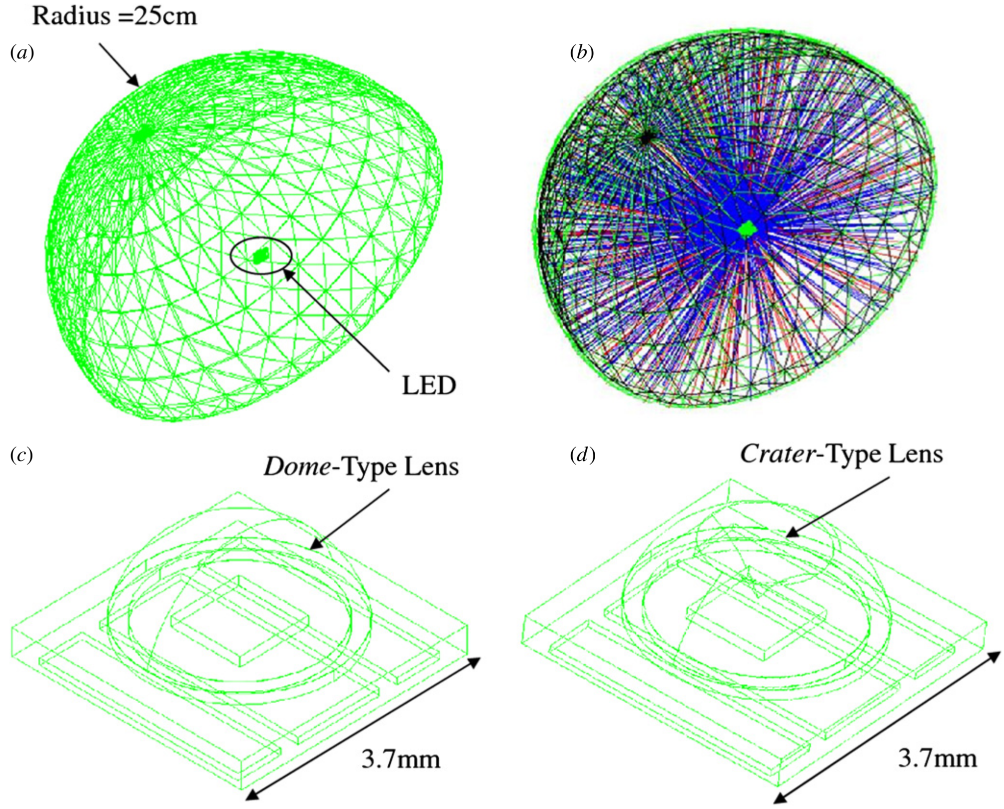

Figure 3. Model for optical simulation, (*a*) the package is arranged in the center of hemisphere shell, (*b*) light emit to the inner surface of hemisphere shell, and (*c*) dome-type package, and (*d*) crater-type package.

is employed to confine the liquid silicone during the lens formation process. The silicone also acts as the encapsulant material to protect the gold wire and chip. Thus, the shape of the dome-type silicone lens indicated in figure 1(*a*) is determined by the surface tension along the sidewall of the ring and silicone surface and the gravity of silicone. Moreover, the dome-type lens can be further re-shaped by means of an additional embossing process during the silicone curing. Thus, the silicone lens can be re-shaped for different applications. For instance, this study presents the crater-type silicone lens design shown in figure 1(*b*). Figure 2 schematically illustrates the light progressing path of the plastic leaded chip carrier (PLCC), dome and crater types LED packaging approaches, respectively. It shows that the cone shape of the crater-type lens can modulate the incident angle on the top surface of the lens. A similar concept has also been reported in [12]. Thus, the total internal reflection on the lens surface is modulated to alter the progressing path of the light from the top center to the side area. As a result, the enhancement of side-emitting light can be achieved by the crater-type lens.

To clarify the characteristics of the spatial radiation patterns of these two types of package designs, an LED package with a monochromatic blue light LED chip is considered herein, using numerical optical simulation which is based on Monte-Carlo ray-tracing method [13]. A commercial software TracePro was also employed for optical simulation. As shown in the optical simulation model in figure 3(*a*), the packaged LED is arranged at the center of a hemisphere shell with an inner radius of 25 cm. As specified by this

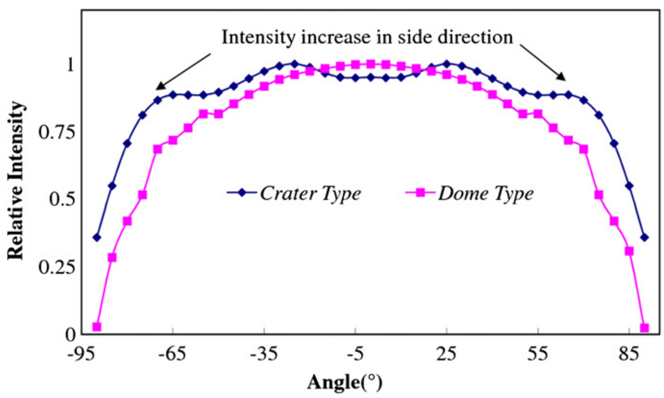

Figure 4. The intensity distribution of spatial radiation in the inner surface of hemisphere shell.

simulation model, the LED emits toward the inner surface of the hemisphere shell. The model agrees well with the measurement conditions afterward. Figure 3(*b*) displays a typical ray-tracing plot predicted by the model. The packaged LED is arranged in the center of the hemisphere shell for ray-tracing calculation. The models in figures 3(*c*) and (*d*) further respectively display the dome-type and crater-type package designs investigated in this study. The typical simulation results, shown in figure 4, of a monochromatic blue light LED for both dome-type and crater-type packaged LEDs, depict the relative intensity of spatial radiation distributed along different angles on the inner surface of the hemisphere shell

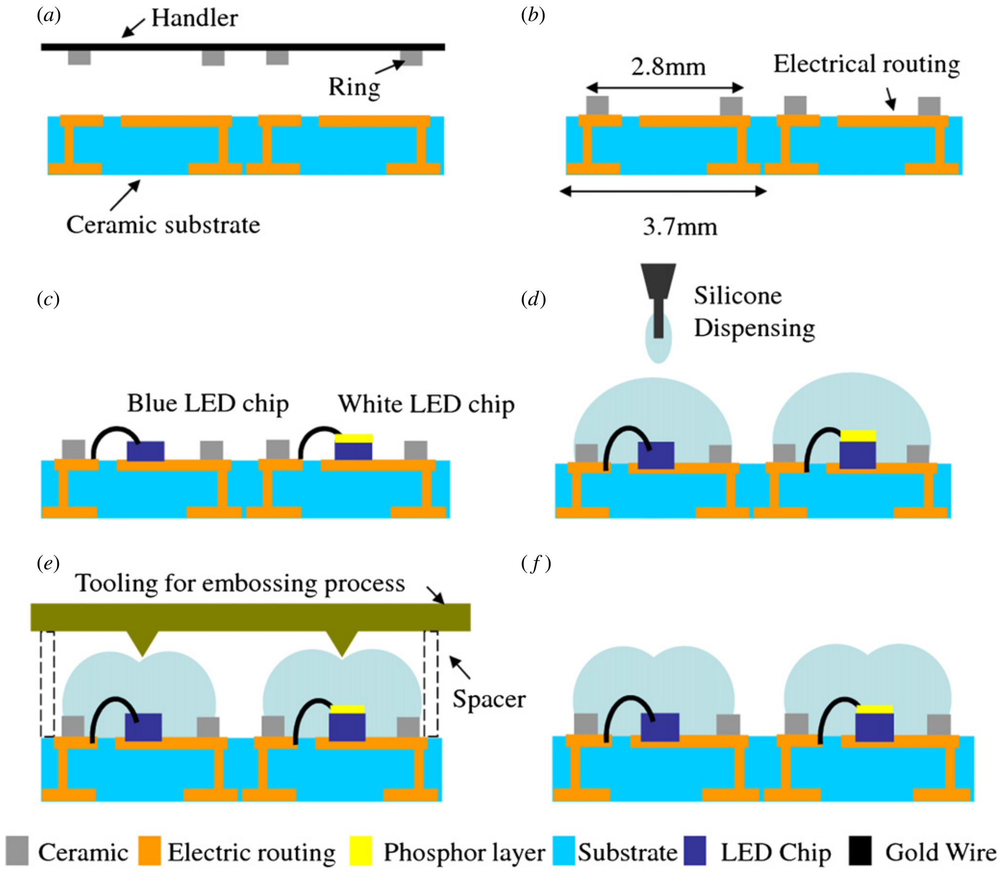

Figure 5. Fabrication and packaging steps, (*a*) ring type micro structure bonding on ceramic substrate, (*b*) ceramic substrate with ring type micro structure and electrical routing, (*c*) LED chip bonding and wire bonding, (*d*) silicone dispensing to achieve the dome-type package, and (*e*), (*f*) an additional embossing process to implement the crater-type package.

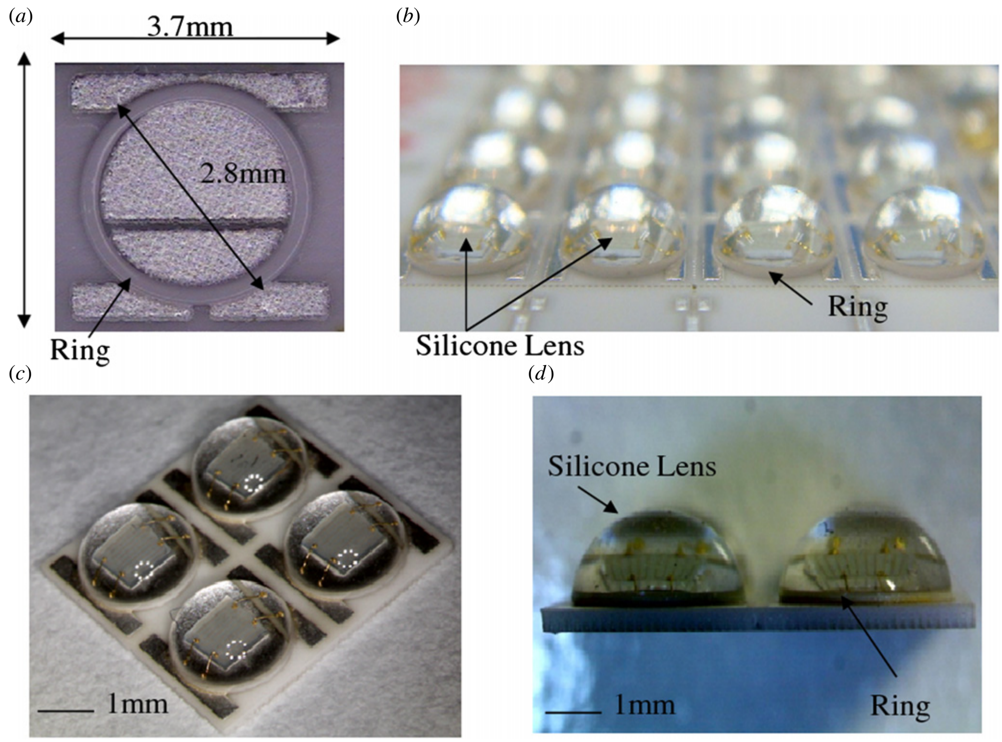

Figure 6. Typical fabrication results of (*a*) ceramic substrate, (*b*) dome-type package, and (*c*), (*d*) the zoom-in top and side views of dome-Type package.

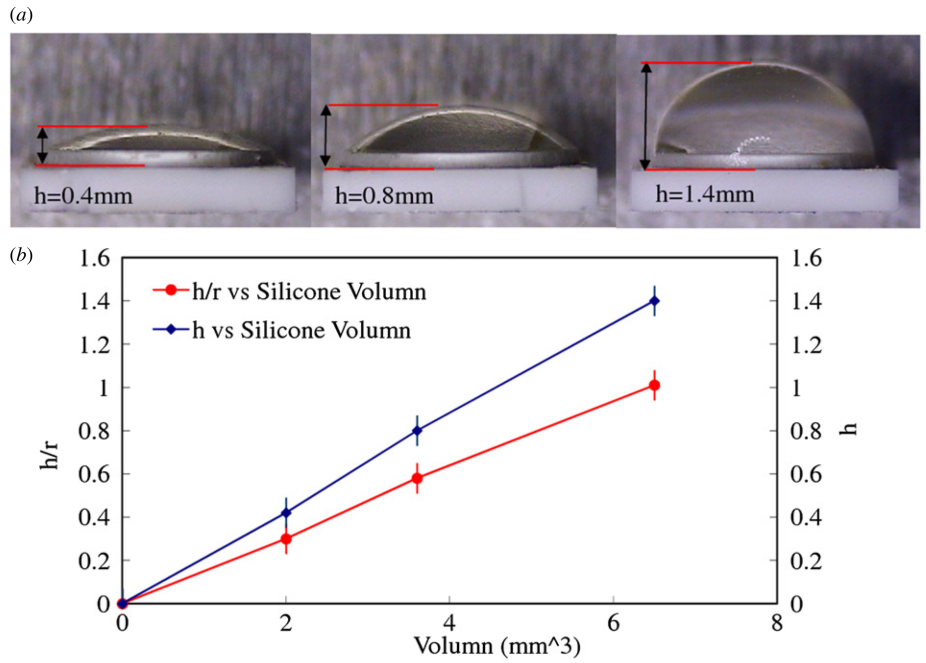

Figure 7. Dome-type lens shape modulated by the volume of dispensed silicone, (*a*) various lens heights, (*b*) h and h/r versus silicone volume by measurements.

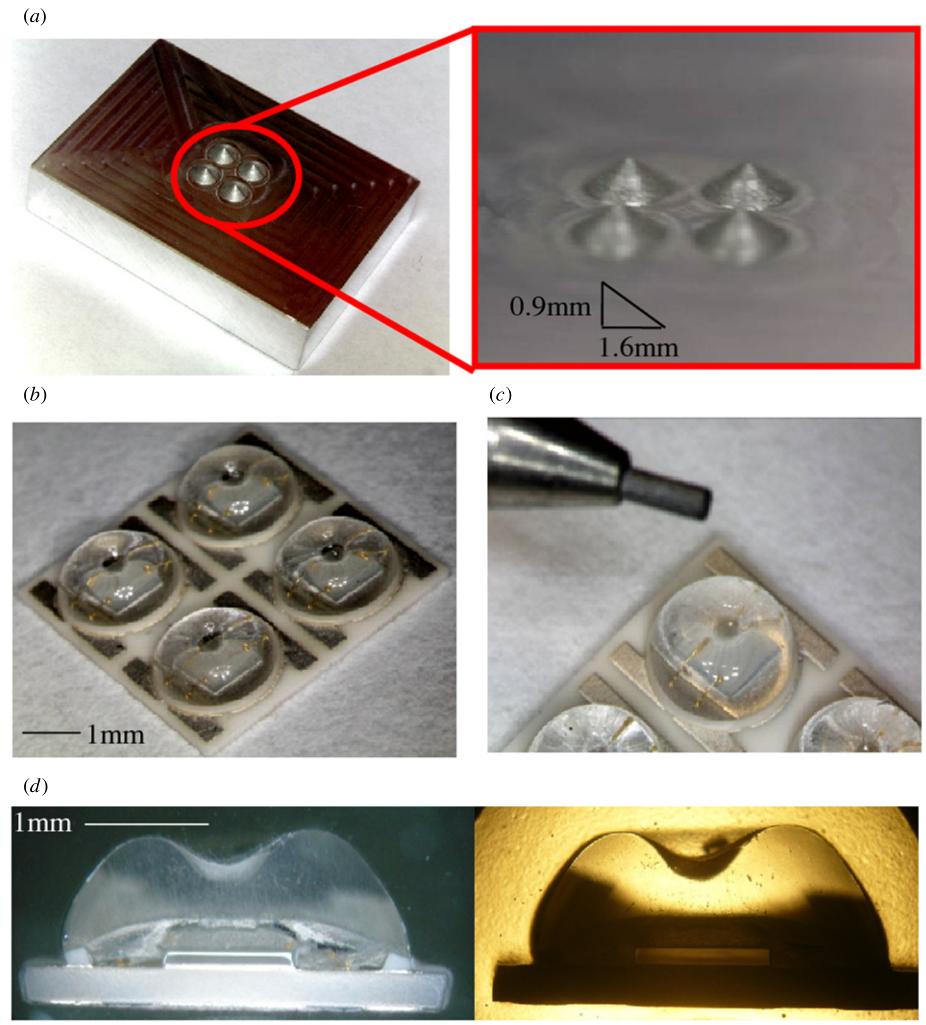

Figure 8. Typical fabrication results of crater-type package, (*a*) tooling used for embossing process, (*b*) and(*c*) crater-type package, (*d*) cross-sections of crater-type lens.

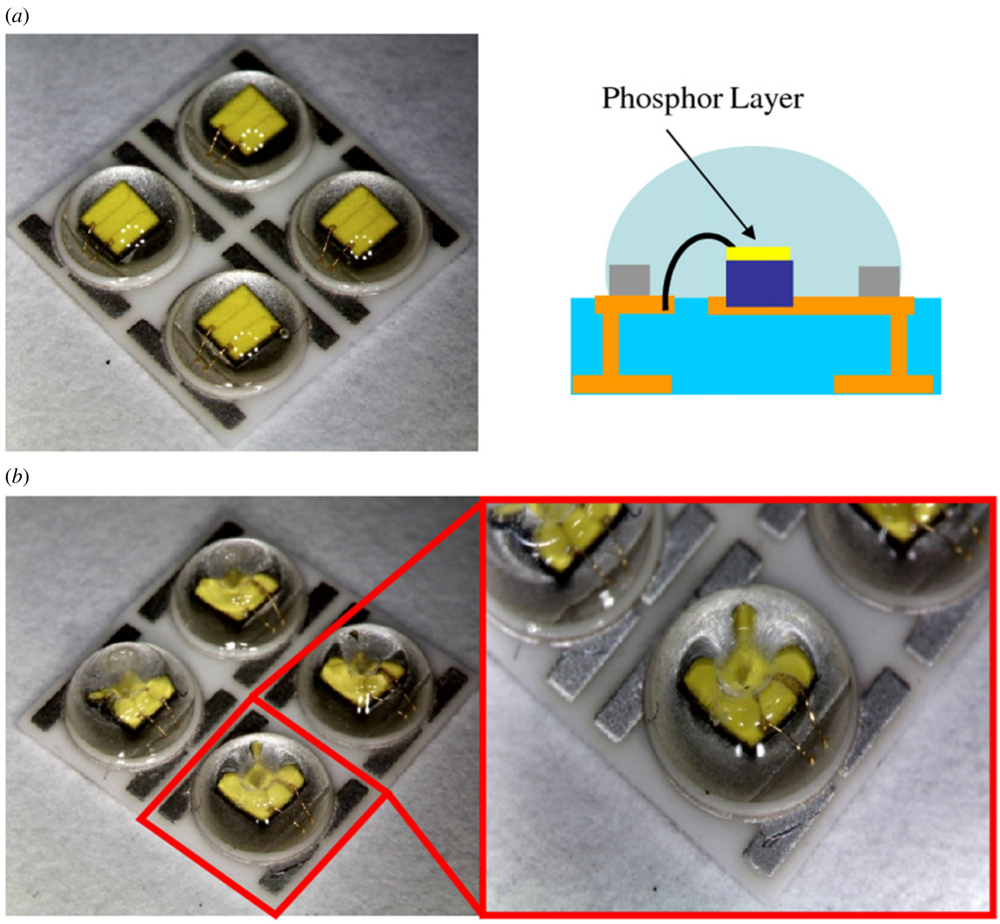

Figure 9. Typical fabrication results of white light LED, (*a*) dome-type package, and (*b*) crater-type package.

seen in figure 3(*a*). The results indicate that the distribution of relative intensity can be changed by varying the shape of the encapsulated silicone lens. For instance, as compared with the dome-type package, the crater-type one could significantly increase the relative intensity of spatial radiation from 0 to 0.3 at the angles of 90° and −90°. In short, the crater-type package could enhance the relative intensity of spatial radiation at the side direction of a packaged LED. As compared with the curves in figure 4, the relative intensity of spatial radiation of the crater-type package is more uniform than that of the dome-type package within the angle range of (−75°, 75°).

3. Fabrication and results

Figure 5 shows the proposed process flow to achieve the LED packaging indicated in figure 1. The process started with the preparation of ring-type micro structures on a handler using the molding process, as shown in figure 5(*a*). After that, ring-type micro structures with the dimensions of 200 μm in width and 120 μm in height were bonded and transferred onto the ceramic substrate with electrical routing, as shown in figure 5(*b*). The typical in-plane dimension of a packaged unit is 3.7 mm × 3.7 mm, while the radius of the ceramic ring was 1.4 mm. The through hole filled with the conductive material was used for the electrical connection between the top and bottom surfaces of the ceramic substrate. As shown in figure 5(*c*), LED chips were bonded on the top surface of the substrate and then the electrical connection between chip and substrate was achieved by wire bonding. In this study, two different LED chips including (1) the monochromatic blue light LED chip, and (2) the white light LED chip which has a phosphor layer attached on the top surface of blue chip, were bonded in each package structure in figure 5(*c*). After bonding, liquid silicone, with a high viscosity and thixotropy index, was dispensed (using a commercial pneumatic dispensing system) as the lens as well as an encapsulant material. As displayed in figure 5(*d*), the liquid silicone was trapped inside the ring structure and further formed a silicon lens on top of the ceramic substrate. The dome-type lens shape was determined by the ring diameter and the dispensed silicone volume. The dome-type package was achieved after the silicone was fully cured. As indicated in figure 5(*e*), an additional embossing process could be applied to further modify the shape of the silicone lens. For instance, this study employed a cone-shape stamp to emboss patterns on the lens before the silicone was cured. The indentation depth of the stamp during embossing was controlled by the spacers indicated in the figure. After fully curing the silicone, the cone-shape stamp was removed and the LED was packaged by the silicone lens with a pattern for special application (a crater-type package for the enhancement of side-emitting light in this case) was achieved, as shown in figure 5(*f*). Thus, the influence of the two presented

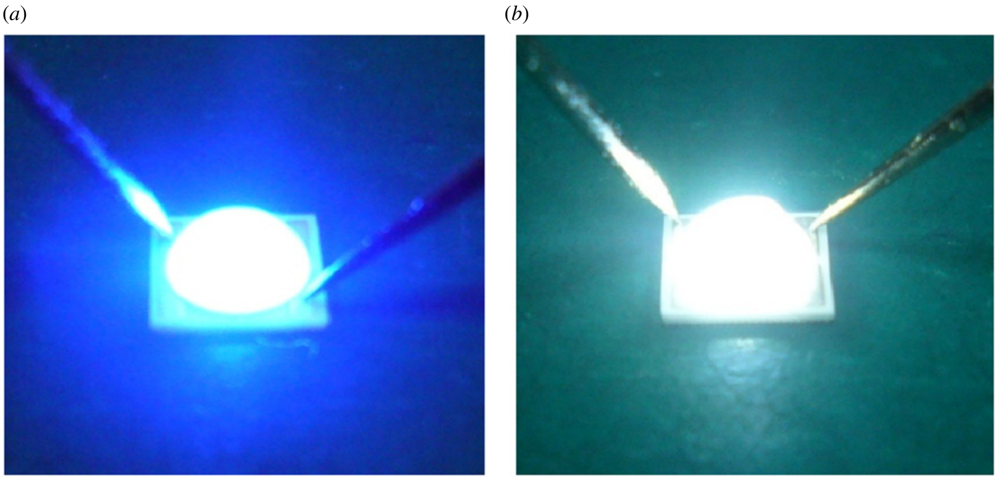

Figure 10. Light emitting from dome-type package with (*a*) monochromatic blue light LED chip, and (*b*) white light LED chip.

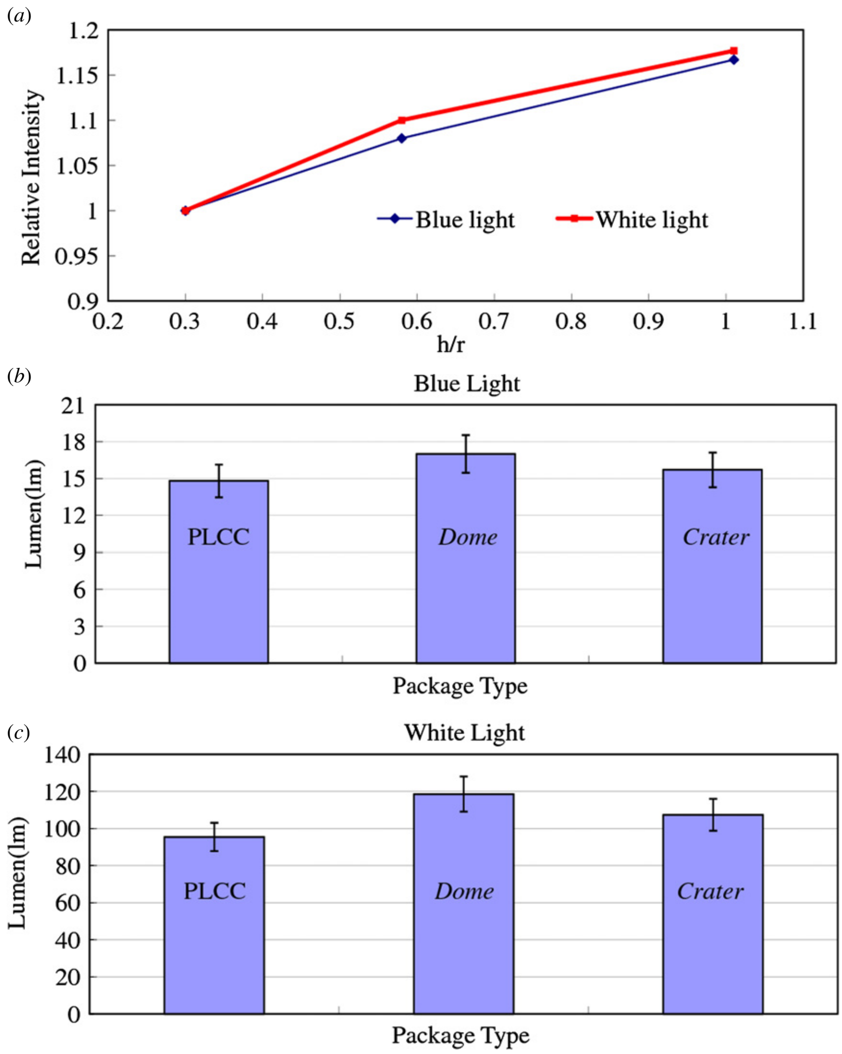

Figure 11. Measurements of LED package, (*a*) relative intensity versus h/r for dome-type package, and (*b*), (*c*) luminous flux of monochromatic blue light and white light LED chips packaged in three different approaches.

package techniques (dome-type and crater-type) on the optical characteristics of two different LED chips (blue light LED and white light LED) could be investigated accordingly.

The typical fabrication results are shown in figures 6–8. The photo in figure 6(*a*) shows the ring-type micro structure successfully transferred to the ceramic substrate with electric

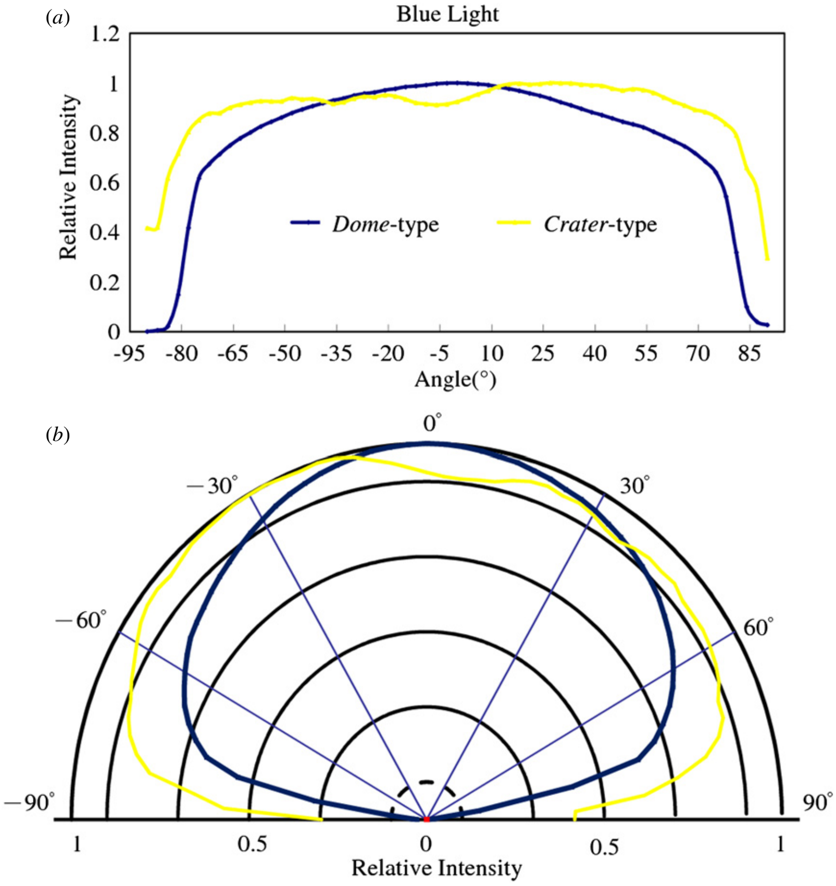

Figure 12. Measurement results of spatial radiation patterns for packaged monochromatic blue light LED, (*a*) rectangular coordinates and (*b*) polar coordinates.

routings. The photo in figure 6(*b*) demonstrates the formation of a dome-type lens on a ceramic substrate after the silicone dispensing and curing process. Moreover, four dome-type LED packaged units and their corresponding side view photo are displayed in figures 6(*c*) and (*d*), respectively. In this case, the monochromatic blue light LED chip was packaged in a dome-type lens. The lens shape can be modulated by varying the volume of dispensed silicone. For example, the lens radius r confined by the ring structure is 1.4 mm, as shown in figure 7(*a*). However, the lens height h is changed from 400 μm to 1.4 mm after increasing the volume of dispensed silicone. Figure 7(*b*) shows the relationship between the lens shape (h/r and h) and silicone volume. The photo in figure 8(*a*) shows the stamp with cone shape structures for the embossing process to define a crater-type lens. Each cone has a bottom radius of 1.6 mm and a height of 0.9 mm. The photos in figures 8(*b*) and (*c*) show the blue LED chip encapsulated by the typical fabricated crater-type silicone lens. The photos in figure 8(*d*) show the cross-sections of embossed crater-type lenses. The center indentation in the crater-type lens is defined by the cone in figure 8(*a*). Furthermore, the micrographs in figure 9 depict the typical fabrication results of the white LED chip packaged using the present approach. Figures 9(*a*) and (*b*) respectively show the LED encapsulated by the dome-type and crater-type silicone lens. It is clearly observed that the top surface of the LED chip is covered with a yellow phosphor layer. Thus the blue light emitted from the LED chip could be converted into white light by the yellow phosphor layer [14, 15]. Figures 10(*a*) and (*b*) show the results of emitting lights respectively from the monochromatic blue light LED chip and the white light LED chip encapsulated by a dome-type package.

4. Measurement and results

As shown in figure 2, the lens design is important for the emitting characteristic of the LED package. This study characterizes the luminous flux for different packaged LEDs. In addition to the dome-type and crater-type packages, a commercial PLCC-type LED package with dimensions of 3.5 mm × 3.5 mm × 1 mm was also fabricated and tested. The 45 mil monochromatic blue and white light LED chips with a radiation power of 380 mW and driving current of 350 mA were used to further characterize the emitting efficiency of the proposed package structures. Measurement results in figure 11(*a*) show the relationship between the relative intensity and h/r for a dome-type package. Figure 11(*b*) shows that the luminous flux of a monochromatic blue light LED is improved by 15% by the dome-type package (improved by 7% by the crater-type package), as compared with the commercial PLCC-type LED package. In addition, measurement results in figure 11(*c*) show that the luminous flux of the white light LED is improved by 25% by the dome-type package (improved by 13% by the crater-type package), as compared with the

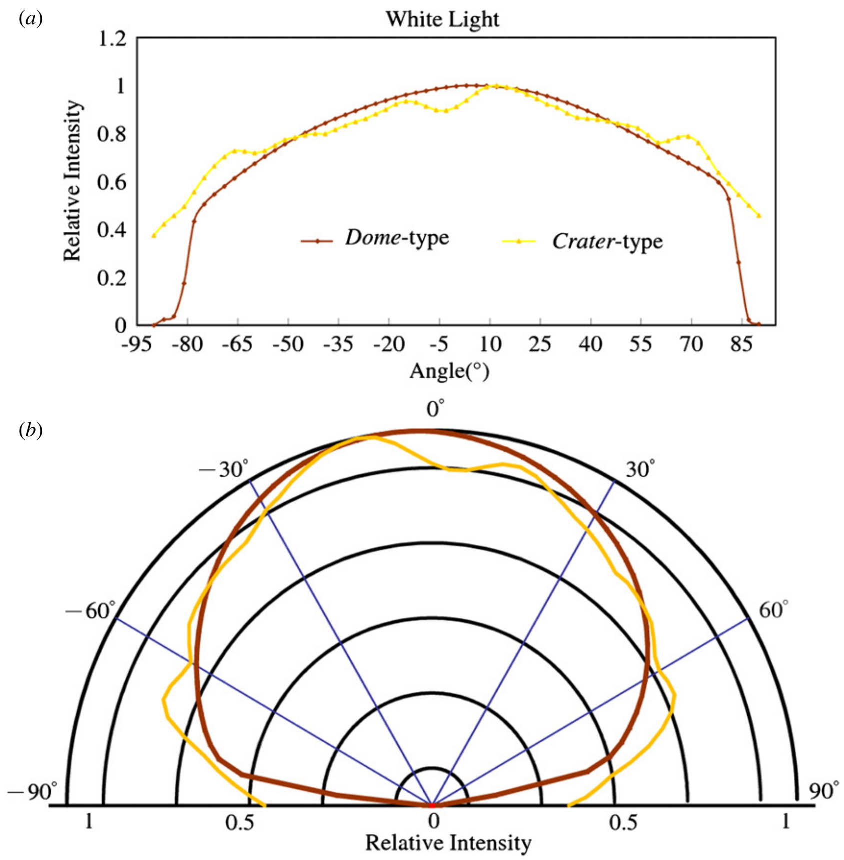

Figure 13. Measurement results of spatial radiation patterns for packaged white light LED, (*a*) rectangular coordinates and (*b*) polar coordinates.

commercial PLCC-type LED package. In other words, the luminous flux of a monochromatic blue light LED and white light LED are respectively improved by 8% and 12% by the dome-type package as compared with the crater-type package.

Figure 12 depicts the measured spatial radiation patterns of the monochromatic blue light LED package by the proposed approaches. The view angles of the dome-type and crater-type packaged LEDs could reach 156° and 176°, respectively. Moreover, the crater-type packaged LED has higher relative intensity within the angle of (25°, 90°) and (−90°, −40°), as compared with the dome-type package design. The measurements agree well with the simulations in figure 4. Note that a 40% relative intensity can be achieved at the angles of 90° and −90° as the crater-type package is adopted. In other words, the crater-type lens indeed enlarges the view angle of a packaged LED. Measurements in figure 13 further show the spatial radiation patterns of the white light LED packaged by the proposed approaches. Measurements indicate the view angles of dome-type and crater-type packaged LEDs could respectively reach 153° and 171°. The crater-type packaged white light LED also has a 40% relative intensity at the angles of 90° and −90°. Thus, the view angle of a packaged white light LED is also increased by the crater-type lens.

5. Conclusions

By utilizing the micro-fabrication, micro-structure design and material property, the low-cost methods of two lens types of LED package are presented. In this study, the ring-type micro structure is adopted to confine the encapsulant material. dome-type or crater-type silicone lenses are achieved by a dispensing and embossing process rather than a molding process. Silicone with a high viscosity and thixotropy index is used as the encapsulant material. Since the encapsulation method is not confined by the mold and the substrate material is not restricted to the fabrication process, the flexibility of package design could be enhanced. To clarify the characteristics of the spatial radiation patterns of these two types of package designs, the LED package with a monochromatic blue light LED chip is considered herein and a numerical optical simulation based on the Monte-Carlo ray-tracing method is carried out. Moreover, the monochromatic blue and white LED chips are employed to investigate the influence of phosphor on the corresponding optical characteristics of the dome-type and crater-type package designs. Measurement results indicate the ratio between the lens height and lens radius for the dome-type lens could vary from 0.4 to 1 by changing the volume of dispensed silicone. As compared with the commercial PLCC-type package, the luminous flux of monochromatic blue light LED is improved by 15% by the dome-type package (improved by 7% by the crater-type package) and the luminous flux of white light LED is improved by 25% by the dome-type package (improved by 13% by the crater-type package). The luminous flux of monochromatic blue light LED and white light LED are respectively improved for 8% and 12% by the dome-type package as compare with the crater-type package. The view angles of dome-type and crater-type LED packaged devices can reach $155^\circ \pm 5^\circ$ and $175^\circ \pm 5^\circ$, respectively. The crater-type packaged monochromatic blue light and the white light LED have a 40% relative intensity at the angles of 90° and -90°. Thus, the view angle of the packaged LED chip is successfully enlarged by the crater-type lens. In application, the dispensing method for a dome-type packaged LED will cause a 4∼5% lens height variation, and will further lead to a 2∼4% efficiency variation. As to the crater-type packaged LED, the lens shape variation could come from both the polymer dispensing and embossing processes. Thus, the cone-shape stamp for the embossing process was prepared by the computer numerical control machine. Moreover, this study employed a spacer to control the indentation depth of the cone-shape stamp during the embossing process, as indicated in figure 5(*e*). The measurements show that the variation of indentation depth in the crater-type packaged LED is 8∼12%, which leads to a 2∼3% variation in view angle. The geometrical accuracy of the crater-type lens can be improved with a better controlled indentation depth, as shown in figure 5(*e*).

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