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TiO_2/silicone encapsulation film for achieving optical performance improvement of chip-on-board packaging LEDs

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ABSTRACT

TiO_2 nanoparticle and silicon composite has powerful effect of scattering, thus it is famous in enhancing the scattered light in light-emitting diode (LED) packages. To accomplish higher lighting performance in LED devices, a thin encapsulation layer of TiO_2 with high concentration and silicon glue is introduced to complement the main encapsulation one. After conducting experiments, the results present that in the case of the main encapsulation including only silicone, the light extraction efficiency (LEE) of COB LEDs increases to 65%. On the other hand, when there is the additional layer of TiO_2 and silicone, the improvement of LEE depends on the concentration of TiO_2. As this nanoparticle concentration decreases from 0.12 to 0.035 g/cm^3, the LEE can be enhanced from 6% to 24%. Moreover, at the average correlated color temperature (CCT) of approximately 8500 K, the layer of TiO_2/silicone composite can help to accomplish the reduction of the angular correlated color temperature (CCT) deviation, from 900 to 470 K, within −90° to 90° viewing angle range.

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1. INTRODUCTION

Recent years, the phosphor-converted white light-emitting diodes (LEDs) have been recognized as they have impressive features such as high efficiency and stability, low-energy consumption, cost-saving, and eco-friendly nature. Thus, they have spread their applications over major general lighting fields, for example, lighting system for street, museum, and residential area [1-3]. Moreover, white LEDs are now utilized in other special lighting aspects, including vehicle forward lights, and lightings for gymnasium and projector [4-8]. However, there are more difficult challenges related to technical requirements for WLEDs to overcome to be successfully used in these applications, which are lower thermal resistance and higher input power, light efficiency, light quality, and durability. The packaging method that is mostly applied for LED equipment requiring power input of or over 10 W is the chip-on-board (COB) packaging. This technique bounds the LED chips onto the substrate surface of WLEDs, which brings more benefits to the performance of the LED than the traditional single-chip packaging. This new package has relatively low manufacturing cost, is easy to produce, and takes up less space than the usual package [9-11]. Nevertheless, due to the poor light efficiency caused by the total internal reflection (TIR), the package is not applied in advanced lighting applications. Additionally, COB packaging method also results in low angular color homogeneity for WLEDs [12-15].

Therefore, several approaches aiming to achieve the improvement of the light extraction efficiency for COB WLEDs through reducing the effect of TIR at the air-encapsulation interface were proposed, consisting of patterned substrates [16], roughening the interface of encapsulation layer [17], and domed-shaped encapsulation lenses [18]. These techniques gained positive results in light extraction efficiency (LEE) enhancements. Specifically, the patterned substrates with an optimized structure of the interface showed the highest value of LEE at 0.85, while the LEE of the roughened interfaces of encapsulation layer showed 12.13% enhancement. However, these results were much lower than that of the original single-chip packages [19-21]. For the domed-shaped encapsulation lens method, it possibly yielded better LEE but its size is not compact, and the production cost is also higher due to the large quantity of the encapsulation materials [22, 23]. Additionally, previous researches mostly concentrated on the LEE and color uniformity of the encapsulation containing only silicone, and the effect of COB LED with phosphor-silicone encapsulation on these properties are rarely reported. Thus, the way of figuring out an optimal COB packaging structure for better LEE and angular color uniformity (ACU) of WLEDs confronts many obstacles [24, 25].

This article will propose a COB packaging structure that can attain the improvement in both LEE and ACU for WLED packages. The new method adds a thin layer of high-concentration TiO_2 nanoparticles and silicone underneath the original plate. Then, the two encapsulation structures, one with only silicone and one with silicone and TiO_2 particles, are examined. The outcomes from experiments and calculations demonstrates a significant improvement in LEE of both encapsulation layer structures. Moreover, the addition of the phosphor silicone composite also increases the ACU.

2. SIMULATION

In Figure 1 is the illustration of a square LED model utilizing COB with the size of 40×40 mm. The COB substrate is comprised of a copper substrate with 340 W/(m·K) thermal conductivity and a 1.88 mm high square dam for encapsulation material coating. The top surface of the substrate has hollow dent covered by a sheet of silver to reflect the lights. The aera that is surrounded by the dam has a size of 20×20 mm, and has twenty 1×1×0.15 mm conventional blue LED chips attached in two parallel columns. Between each chip column is a 6mm separation distance while the space from each column to the boundary is 7 mm. The process of gold wire bonding in series is used to connect the two chip columns electronically.

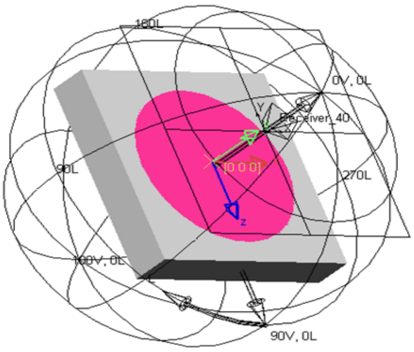

Figure 1. Simulation of LED COB packaging

Because of owning a high index of refraction (=2.7), TiO_2 nanoparticles have been added into encapsulation layer covering the blue LED chips to achieve a better LEE for WLED packages [10]. Besides the high refractive index, TiO_2 has a strong scattering capability, so we decided to take advantage of this characteristic to reduce impacts of the TIR occurring at the air-encapsulation interface by utilizing TiO_2 with high concentration [11]. Specifically, in addition to the main encapsulation layer, another encapsulation film is formed by mixing the silicone with high-concentration TiO_2 particles and located above the substrates. Moreover, this layer is very thin, approximately 40 micro thick in our conducted experiments. The notable point in this structure is the LED chips are not coated with the added phosphor silicone composite layer as this layer is placed next to each chip to prevent the chips from emitting light. This plate of TiO_2 and silicone composite has its thickness controlled by the dispensed volume of the composite. The TiO_2 particles used in this study have 50 nm particle size and no light absorption in the visible range. Meanwhile, the concentration of TiO_2 ranges from 0.035 g/cm^3 to 0.12 g/cm^3. In addition, the applied TiO_2/silicone composite has a refractive index that is directly proportional to the amount of TiO_2 and the distribution deviation in the layer [11]. In this article, the refractive index of the composite layer is approximately 1.799. Once the packaging procedures are done, the WLED simulations will be set on a heat sink for thermal ventilation. The integrating sphere is utilized to measure the LEE in the condition of air temperature, while the method similar to the one in [3] is responsible for the calculation of the ACU.

3. RESULTS AND DISCUSSION

Figure 2 illustrates the luminous flux corresponding to various concentrations and sizes of TiO_2 of different WLED modules, including the structure with no layer, the one with only silicone layer, and the double layers consisting of a thin film of TiO_2/silicone composite, respectively. As can be seen, the light efficiency from the dual-layer of encapsulation structure performs the best result. Meanwhile, the result attained from the structure with a pure silicone encapsulation film is the smallest one. These results are determined by the proportion between the radiation capacities from the package with material layers to the structure without any layer under identical energy source. Furthermore, the normalized LEEs are based on this description.

When the input current is in the range of 100 mA, the normalized LEEs are quite stable in both encapsulation structures. Specifically, the LEE of the double encapsulation structure remains at 1.12, while that of the single one stays at 0.68. In other words, the LEE yielded from the dual encapsulation layer is enhanced by 64.7%, higher than the improvement from the single encapsulation. The explanation for this difference can be demonstrated as the following points. In the structure of single encapsulation, at the surface where the encapsulation contacts with the air, a large proportion of light is reflected as a result of the TIR effect, and directed back to the packaging substrate. After that, the smooth substrate and the silver film in the structure get these lights reflected again, which leads to a circle of reflection of these light beams inside the LEDs, and in the end, such lights are absorbed by the packaging materials. However, the TiO_2/silicone film in the double encapsulation layer design causes the backward scattering of reflected lights at the upper interface to happen. Then, the scattered lights could be redirected and finally be able to get out. Therefore, the LEE in this double layer structure is improved considerably. On the other hand, the LEE depends on the concentration of the TiO_2 particles in the auxiliary encapsulation of the structure with two encapsulation layers. When the TiO_2 concentration increases from 0.035 g/cm^3 to 0.12 g/cm^3, the LEE decreases from 24% to 6%. This can be explained by the scattering effect of the nanoparticle: as its concentration gets higher, the light scattering becomes stronger. Hence, the scattering effect of TiO_2/silicone composite is lessened. Besides, both encapsulation structures also achieve lumen efficacy (LE), especially, the LE of the LED packages having 8500K CCT are 98 lm/W and 110 lm/W for the single and double encapsulation layer structure, respectively. Thus, it can be said that the double encapsulation layer design can result in 12.2% LE improvement.

In Figure 3, the CCT deviation of the encapsulation layer structures in connection with the TiO_2 concentration is demonstrated. It is noted that the average CCTs of both encapsulation layer structures, single and double ones, are maintained at 8500K for a better comparison. Obviously, within the range of -90° and 90°, the color temperature deviation of dual-layer structure is around 470 K while that of the single-layer one is approximately 900 K. Therefore, the dual encapsulation layer yielded 49% enhancement in ACU. This enhancement is attributed to the effect of strong scattering capability of the TiO_2/silicone composite film on reflected blue and yellow lights at the upper interface of the main encapsulation layer, resulting in a better uniformity between the blue and yellow light patterns of LED packages.

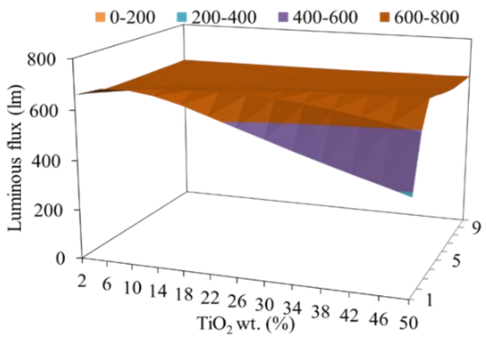

Figure 2. Comparison of luminous flux of TiO_2 particles with various diameters

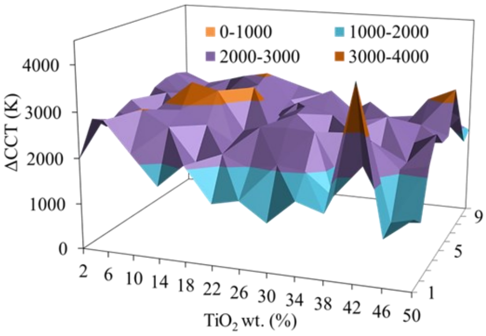

Figure 3. Comparison of CCT deviation of TiO_2 particles with various diameters

4. CONCLUSION

This article proposed a new method of constructing a COB packaging for better LEE and ACU, which is using a thin layer of encapsulation consiting of TiO_2 nanopaticle with silicone composite besides the main layer one. The results show that the complemeted TiO_2/silicone composite layer contributes much to the enhancemnet of LEE and ACU of LED packages. After being experimented, this kind of dual encapsulation layer proved its benefits in improving the optical properties of WLED COB packaging structure. According to the outcomes, the single pure silicone encapsulation layer can reach approximately 65% LEE enhancement. Meanwhile, the LEE of dual-layer encapsulation structure with TiO_2/silicone composite, which is in a close connection with the concentration of TiO_2, can peak at 24% when TiO_2 concentration declines to 0.035 g/cm^3. In addition to that, the ACU in the proposed encapsulation structure shows 49% improvement for 8500K CCT LED packages. In short, this dual encapsulation layer having TiO_2/silicone composite is a good choice for manufacturers who aim to achieve both LEE and ACU enhancements for their WLED products.

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