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Investigation of the thermal characteristics with the conformal and remote phosphor structures in white light-emitting diodes

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1. Introduction

Recently, white light-emitting diodes (LEDs) have become considerable attention due to the small size, high luminous efficiency, and longer lifetime of solid-state lighting (SSL). [1] In particular, the advantage of being mercury-free is more environmentally friendly than conventional lighting source. [2] Therefore, developing a high-luminous and high-quality steady light source is necessary to apply in SSL, especially in white LEDs. Currently, several methods are used to fabricate white light, of which the combination of a white LED chip and yellow-emitting phosphor has been determined to be of higher luminous efficiency than others such as the conformal and remote phosphor structures. [3]

This study analyzed the thermal characteristics of conformal and remote phosphor structures in white LEDs by investigating specifically both the junction temperature and phosphor temperature. The IR thermometer was used to measure the actual temperatures of the phosphor layers in the conformal and remote structures. In particular, the phosphor temperature in different positions is determined using finite element method (FEM) simulations. Furthermore, the simulation results clearly correspond favorably with the simulation results.

2. Experiments

In our experiment, the conformal and remote phosphor structures were fabricated using the pulse spray coating (PSC) method, which can spray phosphor film uniformly to generate high-quality white LEDs. The LED chip size is 24 mil/sq and the wavelength is 450 nm; the radiant fluxes of the blue chip are 400 mW at 350 mA. The phosphor slurry was prepared by combining a solvent, a silicone binder, and phosphor powders. For the conformal and remote structures, the phosphor slurry was sprayed onto the blue chip and silicone, as shown in Fig. 1. The phosphor layer coating step is the only fabrication difference of the two structures. The phosphor powder used in this experiment was silicate-based, with a particle size of 15 μm. To compare both structures, the color temperature was maintained at an injection current of 350 mA.

To examine the thermal effect on the conformal and remote phosphor structures, continuous wave and pulsed current sources were employed to compare the different operation currents. The correlated color temperature (CCT) of the conformal and remote phosphor structures is shown in Fig. 2(a). Both types of LEDs were driven by the current between 10 mA and 500 mA. Under pulsed current sources, the CCT of both types of LEDs remains nearly the same with the increased current. However, under the continuous-wave current sources, the CCT difference of the conformal phosphor structure is better than that of the remote phosphor structure, especially under higher current driving. This is attributed to the thermal effect of the LED devices. Furthermore, the phosphor efficiency in white LEDs is defined as

$$\eta_{pe} = \frac{I \times V}{W} \times WPE$$

where I is the operation current and V is the operation voltage, and W and WPE are the power and wafer package efficiency, respectively. The conversion efficiency of phosphor at different driven currents under the continuous wave (CW) and pulsed conditions are shown in Fig. 2(b). The Phosphor conversion efficiency decreases more rapidly in the remote phosphor structure than that in the conformal phosphor structure, especially under CW conditions. The results are attributed to the heat accumulation in the remote phosphor structure is faster than that in the conformal phosphor structure. Therefore, the phosphor conversion efficiency of the remote structure is strongly dependent to the thermal effect of the phosphor layer.

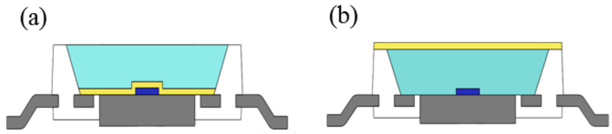

Fig. 1 Schematic diagrams of (a) conformal and (b) remote phosphor structure.

3. Results and Discussion

For the thermal characteristics of white LEDs, the junction temperature becomes a critical standard using the forward voltage method. The junction temperatures of the conformal and remote phosphor structures, from 50 mA to 550 mA, are shown in Fig. 3(a). In both structures, the junction temperature increases in conjunction with the current source. Moreover, the conformal phosphor structure has higher junction temperatures than does the remote phosphor structure, meaning that more backscattering light is absorbed by the blue chip and transfers heat to the conformal phosphor structure, leading to a higher junction temperature, particularly with the higher current. The actual temperatures of the phosphor layers in the conformal and remote phosphor structures were then measured by the IR thermometer. The samples were prepared for conformal phosphor structure without silicone, conformal phosphor structure with silicone and the remote phosphor structure, as shown in Figs. 3(b)-3(d). The surface temperature of the conformal structure without silicone is higher than that of the conformal structure with silicone. This is because the silicone layer blocks the heat transfer from the bottom phosphor layer. The phosphor temperature of the remote structure is much higher than the temperature of the conformal structure. This is attributed to the lower thermal conductivity of the silicone, which hardly dissipated the heat into the substrate. Consequently, this indicates a serious thermal problem in the remote phosphor structure.

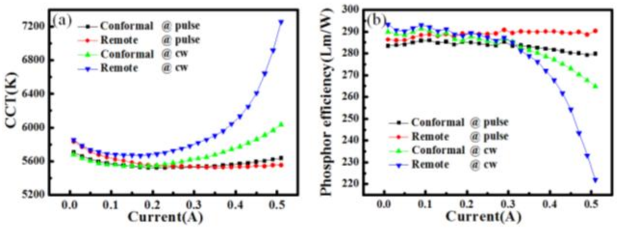

Fig. 2 (a) Correlated color temperature (b) phosphor efficiency with different currents using continuous wave and pulsed current sources.

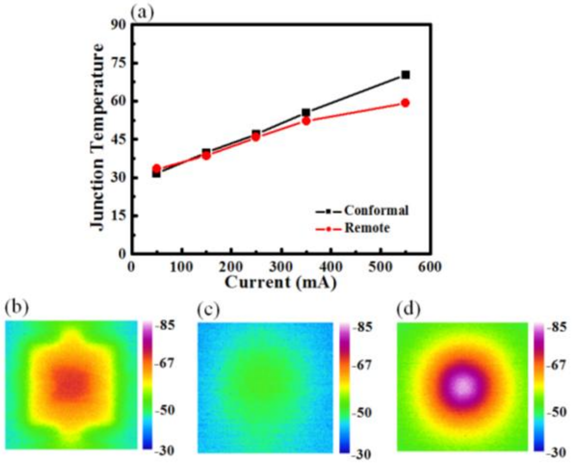

Fig. 3 (a) Junction temperature of conformal and remote phosphor structures at driving currents from 50 mA to 550 mA. IR images in (b) conformal without silicone (c) conformal with silicone and (d) remote phosphor structures.

The three simulated device structures are shown in the top of Fig. 4. The thermal conductivity parameters were used as the reported values in ref. 4 for the conformal and remote phosphor structures. Generally, the remote phosphor structure has a higher temperature than that of the conformal phosphor structure with and without silicone, which is obviously in the phosphor layer. For the conformal phosphor structure, the higher temperature is centralized on the chip because of the backscattering light of the phosphor. The heat can transmit from the chip and leadframe to the outside because of the higher thermal conductivity. This simulation demonstrates that such a conformal phosphor structure can effectively increase the capability of the heat conduction path from the package, thus reducing the effect of thermal problem in the phosphor.

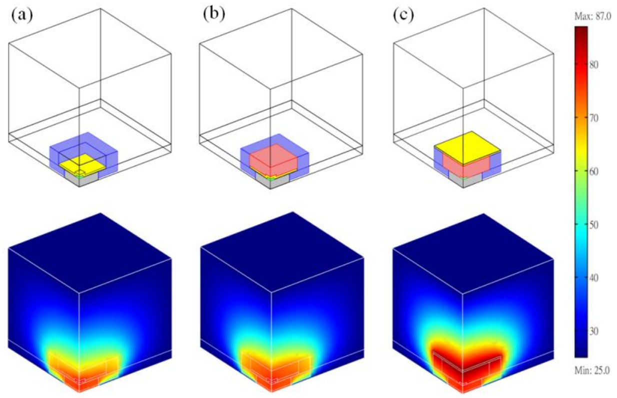

Fig. 4 Schematic diagrams of thermal distribution of (a) conformal without silicone (b) conformal with silicone (c) remote phosphor structure

4. Conclusions

In conclusion, the effect of thermal influence on the conformal and remote phosphor structures is demonstrated using the junction temperature and phosphor temperature. The correlated color temperature and phosphor efficiency vary dramatically with the increased current in the remote phosphor structure. Then, the junction temperature in the conformal structure is higher than that in the remote phosphor structure because of its lower thermal conductivity. Consequently, the results shown the thermal characteristic of the phosphor layer in the conformal structure is better than in the remote structure.

5. Acknowledgment

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