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Effect of gold wire bonding on optical performance of high power light-emitting diode packaging

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Gold wire bonding is an essential process of light-emitting diode (LED) packaging. This work aims to study the effect of gold wire shape and height on optical performance of LED package with freely dispersed phosphor layer. Three types of wire bonding are discussed. The geometry of phosphor layer affected by gold wires is simulated based on microfluidics theory. Simulation results show that different gold wire bonding affects the geometry of phosphor layer differently. When the outside part of gold wire is lower and closer to the surface of phosphor gel, the geometry will be impacted seriously and it results in obvious fluctuation trends of angular correlated color temperature (CCT) at different spatial planes in LED package. However, gold wire bonding has slight impact on the distribution of light intensity in the package. In the manufacturing process, the gold wire bonding process should be further designed and optimized for better LED products.

Keywords: Light-emitting diode, Wire bonding, Light intensity, Correlated color temperature.

Introduction

In recent years, due to the special advantages, such as low power consumption and long lifetime, light-emitting diode (LED) has more and more applications in our daily life and is widely accepted as the candidate for the next general illumination source. So far, most of white LEDs (WLEDs) are based on phosphor-converted principle, in which a blue GaN based LED is covered by a yellow phosphor layer [1]. Besides luminous efficiency, the major optical challenges for WLED are in terms of light intensity uniformity and angular CCT uniformity [2]. Phosphor coating technology plays an important role in overcoming the abovementioned challenges. Various phosphor coating technologies, such as conformal coating, spinning coating and so on [3-6], have been explored by corporations. Based on Monte Carlo ray tracing method, heavy works have been carried out to study the influence of structures and parameters of phosphor layers on optical per-formances of WLEDs. Our group studied the effects of phosphor's location [7] and phosphor settling [8] on LED package's optical performance, and we also investigated the impact of thickness of conformal coating phosphor layer [9] and the method to form conformal coating by using capillary microchannel [10]. Shi et al. optimized the phosphor layer's structure [11] and found that LED packaged with lower concentration and higher thickness phosphor had higher luminous efficiency [12]. Sommer et al. pointed out phosphor concentration and the geometry size should be precisely adjusted to assure angular-homogeneous white light [13]. However, the effect of gold wire bonding, as one essential process of LED packaging, on LED package's optical performance is not considered by most groups.

Phosphor freely dispersed coating process is widely adopted in WLED production due to its simplicity and low cost. In this kind of WLED product, the phosphor is made of YAG : Ce bound in silicone. LED manufacturers almost shorten the length of gold wire in order to cut down cost, and neglect the effect of wire bonding on phosphor layer's geometry, which ultimately affects WLED product's optical performance. Therefore, it is necessary to study the effect of gold wire bonding process on optical performance and optimize the appropriate gold wire bonding parameter for LED production. In our recent work, we conducted many experiments and found that the gold wire bonding affected the geometry of phosphor layer and CCT distribution distinctly [14]. In this work, we will try to utilize simulation to study the effect of different gold wire bondings on the optical performances of LED; both lighting intensity distribution and CCT are investigated.

Effect of wire bonding on geometry of phosphor layer

Geometry modeling

Fig. 1 shows one of the typical LED package without phosphor and encapsulates. After gold wire bonding, the phosphor gel is freely doped on the LED chip bonded on the round substrate, as shown in Fig. 2. After the phosphor gel is cured, the lens is laid on the substrate, and silicone gel is injected inside, as shown in Fig. 3. Phosphor gel is often the mixture of phosphor

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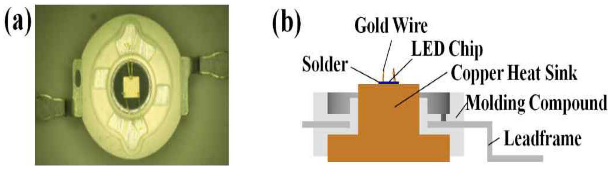

Fig. 1. LED module without phosphor layer and encapsulates: (a) Top view; (b) Sectional drawing.

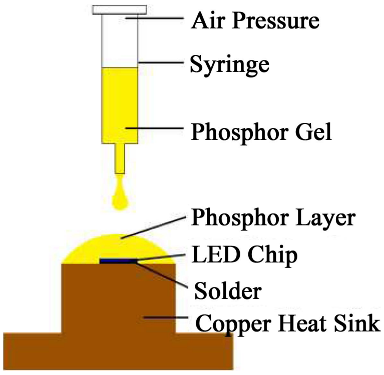

Fig. 2. Freely dispersed phosphor coating process.

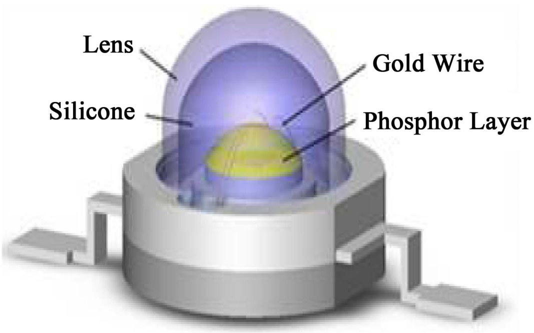

Fig. 3. Typical 1W LED package

powder and silicone, and surface of copper heat sink and gold wires are wettable for phosphor gel. On the one hand, phosphor gel spreads on the chip surface and top surface of copper heat sink in LED substrate; on the other hand, it spreads over the wire surface.

In LED packaging, for phosphor layer feature in the micro range, the surface to volume ratio is exceedingly large. Thus, the energy associated with the boundary surface and interfaces determines the overall shape and stability of liquid microstructure. Phosphor gel will spread over the wettable surfaces until reaching at equilibrium state. In equilibrium, the Young's equation (1) must be met in three phases line. Fig. 4 shows the line of contact where three phases meet.

$$\gamma_{SG}-\gamma_{sl}=\gamma_{GL}cos\,\theta \quad (1)$$

where γ_{ij} is the surface energy between the two indicated phases, S, L and G are short for solid, liquid and gas, respectively, θ is the contact angle.

Optical performance of LED package is sensitive to

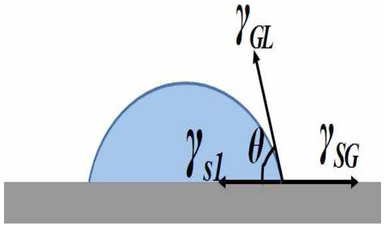

Fig. 4. Coexistence of 3 phases in mutual contact.

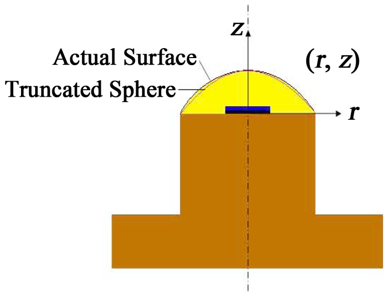

Fig. 5. Actual geometry of phosphor layer.

Fig. 6. Front view and left view of phosphor layers in LED module without gold wires.

the geometry of phosphor layer; thus, the precise model of phosphor gel is very important. In previous simulations of WLEDs, the phosphor layer is usually considered as a part of spherical cap. However, its real geometry, even without the impact of gold wires, is not exact truncated sphere, and it is closer to oblate spheroid, as shown in Fig. 5. A theory based on minimum free energy is applied to explain microfluidic morphology. Based on Laplace-Young equation, we know that, without the impact of gold wire, profile of phosphor layer is axially symmetric shape and it can be described as follows [15]:

$$\gamma\frac{\frac{d^2z}{dr^2}}{\left[1+\left(\frac{d^2z}{dr^2}\right)^2\right]^{\frac{1}{2}}}+\frac{\gamma}{r}\frac{\frac{dz}{dr}}{\left[1+\left(\frac{dz}{dr}\right)^2\right]^{\frac{1}{2}}}=-\gamma K_0+(\rho_l-\rho_g)gz \quad (2)$$

Where γ is the surface tension between liquid and gas; r and z are the radial and axial co-ordinate respectively; K_0 is the curvature of the interface of phosphor gel geometry at the edge of top surface in copper heat sink; ρ_l and ρ_g mean the densities of the liquid and gas respectively; g is the gravity acceleration. Although this second-order differential equation has no analytical solution, it can be solved by the numerical algorithm

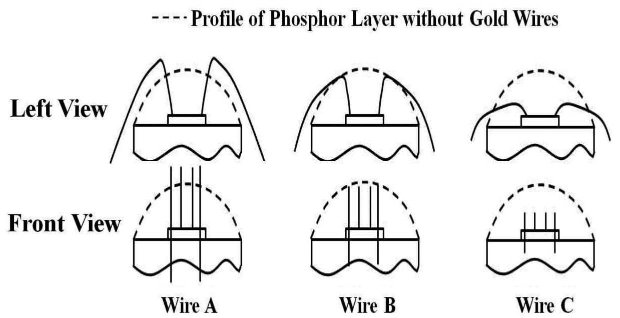

Fig. 7. Three kinds of gold wire bonding heights and shapes.

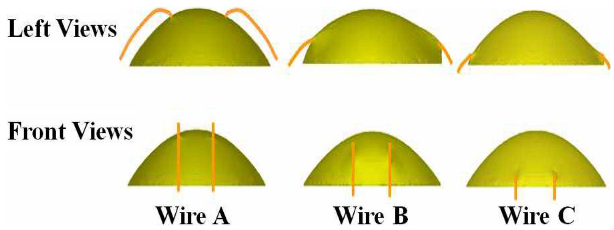

Fig. 8. Phosphor profiles of three LED package samples.

based on four-order Runge–Kutta method.

Fig. 6 shows the geometry shape of phosphor gel when not considering the gold wire based on the equation (2). In fact, the gold wires' effect cannot be neglected. In this work, three kinds of gold wire bonding heights and shapes are considered, as show in Fig. 7. For wire B, its outside part is closer to the surface of phosphor layer and its height is lower. The flow simulations, based on wetting theory, are carried out to obtain the geometry of phosphor layer. In the simulations, the volume of phosphor gel freely doped is set as the same as that shown in Fig. 6.

Geometry simulation results

The simulation results of phosphor layer geometry are shown in Fig. 8. It is found that the profiles of phosphor layers in packages with wire A and wire C are affected by gold wires slightly. Due to the wetting effect, more phosphor gel spreads along the gold wires' surfaces for the package with wire B. The shape of phosphor layer is influenced seriously in this case. With the impact of gold wires, the shape of phosphor layer will not be axially symmetric. It will result in the nonuniformity of optical performance in the package. Therefore, it is necessary to carry out the optical simulations.

Effect of wire bonding on optical performance of LED package

Optical modeling

Four optical models of LED packages are established in ray tracing simulation software, and the simulation theory is based essentially on Monte Carlo approach. This optical modeling method has been successfully used by our group in the previous works [2, 7-10, 16-18].

The structure of the LED optical model is described

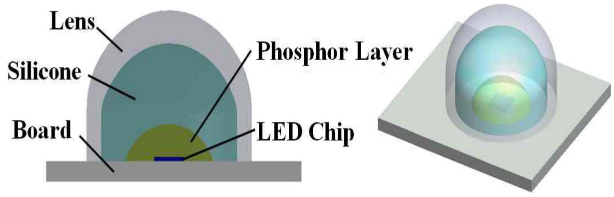

Fig. 9. Schematic of optical model.

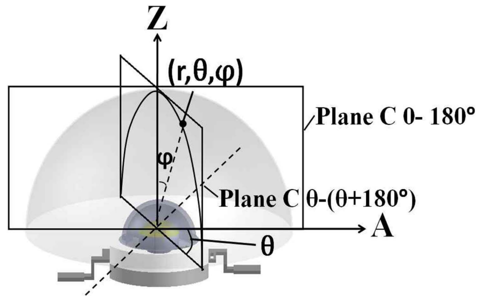

Fig. 10. Schematics of spatial planes.

in Fig. 9. Some essential simplifications are done while building the optical model. The size of LED chip is 1 mm × 1 mm, and the phosphor layer is set to behave as a bulk scattering medium with bulk absorption. Its concentration is 0.35 g/cm^3. The optical property of the phosphor layer can be calculated from our previous work [16-18].

The four optical models are labeled as samples 1 to 4. Geometry of phosphor layer in sample 1 is shown in Fig. 6. The phosphor layers in sample 2, sample 3 and sample 4 are corresponding to the ones with wire A, wire B and wire C, respectively, as shown in Fig. 8.

Blue and yellow light are calculated by Monte Carlo approach separately. The phosphor layer absorbs blue light, and then re-emits yellow light. In order to analyze the distributions of light intensity and angular CCT in the package, optical power of blue and yellow light are collected from inclination angle $\varphi = 0°$ to $\varphi = 180°$, at spatial plane and plane , as shown in Fig. 10.

Optical simulation results and discussions

Simulation results are shown in Fig. 11 and Fig. 12. Light intensity distributions (LIDs) of LED are very important. As shown in Fig.11, the LIDs for all the samples are close to Lambertian. And the largest light intensity is at the center, with the value around 0.075 W. The LIDs at plane $C0°-180°$ and $C90°-270°$ plane in every sample are nearly the same. It indicates that the gold wires, which affect the geometry of phosphor layer, have slight impact on package's LIDs.

In this analysis, the yellow-blue ratio (YBR) is introduced to illustrate the variation of angular correlated color temperature (CCT) [2]. The large YBR means lower CCT. As shown in Fig. 12, it can be found that the smallest YBR is at the center, while it rapidly increases at the edge. Taking sample 1 as

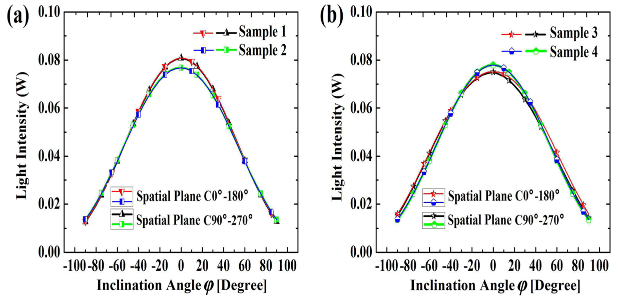

Fig. 11. LIDs distributions at plane *C*0 ° - 180 ° and plane *C*90 ° - 270 ° : (a) Sample 1, Sample 2; (b) Sample 3, Sample 4.

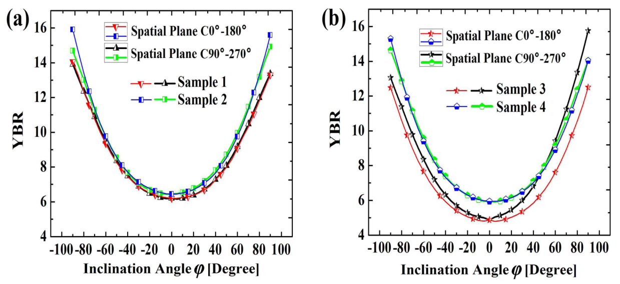

Fig. 12. YBR distributions at plane *C*0 ° - 180 ° and plane *C*90 ° - 270 ° : (a) Sample 1, Sample 2; (b) Sample 3, Sample 4.

example, YBR increase dramatically from 6.19 (at φ = 0 °) to 13.37 (at φ = 90 °) at plane *C*90 ° - 270 °. At φ = 0 °, YBR is 4.87, 5.94 for sample 3 and sample 4, respectively. It is smaller than the value for sample 1, and it means higher angular CCT at the center. That is because the heights of phosphor layers are dragged down in LED packages with wire B and wire C, resulting in less blue light absorption and less re-emitted yellow light at the center of phosphor layer.

Fig. 12 also indicates that the YBR distributions for sample 1, sample 2 and sample 4 have the similar trends at plane *C*0 ° - 180 ° and plane *C*90 ° - 270 °. However, for sample 3, YBR deviates from each other obviously when inclination angle *φ* changes from 0 ° to ± 90 ° at the two planes. And at the same inclination angle *φ*, YBR at plane is larger than that at plane *C*0 ° - 180 °. This is due to that more phosphor gel is dragged by gold wires B and accumulates at plane *C*90 ° - 270 ° in sample 3, as shown in Fig. 8. It illustrates that gold wire B has obvious impact on LED package's angular CCT distributions.

From above discussions, we can find that wire B has the worst effect on shape of phosphor layer and optical performance. Compared with other two kinds of wire bonding, wire A has smallest influence on LED package. Though wire C causes small impact, it is not the suitable one for LED packaging. It is close to the top surface of copper heat sink and will probably induce short circuit, and then damages the LED package. Therefore, wire A would be the proper form of wire bonding for LED packaging, and the detailed parameters need to be further optimized.

Summary

The effect of gold wire bonding process on the optical performance of WLED package was analyzed. Three kinds of wire bonding with different shapes and heights were discussed. The geometry simulation study indicates that the gold wire bonding impacts the geometry of phosphor layer distinctly, and it induces the different fluctuation trends of YBR at different spatial planes in the LED package. But different wire bonding type has slight effect on package's LIDs.

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References

1. X.B. Luo, B.L. Wu, and S. Liu, IEEE Trans. Device Mater. Reliab. 10 (2010) 182-186.
2. Z.Y. Liu, S. Liu, K. Wang, and X.B. Luo, IEEE Photonics Technol. Lett. 20 (2008) 2027-2029.
3. B.P. Loh, P.S. Andrews, and N. W. Medendorp, U.S. Patent (2008) 0054286.
4. G.H. Negley and M. Leung, U.S. Patent (2007) 7217583.
5. G.O. Muller, R.G. Muller, M.R. Krames, P.J. Schmidt, H.H. Bechtel, J. Meyer, J. Graaf, and T.A. Kop, U.S. Patent (2008) 7361938.
6. B. Braune, K. Petersen, J. Strauss, P. Kromotis, and M. Kaempf, Proc. SPIE 6486 (2007) 64860X.
7. Z.Y. Liu, S. Liu, K. Wang, and X.B. Luo, IEEE Trans. Device Mater. Reliab. 9 (2009) 65-73.
8. R. Hu, X.B. Luo, H. Feng, and S. Liu, J. Lumin. 132 (2012) 1252-1256.
9. R. Hu, X.B. Luo, and S. Liu, IEEE Photonics Technol. Lett. 22 (2011) 1673-1675.
10. H. Zheng, X.B. Luo, R. Hu, B. Cao, X. Fu, and Y.M. Wang, Optics Express 20 (2012) 5092-5098.
11. Y. Shuai, Y.Z. He, N.T. Tran, and F.G. Shi, IEEE Photonics Technol. Lett. 23 (2011) 137-139.
12. N.T. Tran, and F.G. Shi, J. Lightwave Technol. 26 (2008) 3556-3559.
13. C. Sommer, F.P. Wenzl, P. Hartmann, P. Pachler, M. Schweighart, and G. Leising, IEEE Photonics Technol. Lett. 20 (2008) 739-741.
14. B.L. Wu, X.B. Luo, H. Zheng, and S. Liu, Optics Express 19 (2011) 24115-24121.
15. H. Zheng, J.L. Ma, X.B. Luo, and S. Liu, in Proceedings of the 12th International Conference on Electronic Packaging Technology and High Density Packaging, August (2011) 1077.
16. K. Wang, D. Wu, F. Chen, Z.Y. Liu, X.B. Luo and S. Liu, Optics Lett. 35 (2010) 1860-1862.
17. K. Wang, F. Chen, Z.Y. Liu, X.B. Luo and S. Liu, Optics Express 18 (2010) 413-425.
18. Z.Y. Liu, K. Wang, X.B. Luo and S. Liu, Optics Express 18 (2010) 9398-9412.