Light Output Efficiency of Surface-Mount Lamp Beads Based on New Solid–Liquid UV Encapsulation

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Abstract

To address the problem of low efficiency of AlGaN-based UV LED chips, this study developed a type of solid–liquid packaged UV LED chip and analyzed its light output efficiency under different parameters. The light output efficiency of UV LED chips with and without solid–liquid encapsulation were analyzed using different reflective materials inside the chips. It was found that Au, Ag, and total-absorption reflective materials could not improve the light-output efficiency of UV LED liquid packaging. In addition, Al reflective materials and total reflection photonic crystals can improve the light output efficiency of UV LED liquid packaging, with the highest efficiency increase reaching over 74%. The light output efficiencies of liquid packaging with quartz cover sheets of different thicknesses were analyzed; the results revealed that the thinner the quartz cover sheet, the higher the efficiency; Under the same conditions, the efficiency improvement of UV LED surface-mount beads is not significant with different thicknesses of quartz cover sheets; Under the same thickness of quartz cover, Al reflective material and total reflection photonic crystal can improve the light output efficiency of UV LED liquid packaging.

Introduction

Ultraviolet (UV) light-emitting diodes (LEDs) have a wide range of applications, including water purification, air purification, sterilization, disinfection, phototherapy, and synthetic biology, and a large market[1-9]. However, compared with traditional UV fluorescent tubes, the efficiency of UV LED beads is relatively low. To replace traditional UV tubes, it is necessary to continue researching UV LEDs and improve their light output efficiency [10-13].

Owing to the use of AlGaN-based materials in UV LEDs, the mismatch between AlGaN materials and sapphire substrates is significant, resulting in poor quality of AlGaN crystals and low light output efficiency of AlGaN-based LEDs [14-17]; Moreover, owing to the high absorption of UV light, especially UVB and UVC light, by organic compounds, visible-light LED packaging materials cannot be applied to UV LED packaging. Therefore, currently, UV LEDs use quartz packaging [18-21]; Due to the high melting point of quartz, it cannot be melted and poured into the LED package, and therefore, there is an air layer between the quartz package cover and UV LED; This air layer prevents the heat of UV LED from dissipating through quartz, and also results in significant heat and light losses due to the low refractive index of air, which makes it difficult for light to exit from the quartz side [22-26]. Therefore, improving the light output efficiency of UV LEDs through UV packaging has become an urgent issue [27-30]. The current solution is that Japan uses fluorinated organic compounds to reduce their absorption of UV light. However, these fluorinated organic compounds are banned in China. There is an organic compound in Taiwan that has weak absorption of UV radiation, but its absorption coefficient is higher than that of quartz, which is relatively brittle, posing certain reliability issues when used for packaging. Overcoming the defects in existing organic compounds and improving the light output efficiency of UV LEDs have become urgent problems that need to be solved.

Therefore, in this paper, we propose a type of solid–liquid encapsulated UV LED bead, and the specific structure is shown in Figure. The key to this structure is to combine the high UV transmittance of quartz and water with the high reliability of quartz. By filling the quartz and chip with a liquid, specifically water, the high thermal conductivity and refractive index of water (with respect to air) are utilized to increase heat dissipation and improve the light output efficiency of UV LEDs.

Light Simulation Model

The optical simulation calculation in this study adopted the ray tracing method, Monte Carlo method, and the Traepro software. A schematic of the patch-lamp bead structure is shown in Figure 1.

The model parameters used in this study conform to Table 1, where sapphire, N-type AlGaN, MQW, and P-type AlGaN

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have refractive indices of 1.7, 2.4, 2.56, and 2.4, respectively; The absorption coefficients of sapphire, N-type AlGaN, MQW, and P-type AlGaN are 0.004, 0, 10, and 0 mm-1, respectively; The thicknesses of sapphire, N-type AlGaN, MQW, and P-type AlGaN are 80, 6, 0.1, and 0.15 μ m, respectively, as shown in Table 1 [31-34]. The dimensions of the Micro LED chips are 350 * 350 μ m * μ m. The size of the patch-lamp bead bracket was 5 mm × 5 mm, and the interior of the bracket resembled a four-sided conical platform with an inclination angle of 85°. The brackets were made of gold, aluminum, silver, fully absorbing materials, and fully reflective materials. The refractive index and absorption index of copper, aluminum, silver, and titanium are respectively 1.684916.9/mm; 0.22 , 148256/mm; 1.41 , 61827.3;- , Infinity/mm; -, 0. The encapsulation material is water, and the refractive index and absorption index of SiO2 are 1.37 and 0.0002/mm, respectively; At 1.5, 0.0002/mm, the chip size is 350 μ m, as shown in Table 1-3 [35-38]. All chips were AlGaN LED chips, and the packaging size met the requirements for 5050 surface-mount packaging. The LED device structure is shown in Figure 1-4.

Table 1 Simulated optical parameters of different materials

Material	**Refractive Index**	**Absorption Index [mm^{-1}]**
Au	1.60217	84916.9
Al	0.216432	148256
Ag	1.40708	61827.3
Perfect absorption	-	∞
Perfect reflection	-	0

Table 2 Simulated optical parameters of different materials

Material	**Refractive Index**	**Absorption Index [mm^{-1}]**
Water	1.37	0.0002
SiO_2	1.5	0.0002

Table 3 Simulated optical parameters of LEDs of different sizes

Material	**Thickness**	**Refractive Index**	**Absorption Index [mm^{-1}]**
Sapphire	80 μm	1.70	0.004
p-AlGaN	150 nm	2.4	0
Active layer (MQW)	100 nm	2.56	10
n-AlGaN	6 μm	2.4	0

The structures of the UV chip and patch-lamp bead used in this simulation are shown in Figure 1-3. The UV LED chip includes a sapphire substrate, an N-type AlGaN material, a quantum well, and a P-type AlGaN material; its front-top view is shown in Figure 1, and its cross-sectional view is shown in Figure 2. As shown in Figure 3, the UV patch-lamp bead includes packaging materials, UV LED chips, filling materials, such as air or water, and a quartz cover from bottom to top; the angle between the inner and bottom surfaces is 85°.

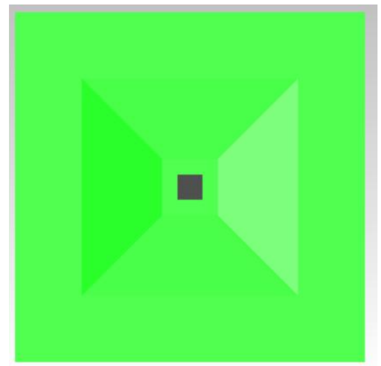

Figure 1. Top view of LED device structure in TracePro software

Figure 2. Sectional view of unpacked micro LED device structure

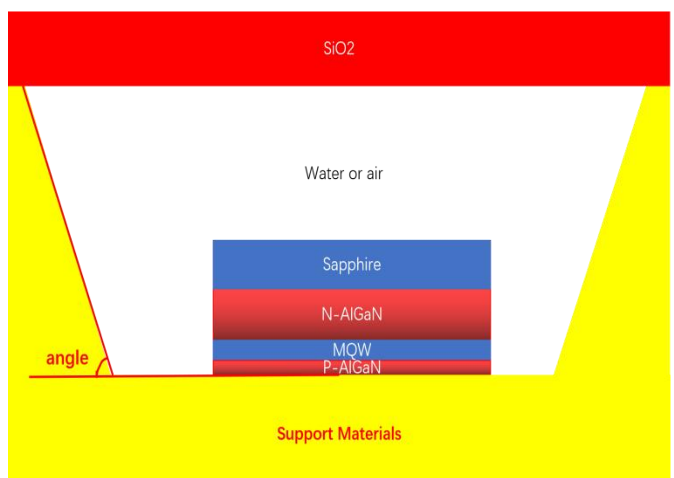

Figure 3. Sectional View of the 5050 encapsulated SMD beads

A structural cross-sectional view of the AlGaN LED chip packaged in this study is shown in Figure 2. Figure 1 shows a top view of the 5050 chip packaged in TracePro, and Figure 3 shows a cross-sectional view of the Micro LED chip

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packaged in the 5050 chip. First, all the other conditions remained unchanged. At this point, the chip size was set to 350 μ m. The beam angle and output efficiency of a patch LED with an inclination angle of 85° were simulated and calculated for various substrates. Finally, when the fixed tilt angle is 85° and the bracket material is aluminum, the encapsulation material is water, and the thickness dimensions of the quartz cover are changed to 0.1, 0.2, 0.3, and 0.4 mm for different sizes, the luminous efficiency of the patch LED with an encapsulation angle of 85° were calculated.

Optical Simulation Results and Analyses

Table 4 The light efficiency of the different packaging material

Diameter of the square [mm]	Light efficiency
Au without water	0.074
Au	0.074
Ag without water	0.072
Ag	0.068
Al without water	0.154
Al	0.241
Perfect Reflection without water	0.179
Perfect Reflection	0.312
Perfect Absorption without water	0.049
Perfect Absorption	0.052

As shown in Table 4, when the inner surface of the package is made of a total reflection material, the light output efficiency is the highest, and this total reflection material can be a photonic crystal; When the packaging material is Al, the light output efficiency is the second highest, and when the packaging material is fully absorbing, the light output efficiency is the lowest; When the packaging material is Ag, the light emission efficiency is second to last lowest; When the packaging materials are Ag and Au, the difference in light emission efficiency is insignificant; When the inner surface of the package is made of total reflection material or Al, the light output efficiency increases by 74.3% and 56.5%, respectively after being packaged with water and quartz cover plates; When the packaging material is Au, its light output efficiency remains unchanged after being packaged with water and quartz cover plate; When the inner surface encapsulation material is Ag, its light output efficiency decreases after being encapsulated by water and quartz cover plate; When the inner surface of the encapsulation is a total absorption surface, its light output efficiency remains nearly unchanged after being encapsulated by water and quartz cover plate.

Table 5 The light efficiency of the different SiO_2 thickness

Diameter of the square [mm]	Light efficiency
0.1 without water	0.153
0.2 without water	0.153
0.3 without water	0.154
0.4 without water	0.154
0.1	0.256
0.2	0.253
0.3	0.241
0.4	0.240

As shown in Table 5, for UV LEDs with Al encapsulation material and without liquid encapsulation, the light output efficiency of the UV LED decreases with the increase of encapsulation material thickness; As the thickness of the packaging material increases, the light output efficiency of UV LEDs packaged in liquid decreases; UV LEDs without liquid encapsulation have a slight change in light output efficiency as the thickness of the quartz cover increases; As the thickness of the quartz cover increases, the light output efficiency of UV LEDs encapsulated in liquid does not change significantly; Under the same conditions, after liquid encapsulation, the light output efficiency of UV LEDs has increased; UV LEDs with quartz cover thicknesses of 0.1, 0.2, 0.3, and 0.4 mm showed an increase in light output efficiency of 67.3, 65.4, 56.5, and 56.5%, respectively, after liquid encapsulation.

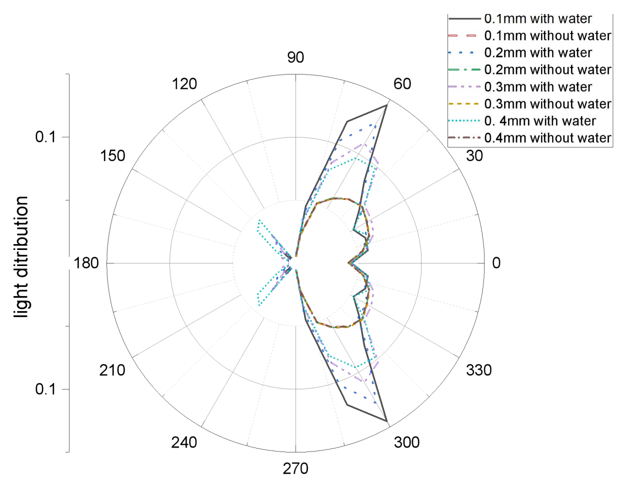

Figure 4 Schematic diagram

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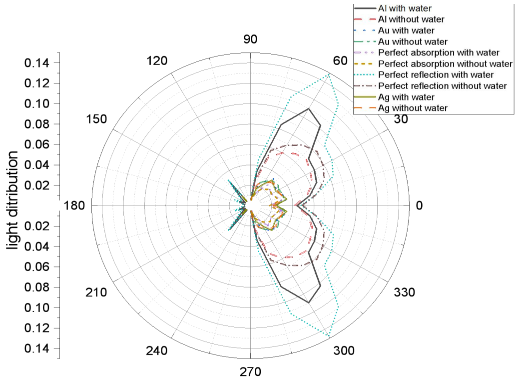

Figure 5 Far-field light disc.

Conclusions

Through the above simulation calculations, it was found that Au, Ag, and the total-absorption reflective materials could not improve the light-output efficiency of UV LED liquid packaging. In addition, Al reflective materials and total reflection photonic crystals can improve the light output efficiency of UV LED liquid packaging, with the highest efficiency increase reaching 74%. Under the same conditions, it was found that the thinner the quartz cover, the higher the efficiency, and the efficiency improvement of the UV LED chip was not significant. For the same thickness of quartz cover, the Al reflective material and total reflection photonic crystals can improve the light output efficiency of UV LED liquid packaging.

Acknowledgments

This paper is supported by the following projects: Key R&D Program of Jiangsu Province (Grant No. BE2023048). Key R&D Plan in Yancheng City (YCBE202332). "Dr. Shuang chuang" in Jiangsu Province in 2021, project number JSSCBS20211145, "Research on New Micro LED Chips for High Optoelectronic Properties", and the 2022 open project "Research on Pulsed Dimmable LED Plant Lighting Fixtures" by the Jiangsu Intelligent Optoelectronic Device and Measurement and Control Engineering Research Center.

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