Journal of Physics: Conference Series

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To cite this article: Mohammad Azarifar *et al* 2021 *J. Phys.: Conf. Ser.* **2116** 012121

Journal of Physics: Conference Series **2116** (2021) 012121 doi:10.1088/1742-6596/2116/1/012121

Optical and Thermal Analysis of Secondary Optics in Light Emitting Diodes' Packaging: *Analysis of MR16 Lamp*

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Abstract. Optical and thermal control are two main factors in package design process of lighting products, specifically light emitting diodes (LEDs). This research is aimed to study the role of secondary optics in opto-thermal characterization of LED packages. Novel thin total internal reflection (TIR) multifaceted reflector (MR) lens is modelled and optimized in Monte-Carlo ray-tracing simulations for MR16 package, regarded as one of the widely used LED lighting products. With criteria of designing an optical lens with 50% reduced thickness in comparison to commercially available lenses utilized in MR16 packages, nearly same light extraction efficiency and more uniform beam angles are achieved. Optical performance of the new lens is compared with the experimental results of the MR16 lamp with conventional lens. Only 2.3% reduction in maximum light intensity is obtained while lens size reduction was more than 25%. Based on the detailed CAD design, heat transfer simulations are performed comparing the lens thickness effect on heat dissipation of MR16 lamp. It was observed that using thinner lenses can reduce the lens and chip temperature, which can result in improved light quality and lifetime of both lens and light source.

1. Introduction

Emerging need of high-power demand in lighting industry reinforced advanced improvements of illumination devices. In case of light emitting diodes (LEDs), rapid improvements still can be seen with same pace in 1960s after release of first commercialized LED [1]. When compared to the other products, LEDs are the most advantageous lighting solution that can provide reliability, efficiency, long-life and good colour quality at the same time. In fact, according to the analysis of U.S Department of Energy (DOE), by the year 2035, extensive usage of LEDs will cover almost 84% of indoor and outdoor illumination requirements of the market with vide range of emission alternatives [2]. Illumination market requires lighting devices with variety of emission behaviours; directional, decorative, linear, etc. In order to utilize light emission for desired illumination purpose, a secondary optics is necessary to control nearly Lambertian light emission of a sole LED.

In the past years, MR16 lamps are designed to create concentrated beam to create spotlights. Cree developed a replacement for the traditional 20-W MR16 halogen bulb, Cree XLamp XP-E LED MR16 [3], which is powered by three phosphor converted Cree LED (XPEWHT-L1-WW). Improved MR16 LED lamp that consist of an internal reflection (TIR) with multifaceted reflector (MR), collimates light from the LED and creates concentrated beam of light to provide better optical control. On the contrary, constant heat generation of multi high power LED chips, introduce excessive thermal loads that needs to be dissipated with an effective cooling solution [4].

Lenses are generally made up of UV stabilized clear polycarbonate material with low a thermal conductivity of 0.19 to 0.22 W/m-K, thus designing a thinner lens can reduce thermal resistance introduced by MR lenses. Traditional MR16 lens of market come in height of 6 mm or higher. For example, triple optic spot MR lens manufactured by Carclo Technical Plastics for Cree Xlamp XP-E is manufactured with a height of 6 mm. In another example, Chen et al. [5] designed free form lenses with height of 5.6 mm.

Thermal effect of MR16 lens thickness is not well covered yet in the literature. Therefore, in this study, a thin 3 mm TIR-MR lens is modeled and optimized in Monte-Carlo ray-tracing simulations performed in LightTools software. Optical results of simulations are compared to experimental data gathered from spectroradiometer (illumia®Plus2) and goniophotometer (LMT LICHTMESSTECHNIK GMBH BERLIN GO-V 1900). Next detailed CAD models of the MR16 with new lens and conventional lens are created and thermal comparison is performed to acquire a thermal map on effect of second optics in thermal management of LED packaging.

2. Optical Analysis

MR16 LED lamps are mainly composed of several LEDs (in this study 3 LEDs) a MR lens array, metal core printed circuit board (MCPCB) substrate, physical frame with attached heatsink, and driver circuit [6]. Three Cree LED (XPEWHT-L1-WW) construct the light source of the studied MR16 lamp. The geometrical illustration of the LED is shown in Figure 1. Square shaped chip is highlighted with yellow color is mounted on the package while chip is protected by a semi-hemispherical dome.

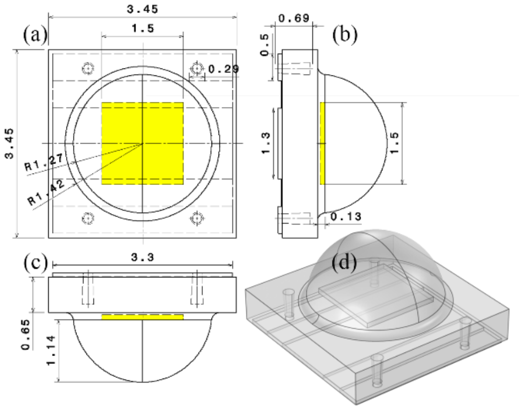


Figure 1. (a) top, (b-c) side, and (d) 3D transparent view of XLamp XP-ELED white LED. (in mm scale)

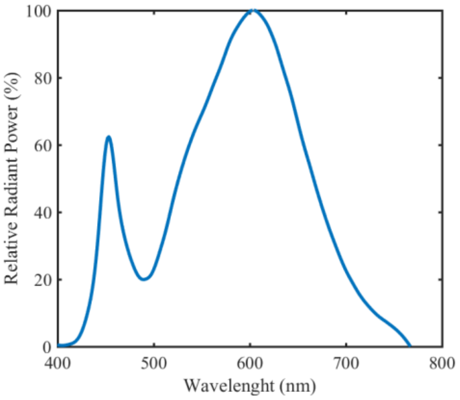


Figure 2. Spectral power distribution of LED

Figure 2 presents the spectral power distribution of the XPEWHT-L1-WW LED where its luminous flux is 80.6 lm, CRI is 81.33, CCT is 3044.3 K, maximum intensity is 29.96 cd, and view angle is 115°. To collimate the light rays emitted from the LED with a wide view angle of 115°, a compact lens is required. With objective of obtaining maximized peak intensity and with geometrical constraints of height of below 3 mm and radius below 4.62 mm, geometrical optimization process is performed in LightTools software. Sample ray emission shown with white lines in Figure 3 shows the working principle of the designed lens. Lateral rays are collimated by TIR effect of Bezier shape of lens in sidelong. Centered rays, on the other hand, are collimated using two conic lenses shown with red color. There is a hemispherical gap in bottom of the

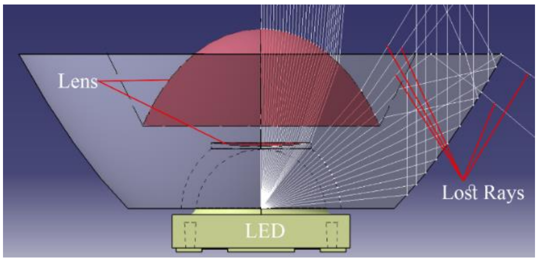


Figure 3. Optimized lens and ray interactions.

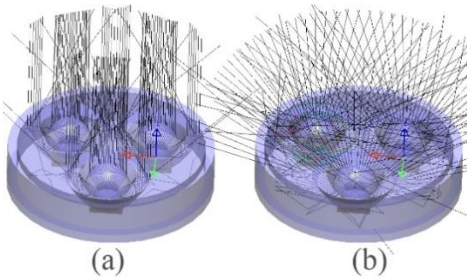


Figure 4. (a) ray tracing simulation of lens, (b) ray tracing when lens effect is ignored in the simulation.

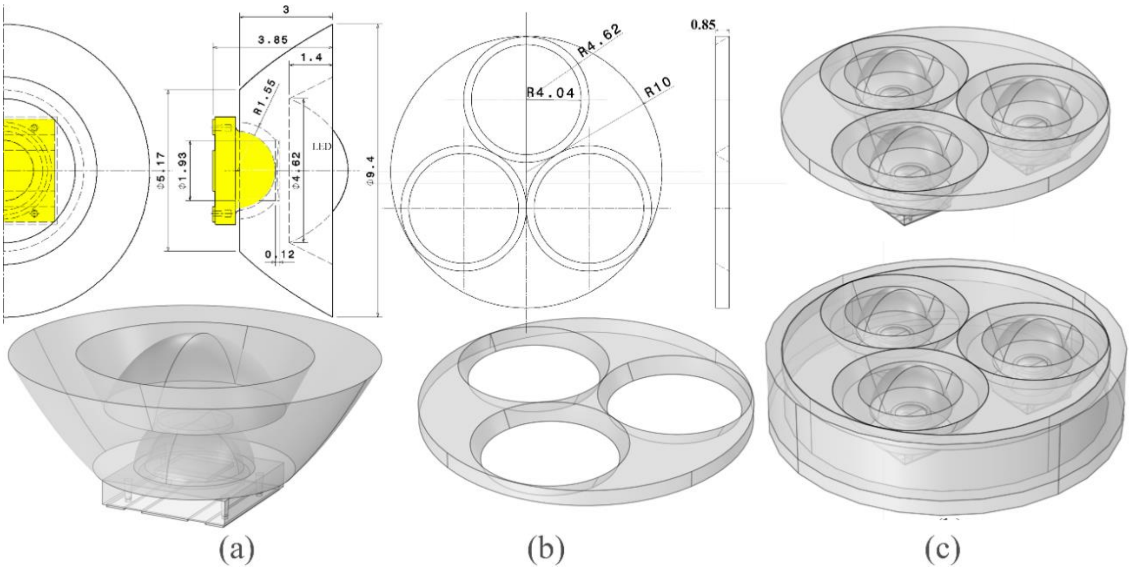


Figure 5. (a) Single lens view with geometrical illustration and LED position under the lens. (b) connection lens view and geometrical illustrations. (c) lens configuration and casing view. (mm scale)

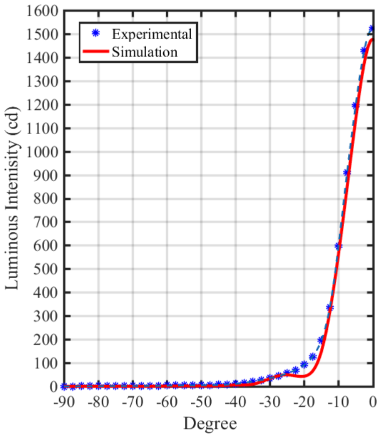


Figure 6. Luminous intensity comparison of numerical and experimental results.

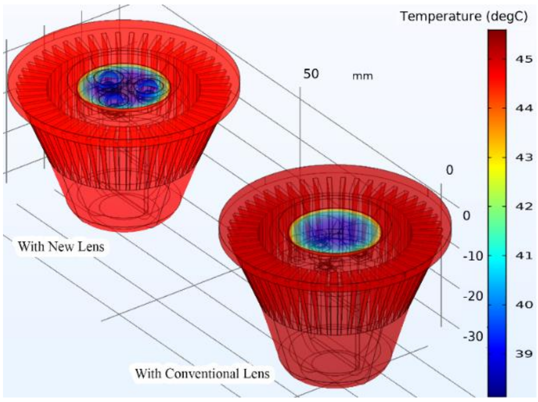
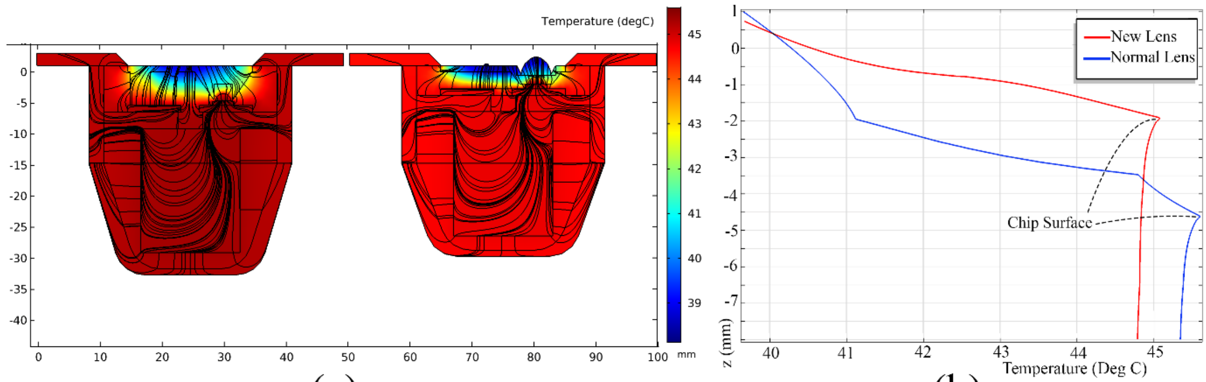


Figure 7. 3D temperature profile of MR16 package in a transparent view



(a) (b)

Figure 8. (a) Cut plane temperature profile passing from middle of the chip of conventional package (left) and package with new lens (right), heat transfer streamlines are shown with black lines. (b) Temperature profile in vertical line passing from middle of the chip in z-direction

lens in order to place the lens above the LED which is shown with yellow color and dotted lines. Fraction of rays are diverged from the desired direction which are pointed as lost rays. The geometrical parameters of the lens and position of the LED are presented in Figure 5(a) and it can be seen that height of the lens is 3 mm. Figure 5(c) illustrates the final lens design and positioning inside the casing. A ray tracing schematic of the final design is shown in Figure 4. Figure 4(a) is showing light rays' direction when lens effect is considered in the ray tracing simulation and Figure 4(b) is showing ray directions when lens effect is ignored. It is obvious that lens is collimating rays successfully to desired direction making parallel and tidy ray emission in perpendicular direction. Without a proper lens, rays will propagate in random direction in similar wide angle to the LED itself. Figure 6 presents the luminous intensity comparison of the simulated MR16 with new thin lens design and experimental result obtained from commercially available MR16 with thicker lens design. Optical comparison with commercially available MR16 package shown that new lens offers -3.4% lower total flux, -2.3% lower maximum intensity, 3.5% higher CRI, and 1.5% higher CCT values. In geometrical scales, new lens uses 25% less material, and 21% less surface area.

3. Thermal Analysis

In order to study the effect of using thinner lens on thermal performance of MR16 packaging, conduction equation is solved in three-dimensional steady state FEM simulations in COMSOL Multiphysics environment. Detailed CAD design of packaging with new lens and with conventional lenses are prepared while same heat sink is considered for both cases. Exposed surfaces including the top aluminium cap and top surface of the lens is set to have convective heat transfer coefficient of hot surface facing downward. Heatsink and surfaces are set to convective heat transfer boundary condition with relatively low heat transfer coefficient of 3 W/m^2-K since the heat sink is in a recess in the surrounding wall or surface. The verification of simulation with experiments is provided in previous research [7]. Three-dimensional temperature profile of MR16 packages with new and normal lenses are provided in Figure 9. Although the main heat transfer path is through the aluminium package, having thinner lens improved the heat passage at the top of the package where 28.5% more heat transfer is achieved through the new lens to the ambient air. This issue can be seen in Figure 8(a) where 2D temperature profile with heat streamlines are provided. It can be seen that since smaller air is trapped between the lens and the board easier heat transfer is occurred toward top of the lens. This issue resulted in lower hotspot temperature in LED chip which can be shown in Figure 8(b); maximum chip temperature in new package is recorded 45.07 °C while in conventional package this value is 45.6 °C. It should be mentioned that using smaller lens resulted in total of 3 mm shorter packaging as it can be seen in Figure 8(a). Moreover 0.68 °C lower lens temperature is achieved in the new lens design. Using thinner lenses can improve the thermal performance of LED packaging, since thermal resistance barrier introduced by low thermal conductivity trapped air, and lens is going to be reduced. This issue can also improve the overall lens performance and increase its life cycle.

4. Summary and Conclusions

In this study, it is shown that similar optical behaviour and better thermal performance can be achieved by optimizing lens design for an LED lighting system. A novel lens design was introduced and it has a 50% thinner structure compared to available lens designs where improvement in thermal passage for heat dissipation is observed based on the thermal analysis of the package. New lens approach presented a similar optical behaviour while its volume is 25% smaller than commercially available lenses. This thinner lens will result in more compact packaging designs so high lumen and better light quality controlled products will be enabled.

Acknowledgments

This work was supported in part by the Ozyegin University College of Engineering and EVATEG Center.

References

[1] McFarlane W 1974 An inexpensive nanosecond light pulser for use in photomultiplier system testing *Review of Scientific Instruments* **45**, 286-289
[2] State Lighting in General Illumination Applications *Navigant Consulting* DOE/EERE 2001
[3] Cree XLamp XM-L EZW MR16 Reference Design, Application Note AP71
[4] Arik M, Becker C A, Weaver S E and Petroski J 2004 Thermal management of LEDs: package to system *Third international conference on solid state lighting* **5187**, 64-75
[5] Chen F, Liu S, Wang K, Liu, Z and Luo X 2009 Free-form lenses for high illumination quality light-emitting diode MR16 lamps *Optical Engineering* **48**, 123002
[6] Wang K, Liu S, Luo X, Liu Z and Chen F 2008 Optical analysis of a 3W light-emitting diode (LED) MR16 lamp *International Conference on Electronic Packaging Technology & High Density Packaging* 1-5
[7] Cengiz C, Azarifar M and Arik M 2021 Thermal and Optical Characterization of White and Blue Multi-Chip LED Light Engines *20th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (iTherm)* 285-293