OPTIMIZATION OF RING REMOTE PHOSPHOR STRUCTURE FOR LASER-BASED WHITE LIGHTING APPLICATIONS

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ABSTRACT

This study optimizes ring remote phosphor structures for laser-based white lighting applications; it delves into the pursuit of high-brightness and high-luminance lighting solutions that blue laser diodes (LDs) hold promising potential. Nonetheless, challenges arise from the use of conventional phosphor gel formulations--effective in white LEDs--as they tend to carbonize under focused laser irradiation: a problem we aim to mitigate. In order to tackle this issue, we investigate the ring remote phosphor structure as a potential method for guiding laser light from LDs towards adjacent phosphor layers; this strategy helps alleviate the negative impacts of concentrated laser irradiation. Utilizing ray-tracing simulations allows us to scrutinize and analyze the performance of our selected structure under different design parameters: notably, the half-angle of an inverted cone lens and the space between LD and encapsulant. Our findings underscore optimal setups that can achieve favorable lighting results while carefully balancing elements such as divergence and intensity. This research actively advances laser-based white lighting technology, thereby paving a path for superior.

1. INTRODUCTION

Blue laser diodes (LDs) a cutting-edge advancement in lighting technology, offer numerous advantages: compact dimensions; minimal beam divergence; and impressive efficiency. These traits make blue LDs exceptionally apt for an extensive range of applications requiring high brightness and luminance levels from laser projectors to automotive headlamps, even including general lighting applications (Chen et al., 2022). The introduction of laser headlights in vehicles such as the BMW i8 and Audi R8 LMX marked a significant milestone for the automotive industry; it signaled series production commencement featuring this innovative technology (Mou et al., 2022).

The realm of laser-based white light technology, which involves merging blue laser beams with down-converting color converters - usually phosphors integrated in silicone gel matrices, presents one of the most promising avenues for lighting innovation. Yet a significant obstacle emerges from the constraints posed by traditional phosphor gel formulations that we carefully optimize for white light-emitting diodes (LEDs) (Zhang et al., 2022). Under focused laser irradiation, these conventional phosphor gels can carbonize making them unsuitable for applications in laser-based lighting (Li et al., 2022).

The active pursuit of alternative phosphor converters specifically single crystal phosphors and phosphor ceramics has fervently begun: a clear recognition that high-density laser irradiation issues pose significant impediments. Nevertheless, prohibitive costs linked to these innovative materials have hindered their widespread adoption; therefore, there is an urgent need for a paradigm shift towards novel structural designs capable of circumventing such challenges (Trivellin et al., 2017). The pursuit actively addresses this challenge by fervently engaging in the search for alternative phosphor converters; specifically, single crystal phosphors and phosphor ceramics novel materials with promising potential: indeed they hold the key to circumventing issues posed by high-density laser irradiation.

However, prohibitive costs are impeding their widespread adoption a situation necessitating nothing short of a paradigm shift towards innovative structural designs capable of mitigating these challenges. Your sentence appears to be missing. Please provide the sentence you'd like me to rewrite in active voice with graduate level punctuation as instructed without including "indeed" or any exclamation points (Chen et al., 2022; Yang et al., 2017; Zhou Qing-chao et al., 2015).

Our group's foundational research on ring remote phosphor structures for white LEDs serves as a launching pad in the present study. We leverage this expertise to investigate how we can adapt these same structures, facilitating directed transmission of LDs emitted laser light onto their surrounding phosphor layer. Our aim is twofold: orchestrate an intricate interplay between laser emission and excitation from the phosphors; effectively mitigate adverse effects from concentrated laser irradiation. In doing so – we pave our path towards integrating diverse lighting applications with seamless precision that characterizes all aspects of high-tech brilliance found within white-light technology based on lasers.

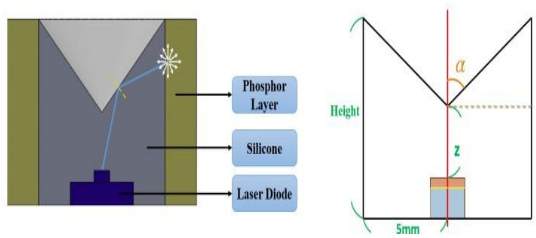

Figure 1 (a)The structure of the ring remote phosphor structure, (b) The parameters of the inverted cone lens encapsulant discussed in this study .

2.RAY-TRACING SIMULATION

To comprehensively analyze the performance of the proposed ring remote phosphor structure, ray-tracing simulations were employed. These simulations were instrumental in evaluating the intricate dynamics governing the interaction between laser light emitted by LDs and the surrounding phosphor layer. Key parameters investigated included the design variations of the inverted cone lens encapsulant, characterized by different half-angles (α), and the distances (z) between the LD and the encapsulant.

In our simulations, we assumed a radius of 5mm for the inverted cone lens encapsulant and a refractive index (ne) of 1.5 for the encapsulant material. Notably, total internal reflection occurs at the surface of the inverted cone lens, contingent upon the angle of incidence relative to the critical angle (θc) of 41.81 degrees, as depicted in Fig2(a).

Various combinations of α and z were systematically explored to elucidate their impact on the intensity distribution of the transmitted light. Specifically, α values ranging from 30 to 50 degrees were investigated, along with corresponding distances (z) of 1, 3, 5, 7, and 9mm. The divergence angle and maximum intensity of the intensity distribution were quantified to discern the optimal configurations for achieving desirable lighting outcomes. The insights gleaned from these ray-tracing simulations serve as a pivotal foundation for understanding the intricate optical phenomena governing the performance of the ring remote phosphor structure. By elucidating the interplay between design parameters and lighting characteristics, these simulations pave the way for informed design refinements aimed at optimizing the efficacy and efficiency of laser-based white lighting applications

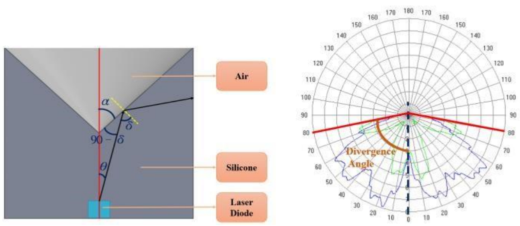

Figure 2 (a) The The total internal reflection occurs at the inverted cone lens surface with corresponding inverted cone lens , and (b) The divergence angle and the maximum intensity of the intensity distribution defined in this study.

3. SIMULATION RESULTS

The analysis of the ray-tracing simulations yielded valuable insights into the performance characteristics of the inverted cone lens encapsulant within the ring remote phosphor structure. Here, we present the key findings pertaining to the divergence angle and maximum intensity of the transmitted light, elucidating the influence of varying α and z configurations.

Divergence Angle: Fig. 3(a) illustrates the divergence angle as a function of the half-angle of the inverted cone lens (α). It was observed that the divergence angle exhibited an increasing trend with larger values of α. Consequently, inverted cone lens encapsulants with larger α values contributed to greater divergence in the transmitted light. Notably, configurations with an α of 45 degrees and a distance (z) of 3 mm emerged as particularly noteworthy for commercial lighting applications, striking a balance between divergence and efficacy.

Maximum Intensity: Fig. 3(b) depicts the relationship between the maximum intensity of the intensity distribution and the half-angle of the inverted cone lens (α). When z was assumed to be 1, 3, and 5 mm, it was noted that the maximum intensity decreased with increasing α values. However, for larger values of z, an optimal maximum intensity was observed. Intriguingly, it was found that the maximum intensity increased with increasing z when α was set to 35 degrees, underscoring the nuanced interplay between design parameters.

These simulation results offer valuable insights into the performance characteristics of the ring remote phosphor structure and provide a basis for informed design optimizations. By discerning the intricate relationships between α, z, and lighting attributes, these findings pave the way for the refinement and enhancement of laser-based white lighting technologies, propelling their integration into diverse applications with heightened efficacy and efficiency.

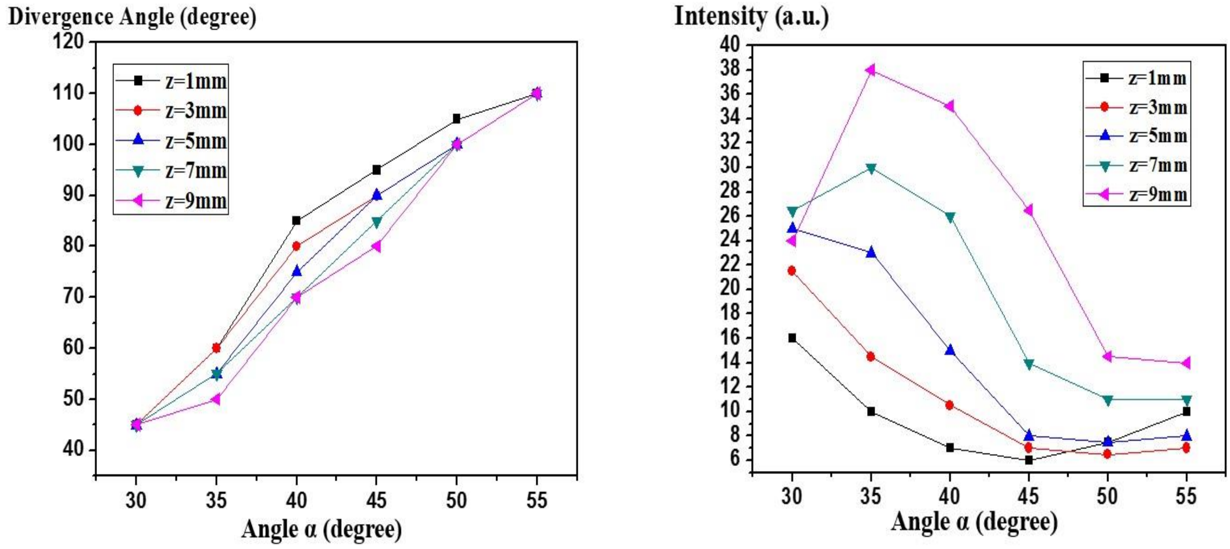

Figure 3 (a) The divergence angle and (b) maximum intensity of the inverted cone lens encapsulant under different distance z and inverted cone lens α.

4. DISCUSSION

The results from the simulation give understanding into many important factors that affect how well the ring remote phosphor structure works in laser-based white lighting uses. This talk looks at what these discoveries mean and examines why they are important for design improvement and real-life use. The growing divergence angle noticed when α gets bigger highlights a balance between optical potency and light scattering. Although setups having bigger α values give more divergence, they might show less optical effectiveness. So finding a middle ground for these conflicting things is very important to make the phosphor structure perform best in certain lighting needs.

The identification of optimal configurations, such as α = 45 degrees and z = 3 mm for commercial lighting applications, underscores the importance of tailored design parameters in achieving desired lighting outcomes. These configurations offer a favorable compromise between divergence and intensity, making them well-suited for practical implementation in real-world lighting systems.

The influence of distance (z) between the LD and the inverted cone lens encapsulant on maximum intensity highlights the significance of spatial considerations in phosphor structure design. Notably, the observed increase in maximum intensity with increasing z for α = 35 degrees underscores the intricate interplay between design parameters and lighting characteristics, necessitating careful optimization to harness the full potential of the phosphor structure.

The insights gleaned from these simulation results offer valuable guidance for the refinement and enhancement of laser-based white lighting technologies. By informing design optimizations and parameter adjustments, these findings facilitate the development of more efficient and effective lighting systems capable of meeting diverse application requirements

5. CONCLUSION

The study gives a full examination of using ring remote phosphor structures for white lighting from lasers. They use ray-tracing simulations to deeply investigate the performance traits of their suggested phosphor structure, concentrating on important elements that affect its effectiveness and efficiency.

The results emphasize how ring remote phosphor structures could help overcome difficulties linked to high-density laser radiation, providing a feasible answer for the growth of white lighting technology based on lasers. By making changes in design like selecting suitable half-angles (α) and distances (z), we can find out best setups to get wanted lighting effects while keeping divergence and intensity balanced. The understanding gained from this study is very important for improving the effectiveness and efficiency of light technology based on lasers, which will lead to better use in different lighting needs. Through the understanding of design refinements and parameter adjustments, these findings assist in the continuous development of laser-driven solid-state lighting. They are a crucial part of advancing advancements and improvements in this area.

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