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Laser driven white light generation with specially shaped phosphor

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Abstract: In this work, two types of phosphors, a flat surface and a curved surface, are simulated with LightTools software to show that the introduction of curvature on the material can help with heat accumulation and light generation in laser driven phosphor conversion applications.

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1. Introduction

In recent years, the field of lighting technology has undergone a major shift, with the emergence of Solid-State Lighting (SSL) systems. LEDs, OLEDs and other major SSL sources are replacing conventional light sources such as halogen lamps. One such SSL system is the laser driven white light source, which becomes more attractive due to various potential applications such as in automotive industry and aviation. While LEDs have emerged as frontrunners in the pursuit of energy-efficient and sustainable illumination and have significantly contributed to reducing energy consumption, lowering environmental impact, and providing novel applications in various sectors such as agriculture [1], interior and exterior lighting [2], biomedical applications and displays [3], there are certain problems with their usage. The absence of a significant heat signature causes aviation systems which operate in the infrared spectrum to be blind to LEDs and thus does not allow the overall replacement of older, high energy consumption lighting systems. Furthermore, an even more significant flaw of LEDs is the result of the decrease of their external quantum efficiency, usually taking place when the device is operating under high current densities or high temperatures, with the effect being referred to as efficiency droop [4]. Many mechanisms can contribute to the droop effect, but the recombination of electron-hole pairs without the subsequent emission of a photon, known as Auger effect [5], is the principal mechanism behind the quantum efficiency drop of the device. This, in turn, causes a shift in the peak emission wavelength and broadening of the emission spectrum. This results in a spectrum with a different ratio of emitted light, which affects the colorimetric parameters of the light source such as the Correlated Color Temperature (CCT) and the Color Rendering Index (CRI). To solve this issue, the LED can be replaced by a laser diode, taking advantage of the laser's output power and external quantum efficiency following a linear increase with the operating current, thus obtaining a stable light emission. The replacement of the LED in phosphor conversion lighting systems with a laser diode, solves the efficiency issues but, at the same time, introduces certain new variables to consider such as the accumulative heating of the phosphor material due to the intensity of the laser beam and issues with the distribution of the emitted light due to the laser beam profile. The constant and non-uniform heating of the phosphor can result in overheating and degradation of the material, thus reducing the efficiency, while the beam profile does not allow uniform illumination by the lighting source. This work will address the above issues by working on the shape of the phosphor material in order to alleviate the effects of heat accumulation and non-uniform light distribution.

2. Simulation and results

In order to solve the issues of the accumulative heat and the non-uniform distribution of light by the phosphor conversion laser driven light source, we propose a modification in the shape of the phosphor. This shape modification will help reduce the heat strain on the material while it will allow for a more homogenous white light distribution. To achieve this, we will perform the simulations with the software LightTools. Using LightTools, we define a blue laser diode model, provided by the software library, with an emission wavelength at 450 nm and a Gaussian beam profile. In the same sense, we test two types of phosphor shapes, a flat surface phosphor, as it is being used in most laser driven white light applications, and a second phosphor with a Gaussian shape. The aim is to match the increased intensity of the central part of the laser beam with higher phosphor quantity at its direction. In this way, we try to achieve homogeneity by having the most intense parts of the laser beam traverse more material. We tried many different thickness profiles until we achieved a satisfying homogenous light distribution. The figure below depicts the interaction of the laser beam with the flat surfaced phosphor and the corresponding irradiance profile.

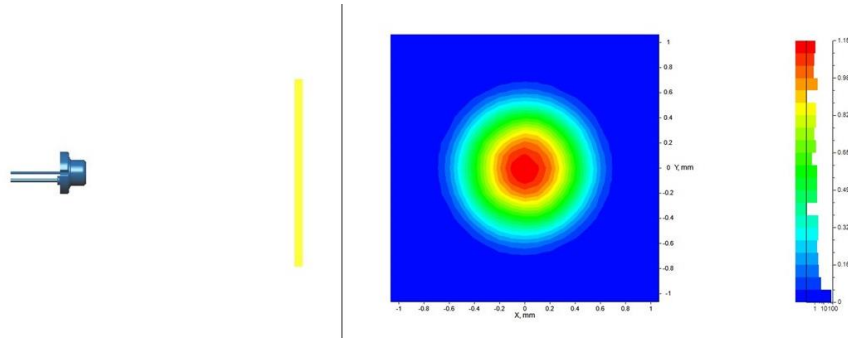


Fig. 1. Flat surface phosphor (left), with corresponding irradiance figure- (right).

The next figure shows the results of the modified phosphor and how its new shape affects the light distribution. When the flat surface changes to match the laser beam profile, we obtain a uniform light generation from the interaction of the phosphor material with the laser beam light. This in turn will affect the heat distribution on the material in that the high intensity part of the laser beam traverses a thicker medium than its peripheral parts, which interact with low thickness phosphor material. The result is less heat strain on the phosphor, thus increasing the time before material degradation commences.

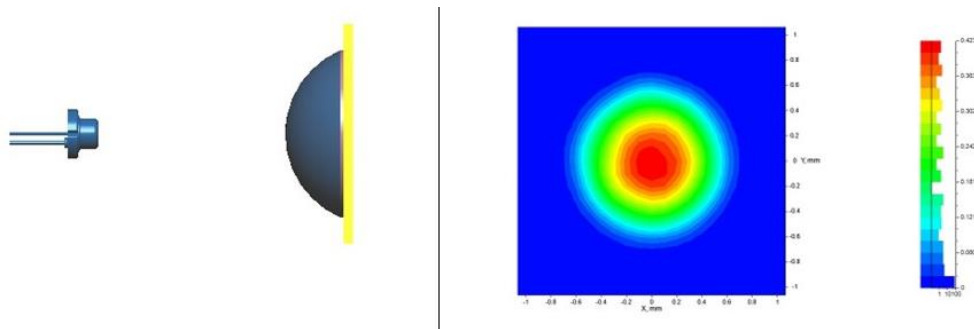


Fig. 2. Modified surface phosphor (left), with corresponding irradiance figure (right).

3. Conclusions

We have seen that flat shaped phosphors in laser driven white light generation sources suffer from heat degradation and uneven light distribution due to the characteristics of the laser beam profile. This results in efficiency issues in a potential lighting device. After modifying and simulating the above configuration, we observed that a Gaussian shaped phosphor, matching its profile with the beam profile of the laser diode, consists of an interesting alternative to alleviate those issues and obtain a lighting device with homogenous lighting generation.

4. References

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