Integrated of LED/Laser-SCP Light Source for High-Output Smart DMD Headlight

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ABSTRACT

Most of smart headlight engines are designed using blue LED or laser light sources for the exciting the phosphor conversion layer producing white light output. The phosphor conversion layers have been fabricated by silicone-based phosphor, glass-based phosphor, ceramic-based phosphor, and single crystal-based phosphor. Among these different phosphor materials, the single crystal phosphor (SCP) exhibits excellent thermal stability, better conversion efficiency, and high transparency to yellow light, but the required high-temperature fabrication process, has been an impediment for widespread commercial production. Recently, the issues of higher fabrication temperature of the SCP have been overcome by using a novel design of single crystal growth to produce SCP with higher yield and better uniformity. In this study, the smart headlight consists of a well-developed, high efficiency, automotive qualified white LED, a TI digit mirror device (DMD), a projection lens, and a LED together with two laser diodes and a SCP plate.

1 Introduction

To achieve the high-power output with the addition of laser diode outputs, the SCP plate is used for the conversion layer in this study. The SCP plates are fabricated by Czochralski technology at the high temperature of 1,940°C. Using the additional laser excited SCP, a 50% increase in the LED is obtained. This increase in output enables the increase in FOV and brightness of the smart headlight, which results in significant improvement of the visibility and the illumination distance. The proposed advanced smart headlight with ultra-reliable SCP, will become one of the most promising smart headlight candidates for use in the next-generation automotive applications.

2 Single Crystal Phosphor Plate Fabrication

Contrary to common phosphor materials including silicone phosphor, ceramic phosphor [1], or glass phosphor, the single crystal phosphor is formed by growing the crystal at high temperature over a molten liquid of phosphor and carrier materials. The Ce:YAG-based Single Crystal Phosphor (SCP) is a highly transparent material with virtually no scattering. Czochralski (CZ) technique is used with RF heating. Commercially available oxides are used as raw materials, which are mixed and melted in an iridium or crucible at temperatures in the 1,940 C range. A grown preforms is shown in Figure 1 with a length of 200 mm and diameter of 55 mm.

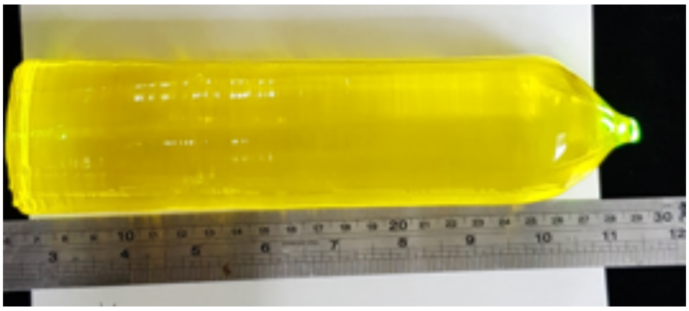
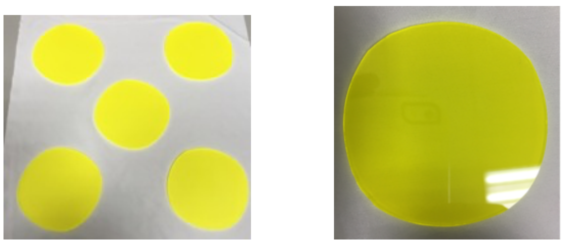


Figure 1. The As-Grown SCP Preform

The next step is to cut the preform into thin wafers as shown in Figure 2(a) and polished on both sides as shown in Figure 2(b). Depending on the end products, the thickness of each wafer ranges from 0.2 mm for simple wavelength conversion applications, and to over 1 mm thick for waveguide applications.



(a) (b)

Figure 2. Cut SCP Wafers – (a) un-polished, (b) polished

The wafers can then be cut into chips as shown in Figure 3. These chips can have both sides polished, one side polished, or both side un-polished. For certain applications, the surfaces can be polished to a certain roughness to promote certain output properties and efficiencies. When the wafer is cut into waveguides, all surfaces will be polished to optical finish.

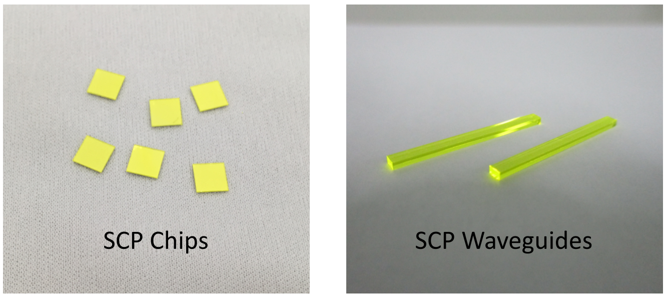


Figure 3 – SCP Wafers can be Cut into Chips or Waveguides

3 Laser Excitation of SCP

Single crystal phosphor is a transparent material, which absorbs blue light and emits yellow light. As a result, it is the ideal material for conversion of blue laser light into yellow visible light allowing high efficiency, and high temperature operations. When fabricated into a waveguide, it provides a large volume and surface area for ease of heat sinking. The transparent property of the crystal phosphor material provides features are not available in other phosphor materials such as glass phosphor and ceramic phosphor in which the laser energy is all concentrated in a small spot with small thickness making heat removal very challenging.

Figure 4 shows the schematic diagram of front and back excitation of a SCP. When the crystal phosphor plate is coated with a yellow reflective coating on one side, the yellow output will be emitted from the opposite side. Together with the residue blue laser light, white light output is produced. The front laser excitation, in this case, enhances the output brightness.

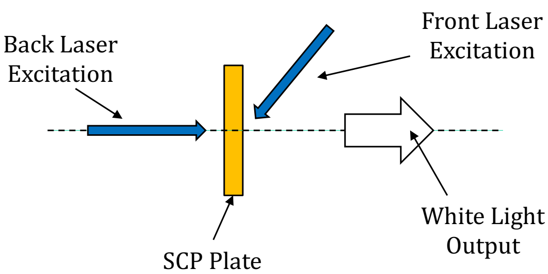


Figure 4 – White Light Source using Laser Excited SCP

4 Structure of a Laser-Assisted LED

To capitalize on the advanced developments of the high brightness LED and the transparent property of the SCP, Figure 5 shows a laser assisted LED where a SCP plate is placed on top of a white LED with the additional laser excitation from the front. The white light output of the LED, which consists of the blue LED light and the yellow phosphor light passes the SCP. The yellow light will pass through with little or no loss as the SCP is transparent to yellow light. On the other hand, the blue light will be partially absorbed by the SCP and emits yellow light. As a result, the total yellow light output is increase while the blue light output will be reduced. Using two laser diodes, a crystal phosphor plate, and the Nichia LED, a 50% increase in output has been obtained.

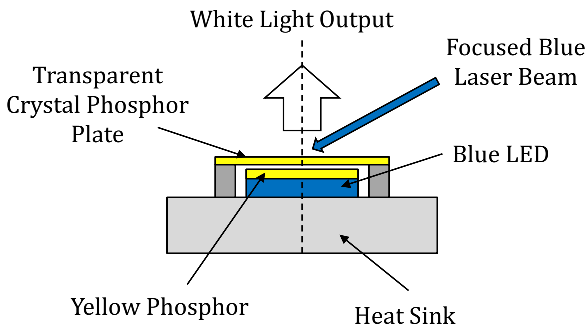


Figure 5 – Structure of a Laser-Assisted LED

When the blue laser beam incidence at the SCP, the laser light will be absorbed by the SCP and converted into yellow light. A small amount of blue light will pass through the SCP and absorbed by the phosphor layer of the white LED and re-emit as yellow light. The final output of this laser assisted LED would include the yellow light from the original white LED, yellow light from the laser excited SCP and the yellow light from the residue laser light incidence at the phosphor layer of the white LED. In addition, it also includes residue blue light from the white LED not absorbed by the SCP and the back scattered blue light from the laser excited SCP. To provide the desired output and color temperature of the output, the amount of blue light from the white LED and the amount of back scattering of the blue light from the SCP will have to be adjusted.

Figure 6 shows a configuration where the LED is partially covered by the SCP such that most of the LED output does not have to pass through the SCP, while the laser excitation is confined only to the SCP strip. In this case, the output color temperature is minimally changed by such Laser-Assist™ configuration.

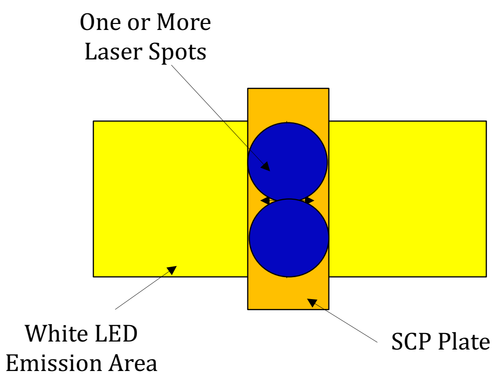


Figure 6 – White LED Partially Covered by SCP Strip

Figure 7 and Figure 8 shows other configurations that could have the same outcomes, but will facilitate assembly. The rectangular holes in Figure 7 can be made by laser cutting. The round holes in Figure 8 can be made either by laser cutting or by mechanically drilling.

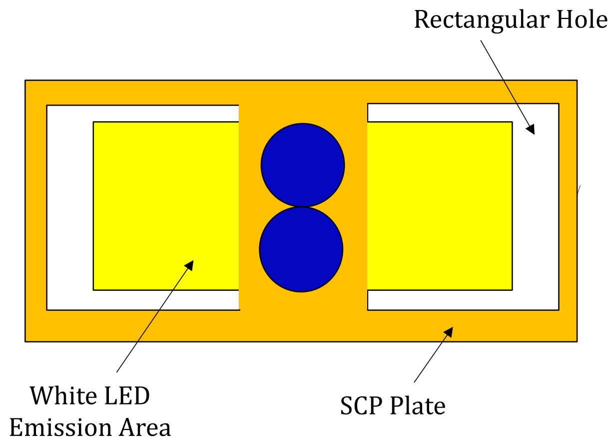


Figure 7 – White LED Covered by SCP with Rectangular Apertures

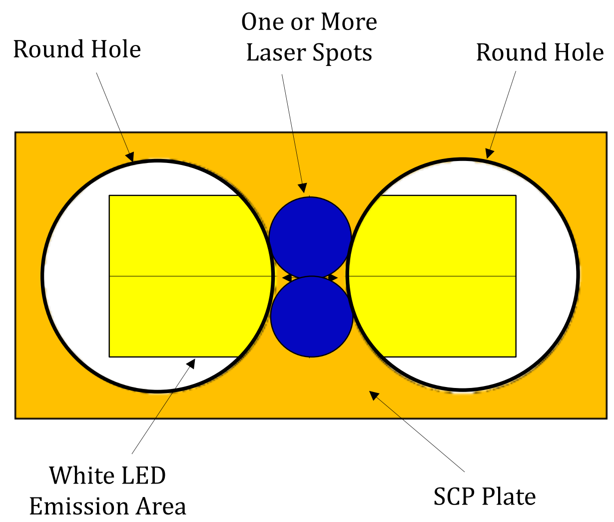


Figure 8 – White LED Covered by SCP with Round Apertures

5 DMD Projection Headlight with Standard LED

The DMD panel, such as the DLP™ imager made by Texas Instruments, modulates the spatial output allowing beam control of the illumination on the roadway. This imager has a dimension of 6.226 mm x 12.447 mm with an aspect ratio of 2:1. The mirrors, 1152 x 1152, are configured at 45-degree in the x-y plane producing a 2:1 aspect ratio even though the number of pixels seems to be in a square configuration. Various patterns can be projected such as standard illuminations, symbols, characters, etc. Figure 9 shows the design of the prototype DMD headlight fabricated using a 4,000-lumen LED manufactured by Nichia. The overall unit is very compact and is only 92.4 mm high. The emission area is 1.4 mm x 3.5 mm. The output density is one of the highest in the industry and is qualified for automotive applications. The output is transformed into a larger area with a smaller output angle using a hollow tunnel. The light tunnel asymmetric in the x-y plane such that the output angle matches with the output angle ratio of the projection lens, which has a smaller vertical divergence and a larger horizontal divergence. The output illumination level has met the standard specifications. In order to provide even high illumination so that other advanced functions, such as extended long-range beam, widened low beam, etc. more light is required for the DMD to be modulated.

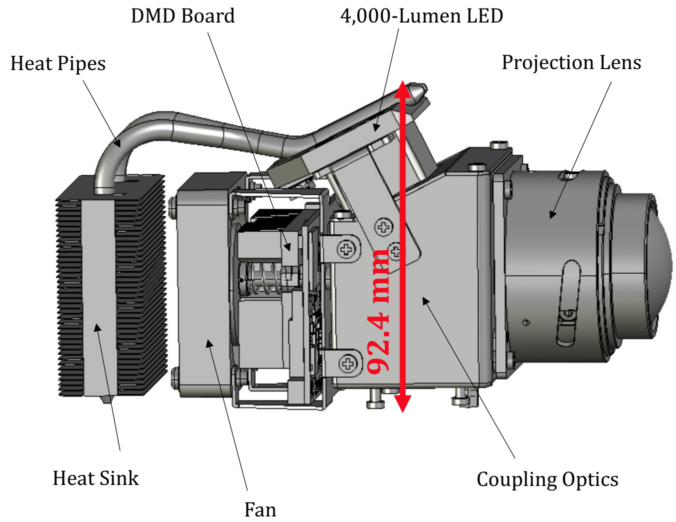


Figure 9 – A DMD Headlight using Standard LED Light Source

6 DMD Projection Headlight with Laser-Assisted LED

A novel design of such illumination system is being developed using the laser assisted LED. Over 50% improvement in output are expected with this laser assisted LED improving the performance and providing new functionalities to the DMD headlight. Figure 9 shows the schematic diagram of a DMD headlight using a high-power white LED as the light source. DMD Projection Headlight using Laser-Assisted LED

Figure 10 shows the schematic diagram of a DMD headlight using a high-power white LED as the light source. The output of the high-power LED is coupled to the output using a tapered light pipe as shown. The output is further coupled to the DMD through the use of a concave mirror such that the light is incidence onto the DMD at the operating angle. As the DMD is turned ON and OFF, the output is directed to the output projection lens and the desired pattern is projected onto the roadway.

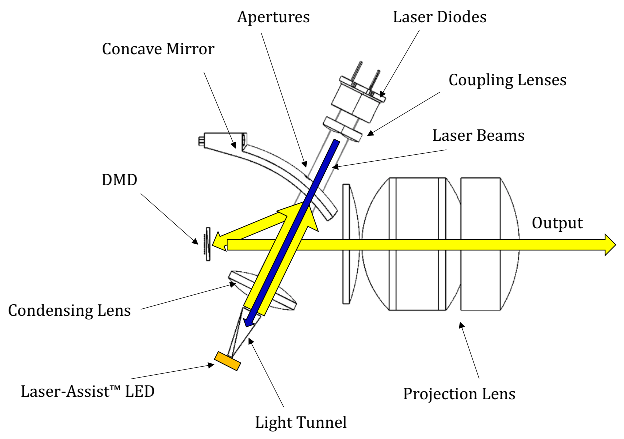


Figure 10 – Schematic Diagram of a Laser-Assisted LED DMD Headlight using a Light Tunnel

As shown in the figure, two laser diodes with parallel beam outputs are used for excitation of the SCP on top of the LED through the apertures at the concave reflector. The input will be within the acceptance angle of the DMD such that it will not be block by other mechanical fixtures. The apertures are made to be as small as possible, reducing the loss of the coupling efficiency. As needed, a coupling lens is used in front of each laser such that the spot size of the laser excitation can be adjusted providing the desired uniform intensity profile.

Figure 11 shows the schematic diagram of the Laser-Assist™ LED headlight using a set of coupling lens instead of the light tunnel. In this case, the output intensity profile of the LED is projected directly onto the DMD, which in turn, will be projected onto the roadway. For application where a long-distance beam is desired, it will be advantageous to have the center of the DMD illuminated with a higher intensity spot, the hot spot, relative to the general illumination of the rest of the area. Such hot spot can be achieved using the configuration as shown in Figure 7 and Figure 8 with higher intensity at the center of the LED. Such intensity will be used for projection on the roadway for long-distance illumination.

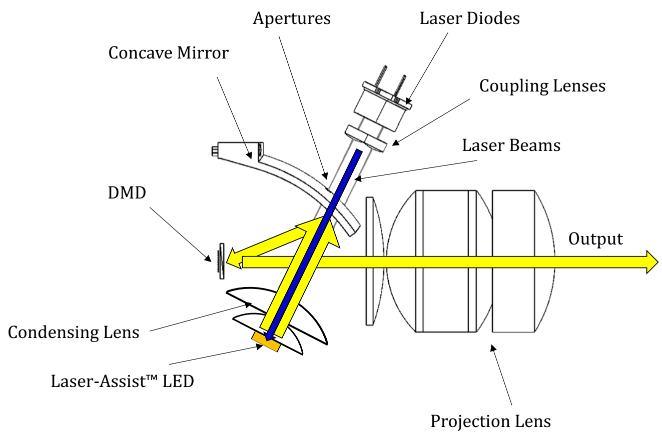


Figure 11 – Schematic Diagram of a Laser-Assist™ LED DMD Headlight using Coupling Lenses

7 Conclusions

This paper has presented the growth of the Single Crystal Phosphor material for the fabrication of the phosphor plate used for the Laser-Assisted LED. It has been shown that over 50% improvement in output has been achieved without any change in etendue. A DMD headlight using the high-power LED has also be fabricated with performance meeting the headlight standards. The Laser-Assist™ LED is being added to the DMD headlight improving the performance without and without hot-spots.

8 References

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