Etendue Preserving Stationary Phosphor Plate with Rotating Optics for High-Power Projection Applications

Kenneth Li

Optonomous Technologies Inc., Agoura Hills, CA 91301, USA

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ABSTRACT

With the advancement of blue laser developments at low cost, laser diodes and laser diode arrays are getting popular in various light system from low power to very high power. This paper presents a stationary phosphor system in which the phosphor plate is not in motion and can be attached to heat sinks for efficient removal of heat at high power operations, which cannot be achieve easily when the phosphor material is coated onto a rotating wheel. The highest power density, limited by the available laser source, of over 54 W per sq. mm has been achieved and is expected to increase in the near future with higher power laser sources, development of homogenizing and diffusing optics at the input, and micro and photonic structures at the output surfaces.

1 INTRODUCTION

While LEDs have been the used in many of the high “lumen” applications, they are not “bright” enough for projectors, entertainment spotlight, etc., where the etendue of the systems are small. Laser phosphor system have been developed in the last 10 years using mostly silicone, ceramic [1] and glass, phosphors for low power applications. For higher power systems such as projectors, phosphor wheels are used so as to dissipate the heat in a larger area, allowing the operating temperature to be below the damage and droop threshold of the phosphor material. For silicone phosphor, the outputs are usually limited by the organic bonding materials. This paper presents a static, without a rotating wheel, high power laser excited crystal phosphor system in which the crystal phosphor has a very high damage and drooping threshold temperature. Using 2 laser diode arrays, a total of 170 W of blue laser light is focused into an area of smaller than 2 mm in diameter, giving a power density of over 54 W/sq. mm., which is limited by the available laser power. It is expected to increase in the near future with higher power laser sources, development of homogenizing and diffusing optics at the input, and micro and photonic structures at the output surfaces. For projector applications, this high-power static crystal phosphor system can replace the current phosphor wheel, in most case, directly without redesign of the other projector components in terms of mechanical, optical, and electronics.
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2 PHOSPHOR WHEEL VS STATIC PHOSPHOR

There are many advantages in which the phosphor wheel is replaced by a static phosphor especially for very high-power operation. For a phosphor wheel, it will be difficult to heat sink the wheel properly as it is away in motion. On the other hand, the static phosphor can be mounted on a heavy heat sink with fins, heat pipes, vapor chamber, fans, etc. A large amount of heat can be dissipated when the phosphor plate can be mounted onto the heat sink in a permanent fixture. Figure 1 shows an example of a static phosphor plate with mounting holes on the submount for attachment to the heat sink. The laser spot is incidence on the phosphor plate at all time with high intensity. There are two critical issues that need to be resolved. The first is the heat sinking of the static phosphor plate as only a percentage of the laser power is converted to visible power, the rest will be heat. The second is the power density on the phosphor materials. When the power density is too high, the phosphor material might burn or crack mechanically, and the conversion efficiency might be limited at high power density with saturation. As a result, the static phosphor plate system allows the use of extensive heat sinking mechanisms for better control of the temperature.

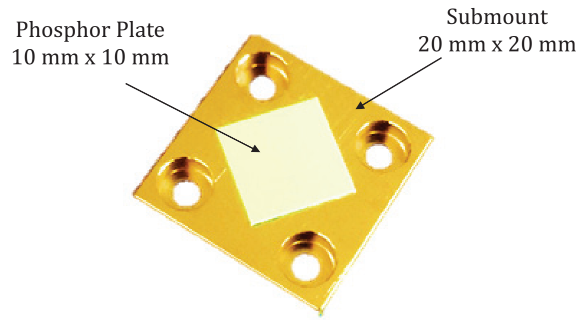


Figure 1 – Large Phosphor Plate on Submount

For high temperature operations, suitable phosphor materials include glass phosphor, ceramic phosphor, crystal phosphor, and composites with inorganic binders or bonding. The most common type is the Ce:YAG, which emits yellowish light. When mixed with the stray blue light, white light output is obtained. The other common type is the Lu:YAG, which emits slightly greenish light. This material is suitable when a single green output is required with higher overall conversion efficiency compared to that of the Ce:YAG materials. The spectral characteristics of these materials are shown in Figure 2. The glass and ceramic phosphor materials are generally opaque and the lateral dispersion of light is relatively small compared to that of the crystal phosphor in which the material is transparent to yellow light. Special considerations have to be made to confine the lateral spread increasing the spot size.

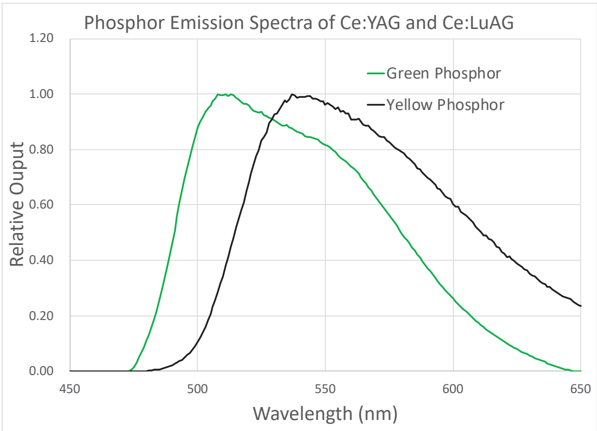
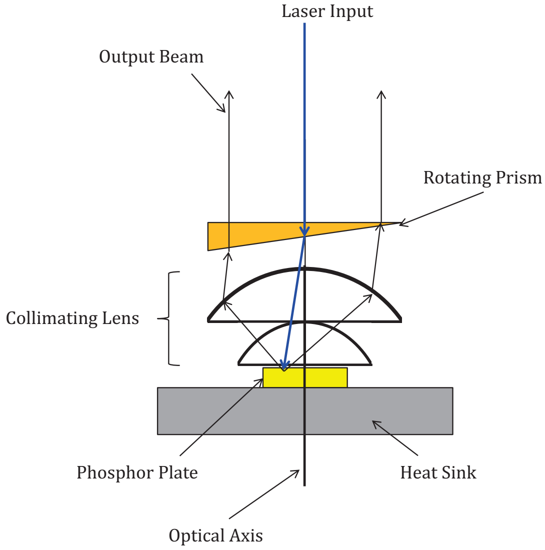


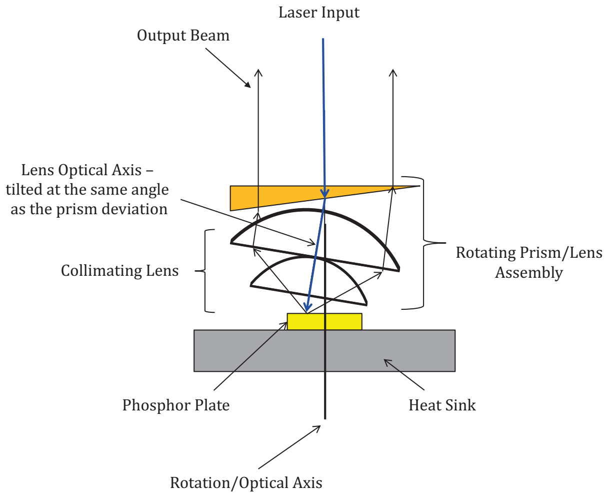
Figure 2 – Emission Characteristics of Yellow and Green Phosphors

3 FOCUSED BEAM SCANNING SYSTEM

The limits for using phosphor plates are usually in the range of about 40 to 60 optical watts per sq. mm. This severely limits the applications of static phosphor to higher power applications such as digital cinema projectors. To overcome such limitations, a patent pending configuration as shown in Figure 3(a) is used to produce a scanned phosphor pattern as shown in Figure 4, resulting in a much larger effective area while maintaining the output beam being stationary, keeping the same etendue as a non-scanning laser beam. A rotating wedge prism is placed in line with the collimating lens. The input laser beam passes through the wedge prism will be deflected by a certain angle. When this angled beam is focused onto the static phosphor plate at the focused, the location of the focus will be offset by an amount dependent on the deviation angle of the wedge prism and the focal length of the collimating lens. As the wedge prism is rotating, the focused spot will draw a circle as shown in Figure 4. The total area scanned by the focused beam will be larger than the focus of the beam itself, increasing the effective area of the laser excitation, reducing the power density to be below the intensity limit. In addition, the total heat generated are spread over a larger area such that it can be transferred to the submount with a larger area. The emission from the phosphor plate will be collected and collimated by the collimating lens, passing through the wedge prism and deflected by the same amount as the excitation laser beam, back to the same axis of the excitation laser beam. The axis of the output beam remains stationary while the wedge prism rotates. As a result, the etendue of the output beam will be the same as the output beam from a stationary focused beam area and not that from the larger scanned focused area. The result is a much higher output with the same small etendue for high power projection applications.



(a)



(b)

Figure 3 – Static Phosphor using Scanning Focused Beam with Prism

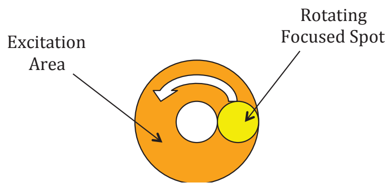


Figure 4 – Scanned Circular Pattern of the Focused Spot

Due to the input of the laser beam is deviated from the optical axis of the collimating lens introducing a small amount of aberration, thus reducing the efficiency of the system. Figure 4(b) shows another system in which the collimating lens is also tilted matching the deviation angle of the wedge prism, eliminating the aberration, thus increasing the efficiency. The drawback is the rotating of the wedge prism together with the collimating lens, increasing the weight of the rotating column. This will be suitable for system where efficiency is of the utmost importance. Figure 5 shows another system in which a proprietary system is used to deviate the beam such that the collimating lens has an optical axis perpendicular to the phosphor plate further increases the efficiency of the system. A prototype has been fabricated using a blue laser diode mounted in a TO-9 package. The rotating optics are driven using a motor and a pulley system such that the laser beam is scanned and focused onto the phosphor plate. The phosphor emission is than collected and collimated by the focusing lens and projected onto the screen as a stationary light spot, preserving the etendue of a single focused spot.

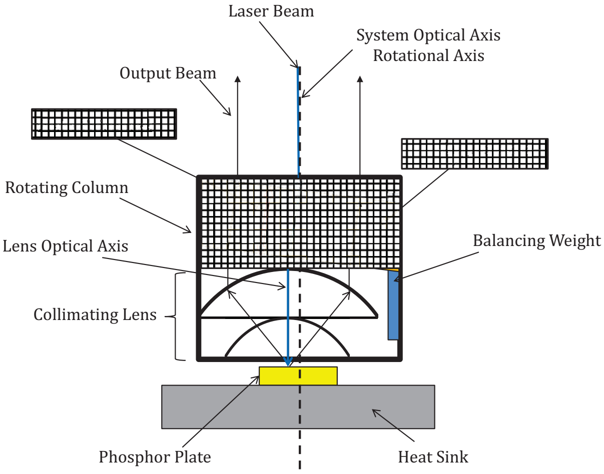


Figure 5 – Static Phosphor using Scanning Focus Beam with Proprietary Optics

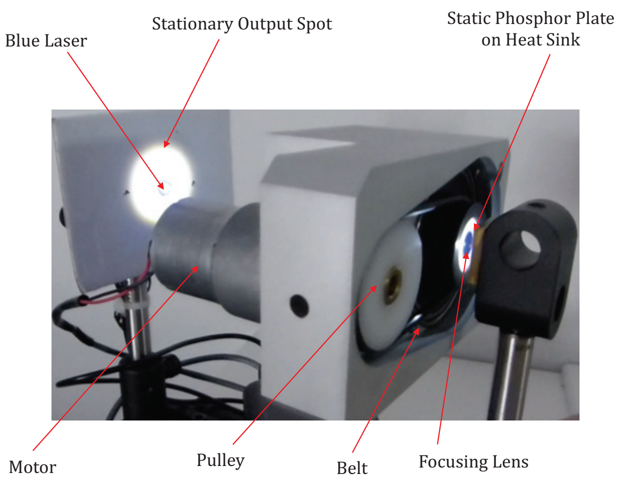


Figure 6 – Working Prototype of the System

To demonstrate the applicability of such a system, the following target system is evaluated and to be built for demonstration. In this example, a focused spot size of 2 mm is assumed, which is the requirement from most high-power projector manufacturers. With a power density limit of 50 W/sq. mm. and an efficiency of 300 lm/W, the total output is 47,100 lumens, which will be sufficient for a projector with screen output in the 10,000 ranges. With this scanning focused beam system, assuming the scanned circle is 6 mm in diameter, the total focused area is 8 times the size of the original 2 mm spot. As a result, the total output from the phosphor is 376,000 lumens allowing projectors to have screen lumens in the 120,000 screen lumens ranges. Again, further power increase can be achieved by further increase in outer diameter while the etendue maintains to be the same as that of the 2 mm spot.

4 CONCLUSION

A crystal phosphor light source using static phosphor has been designed with the potential of achieving outputs levels suitable for digital cinema and beyond. The focused beam scanning system forms the basic module in which the desired power level can be achieved with the proper choice of beam scanning diameters. The estimated output of the system could be as high as 12 times that of a non-scanning system, increasing the screen output from the 10,000-lumen range to over 120,000-lumen ranges. The remaining challenge will be the removal of the heat from the laser banks providing output laser power required and the heat generated by the ceramic or crystal phosphor plate itself.

REFERENCES

[1] V. Hagemann, A. Seidl, G. Weidmann, “Ceramic phosphor wheels for high luminance SSL-light sources with >500W of laser power for digital projection”, Proceedings Volume 10940, Light-Emitting Devices, Materials, and Applications; 1094017 (2019)