High Power Stationary Laser Phosphor with Rotating Tilted Mirror with White Light for Projection Applications

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ABSTRACT

Laser excited phosphor has been used replacing LEDs in many high power, low etendue applications such as projectors, spot lights, and others. One of the major obstacles is heat sinking of the phosphor in high power applications with the phosphor material coated onto a rotating wheel. This paper presents a stationary phosphor system in which the phosphor plate is stationary and can be attached to traditional heat sinks for efficient removal of heat at high power, which cannot be achieve easily when the phosphor material is on a rotating wheel. The highest power density of over 305 W per sq. mm has been achieved, which is 6 times higher than the original limit of the phosphor material. It is also found that the thickness of the phosphor plays an important role in the power density limits. Thinner phosphor plates are being investigated for even higher power operations with expected high limits.

1 Introduction

For many high-power applications such as cinema projectors, entertainment spot lights, etc., the etendue of the light source is of great importance as it allows a high coupling efficiency into the output beam in which a large area LED light source cannot be achieved. 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 binding materials. This paper presents a stationary phosphor system in which the heat generated by the phosphor plate can be heat sunk effectively using traditional system including active refrigeration as needed. A compact module has been designed and fabricated combining the yellow phosphor output together with part of the original blue laser light, diffused, producing a single output white light beam. Thinner phosphor materials are being prepared increasing the limit of the system.

2 Rotational vs Stationary Phosphor

When a phosphor wheel is replaced by a stationary phosphor plate, heat sinking can be achieved using traditional cooling technologies including active refrigeration. For a phosphor wheel, it will be difficult to heat sink the wheel properly as it is always in motion. For the static phosphor, it 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 three 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. The third is the heat transfer from the top of the phosphor material to the bottom of the phosphor material at the bonding between the phosphor and the heat sink. 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

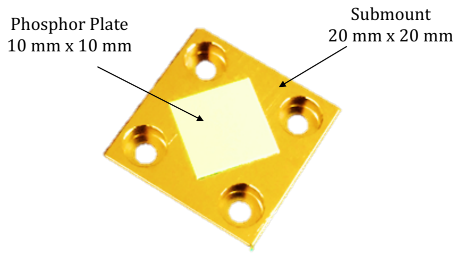

Figure 1 – Large Phosphor Plate on Submount

For high temperature operations, suitable phosphor materials include glass phosphor, ceramic phosphor, crystal phosphor, and composites with inorganic binders. 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.

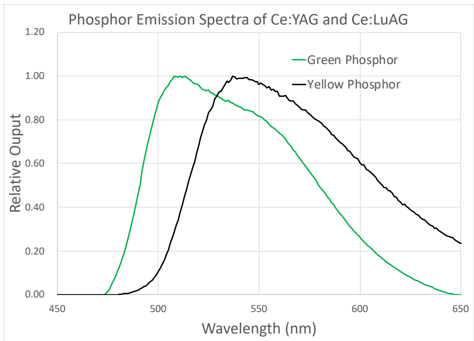

Figure 2 – Emission Characteristics of Yellow and Green Phosphors

Figure 3 shows an example where a 2 mm spot size at the focus is moving in a circular path with an outer diameter of 6 mm. The effective area increases from 3.14 sq. mm. to 25.1 sq. mm., which is 8 times the area of the focused spot, thus increasing the effective area and saturation threshold by 8 times. The key to the design and operation of this system is to maintain the original etendue of the single focus spot with area of 3.14 sq. mm.

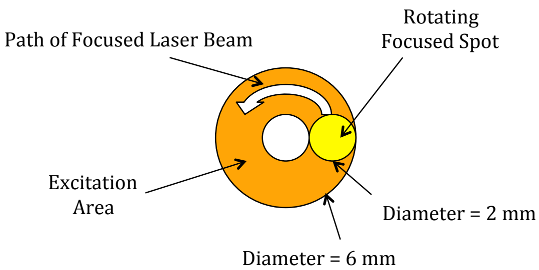

Figure 3 – Locus of the Focus Laser Spot on the Phosphor Plate

3 Tilted Rotating Mirror System

Figure 4 shows the schematic diagram of a white light source driven by a 2-D laser array with output optical power up to 125 W composed of 28 individual parallel beams. The laser beams are partially, e.g. 20%, reflected towards the Lambertian reflective diffuser through the collimating lens. The blue laser focused onto the diffuser will be scattered and collected by the collimating lens, passes through the partial reflector to the output. The overall efficiency will be 80% due to 20% reflective loss in the partial reflector. The blue laser beam transmitted through the partial reflector will then be reflected by the rotating tilted mirror with details as shown in Figure 6, with the output beam scanning in a conical fashion.

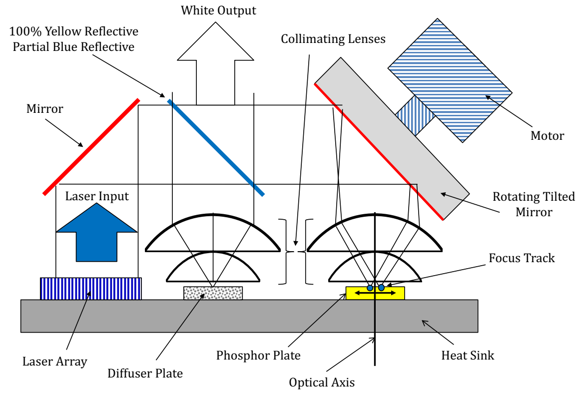

Figure 4 – Scanning Focus Beam Static Phosphor System with White Light Output

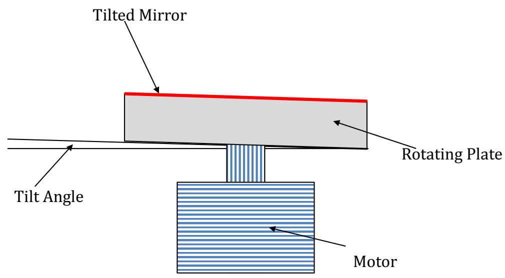

Figure 6 – A Tilted Rotating Mirror

The tilted beams are then focused onto the phosphor plate by the collimating lens with a round locus as shown in Figure 3. With a mirror tilting angle of 1.6 degrees in the initial test, which produces an output beam with 3.2 degrees tilt angle, the output locus of the focused beam has a diameter of 1.96 mm. The power of the laser reached a maximum of 24.7 W before the phosphor plate was degraded as shown in Figure 7.

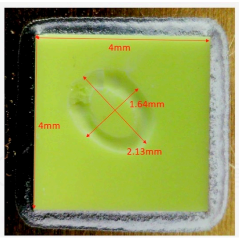

Figure 7 – Locus of the Damaged Laser Spot on the Phosphor Plate

Figure 7 shows the damaged path of the focused laser beam on the phosphor surface, which is slight elliptical instead of circular due to the directional tilting of the rotating mirror.

For further increase in the power handling capability, a tilted rotating mirror with 3.5 degrees is used such that the diameter of the focused spot locus is made larger with larger scanned area with a diameter of 4.3 mm. The testing stopped when the output intensity reaches the maximum value and decreased with further increase in laser array drive current. At this point, the laser power was 60 W, the spot size was 0.5 mm. The calculated equivalent power density was 305 W per sq. mm, which is over 6 times the specification of 45 W per sq. mm. No visible damage of the phosphor plate was observed indicated that the output temperature at the surface of the phosphor plate has not reached the damage threshold and is limited by heat sinking. On the other hand, the temperature of the heat sink has been maintained to be low and should not be the cause of the heat problem. It is postulated that the limitation is due to the temperature difference between the top and bottom of the phosphor plate. To reduce this temperature difference such that the instantaneous temperature at the top surface remains low, thinner phosphor plate samples are being prepared and to be tested for the value of the limiting laser power. To further increase this limit, the focal spot size will be increased such that the it matches with the etendue of the system, and not smaller.

A model of the system has been set up for raytracing. Several tilt angles of the rotating mirror were used and the locations of the focal spots for the various tilt angles were calculated and are shown in Figure 8. At the same time, the dimensions of the focal spots are also calculated showing that there is a certain amount of aberration when the mirror is tilted, producing larger spots at larger tilt angles as shown in Figure 9.

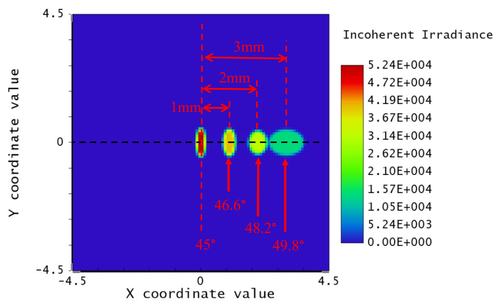

Figure 8 – Calculated Spot Locations at Focal Plane versus Rotating Tilted Mirror Angles

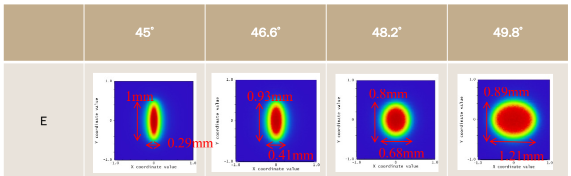

Figure 9 – Calculated Spot Dimensions at Focal Plane versus Rotating Tilted Mirror Angles

4 Potential Performance of the System

To demonstrate the applicability of such a system, the following target system is evaluated and to be built for demonstration as shown in Figure 10. 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.

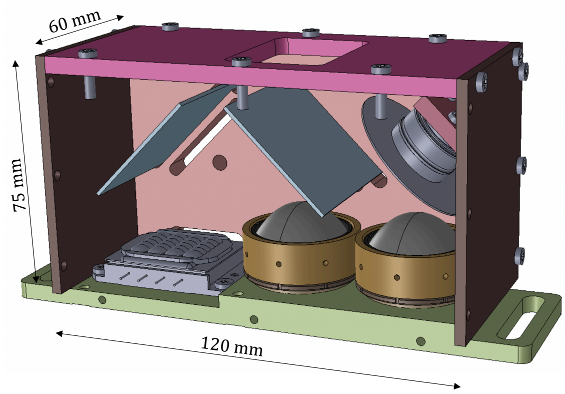

Figure 10 – Prototype Design of the Scanning Focus Beam Static Phosphor System with White Light Output

5 Conclusion

A ceramic phosphor light source using static phosphor has been designed and fabricated 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 thickness of the phosphor plate is being investigated so as to conduct heat quickly from the top surface to the bottom surface increasing the heat sinking capacity. 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

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