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High luminous flux laser lighting using single-crystal Ce:YAG phosphor

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***Abstract*—Laser lighting is rapidly becoming a viable alternative to LEDs in many applications. However, the high power density from the lasers put strict requirements on the phosphor materials used for downconverting the blue laser light. Here we demonstrate high efficiency white light generation using single-crystal Ce:YAG phosphors. More than 4700 lm is achieved using 30 W of incident blue laser light.**

***Index Terms*—Laser lighting, Ce:YAG, Blue laser diodes, phosphor, Single crystal, diode laser.**

I. Introduction

SOLID-state lighting is dominated by LEDs, which deliver high efficiency and good colorimetric properties. However, LEDs suffer from a decrease in efficiency when driven at high current densities limiting the emitted flux per area or luminous exitance. Diode lasers on the other hand become more efficient at high current densities as they do not suffer from the efficiency droop [1]. Converting blue laser diode light into white light using phosphor materials has proven to be a viable method for generation of high luminous exitance lighting. The light from the laser diodes can be focused to very small spots on the phosphor material and thus the emitting point can be very small. Laser lighting is currently installed in projectors and car headlights. However, the very high power density on the phosphor materials has appeared as one of the main limitations for achieving high luminous exitance as some phosphor materials saturate under high incident power density [2]–[4].
In this paper, we show results for white light generation using single-crystal Ce:YAG. We generate up to 4700 lm from 30 W of incident blue light from a diode laser array. We also investigate the saturation threshold for high incident power density.

II. Method and materials

We used an integrating sphere-spectroradiometer to investigate the generation of white light from the phosphor

Figure 1.

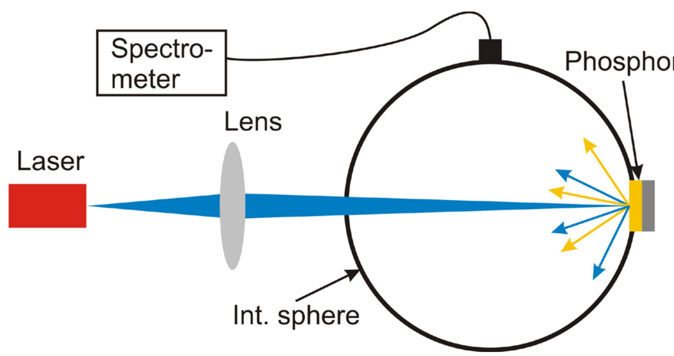

Figure 1. Schematic of the measurement system used.

We used two different laser diodes (LD) in the characterization. The first LD is a single broad area laser diode (Nichia) emitting up to 3.5 W at 445 nm, which is beam shaped to generate a circular spot in the focus. With this laser, we are able to controllably change the spot size on the phosphor material to use different power densities at all power levels. The second LD is an array of eight blue laser diodes (Nichia) emitting up to 38 W of blue light at approximately 450 nm. This laser array is beam shaped to a spot size of approximately 3 mm × 5 mm 200 mm from the focus lens to allow for insertion of an integrating sphere. The integrating sphere (Labsphere) is 6 inches in diameter and fiber-coupled to an array spectrometer (Instrument Systems) to allow for calibrated measurements of the light.

As the phosphor material, we used two different single-crystal Ce:YAG materials. One material (Crytur) was bonded to a copper mount for good thermal handling and mounted on a passive heat sink, while the other material (MTI) with a mirror coating on the back facet was left uncooled. The phosphors were positioned at the exit port of the integrating sphere, which collects the emitted light.

III. Experimental results

For the uncooled Ce:YAG we used up to 3.5 W of incident blue light. The power density was increased from less than

10 W/mm^2 to 360 W/mm^2. Only a small drop in the luminous efficacy from 144 lm/W to 136 lm/W was observed for the maximum power density [5]. The drop can be attributed to reduced conversion efficiency at elevated temperatures for the Ce:YAG. The change in power density also had only minor influence on the colorimetric properties. When illuminated by a higher power laser with lower power density, thermal quenching led to saturation of the luminescent light output. The saturation was also evident in a large increase in correlated color temperature due to the excess amount of blue light.

With the Ce:YAG crystal bonded to a copper mount, the input laser power was increased up to 30 W. At this laser power level, the luminous flux from the phosphor reached more than 4700 lm as seen in Figure 2. The luminous efficacy stayed relatively constant around 160 lm/W at all power levels as seen in Figure 3. Using ceramic phosphor materials, the luminous efficacy is typically more sensitive to the input power and power density. The luminous efficacy for a nanostructured ceramic Ce:YAG dropped from approximately 200 lm/W to 120 lm/W at a laser power density of 20W/mm^2, while the efficiency for bulk Ce:YAG was considerably lower [2].

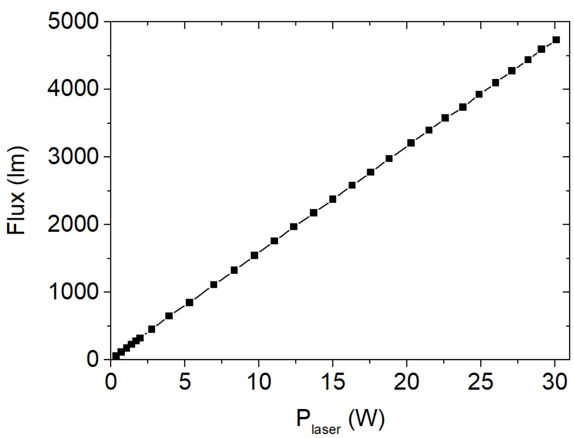

Figure 2. Luminous flux vs input laser power for single-crystal Ce:YAG.

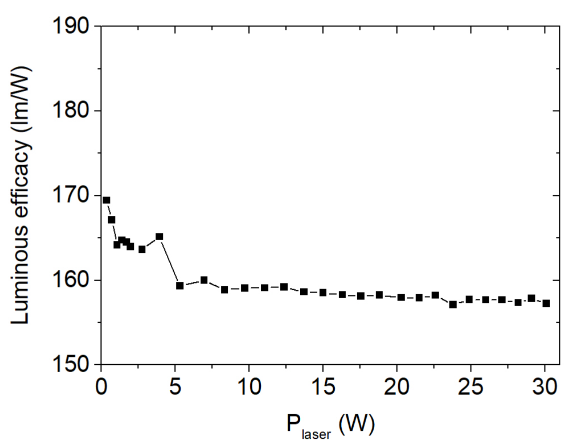

Figure 3. Luminous efficacy of the single-crystal Ce:YAG phosphor.

The spectrum of the white light is seen in Figure 4. The spectrum consisted of the peak from the blue lasers and the broad luminescence from the Ce:YAG centered around 550 nm. The correlated color temperature (CCT) was 5300 K and the color rendering index (CRI) was 63. The colorimetric properties may be improved by employing an AR coating on the surface of the phosphor to enhance the transmission into the phosphor and thus enhance the absorption of the blue light. In order to enhance the colorimetric properties even further, combination with other phosphor materials emitting in the red spectral region is a possibility.

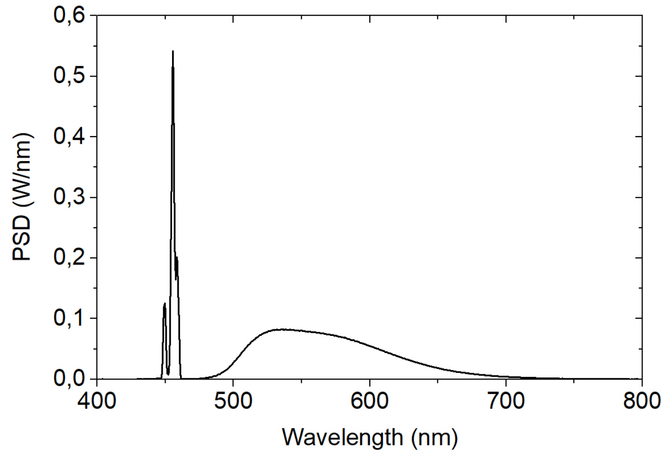

Figure 4. Spectrum of the phosphor generated light at 30 W input laser power.

IV. Conclusion

We have investigated single-crystal Ce:YAG for generation of white light. A high saturation threshold with respect to power density was observed for the phosphors at moderate input power. At low power density and 30 W input power, we have demonstrated more than 4700 lm white light. The results indicate that Ce:YAG is a strong candidate for achieving high luminous exitance.

Acknowledgment

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