7 W Diode-End-Pumped PLD-Grown Yb:Lu_2O_3 Planar Waveguide Laser

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Abstract: An Yb:Lu_2O_3 planar waveguide laser fabricated by pulsed laser deposition has reached an output power in excess of 7 W, with a slope efficiency of 38%, end-pumped by a diode bar.

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1. Introduction

The sesquioxides Lu_2O_3, Y_2O_3, and Sc_2O_3 have been identified as promising host materials for high-power lasers due to their excellent thermomechanical properties [1], with the potential to out-perform YAG-based lasers. However, these materials are challenging to grow from the melt due to their high melting points, ~2500 °C, and therefore are far less widely researched and used in commercial laser systems.

Pulsed laser deposition (PLD) is a technique for thin-film growth that allows crystalline films to be deposited on a substrate without the requirement to reach temperatures typically required for bulk growth. PLD of sesquioxides, doped with rare-earth ions, therefore lends itself to the manufacture of planar waveguide lasers. This laser configuration has a high surface area to volume ratio that allows for effective thermal management of the laser system, which is important for high-power, efficient lasers. However, only two examples of Watt-class PLD-grown planar waveguide lasers have been reported to date, with the highest output being 4 W [2], to the best of our knowledge. Here we report our recent progress progress towards power scaling these devices with a demonstration of more than 7 W from a diode-end-pumped Yb:Lu_2O_3 planar waveguide grown by PLD.

2. Fabrication

PLD was used to deposit an ~8 μm-thick Yb:Lu_2O_3 layer on a 10 x 10 x 1 mm YAG <100> substrate. A KrF excimer laser operating at a wavelength of 248 nm, with pulse duration of 20 ns, and at a repetion rate of 20 Hz was focused to produce a fluence of ~1.3 Jcm^{-2} at the ceramic Yb:Lu_2O_3 target being laser ablated. The YAG substrate was heated to ~900 °C from the rear by a 10.6 μm CW CO_2 laser, in an oxygen atmosphere at 2 x 10^{-2} mBar. An interfacial layer of ~2 nm Yb:Lu_2O_3 was deposited and annealed at $>$1000 °C for 5 hours prior to the main deposition to promote epitaxial growth at the YAG-Lu_2O_3 interface.

3. Sample Characterisation

The sample was analysed by X-ray diffraction (XRD) to characterise the crystallography, a stylus profiler to measure the thickness and an optical interferometric microscope to analyse the surface morphology. Following initial characterisation of the deposited material, the sample was end-polished in a plane-parallel geometry, resulting in a waveguide length of ~8 mm.

In the case of Yb:Lu_2O_3 on YAG <100>, XRD analysis shows sharp peaks, as shown in figure 1, indicating highly crystalline material. However, the Yb:Lu_2O_3 grows in the <111> orientation on the YAG <100> substrate due to lattice matching considerations. This is illustrated by the (222) and (444) peaks detected from the Lu_2O_3 overlapping the (400) and (800) peaks of the YAG on the XRD spectrum, making them practically indistinguishable.

The number of particulates on the surface sample was measured in five positions over the sample surface by an optical interferometric microscope and software. Using the mean of these readings, the particulate density for this sample has been calculated to be approximately 1.5 x 10^4 / cm^2 particulates $>$100 nm and 2.2 x 10^4 / cm^2 particulates $>$50 nm.

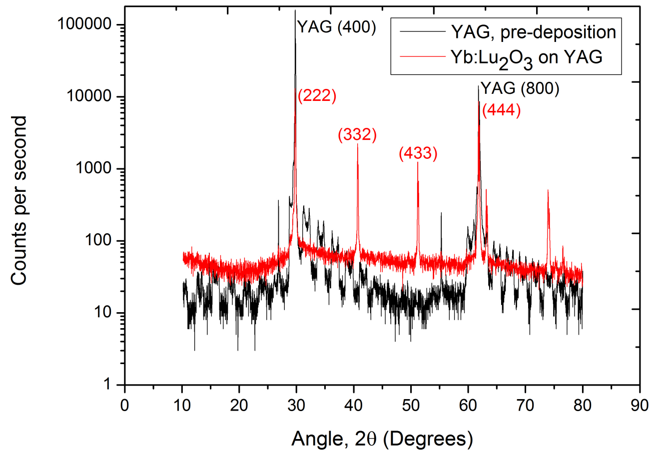

Fig. 1. XRD spectrum of Yb:Lu_2O_3 on YAG substrate (red), plotted with the XRD spectrum obtained from the YAG substrate prior to deposition of the Yb:Lu_2O_3 (black).

A HeNe laser beam was launched into the waveguide to assess the optical loss and sample uniformity. Several measurements were taken at different locations across the guide, with the lowest measured propagation loss being 0.75 dB/cm.

4. Laser Results

The waveguide was mounted on a water-cooled heatsink attached to a 5-axis translation stage and a pump input mirror (HT 950-990 nm, HR 1020-1100 nm) brought into close proximity to the pump input facet. The other facet was either used as the output mirror, relying on the Fresnel reflection from the Lu_2O_3-air interface to provide feedback, or had an output coupling (OC) mirror brought close to the output facet. The Yb:Lu_2O_3 waveguide was pumped by a laser beam from a diode bar operating around 976 nm that was focused to a diameter estimated to be 10 μm in the fast axis, at the input facet, and 1.2 mm in the slow axis, approximately half way through the guide, with a system of cylindrical lenses.

To fix the laser diode wavelength to the maximum absorption peak, the diode current and heatsink temperature were kept constant, and the pump power varied using a half-wave plate and polarising beam splitter, as shown in [3]. The ouput from the waveguide was collimated with an aspheric lens (f=18 mm, NA=0.54) and the laser light reflected by a dichroic mirror (HT 900-990 nm, HR 1020-1100 nm) onto a calibrated power meter. Light transmitted through the dichroic mirror, mainly from the extremes of the diode spectrum that have poor overlap with the Yb:Lu_2O_3 absorption spectrum was recorded with another power meter, to assess the pump absorption efficiency. The laser output performance as a function of absorbed pump power for the different laser configurations trialled is presented in figure 2.

The best performance obtained was from the laser setup using the Fresnel reflection of the output facet, which gave a maximum output power of 7.4 W and a slope efficiency of 38% with respect to estimated absorbed pump power. A Caird analysis of the laser performance gives an upper estimate of the waveguide propagation loss to be 2.9 dB/cm. The laser output wavelength was 1034 nm for all output couplers trialled, showing a high inversion density was required to reach threshold, consistent with moderate to high round trip losses. A second moment beam quality measurement, M^2, established the laser output to be highly multimode with an M^2 of 6.3 in the guided axis and 49 in the unguided axis, at full power.

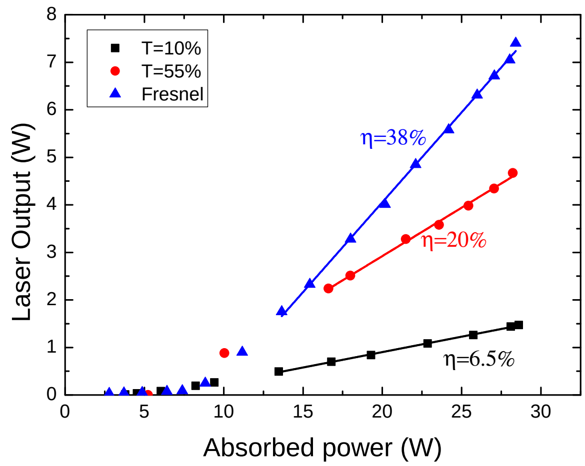

Fig. 2. Laser output results for three different configurations, with the highest power measured at 7.4 W. The slope efficiency for each output coupler is displayed next to each slope in the corresponding colour. T = 10% OC in black, T = 55% OC in red, and lasing from Fresnel reflection at the output facet in blue.

5. Conclusion

More than 7 W of laser power has been obtained from a PLD-grown Yb:Lu_2O_3 waveguide, with a slope efficiency of 38% with respect to absorbed pump power. There is no sign of thermal rollover, even at the highest pump powers used so far, despite minimal thermal management.

Further investigation of Yb:Lu_2O_3 growth by PLD for planar waveguide lasers is underway, including thicker samples for increased launch efficiency from the diode bar, multilayer samples for improved beam quality in the guided axis [4], and samples with a capping layer to decrease scattering losses from the top of the guides. Progress towards higher power, more efficient planar waveguide laser results will be reported.

Acknowledgements

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References

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