1.2 W Yb:Y_2O_3 Planar Waveguide Laser

Stephen J. Beecher, Tina L. Parsonage, Jacob I. Mackenzie, Katherine A. Sloyan, James A. Grant-Jacob, and Robert W. Eason
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
S.J.Beecher@soton.ac.uk

Abstract: A 12µm thick composite Yb-doped and undoped yttria layer is grown on a YAG substrate by pulsed laser deposition. For 8.5W of incident laser diode pump power the waveguide laser emits 1.2W at 1030nm.

OCIS codes: (310.0310) Thin films; (220.4610) Optical fabrication; (230.7390) Waveguides, planar; (130.0130) Integrated Optics; (140.3380) Laser materials; (140.5680) Rare earth and transition metal solid-state lasers.

1. Introduction

Crystalline planar waveguides present a route to scaling the average power from laser oscillators which, with a few notable exceptions [1,2], has not been fully capitalized upon. The absence of commercialization of this laser architecture has been due in part to the difficulty of the fabrication of the inhomogeneous crystalline gain element. Here we present work on the growth of crystalline ytterbium-doped yttria (Yb:Y_2O_3) on to YAG substrates by pulsed laser deposition and laser experiments conducted on these waveguides.

2. Fabrication

The waveguide was designed to have a 2 at.% Yb doped core of 6 µm surrounded by two 3µm undoped yttria layers giving a total thickness of 12 µm. The films were grown onto a <100>-orientated YAG substrate of dimensions 10 x 10 x 1 mm^3 using the setup described in [3]. The PLD layers were fabricated using a KrF excimer laser producing 20 ns pulses at 20 Hz at a wavelength of 248 nm. This laser output was focused to a fluence of 1.7 J/cm^2 on the Y_2O_3 or Yb:Y_2O_3 ceramic target. The substrate was heated to 900°C using a CW CO_2 laser and during deposition the target was rotated by an offset cam assembly to make efficient use of the target surface via the epitrochoidal ablation path. Depositions were conducted in an oxygen background of 4 x 10^{-2} mBar. Fig. 1. Presents the designed structure and a backscatter scanning electron microscope (BS-SEM) image of the waveguide facet. Vertical striations are visible in the BS-SEM image, these do not appear to be surface features but continue across the interface between undoped and doped material.

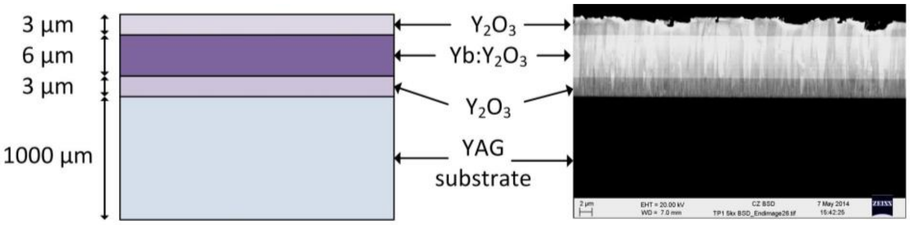

Fig. 1. The designed waveguide structure and a backscatter scanning electron microscope image of the waveguide facet. Some edge chipping of the top Y_2O_3 layer is visible.

3. Sample characterization

The material quality was investigated via X-ray diffraction using a Bruker D2 Phaser powder diffractometer over a 2θ range of 10-80°, see fig. 2(a). The film shows a highly ordered crystalline phase with the largest peak corresponding to the <222> and <444> orientations of cubic yttria and the <400> and <800> peaks from the YAG substrate. A pole figure of Yb:Y_2O_3 grown on <100> YAG is also presented showing 12 peaks separated by 30°, see fig. 2(b). The peaks indicate that the yttria film has four distinct rotationally-orientated domains about the <111> direction. The presence of four different domain orientations will likely lead to structural inhomogeneity within the crystal, particularly at grain boundaries.

Energy dispersive X-ray analysis was used to characterize the dopant concentration across the multiple layers of the waveguide and shows a 1.9 at.% Yb concentration in the central layer and zero Yb concentration outside of this layer. Following material characterization two opposing facets of the waveguide structure were polished plane parallel for optical analysis and laser experiments, this resulted in a waveguide length of 8.0 mm.

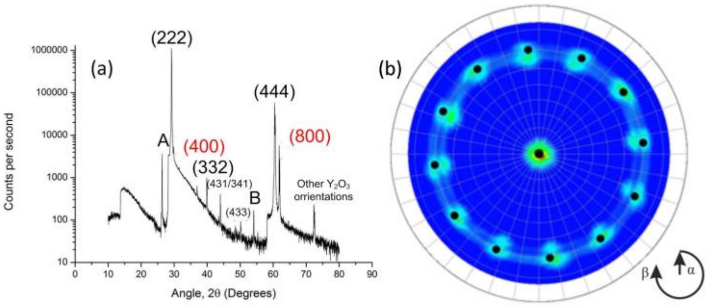

Fig. 2(a). XRD spectrum of the 12 μm-thick Yb:Y_2O_3 multilayer waveguide. Yttria orientations are labeled in black and those from the substrate in red. (b) Pole figure of single layer Yb:Y_2O_3 grown on <100> YAG with overlay (black dots) of predicted (222) pole figure with <111> orientation.

4. Optical properties, spectroscopy and laser performance

Fluorescence lifetime measurements were taken by face pumping the sample under loose focusing with a 965nm laser diode. Fluorescence was collected, the pump light removed with a 1 μm long pass filter and then refocused onto a photodiode. The fluorescence followed an exponential decay with a lifetime of 860 μs, see Fig. 3(a), in keeping with reports of this material grown via other methods [4]. For measurement of the fluorescence spectrum the same laser diode was coupled into the waveguide and a 62.5 μm core diameter 0.22 NA fiber was used to capture light emerging from the face of the sample. This collection orientation minimizes the distance through doped material that the fluorescence must travel, reducing the effect of spectral dependent absorption on the fluorescence spectrum measurement. The Füchtbauer-Ladenburg equation was used to calculate the emission cross section, and McCumber analysis was then used to calculate the absorption cross section for the material using Stark levels calculated from data in [5], see Fig. 3(b). The spectroscopic characteristics of the film are indistinguishable from material grown by more conventional crystal growth techniques [2].

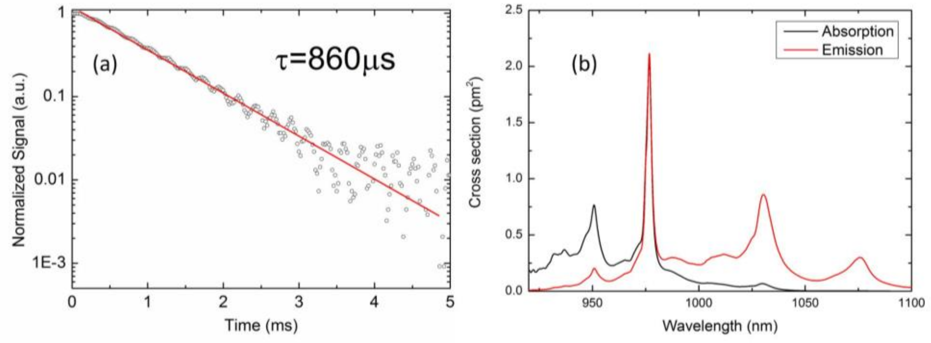

Fig. 3. Spectroscopic characterization of a Yb:Y_2O_3 PLD grown film: (a) fluorescence lifetime, and (b) absorption and emission cross sections.

The waveguide was surrounded by two mirrors placed within the Rayleigh length of light emerging from the waveguide facets and pumped by the laser diode temperature tuned to the 976.5 nm absorption peak, see Fig. 4(a). One mirror was selected to be highly transmitting at the pump wavelength and highly reflecting at the signal wavelength and the other partially reflective at the signal wavelength. The fast axis of the broad area diode laser was coupled into the guided axis of the waveguide and the slow axis was quasi-collimated with a beam radius of 400 μm. Output coupling mirrors with reflectivities of 90%, 75% and 30% at the laser wavelength were trialed. In all cases oscillation occurred at 1030 nm, with incident pump power thresholds of 2.0 W, 2.25 W and 2.70 W respectively and slope efficiencies of 5%, 16% and 22% respectively. An analysis of the type reported in [6], with the pump efficiency term used to take into account pump propagation losses of the same magnitude as the signal losses leads to a calculated propagation loss of 1.1 dB for a single pass of the 8 mm waveguide, equivalent to 1.4 dB/cm assuming all parasitic cavity losses are due to waveguide propagation loss. After recording slope efficiencies the polarizing beam splitter was removed to give an incident pump power of 8.5 W, at this pump power the 30% reflectivity output coupler gave a 1030nm output power of 1.2 W.

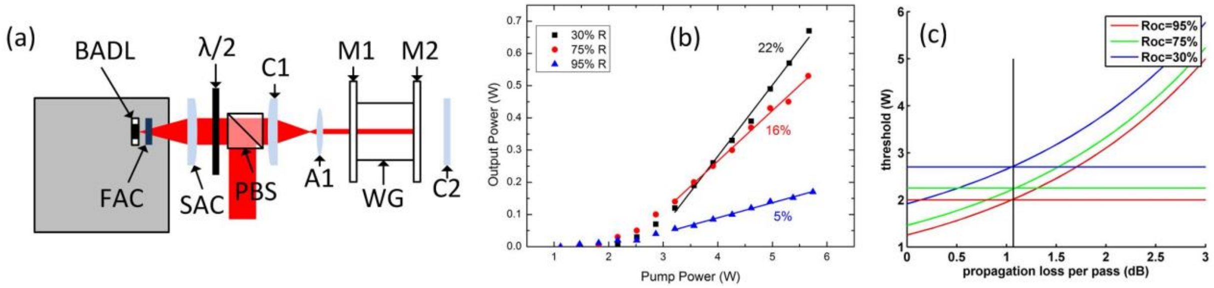

Fig. 4. Performance of the waveguide laser: (a) experimental setup, (b) laser output for different incident pump powers, (c) experimental (horizontal lines) and theoretical thresholds (curves) for different intracavity losses. The intercept of the experimental and theoretical lines for each output coupler gives an estimate of the propagation loss.

4. Conclusions

We have demonstrated a 1.2 W diode-end-pumped planar waveguide laser based on a multi-layer waveguide fabricated by pulsed laser deposition. A slope efficiencies of 22% is demonstrated and waveguide propagation losses of less than 1.4 dB/cm are reported. Striations in the crystal structure and the existence of four different crystal orientations are believed to contribute significantly to the waveguide losses. Work is currently underway to reduce or eliminate this poly-crystallinity in the film. With further reduction of losses and an increase in pump power we believe these PLD grown planar waveguides to be capable of multiple 10’s of W output.

5. References

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