Pulsed-laser-deposited Yb:YAG planar-waveguide amplifier

S.V. Kurilchik, J.A. Grant-Jacob, J.J. Prentice, P. Hua, R.W. Eason, and J.I. Mackenzie

Optoelectronics Research Centre, University of Southampton, SO17 1BJ, UK

Pulsed laser deposition (PLD) has proven to be a fast and a reliable method for the fabrication of optical-quality crystalline films for laser applications, allowing precise engineering of the layered structure [1,2]. Rare-earth doped garnets [3], sesquioxides [4] and sapphire [5] crystalline layers have been successfully grown by this technique and impressive laser performance was demonstrated using them as active waveguides. Recently, beyond Watt-level output powers for PLD-grown planar waveguides were achieved using ytterbium doped garnet films, such as GGG, YGG and YAG, where 16W of output power with a 70% slope efficiency was demonstrated with the latter [3]. Here we present our recent advances in the development of a planar-waveguide amplifier and improved laser performance with a PLD-grown Yb:YAG thin film.

In this work a Yb(7.5%):YAG layer, with 12.0 μm thickness, was deposited by the PLD technique onto a 1 cm^2 1-mm thick <100>-YAG substrate. Following the growth, two opposing facets of the sample were polished plane-parallel and AR-coated for 1030nm, resulting in an ~8 mm long waveguide. The refractive index contrast between the film and the substrate was evaluated to be 1.06×10^{-3}, supporting just two guided modes at 1μm. Fluorescence spectra and lifetime measurements of the films were found to be very similar to those of equivalent bulk crystals.

The laser experiments were performed using a 40-W diode-laser bar as a pump source, operating at around 940 nm. The pump radiation was focused to a 12 μm×1.5 mm (D4σ) spot on the input facet of the waveguide by a set of cylindrical lenses. The laser cavity was formed by plane input and output mirrors brought into close proximity to the facets. In this setup, we achieved a maximum output power beyond 21W with a slope efficiency of 70% for a 20% reflectivity output coupler (OC) mirror and slightly reduced performance for other output couplers (Fig.1a). The laser operated at 1030nm wavelength for all tested OCs. From the laser performance, we calculated intracavity passive losses by use of a modified Caird analysis [6] (Fig.1b). The losses were estimated to be 1.82dB per round trip, and maximum waveguide propagation loss of 1.14dB/cm, although in reality it is lower as this includes several other loss mechanisms, such as coupling and coating losses.

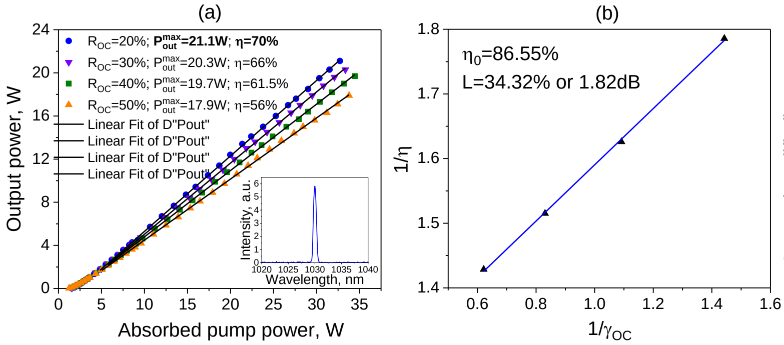

Fig. 1 Input-output performances with laser spectrum as the inset (a) and losses curve (b) of Yb:YAG planar waveguide laser.

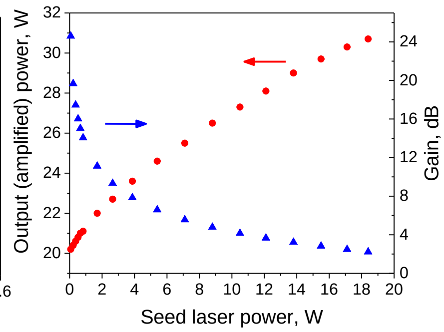

Fig. 2 Yb:YAG planar waveguide amplifier output power and gain.

Amplification in the waveguide was studied using a home-built seed laser based on a Yb:YAG bulk crystal, emitting up to 20W of output power at 1030nm, with excellent beam quality (M^2<1.2). Using the same pumping and in-coupling HR mirror as the laser results, the seed laser beam was launched into the waveguide in an initially counter-propagating configuration, with comparable beam dimensions as the pump. The amplification was detected by measuring transmitted power of the seed laser beam double-passed through the waveguide. In this way, we demonstrated for the first time >20dB amplification in a PLD-grown Yb:YAG planar waveguide in the small signal regime. Furthermore, >30W (2dB gain) output power in the saturated amplifier regime (Fig.2) was obtained with a 55% conversion efficiency. We aim to demonstrate pulsed radiation amplification, to be reported at the meeting.

References

[1] J.A. Grant-Jacob, S.J. Beecher, H. Riris, A.W. Yu, D.P. Shepherd, R.W. Eason, and J.I. Mackenzie, "Dynamic control of refractive index during pulsed-laser-deposited waveguide growth," Opt. Mater. Express **7**, 4073-4081 (2017)

[2] J.A. Grant-Jacob, S.J. Beecher, J.J. Prentice, D.P. Shepherd, J.I. Mackenzie, R.W. Eason, "Pulsed laser deposition of crystalline garnet waveguides at a growth rate of 20 μm per hour," Surface and Coatings Technology **343**, 7-10 (2018).

[3] S.J. Beecher, J.A. Grant-Jacob, P. Hua, J.J. Prentice, R.W. Eason, D.P. Shepherd, and J.I. Mackenzie "Ytterbium-doped-garnet crystal waveguide lasers grown by pulsed laser deposition," Optical Materials Express **7**, 1628-1633 (2017).

[4] J.J. Prentice, J.A. Grant-Jacob, D.P. Shepherd, R.W. Eason, J.I. Mackenzie,"Yb-doped mixed-sesquioxide films grown by pulsed laser deposition," Journal of Crystal Growth 491, 51-56 (2018).

[5] S.H. Waeselmann, S. Heinrich, C. Kränkel, G. Huber, "Lasing of Nd^{3+} in sapphire," Laser and Photonics Reviews **10**, 510-516 (2016).

[6] J. Morris, N. K. Stevenson, H. T. Bookey, A. K. Kar, C. T. A. Brown, J.-M. Hopkins, M. D. Dawson, and A. A. Lagatsky, "1.9 μm waveguide laser fabricated by ultrafast laser inscription in Tm:Lu2O3 ceramic," Optics Express **25**, 14910-14917 (2017).