PLD-grown Yb:Y_2O_3 waveguide laser Q-switched by a graphene saturable absorber

A. Choudhary[1], S. Dhingra[2], B. D'Urso[2], T. L. Parsonage[1], K. A. Sloyan[1], R. W. Eason[1] and D. P. Shepherd[1]

[1] Optoelectronics Research Centre, University of Southampton, Southampton, Hampshire, UK
a.choudhary@soton.ac.uk, tlp1g08@orc.soton.ac.uk, kas@orc.soton.ac.uk, rwe@orc.soton.ac.uk, dps@orc.soton.ac.uk
[2] Department of Physics and Astronomy. University of Pittsburgh, Pennsylvania, USA
shd28@pitt.edu, dursobr@pitt.edu

Abstract: In this paper, we present an Yb^{3+}-doped Y_2O_3 waveguide laser fabricated by pulsed laser deposition (PLD) that is Q-switched using a mono-layer graphene saturable absorber. 140 ns pulses at a repetition rate of 1.21 MHz and pulse energy of 14 nJ are achieved at an absorbed pump power of 528 mW.

Introduction: Pulsed lasers have a range of applications in areas such as medicine, material processing, telecommunications and defence. Waveguide-based pulsed laser systems have the additional potential to be integrated, compact, mass-producible and efficient, making them exciting prospects for future industrial applications. We have recently demonstrated mode-locked femtosecond waveguide lasers at multi-GHz repetition rates[1-3] using semiconductor saturable absorber mirrors (SESAMs). However, SESAMs are expensive, complicated to fabricate and have a narrow operating wavelength range. In the last decade, graphene saturable absorbers[4] have become very popular because of the ease of fabrication and their broadband operation, with Q-switched waveguide lasers[5] and Q-switched mode-locked waveguide lasers[6] being demonstrated. Yttria (Y_2O_3) is a promising laser host due to good thermal properties, ease of rare-earth doping and waveguide fabrication by pulsed laser deposition (PLD)[7]. In this paper, we demonstrate a PLD-grown Yb:Y_2O_3 waveguide laser that has been Q-switched using a mono-layer graphene saturable absorber.

Experimental details and results: A multi-layer clad waveguide structure, consisting of 3-μm-thick Y_2O_3 lower and upper cladding layers and a 6-μm-thick Yb:Y_2O_3 core layer, was grown on a YAG substrate by PLD and end-polished to a final device length of 8 mm. A fibre-coupled laser diode operating at 975 nm was used as the pump source for the initial continuous wave (CW) characterisation of the Yb:Y_2O_3 waveguide laser. The pump output was collimated by an aspheric f = 8 mm lens and launched into the waveguide using a further aspheric lens with f = 8 mm, making a spot size of w_0 ~3.3 μm at the input facet. A half-wave plate and a Faraday isolator were installed in the beam path to block any back reflections from the waveguide and to protect the laser diode. The laser cavity was formed by end-butting a 200-μm-thick high reflectivity (HR) mirror at the input-facet, and 200-μm-thick output coupling (OC) mirrors with transmission (@1030 nm) of 0.8%, 2%, 5%, 14% and 19.6%, respectively at the output facet. CW laser action was observed at 1030 nm at a threshold power of 123 mW for the 0.8% OC and a slope efficiency as high as 25% was observed for the 19.6% OC. The laser mode radius was measured to be 3.2 μm in the guided plane and 170 μm in the un-guided plane. The losses were estimated to be 1.6 dB/cm, based on the measured slope efficiency for each output coupler and using Caird analysis[8].

In order to obtain pulsed operation, single-layer graphene was used as a saturable absorber. It was grown on large-domain ultra-flat copper using atmospheric-pressure chemical vapour deposition (APCVD)[9], and was then transferred onto a fused silica substrate using PMMA. The single-layer was subsequently transferred to the waveguide when the substrate was pressed against the output end-facet of the waveguide.

A counter-propagating laser cavity was formed by putting the HR mirror on the output facet of the waveguide and aligning a mirror (2% transmission at 1030 nm, 99.9% transmission at 975 nm) on the input facet. A dichroic mirror (T=99% @ 975 nm, R=97% @1030 nm) was installed before the launch objective to separate the pump and laser beams. The laser output was reflected by the dichroic mirror and was characterized using a photodiode, a power meter and an optical spectrum analyser.

The output from the waveguide laser was focused on a silicon photodiode (1 ns rise time), which was connected to an oscilloscope (1 GHz bandwidth). On increasing the pump power, CW operation was observed at an absorbed power of 138 mW. At an absorbed power of 292 mW, Q-switched pulses were generated at an average output power of 6 mW. The pulse duration and repetition rate at the threshold for Q-switching were measured to be 310 ns and 830 kHz respectively, and the pulse energy was calculated to be 7 nJ. On increasing the pump power, the pulse duration was found to decrease from 310 ns (at 292 mW) to 140 ns (at 528 mW) and the pulse energy increased from 7 nJ to 14 nJ as seen from Fig.1.a. A maximum output power of 16 mW and a maximum repetition rate of 1.21 MHz were measured at an absorbed power of 528 mW as seen from Fig.1.b. The slope efficiency under Q-switched operation was measured to be 4.4%. In comparison, during CW characterisation (without graphene), the slope efficiency was measured to be 4.9% and a maximum output power of 20 mW was obtained for an HR/2% OC cavity. The output pulse with a full width at half maximum (FWHM) of 140 ns and the pulse train with a repetition rate of 1.21 MHz, measured at maximum pump power are shown in Fig.1.c and Fig.1.d, respectively.

Conclusions: We have demonstrated the first, to the best of our knowledge, Q-switched operation of a PLD-grown waveguide laser. Passive Q-switching was achieved by using CVD-grown graphene as a saturable absorber. A repetition rate as high as 1.21 MHz was obtained with a pulse energy of 14 nJ. Future work would include fabrication of channels to reduce the laser threshold followed by mode-locking experiments.

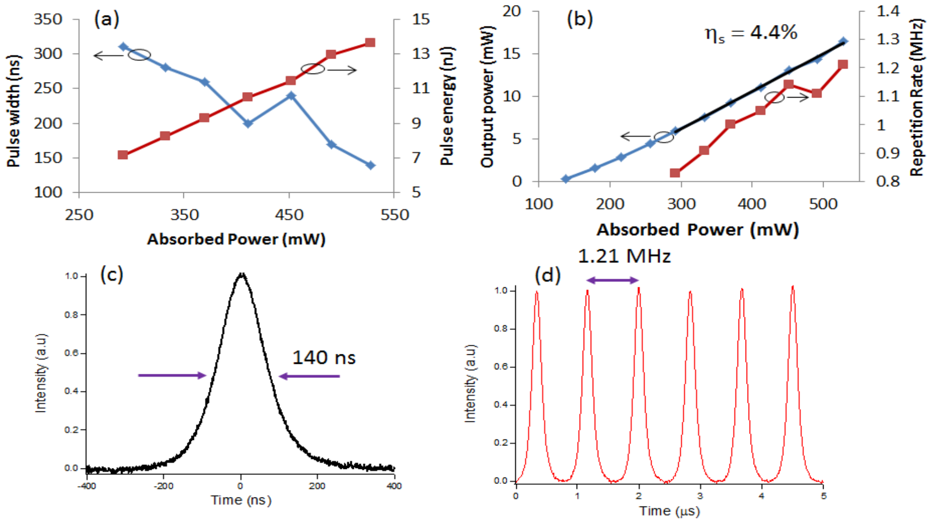

Fig.1. (a) Pulse width and pulse energy vs. absorbed power, (b) Output power and repetition rate vs. absorbed power, (c) 140 ns pulse measured at an absorbed power of 528 mW, and (d) pulse train measured at an absorbed power of 528 mW.

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