Graphene Q-switched Yb:Yttria waveguide laser by evanescent-field interaction delivering an average output power of 0.5 W

A. Choudhary,[1] S.J. Beecher,[1] S. Dhingra,[2] B. D'Urso,[2] T. L. Parsonage,[1] J. A. Grant-Jacob,[1] P. Hua,[1] J.I. Mackenzie,[1] R.W. Eason,[1] and D.P. Shepherd[1]

1. Optoelectronics Research Centre, University of Southampton, Highfield, Southampton SO171BJ, UK

2. Department of Physics and Astronomy, University of Pittsburgh, Pennsylvania 15260, USA

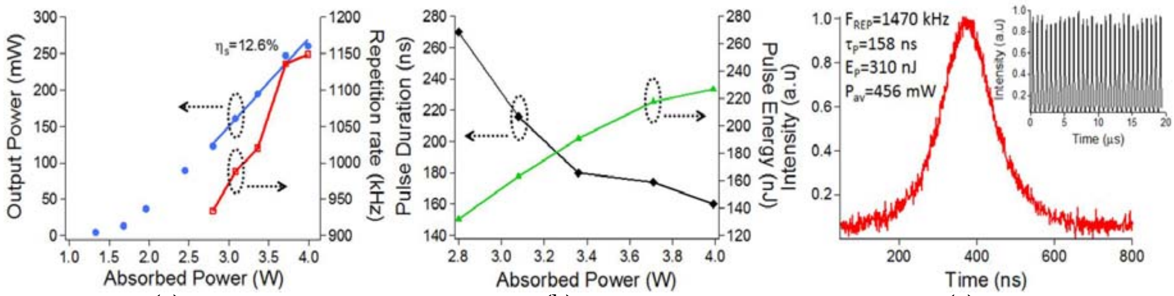
Pulsed waveguide lasers [1] are interesting sources for a wide range of applications ranging from medicine, industrial processing and defence. Waveguides offer monolithic integrated structures with a natural geometric compatibility with high-power diode laser pump sources allowing compact devices. Additionally, if propagation losses can be kept low, the optical confinement can lead to low laser thresholds, high efficiencies, and low power requirements for passive Q-switching or mode-locking via saturable absorbers (SAs). Rare-earth-doped sesquioxide materials, such as yttria, possess physical and spectroscopic properties that make them very interesting for high-power solid-state lasers, and we have recently reported Q-switched operation of a pulsed laser deposited (PLD)-grown Yb:Y_2O_3 [2] waveguide using a graphene-covered output coupler as an SA. The output power of this laser was limited by damage to the graphene layer, which is directly in the path of the laser beam. However, waveguides also offer the opportunity of coupling the laser beam to the saturable absorber via evanescent-field coupling and this in turn offers the possibility of high-power pulsed operation.

In this paper, we demonstrate an Yb:Y_2O_3 waveguide laser Q-switched using evanescent-field interaction with graphene. 310 nJ pulses at an average power of 456 mW were obtained from a graphene-covered Yb:Y_2O_3 waveguide, which represents more than an order of magnitude improvement when compared to previous Q-switched waveguide lasers using end-butted graphene.

A 13-μm-thick layer of (2 at.%) Yb:Y_2O_3 was grown onto a <100>-oriented YAG substrate, using PLD. The waveguide sample was polished to a length of 8 mm and atmospheric pressure chemical vapour deposition grown graphene was transferred on the top surface. The graphene-covered waveguide was pumped using a broad area diode laser at a wavelength of 975 nm. The pump was tightly focussed at the waveguide facet in the guided direction making a spot diameter of 10 μm, and a spot diameter of 190 μm was made in the centre of the waveguide for the un-guided axis. The laser cavity was formed between a HR mirror at the input facet and different output coupler (OC) mirrors, with transmission values of 12% and 19.5%, at the second waveguide facet attached using surface tension of a fluorinated liquid.

With the 12% OC, CW operation was observed at a threshold power of 1.33 W and on increasing the absorbed pump power to 2.8 W, Q-switched operation initiated at an average output power of 123 mW and pulse energy of 132 nJ. The pulse duration was measured to be 270 ns and the repetition-rate was measured to be 934 kHz. The output power and repetition rate as a function of pump power is shown in figure 1 (a) and it can be observed that both of these increase with pump power, with a maximum output power of 261 mW and a repetition-rate of 1149 kHz at an absorbed pump power of 4 W. The slope efficiency was measured to be 12.6% with respect to the absorbed power. The pulse duration was found to decrease from 270 ns to 160 ns and the pulse energy increased from 132 nJ to 227 nJ on increasing the pump power as seen from figure 1 (b).

Finally, the best performance was achieved at 4 W of pump power using a 19.5% OC as seen from figure 1 (c) with pulses being generated at an average power of 456 mW and as short as 158 ns at a repetition-rate of 1470 kHz and a pulse energy of 310 nJ.



(a) (b) (c)

Fig. 1 (a) Output power and repetition rate vs. absorbed power using a 12% OC, (b) Pulse duration and pulse energy vs. absorbed power with a 12% OC , and (c) pulse profile and pulse train (inset) at maximum pump power using a 19.5 % OC for the graphene-covered Yb:Y_2O_3 waveguide laser.

References

[1] A.A. Lagatsky, A. Choudhary, P. Kannan, D.P. Shepherd, W. Sibbett, and C.T.A Brown, "Fundamentally mode-locked, femtosecond waveguide oscillators with multi-gigahertz repetition frequencies up to 15 GHz," Opt. Express **21**, 19608-19614 (2013).

[2] A. Choudhary, S. Dhingra, B. D'Urso, T.L. Parsonage, K.A. Sloyan, R.W. Eason, and D.P. Shepherd, "Q-switched operation of a pulsed-laser-deposited Yb:Y_2O_3 waveguide using graphene as a saturable absorber," Opt. Lett. **39**, 4325-4328 (2014).