High-power Ultrafast Solid-state Laser Using Graphene Based Saturable Absorber

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Abstract: We demonstrate a graphene based saturable absorber mode-locked $Nd:YVO_4$ solid-state laser, generating ~14nJ pulses with ~1W average output power. This shows the potential for high-power pulse generation.

OCIS codes: (320.7090) Ultrafast lasers; (140.3580) Lasers, solid-state; (160.4330) Nonlinear optical materials.

1. Introduction

Passively mode-locked solid-state lasers are the main work-horse for various applications in industry, research and military [1-2]. Currently, high-power ultrafast solid-state lasers are mainly mode-locked by semiconductor saturable absorber mirrors (SESAMs)[1-3]. These devices require expensive and complex epitaxial growth techniques (e.g. molecular beam epitaxy)[2–3] and subsequent post-processing to reduce recovery time[2-3]. Single wall carbon nanotubes[4-13] and more recently, graphene [13-19] based saturable absorbers have attracted great attention for ultrafast pulse generation, due to their unique properties, such as sub-picosecond recovery time, broadband operation, low saturation intensity, easy fabrication and integration. In particular, graphene based saturable absorbers (GSA) are attractive SAs because they do not require bandgap engineering [13-25], due to the linear band dispersions [20]. After the first demonstration of graphene mode-locking [13], most efforts on GSA focussed on fiber laser mode-locking [13-19], while very few groups reported graphene mode-locked solid-state lasers[21-22]. Thus far, for graphene mode-locked solid-state lasers, the maximum output pulse energy and average power are ~1nJ and 100mW [21], not exploiting the high-power capabilities of solid-state lasers.

Here, we report a high-power passively mode-locked $Nd:YVO_4$ laser using GSA, with ~1W average power. The repetition rate and pulse energy are ~75MHz and ~14 nJ, respectively.

2. Experimental Setup and Results

Graphene dispersions are prepared using method in Ref.[17], then spin-coated on quartz to form a GSA. The absorption spectra of the GSA and a reference quartz substrate are presented in Fig.1(a). The GSA absorption is featureless[17], while the quartz substrate contributes small peaks in the infrared spectral range [26].

The GSA is then inserted in a solid-state laser, shown in Fig.1 (b). We use a 3×3×15mm^3 $Nd:YVO_4$ crystal with a Nd^{3+}-doping concentration of 0.3 at.% as the gain medium. Both facets of the crystal are coated with an anti-reflection (AR) coating for 1064 nm. The crystal is pumped by an 880nm fiber-coupled laser diode (LD). The fiber has a 200µm core diameter and a 0.22 numerical aperture (NA). The beam diameter of pump beam inside the crystal is ~400m, coupled with a beam shaping telescope. M1 is a flat mirror with AR coating at 880 nm and high reflection (HR) coating at 1064nm. M2 is a wedge-shaped mirror used as an output coupler with 10% transmittance at 1064nm. Both have HR coating at 1064nm. M5 is a flat mirror with HR coating at 1064 nm. The GSA is put between M3 and M5 for passive mode-locking. The total cavity length is ~2.0m.

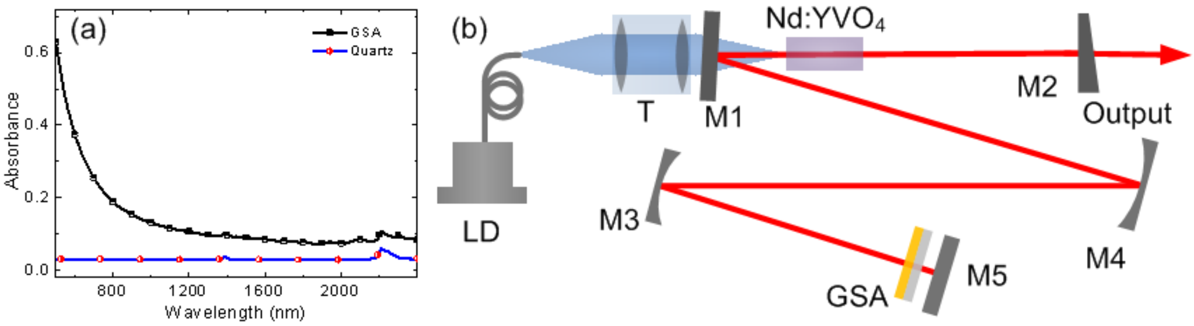

Fig. 1. (a) Absorption spectra of GSA and quartz substrate. (b) Laser setup. LD: Laser diode; T: Telescope.

Continuous wave (CW) lasing threshold is ~2W. Mode-locked pulses are observed when the pump power is increased to 3.6W. The pulses are shown in Fig.2. The pulse profile is measured using a digital oscilloscope (Agilent DSO6104A) with 1GHz bandwidth and a photodiode with 100ps rising time. As shown Fig. 2, the pulse interval equals to ~13.3ns cavity round trip time, indicating mode-locking [2]. The repetition rate is ~75MHz, in agreement with the cavity design parameters. The peak output wavelength is ~1064nm. The full width at half maximum of the output spectrum is ~0.17nm.

The average output power increases almost linearly with the pump power. The maximum average output power we achieved is ~1W at 2.6W pump power. The optical-to-optical conversion efficiency is ~16% with a ~20% slope efficiency. The corresponding pulse energy is ~14nJ. Our output power is around one-order of magnitude higher than previous graphene mode-locked lasers [13-19,21-22].

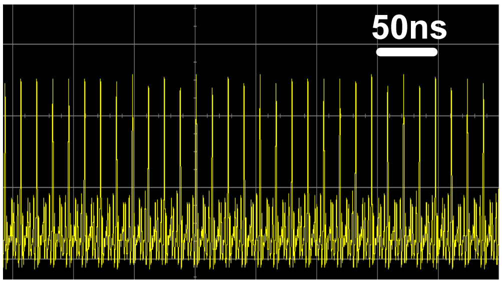

Fig. 2. Mode-locked pulse.

3. Conclusions

We reported a high-power passively mode-locked solid-state laser using GSA, with a ~1W output power and an optical-to-optical conversion efficiency of 16%. The repetition rate and pulse energy are ~75MHz and ~14 nJ, respectively. This work paves a way to GSA based high-power and high-efficiency ultrafast lasers.

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