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Compact passively Q-switched Nd:GGG laser with antimony telluride-graphene oxide as saturable absorber

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ABSTRACT

Saturable absorber (SA) based on antimony telluride (Sb_2Te_3)-graphene oxide (GO) had been fabricated. We demonstrated a compact passively Q-switched Nd:GGG laser with the mixed Sb_2Te_3-GO SA. Stable Q-switching operation at a central wavelength of 1066 nm was performed. The shortest single pulse width of 237 ns with repetition rate of 72 kHz and the maximum output power for Q-switched operation of 408 mW was achieved under the pump power of 4.5 W, corresponding to the optical-to-optical conversion of 9.1%.

1. Introduction

New materials with low cost, good saturable absorber (SA) response, broadband absorption range and high modulation depth were heated research issue of Q-switched or mode-locked lasers. The emerge of graphene and graphene oxide (GO) have open a door to development of new SAs for lasers. As a single carbon atomic layer material and zero-gap semiconductor, graphene has many properties such as high electron mobility, low saturation intensity, fast recovery time and wide operation wavelength range [1–3]. Therefore, it can be used as SA for single wavelength or dual-wavelength, Q-switched or mode-locked lasers [4–10]. With same saturable absorption properties, GO usually be regarded as the same as graphene. However, with modulation depth, graphene and GO were failed to generate larger pulse energies [11,12]. With the development of graphene and GO, two-dimensional (2D) materials such as molybdenum disulfide (MoS_2) and tungsten disulfide (WS_2), have been researched due to the tunable bandgaps and abundance [13,14]. The structure of the 2D materials were quasi-2d layers weakly bound together by Van der Waals interaction but exhibits strong covalent bonds in one layer [15–17]. Moreover, MoS_2 and WS_2 have been reported as SA for fiber lasers and solid state lasers due to their saturable absorber responses with high modulation depth in wide wavelength range [18–22]. Topological insulators, a kind of Dirac-materials, with the graphene-like electronic-band and large nonlinear refractive index have been investigated [23,24]. The surface states of topological insulators contains a single Dirac cone. In the bulk, this materials also have insulating states [25–27]. Topological insulators with large modulation depth and less absorption loss could be employed as good candidate SA materials. Among the topological insulators, Sb_2Te_3 have been studied as a promising SA materials for Q-switched and mode-locked operation in fiber lasers [23–27], there are still few reports about this material or mixed materials as SA in solid state lasers. The mixed SA not only exhibits larger modulation depth than single GO but also shows less absorption loss than Sb_2Te_3. Therefore, mixed saturable absorber with big modulation depth and wide modulation wavelength range seems a promising candidate in solid state lasers [28].

Here we demonstrated preparation process of few layers Sb_2Te_3-GO SA. The mixed SA not only could be used in a wider range of laser wavelength then the Sb_2Te_3 SA, but also exhibits deeper modulation depth than GO SA. Moreover, compact Nd:GGG laser with mixed Sb_2Te_3-GO SA was designed. The maximum output power of 0.408 W and highest energy of 5.67 μJ were obtained, corresponding to repetition rate of 72 kHz and 23.92 W peak power with the pulse width of 237 ns.

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2. Preparation and characterization of Sb_2Te_3-GO saturable absorber

We put 0.01 g of Sb_2Te_3 powder into 2 ml of alcohol-dispersed GO solution at first. And then, 15 ml of alcohol was added into this solution. The mixed solution was ultra-sonicated for 2 h and stirred using the magnetic stirring apparatus for 20 min at the rotation rate of 400 rpm. Next, a quartz sheet was submerged into the as-prepared solution completely. At last, the substrate was left under ambient temperature for 24 h results in a Sb_2Te_3-GO film on it.

Linear transmitted spectrum of Sb_2Te_3-GO SA was shown in Fig. 1. The measurement was done in the wavelength range 400–1200 nm. The transmission varied between 86.4% at 400 nm and 89.3% at 1200 nm.

Fig. 2 shows the nonlinear transmission curve of the Sb_2Te_3-GO SA measured by a 1040 nm Yb-PCF fiber laser with pulse width of 52 fs and repetition rate of 42 MHz. The modulation depth and saturation power intensity were about 7.5% and 1.08 MW/cm^2, respectively.

3. Experimental setup

The schematic of experimental setup is shown in Fig. 3. The compact laser means the cavity length is quite short with a simple structure. We used a standard plano-plano resonator with the length of 13 mm. A fiber-coupled laser diode operating at 808 nm with the fiber core diameter of 400 μm and numerical aperture of 0.22 was employed as the pump source. The incident pump was focused into Nd:GGG with a spot diameter of 100 μm by a focusing system. The plane mirror M was antireflection (AR) coated for the 808 nm laser and highly reflective (HR) for the 1.06 μm laser. The 1% Nd^{3+}-doping Nd:GGG crystal with the cross section of 3 × 3 m m^2 and the length of 5 mm was used. The laser crystal was mounted in a water-cooled copper block holding at 20 °C with cooling water. The flat mirrors were employed as output coupler (OC) with 3 and 15% transmission at 1.06 μm laser wavelength.

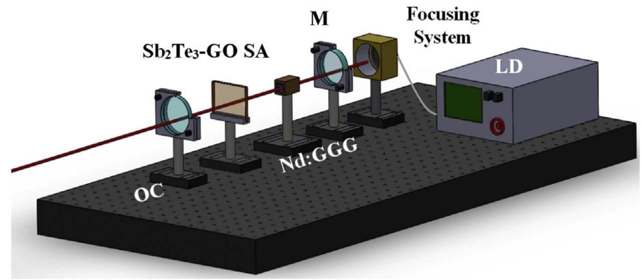

Fig. 3. Schematic setup of the Nd:GGG laser.

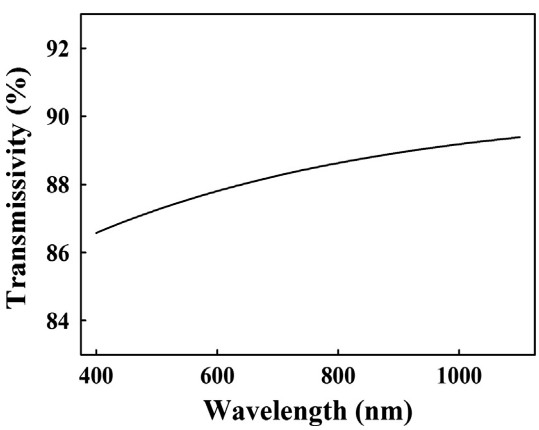

Fig. 1. UV-vis-NIR transmitted spectrum of the mixed Sb_2Te_3-GO saturable absorber.

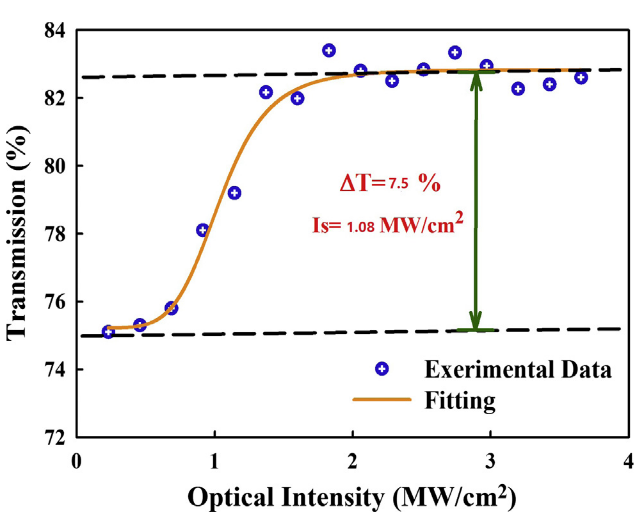

Fig. 2. Nonlinear transmission curve of the Sb_2Te_3-GO SA.

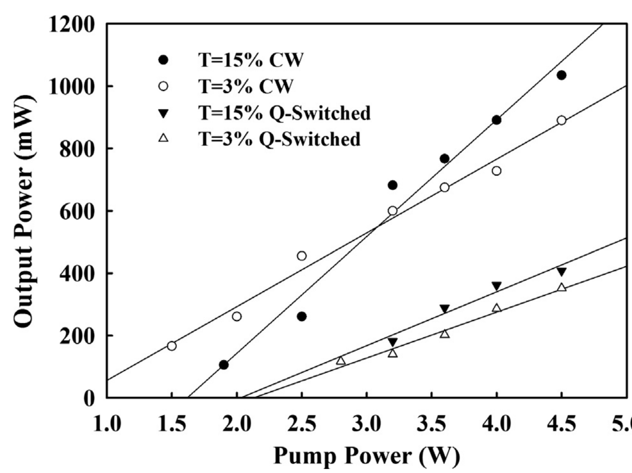

Fig. 4. Power efficiency data of the continuous wave (CW) and Q-switched operation with T = 3% and T = 15% output couplers.

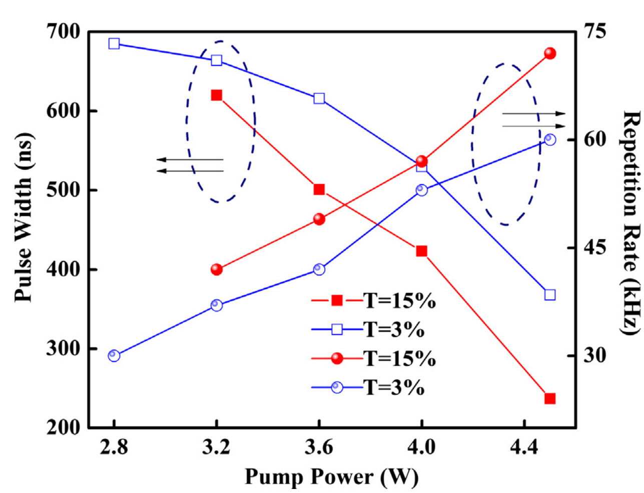

Fig. 5. Variation of the pulse width and repetition rate with the pump power.