Optics and Laser Technology 100 (2018) 261–264

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

$MoTe_2$ saturable absorber for passively Q-switched Ho,Pr:$LiLuF_4$ laser at ~3 μm

Zhengyu Yan [a], Tao Li [a,*], Shengzhi Zhao [a], Kejian Yang [a], Dechun Li [a], Guiqiu Li [a], Shuaiyi Zhang [b], Zijing Gao [c]

[a] School of Information Science and Engineering, Shandong Provincial Key Laboratory of Laser Technology and Application, Shandong University, Jinan 250100, China
[b] Advanced Optoelectronic Materials and Technologies Engineering Laboratory of Shandong, Qingdao University of Science & Technology, Qingdao 266061, China
[c] School of China Agricultural University, Beijing 510000, China

ARTICLE INFO

Article history:
Received 12 July 2017
Received in revised form 13 October 2017
Accepted 16 October 2017

Keywords:
Q-switched lasers
$MoTe_2$ saturable absorber
Solid state lasers

ABSTRACT

Multilayer molybdenum ditelluride ($MoTe_2$) nanosheets were prepared by liquid-phase exfoliation (LPE) method. A YAG-based $MoTe_2$ saturable absorption (SA) was consequently fabricated. The $MoTe_2$-SA was employed in a passively Q-switched Ho,Pr:$LiLuF_4$ laser at 2.95 μm. Under the absorbed pump power of 3.8 W, an average output power of 90 mW was achieved. The shortest pulse duration of 670 ns was generated with an output power of 73 mW and a repetition rate of 76.46 kHz, corresponding to a pulse energy of 0.95 μJ.

1. Introduction

Lasers operating in the mid-infrared (MIR) spectral region, the security range of the eyes, are of great interest for a comprehensive scientific and technological applications, such as air pollution monitoring, gas analysis, medical and optical space communications [1–3], since water strong absorption is about $10^4\,cm^{-1}$ in this wavelength range [4].

In contrast with active Q-switching, passive Q-switching possesses several advantages: cheapness, compactness, briefness, and has been successfully applied for a wide range of pulsed lasers. Recently, graphene, topological insulators, semiconducting transition metal dichalcogenides (TMDs) and other two-dimensional materials are of great application for Q-switched lasers as saturable absorbers (SAs) in an ultrabroad spectral range, attributing to their distinctive properties [5–12]. However, graphene possesses a low modulation depth [6], topological insulators are limited to complex preparation processes [13], and black phosphorus is prone to oxidation [14]. In contrast with them, TMDs have outstanding layer-dependent semiconducting and nonlinear optical properties [15].

Compared to other semiconducting TMDs, telluride material has not attracted adequate attention. The research of $MoTe_2$ nanosheets is merely focused on fabrication methods and electronic properties [16–20]. In addition, $MoTe_2$, in contrast to MoS_2 and $MoSe_2$, has smaller bandgap and higher conductivity [16,21]. However, the nonlinear optical performance of $MoTe_2$ has not been investigated sufficiently, excepting a mode-locking Er-doped fiber laser at 1.55 μm [22]. The saturable absorption property of $MoTe_2$ at ~3 μm has not been reported so far.

In this contribution, a multilayer $MoTe_2$ nanoplatelet on a yttrium aluminum garnet (YAG) substrate was fabricated and used as saturable absorber in a Q-switched Ho,Pr:$LiLuF_4$ laser near 2.95 μm. Under an absorbed pump power of 3.8 W, an average output power of 90 mW was generated. The minimum pulse duration was 670 ns with a repetition rate of 76.46 kHz, corresponding to a pulse energy of 0.95 μJ. Despite somewhat low output power, it will be useful for manufacturing of ultra-compact diode pumped environmental laser sensors.

2. Preparation and characterization of $MoTe_2$ SA

The liquid-phase exfoliation (LPE) method was explored for fabricating $MoTe_2$ film [23]. The exfoliation was obtained by ultrasonicating the bulk $MoTe_2$ in ethanol solvent for 12 h. After centrifugation at 2500 rpm for 20 min, the supernatant was transferred to another centrifuge tube for further processing. These suspensions were extraordinary stable without precipitation after a month under ambient conditions, as shown in Fig. 1(a).

Raman spectra and atomic force microscopy (AFM) were utilized to systematically characterize the $MoTe_2$ samples. By using a He-Ne laser at 632.8 nm, the Raman spectra was recorded to

* Corresponding author.
E-mail address: litao@sdu.edu.cn (T. Li).

https://doi.org/10.1016/j.optlastec.2017.10.012
0030-3992/

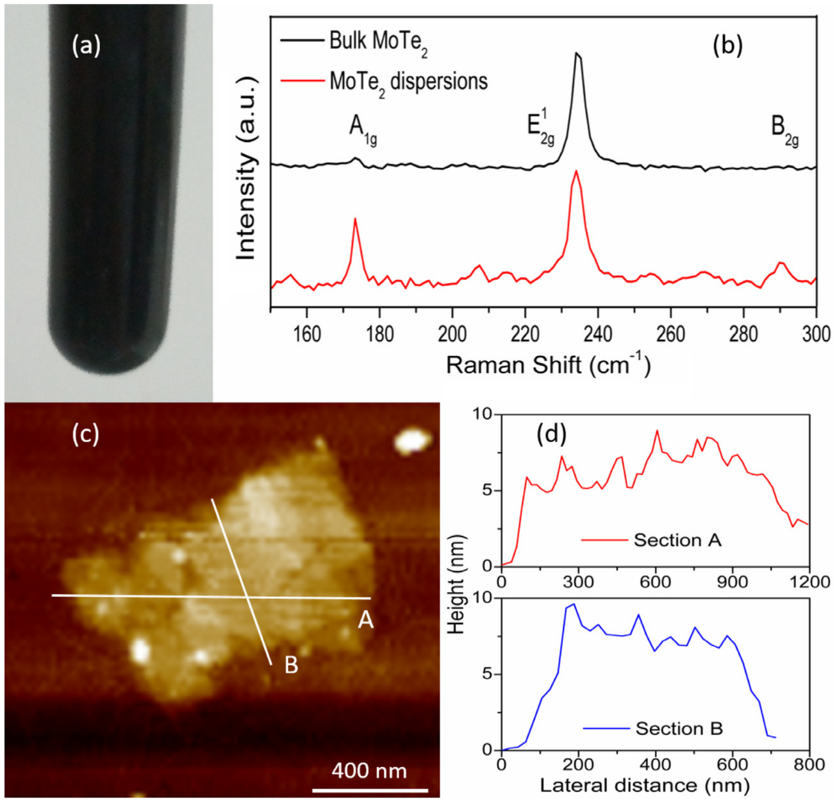

Fig. 1. (a) Suspension of the $MoTe_2$ nanosheet, (b) Raman spectra, (c) AFM image and (d) height variation.

prove that a multilayer structure had been successfully exfoliated from the bulk $MoTe_2$, the result is shown in Fig. 1(b). The characteristic vibrational modes of $MoTe_2$, A_{1g} at 170 cm^{-1}, E1 2 g at 234 cm^{-1}, and B_{2g} at 290 cm^{-1} were detected, while the A_{1g} mode was stronger than B_{2g} [24]. The B_{2g} mode was inactive in the bulk, however could be observed in the few-layer $MoTe_2$, attributing to the reduced symmetry [25]. Fig. 1(c) shows the AFM morphology of as-prepared $MoTe_2$-SA, which clearly reveals the $MoTe_2$ has been exfoliated to submicron scale sheets. Fig. 1(d) shows a height profile of section A and B in Fig. 1(c). The height of $MoTe_2$ thin film was estimated to be between 5 and 9.6 nm. The layer thickness was accordingly calculated to be 8–15 atomic layers, assuming the mono-layer thickness of $MoTe_2$ is 0.65 nm [24].

The optical transmission spectrum of the $MoTe_2$ film was measured from 200 nm to 3200 nm by an UV/VIS/NIR spectrophotometer (U-4100, Hitachi, Japan). A certain amount of the supernatant was dropped onto a MIR quartz plate with a dimensions of 50 m m × 20 mm, which was used as the test sample. As shown in Fig. 2, the transmission coefficient, revealing a smooth wide spectrum, increases with the augment of wavelength from the visible to mid-infrared, which may induced by the defect state, the edge state saturable absorption, or the coexistence of semiconducting and metallic states [10,26,27].

A $MoTe_2$-SA was prepared by dropping 5 μL dispersion onto a YAG substrate and drying in the air at room temperature. The $MoTe_2$-SA has a modulation depth of 22% and a saturated transmission of 88.7%, as shown in Fig. 2(inset). The surface reflection of the uncoated YAG substrate was measured to be 6.8%, which perhaps resulted from Fabry-Perot effects. Consequently, the nonsaturable loss of the $MoTe_2$ film is estimated to be 4.5%. The saturation fluence of the $MoTe_2$ nanosheet flake was calculated to be 0.14 mJ/cm^2.

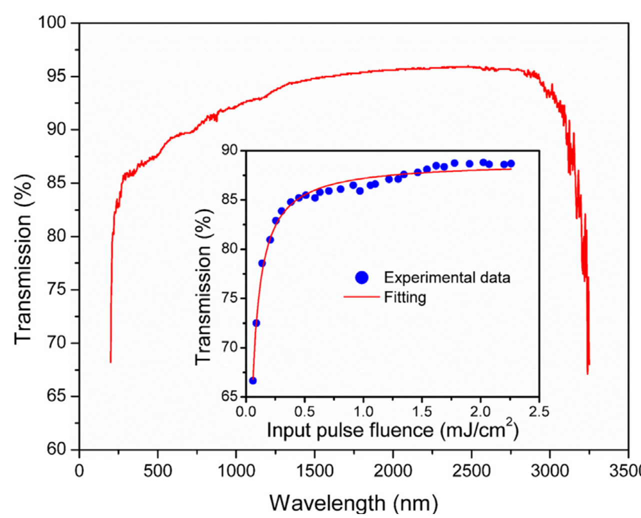

Fig. 2. Optical transmission spectrum of the $MoTe_2$ film; inset: nonlinear transmission of $MoTe_2$-SA.

3. Experiment

3.1. Experimental setup

Fig. 3 shows the schematic experimental setup of the $MoTe_2$ Q-switched laser with a 30 mm long plane-concave linear cavity. An uncoated Ho,Pr:$LiLuF_4$ crystal (2 mm × 5 mm × 10 mm) with Ho and Pr doping concentrations of 0.185 and 0.008 at.% was employed as the gain medium. The crystal was wrapped by indium foil and mounted in a copper block water-cooled to 12 °C. The pump source was a fiber-coupled laser diode emitting at 1150