Optics and Laser Technology 108 (2018) 355–359

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

Watt-level passively Q-switched and mode-locked Nd:YAG laser with a reflective MoS_2 saturable absorber

Yingjie Zeng [a], Yonggang Wang [a,d,*], Wei Ren [b], HongYing Wang [c], Fuxing Fu [c], Xi Wang [d], Qiqi Zheng [a], Zhendong Chen [a], Lianglei Wei [a], Xiguang Yang [a], Jiang Wang [a]

[a] School of Physics & Information Technology, Shaanxi Normal University, Xi'an 710119, China
[b] School of Science, Xi'an University of Posts and Telecommunications, Xi'an 710119, China
[c] The Key Laboratory for Surface Engineering and Remanufacturing of Shaanxi Province, Xi'an University, Xi'an 710065, China
[d] State Key Laboratory of Transient Optics and Photonics, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710119, China

ARTICLE INFO

Article history:
Received 31 January 2018
Received in revised form 29 May 2018
Accepted 6 July 2018
Available online 19 July 2018

Keywords:
Nd:YAG
MoS_2
Saturable absorber
Q-switched mode-locked

ABSTRACT

A passively Q-switched mode-locked Nd: YAG laser with a reflective molybdenum disulfide (MoS_2) saturable absorber (SA) was demonstrated. The MoS_2 SA was made by spin-coating the MoS_2 nanoplates onto a home-made silver mirror. The modulation depth of the MoS_2 SA was measured to be 3.05%. We optimized the laser beam radii in the crystal and on the reflective silver mirror with MoS_2 by accurately designing the oscillator cavity. Under an incident pump power of 11 W, we got the maximum average output power as high as 1.06 W with a repetition rate of 94.72 MHz. The experimental results validated the outstanding characteristics of MoS_2 SA and its further amplification possibility in high power all-solid-state pulse lasers.

1. Introduction

All-solid-state lasers pumped by semiconductor lasers with short pulses have many advantages, such as superior stability, higher single pulse energy, and multi-wavelength range availability, etc [1]. Thus, they are widely used in the fields of physical chemistry, biomedicine, and nuclear fusion, etc [2]. At present, passive Q-switching and passive mode locking based on the saturable absorbers (SAs) are two popular techniques to obtain short or ultra-short pulses [3]. Q-switched and mode-locked (QML) laser has high pulse energy as Q-switched laser pulse and has the short pulse width as same as that of CW mode-locked lasers. In addition, the repetition rate of pulses was reduced with the enhanced peak pulse in QML [4]. Traditional SA, such as Cr^{4+}:YAG [5–7], GaAs [8], and SESAM [9–12] have been extensively applied to the pulsed generation of Q-switching and mode locking techniques so far. In recent years, some cheap low-dimensional nanomaterials, like carbon nanotubes [13], Graphene [14–15], and transition-metal dichalcogenide [16–19] were found to possess the nonlinear absorption property and have been paid much attentions of the researchers. Especially, as a kind of transition-metal dichalcogenide, MoS_2 has become an important promising two-dimensional nanomaterial SA. MoS_2 nanomaterial shows a graphene-like layer structure and more excellent nonlinear optical response than graphene. The saturable absorption can be perceived when the linear absorption cross sections of the trap states are larger than that of the ground states. The direct excitation from these surface-trapped states will promote the photo carriers to higher energy levels in the nanomaterials [20]. Meanwhile, the Pauli blocking causes one-photon absorption, the result shows the saturable absorption in material [21]. Zhang et al. [22] infer that the absorption property may arise from the coexistence of semiconducting and metallic states in the MoS_2.

MoS_2 nanomaterial has been reported as the mode-lockers and Q-switchers as far. In 2013, MoS_2 as a new saturable absorber was reported by Wang et al. [23]. In 2014, Zhang et al. [22] got a 800 ps mode-locking operation by using the MoS_2 saturable absorber in the ytterbium-doped fiber laser at 1054 nm. After that, Liu et al. [24] showed ~710 fs pulses in a 1569.5 nm EDF laser based on a MoS_2/PVA composite film SA with 1.78 mW average output power. Wang et al. [25] obtained a high fundamental repetition rate of 463 MHz mode-locked fiber laser with a linear cavity of 5.9 mW output power in 2015. Chang et al. [26] used the MoS_2 SA to obtain a Q-switched laser with the pulse width of 320 ns and the average output power of 323 mW in 2017. Up to now, the average output

* Corresponding author at: School of Physics & Information Technology, Shaanxi Normal University, Xi'an 710119, China.

E-mail address: chinawygxjw@snnu.edu.cn (Y. Wang).

https://doi.org/10.1016/j.optlastec.2018.07.003
0030-3992/

powers of these papers are less than one Watt because of the low damage threshold of MoS_2 SA.

In this paper, we fabricated the MoS_2 SA by depositing the nanomaterial onto a home-made silver mirror. The silver mirror can be used not only a reflecting mirror but also a saturable absorber substrate. The SA was used in a Nd:YAG laser and the laser spot on the absorber was designed exactly. A stable passively Q-switched mode locking operation was achieved. The maximum average output power was 1.06 W. The results proved that MoS_2 absorber with such structure can be used in Watt level all-solid-state pulse lasers.

2. The fabrication and characterization of MoS_2 absorber

At first, 10 mg of the MoS_2 powders is poured into 10 ml deionized water to prepare for 1 mg/ml MoS_2 aqueous solution. In order to obtain MoS_2 aqueous dispersion with high solubility, MoS_2 aqueous solution is ultrasonically agitated for 10 h. The clear supernatant MoS_2 solution is extracted by centrifuge with 3000 rpm for 5 min. Then the prepared MoS_2 solution is directly dripped onto a home-made silver mirror by spin coating method. The silver mirror with high reflectivity is made by electron beam evaporation. A hydrophilic quartz plate is coated with silver film under the electron beam current of 1 A/s by the electron beam evaporation apparatus (DETECH, DE400). The growth rate of Silver film is 0.1 nm/s and the vacuum degree of the cavity is $6.8 * 10^{-6}$ Pa. The average thickness of silver films are about 170 nm. In order to increase the adhesion of the SA to the substrate, the silver mirror with MoS_2 was dried in an oven with the constant temperature of 50 °C for 10 h. The reflectance spectrum of the MoS_2 film absorber was measured by a spectrophotometer (PRESEE TU-1810), as shown in Fig. 1. The reflectivity of silver mirror without MoS_2 is 89.1% at 1064 nm. After coating MoS_2 film, the reflectivity of the device is 79%. The surface morphology of MoS_2 absorber is measured via scanning electron microscope (SEM), which was shown in Fig. 2. The Raman spectrum of the absorber is shown in Fig. 3. The excitation laser wavelength is 532 nm. From the figure, the E^1_{2g} mode and the A_{1g} mode can be observed and located at 379.9 cm^{-1} and 405.1 cm^{-1}, respectively. The Fig. 4 shows the nonlinear optical absorption of the SA by a home-made picosecond pulsed Nd:YAG laser at 1064 nm. As shown in Fig. 5, the experiment of nonlinear transmission rate is set up including two same power meters. One of the beams is focused on the SA and the other is used as reference optical beam. The different input power is got by changing VOA(Variable Optical Attenuator), the focal lens decrease the laser spot on the SA. The pulse width of the CW-mode locked laser is about 200 ps, and the pulse repetition is ~100 MHz. The modulation depth (ΔT) and non-saturable losses are found to be 3.05% and 13.7%, respectively. The damage threshold was 0.89 MW/cm^2 and shown in Fig. 6.

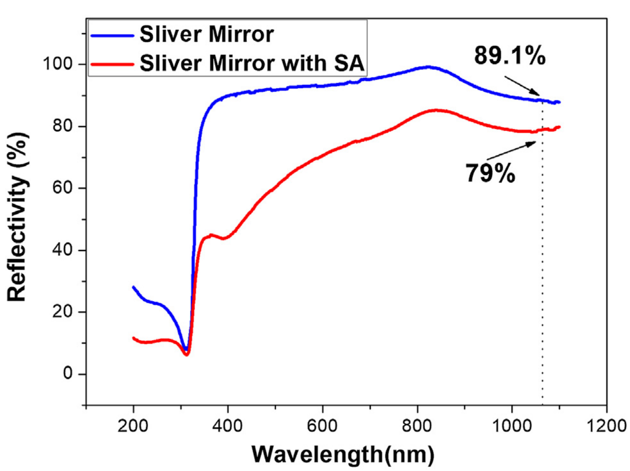

Fig. 1. The reflectance spectrum of the MoS_2 absorber and the silver mirror.

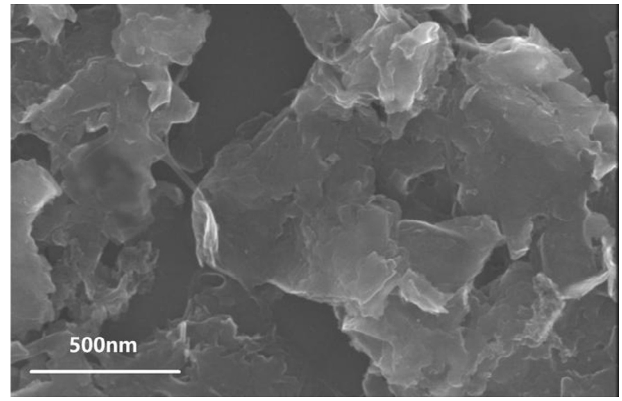

Fig. 2. SEM image of the surface of the MoS_2 absorber.

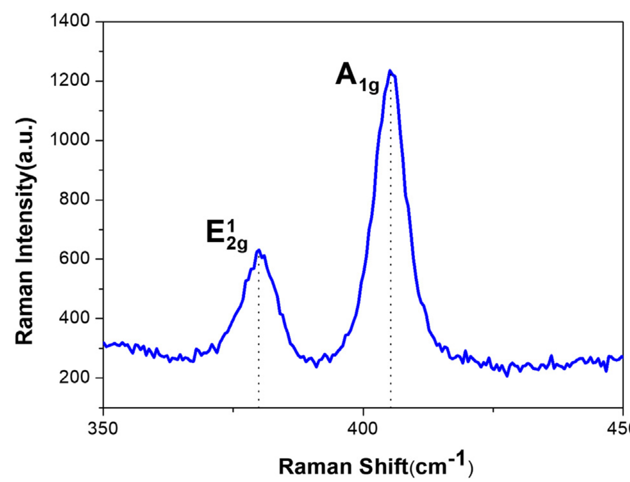

Fig. 3. The Raman spectrum of MoS_2 absorber.

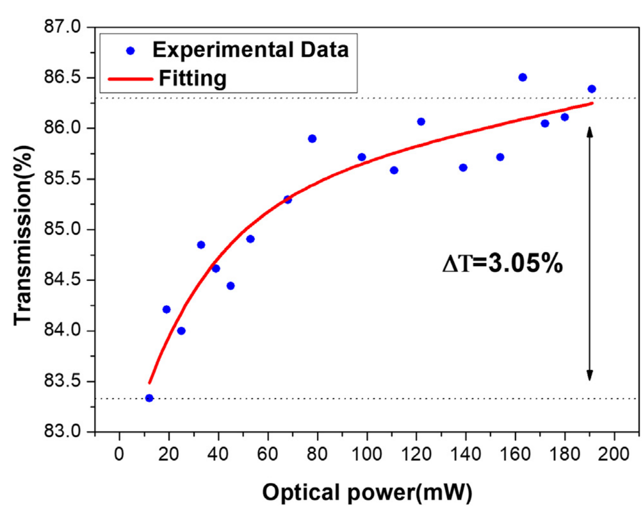

Fig. 4. Nonlinear optical absorption of SA.