Optics & Laser Technology 79 (2016) 20–23

Contents lists available at ScienceDirect

Optics & Laser Technology

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

Full length article

Q-switched Erbium-doped fiber laser using $MoSe_2$ as saturable absorber

H. Ahmad [a,*], M. Suthaskumar [a], Z.C. Tiu [a], A. Zarei [a], S.W. Harun [b]

[a] Photonics Research Center, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 22 September 2015
Received in revised form
23 October 2015
Accepted 5 November 2015
Available online 21 November 2015

Keywords:
Q-switched
Ultrafast laser

ABSTRACT

A Q-switched Erbium-doped fiber laser by using $MoSe_2$ thin film as saturable absorber is experimentally demonstrated. The bulk $MoSe_2$ is processed into few layer $MoSe_2$ based on liquid phase exfoliation technique, and further fabricated into thin film by using polyvinyl alcohol polymer. Q-switching operation is obtained from pump power range of 22.4–102.0 mW. The pulse repetition rate shows an increasing trend from 16.9 kHz to 32.8 kHz, whereas the pulse width exhibits a decreasing trend from 59.1 μs to 30.4 μs. The highest pulse energy of 57.9 nJ is obtained at pump power of 102.0 mW.

1. Introduction

Two-dimensional (2D) materials exhibit great nonlinear optical (NLO) responses that have attracted intense interest in photonic field. Graphene, which is the first 2D nano-material to be discovered, has shown impressive NLO [1] and widely used as a saturable absorber (SA) to generate pulsed laser [2–7]. The success of graphene has broadened the study to different types of 2D materials.

In the post graphene era, transition metal dichalcogenides (TMDs) materials have shown great potential as next generation 2D materials [8,9]. In general, TMDs exhibit formula of MX_2, where M refers to transition metals (e.g. Tungsten (W) and Molybdenum (Mo)) while X refers to chalcogen atoms (e.g. Sulfur (S) and Selenium (Se)). TMDs attract considerable attention as future optical materials because they exhibit layer-dependent optical properties [10]. For instance, TMDs can transform from indirect bandgap to direct bandgap at near-infrared wavelengths when changing from bulk TMDs to monolayer TMDs. Moreover, TMDs also exhibit other important optical properties such as high nonlinearity, great photoluminescence, ultrafast carrier dynamics and strong optical absorption [11,12].

Sulfide-based TMDs and selenide-based TMDs possess similar characteristics. The main advantage of selenide-based TMDs over sulfide-based TMDs is that selenide-based TMDs have heavier chalcogenide atoms that lead to reduced bandgap energies [13]. To date, most of the pulsed laser generations with TMD materials as saturable absorber are sulfide-based whereas the exploration of selenide-based TMDs as saturable absorber is yet to be fully explored.

In this work, we have experimentally investigated one of the selenide-based TMDs, $MoSe_2$ for short-pulse generation. The fabrication from bulk $MoSe_2$ to few layer $MoSe_2$–polyvinyl alcohol (PVA) thin film is reported. Furthermore, the $MoSe_2$–PVA composite film is used as saturable absorber to generate Q-switching operation in Erbium-doped fiber laser.

2. $MoSe_2$ thin film fabrication

The few layer $MoSe_2$ used in this experiment were prepared with liquid phase exfoliation (LPE) method [14]. In brief, the N-methyl-2-Pyrrolidine (NMP) solvent for the exfoliation of TMDs is mixed with bulk powder with an initial concentration of 5 mg/ml. The solution is treated with high power ultrasonicator for 8 h. The suspension is centrifuged at 3000 rpm for 60 min and the top 2/3 supernatant solution is pipetted out for further characterization. The obtained supernatant is diluted to 10 vol% and the linear absorption characterization is carried out using SPECORD 210-Plus UV–vis Spectrophotometer. As seen from Fig. 1, the two observed peaks at ~697 nm and ~800 nm match perfectly with the previously reported values [15]. These two bands correspond to the interband excitonic transitions at the K point which indicates a pristine 2H poly type. Next, the crystalline nature of both the bulk and exfoliated $MoSe_2$ were characterized with X-Ray Diffraction (XRD) analysis using Bruker D8 Advanced equipment at an excitation wavelength of 1.5406 Å. As seen from Fig. 2, all the labeled peaks of the bulk $MoSe_2$ are indexed to rhombohedral $MoSe_2$

* Corresponding author.
E-mail address: harith@um.edu.my (H. Ahmad).

http://dx.doi.org/10.1016/j.optlastec.2015.11.007
0030-3992/

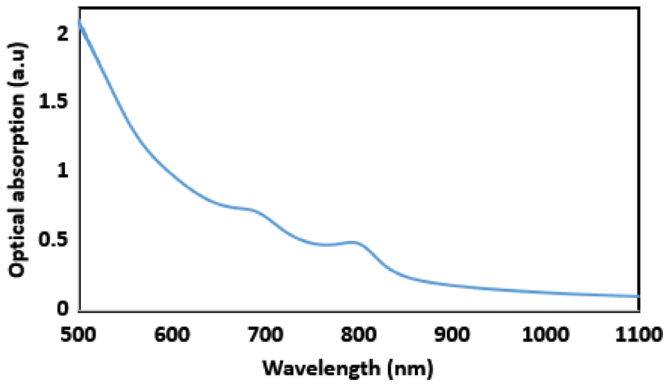

Fig. 1. The linear optical absorption spectrum measured by UV–vis Spectrophotometer after diluting the sample to 10 vol%.

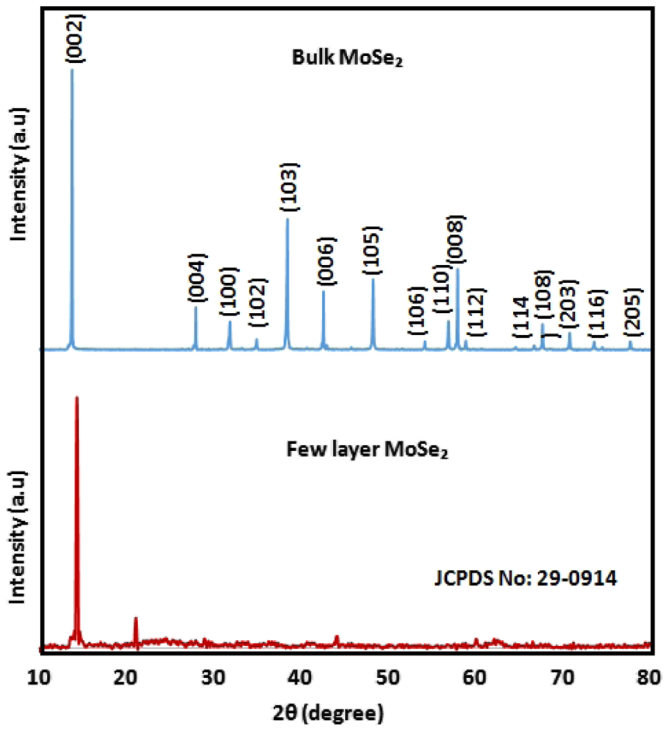

Fig. 2. The XRD pattern of the bulk and few layer $MoSe_2$.

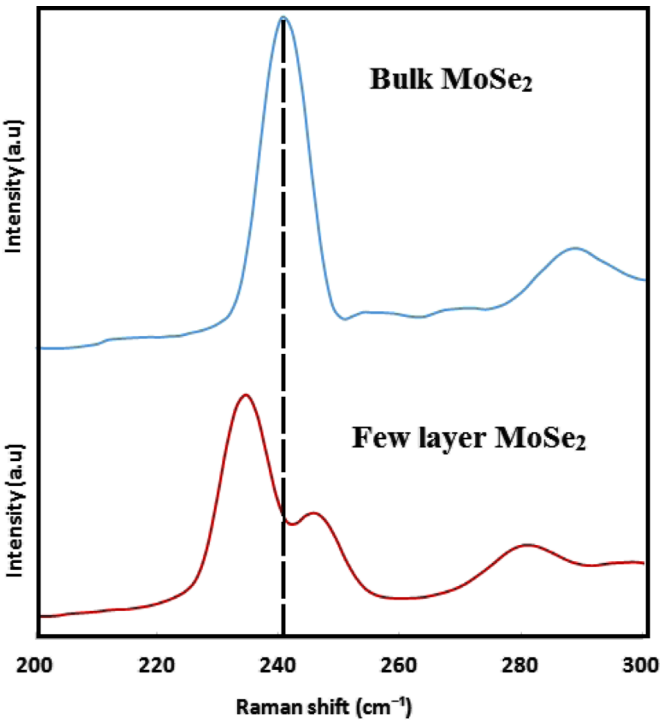

Fig. 3. The Raman spectroscopy characterization of bulk and few-layer $MoSe_2$.

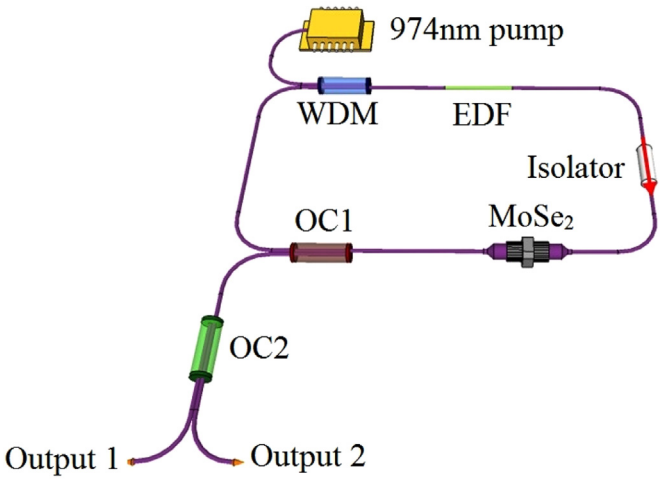

Fig. 4. Configuration of the proposed EDFL.

(JCPDS no: 06-0097). The few-layer $MoSe_2$ showed a high [0 0 2] orientation and disappearance of some characteristic peaks, which attests that the bulk MoS_2 had been successfully exfoliated to few-layer $MoSe_2$.

The few-layer solution were then drop casted onto silica wafers to conduct the Raman spectroscopy using Renishaw inVia confocal Raman Microscope at an excitation wavelength of 488 nm and 3.5 mW power. As depicted in Fig. 3, the out of plane vibration (A_g^1) for bulk $MoSe_2$ is centered at 240 cm^{-1}, whereas the few layer $MoSe_2$ is centered at 235 cm^{-1}. This shows a peak shift for few-layer $MoSe_2$ as compared to the bulk and further confirms the exfoliation of few layers. Next, the few layer $MoSe_2$ solution were processed to become thin film. The few layer $MoSe_2$ solution were placed in a bath sonicator for 10 min. Then, 15 ml of the few layer $MoSe_2$ solution were added with 200 mg of polyvinyl alcohol (PVA) dissolved in 15 ml of deionised (DI) water (concentration of 10 mg/ml). The 30 ml solution mixture was stirred using magnetic stirrer and heated continuously at a fixed temperature of 80 °C till the solution were reduced to approximately 10 ml. This process takes approximately 6 h to finish. This was followed by drying the remaining solution on a glass substrate in an oven at 80 °C for another four hours to obtain the $MoSe_2$ thin film.

3. Experimental arrangement

The experimental set-up of the proposed EDFL is illustrated in Fig. 4. The ring resonator consists of a 3 m long Erbium-doped fiber (EDF) as the gain medium, a wavelength division multiplexer (WDM), an isolator, 95:5 output coupler (OC1) and 50:50 output coupler (OC2). The EDF used has a doping concentration of 2000 ppm and GVD parameter of about −21.64 (ps/nm)/km. This fiber was pumped by a 974 nm laser diode via the WDM. Other fibers in the cavity is a standard SMF (18 (ps/nm)/km), which constituted the rest of the ring. Unidirectional operation of the ring was achieved with the use of an isolator. The output of the laser is collected from the cavity via a 95:5 coupler and retains 95% of the light in the ring cavity to oscillate. The optical spectrum