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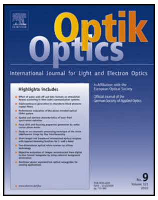

Compact stable passively Q-switched Nd:YVO_4 laser with tungsten disulfide saturable absorber

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ABSTRACT

In this work, tungsten disulfide (WS_2) based saturable absorber for passively Q-switched Nd:YVO_4 laser was demonstrated. WS_2 saturable absorbers were prepared by transferring the WS_2-alcohol dispersion onto substrates. Stable Q-switching operation at a central wavelength of 1064 nm was performed. The stable pulses were achieved with the single pulse width of 98 ns. WS_2 seems to be a good candidate as a cost-effective material for saturable absorbers for solid-state lasers with simpler manufacturing process.

1. Introduction

Passively Q-switched laser with the pulse width of nanosecond to microsecond are of great interest for scientific, medical applications, material processing, range finding, remote sensing and nonlinear frequency conversion [1]. In order to develop highly compact laser system, many saturable absorbers have been researched, such as Cr^{4+}:YAG [2], Cr^{2+}:ZnSe [3], semiconductor saturable absorption mirror (SESAM) [4], single-walled carbon nanotubes [5]. Graphene and graphene oxide (GO) have been widely investigated as novel saturable absorber [6–9]. However, graphene and GO saturable absorbers fail to generate larger pulse energies with rather lower modulation depth. Saturable absorbers with the characters of high saturated absorption characteristics, wavelength independent, high damage threshold, simple manufacturing process and low cost, were issues still to be researched. Exploration of some new nonlinear optical materials was an essential task for researchers.

Study of graphene and GO materials also usher a door to new layered structured materials with the characteristics of strong covalent bonds in one layer and weak van der Waals interaction between layers [10]. Recently, research on two-dimensional (2D) nanosheet materials have received more attention for the layer-dependent band-gap properties. Various methods were reported to obtain few-layer nano-sheets from bulk, such as chemical vapor deposition, mechanical exfoliation and liquid phase exfoliation methods [11]. Among them, liquid-phase exfoliation method was a practical and cost-effective way to manufacture nano-sheets of 2D materials. According to previous reports, these 2D materials exhibit many applications in various areas, such as optoelectronics and short pulse generation [12]. Moreover, WS_2 shows greater saturable absorber performances in broadband wavelengths and larger modulation depth.

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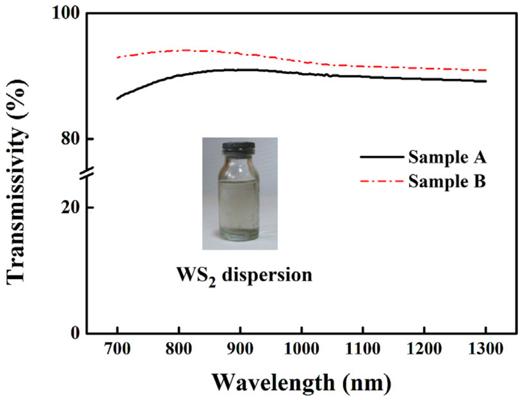

Fig. 1. UV–vis-NIR transmitted spectrum of WS_2 saturable absorbers.

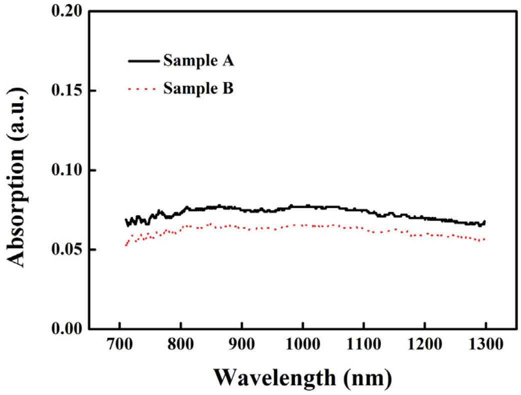

Fig. 2. Linear absorption spectrum of WS_2 saturable absorbers.

Most of important, compared with SESAM and GO saturable absorber, the graphene-like, direct band-gap WS_2 saturable absorber is simple to prepare [13]. There are some reports to show the performance of mode-locked fiber lasers with WS_2 [14,15], but there are few articles to perform solid state Q-switched and mode-locked lasers by the same saturable absorber.

Here we report a stable 1064 nm Q-switched Nd:YVO_4 laser by using few layers WS_2 deposited on a quartz glass substrate as saturable absorber in a rather short cavity. The maximum output power was 173 mW, corresponding to the optical to optical conversion of 7.9%. The minimum pulse width was 98 ns with the pulse repetition rate of 392 kHz. A simple method to prepare the WS_2 saturable absorber was presented too.

2. Preparation and characterization of WS_2 saturable absorber

First, 0.01 g of WS_2 powder with the purity of 99.99% was added into 10 ml and 15 ml of analytically pure alcohol marked sample A and B respectively. Then mixed solution was stirred by ultrasound for 20 min. After that, quartz substrate with dimensions of 25 mm × 10 mm was immersed into the mixed solution. This step is crucial to obtain high-quality saturable absorber. At last, the substrate with WS_2 was left in the drying oven at temperature of 60 °C for 4 h to remove the alcohol thoroughly. The WS_2 solution was directly deposited onto the quartz substrate equably.

Fig. 1 shows transmitted spectrum of sample A and B WS_2 saturable absorbers, the transmissivity at 1064 nm were 88.1% and 91% respectively. This performance shows the sample A and B can be employed as saturable absorber stably in a wide wavelength range from 700 nm to 1300 nm. With heavier WS_2 film on the sample A, the transmissivity of sample A is lower than sample B. Fig. 2 shows linear absorption spectrum of sample A and B WS_2 saturable absorbers. The absorption coefficients at 1064 nm were 0.078 and 0.065.

Raman spectra of the two samples were recorded by a Raman spectrometer. Fig. 3 shows the Raman spectra of WS_2 saturable absorbers. In-plane and out-plane vibrational mode $E^1{}_{2g}$ and A_{1g} were located at 347 cm^{-1} and 418 cm^{-1} respectively [16]. The intensity of sample A is higher than sample B due to heavier WS_2 film on the sample A.