Opto-Electronics Review 25 (2017) 10–14

Contents lists available at ScienceDirect

Opto-Electronics Review

journal homepage: http://www.journals.elsevier.com/opto-electronics review

# Tunable Q-switched ytterbium-doped fibre laser by using zinc oxide as saturable absorber

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ARTICLE INFO

*Article history:*
Available online 14 February 2017

*Keywords:*
Tunable Q-switched
ZnO
Tunable bandpass filter
Ytterbium

ABSTRACT

This paper demonstrates the use of a zinc oxide (ZnO) thin film in a 1-μm ring laser cavity as a saturable absorber to successfully generate Q-switching pulses. The tunability of the laser pulses is achieved by integrating a tunable bandpass filter (TBPF) in an ytterbium-doped laser cavity that results in 9.4 nm of tuning range, which wavelength is from 1040.70 nm to 1050.1 nm. The peak energy in the pulse which is 1.47 nJ was measured together with a minimum pulse width of 2.4 μs. In addition, the repetition rate increases from 25.77 to 45.94 kHz as the pump power level being increased from 103.1 to 175.1 mW. The results obtained in this experiment demonstrated consistent results and stable throughout the experiment. Therefore, ZnO thin film is considered as a good candidate in 1-μm pulsed laser applications.


## 1. Introduction

Since its invention in 1987, erbium-doped fibre amplifier (EDFA) has been widely used in broad area of application due to many advantages, such as low transmission loss, high gain, high optical efficiency and high saturation power [1–3]. However, there has been a growing interest in a 1-μm region using ytterbium-doped fibre laser (YDFL) because of its special properties, for example, high power efficiency, broad gain bandwidth, low quantum defect, flexible and compact [4–7].

In terms of Q-switching pulses generated in a 1-μm region, they are said to be more reliable with the existing of noise and pulse also spread gradually when the fibre loss exists compared to a 1.5-μm region [8]. Laser pulses have been used extensively in applications such as nonlinear optic, optical signal processing, excitonic absorption saturation and mechanical system controller [9–12]. Particularly, tunable Q-switched pulses generation using YDFL has sparked current research interest in applications such as spectroscopy and biomedical diagnostics [13] where the pulses can be adjusted to a different operating wavelength with ease which is the interest of this paper.

In general, there are two types of Q-switching generation methods which are active and passive techniques. Active Q-switching pulse method relies upon external electrically powered modulator to induce and to restore a high Q-factor in order to generate pulses [14]. On the other hand, passive Q-switching technique does not depend on any external signal but can use additional passive components such as saturable absorber (SA) material [14,15], semiconductor saturable absorber mirror (SESAM) [16], and nonlinear polarization rotation (NPR) [17] to induce pulses in the cavity.

Lately, there has been extensive works on Q-switch pulse laser generation using a different type of SA materials: carbon-based SAs such as single-walled (SW-) and multi-walled (MW-) carbon nanotubes (CNTs) [18], and graphene [19]; transition metal dichalcogenides (TMD) such as MoS2, MOSe2, WS2 [20–24]; topological insulator (TI) materials such as Bi2Te3, BiSe2, Bi2Se3m, Bi2Te3; black phosphorus; TiO2 have been demonstrated in various publications [25–27].

Various types of SA such as crystal SA and SESAMs can be used in order to cover various operation wavelengths [28–30]. In a 1-μm region, the use of SA materials such as graphene, $Cr^{+3}$:YAG, TI, TI:$Ni_2Se_3$, Molybdenum Disulfide ($MoS_2$) and tungsten disulfide ($WS_2$) has been reported in Q-switching pulses generation [5,31–35]. Recently, ZnO has been identified as a potential of a good SA since it exhibits a short recovery time and possesses a good saturable absorption [36]. There are few techniques that had been reported to achieve tunability in Q-switching operations, such as by inserting polarization controller (PC), TBPF or inserting both PC and TBPF in the laser cavity [37–39].

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http://dx.doi.org/10.1016/j.opelre.2017.01.002
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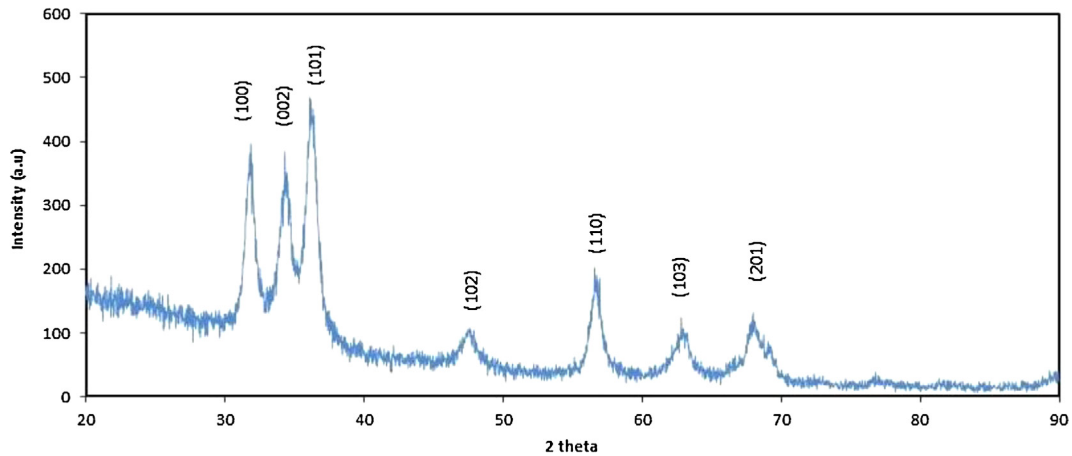


**Fig. 1.** ZnO nanoparticles XRD pattern [36].

In this paper, we have demonstrated the use of TBPF in the laser cavity between the isolator and the SA (ZnO) in order to investigate tunability of a Q-switching behaviour. A stable Q-switching operation with the tunability range of 9.4 nm covering from 1040.70 nm to 1050.1 nm was observed. In addition, the fabrication of ZnO has been well explained in this paper.

## 2. Zinc oxide saturable absorber characterization

The ZnO thin film SA used in the experiment was prepared by using a ZnO powder of 5 wt%. Firstly, the ZnO was prepared into a mixture by adding silane and ethanol with a ratio of 1:1 ethanol to silane [36]. Next, the mixture undergoes ultrasonification process for about 30 min. After that, sulphuric acids of 10 wt% were added into the mixture containing the ZnO, ethanol and silane. Next, the solution undergoes ultrasonification process for about 5 min. Lastly, the prepared mixture was then poured into a plastic mould and was set dry for three days at a room temperature.

Fig. 1 shows the result of X-ray diffraction (XRD) of the ZnO powder nanostructures. Each peak on the graph indicates that ZnO consists of a particle (nanoscale). Full-width at half maximum (FWHM) data, peak intensity and, position and width can be determined based on the XRD patterns analysis [26]. Each planes, ⟨1 0 0⟩, ⟨0 0 2⟩, ⟨1 0 1⟩, ⟨1 0 2⟩, ⟨1 1 0⟩, ⟨1 0 3⟩, and ⟨2 0 1⟩ correspond to different diffraction peaks. The result confirmed the existence of a ZnO peak as it shows no characteristics of XRD peaks. Thus, it proves that no impurities exist in the synthesized nanopowder.

To analyze the absorption and modulation depth of ZnO, an experimental set-up shown in Fig. 2(a) was utilized. A laser diode pump with an output wavelength of 974 nm was connected to a wavelength division multiplexer (WDM) and, subsequently, connected to an erbium-doped fibre (EDF) gain medium. In order to ensure unidirectional lasing in the cavity, an isolator is used in the ring cavity. Then, the isolator was connected to a fibre ferrule that contains the SA, which is a piece of CNT thin film that is used to generate a pulse seed source. Generating a pulse seed source using the CNT film is crucial in order to induce mode lock pulses for the measurement. The mode lock pulses were then amplified by using self-assemble EDFA in order to produce maximum peak power that covering 1550 nm region (the S, C and L band) [40–42].

The high peak power pulses generated using the CNT SA are then used to saturate the ZnO sample. In order to do this, the high power output pulses, which are about 10 dB, were channelled thru a variable optical attenuator (VOA) to gradually vary the power level. The signal pulses were attenuated from 0 dB to −60 dB by using the VOA with a 1 dB step. A 3 dB optical coupler (OC2) is connected to

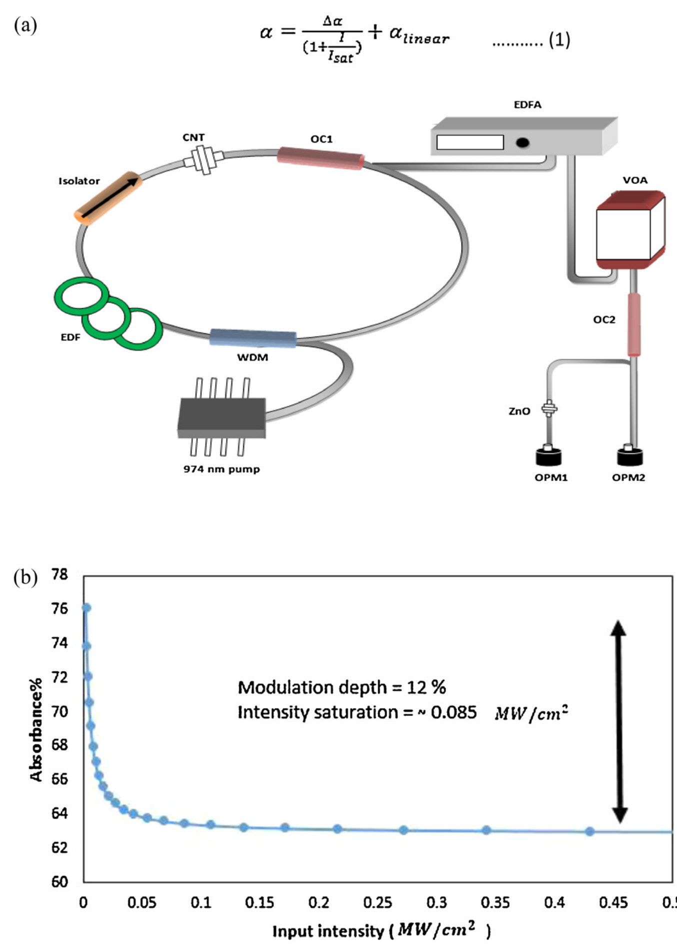


**Fig. 2.** (a) Cavity design to measure nonlinear absorption of ZnO, (b) saturable absorption characteristic of ZnO.

the VOA to split the signal equally into two parts. One part of the output of the OC2 acts as a reference and is connected to the optical power meter (OPM1). On the other hand, another output of the OC2 passes through a connector containing the ZnO thin film. The SA is put between two fibre ferrules. The fibre ferrule is then connected the second OPM (OPM2) for comparison.

The magnitude difference between readings of OPM1 and OPM2 was analyzed to measure the modulation depth of the ZnO. By using Eq. (1), the calculated modulation depth was found nearly 36%,