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Multi-walled carbon nanotubes saturable absorber in Q-switching flashlamp pumped Nd:YAG laser

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ABSTRACT

Passively Q-switched Nd:YAG laser pumped by flashlamp is demonstrated by using a saturable absorber made of a multi-walled carbon nanotubes-polyethylene oxide (MWCNTs-PEO) film. Two positions of the film are tested in the resonator to optimize its performance. The maximum pulsed energy obtained for the Q-switching operation is 1.68 mJ corresponding to 88.36 J electrical pump energy. The pulse duration of 83.64 ns is achieved with a peak power of 20.1 kW. A MWCNTs-PEO-film is a promising saturable absorber because of its simple cavity design, reliable and low cost fabrication compared to normal nonlinear crystal absorber.

1. Introduction

Solid state 1.06 μm Q-switched lasers have wide application in the area of electronic devices, scientific researches and even medical treatment because of its high photon energy, broad absorption bandwidth and easy thermal management [1]. In addition, more advantages are offered from 1064 nm laser due to its capability to convert the frequency in second (532 nm), third (266 nm) and fourth (133 nm) harmonic generation [2]. Passive Q-switching is competent and most easy way to generate short pulses with high output energy compared to active switching.

In conjunction with current demand nowadays which is in favor to have a simple, reliable and cost effective method for switching, much attention nowadays focuses on material like carbon nanotubes as an alternative way. This type of material has been widely used for light modulation especially in generating Q-switching laser. Carbon nanotubes (CNTs) as saturable absorber (SA) has been successfully employed in a variety of fiber lasers [3–6] and diode laser [7–9]. However, most of the previously written reports concentrated on mode-locking [10–15] and only few were focused on Q-switching [16,17], either for single or double-walled CNTs. The double-walled CNT has high damage threshold and better thermal stability [18,19] than other carbon nanotubes. Fabrication of multi-walled carbon nanotubes MWCNTs does not need special treatment compared to single-walled carbon nanotubes SWCNT. Furthermore it is less sensitive with the environment changes due to its multiple-walled structure [8]. The application of doubled–walled CNT as a saturable absorber on diode end-pumped Nd:YAG have been reported by Yu et al., [20]. The 2 μJ pulsed energy had been achieved with 90 ns pulse duration. Other similar work also claimed by Yanet al., [21] who produced a maximum output power of 780 mW with 1.15 μs pulse duration on diode side pumped Nd:YAG single-walled CNT.

Apart from CNTs based saturable absorber in Nd:YAG crystal, it also been declared in Nd:YAG ceramics applications. Li et al. [22] reported the pulse energy of 4.5 μJ obtained at pulse duration of 1.2 μs while De Tan et al. [23] was deal in mode-locking ceramics gain medium. Then, Fong et al. [24] released a mode-locking research by using CNTs film in Er:Yb:Glass. However, all these ceramics and glass works still can't beat the high output energy and narrow pulse duration generated in crystal's laser. Even

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though much works on the CNT as passive Q-switch saturable absorber has been addressed on diode and fiber optic laser but yet very rare its application on flashlamp pumped neodymium doped YAG crystal have been established. Therefore, we intend to use and observe its characteristics toward laser light modulation especially in flashlamp pumping source. In addition, the intention of this work also is to explore the suitability and reliability of applying MWCNTs-PEO based saturable absorber in generating Q-switched laser by using flashlamp pumping source. The enthusiasms regarding this work proceed with further cavity compactness in attempt to gain optimization of the output Q-switched laser. The performance of the MWCNTs-PEO film as a saturable absorber is described in detailed in this present work.

2. Fabrication and characterization of MWCNTS-PEO film

The mean diameter of MWCNTs used in this experiment is about 10–20 nm and the length distribution is from 1 to 2 µm. Initially, 250 mg of MWCNT is homogenized with pre-dissolved 400 ml Sodium Dodecyl Sulfate (SDS) solution (0.01 g/ml) via stirring in an ultrasonic cleaner (50 W) for 1 h to improve its overall water solubility. Undispersed MWCNTs are removed via centrifugation (1000 rpm). Polyethylene oxide (PEO) solution with a concentration of 10.1 wt%, (1 g of PEO in 120 ml of deionized water) is added into the dispersed MWCNTs solution and sonicated for 1 h to form MWCNTs-PEO composite mixture. Finally, the MWCNTs-PEO composite is casted on a glass petri dish and dried in room temperature for a week; producing a thin film with thickness of about 50 µm. Typical field emission scanning electron microscope (FESEM) image of the MWCNTs-PEO film as in Fig. 1 shows the randomness of CNTs within the MWCNTs-PEO film. The MWCNTs-PEO is integrated into laser's cavity forming based SA.

As expected, the Raman spectrum of the MWCNTs film as illustrated in Fig. 2 is similar to the graphene [25] since MWCNTs are essentially formed by multi layers of graphene enveloped around the core tube. The G^{+} and G' bands commonly found in the Raman spectrum of graphene and graphite are observed in the Raman spectrum of the MWCNTs film as well at Raman shift of 1579.3 cm^{-1} and 2719 cm^{-1}, respectively. The G band emerges due to the tangential stretching of carbon–carbon bonds within the graphene sheet. The D band, which is observed around 1356.75 cm^{-1} in the figure indicates that multiple layers of walls exists within the CNTs type with some disorders in the graphene structure [26]. Fig. 3 shows the transmission spectra of MWCNTs film made from these solutions to measure the linear optical transmission. The transmission rate is around 71% at 1064 nm when the transmission spectrum of MWCNTs-PEO film is analyzed with spectrophotometer (Lambda 750 UV/Vis/NIR spectrophotometer). At last, we cut out the absorber cell into many pieces thus made this preparation as a simple fabrication process and low-priced in the making for Q-switched laser application.

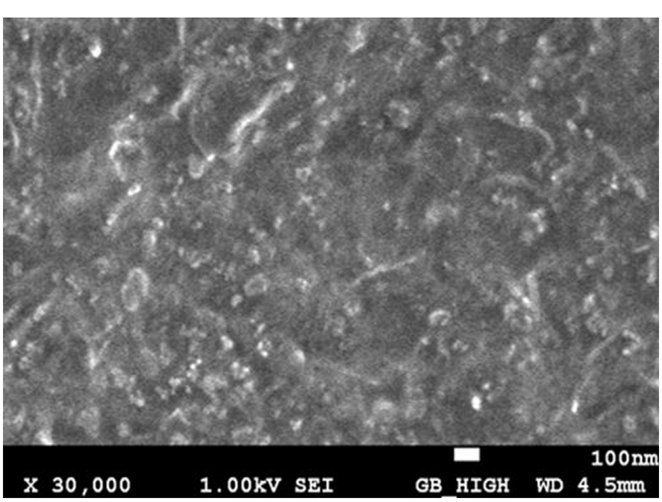

Fig. 1. FESEM image of the MWCNTs-PEO thin film absorber (30,000× magnifications).

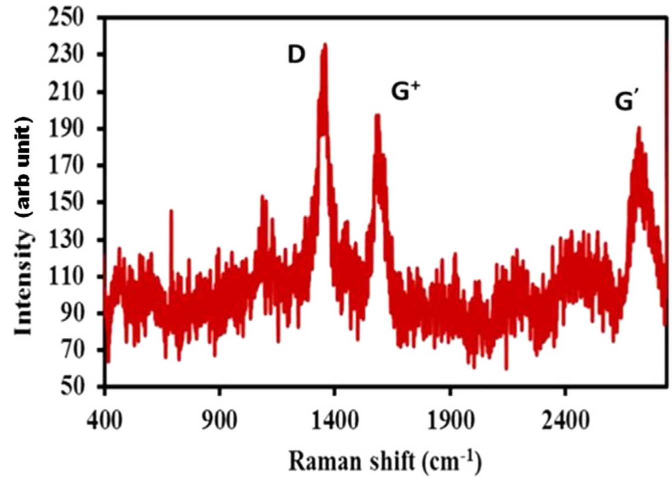

Fig. 2. Raman spectroscopy of MWCNTs-PEO film.

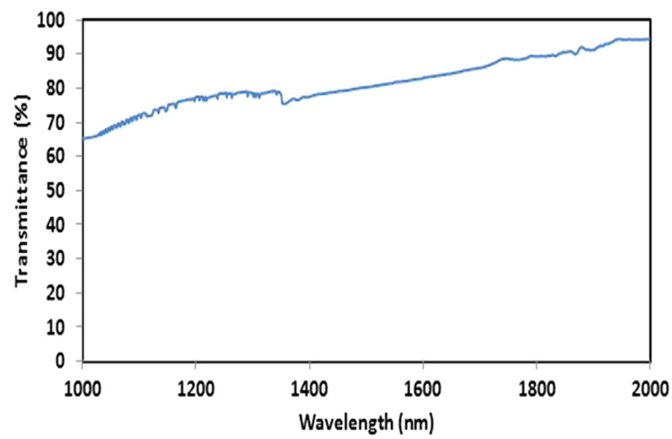

Fig. 3. Transmission curves of MWCNTs-PEO film.

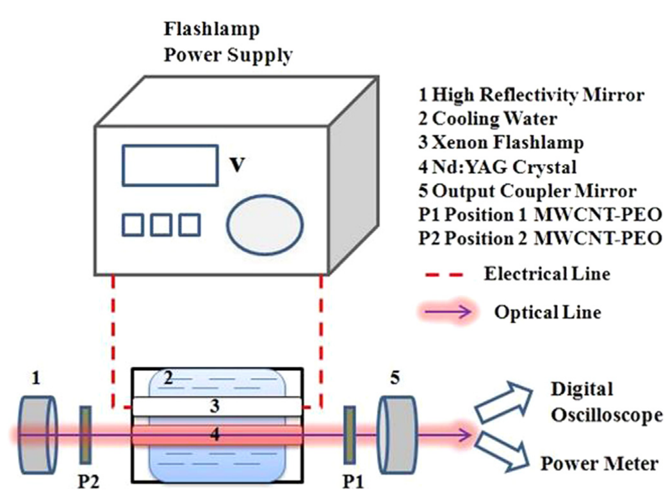

Fig. 4. Schematic diagram of the experimental set up.