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Q-SWITCHED THULIUM-DOPED FIBER LASER AT 2 MICRON REGION BY 802 NM PUMPING

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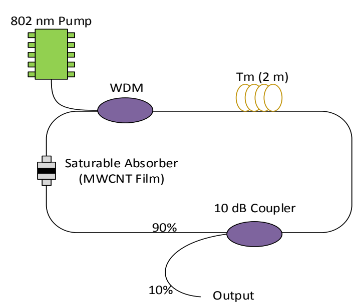
Graphical abstract



Abstract

An 1892.4 nm ultrafast passive Q-switched fiber laser is demonstrated by using Thulium-doped fiber (TDF) in conjunction with a multi-walled carbon nanotubes (MWCNTs) as a saturable absorber (SA). The MWCNTs film is sandwiched between two FC/PC fiber connectors and integrated into the laser cavity with 802 nm pump for Q-switching pulse generation. The pulse repetition rate can be tuned from 3.8 to 4.6 kHz while the corresponding pulse width reduces from 22.1 to 18.4 μs as the pump power is increased from 187.3 to 194.2 mW. A higher performance Q-switched Thulium-doped fiber laser (TDFL) is expected to be achieved with the optimization of the MWCNT-SA saturable absorber and laser cavity.

Keywords: Thulium-doped fiber, Q-switching, multi-walled carbon nanotubes

Abstrak

Satu 1892.4 nm ultrafast pasif Q-switched serat laser ditunjukkan dengan menggunakan gentian tulium-didopkan (TDF) dengan tiubnano karbon berbilang-dinding (MWCNTs) sebagai penyerap mendapan (SA). Filem MWCNTs diapit di antara dua penyambung FC / serat PC dan disepadukan ke dalam rongga laser dengan 802 nm pam untuk generasi nadi Q-switched. Kadar pengulangan nadi boleh ditala dari 3.8 hingga 4.6 kHz manakala lebar denyut yang sama berkurang dari 22.1 hingga 18.4 μs apabila kuasa pam meningkat dari 187.3 hingga 194.2 mW. Q-switched laser gentian tulium-didopkan (TDFL) dengan prestasi yang lebih tinggi dijangka dapat dicapai dengan mengoptimumkan MWCNT-SA penyerap mendapan dan laser rongga.

Kata kunci: Gentian tulium-terdop, Q-switching, tiubnano karbon berbilang-dinding

1.0 INTRODUCTION

Q-switched fiber-based laser systems operating in the "eye-safe" wavelength of 1900 nm region are promising for applications such as light detection and ranging (lidar), differential absorption lidar, and as pumps for mid-IR generation. They can be realized using Thulium-doped or Holmium-doped fiber lasers based on either active or passive methods [1-3]. Compared with the active ones, passively Q-switched fiber lasers feature flexibility of configuration and do not require additional switching electronics. These lasers have been successfully demonstrated using different kinds of saturable absorbers (SAs), such as semiconductor saturable absorber mirrors (SESAMs) [3-4], and single-wall carbon nanotubes (SWCNTs) [5-6]. However, SESAMs are still expensive and complex to be fabricated. Therefore, more focus has been given on the utilization of SWCNTs as a SA in recent years especially for all-fiber Q-switched and mode-locked fiber lasers [7-9]. This is due to their inherent advantages, including good compatibility with optical fibers, low saturation intensity, fast recovery time, and wide operating bandwidth.

Recently, a new member of carbon nanotubes family, multi-walled carbon nanotubes (MWCNTs) [10-11] have also attracted many attentions for nonlinear optics applications due to their production cost, which is about 50%-20% of that of SWCNT material [12]. The growth of the MWCNT material does not need complicated techniques or special growing conditions so thus its production yield is high for each growth. Compared with SWCNTs, the MWCNTs have higher mechanical strength, better thermal stability as well as can absorb more photons per nanotube due to its higher mass density of the multi-walls. These favorable features are due to the structure of MWCNTs which takes the form of a stack of concentrically rolled graphene sheets. The outer walls can protect the inner walls from damage or oxidation so that the thermal or laser damage threshold of MWCNT is higher than that of the SWCNTs [13-14]. To date, there are only a few reported works on application of MWCNTs material as a saturable absorber. For instance, Zhang et. al. [12] employs multi-walled MWCNTs based saturable absorber for mode locking of a Nd:YVO_4 laser. In another work, Q-switched Nd-YAG laser is demonstrated using the MWCNTs based saturable absorber as a Q-switcher.

In this paper, an all-fiber Q-switched TDFL is demonstrated using a simple and low cost newly developed MWCNTs based SA as the Q-switcher. The saturable absorber employs MWCNTs-PVA film, which is fabricated by mixing a dispersed MWCNTs suspension into a polyvinyl alcohol (PVA) solution. The SA is integrated in the TDFL by sandwiching the film between two fiber connectors that results in a stable pulse train with 4.6 kHz repetition rate, 18.4 μs pulse width and 126.1 nJ pulse energy at 194.2 mW 802 nm pump power.

2.0 EXPERIMENTAL

The schematic of the proposed Q-switched TDFL is shown in Figure 1. It was constructed using a simple ring cavity, in which a 2 m long TDF with absorption of 27 dB/m at 785 nm was used for the active medium and the fabricated MWCNT-based SA was used as a Q-switcher. The SA is fabricated by cutting a small part of the prepared MWCNTs-PVA film and sandwiching it between two FC/PC fiber connectors, after depositing an index-matching gel onto the fiber ends. The insertion loss of the SA is measured to be around 3.3 dB at 1900 nm. The TDF was pumped by an 802 nm laser diode via a 800/2000 nm WDM. The temporal characteristics of the laser output were monitored using a combination of a photo-detector and a real time oscilloscope. The optical spectrum was measured using an optical spectrum analyser (OSA). The cavity length is measured to be approximately 7.6 m.

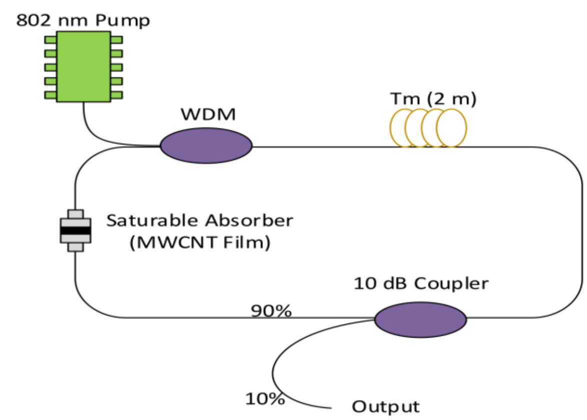


Figure 1 Schematic configuration of the Q-switched TDFL with 802 nm pumping

3.0 RESULTS AND DISCUSSION

Figure 2 shows the output power of both Q-switched and CW lasers against the input pump power, which are obtained with and without the SA, respectively. Without the SA, a CW laser operates with an efficiency of 3.77% and threshold pump power of 133.1 mW. The efficiency is relatively low since the components used have a considerably high insertion loss at 1900 nm region. As the SA is inserted into the ring cavity, a stable and self-starting Q-switching operation is obtained just by adjusting the pump power over a threshold of 187.3 mW. However, the efficiency of the laser is slightly reduced to 2.68% due to the increased cavity loss. Figure 3 shows the output spectrum of the TDFL with and without SA at the pump power threshold of 187.3 mW. As can be seen from the figure, the Q-switched laser operates at a wavelength of 1892.4 nm with an optical signal to noise ratio (OSNR) of more than 30 dB. Compared to the CW laser (without SA), the operating wavelength of the Q-switched laser has shifted to a shorter wavelength. This is attributed to the cavity loss which increases with the incorporation of SA. Thus, the oscillating light in the cavity shifts to a shorter wavelength, which is closer to the peak absorption of the TDF at around 1800 nm to compensate for the loss. The spectrum bandwidth is also broadened in the Q-switched laser due to the self-phase modulation effect in the ring cavity.

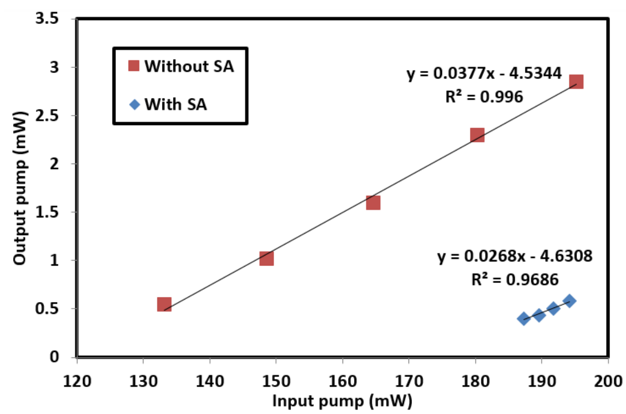


Figure 2 Output power characteristic against the pump power with and without the SA

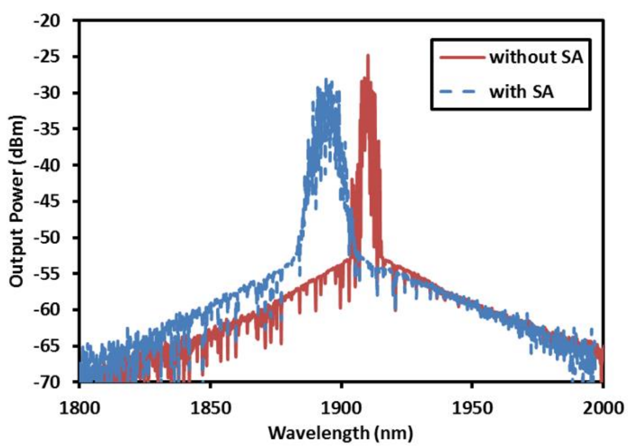


Figure 3 The output spectrum of the ring TDFL with and without the SA

Figure 4 shows the oscilloscope trace of the Q-switched pulse train at the pump power of 191.7 mW. As shown in the figure, there is no distinct amplitude modulation in each Q-switched envelop spectrum, which means that the self-mode locking effect on the Q-switching is weak. At this pump power, the proposed TDFL generates a stable Q-switching pulse with an average output power of 0.5 mW and repetition rate of 4.5 kHz. The pulse energy is calculated to be around 111.1 nJ at this pump power. The pulse energy could be improved by reducing the insertion loss of the saturable absorber and optimizing the laser cavity. Figure 5 shows the typical oscilloscope trace of the pulse envelop at the pump power of 191.7 mW. As seen in the figure, the full-width at half maximum or pulse width was obtained at 18.4 μs.

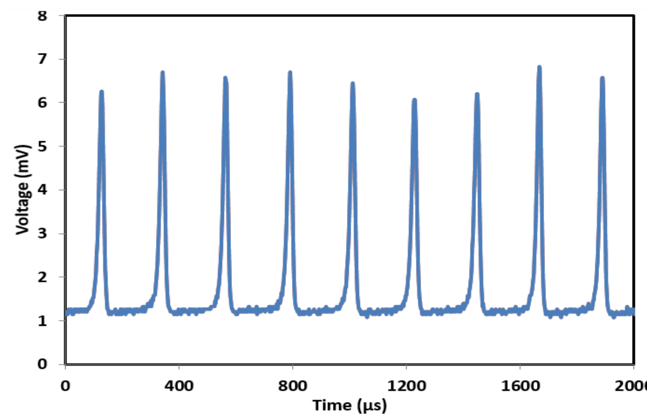


Figure 4 Q-switching pulse train at the pump power of 191.7 mW

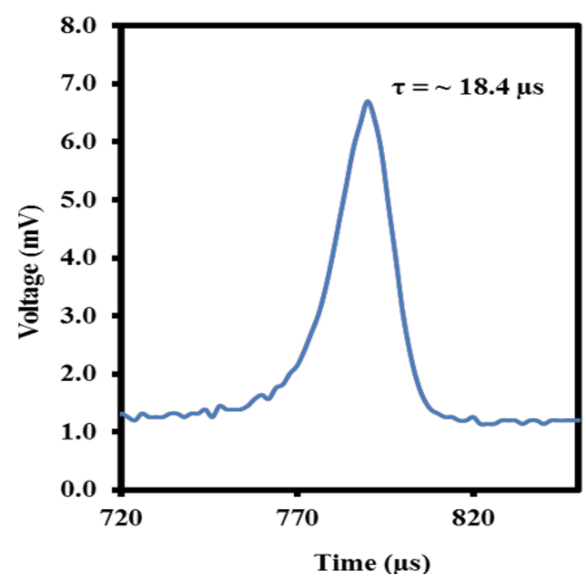


Figure 5 The pulse envelop of the Q-switched laser at the pump power of 191.7 mW

Figure 6 shows the repetition rate and the pulse width of the proposed Q-switched TDFL versus the pump power. The repetition rate has a monotonically increasing, near-linear relationship with the pump power level, which is consistent with other reported results of the SWCNT based fiber lasers [8]. When the pump power is tuned from 187.3 to 194.2 mW, the pulse train repetition rate varies from 3.8 to 4.6 kHz. On the other hand, the pulse width is inversely proportional to the pump power, where the pulse duration becomes shorter as the pump power increases. The shortest pulse width of 18.3 μs is achieved at the maximum pump power of 194.2 mW. The pulse width is expected to decrease further if the pump power can be augmented beyond 194.2 mW as long as it is still kept below the damage threshold of the MWCNT-PVA based SA. Shortening the total cavity length of the fiber laser is another alternative to get a shorter pulse. Figure 7 shows the output power and pulse energy as functions of pump power. It is found that both output pump power and pulse energy increase with the pump power. At the maximum pump power of 194.2 mW, the average pump power and pulse energy of the Q-switched laser are obtained at 0.58 mW and 126.1 nJ.

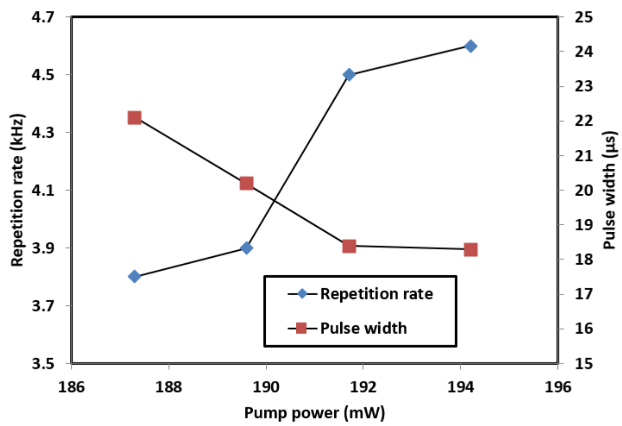


Figure 6 Repetition rate and pulse width as a function of pump power

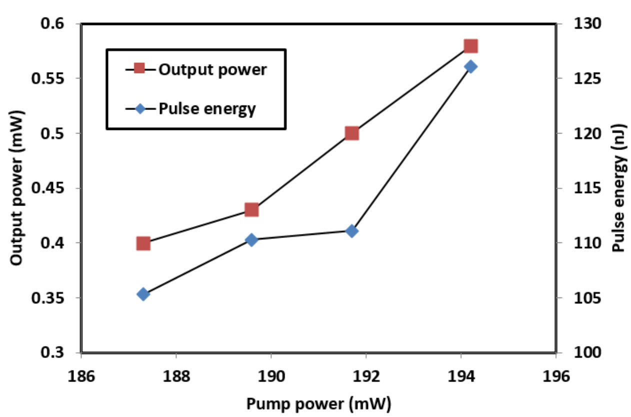


Figure 7 Average output power and pulse energy as a function of pump power

4.0 CONCLUSION

A stable passive Q-switched TDFL operating at 2 micron region is successfully demonstrated using 802 nm pumping schemes, in conjunction with MWCNTs-SA. The Q-switched TDFL configured by 802 nm pump gives the pulse width, repetition rate and output power of 18.4 µs, 4.6 kHz and 0.58 mW respectively, when the pump power is 194.2 mW. The highest pulse energy of 126.1 nJ is also obtained at this pump power.

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