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ALL-FIBER Q-SWITCHED FIBER LASER BASED ON SILVER NANOPARTICLES SATURABLE ABSORBER

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Q-switching pulses generation in an Erbium-doped fiber laser (EDFL) passively Q-switched by a silver nanoparticles (AgNP) based saturable absorber (SA) was experimentally demonstrated. The SA was fabricated by depositing nano-sized particles of Ag layer onto the surface of polyvinyl alcohol (PVA) film through the thermal evaporation process. By inserting the SA into an EDFL cavity, stable Q-switched operation was achieved at 1565 nm with the maximum pulse energy up to 34.7 nJ. The laser produced a range of pulse repetition frequency from 42.5 to 55.7 kHz with a minimal pulse width of 8.16 µs. These results suggested that AgNP could be developed as an effective SA for Q-switching pulses generation.

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1. Introduction

Q-switched fiber lasers erbium-doped fiber lasers (EDFLs) have attracted substantial attentions due to their wide range of applications, including telecommunications, medicine and sensing [1-2]. Many studies have been devoted to construct various kinds of Q-switched EDFLs [3-5]. The Q-switching operation can be achieved by modulating the quality factor, Q of a cavity via active or passive Q-switching techniques. Compared with the active one, passive Q-switching with saturable absorbers (SAs) in laser cavities is more attractive due to the simple configuration and fewer required external electronic components. Up to date, various SAs have been widely investigated in realizing all-fiber Q-switched fiber lasers. Carbon nanotubes (CNTs) and graphene have gained more attention in recent years due to their wide absorption range and good compatibility with optical fibers [6-7]. However, the CNTs and graphene based SAs possess relatively low modulation depth, which limited their applications for high power pulse fiber lasers [8].

Recently, metal nanoparticles-based materials especially transition metal elements have revealed a high potential in electronic and optic applications. This is attributed to their unique optical properties such as ultrafast response time, broad saturable absorption band and large third-order nonlinearity [9-10]. For instance, Wu et. al. has demonstrated a Q-switched laser with a copper nanowires saturable absorber. The laser operated at visible wavelength region of 635 nm with repetition rate and pulse width were tunable in a range of 239.8 – 312.4 kHz and 0.685 - 0.394 µs, respectively while the maximum output power was obtained at 9.6 mW [11]. In another work, a Q-switched EDFL was reported using gold nanoparticles based SA [12]. Most recently, Ahmad et al reported a Q-switched EDFL by sandwiching a silver nanoparticles (Ag NP) SA in between the fiber ferrules. The Ag NP SA was prepared by mixing the Ag NP with methyl-tri-methoxylane (MTMS) as the host polymer. The saturable absorption of the Ag NP SA was reported at around 31.6 % indicating that the Ag NP embedded in MTMS has strong potential to be used as SA. The stable pulsed started at a relatively low pump power threshold with maximum

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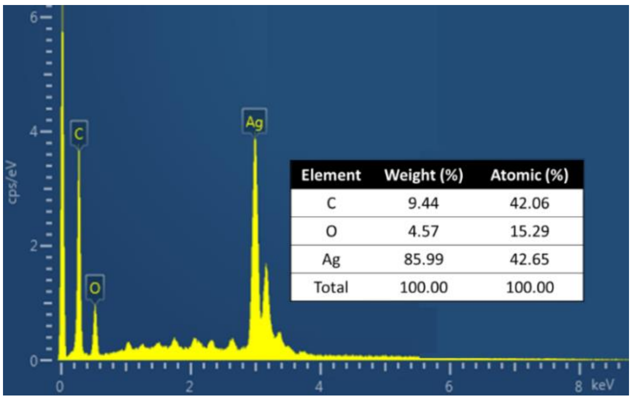
pulse energy of 8.17 nJ was successfully obtained [13]. However, the technique proposed may easily cause damages on the nanoparticles due to usage of strong acids as well as it can cause a large scattering due to agglomeration of NP.

In this paper, we demonstrate a passively Q-switched EDFL using a silver nanoparticles (AgNP) polymer film SA obtained through a new technique. The high quality AgNP SA was obtained by depositing nano-sized particles of Ag onto the surface of polyvinyl alcohol (PVA) film through the thermal evaporation process. The fabrication technique was used to order to reduce the agglomeration and increase the damage threshold of NP. By incorporating the SA into an EDFL cavity, it emits stable Q-switching pulses train operating at wavelength of 1560 nm with pulse duration in a range from 11.4 μs to 8.16 μs, and repetition rates from 42.5 kHz to 55.7 kHz. Maximum single pulse energy of 34.7 nJ was achieved, which was relatively higher than the pulse energy generated with the previous AgNP based Q-switched fiber laser [13].

2. Fabrication and characterization of SA

In the experiment, pure silver (Ag) pallets were used as the SA material while the water-soluble synthetic polymer, PVA was prepared in the form of thin film as a host material. PVA thin film was selected as it has a low optical absorption at 1560 nm wavelength. In addition, PVA has a high flexibility, high strength and easy to integrate onto the fiber ferrule. Before the depositing Ag NP on the PVA thin film, pure PVA film was prepared by dissolving 1 g PVA powder [40000 MW, Sigma Aldrich] into 120 ml of DI water. With the aid of heat at 145 ºC, the mixture was stirred until the powder are completely dissolved. Then, 5 ml of PVA solution was carefully poured into a petri dish and left to dry in ambient condition for 3 days to obtain a 50 μm thin layer film. Ag was deposited onto the surface PVA thin film inside thermal evaporation chamber of KENOSISTEC E-beam with pre-set layer of 16 nm thickness. During the deposition process, Ag pallets were intensely heated by Joule effect until it evaporated to produce nanoparticles of Ag, which were deposited into the film surface. The fabricated Ag NP film was kept and sealed in the vacuum bag, and place in the humidity cabinet to prevent the oxidation of Ag.

Fig. 1 shows the energy dispersive Spectroscopy (EDS) graph of the fabricated AgNP PVA film. It consists of 85.99 Wt% of Ag element and 9.44 Wt% of carbon from PVA $(C_2H_4O)x$. The transmission loss of the film is measured to be around 5 dB. Fig. 2 shows the image of Ag NP deposited on the PVA film. In addition, the surface morphology of Ag NP on PVA was characterized using FiB-SEM at magnification of 40 kX as shown in the inset figure. The image also shows the high density AgNP, which was homogenously distributed onto the PVA film without any aggregation. The average diameter of the AgNP is measured to be around 50 nm.



Element	Weight (%)	Atomic (%)
C	9.44	42.06
O	4.57	15.29
Ag	85.99	42.65
Total	100.00	100.00

Fig. 1. EDS spectrum of CuNP PVA film.

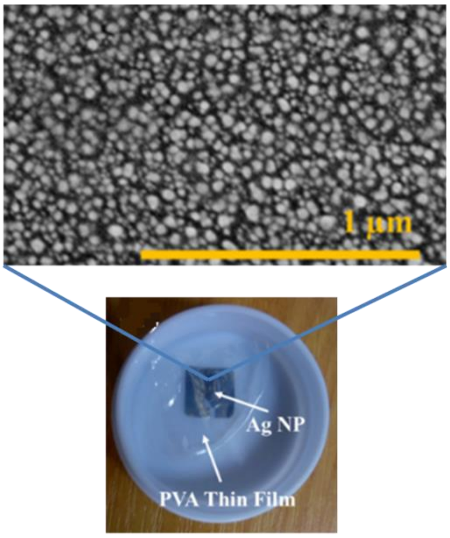


Fig. 2. Image of Ag NP deposited on the PVA film. Inset shows the surface image of Ag NP SA using focused ion beam scanning electron microscopy (FiB-SEM) at magnification 40 kX.

3. Laser configuration

Fig. 3 shows the schematic diagram of the proposed Q-switched EDFL. The laser cavity consists of a 2m long Erbium-doped fiber (EDF) as the gain medium, a 90/10 output coupler, an isolator, a 980/1050 nm wavelength division multiplexer (WDM), and a newly developed AgNP thin film based SA. The EDF has a pump absorption rate of about 14.5 dB/m at 980 nm. It was forward pumped by a 980-nm pump via the WDM. The isolator was incorporated inside the laser cavity to ensure unidirectional propagation of light and thus preventing any detrimental effects inside the laser resonator. The prepared AgNP PVA film was sandwiched between two fiber ferrules via a fiber adapter to form a fiber-compatible SA device. The insertion loss of the SA device was recorded as 5.5 dB at 1560 nm. The output coupler was used to tap out 10% of output for observation and retains 90% to oscillate in the cavity. An optical spectrum analyzer (OSA) with spectral resolution of 0.05 nm was used to observe the optical spectrum of the Q-switched YDFL, while the oscilloscope was used to analyze the output pulse train via a photodetector. Optical power meter was swapped with OSA to measure the average output power of the laser output.

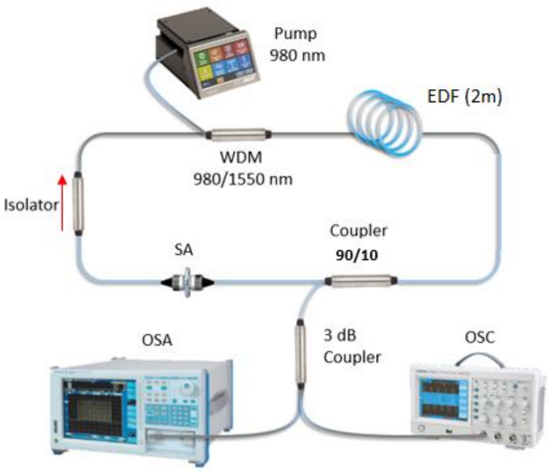


Fig. 3. Schematic diagram of the Q-switched EDFL configuration.

4. Results and discussion

The self-started Q-switching pulse train was obtained as the 980-nm pump power was raised to 140.8 mW and its operation was maintained up to the maximum pump power of 236.2 mW. The pump threshold was higher than that of the graphene or graphene-like two-dimensional-material based Q-switched fiber lasers, which were mainly due to a higher saturation intensity of the AgNP SA. Fig. 4(a) shows the optical spectrum of CW lasing (at the pump power of 130 mW) and Q-switched pulses under different pump power. The CW lasing was centered at the wavelength of around 1565 nm and the Q-switched laser operated in the 1560.0 nm center wavelength with 3 dB spectral bandwidth of 1.2 nm at maximum pump power of 236.2 mW. The spectrum shifted to a shorter wavelength as the pump power was increased above the threshold indicating that transition of CW to Q-switching takes place due to absorption of light by SA. The nonlinear effects of the fiber and the SA also cause spectrum broadening to occur. The spectrum peak was observed to increase and slight spectral broadening happened when the pump power was increased due to the reduction of pulse width which was induced by self-phase modulation (SPM).

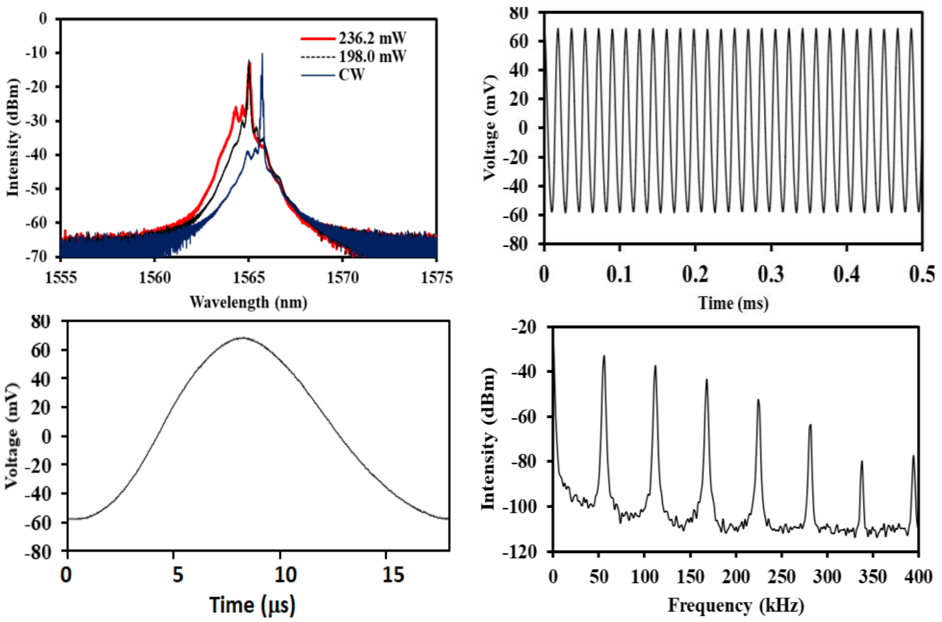


Fig. 4. Typical Q-switching output performance:
(a) Output spectra at various pump power (b) typical pulses train operating at 55.7 kHz
(c) Corresponding single pulse envelope showing the pulse width of 8.16 µs (d) RF spectrum.

Figs. 4 (b) and (c) illustrates the oscilloscope trace of Q-switched EDFL and single pulse envelop respectively at the maximum pump power of 236.2 mW. It indicates a typical Q-switching pulse shape with 17.95 µs of distance between pulses, which corresponds to a repetition rate of 55.7 kHz. A single pulse profile at this pump power has full width half maximum (FWHM) of 8.16 µs. To investigate the laser stability, the RF spectrum was investigated. Fig. 4(d) shows the spectrum with a span resolution bandwidth of 400 kHz. The signal-to-noise (SNR) of the fundamental frequency was over 63 dB, which indicates that the Q-switched pulses operated in a relatively stable regime. The broadband RF spectrum further confirms the stability of the Q-switched laser operation. Ahmad et al. reported an SNR value of 35 dB, which is lower when compared to the one obtained in this work. No other external frequency component was observed in the RF span which approved the good stability of the laser operation.

In addition, the performance of the repetition rates and pulse widths at different pump powers have also been investigated. As shown in Fig. 5, the repetition rate increased from 42.5 kHz to 55.7 kHz when the pump power changed from 140.8 mW to 236.2 mW. Meanwhile, the pulse widths have descendant tendency with the increase of the pump power, and the minimum pulse width of 8.16 µs was obtained under a pump power of 236.2 mW. The result is a typical characteristic of Q-switching operation. Fig. 6 shows the relationship between average output power and single pulse energy of the Q-switched laser with different input pump power. It is observed that the output power is monotonically increased from 0.73 mW to 1.93 mW as the 980-nm pump power was increased from 140.8 mW to 236.2 mW. Likewise, the pulse energy also increases with pump power. The maximum pulse energy of 34.7 nJ was obtained at the maximum pump power of 236.2 mW. The performance of Q-switched pulses is expected to be further improved by optimization of both SA parameter and the laser cavity design.

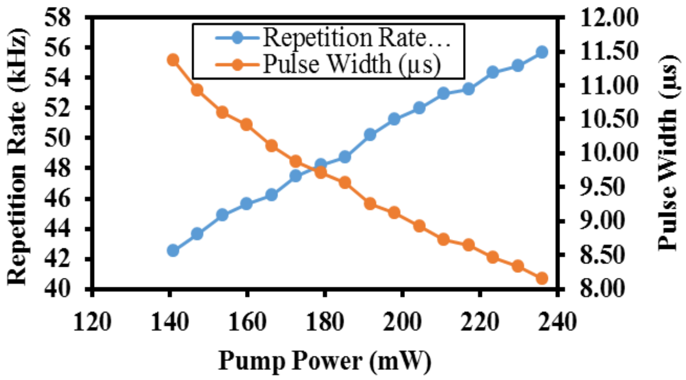


Fig. 5. The repetition rate and pulse width as a function of pump power.

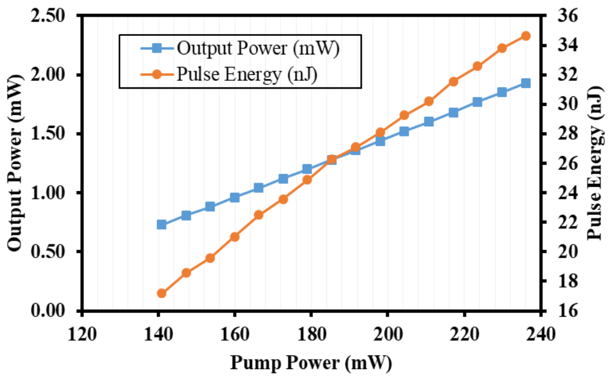


Fig. 6. Average output power and pulse energy against pump power.

5. Conclusions

In summary, a stable all-fiber passively Q-switched EDFL operating at 1565.0 nm was successfully demonstrated based on the AgNP PVA SA. The SA used in our experiment was prepared by depositing nano-sized particles of Ag onto the surface of PVA film through the thermal evaporation process. By incorporating the SA into the laser cavity, Q-switching pulses train was generated at the threshold pump power of 140.8 mW. By adjusting the pump power level, the Q-switched laser produced a range of pulse repetition frequency from 42.5 to 55.7 kHz with a minimal pulse width of 8.16 µs. These experimental results clearly indicated that the AgNP can be considered as a great alternative SA material for the Q-switching pulse generation.

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References

[1] A. Grudinin Nature Photonics **7**, 846 (2013).
[2] C. Xu, F. W. Wise Nature Photonics **7**, 875 (2013).
[3] A. A. Latiff, M. F. M. Rusdi, Z. Jusoh, M. Yasin, H. Ahmad, S. W. Harun, Optoelectron. Adv. Mat. **10**, 801 (2016).
[4] H. Ahmad, M. R. K. Soltanian, L. Narimani, I. S. Amiri, A. Khodaei, S. W. Harun, IEEE Photonics Journal **7**(3), 1 (2015).
[5] H. Haris, S. W. Harun, A. R. Muhammad, C. L. Anyi, S. J. Tan, F. Ahmad, R. M. Nor, N. R. Zulkepely, H. Arof, Optics & Laser Technology **88**, 121 (2017).
[6] M. A. Ismail, F. Ahmad, S. W. Harun, H. Arof, H. Ahmad, Laser Physics Letters **10**, 025102 (2013).
[7] S. W. Harun, M. A. Ismail, F. Ahmad, M. F. Ismail, R. M. Nor, N. R. Zulkepely, H. Ahmad, Chinese Physics Letters **29**, 114202 (2012).
[8] Z. Sun, T. Hasan, F. Torrisi, D. Popa, G. Privitera, F. Wang, F. Bonaccorso, D. M. Basko, A. C. Ferrari, ACS Nano **4**, 803 (2010).
[9] H. Guo, M. Feng, F. Song, H. Li, A. Ren, X. Wei, Y. Li, X. Xu, J. Tian, IEEE Photonics Technology Letters 28 135 (2016).
[10] D. A. Glubokov, V. V. Sychev, A. S. Mikhailov, A. E. Korolkov, D. A. Chubich, B. I. Shapiro, A. G. Vitukhnovskii, Quantum Electronics **44**, 314 (2014).
[11] D. Wu, J. Peng, Z. Cai, J. Weng, Z. Luo, N. Chen, H. Xu, Optics Express **23**, 24071 (2015).
[12] Z. Kang, X. Guo, Z. Jia, Y. Xu, L. Liu, D. Zhao, G. Qin, W. Qin, Optical Materials Express **3**, 1986 (2013).
[13] H. Ahmad, N. E. Ruslan Z. A. Ali, S. A. Reduan, C. S. Lee, R. A. Shaharuddin, N. Nayan, M. A. Ismail Optics Communications **381**, 85 (2016).