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Silver Nanoparticles Embedded in Polyvinyl Alcohol Based Passive Saturable Absorber

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Abstract. Silver nanoparticles (AgNP), a novel candidate of noble metal nanoparticles, which has great potential for pulsed laser applications due to strong saturation absorption behaviour. This study demonstrated the passively Q-switched laser operating within an Erbium-doped fibre laser cavity using AgNP saturable absorber (SA). The AgNP was synthesized via the chemical reduction method and the average size of nanoparticles was around 52.39 nm. The AgNP was incorporated with polyvinyl alcohol (PVA) polymer to form an AgNP-PVA composite SA. The proposed experimental works generated single pulse energy and peak power of about 66.14 nJ and 18.71 mW corresponds to the repetition rate and pulse width of 62.89 kHz and 3.32 μs.

1. Introduction

The development of saturable absorber (SA) technology has been practically parallel with the evolution of fibre lasers. 2D family, including graphene, MXenes, transition metal dichalcogenides, and topological material has expanded significantly in recent years. In 2D materials, the bandgap is an important characteristic for SA selection to identify the saturable absorption at the responding operation wavelength. Supposing, for the 2D family, the saturable absorption process occurs when the absorption of light reduces with the increasing light intensity just above the respective SA bandgap [1]. The bandgap of the SA determines the operation wavelength and the larger bandgap induced the weak electron-hole interaction due to the long separation of conduction and valence band [1]. Nonetheless, in noble metal nanoparticles, especially silver nanoparticles (AgNP), the saturable absorption can happen in two possibilities: the ground state plasmon bleaching due to intrinsic electron dynamics and intensity-dependent shift of the plasmon resonance induces the strong saturation behaviour [2,3].

In this work, we reported the Q-switched pulsed fibre laser using AgNP-PVA composite thin film as SA at Erbium operating wavelength. The AgNP was synthesized using the chemical reduction method and incorporated into PVA polymer composite. The obtained results show that the pulsed able to generate the pulse energy, peak power, repetition rate, and pulse width of 66.14 nJ, 18.71 mW, 62.89 kHz, and 3.32 μs, respectively.

2. Methodology

All the chemicals were used without any further purifications. The AgNP was synthesized using chemical reduction process in which sodium nitrate was used as the reducing agent. The average AgNP sizes are 52.39 nm with d-spacing of 2.17 Å (200 plane) shows that sodium citrate was successfully reduced from Ag salts to Ag^+ ions and resulting in the formation of Ag cluster. Additional information on characterization and methodology of AgNP, one can refer from our previous report [4,5]. Briefly, the

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AgNP-PVA SA was prepared by separating the AgNP and excess sodium citrate using centrifuges. The process was repeated at least three times in order to produced high purity AgNP. Then, a known amount of AgNP was added into 5 mL PVA solution (10 mg/mL: PVA/DI water) and ultrasonicated for an hour followed by magnetic stirring for 3 h. Finally, the AgNP-PVA was transferred to the surface of a clean plastic mould and dried under ambient for 72 hours.

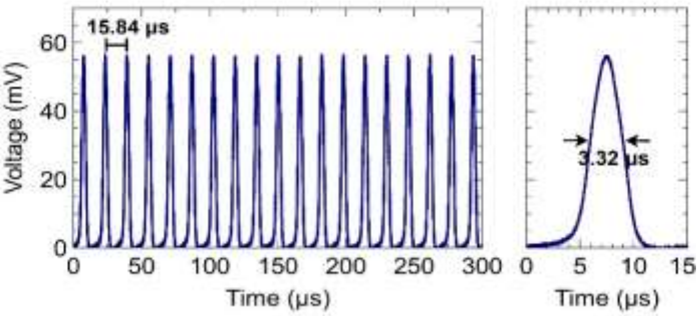
To generate the Q-switched pulsed, AgNP-PVA SA was further cut into small pieces of 1 mm^2 and transferred onto fibre ferrules to function as SA. The arrangement of the Q-switched pulsed laser used in this experiment was identical to our previous work reported elsewhere [5]. Worth mentioning that, our previous report focused on the Q-switched using Erbium-doped fibre (gain medium) with a length of 2.4 m. However, in this experiment, we used a gain medium with a length of 1.7 m to observed the changes of Q-switched pulsed laser performance. Figure 1 (a) and (b) shows the physical image of AgNP-PVA SA and Ag-PVA onto the fibre ferrule end.

(a) (b)

Figure 1. Physical image of AgNP-PVA SA after 3 days drying under room temperature and (b) transferred onto a FC/PC fibre end.

3. Results and Discussions

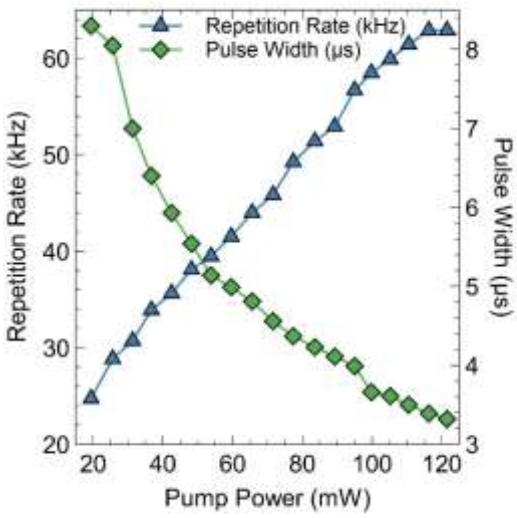
The stable Q-switched operation was obtained at the pump power of 19.4 mW. However, the pulsed was observed to be distorted and vanished when the pump power increased exceeded 121.5 mW due to the oversaturation of the SA at high input intensity. In addition, pure PVA composites was tested in the Q-switched laser cavity and no pulse was observed shows that AgNP was operated in a Q-switched mode. Figure 2 (a) shows the Q-switched pulse train at a maximum pump power of 121.5 mW with pulse-pulse separation of 15.84 µs retrieved from the digital oscilloscope. Figure 2 (b) depicts the single pulse profile of the pulse train at a maximum pump power of 121.5 mW. The single pulse shows a symmetrical Gaussian-like shape with full-width at half maximum of 3.32 µs which is a typical time regime of Q-switched pulsed laser operation.



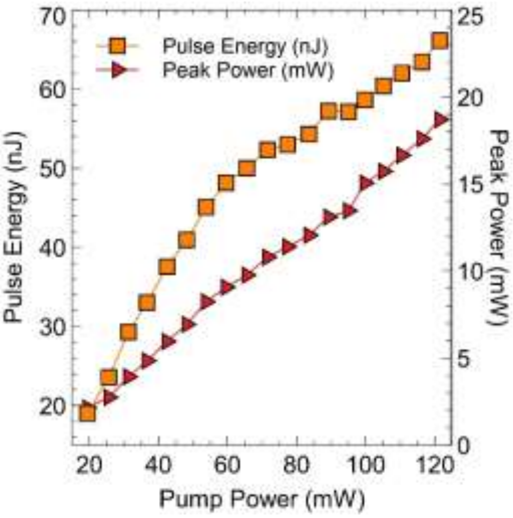
(a) (b)

Figure 2. (a) Typical pulse train and pulse width at pump power of 121.5 mW and (b) the pulse-to-pulse separation in 15.84 µs with single pulse width of 3.32 µs.

The repetition rate, pulse width, pulse energy, and peak power as a function of pump power of the Q-switched pulsed are presented in figure 3 (a) and (b). The results show that as the pump power increased, the repetition rate was monotonically increased from 24.75 to 62.89 kHz and the pulse widths were decreased as the pump power increases show the typical Q-switched operation. This is due to the higher pump power allowed more gain to saturate the AgNP-PVA SA in a shorter period of time, which leads to faster bleaching of AgNP-PVA. As a result, the repetition rate has increased. By tuning the pump power, the pulse energy and peak power were observed to increased. At the maximum pump power of 121.5 mW, the calculated single pulse energy is 66.14 nJ with instantaneous peak power of 18.71 mW.



(a)



(b)

Figure 3. Relationship between (a) repetition rate and pulse width, and (b) pulse energy and instantaneous peak power at different pump power.

4. Conclusion

In a conclusion, AgNP embedded into the PVA as SA demonstrated the ability to generate Q-switched pulse at an Erbium window. The AgNP was synthesized using the chemical reduction method and then mixed with PVA aqueous solution. The AgNP-PVA was left to dry in the ambient for 72 hours to develop an SA. The proposed experimental works generated pulse energy and peak power of about 66.14 nJ and 18.71 mW. The pump power when increased from 19.4 mW to 121.5 mW, generates a maximum of 62.89 kHz of repetition rate with a shortest pulse width of 3.32 μs.

References

[1] Woodward R I and Kelleher E J 2015 2D Saturable Absorbers for Fibre Lasers *Applied Sciences* **5(4)** 1440-56

[2] Kim K H, Husakou A and Herrmann J 2010 Saturable Absorption in Composites Doped with Metal Nanoparticles *Optics Express* **18(21)** 21918-25

[3] Philip R, Kumar G R, Sandhyarani N and Pradeep T 2000 Picosecond Optical Nonlinearity in Monolayer-protected Gold, Silver, and Gold-Silver Alloy Nanoclusters *Physical Review B.* **62(19)** 13160

[4] Lokman M Q, Shafie S, Shaban S, Ahmad F, Jaafar H, Mohd Rosnan R, Yahaya H and Abdullah S S 2019 Enhancing Photocurrent Performance Based on Photoanode Thickness and Surface Plasmon Resonance using Ag-TiO_2 Nanocomposites in Dye-Sensitized Solar Cells *Materials* **12(13)** 2111

[5] Lokman M Q, Rusdi M F, Rosol A H, Ahmad F, Shafie S, Yahaya H, Rosnan R M, Rahman M A and Harun S W 2021 Synthesis of Silver Nanoparticles Using Chemical Reduction Techniques for Q-switcher at 1.5 µm Region *Optik* **244** 167621