Fiber laser mode-locked with MoS_2 saturable absorber

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Abstract: We demonstrate a picosecond erbium-doped fiber laser mode-locked using a MoS_2-polymer composite saturable absorber.
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1. Introduction

Remarkable progress in two-dimensional (2D) material research has highlighted their promising (opto)electronic properties. In particular, graphene has attracted considerable attention as a saturable absorber in passively mode-locked lasers [1, 2]. Significant efforts are now being directed towards the exploration of other 2D nanomaterials, such as metal dichalcogenides for photonic and optoelectronic applications. Molybdenum Disulfide (MoS_2) is one such layered material, which exhibits saturable absorption [3], high third-order nonlinear susceptibility [4] and ultrafast carrier dynamics [5]. Observation of these properties suggests the possibility of using MoS_2 as a viable alternative to conventional saturable absorbers. However, the generation of ultrashort pulses mode-locked by MoS_2 has yet to be reported. In this paper, we demonstrate that this layered nanomaterial can promote self-starting mode-locking in a compact erbium-doped (Er-doped) fiber laser cavity.

2. Sample Preparation

We prepare the saturable absorber as a freestanding MoS_2-polymer composite by solution phase exfoliation of MoS_2 crystals. MoS_2 powder (~120 mg) is mixed with sodium deoxycholate (~90 mg) surfactant in deionized (DI) water and ultrasonicated for 2 hours at ~5 ºC. The resultant dispersion is centrifuged at ~7,000*g* in a swinging bucket rotor. The concentration of exfoliated MoS_2 flakes is estimated to be ∼0.03 g/L by optical absorption spectroscopy (OAS). 4 mL of this dispersion is then mixed with 2 mL of 15 wt% aqueous polyvinyl alcohol polymer solution. The mixture is next dried at ∼20ºC to form a ∼30 µm free-standing composite film. Figure 1(a) shows the linear transmission spectrum of the MoS_2 saturable absorber composite.

3. Experimental setup, results and discussion

The schematic of the Er-doped fiber laser is shown in Fig. 1(b). This consists of all-fiber integrated components for an alignment-free and compact system. An Er-doped fiber amplifier module is used to provide a noise seed and amplification at ~1.55 µm, followed by an inline optical isolator to ensure unidirectional propagation. The MoS_2 saturable absorber is integrated into the fiber laser cavity by sandwiching a small piece of the composite between two fiber connectors. Index matching gel is used to reduce the insertion losses. Intensity-dependent loss, to initiate and stabilize mode-locking, was achieved by using the MoS_2 saturable absorber device with ~81% transmission at 1545 nm; Fig. 1(a). The output signal was delivered through a 15:85 fused-fiber output coupler (OC) to both spectral and temporal diagnostics. A polarization controller (PC) was added to adjust the polarization state within the cavity, but was not fundamental to the mode-locking action.

Self-starting mode-locking was obtained at the fundamental repetition frequency of the cavity of 15 MHz, with a corresponding single pulse energy of 66 pJ. Figure 2 shows the temporal and spectral profile of the output pulses. The pulse duration, measured using an intensity autocorrelation, was 1.07 ps (deconvolved), well fitted with a $sech^2$ pulse shape and plotted in Fig. 2(a). The optical spectrum was centred at 1544.6 nm [Fig. 2(b)], with a full width at half maximum (FWHM) of 3 nm, corresponding to a transform limited pulse duration of 850 fs. The spectral sidebands indicate solitonic pulse shaping. The overall cavity group velocity dispersion (GVD) was estimated as -0.295 ps^2 from sideband spacing measurements. The fundamental frequency is shown in Fig. 2(c), with a signal to noise ratio of 50 dB. Figure 2(d) shows higher cavity harmonics without any noticeable beat frequency shift, indicating good mode-locking performance of the cavity [6].

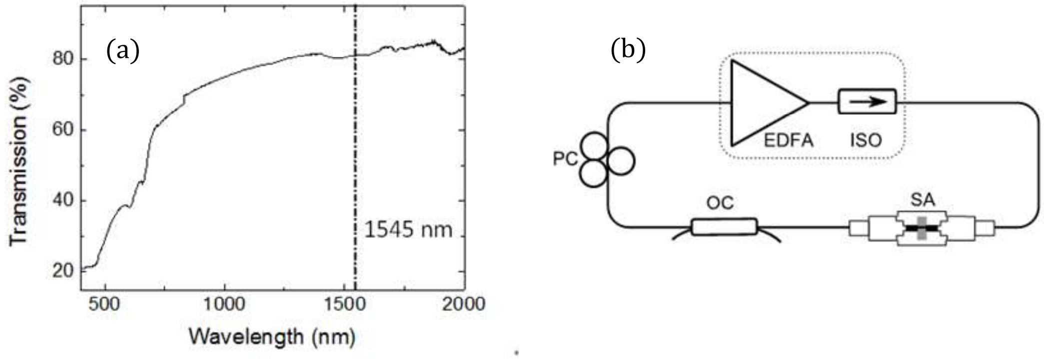

Fig. 1. (a) Linear transmission of MoS_2 saturable absorber. The dashed line indicates the wavelength of operation. (b) Schematic of the Er-doped fiber laser cavity: EDFA: erbium-doped fiber amplifier; ISO: isolator; SA: saturable absorber; OC: fiber output coupler; PC: polarization controller.

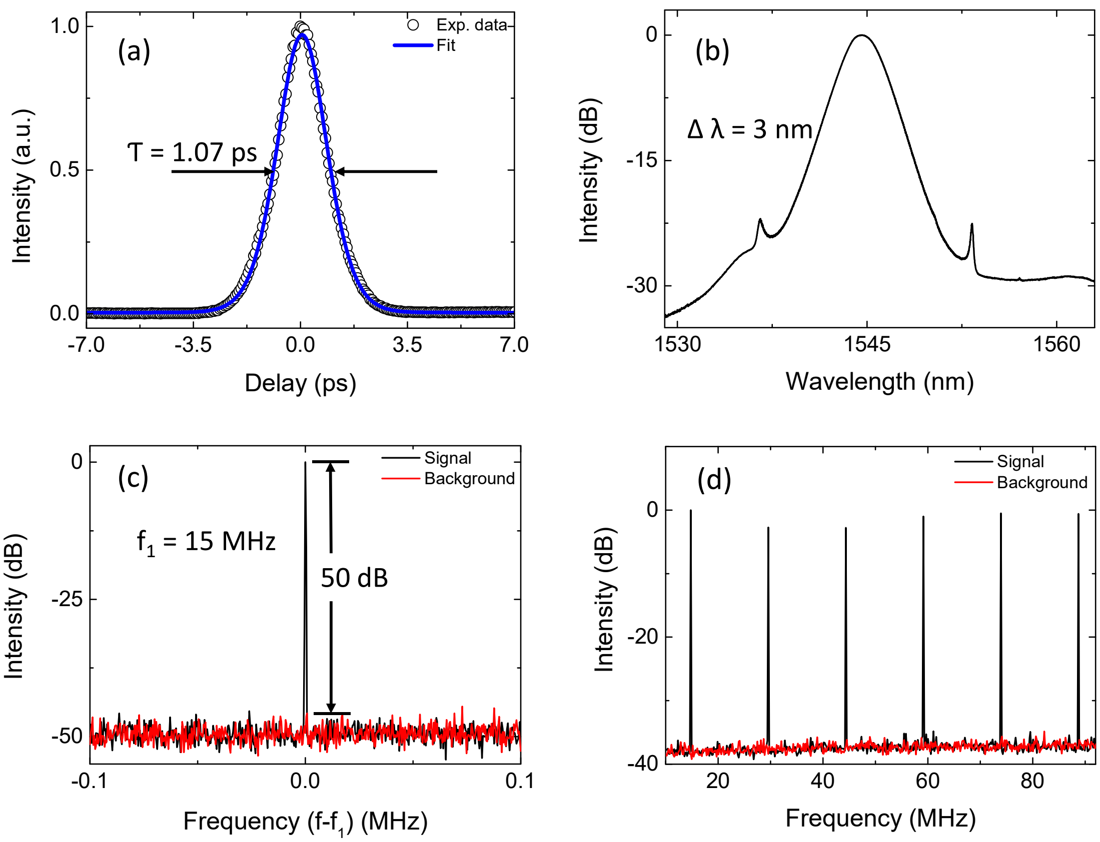

Fig. 2. (a) Measured optical spectrum. (b) The corresponding experimentally measured intensity autocorrelation. (c) Fundamental radio frequency on a span of 200 kHz, where f_1=15 MHz is the fundamental cavity frequency. (d) Harmonic radio frequency spectrum on a span of 80 MHz.

3. Conclusion

In conclusion, we have fabricated a freestanding MoS_2-polymer composite saturable absorber to demonstrate passive mode-locking. Stable, picosecond pulses at 1545 nm with 66 pJ single pulse energy were generated from our MoS_2 mode-locked fiber laser, highlighting the potential of this layered nanomaterial for ultrafast photonics.

4. References

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