Er- and Tm-doped mode-locked fiber laser with a broadband, microfiber-based MOF saturable absorber

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Abstract: We demonstrate mode-locked pulse generation in erbium-doped and thulium-doped fiber lasers by using a microfiber-based metal–organic frameworks saturable absorber. Our results highlight the applicability of such nanomaterial as a broadband SA for ultrafast photonic applications.

OCIS codes: (160.4236) Nanomaterials; (140.3510) Laser, fiber; (140.3538) Lasers, pulsed.

1. Introduction

Two-dimensional (2D) nanomaterials such as graphene, semiconducting transition metal dichalcogenides (s-TMDs), and black phosphorus (BP) have emerged as a promising platform for a variety of nonlinear photonic and optoelectronic applications due to their remarkable properties, including ultrafast carrier dynamics wideband working wavelength, and high optical nonlinear susceptibility [1-3]. While graphene and graphene-like 2D nanomaterials have been successively demonstrated as wideband saturable absorbers (SAs) for short pulse generation, they are not without limitations. For instance, graphene has relatively low absorption, and the intrinsic bandgaps of s-TMDs are in the visible/near infrared, limiting their practical applications [4]. BP has been reported to exhibit strong nonlinear optical properties bridging the gap between graphene and s-TMDs. However, the stability of the BP-based devices is generally poor due to the unstable nature of such material in ambient conditions, which is not ideal for applications requiring long-term stability [5]. Recently, another new family of graphene-like 2D nanomaterial, nickel-p-benzenedicarboxylic acid metal–organic frameworks (Ni-MOF) has triggered growing interests for nonlinear photonics applications as the bandgaps could be conveniently varied by controlling the doping concentration of Ni ions. It has been shown that the bandgap of Ni-MOF decreases when the doping of Ni ions increases, indicating the excellent promises of this novel 2D nanomaterial for SA applications in a wide operation spectral region [6]. Here, we fabricate a microfiber-based Ni-MOF SA for short pulse generation. Using a single Ni-MOF SA device, fiber lasers based on erbium- (Er) doped and thulium- (Tm) doped gain media are demonstrated, for the first time, operating at 1563.2 nm and 1881.3 nm, respectively.

2. Experimental setup and results

Ni-MOF is prepared by a solvothermal method [7]. Briefly, 0.16g of p-benzenedicarboxylic acid (PTA) is added into the mixed solution which contains 15 mL of alcohol and 10 mL of N-dimethylformamide (DMF). Nickel ions are supplied with 0.5 g of Ni $(NO_3)_2{\cdot}6H_2O$, which is dissolved in 5 mL of deionized water. This precursor is then transferred into a Teflon-lined stainless-steel autoclave for thermal formation of the crystalline MOF at the temperature of 110 °C for 12 h. After the crystallization process, the solution is cooled to room temperature in air. The resulting precipitate is then thoroughly washed with DMF and alcohol. The resultant dispersion is centrifuged at a speed of 11000 rpm for 15min and dried in vacuum at 55 °C for 12 h.

The schematic of the Er-doped and Tm-doped mode-locked fiber lasers is summarized in Fig. 1. For the Er-doped fiber laser, a ring configuration is adopted, including a fiber amplifier consisting of a 4.5 m Er-doped active fiber co-pumped by a 980 nm pump laser diode, an isolator (ISO) to ensure unidirectional propagation, a 10:90 fiber output coupler for both spectral and temporal diagnostics, and a polarization controller (PC) to adjust the net cavity birefringence.

Self-starting mode-locking is observed at a pump power of 34.59 mW. The interval time of the laser pulses is measured to be 58.41 ns, with an output power of 106.4 μW [Fig. 2(a)]. The spectrum is centered at 1563.2 nm, with a full width at half maximum (FWHM) of 6.72 nm [Fig. 2(b)]. The corresponding pulse duration is 385 fs (deconvolved), well fitted with a $sech^2$ pulse shape [Fig2(c)]. The time-bandwidth product (TBP) is calculated to be 0.318, which is close to the Fourier transform limit of a $sech^2$ pulse, indicating very low chirp. The fundamental radio frequency spectrum of the cavity is presented in Fig 2(d), with a signal-to-background ratio of >64 dB indicating good mode-locking performance.

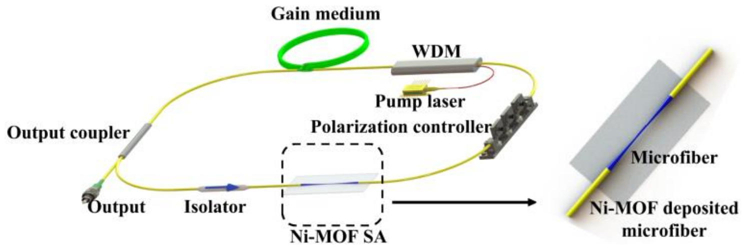

Fig. 1. Experimental setup of the mode-locked fiber laser using a microfiber-based Ni-MOF SA and enlarged configuration of the SA. Gain medium: Er-doped or Tm-doped fiber; Pump laser: a 980 nm laser diode for the Er-doped fiber laser and a 1570 nm laser diode for the Tm-doped fiber laser.

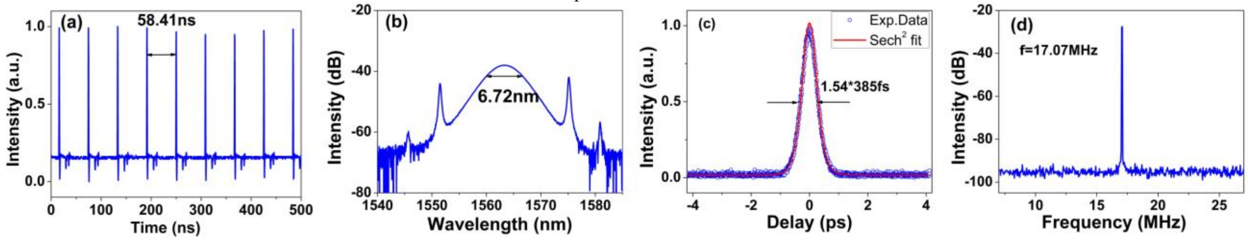

Fig. 2. Output performances of the Er-doped fiber laser based on a Ni-MOF SA. (a) Oscilloscope trace, (b) optical spectrum, (c) autocorrelation trace, (d) fundamental radio frequency spectrum.

To demonstrate the broadband saturable absorption of Ni-MOF, the same SA device is implemented into a Tm-doped fiber laser [Fig. 1], consisting of a 2.4 m Tm-doped active fiber co-pumped by a 1570 nm pump laser diode, an isolator and a 50:50 fiber output coupler. Self-starting mode-locking is observed at a pump power of 366 mW, with an output power of 2.87 mW. The interval time of the laser pulses is measured to be 72 ns [Fig. 3(a)]. The optical spectrum, centered at 1881.3 nm with FWHM of 3.495 nm is shown in Fig. 3(b). The corresponding pulse duration is 1.33ps [Fig. 3(c)], resulting in a TBP of 0.393. The fundamental radio frequency spectrum is shown in Fig. 3(d) without any anharmonic components, indicating our laser has relatively low supermode noise.

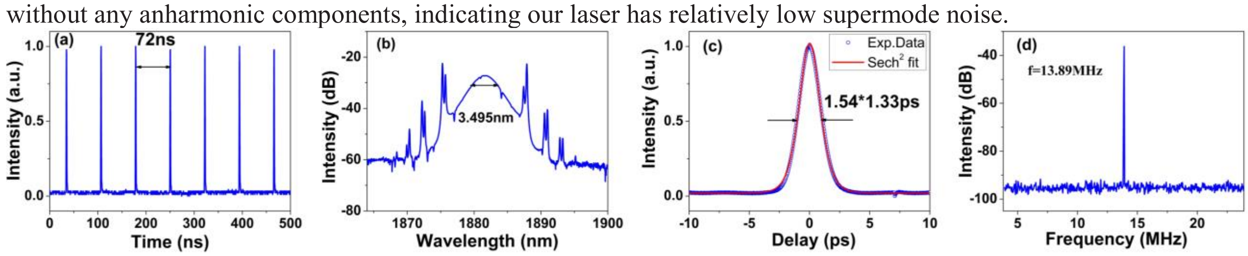

Fig. 3. Output performance of Tm-doped fiber lasers based on Ni-MOF SA. (a) Oscilloscope trace, (b) Optical spectrum, (c) Autocorrelation trace, (d) Fundamental radio frequency spectrum.

3. Conclusion

In summary, we have reported the production of a microfiber-based Ni-MOF by optical deposition process. For the first time, we have demonstrated that the Ni-MOF is able to generate ultrashort pulses by mode-locking: we developed Er- and Tm-doped fiber lasers, operating at 1563.2, and 1881.3nm, respectively. Our results highlight the potential of such nanomaterial with exceptional optical properties and remarkable opportunities for future SA technologies.

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5. References

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