Graphene enabled 3 μm pulsed fiber lasers

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Abstract: Graphene has emerged as innovative and effective saturable absorber for mid-infrared lasers. Pulsed erbium- and holmium-doped ZBLAN fiber lasers in the 3 μm region based on graphene saturable absorbers are reported.

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1. Introduction

Mid-infrared (mid-IR) lasers have found numerous applications in spectroscopy, remote sensing, frequency metrology, free-space communication, laser surgery, light detection and ranging (LIDAR), missile countermeasure, and high-efficiency pump sources for longer-wavelength oscillators. Due to the advantages of compactness, excellent beam-quality, high efficiency and power scalability, mid-IR fiber lasers have recently attracted increasing attention. Several 10-watt-level continuous-wave (CW) fiber lasers at 3 μm have been demonstrated by using heavily Er^{3+}-doped ZBLAN fibers [1]. Pulsed mid-IR fiber lasers are of great interest because they can be used for specific applications such as mid-IR nonlinear wavelength conversion and laser surgery where high peak-power is essential and shorter pulses are preferred since they can significantly reduce collateral damage. Graphene is an outstanding ultra-broadband saturable absorber because of the extraordinary nonlinearities and ultrafast recovery times of photo-excited electrons at sub-picosecond timescales and wavelength independent absorption. Graphene Q-switched and mode-locked operation of Yb^{3+}-, Er^{3+}-, and Tm^{3+}-doped silica fiber lasers have been successfully demonstrated in the 1 μm, 1.5 μm and 2 μm wavelength regions, respectively [2-4]. In this paper, we report pulsed Er^{3+}- and Ho^{3+}-doped ZBLAN fiber lasers in which graphene saturable absorbers were employed as the modulation element.

2. Experimental setup

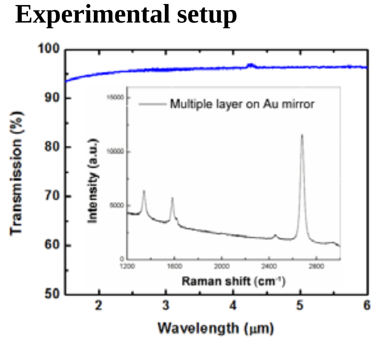

Fig. 1. Transmission of graphene deposited on silicon substrate and Raman spectrum of graphene transferred onto gold mirror.

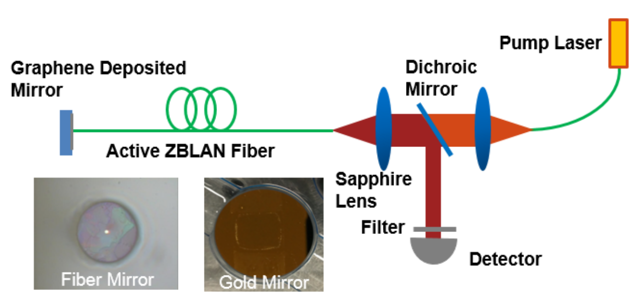

Fig. 2. Experimental setup of pulsed fiber lasers at 3 μm utilizing graphene deposited fiber mirror and graphene transferred gold mirror.

In our experiment, two different types of graphene saturable absorber devices were fabricated and tested. One is a fiber mirror device that was fabricated by the method of optically-driven deposition using graphene dispersion purchased from Graphene Supermarket Inc. The other is a bulk device that was fabricated by transferring CVD grown graphene onto a gold mirror. The absorption of graphene in the mid-IR range was measured and is shown in

Fig.1. The Raman spectrum of the graphene transferred onto a gold mirror was measured using a Horiba Jobin Yvon Raman system with a pump laser at 514 nm and is shown in the inset of Figure 1. The experimental setup of a graphene pulsed 3 μm fiber laser is depicted in Figure 2. Er^{3+}-doped and Ho^{3+}-doped ZBLAN fibers were used as the gain media. A 976 nm multimode laser diode and an 1150 nm Raman fiber laser were used as the pump source for the Er^{3+} and the Ho^{3+} laser, respectively. The pump laser was first collimated and then focused into the fiber inner cladding by two identical antireflection-coated plano-convex sapphire lenses with focal lengths of 25 mm. The flat cleaved end of the ZBLAN fiber was used as the output coupler mirror with ~ 4% Fresnel reflection. The other end of the gain fiber was angle cleaved (~8°) to eliminate the influence of the Fresnel reflection. The angle-cleaved fiber end was directly butted against the fiber graphene deposited dichroic mirror or graphene transferred gold mirror. The output laser beam was coupled out with a dichroic mirror inserted between the two sapphire lenses at 45° to the collimated pumping beam. A long-wavelength pass filter was placed before the detector to remove background light. The output spectrum of the fiber laser was measured with a monochromator and the pulse trains were measured with a PbSe photodetector and recorded by an oscilloscope.

3. Experimental results and Conclusion

The spectrum, pulse train, and pulse shape of the Q-switched Er^{3+}-doped ZBLAN fiber laser are shown in Fig. 3. Stable Q-switched pulses at 2.78 μm with a pulse duration of 2.9 μs and a pulse energy of up to 1.67 μJ at a repetition rate of 37 kHz have been obtained. The spectrum, pulse train, and pulse shape of the Q-switched Ho^{3+}-doped ZBLAN fiber laser are shown in Fig. 4. When the laser was pumped with 1.5 W, the average output power was measured to be 102 mW and the pulse duration was 1.18 μs. The pulse energy and the peak power were found to be 1.1 μJ and 0.95 W, respectively. In both lasers, the repetition rate of the fiber laser increased with the pump power, while the pulse width decreased with the pump power. Preliminary mode-locking operation of an Er^{3+}-doped ZBLAN fiber was obtained by using a graphene transferred gold mirror. The pulse trains were measured and are shown in Fig. 5. Mode-locking optimization of the Er-doped ZBLAN fiber laser is underway.

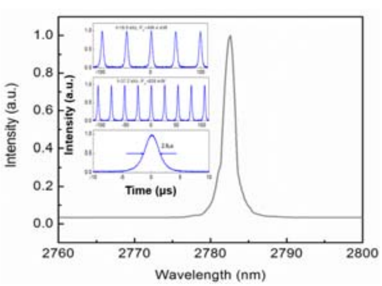

Fig. 3. Spectrum, pulse train, and pulse shape of a graphene Q-switched Er^{3+}-doped ZBLAN fiber laser.

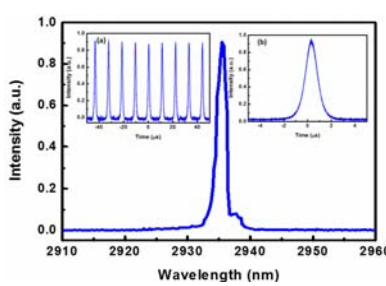

Fig. 4. Spectrum, pulse train, and pulse shpae of a graphene Q-switched Ho^{3+}-doped ZBLAN fiber laser.

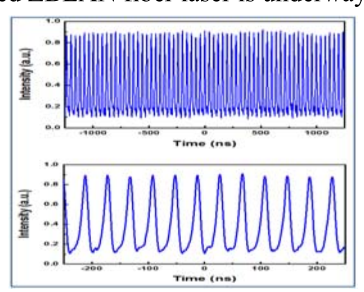

Fig. 5. Pulse train of a graphene mode-locked Er^{3+}-doped ZBLAN fiber laser.

In conclusion, we have demonstrated graphene pulsed Er^{3+}- and Ho^{3+}-doped ZBLAN fiber lasers in the 3 μm region. Further development of compact and stable Q-switched and mode-locked 3 μm fiber lasers is in progress.

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