Graphene passively Q-switched two-micron fiber lasers

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Abstract: We demonstrate a passively Q-switched thulium fiber laser, using a graphene-based saturable absorber. The laser is based on an all-fiber ring cavity and produces ~2.3 μs pulses at 1884nm, with a maximum pulse energy of 70 nJ.
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1. Introduction
There are growing interests in compact Q-switched laser sources that operate in the mid-Infrared spectral region, around 2 micron, mainly driven by applications in spectroscopy, sensing, medicine and nonlinear optical research [1-4]. Unlike active Q-switching, passive Q-switching is a more convenient and cost-effective way to achieve high energy pulses because it does not require additional switching electronics [5]. Compared with lasers based on bulk gain media, a fiber format offers distinct advantages including small footprint, robust beam confinement and environmental stability [5]. Thulium (Tm)-doped silica fiber is a promising two-micron gain material. It exhibits high quantum efficiency as well as a broad gain spectrum extending from 1.8 to 2.1 μm [6]. Passive Q-switching of Tm fiber lasers has so far been realized by a number of techniques including multiple quantum wells [7], Cr:ZnS or Cr:ZnSe crystals [8,9]. However, all of these implementations require the use of additional bulk components such as mirrors or lens pairs, thus compromising the key benefits of fiber lasers, i.e. their compactness and alignment-free operation [5].

Both carbon nanotubes (CNTs) and graphene are promising materials for saturable absorbers (SAs) [10-14]. They have key advantages such as ultrafast recovery time, wide operating bandwidth as well as easy integration with fiberoptic systems [10-14]. In particular, due to the linear dispersion of Dirac electrons [14], graphene based SAs have the potential to operate at wavelengths much longer than any other SAs. Both Q-switching and mode-locking of fiber lasers have been reported for graphene-based SAs at 1.0 micron [15] and 1.5 micron [16], but not in the very important long wavelength region around 2.0 micron.

Here, we fabricate a graphene-based SA (GSA) and use it to passively Q-switch a Tm-doped all-fiber laser. The laser generates ~ 2.3 μs pulses with a maximum pulse energy of 70nJ, and the repetition rate varying from 12 to 26kHz, depending on the pump power.

2. Experimental Setup and Results
Natural graphite flakes are exfoliated for 9 hours in a ultrasonic bath in N-Methylpyrrolidone (NMP) [17].The un-exfoliated flakes are allowed to settle for 10 minutes. Dispersions are then ultra-centrifuged at 10,000 rpm (17,000g) for an hour. The top 70% is decanted for characterization and composite fabrication. 200 mg Styrene Methyl Methacrylate (SMMA) polymer dissolved in NMP is mixed with 2ml centrifuged NMP-graphene dispersion as described in [18]. The mixture is then decanted on a petri dish, dried in vacuum overnight and then baked in oven at 80°C for 45 minutes, resulting in a 50μm free-standing composite. Fig.1 shows the linear absorption of the Graphene-SMMA composite.

Fig.1 Linear absorption of Graphene-SMMA film.
Fig.2 Q-switched thulium fiber laser setup.

Fig.2 illustrates the schematic setup for the Q-switched thulium fiber laser. The Q-switched laser is based on a

![Diagram](https://example.com/diagram.png)
Q-switching operation starts at a pump power of ~320mW. The initial pulse repetition rate is ~12kHz, with an output power of 0.57mW. This corresponds to a pulse energy of ~48nJ. Q-switching can be maintained up to a pump power of 400mW, where we obtain the maximum output power ~1.8mW and repetition rate ~26kHz. At this condition, the pulse energy is increased to ~70nJ, larger than previously reported GSA Q-switched fiber lasers at 1.5 μm [16]. Further increase of the pump power results in unstable pulsation. Fig. 3 shows the output waveforms at 400mW pump power, using an ultrafast photo-detector (with 10GHz bandwidth). Fig.4(a-b) illustrates the pulse duration, output power and repetition rate as a function of pump power. As pump power increases, we observe increasing repetition rate and decreasing pulse duration, typically expected for Q-switched lasers [5]. The optical spectrum of the Q-switched laser is measured using a scanning spectrometer (Bristol 721B) and the spectrum exhibits a single peak at 1884nm (Fig.4c).

![Fig.3 Q-switched (a) pulse profile, (b) pulse train.](image)

![Fig.4 Trends for (a) output power and pulse duration (b) repetition rate; (c) output spectrum](image)

In summary, we have demonstrated a 2.0 micron Q-switched thulium fiber laser using graphene based saturable absorber. The experimental results indicate that GSA can be used as an effective saturable absorber for mid-Infrared pulse generation.

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**References**

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