Graphene mode locked, wavelength-tunable, dissipative soliton fiber laser

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Atomic layer graphene possesses wavelength-insensitive ultrafast saturable absorption, which can be exploited as a “full-band” mode locker. Taking advantage of the wide band saturable absorption of the graphene, we demonstrate experimentally that wide range (1570–1600 nm) continuous wavelength tunable dissipative solitons could be formed in an erbium doped fiber laser mode locked with few layer graphene. © 2010 American Institute of Physics. [doi:10.1063/1.3367743]

Recently, passive mode locking of fiber lasers with single walled carbon nanotubes (SWCNTs) has attracted considerable attention.1–7 It has been shown that SWCNT mode lockers have the advantages such as intrinsically ultrafast recovery time, large saturable absorption, easy to fabricate, and low cost. In particular, as SWCNTs are direct band gap materials with a gap that depends on the nanotubes’ diameter and chirality, through mixing SWCNTs with band gap materials with a gap that depends on the nanostructure and photon absorption of graphene. Li4,13 had experimentally shown that atomic layer graphene could absorb a considerable amount of infrared light without any bandwidth limitation. In previous papers we have also experimentally shown passive mode locking of an erbium-doped fiber laser15 and a solid-state Nd:YAG ceramic laser16 respectively using graphene as a mode locker. It is to point out that determined by its unique energy band structure the saturation intensity of graphene is wavelength sensitive. We had experimentally measured the saturation intensity of graphene at ~1.06 μm and 1.56 μm, respectively. It varies from ~0.87 MW cm−2 at 1.06 μm to ~0.71 MW cm−2 at 1.56 μm.13,15,16

To exploit the wideband saturable absorption of graphene for wavelength tunable soliton generation, we further specially designed an erbium-doped dissipative soliton fiber laser. We note that dissipative soliton operation of fiber lasersmode locked with SWCNTs was reported by Kieu and Wise,7 and Sun et al.11 However, dissipative soliton operation of fiber lasers mode locked with atomic layer graphene has not been demonstrated. Moreover, no wavelength tunable dissipative soliton lasers were ever reported. Our fiber laser is schematically shown in Fig. 1(b). The laser cavity is made of a piece of 5.0 m erbium-doped fiber (EDF) with erbium-doping concentration of 2280 ppm and a group velocity dispersion (GVD) parameter of ~32 (ps/nm)/km, a total length of 5.0 m.
of 9.0 m single mode fiber with GVD parameter of 18 (ps/nm)/km from optical components, and 118 m dispersion compensation fiber (DCF) with GVD parameter of about −2 (ps/nm)/km. A polarization independent isolator was used to force the unidirectional operation of the ring, and an intracavity polarization controller (PC) was used to adjust the cavity birefringence. The laser was pumped by a high power Fiber Raman Laser of wavelength 1480 nm. The graphene saturable absorber was inserted in the cavity through transferring a piece of free standing few layers graphene film onto the end facet of a fiber pigtail via the van der Walls force. Details on the graphene preparation and graphene saturable absorber characterization were reported in Ref. 13. The main difference of the current fiber laser from that reported in Ref. 15 is that normal dispersion EDF instead of anomalous dispersion EDF was employed as the gain medium. To assure large net positive cavity dispersion we also added a long piece of DCF to the cavity. In addition, we deliberately introduced large cavity birefringence in the laser, which strengthens the effect of the artificial birefringence filter formed in the cavity.17

Mode locking of the laser was always achieved. Figure 2 shows a typical mode locking state of the laser. Figure 2(c) is the oscilloscope trace of the measured laser emission. The pulse-to-pulse separation is ~660 ns, which matches the cavity roundtrip time, indicating that the pulses were formed as a result of the laser mode locking. Figure 2(a) is the optical spectrum of the mode locked pulses. It has sharp steep spectral edges and a 3 dB spectral bandwidth of ~7.2 nm. Using a 50 GHz high-speed oscilloscope (Tektronix CSA 8000) together with a 45 GHz photodetector (New Focus 1014), we measured the pulse profile of the mode locked pulses, as shown in Fig. 2(b). The pulse width is ~49 ps. Therefore, the time-bandwidth product of the pulses is ~44.3, indicating that the mode locked pulses are strongly chirped. In our experiment we had also measured the mode locked pulses with a commercial autocorrelator and confirmed that no fine structures within the pulses. We note that the pulses possess the typical features of the dissipative solitons formed in positive dispersion cavity fiber lasers.7–11 As the total cavity dispersion of our laser is ~0.3047 ps², the above experimental result suggests that the mode locked pulses in our laser have been shaped into dissipative solitons. In weakly birefringent cavity fiber lasers, where the cavity birefringence induced artificial birefringence filter has a large bandwidth, the filtering effect of the birefringence filter could normally be ignored. In our laser, the effect of cavity artificial birefringence filter no longer can be ignored, instead it together with the erbium fiber determines the effective laser gain and gain profile. As transmission of the artificial birefringence filter varies with the cavity birefringence, therefore, in our laser simply adjusting the orientation of the intra cavity polarization controller both the peak wavelength and the pulse width of the formed dissipative solitons could be continuously tuned. Figure 3(a) shows the optical spectral evolution of the formed dissipative solitons with the orienta-
tion variation of the intra cavity polarization controller. It is to see that the wavelength of the formed dissipative solitons could continuously be shifted from 1570 to 1600 nm. We note that in order to keep stable dissipative soliton operation, as the PC orientation changed, the pumping strength was also adjusted. Figure 3(b) further shows the soliton pulse width and the 3 dB spectral bandwidth variations. The soliton pulse width changed from ~140 to 40 ps, and the corresponding 3 dB spectral bandwidth changed from ~3 to 9 nm. It is worth of mentioning that in our experiment we had also constructed a wavelength tunable conventional soliton fiber laser mode locked with graphene. Continuous wavelength tuning of the formed solitons in the same wavelength range (1570–1600 nm) was also observed.

We point out that the artificial cavity birefringence filter in our laser has played the same role as the intracavity tunable birefringence filter possesses the advantage of always having a relatively broader transmission bandwidth variable through adjusting the cavity birefringence. The effective gain bandwidth limitation effect in our laser is less significant. Consequently, large energy dissipative soliton pulses could be formed in the laser. In our laser dissipative solitons with single pulse energy of 2.3 nJ have been directly generated. It is anticipated that larger pulse energy could be readily generated through further improving the cavity design, such as larger cavity output ratio. Wavelength tunable lasers have widespread applications in many fields, e.g., laser spectroscopy, biomedical research, and telecommunications. The developed wavelength tunable dissipative soliton fiber laser provides a cost effective solution for such a light source. Furthermore, the fiber laser could also be used as a compact, cost effective seed source for the generation of large energy wavelength tunable ultrashort pulses.

In conclusion, we have reported a wavelength tunable erbium-doped dissipative soliton fiber laser with atomic layer graphene as the mode locker. We have shown experimentally that by taking advantage of the artificial cavity birefringence filter effect and the broad band saturable absorption of atomic layer graphene, a wide range wavelength tunable dissipative soliton fiber laser could be constructed. Our studies clearly show that graphene could be a promising wide-band saturable absorber.

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