Ultrafast Fiber Laser Mode-locked by Graphene Based Saturable Absorber

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Abstract: A Graphene-based saturable absorber is fabricated using wet chemistry techniques. We use it to passively mode-lock an Erbium doped fiber laser. ~500fs pulses are produced at 1560nm with a 5.2nm spectrum bandwidth.

OCIS codes: (160.4330) Nonlinear optical materials; (060.2320) Fiber optics amplifiers and oscillators; (320.7090) Ultrafast lasers

1. Introduction

Saturable absorber with broad operation wavelength are of great interest for ultrafast pulse generation[1-2]. Semiconductor Saturable Absorber Mirrors (SESAMs) currently dominate passive mode-locking for ultrafast pulse generation [3,4]. However, SESAMs have a narrow tuning range (tens of nm)[3,4]. A simpler and cost-effective alternative relies on Single Wall Carbon Nanotubes (SWNTs) [1-2,5-13], where the operation wavelength is defined by the SWNT diameter (i.e. bandgap)[1-2]. Tunability is possible by using SWNT samples with a large diameter distribution [1]. However, when operating at a particular wavelength, the off-resonant SWNTs does not contribute to saturable absorption, rather cause unwanted insertion losses, compromising device-performance [11]. Novel nonlinear materials with broadband absorption are therefore required for wideband, tunable operation without any performance penalty.

The linear dispersion of the Dirac electrons in graphene offers the ideal solution [14,15]. Unlike SESAMs and SWNTs, graphene can be used as broadband saturable absorber without bandgap engineering or chirality/diameter selection. Here, we report the fabrication of a graphene-based polymer composite and its implementation as a passive mode-locker for ultrafast pulse generation [16].

2. Experimental Setup and Results

Graphene flakes are incorporated into a host polymer matrix for ease of integration and stability. We use surfactant aided exfoliation of natural graphite in water. The dispersions are mixed with polyvinyl alcohol (PVA) via ultrasonication. PVA is chosen as the host polymer for its mechanical properties and solvent compatibility. The solvent is then evaporated to obtain a free-standing ~50μm thick composite. This simple, wet-chemistry based approach is scalable and, more importantly, allows easy integration into a range of photonic systems.

Scanning Electron (SEM) and Atomic Force Microscopy (AFM) of the exfoliated graphene flakes deposited on SiO_2 substrates indicates the presence of flakes of submicrometer dimensions. This is further confirmed by Raman (514nm excitation) measurements on the same flakes [17]. The absorption spectra of the graphene-PVA composite and a reference PVA film are presented in Fig.1(a). The linear absorption of the flakes is featureless save a characteristic UV plasmon peak[18], while the host polymer only contributes a small background for longer wavelengths. Fig.1(b) plots the transmission as a function of average pump power at six different wavelengths. The wavelength-independent saturable absorption of the composite is indicated by the increase in transmission with pump power at all the wavelengths.

The mode-locker is assembled by sandwiching the graphene-PVA composite between two fiber connectors with a fiber adapter, as schematized in Fig.1(c). The input mode diameter is ~10μm. A 0.8m Erbium doped fiber (EDF) is used as the gain medium. It is pumped by a 980nm diode laser via a wavelength-division-multiplexer (WDM). An isolator (ISO) is placed after the gain fiber to maintain unidirectional operation. A polarization controller (PC) optimizes mode-locking. A 20/80 coupler is used. The 80% port is selected to feed pulses back to the cavity. The total cavity length is 10.54 m.

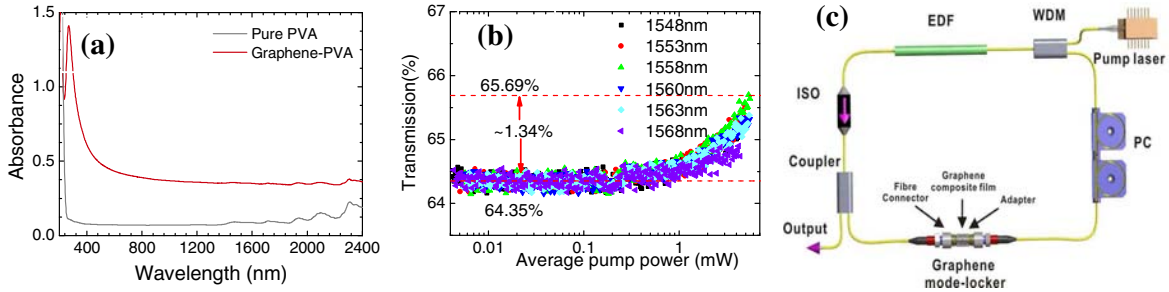

Fig. 1. (a)Absorption spectra of graphene-PVA composite and reference PVA film; (b) Typical transmission of the composite as a function of average pump power at different wavelengths. (c) Graphene mode-locked fibre laser.

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The threshold pump power for continuous wave lasing is ~10mW. When the pump power is increased to ~27mW, stable mode-locking can be initiated by introducing a disturbance to the intracavity fiber. Once stable output is achieved, no further polarization controller adjustment is needed. It is possible to decrease the pump power to ~22mW while maintaining mode-locking. The laser produces a 19.9 MHz pulse train.

Fig.2(a) shows the typical output spectrum, with a ~1560nm central wavelength. The full width at half maximum (FWHM) bandwidth is 5.2nm. The sidebands at 1548.6 and 1570nm resulting from intracavity periodic perturbations, are typical of soliton-like pulse formation. Fig.2(b) is a second harmonic generation (SHG) autocorrelation trace of the mode-locked pulses after a 50cm single mode fiber lead from the coupler. The FWHM of the trace is 713 fs. Assuming a *sech*^{2} temporal profile, the de-convolution gives a 464fs pulse duration. The time bandwidth product (TBP) is ~0.3.

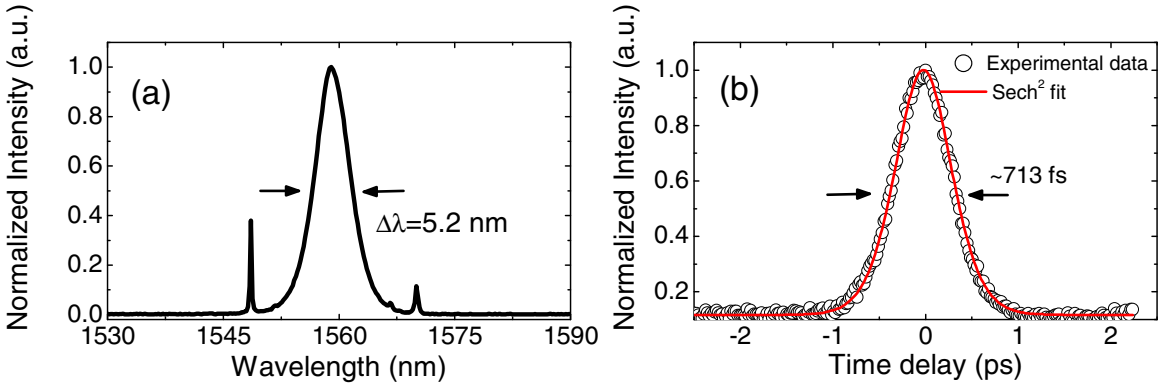

Fig. 2. Mode-locked pulses characteristics. (a) Output spectrum; (b) Autocorrelation trace.

3. Conclusions

In summary, graphene based composite is fabricated and used to passively mode-lock an Erbium-doped fiber laser working at 1560nm, with a 5.2nm spectral bandwidth and ~500fs pulse duration. Our graphene-based ultrafast laser, harnessing the wideband optical nonlinearity of graphene, without the need of bandgap engineering, extends the practical potential of this novel material from nanoelectronics to optoelectronics and integrated photonics.

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4. References

[1] F. Wang et al., "Wideband-tuneable, nanotube mode-locked, fibre laser," Nat. Nanotechnol. **3**, 738-742 (2008).
[2] S. Kivistö et al., "Carbon nanotube films for ultrafast broadband technology," Opt. Express **17**, 2358-2363 (2009).
[3] O. Okhotnikov et al.,"Ultra-fast fibre laser systems based on SESAM technology:new horizons and applications," New J. Phys.**6**, 177 (2004)
[4] U. Keller, "Recent developments in compact ultrafast lasers," Nature **424**, 831-838 (2003).
[5] S. Y. Set et al., in Optical Fiber Communication Conference (OFC), Vol. 87 of OSA Trends in Optics and Photonics (Optical Society of America, 2003), postdeadline paper PD44.
[6] F. Wang et al., "Wideband-tuneable, nanotube mode-locked, fibre laser," Nat. Nanotechnol. **3**, 738-742 (2008).
[7] V. Scardaci et al., "Carbon Nanotube Polycarbonate Composites for Ultrafast Lasers." Adv. Mater. **20**, 4040-4043 (2008).
[8] E. J. R. Kelleher et al., "Generation and direct measurement of giant chirp in a passively mode-locked laser," Opt. Lett. **34**, 3526-3528 (2009).
[9] E. J. R. Kelleher et al., "Nanosecond-pulse fiber lasers mode-locked with nanotubes," Appl. Phys. Lett. **95**, 111108 (2009).
[10] Z. Sun et al., "L-band ultrafast fiber laser mode locked by carbon nanotubes." Appl. Phys. Lett. **93**, 061114 (2008).
[11] T. Hasan et al., "Nanotube-Polymer Composites for Ultrafast Photonics," Adv. Mater. **21**, 3874-3899 (2009).
[12] K. Kieu et al., "All-fiber normal-dispersion femtosecond laser," Opt. Express **16**, 11453-11458 (2008).
[13] A. Schmidt et al., "Sub-100 fs single-walled carbon nanotube saturable absorber mode-locked Yb-laser operation near 1 μm," Opt. Express **17**, 20109-20116 (2009).
[14] A. K. Geim et al., "The rise of graphene," Nat. Mater. **6**, 183-191 (2007).
[15] K. Seibert et al., "Femtosecond carrier dynamics in graphite." Phys. Rev. B, **42**, 2842 (1990).
[16] Z. Sun et al.,"Graphene Mode-Locked Ultrafast Laser". Arxiv 0909.0457v1(2009)
[17] A. C.Ferrari et al., "Raman Spectrum of Graphene and Graphene Layers", Phys. Rev. Lett., **97**, 187401 (2006)
[18] T. Eberlein et al., "Plasmon spectroscopy of free-standing graphene films", Phys. Rev. B **77**, 233406 (2008).