Graphene-Covered-Microfiber as Saturable Absorber for Wavelength-Tunable Passive Mode-Locking

Xiaoying He
Shanghai Ultra-Precision Optical Manufacturing Engineering Center and Department of Optical Science and Engineering, Fudan University, Shanghai, 200433, P.R.China
Author e-mail address: xiaoyinghe@fudan.edu.cn

D.N.Wang
Department of Electrical Engineering, The Hong Kong Polytechnic University, Hung Hom

Abstract: A novel graphene saturable absorber is used in fiber laser for optical pulse generation. Such saturable absorber is created by tightly attaching the graphene film onto the surface of microfiber based on its evanescent field.
OCIS codes: (140.7090) Ultrafast lasers; (140.4050) Mode-locked lasers; (140.3510) Lasers, fiber;

1. Introduction

Passively mode-locked fiber lasers have attracted significant attention because of their compactness, low cost and widespread applications in optical communications, medicine, and materials processing. One of the efficient methods for passively mode-locked fiber lasers to generate high-quality pulses is by use of saturable absorber. Currently, the majority of fiber lasers employ semiconductor saturable absorber mirror (SESAM) and single-wall carbon nanotubes (SWCNTs) as a saturable absorber, to convert the continuous laser light into optical pulse trains [1–4]. It is desirable to have an ultrafast and broadband SA, as the central wavelength of the ultrafast pulses can be tuned across a number of available transmission channels. Graphene is a promising candidate for this ultrafast and broadband SA, because of the gapless linear dispersion of Dirac electrons and Pauli blocking, which enable ultrafast and broadband saturable absorption prosperity [5–7]. Moreover, the graphene-based SA is superior to SESAM and SWCNTs as it requires no bandgap or diameter control to achieve broadband saturable absorption.

Various approaches have been exploited to enable wavelength-tunable operation in passively mode-locked fiber lasers, such as to use a tunable bandpass filter [8,9], an unbalanced Mach–Zehnder interferometer (UMZI) [10], or a Sagnac fiber filter with a thermoelectric cooler (TEC) [11] as the wavelength selective element. However, to maintain the mode-locking stability in the above-mentioned systems, each wavelength tuning step should adjust the polarization controller (PC).

In this paper, we propose and demonstrate a wavelength-tunable, passively mode-locked fiber laser based on graphene saturable absorber (SA) and chirped fiber Bragg grating (CFBG). The graphene SA is fabricated by transferring graphene film onto a microfiber to enable light-graphene interaction along the fiber length. In this system, once the mode-locking operation is established, no adjustment of polarized controller is needed, even when the peak wavelength of the CFBG is tuned.

2. Experimental setup

The passively mode-locked erbium-doped fiber (EDF) laser with a ring cavity configuration is shown in Fig. 1. A 1.5 m high concentration EDF (OFS EDF-80) is used as the gain medium, pumped by a 1480 nm high power laser diode via a wavelength division multiplexer (WDM) coupler. The function of the isolator is to further enhance the unidirectional pulse propagation in the fiber laser system. An optical circulator (OC) is used to direct the light into the CFBG, which is mounted on the top surface of a triangular cantilever beam. By pressing the vertex of the cantilever beam, the wavelength of the output pulses can be changed. The PC is used to control the polarization state of the light launched into the graphene-based SA. The mode-locked pulses generated are directed out by a 90：10 optical coupler. The output spectrum of the fiber laser is recorded by an optical spectrum analyzer (ANDOAQ6319) with a 0.01 nm resolution. The radio frequency (RF) spectrum of the passively mode-locked fiber laser is measured by use of a high speed photo-detector (Newfocus 1414, 25 GHz) connected to a real-time spectrum analyzer (Tektronix RSA 3303A, 3 GHz). The pulse is monitored by a second harmonic generation (SHG) autocorrelator (FEMTOCHROME FR-103XL, resolution <5 fs) together with a high speed photo-detector connected to an oscilloscope (Tektronix, TPS 2024).

The CFBG used in fiber laser, as shown in Fig.2, has a reflection peak wavelength at 1547.1nm, with peak reflectivity of 16dB and a 3-dB bandwidth of 1.6nm. This CFBG is a type-II grating written in H_2-free SMF-28 fiber by use of 800nm/120fs femto-second laser pulses and a phase mask (Ibsen Photonics). The laser pulse energy is

300-400μJ, with 1/e Gaussian beam radius of 3mm, and exposure time of ~ 45 min.

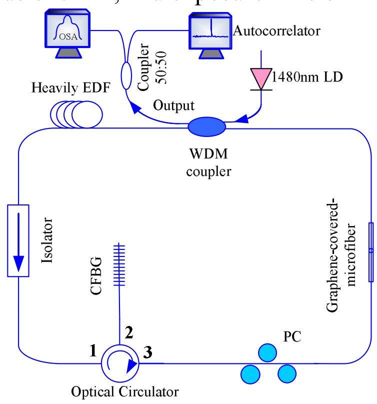

Fig.1 Configuration of the wavelength-tunable, passively mode-locked fiber laser. LD, Laser diodes; WDM, wavelength division multiplexer; EDF, Erbium-doped fiber; CFBG, chirped fiber Bragg grating; PC, Polarization controller.

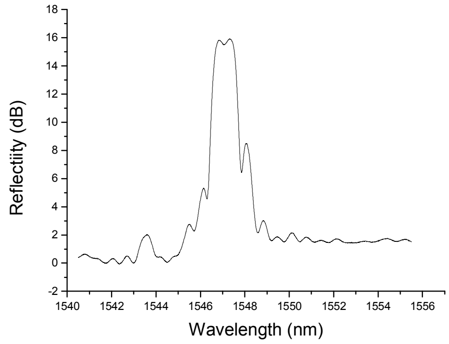

Fig.2 The reflectivity of CFBG with central wavelength of ~1547.1nm

The Graphene SA used in fiber laser is fabricated by using a monolayer graphene film on the polycrystalline Cu substrate. Firstly, we spin the polymer clad resin (EFIRON, PC-373) on the graphene film, and then cure it by ultraviolet light. After 24 hours, the supporting/graphene/metal layers are soaked with $FeCl_3$ solution to remove the metal layers. Finally, the resulting polymer-supported graphene film can be transferred onto the upper surface of the 12μm-diameter-microfiber. The microfiber can be fabricated by use of the flame brushing method from the single mode fiber with low loss. Compared with other graphene SA, our approach can lead to a large evanescent light-graphene interaction length. The schematic structure of the graphene SA is shown in Fig.3(a). The power dependent saturable absorption properties of the graphene SA is shown in Fig.3(b), where a typical high modulation depth of 12.88% is presented.

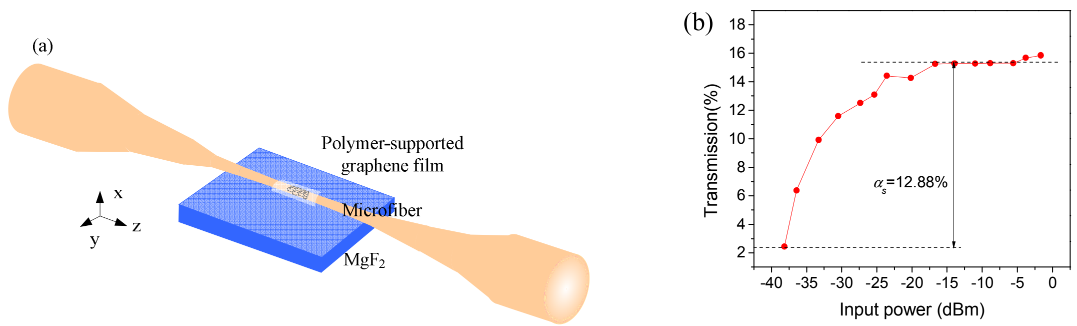

Fig.3 (a) Schematic structure of the graphene SA. (b) Power dependent saturable absorption properties of the graphene SA.

3. Results and discussion

A series of experiments on the fiber laser system employing the graphene-based SA have been carried out. As demonstrated in Fig. 4(a), the laser output pulse train has a period of ~74.8 ns which matches well with the cavity round-trip time and verifies that the laser is indeed in passive mode-locking scheme. Figure 4(b) shows the RF measurement results of the laser output. The basic repetition rate is ~27 MHz, corresponding to the ~74.8 ns round-trip time obtained in Fig. 4(a). The signal-to-noise ratio of > 70 dB is observed, showing the good mode-locking stability of the fiber laser system. By tuning CFBG, the output wavelength can be changed from 1545.5 to 1550 nm, as revealed in Fig. 4(c). The typical soliton sidebands can be observed, due to the periodic intra-cavity perturbations. The AC traces of the laser pulses obtained are shown in Fig. 4(d), with pulse durations of ~14 ps. In the passively mode-locked fiber laser, the pulse duration mainly depends on the dispersion of the system and the chirp introduced by the chirped fiber Bragg grating.

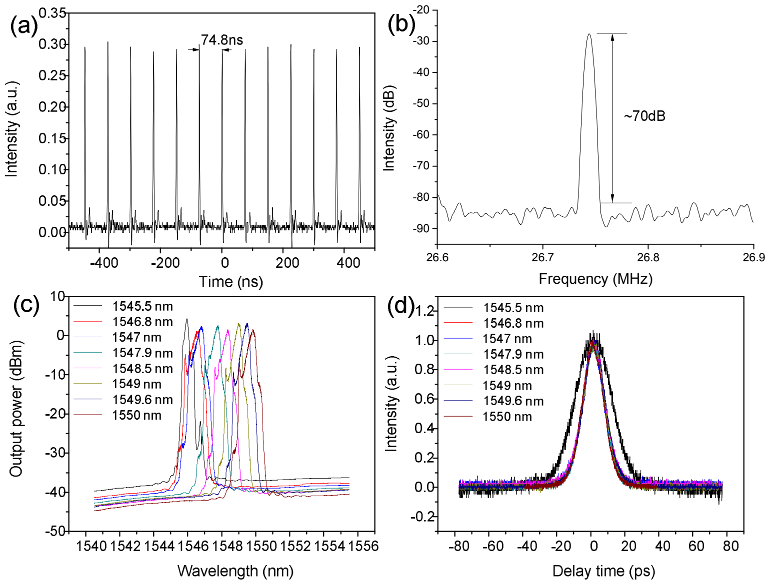

Fig. 4 Characteristics of the wavelength tunable passively mode-locked fiber laser. (a) Output pulse train. (b) RF spectrum, measured around the fundamental repetition rate ~26.7MHz over 1MHz with 10Hz resolution. (c) Output spectra under CFBG. (d) Autocorrelation traces at different wavelengths under CFBG A.

4. Conclusion

A wavelength-tunable, passively mode-locked fiber laser based on graphene SA and a CFBG has been demonstrated. A simple and effective method can been used to transfer graphene onto the upper surface of the microfiber. Without tuning the polarization controller, 14ps output pulses with 4.5m wavelength tuning range can be realized by pressing the vertex of the cantilever beam.

Acknowledgement

This work was supported by the National Natural Science Foundation of China under Grant No.61205132, the Fundamental Research Funds for the Central University GKH1232000/007, and Research Fund for the Doctoral Program of Higher Education of China (Grant no: 20120071120023).

[1]. U. Keller, Nature **424**, 831, (2003).
[2]. O. Okhotnikov, A. Grudinin and M. Pessa, New Journal of Physics **6**, 177, (2004).
[3]. T. Hasan, Z. Sun, F. Wang, F. Bonaccorso, P. H. Tan, A. G. Rozhin, A. C. Ferrari, Adv.Mater. **21**, 3874, (2009).
[4]. F. Wang, A. G. Rozhin, V. Scardaci, Z. Sun, F. Hennrich, I. H. White, W.I. Milne, A. C. Ferrari, Nature. Nanotechnol. **3**, 738, (2008).
[5]. S. Y. Set, H. Yaguchi, Y. Tanaka, and M. Jablonski, IEEE J. Sel. Top. Quantum. Electron. **10**, 137, (2004).
[6]. Z. Sun, T. Hasan, F. Torrisi, D. Popa, G. Privitera, F. Wang, F. Bonaccorso, D. M. Basko, A. C. Ferrari, ACS Nano **4**, 803, (2009).
[7]. Q. Bao, H. Zhang, Y. Wang, Z. Ni, Y. Yan, Z. X. Shen, K. P. Loh, D. Y. Tang, Adv. Funct. Mater. **19**, 1, (2009).
[8]. Q. Bao, H. Zhang, J. Yang, S. Wang, D. Y. Tang, R. Jose, S. Ramakrishna, C. T. Lim, K. P. Loh, Adv. Funct. Mater. **20**, 782, (2010).
[9]. Z. Sun, D. Popa, T. Hasan, F. Torrisi, F. Wang, E. J. R. Kelleher, J. C. Travers, V. Nicolosi, and A. C. Ferrari, Nano Res. **3**, 653, (2010).
[10]. H. Sotobayashi, J. T. Gopinath, E. M. Koontz, L. A. Kolodziejski, E. P. Ippen, Optic. Commun. **237**, 399, (2004).
[11]. S. M. Zhang, Q. S. Meng, and G. Z. Zhao, Eur. Phys. J. D. **60**, 383, (2010).