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Short note

Stretched and soliton femtosecond pulse generation with graphene saturable absorber by manipulating cavity dispersion

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ABSTRACT

Graphene is at the center of a significant research effort for ultrafast photonics due to its unique optical properties. Here, we demonstrated the generation of stretched and soliton femtosecond mode-locking pulses in an erbium doped fiber laser (EDFLs) by using graphene saturable absorber and managing the net cavity dispersion. The novelty of this work arises due to the simple fabrication of the graphene SA and the realization of two types of mode-locking pulse by manipulating the cavity dispersion. At total cavity dispersion of −0.028 ps^2, stretched pulses train was successfully obtained. The laser has a pulse width of 750 fs at repetition rate of 35.1 MHz and pulse energy of 0.054 nJ at maximum output power of 1.9 mW. By varying the net cavity dispersion so that the anomalous dispersion has been achieved with total dispersion of −0.3 ps^2, soliton mode locked pulse train was successfully obtained. The laser has a pulse width of 820 fs at repetition rate of 11.5 MHz and pulse energy of 0.42 nJ at output power of 4.85 mW. These results make the proposed EDFLs suitable for applications in optical communications, metrology, environmental sensing, and biomedical diagnostics.

1. Introduction

Passively mode-locked erbium-doped fiber lasers (EDFLs) have gained a tremendous research interest in recent years because of their unique advantages, such as compactness, flexibility, low cost, and good stability [1,2]. They have widespread applications in optical communications, micromachining, metrology and supercontinuum generation [3,4]. To date, passive mode locking is generally implemented by various types of passive saturable absorbers (SAs), such as semiconductor saturable absorption mirrors (SESAMs) [5], nonlinear optical loop mirrors (NOLMs) [6], nonlinear polarization rotation (NPR) [7], and carbon nanotubes (CNTs) [8]. However, SESAMs are costly, operate in narrow wavelength band and have long recovery time for ultra-short pulse generation. On the other hand, mode locked generation by using NOLMs and NPR techniques are easily influenced by their environment. CNTs have been considered as broadband and cost effective SAs; however, its operating wavelength depends on their diameters [9].

Recently, graphene based SAs have attracted much attention for ultrafast fiber lasers due to its unique optical properties, like broadband saturable absorption, ultrafast recovery time, nonlinear optical response, low saturation intensity, cost-

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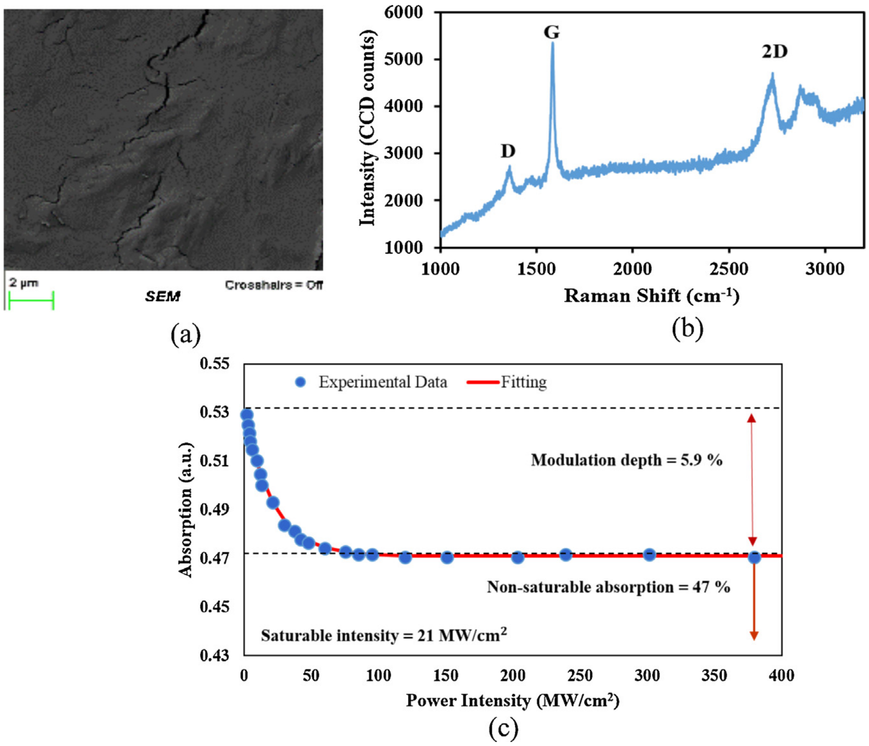

Fig. 1. Characterization of the grapheme PVA: (a) FESAM image of the graphene PVA, (b) Raman spectrum of the fabricated grahene-PVA, (c) nonlinear transmission profile showing saturable absorption.

effective and easy fabrication, which make it an excellent candidate of the low threshold and wideband SA for passive mode locking fiber lasers [10–12]. According to the demonstrated work, the graphene has an intrinsic property of broadband saturable absorption due to its zero-band gap property, which has been experimentally characterized in passively Q-switched or mode locked lasers [11,13]. Since Bao et al. [14] and Hasan et al. [15] demonstrate graphene-based passively mode-locked fiber lasers, graphene SA based mode locked fiber lasers have been used for wide spectral region at 1 µm, 1.5 µm and 2 µm regions [11]. Also, tunable and multi-wavelength ultrafast have been demonstrated [16,17].

The cavity dispersion plays a critical role in the propagation of ultrafast pulses within optical fibers. With different net dispersion of laser cavity, various pulses including solitons pulses, stretched pulses, and dissipative solitons pulses have been observed experimentally [12,18,19]. Also, different types of fibers with alternating anomalous and normal group velocity dispersion (GVD) have been proposed [20–22]. When the laser cavity operates with anomalous GVD, solitons with spectral sidebands can be formed by the balance between GVD and fiber nonlinearity [23,24]. In this paper, we experimentally demonstrate stretched pulse and soliton mode locked erbium doped fiber lasers (EDFLs) based on graphene saturable absorber (GSA) with the variation of net cavity dispersion.

2. Preparation and characterization of graphene

Graphene nanopowder used in this work was purchased from graphene supermarket as it was used as per received. The graphene nanopowder was characterized with specific surface area of 100 m^2/g, purity of 99.9%, average flake thickness of 8 nm (with 20–30 monolayers) and average particle (lateral) size of ~550 nm. To disperse the graphene, 25 mg of graphene nanopowder was mixed with 1% sodium dodecyl sulfate (SDS) in 40 ml deionized (DI) water and undergone bath sonification for 1 h. After sonification process, the dispersed graphene was centrifuged at 1000 rpm to segregate large graphene particles. The host polymer was prepared by dissolving 1 g of polyvinyl alcohol (PVA) (Mw = 89×10^3 g/mol, Sigma Aldrich) in 120 ml of DI water. The graphene suspension after centrifugation process was mixed with PVA solution at ratio of 2 and 3 ml of graphene and PVA respectively. Then the graphene-PVA mixture is poured onto petri dishes and dried at room temperature to obtain free-standing film with thickness of about 50 µm.

Fig. 1(a) shows the Field Emission Scanning Electron Microscopy (FESEM) image of the fabricated graphene PVA film. As seen in the image, the graphene flakes are clearly well dispersed in the PVA matrix. Also, we performed Raman spectroscopy measurement on the fabricated Graphene–PVA film sample. Fig. 1(b) shows the spectrum recorded by the spectrometer when a 514 nm beam of an Argon-ion laser is radiated on the film. As shown in the figure, the sample exhibits signature peaks at approximately D (1353 cm^{-1}), G (1585 cm^{-1}) and 2D (2724 cm^{-1}) bands. G band contributes to an E_{2g} mode of