Sub-50 fs compressed pulses from a graphene-mode locked fiber laser

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Abstract: We demonstrate a graphene mode-locked fiber laser system generating 42 fs pulses with 53 mW output power, ideal for high temporal resolution applications.

OCIS codes: 140.4050; 160.4236; 190.4370.

1. Introduction

Ultrashort pulses produced by mode-locked lasers are necessary for basic research and applications [1]. Over the years, an increasing research effort has been devoted to techniques able to push their temporal resolution towards the optical cycle [1]. Fiber lasers are attractive due to their simple and compact design, efficient heat dissipation, and alignment-free operation [1]. Pulses approaching few-cycle duration are needed for applications where ultrafast dynamics are important, e.g. to monitor photophysical and photochemical relaxation processes [2]. Such short pulses can be created using optical parametric amplifiers (OPAs) [3], covering the visible to near infrared range. However, OPAs are complex and expensive systems in comparison to fiber lasers [1, 3]. In fiber lasers, a typical approach for ultrashort pulse generation relies on soliton mode-locking [1]. Operation in this regime typically requires long cavity lengths (∼10 m [1]) and the nonlinear effects triggered by strong mode confinement limit the generation of few-cycle pulses [1, 4], being further constrained by the limited bandwidth of gain fibers [1]. An alternative approach is to externally compress the pulses [1]: seed pulses generated by a laser oscillator are spectrally broadened by the nonlinear effects of a medium, e.g. a single-mode fiber (SMF) with optimized length [1]. After the fiber, a dispersive compressor is used to obtain near bandwidth-limited pulses with shorter duration [1]. While direct amplification of short pulses might result in optical damage within the amplifier [1], an external compression approach offers an increased design flexibility in terms of pulse energy and pulse duration, attractive for applications [1].

Graphene [5–7] and carbon nanotubes (CNTs) [6, 8–10] are promising saturable absorbers (SAs) for the mode-locking of lasers [5, 6] able to support short pulses [4, 11]. These SAs have a number of favorable properties, such as ultrafast recovery time [2], broadband operation [12–14], and ease of fabrication and integration [5, 6]. Here, we present a pulse compression scheme based on a fiber graphene mode-locked oscillator and an erbium doped fiber amplifier (EDFA) in conjunction with a SMF as external compressor. Seed pulses of 402 fs are compressed down to 42 fs with output power amplified from 1.67 mW to 53 mW.

2. Results

The graphene-SA (GSA) is produced by sonicating 120 mg of graphite and 90 mg of sodium deoxycholate (SDC) at room temperature [4, 5]. The unexfoliated particles are allowed to settle for 10 minutes, followed by 1 hour of centrifugation at ∼17000 g. Then 5 ml of dispersion is mixed with polyvinyl alcohol (PVA) in water (∼2 wt%) and centrifuged at ∼4000 g. Evaporation at room temperature gives a ∼40 μm thick film.

Our oscillator is formed by a fiber ring cavity using ∼3 m of highly-doped erbium fiber (EDF) as gain medium. This is pumped using a 980 nm laser diode via a wavelength division multiplexer (WDM). The output to the cavity is formed using the 30% port of a coupler. A polarization controller is added to optimize mode-locking. Unidirectional operation is achieved using an isolator. Mode-locking is started by adjusting the polarization of the cavity and achieved with a pump power of 21.6 mW corresponding to 1.67 mW output power. Fig.1(a) (blue line) plots a typical oscillator output spectrum, centered ∼1559 nm, with full width at half maximum (FWHM) ∼5 nm. Fig.1(b) (blue line) is a representative second harmonic generation (SHG) autocorrelation trace. Assuming a $sech^2$ profile [1], the deconvolution gives a FWHM pulse duration ∼402 fs.

The external compressor is formed by a Pritel EDFA, with an optimized length (0.25 m) of SMF-28 placed at the output. To avoid excessive nonlinearities, seed pulses are stretched through a ∼1.5 m segment of dispersion compensation fiber (DCF-38) to ∼700 fs, before feeding the EDFA. Fig.1(a) (red line) shows the output spectrum of the compressed pulses with a bandwidth much larger than seeded pulses. Fig.1(b) (red line) plots the SHG autocorrelation trace after compression. Deconvoluted pulses corresponds to a compressed ∼42 fs pulse for a *sech*^{2} profile [1]. After compression, an increased pedestal is observed, likely due to the nonlinearity during amplification and dechirping [15]. The maximum output power is ∼53 mW, limited by our amplifier saturation. Higher output power is possible using a higher saturation amplifier. The pulse duration is limited by nonlinear distortion, which results in un-compressible pulses [15]. Shorter pulse duration is possible by seeding larger chirped pulses to further decrease the nonlinearities [15].

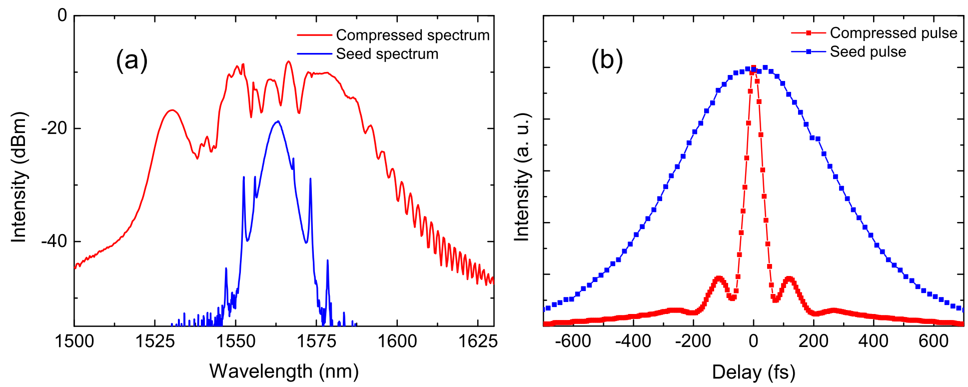

Fig. 1. (a) Optical spectrum from oscillator (blue line) and compressor (red line). (b) Autocorrelation trace from oscillator (blue line) and compressor (red line).

3. Conclusions

We combined a graphene mode-locked fiber oscillator with an external compressor based on an EDFA. The resulting 402 fs pulses are compressed down to 42 fs with 53 mW output power. This simple laser setup has great potential for applications requiring ultrashort pulses, such as micro-machining, spectroscopy, and biomedical diagnostics.

4. Acknowledgments

We acknowledge funding from a Royal Society Wolfson Research Merit Awards, the European Research Council Grants NANOPOTS, Hetero2D, EU Graphene Flagship (contract no.604391), EPSRC grants EP/K01711X/1, EP/K017144/1, Nokia Research Centre, Emmanuel College, Cambridge.

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