Pulsewidth Switchable, Wavelength Tuneable Ultrafast Fiber Laser Mode-locked by Carbon Nanotubes

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Abstract: Employing a nanotube-based saturable absorber, we demonstrate a continuously tunable (1533-1563nm) ultrafast fiber laser, with output pulsewidth switchable between picosecond (1.2 ps) and femtosecond (610 fs) regimes.

1. Introduction

Ultrafast lasers with output pulsewidth switchable in the femtosecond and picosecond regime are useful for a number of biophotonics applications [1-2]. Combining switchable pulsewidth with wideband wavelength tunability makes such sources more flexible and amenable for an even wider range of applications. Saturable absorbers (SAs) based on carbon nanotubes (CNTs) [3-10] and graphene [11-18] have demonstrated key advantages over conventional semiconductor saturable absorber mirrors (SESAMs) in terms of operating bandwidth [3, 11]. In the case of CNTs, wideband operation is achieved through the selection of an appropriate range of nanotube diameters [3-10], while this is an intrinsic property of graphene, due to the gapless linear dispersion of Dirac electrons [11-19]. Although widely tunable fiber lasers based on CNTs [3] and graphene [14, 16] have been reported, so far this has not been combined with pulse duration switchability.

Here, we report a fiber laser with a bandwidth exchangeable tunable filter operating around 1550nm. The passband of the filter can quickly switch between 5 and 12nm by using two different thin-film filters. Using a single-wall carbon nanotube (SWNT) composite saturable absorber with a large modulation depth (~12% in transmittance), we demonstrate, to the best of our knowledge, the first widely tunable ultrafast fiber laser whose pulsewidth can be conveniently switched between picosecond (1.2 ps) and femtosecond (610 fs) regimes.

2. Experimental Setup and Results

We use SWNTs grown by laser ablation [20] to fabricate a ~30 μm thick free-standing SWNT-polymer composite SA using a method similar to the one described in Ref. [6]. After packaging the composite into a FC/PC patchcord (Fig.2), the nonlinear absorption of the SA device is characterised over a 30nm span (1533–1563nm) using a 2.5ps laser operating at a 23 MHz repetition rate. The well overlapping curves shown in Fig. 1 are indicative of the wide operating bandwidth of our SWNT composite mode-locker.

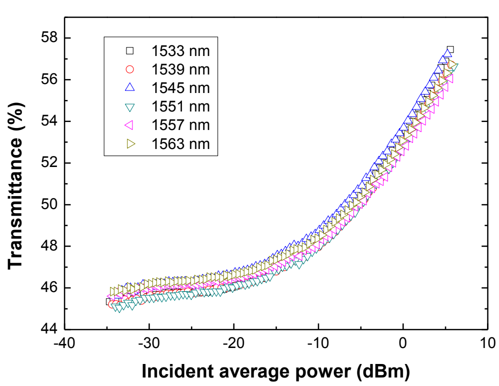

Fig.1 *Nonlinear absorption measurements*

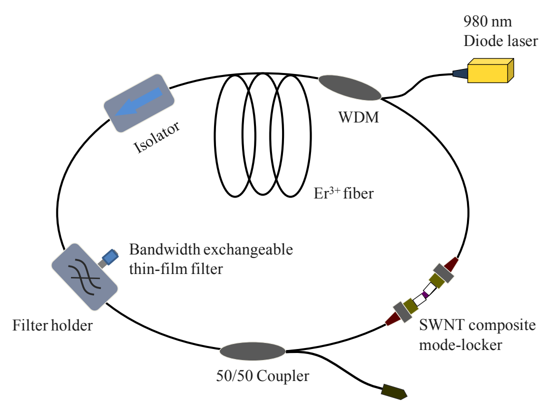

Fig.2 *Schematic of our duration-switchable, tuneable laser*

The experimental setup for the pulsewidth switchable, wavelength tunable laser is illustrated in Fig.2. The Er^{3+} fiber is forward pumped by a 980nm diode laser through a wavelength division multiplexer (WDM). An optical isolator is used to ensure unidirectional operation. A bandwidth exchangeable tunable filter follows the isolator. Two thin-film filters, with 5 and 12nm FWHM (full-width-half-maximum) pass band are used to control the effective cavity gain bandwidth. A 50/50 fused coupler feeds 50% of the input light back into the gain section after passing through the SWNT-composite. The other 50% is subsequently split outside of the cavity into two paths and fed into an autocorrelator and an optical spectrum analyser for analysis. The total cavity length is ~9.5m, corresponding to a

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repetition rate of 20.4MHz.

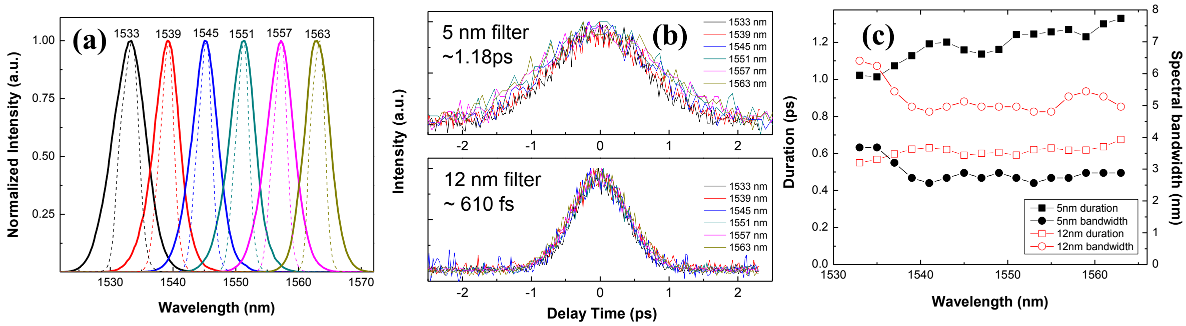

***Fig.3** Comparison of (a) mode-locked spectra, (b) output pump durations, (c) pulse duration and spectral bandwidth as a function of wavelength for 5nm and 12nm filters.*

For both filter settings, the cavities have very similar lasing (14mW) and mode-locking thresholds (20mW). The 12nm cavity can maintain single-pulse mode-locking within a diode current range of 20-29mW while the 5nm one has a shorter range of 20-26mW. In order to investigate pulse duration switchability, the diode current is fixed at a constant value of 23mW. At this pumping condition, continuous and smooth wavelength tuning can be achieved over 30nm (from 1533 to 1563nm) for both filters. The laser self-starts at any wavelength within the tuning range thanks to the consistent large modulation depth of our SWNT mode-locker [3]. Fig.3a depicts the mode-locked spectra when 12 and 5nm filters are used in turn for a series of discrete wavelengths within the tuning range. No sidebands, as typically found in a soliton fibre laser [21], are observed due to spectral filtering [22]. The average FWHM spectral bandwidths are 5.2nm (for the 12nm filter) and 2.9nm (for the 5nm filter). The decreasing ratio of mode-locked spectra and filter passband at larger filter passband is consistent to the results reported in Ref [22]. Fig.3b plots the corresponding autocorrelation traces for both filter settings. The output pulse duration switches from an average ~1.2ps to ~610fs (assuming $sech^2$ shape) when the filter is switched from 5 to 12nm. Fig.3c summarizes the duration and spectral width trends of our duration switchable, wideband tunable laser. The corresponding average output power and time-bandwidth-product (TBP) for the 12 and 5nm filter cavities are 0.53mW, 0.4 and 0.42mW, 0.43.

In conclusion, by using a carbon nanotube composite saturable absorber with a large modulation depth (~ 12% in transmittance), we demonstrated a compact and flexible ultrafast fiber laser that has a tunable wavelength (1533-1563nm) and a switchable pulsewidth between picosecond (1.2 ps) and femtosecond (610 fs) regimes.

Acknowledgements: We thank F. Hennrich for providing nanotubes. We acknowledge funding for a Royal Society Brian Mercer Award for Innovation, the EU ERC grant NANOPOTS, EPSRC grant EP/G030480/1 and King's college, Cambridge.

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