Dual-wavelength, Carbon Nanotube Mode-locked Fiber Laser

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Abstract: We demonstrate a dual-wavelength, carbon nanotube mode-locked Er fiber laser. The laser outputs two wavelengths at 1549nm and 1562nm, and each wavelength corresponds to pulse duration of ~1.3ps and repetition rate of ~11.27MHz.

1. Introduction

Dual-wavelength mode-locked lasers, capable of generating ultrashort pulses at two discrete wavelengths, are desirable sources for a number of applications such as biomedical imaging, optical communications, difference frequency generation, and pump-probe spectroscopy [1-3]. Passive mode-locking is the most attractive way to realize such sources, but requires saturable absorbers with a large nonlinear bandwidth and modulation depth [4]. Recently, carbon nanotubes (CNTs) [5-12] and graphene [13-20] have shown great promise as alternative saturable absorbers for Semiconductor Saturable Absorber Mirrors (or SESAMs), which are widely used in mode-locked fiber lasers. Compared with SESAMs, one major advantage these carbon nanomaterials possess is their large operation bandwidth [5, 13]. In the case of CNTs, wideband operation is achieved through the selection of an appropriate range of nanotube diameters [5-12], while this is an intrinsic property of graphene, due to the gapless linear dispersion of Dirac electrons [13-21]. They have a great promise to enable compact fiber-based dual-wavelength pulse sources.

Here, we report an Er fiber laser that is mode-locked at two customizable wavelengths around 1550nm (defined by an intra-cavity etalon). The mode-locker is a wideband single-wall carbon nanotube (SWNT) composite saturable absorber with a large modulation depth (~12% in transmittance).

2. Experimental Setup and Results

We use SWNTs grown by laser ablation [22] to fabricate SWNT composite films [4]. The nonlinear absorption of the saturable absorber device is characterized using a 2.5 ps mode-locked fiber laser (23 MHz repetition rate) with a central wavelength tuneable between 1545 nm and 1563 nm. Fig.1 illustrates the >12% nonlinear change in transmittance over the spectral range investigated.

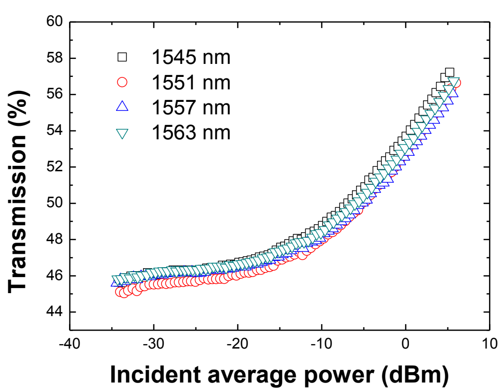

Fig.1 *Nonlinear absorption measurements*

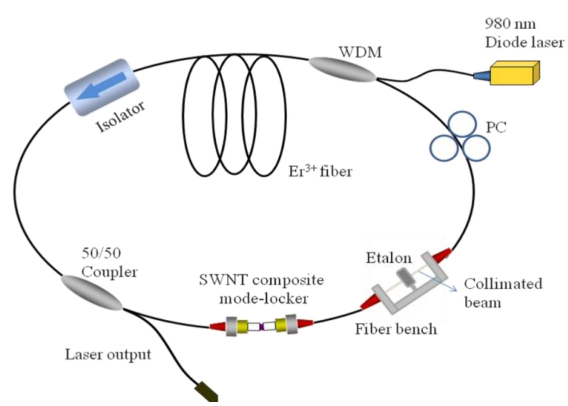

Fig.2 *Schematic of the dual-wavelength laser*

The experimental setup for the dual-wavelength laser is shown in Fig.2. 1.3m-long 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 50/50 coupler feeds 50% of the input light onto a SWNT-composite mode-locker. An etalon with a 13.6nm free spectral range and a finesse of 2.5 is used to select two peak positions at 1549nm and 1563nm respectively. Both pass bands have a full width half maximum (FWHM) bandwidth of 5.4nm. A polarization controller (PC) is used to optimize the mode-locking condition. Light from the output port is subsequently split into two paths and fed into a second harmonic generation (SHG) autocorrelator, and an optical spectrum analyser for analysis. The cavity length is estimated to be around 17.7 m, which corresponds to a fundamental repetition rate of ~ 11.27 MHz.

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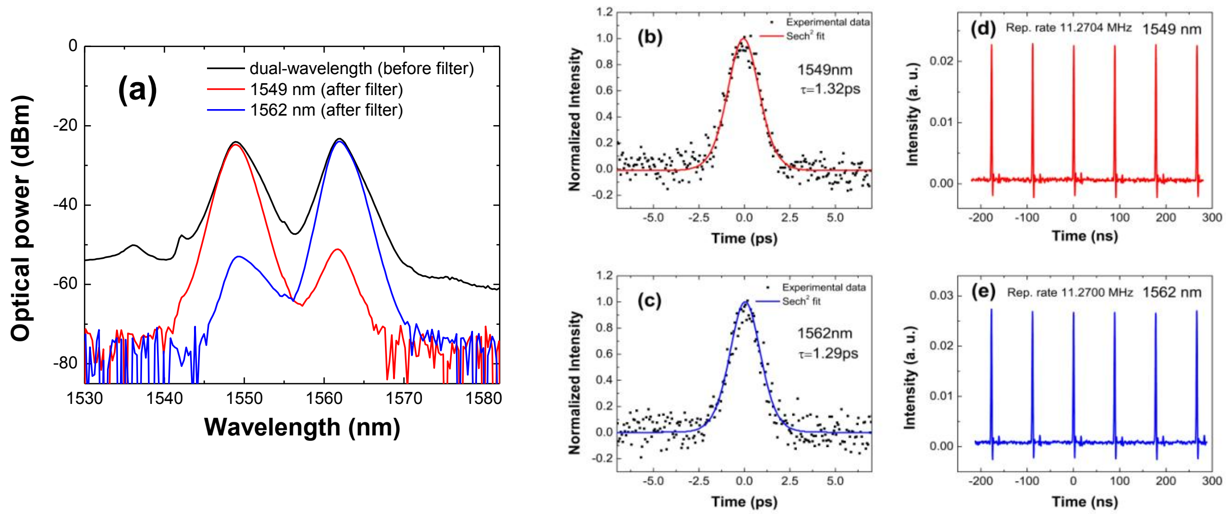

Fig.3 *(a) Dual-wavelength spectrum (black) and spectra obtained after a band-pass filter aligned to 1549nm (red) and 1562nm (blue); (b)1549nm AC trace, (c)1562nm AC trace (d) 1549nm oscilloscope trace (e) 1562nm oscilloscope trace.*

The mode-locking threshold for the Er fiber laser is 15 mW. At 19 mW pump power, we observed mode-hopping between 1549 and 1562 nm (Fig.3a). By adjusting the intra-cavity polarisation controller (PC), stable dual-wavelength mode-locking can be readily obtained. (Fig.3a). The FWHM bandwidth of the 1549 and 1562 nm modes is 2.61 and 2.35 nm respectively. To diagnose the pulse characteristics within these two wavelengths, we use a tuneable filter with a 5nm FWHM passband to separate the two wavelengths (Fig.3a). It is found that both wavelengths correspond to a stable single-pulse train with a repetition rate ~ 11.27MHz and the average power for 1549nm and 1562 nm are 0.4 mW and 0.3 mW respectively. Autocorrelation (AC) and oscilloscope traces of the two individual wavelengths are also shown in Fig.3b-e. The pulse durations for the 1549 and 1562 nm bands are 1.32 ps (Fig.3b) and 1.29 ps (Fig.3c) respectively. The slight difference (~400 Hz) in repetition rate is as a result of the wavelength dependent refractive index (thus group velocity dispersion) of silica fiber for the two operating wavelengths [23].

In conclusion, we reported a dual-wavelength Er fiber laser mode-locked by carbon nanotube saturable absorber with a large modulation depth (~ 12% in transmittance). It is the first demonstration of wavelength controllable dual-wavelength ultrafast fiber laser mode-locked by carbon nanotubes.

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