Ultrafast Erbium-doped Fiber Laser Mode-locked by a Carbon Nanotube Saturable Absorber

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Abstract: We demonstrate an ultrafast stretched-pulse fiber laser mode-locked by a carbon nanotube based saturable absorber. 123 fs pulses at 1.56 μm are generated with an output spectral width of 32 nm.

OCIS codes: (160.4330) Nonlinear optical materials; (060.2320) Fiber optics amplifiers and oscillators; (320.7090) Ultrafast lasers

1. Introduction

Passively mode-locked lasers are of great interest for many applications, such as optical communications, spectroscopy, and biomedical diagnostics [1-4]. Recently, single wall carbon nanotube (SWNT) based saturable absorbers have been demonstrated as efficient mode lockers for passively mode-locked fiber lasers [5-12], offering performance comparable to the lasers using semiconductor saturable absorber mirrors (SESAMs) [3-4]. Furthermore, SWNT based saturable absorbers possess many advantages such as wide operation wavelength range, sub-picosecond recovery time, high optical damage threshold, low cost and easy integration [5-12].

Here, we report a stretched-pulse Erbium-doped fiber laser using a SWNT-based saturable absorber, which generates 123-fs pulses at 1.56 μm. The output spectral width is 32 nm. To the best of our knowledge, this is the shortest pulses with the widest spectral width achieved thus far from erbium doped fiber (EDF) laser mode-locked by SWNT-based saturable absorbers.

2. Experimental Setup and Results

We use SWNT grown by the laser ablation method to fabricate SWNT polyvinyl alcohol (PVA) film as described in Ref. 8. The typical thickness of the resulting free-standing SWNT-PVA film is about 50 μm. Raman and absorption spectroscopy are used to measure its characteristics. From the radial breathing modes in the Raman spectra, we confirm that the film contains both metallic and semiconducting nanotubes with diameters from 1 to 1.4 nm. As shown in Fig.1, the absorption corresponding to the first transition in the semiconducting nanotubes, peaks at ~1600 nm with a bandwidth of ~340 nm. Then a ~2 mm^2 cut film is sandwiched between two fiber ends in FC/PC connectors for nonlinear characterization and mode-locking experiments. The nonlinear optical absorption properties of the packaged device are characterized by power-dependent absorbance measurement with a commercial ultrafast EDF laser (Toptica FFS.SYS-CONT) at 1550 nm. A saturation intensity of ~18.9 MW/cm^2 and a modulation depth of ~16.9% are measured.

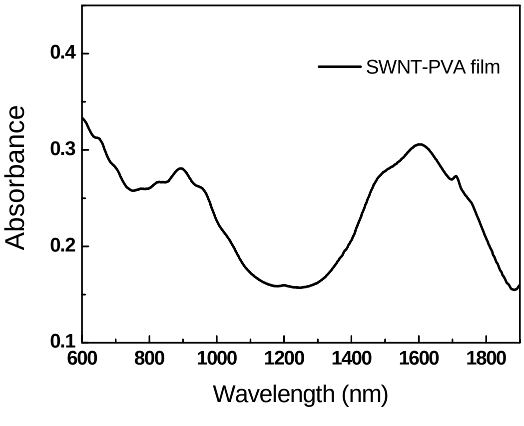

Fig. 1. Absorption spectrum of the SWNT-PVA.

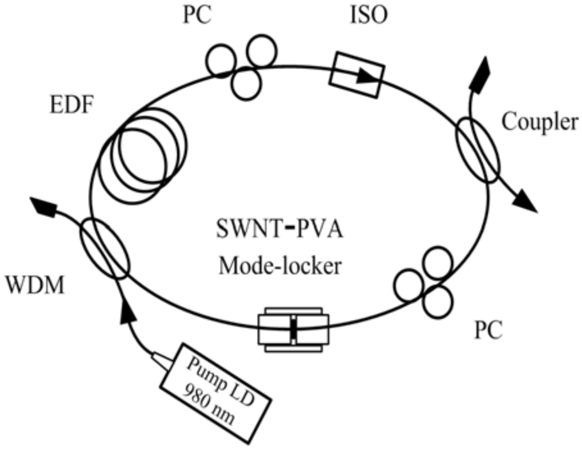

Fig. 2. Stretched-pulse fiber laser setup.

As shown in Fig.2, the packaged SWNT-PVA composite is inserted into a fiber ring cavity. The EDF is forward pumped by a 980 nm laser diode (LD) through a fused wavelength division multiplexer (WDM). A polarization-independent optical isolator (ISO) is used to ensure unidirectional operation. Two polarization controllers (PC) are used to adjust the intracavity polarization for mode-locking optimization. A fused 20/80 coupler is utilized as the output coupler. The 20% port is employed to couple pulses out of the cavity for autocorrelation trace (Inrad autocorrelator, 5-14-LDA), optical spectrum (HP optical spectrum analyzer, 86140A) and other characterizations measurements. The gain material EDF is selected with positive group-velocity dispersion (GVD). Other intracavity fiber components are chosen with negative dispersion to set the total intracavity GVD close to zero [13-14]. The optimised intracavity GVD is set to -800 fs^2. The total cavity length is ~11.17 m.

The continuous wave lasing threshold is ~7.5 mW pump power. Self-starting single-pulse mode-locking, at a repetition rate of 18.76 MHz, is observed at ~12.8 mW pump power. Fig.3 shows a typical output pulse spectrum, with central wavelength around 1560 nm. The full width at a half maximum (FWHM) is 32 nm. The spectrum does not show any soliton sidebands, typically observed in soliton fiber lasers [12]. A typical second harmonic generation (SHG) autocorrelation trace of output pulses and a fitted Gaussian curve are plotted in Fig. 4. FWHM width of the fitted Gaussian curve is 174 fs. Assuming a Gaussian temporal profile normally used for stretched-pulse lasers [13-14], the data de-convolution gives pulse duration of 123 fs. The time-bandwidth product (TBP) of the output pulses is 0.48, only slightly larger than the transform limited value ~0.44. Combining the spectrum and autocorrelation data, our stretched-pulse design is confirmed [13-14].

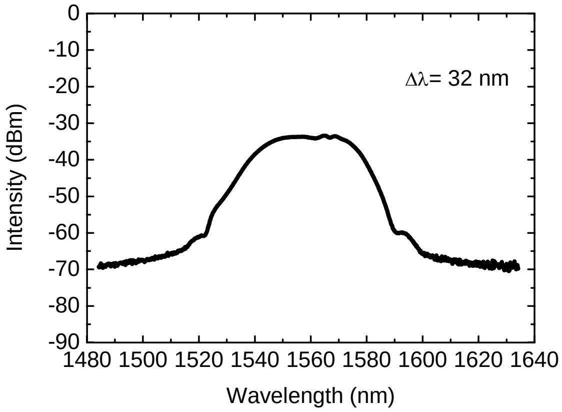

Fig. 3. Spectrum of generated pulses.

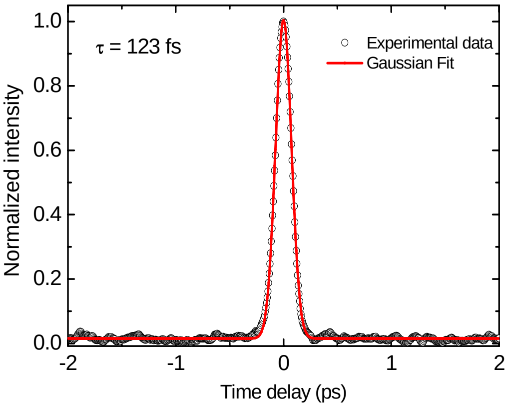

Fig. 4. Autocorrelation trace of generated pulses.

3. Conclusions

In summary, we demonstrate an ultrafast stretched-pulse Erbium-doped fiber laser using a SWNT-based saturable absorber that produces 123 fs pulses with a spectral width of 32 nm at 1.56 μm. This proves the viability of SWNTs based saturable absorbers as mode-lockers for stretched-pulse fiber lasers to achieve practical ultrafast pulses for different applications.

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4. References

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