Generation of 63-nJ pulses from a fiber oscillator mode-locked by nanotubes

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Abstract: We mode-lock a fiber oscillator with cavity length of ~1500m using nanotubes, achieving 1.55ps pulses with pulse energy up to 63nJ at 134 KHz repetition rate.

OCIS codes: (140, 4050) Mode-locked lasers; (230.4320) Nonlinear optical devices.

1. Introduction

Ultrafast fiber lasers attract considerable interest as alternative to bulk solid state lasers, due to their efficient heat dissipation and alignment-free waveguide format [1]. But, so far, the output pulse energy is typically limited by enhanced nonlinear effects [1,2]. Fiber based amplification is a useful way to provide higher output energy, however it needs additional amplifiers, and also typically requires a stretcher and a compressor to decrease nonlinearity when amplifying ultrafast pulses [3]. Recently, highly chirped-pulse generation from all-normal dispersion oscillator has been proposed to generate high energy ultrafast pulses [3-8], with the benefit of simplifying the amplification system [3, 6]. For example, using this scheme, we have recently generated ultrafast pulses with pulse energy up to 65 nJ [6]. However, in this case, the output pulses are highly chirped, therefore de-chirping is required to get near transform-limited pulses with high peak power [5].

Single wall carbon nanotubes (SWNTs) based saturable absorbers have emerged as promising passive mode-lockers because of their low fabrication cost, sub-picosecond recovery time, broad operation range, low saturation power, polarization insensitivity, mechanical and environmental robustness [5-18]. To the best of our knowledge, the maximum pulse energy achieved directly from a fiber oscillator using SWNT based saturable absorber is 6.5nJ [17]. Here, we demonstrate a low repetition rate picosecond fiber ring oscillator mode-locked by a SWNT-carboxymethylcellulose (SWNT-CMC) composite. The laser produces 1.55 ps pulses at a repetition rate of 134 KHz. The maximum pulse energy is 63nJ, the highest achieved thus far directly from fiber oscillators mode-locked by SWNT-based saturable absorbers.

2. Experimental setup and results

We use SWNTs grown by laser ablation [21] to fabricate SWNT-CMC composites as described in Ref. [9]. The film thickness is typically about 20µm. Fig. 1 shows that the film modulation depth is ~25%. The mode-locker is then formed by sandwiching the free-standing film between two fiber ferrules inside a FC/PC connector.

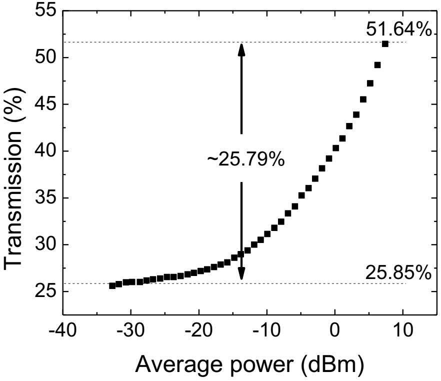

Fig.1. Nonlinear transmission

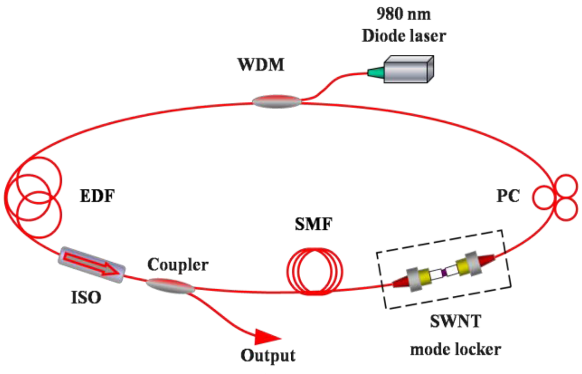

Fig.2. Ring laser setup

The laser setup is shown in Fig. 2. A 1-metre highly-doped Er^{3+} fibre (EDF) acts as the gain medium. It is pumped by a 980nm diode laser via a wavelength division multiplexer (WDM). An isolator (ISO) is placed at the end of the amplification section to maintain uni-directional laser operation. A polarization controller (PC) is used to adjust the intracavity polarization. The light is coupled out of the cavity via a 20/80 coupler. The 20% port is used to couple pulses out of the cavity for measurements. 1500m single mode fiber (SMF28) is used to elongate the laser cavity to decrease the repetition rate. The SWNT-CMC mode-locker is placed after the single mode fiber section. The total length of the laser cavity is estimated to be ~1513m.

At a pump power of 75 mW, mode-locking self-starts with an output power of 1.16 mW and 134kHz repetition rate. At a pump power ~75mW, we detect multiple pulses with a noise-like emission out of the cavity.

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This instability is a typical of such long laser cavities [2, 19, 20]. When the pump power is increased to 101mW, the laser produces an average output power of 2mW under single-pulse operation, as confirmed by an oscilloscope. The single-pulse operation is further confirmed by the radio frequency measurement.

Fig. 3 shows the typical lasing spectra with central wavelength at 1562 nm. The full width at half maximum (FWHM) bandwidth is 2.25 nm. Fig.4 plots a typical single harmonic generation (SHG) autocorrelation trace of output pulses. Assuming a Sech^2 temporal profile, the data de-convolution gives pulse duration of ~1.55ps. The time-bandwidth product (TBP) is 0.34, indicating that the output pulses are nearly transform-limited. The maximum output average power is 8.55mW, with the corresponding pulse energy of 63nJ. The pulse energy is more than 6 times of magnitude higher than so far reported for nanotube mode-locked fiber oscillators. The peak power of the pulse is ~35kW.

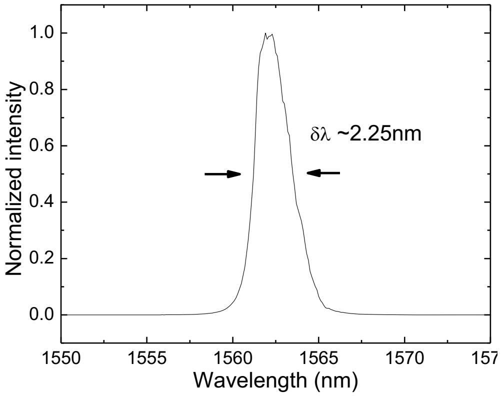

Fig.3 Optical spectrum

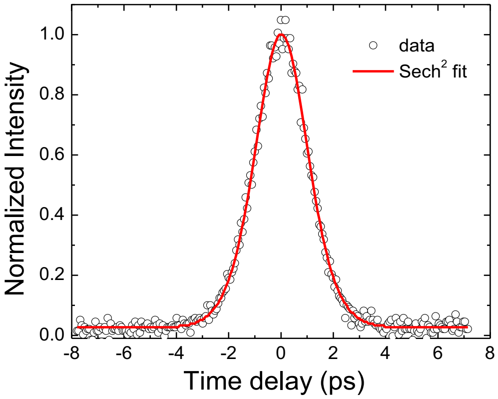

Fig.4 Autocorrelation trace

2. Conclusions

We demonstrated a high-energy picosecond pulsed laser employing a SWNT polymer based saturable absorber. The maximum single pulse energy is up to 63nJ.

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