1 GHz spaced Er:fiber frequency combs based on NPE mode-locked laser

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***Abstract*—We demonstrate a GHz optical frequency comb based on nonlinear polarization evolution mode-locked Er:fiber laser. The laser delivers an average power of 280 mW, and a pulse width of pulse 69 fs. The frequency offset f_{ceo} with the signal-to-noise ratio of 32 dB was obtained by an f-to-2f waveguide module.**

Keywords— high repetition rate, optical frequency comb, mode locked

I. Introduction

High-repetition-rate optical frequency combs (OFCs) find diverse applications in optical metrology, spectroscopy, astronomy, and optical atomic clocks. Notably, gigahertz frequency combs offer high-speed acquisition in three-dimensional imaging and in gas-phase spectroscopy at high-temperatures and pressures. OCFs with GHz mode spacing have several advantages for metrology applications. Their could provide more power per comb tooth compared to lower repetition rates, while remain relatively easy to use when it come to electronic, data acquisition, and nonlinear spectral broadening through fibers. Gigahertz-repetition-rate OFCs at around 1560 nm have been reported by using a GHz oscillator based on semiconductor saturable absorber mirrors (SESAMs), and a monolithic CaF_2 cavity with erbium-glass gain medium[1].

The nonlinear polarization evolution (NPE) mode locked ring fiber laser can output a higher power and a shorter pulse to meet the requirements of spectrum expansion. Our group have generated GHz OFCs based Yb:fiber laser [2]. However, limited by the low doping, the ring cavity Er-doped fiber laser is difficult to generate higher repetition rates [3].

In this work, we demonstrate a GHz OFC base on Er: fiber mode-locked laser. With one stage amplification, the pulse duration and energy can meet the requirement of the f-to-2f waveguide module, and a 32 dB f_{ceo} was achieved at a resolution band width of 300 kHz.

II. Experimental Setup

The ring-cavity oscillator cavity is pumped by four laser diodes, which can offer a total pump power up to 3000 mW. A 19-cm Er-doped fiber laser with a peak core absorption of 80 dB/m at 1530 nm is used as gain medium. The polarization state of laser is adjusted by two quarter-wave plates, and a half-wave plate. The 1.2 mm thick polarization dependent isolator (ISO) is inserted into the free space cavity to ensure the unidirectional operation of the laser. A 5 mm cube polarization beam splitter (PBS) is used as output coupler. In order to shorten the cavity length, the center of the wave plate is fixed to the rotation axis without using traditional wave plate racks, in this case, light passes through the edge positions of the wave plate. The free-space region of the laser cavity is shortened to 14 mm, the coupling efficiency between the collimators is dramatically improved. The pigtail of WDM is gain fiber instead of traditional single mode fiber. The Er 80-8/125 gain fiber is anomalous dispersion of -21.6 fs^2/mm. Accordingly, the net dispersion of the laser cavity is estimated to be −0.4104 fs^2 at the central wavelength of 1560 nm. In an effort to meet the requirements of spread spectrum, we designed and implemented an Erbium-doped fiber amplifier (EDFA), as shown in Fig. 1.

The output was sent through an isolator and 90/10 coupler (for the use of repetition rate detection and stabilization) and then into a nonlinear fiber amplifier. The dispersion compensation fiber ~0.5 m was used dispersion management before the amplifier and ~35 cm PM-1550 fiber to compress the pulse after the amplifier. The amplifier was forward pumped by one 1 W, 976 nm single mode pump diode through a wavelength-division multiplexer. A 1.2 m LIEKKI Er80-8/125-PM gain fiber and 1 W pump power amplify the pulse power from 100 mW to 280 mW.

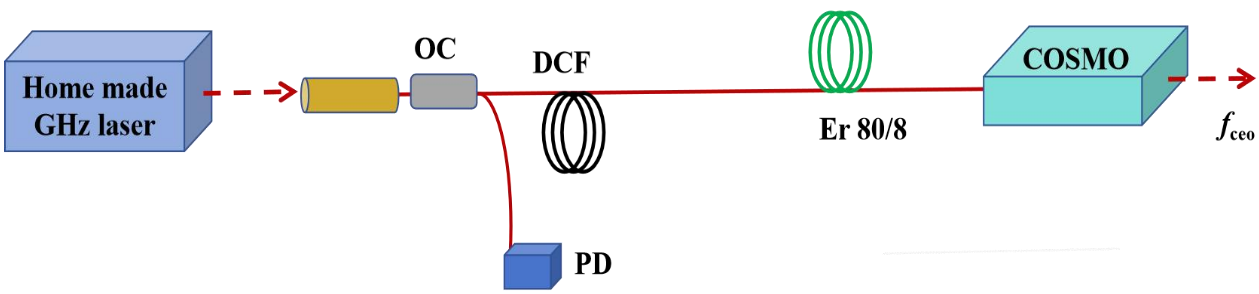

Fig. 1. Schematic diagram of the optical frequency comb based on NPE mode-locked laser. OC:output coupler; DCF: dispersion compensation fiber; PD: detector.

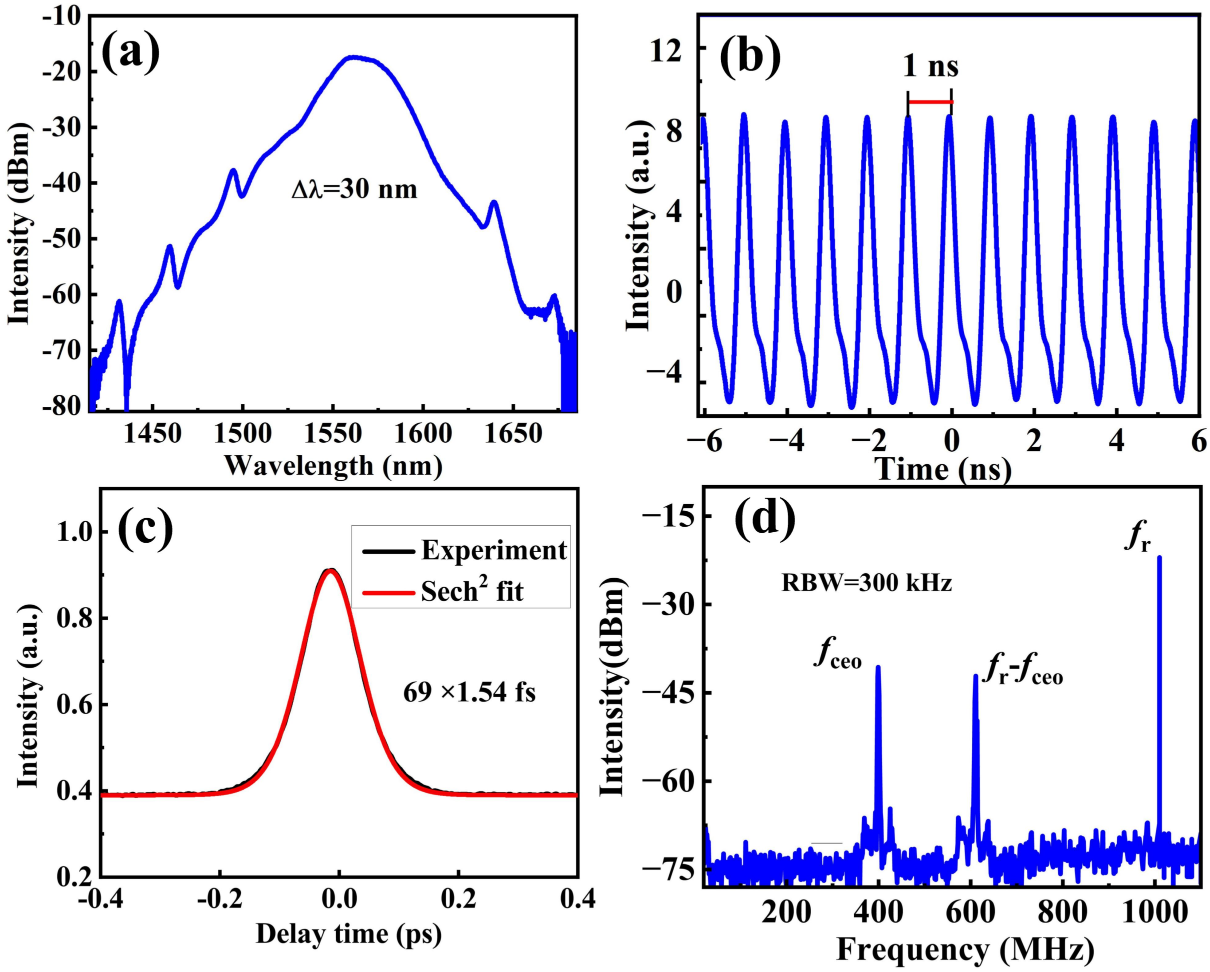

Fig. 2. (a) Spectral profile of the output pulse. (b) Pulse trains of oscilloscope. (c) Autocorrelation trace. (d) Radio frequency spectrum up to 1 1.1 GHz showing f_{ceo}, f_r- f_{ceo} ,and f_r at 300 kHz RBW.

III. RESULT

Achieving mode-locking is easily facilitated by properly rotating the wave plates through the standard NPE process. The fundamental repetition rate, estimated to be 1.006 GHz, aligns with the cavity length, and the stable mode-locking status is indicated by a signal-to-noise ratio of 70 dB at a resolution bandwidth of 30 kHz. The spectral bandwidth is 30 nm, and the direct output pulse duration is 81.8 fs - see Fig 2(a). The mode-locked pulse train is recorded by using a high-speed oscilloscope (Fig.2 (b)). The 1 ns pulse interval is agreed with the cavity round-trip time.

The output power is amplified to 280 mW, and the pulse width is optimized to 69 fs (Fig.2 (c)). Subsequently, the amplified pulses are coupled to an f-to-2f waveguide module based on tantalum pentoxide (Octave Photonics, COSMO). The spectrum is broadened to cover an octave range within the waveguide module, and the carrier envelope offset frequency (f_{ceo}) is obtained after the frequency doubling process. As shown in Fig. 2(d), the signal-to-noise ratio of f_{ceo} is 32 dB at a 300 kHz resolution bandwidth, which is sufficient for locking.

IV. CONCLUSION

We demonstrated an NPE-based erbium-doped ring fiber laser with 1 GHz repetition rate. The output power of 100 mW was amplified to 280 mW, and the pulse width of 81 fs is compressed to 69 fs. A 32 dB f_{ceo} signal was obtained by an f-to-2f waveguide module. To the best of our knowledge, this is the first time that a GHz OFC based on NPE mode locked Er:fiber laser has ever been realized.

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