High-Coherent, Ultra-Broadband Dual-Comb Fiber Laser

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1. Introduction

Optical frequency combs (OFCs) have been demonstrated to be powerful tools for frequency metrology and various applications. In particular, dual-comb spectroscopy techniques are superior to a conventional Fourier transform spectrometer for measurement speed, sensitivity, and resolution. In the conventional dual-comb technique, two independent mode-locked lasers for the generation of two-OFCs with slightly different repetition rates (f_{rep}) and a complex servo system for mutual coherence between two OFCs are required. The high cost of such a system based on two lasers system hinder the wide use of the dual-comb technique beyond research laboratories. In recent years, a “dual-comb laser”, which emits two OFCs with a small difference in their values of f_{rep} from a single laser cavity, has remarked owing its attractive properties such as passive mutual coherence and common mode noise cancellation [1,2]. In these reports, the laser cavity is adopted a single saturable absorber (SA) which is shared in two frequency combs, and it is difficult to optimize the both outputs. The spectral bandwidth of the dual-comb fiber laser is nm-order, and the laser phase noise in the outputs is expected. Moreover, undesirable nonlinear interactions between two pulses in an SA cause instability in the outputs, and it restricts the degree of freedom for tuning of the difference in repetition rate (Δf_{rep}) [3]. The demonstration is reported only around center wavelength of the laser outputs. Although, in ref. [4], super continuum is generated by using a highly nonlinear fiber (HNLF), the coherence degradation in the process of the spectral broadening is confirmed.

In this study, we develop a bidirectional mode-locked Er-fiber laser that generates two high-coherent and ultra-broadband frequency comb spanning more than 1-octave with slightly different f_{rep}s. We use two mode-locking mechanisms, i.e., nonlinear polarization rotation (NPR) and two saturable absorber mirrors (SAMs). We detect the carrier-envelope-offset (f_{ceo}) bear signals in both directions. To the best of our knowledge, this is first demonstration of a dual-comb fiber laser, thus the laser has ultra-broadband high coherency.

2. Experimental setup and results

Figure 1(a) shows a schematic o the developed bidirectional mode-locked Er-fiber laser. It consists of a single mode fiber (SMF) and an Er-doped fiber (EDF) which is bidirectionally pumped by a laser diode (LD). All components are installed in the cavity symmetrically. We install an in-line polarization controller in the laser cavity to ensure NPR.

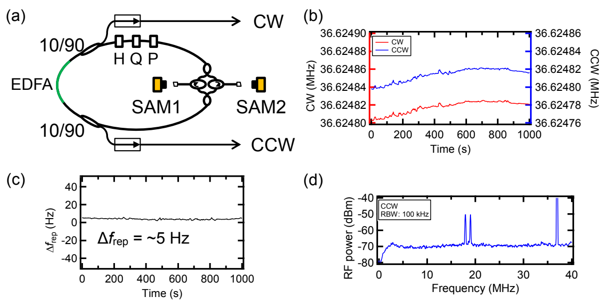

Fig.1 (a) Laser configuration. Temporal variation of (b) both f_{rep}s and (c) Δf_{rep}. (d) Beat notes of f_{ceo}.

The two outputs have a full-width-at-half-maximum (FWHM) bandwidth of the laser spectrum of ~50 nm, simultaneously. The f_{rep}s are also same as 37 MHz, and Δf_{rep} is ~5 Hz, thus the optical spectral bandwidth of dual-comb spectroscopy corresponds to ~130 THz (~1100 nm). Figure 1(b, c) shows the temporal variation of f_{rep}s and Δf_{rep} in the free running. High stability of Δf_{rep} was achieved with the standard deviation of 0.8 Hz owing to common-noise cancellation. We generate two ultra-broadband OFCs spanning more than 1-octave by using a HNLF. As shown in Fig.1 (d), we confirmed f_{ceo} beat notes. The linewidth is ~10 kHz and the signal-to-noise-ratio is ~20 dB. The result implies the outputs have sufficient coherence over 1-octave.

3. Conclusions

We developed a high-coherence, ultra-broadband dual-comb fiber laser toward the realization of a simple and robust ultra-broadband dual-comb spectroscopy system for practical applications.

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