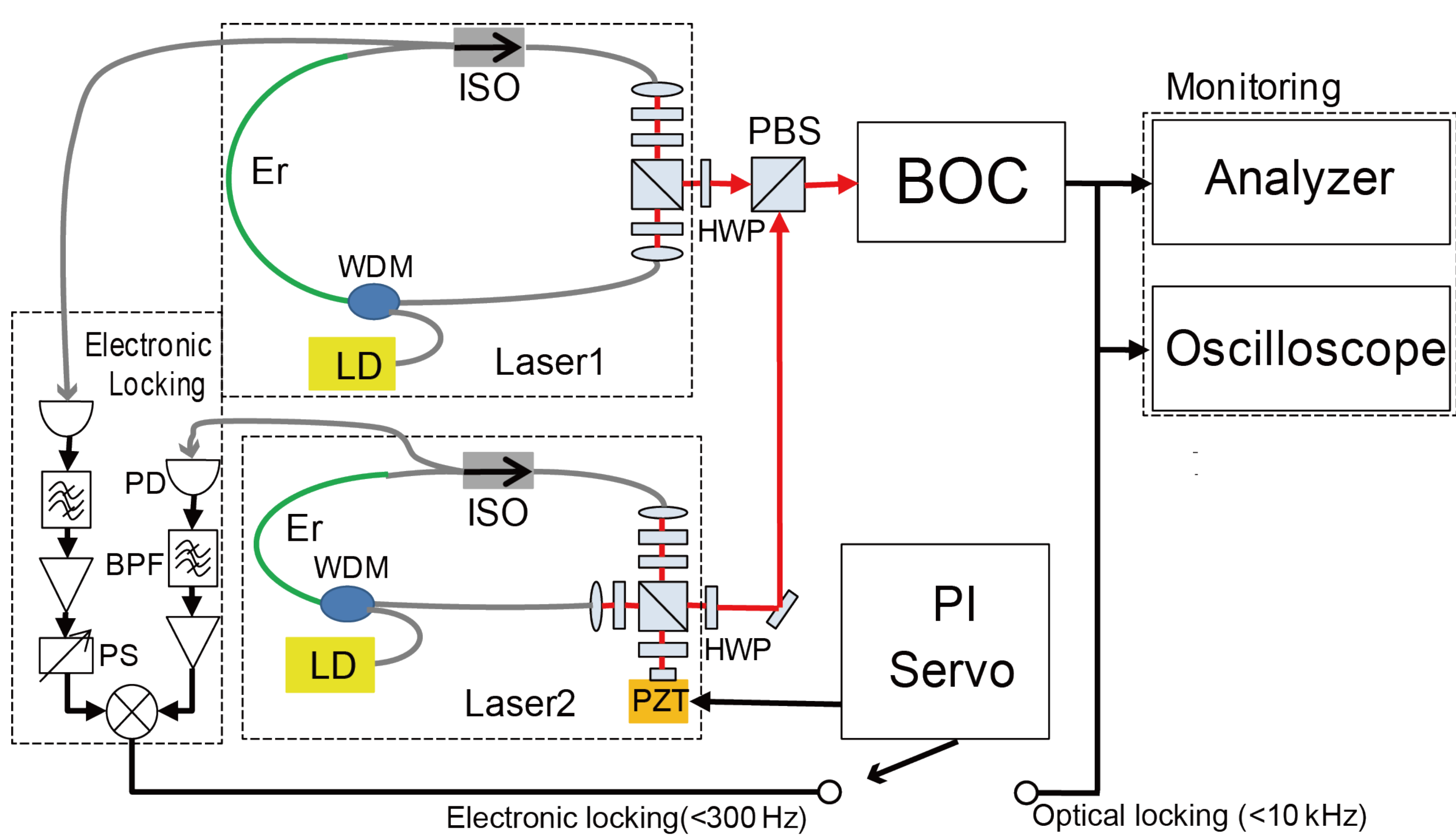


Abstract

For the outstanding characteristics, such as high gain, low noise, good thermal property, compactness and convenience in building and operation, femtosecond mode locked fiber lasers are finding more and more applications. Especially, ultralow noise characteristics of mode locked fiber lasers can be expanded to various time applications. According to the noise theory, ultralow timing jitter of mode-locked fiber lasers can be achieved at short pulse duration, high intra-cavity pulse energy and nearly zero net-cavity dispersion conditions. Stretched-pulse type mode locked Er-fiber lasers have femtosecond level short pulse duration and high intra-cavity pulse energy. Net-cavity dispersion of a stretched-pulse mode-locked Er-fiber laser, consisting mostly of fibers, is controlled by changing the fiber length in cavity. So the timing jitter of laser is reduced by dispersion control. At the optimal dispersion conditions obtained by changing the length of SMF-28 fiber in the cavity, sub-100 attosecond timing jitter can be achieved from a mode locked fiber laser.

Experiment Setup

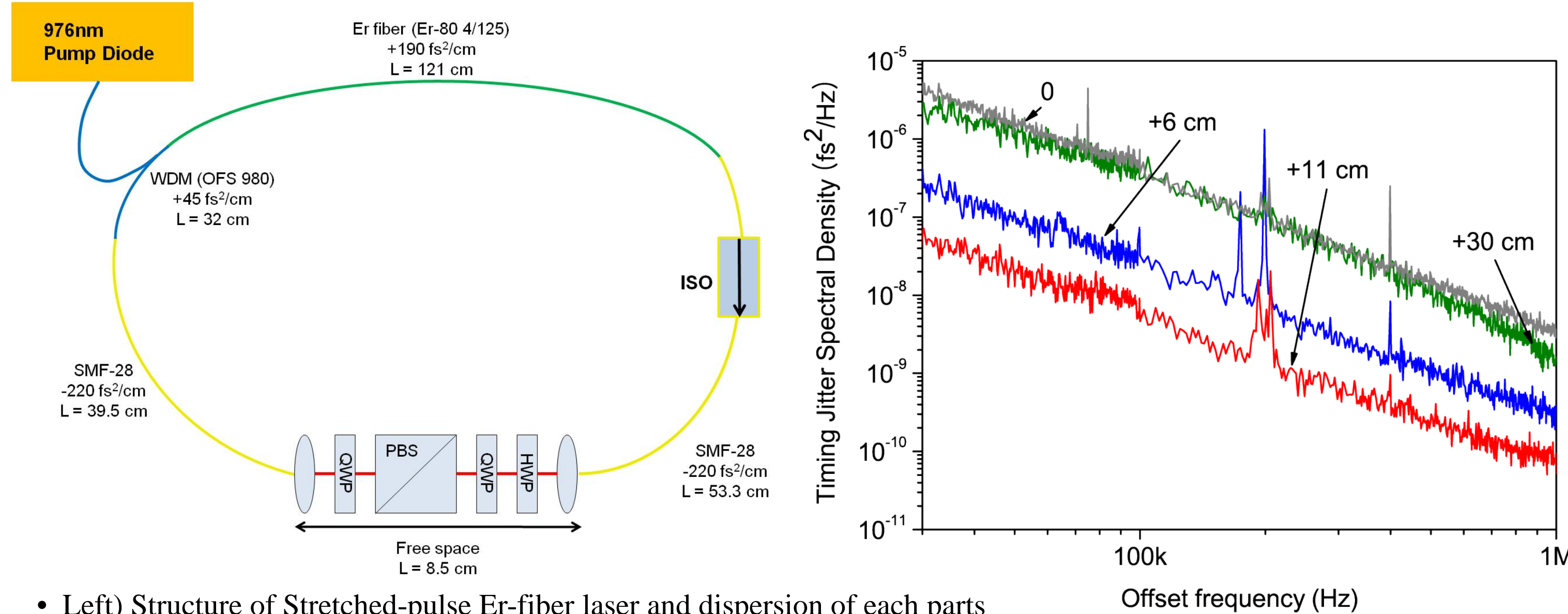


- BOC, balanced optical cross correlator; BPF, 1 GHz bandpass filter; Er, Er-gain fiber; ISO, isolator; PD, photodetector; PS, phase shifter; HWP, half-wave plate; LD, 980nm laser diode; PI, proportional-integral; WDM, 980/1550 wavelength-division multiplexing coupler.
- Two almost identical 77.55-MHz repetition rate, stretched-pulse (dispersion-managed) Er-doped fiber lasers were built.
- For repetition-rate locking, one laser is built as a ring-cavity and the other laser is built as a σ -cavity with a PZT-mounted mirror.

Table 1. Measured and typical laser parameters

Measured parameters	
Pulse width (fs)	60
Center wavelength (nm)	1582
Intra-cavity pulse energy (nJ)	1.6
Intra-cavity power (mW)	122
Output power (mW)	55
Gain	0.4
Repetition rate (MHz)	77.55
Excess noise factor	14(± 0.2)
Dispersion (ps ²)	-0.002(± 0.001)
Typical parameters	
Gain bandwidth (rad/s)	1.51 $\times 10^{15}$
Saturable absorption coefficient α	0.1~0.3
Chirp parameter β	-0.35 ~ -0.62

Dispersion Control



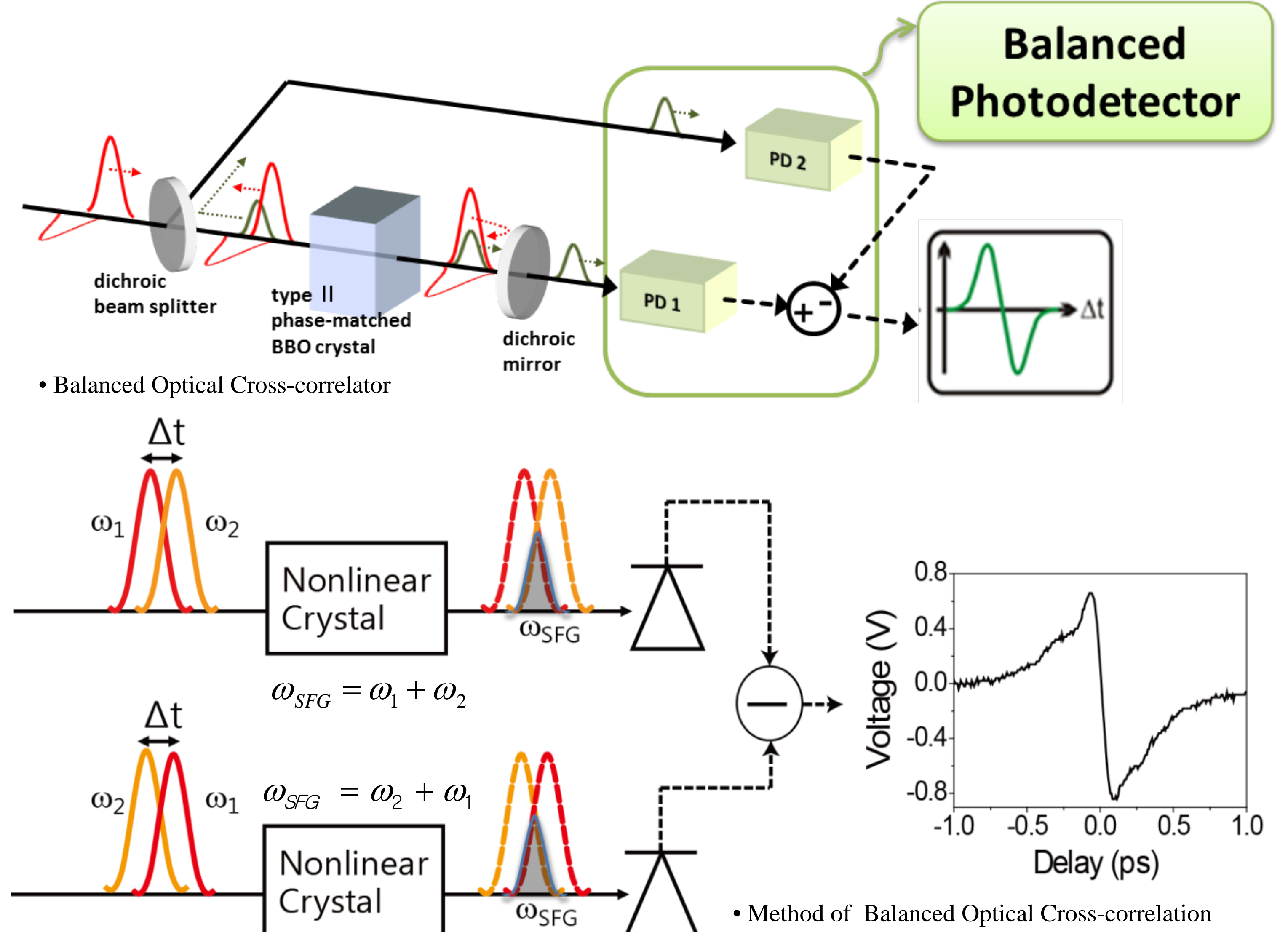
- Left) Structure of Stretched-pulse Er-fiber laser and dispersion of each parts
- Right) Timing jitter change results from adding or cutting SMF-28

- According to the noise theory, ultralow timing jitter of mode-locked fiber lasers can be achieved at nearly zero net-cavity dispersion conditions.
- To find the lowest jitter condition, dispersion control is performed by adding or cutting SMF-28 fiber inside the laser cavity.
- The net cavity dispersion is tuned in the near-zero and slightly negative dispersion regime ranging from -0.006 to +0.002 ps² and the lowest timing jitter is achieved when the net cavity dispersion is set -0.002 (± 0.001) ps².

$$\langle |\Delta t(\Omega)|^2 \rangle = \frac{16}{T_R^2} \left(\beta \frac{g}{\Omega_g^2} + D \right)^2 \frac{D_{pp}}{\Omega^2 \left(\Omega^2 + \frac{1}{\tau_p^2} \right)} - \frac{8}{\tau_p T_R} \left(\beta \frac{g}{\Omega_g^2} + D \right) \frac{D_{pt}}{\Omega^2 \left(\Omega^2 + \frac{1}{\tau_p^2} \right)} + \frac{D_{tt}}{\Omega^2}$$

• Timing jitter Equation

Balanced Optical Cross-correlator (BOC)

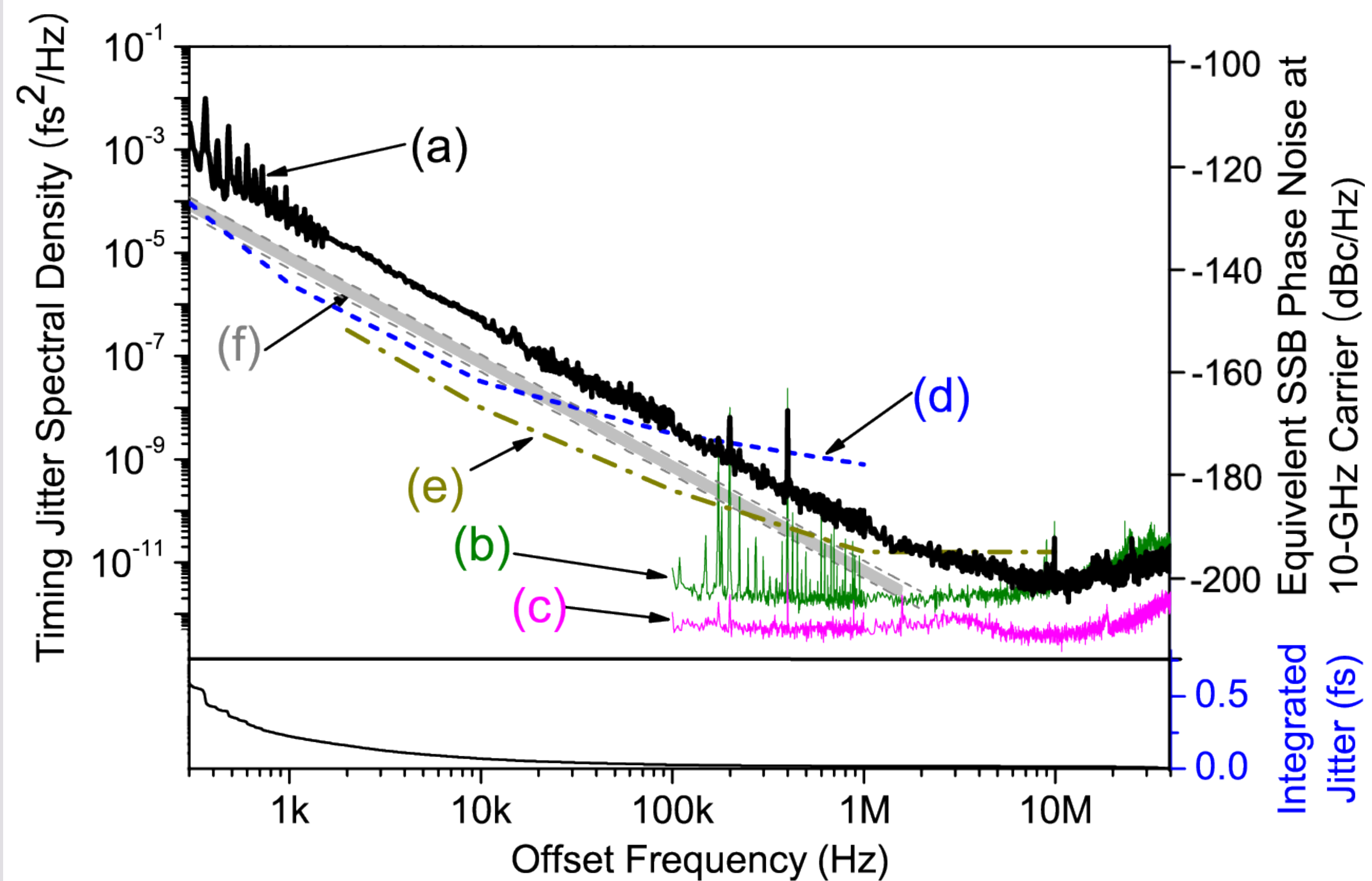


• Balanced Optical Cross-correlator

• Method of Balanced Optical Cross-correlation

- Conventional direct photodetection has limit of resolution. (~10 fs level resolution)
- Balanced optical cross-correlation method can easily and directly measure timing jitter of stretched-pulse Er-doped fiber lasers with attosecond-level resolution.
- The timing jitter is characterized by a 24 attosecond resolution PPKTP-based balanced optical cross-correlation (BOC) method.

Experiment Result



- (a) Best timing jitter spectral density result of mode-locked Er-fiber lasers. The integrated timing jitter is 70 as (224 as) when integrated from 10 kHz (1 kHz) to 38.8MHz offset frequency.
- (b) BOC photodetector noise floor.
- (c) Projected RIN-coupled timing jitter.
- (d) Equivalent timing jitter spectral density of SLCO for comparison.
- (e) Best timing jitter spectral density of mode-locked Ti:sapphire lasers for comparison.
- (f) Predicted timing jitter range from the Namiki-Haus analytic model based on measured laser parameters.

- At -0.002 (± 0.001) ps² dispersion condition, the integrated rms timing jitter from 10 kHz (1 kHz) to 38.8 MHz is measured to be 70 as (224 as).
- As shown in graph, the measured timing jitter spectrum of Er-fiber lasers is comparable to those of the best microwave sources and Ti:sapphire lasers.
- The performance of Er-fiber lasers with ~70 as jitter demonstrated in this work are expected to be attractive photonic signal sources due to their lower cost, simpler design and implementation.

Summary and Future Work

Summary

- Demonstrate sub-100-as timing jitter optical pulse trains generated from mode locked Er-fiber lasers using dispersion control by changing the fiber length in cavity.

Future Works

- Develop cheap and compact size ultra-low timing jitter signal sources using mode locked fiber lasers.

Reference

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- S. Namiki and H. A. Haus, "Noise of the Stretched Pulse Fiber Laser: Part I - Theory" IEEE J. Quantum Electron. 33, 649 (1997).
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