Ultra-Stable and Ultralow-Noise Mode-Locked Fiber Lasers

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Lower-noise and higher-stability mode-locked lasers and frequency combs are becoming more important and useful sources for a variety of applications ranging from precision spectroscopy to photonic signal generation and processing. In particular, all-fiber-based sources have clear advantages such as low cost, alignment-free operation, lightweight, and long-term stability. In this talk, I will overview our recent progress in realizing ultra-stable and ultra-low-noise mode-locked fiber lasers and frequency comb sources.

First, we realized ultralow timing jitter and intensity noise mode-locked fiber lasers by employing several different methods. One of the most powerful methods for noise reduction is dispersion engineering toward zero dispersion. It has enabled 100-attosecond-level timing jitter (integration bandwidth: 10 kHz – 40 MHz offset frequency) from mode-locked Er- and Yb-fiber lasers [1,2]. In addition, proper use of optical bandpass filtering enables dramatic suppression of relative intensity noise to <-140 dB/Hz level for the entire >20 Hz offset frequency range [3].

Second, in order to stabilize the timing of free-running mode-locked lasers, we have developed all-fiber photonic repetition-rate stabilization methods [4]. By using an all-fiber Michelson interferometer with a km-scale fiber delay line in one arm, we can stabilize the repetition-rate of mode-locked lasers to the equivalent stability of the fiber delay ($\delta\tau/\tau$). When using a 10-km long fiber delay, the repetition-rate of a mode-locked Er-fiber laser could be stabilized to 10^{-14}-level frequency instability within 1-s [5]. The timing jitter is also suppressed down to ~1 fs level over 1-s time scale. We also demonstrated the generation of ultralow phase noise and frequency-tunable X-band microwave signals from this source [6].

In summary, by combining an ultralow-noise mode-locked fiber laser and an ultra-stable fiber-delay-based timing reference, we have demonstrated an all-fiber photonic signal generator that emits ultra-low-noise optical pulse trains and microwave signals. With its simple implementation and robust operation, these sources may find more widespread applications outside laboratory environment such as timing and synchronization, microwave generation, photonic radars, analog-to-digital conversion, and time-of-flight sensing, to name a few.

References

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