Sub-10-Attosecond Timing Jitter Mode-Locked Ti:sapphire Lasers

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***Summary*—We demonstrate 9.3-attosencond timing jitter [integrated from 10 kHz to 50 MHz offset frequency] optical pulse trains from 99 MHz repetition-rate mode-locked Ti:sapphire lasers. A phase discrimination signal is obtained using an optical heterodyne technique. The performance is the lowest timing jitter measured from any free-running mode-locked lasers and shows possibility of further suppression.**

Keywords—Ti:sapphire lasers; mode-locked lasers; timing jitter; phase noise

I. INTRODUCTION

Mode-locked lasers (MLL) with ultra-low timing jitter is necessary in applications such as photonic analog-to-digital conversion [1], precision optical metrology [2], and timing synchronization in large research facilities [3]. Timing jitter less than 20 as has been realized on platform including Ti:sapphire MLLs [4], Er:Yb:glass MLLs [5], Yb-fiber MLLs [6]. Demand for lower jitter still exists.

To measure the timing jitter in pulse trains of MLLs, precision phase error discrimination is necessary. A time-domain approach is balanced optical cross-correlation. While optical heterodyne technique extracts phase error signal in frequency domain. Here we show jitter reduction in Ti:sapphire MLLs using optical heterodyne technique. Our results show potential to achieve sub-10-attosecond jitter.

II. METHODS/RESULTS

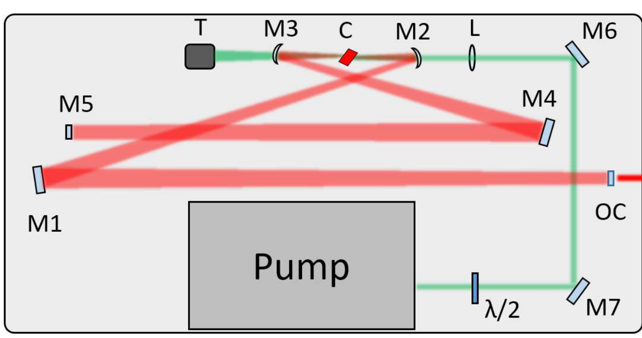

Fig. 1. Schematic diagram of one laser. $\lambda/2$: half wave plate. M2, M3: concave chirped mirror pairs. M1, M4: plane chirped mirror pairs. M5: silver mirror, mounted on a piezoelectric transducer. M6, M7: high reflector at 532 nm. OC: output coupler. C: Ti:sapphire crystal. L: coupling lens. T: laser trash can.

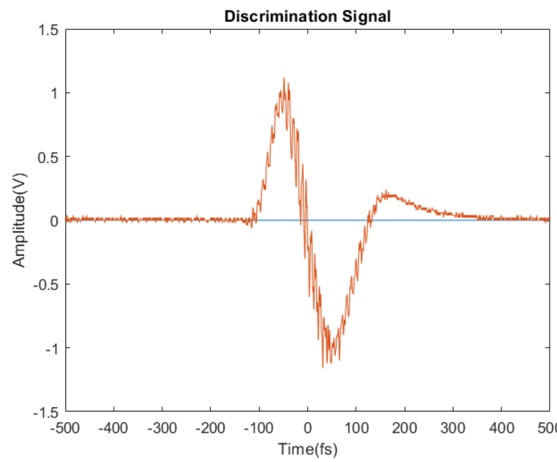

Fig. 2. Discrimination signal.

Two identical Ti:sapphire mode-locked lasers are used in our experiment. As shown in Fig. 1, each laser is formed by x-folded cavity composed of six mirrors and a 2mm Brewster-cut Ti:Sapphire crystal. The cavity of the resonator is 152 cm long, corresponding to 99 MHz repetition rate. When pumped by a 6 W 532 nm laser, the oscillator generates femtosecond pulse trains with an average output power of 900 mW. The generated spectrum has a 120 nm bandwidth at full width at half maximum (FWHM). At present configuration, each laser offers 100 mW light in the phase discrimination stage.

The discrimination stage is similar to that described in [5]. Two photodetectors (Hamamatsu S5972) collect a broadband superimposed light of two lasers at each of the two extremes of the optical spectrum. When difference in repetition rates is set to 1Hz, mixing the response of two photodetectors generates a discrimination signal of 2.2 V, corresponding to a discriminator slope of 22.7 mV/fs.

To suppress acoustic noise and thermal variation, careful attention must be paid both to design and construction of the system. The pump laser and cavity of each Ti:sapphire laser are fixed on a 300 mm × 600 mm × 12.7 mm optical breadboard. Under the breadboard is a cushion composed of 30 mm sponge, 3 mm rubber, 1 mm lead, 3 mm rubber, 1 mm lead, 15 mm rubber from top to bottom. A box made of 5 mm aluminum and 30 mm sponge is used to insulate the laser from acoustic noise. Cushion and box with similar structure are also used in the discrimination stage. The entire system is set on an air floating optical table. We use circulating water (20.0 ± 0.1 ℃) to cool the pump lasers and Ti:sapphire crystals. The temperature of the environment is 25.5 ± 0.3 ℃.

a

b

Fig. 3. **a:** Ti:sapphire laser surrounded by sponge and aluminum box. **b:** Cushion under the breadboard.

III. Discussion

In a best situation, a rms timing jitter (integrated from 10 kHz to 50 MHz) of a single laser reaches to 9.3 as. For the present, only one ninth of the laser power is utilized in discrimination stage. The amplitude of the discrimination signal can be easily multiplied by superposition of several discriminator's output. By increase the pump power and construct more discriminators, the sensitivity can be improved at least 10 times.

IV. Conclusions

In summary, we showed a lowest result in timing jitter measurement of free running MLLs. The performance shows a potential to improve the discrimination sensitivity to support timing jitter measurement under one as. Such precision will make it possible to realize detection with coherent as pulse trains.

References

[1] G. C. Valley, "Photonic analog-to-digital converters," Opt. Express, vol. 15, pp. 1955–1982, 2007.

[2] T. Udem, R. Holzwarth, and T. W. Hänsch, "Optical frequency metrology," Nature, vol. 416, pp. 233–237, 2002.

[3] J. Kim, J. A. Cox, J. Chen, and F. X. Kärtner, "Drift-free femtosecond timing synchronization of remote optical and microwave sources," Nat. Photonics, vol. 2, pp. 733–736, 2008.

[4] A. J. Benedick, J. G. Fujimoto, and F. X. Kärtner, "Optical flywheels with attosecond jitter," Nat. Photonics, vol. 6, pp. 97–100, 2012.

[5] D. Hou, C. C. Lee, Z. Yang, and T. R. Schibli, "Timing jitter characterization of mode-locked lasers with <1zs/$\sqrt{\text{Hz}}$ resolution using a simple optical heterodyne technique," Opt. Letters, vol. 40, pp. 2985–2988, 2015.

[6] H. Kim, P. Qin, Y. Song, H. Yang, J. Shin, C. Kim, K. Jung, C. Wang, and J. Kim, "Sub-20-Attosecond Timing Jitter Mode-Locked Fiber Lasers," IEEE J. Sel. Top. Quant, vol. 20, pp. 0901108, 2014.