Carrier envelope phase stabilization using orthogonally polarized reference pulse

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Carrier envelope phase (CEP) is essential for many ultrafast phenomena studies such as light waveform synthesis [1], ultrafast dynamics probe/control in molecules or atoms [2], isolated attosecond (as, 1 as = 10^{-18} s) pulse (IAP) generation [3,4]. In Particular, micro joule level IAP was obtained for the first time by using two color gating method [4]. Since this method is energy scalable, higher driving laser energy can further increase the energy of IAP. Besides, CEP is better to be stabilized to further improve IAP contrast. Unfortunately, high power laser generally has very low repetition rate such as 10Hz or even lower, which makes the CEP stabilization extremely difficult owing to the slow sampling speed by active phase stabilization. Wu *et al.* challenged the CEP stabilization of a 10 Hz/10 TW laser [5] using a not collinearly propagate reference pulse. But the CEP stabilizing accuracy was not clearly given. Recently, Takahashi *et al.* precisely stabilized CEP of a 10 Hz/16 TW laser using a collinearly propagated reference pulse train [6]. The high repetition rate reference pulses (500 Hz), which are used for CEP characterization and stabilization, are extracted by a precisely synchronized optical chopper.

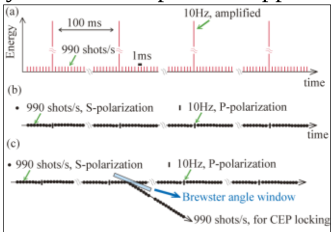

Fig. 1. Experimental method

In this work, we demonstrate another method, which is shown by Fig. 1, to stabilize CEP of high power/low repetition rate laser systems. Collinearly propagated 990 shots/s reference pulses are s-polarization while 10 Hz amplified pulses are p-polarization. Both pulses experience exactly the same noises. By employing a window under Brewster angle incidence, reference pulses are only extracted for CEP stabilization. By stabilizing CEP of the high repetition rate reference pulses, the low repetition rate laser pulses CEP can be stabilized sequentially.

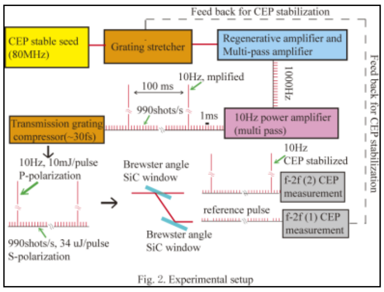

Fig. 2. Experimental setup

Fig. 2 shows the experimental setup. The laser used in this research starts from a 1-kHz front-end preamplifier with a CEP stable oscillator. By employing a pockels cell, 10 Hz of the 1-kHz pulse is changed to s-polarization while the other pulses polarization is not changed. 10 Hz pulses are further amplified to ~400 mJ. The unamplified 990 shots/s pulses are p-polarized, which are used as reference pulses for CEP locking. Two mirrors are used to rotate the reference and 10 Hz pulses to be s- and p-polarizations. A pair of transmission gratings, which have similar efficiencies for s- and p-polarizations, is used to compress 20 mJ/10 Hz and 50 μJ/reference pulses to ~30 fs. Reference pulses are extracted by a SiC plate at set of Brewster angle. CEP error of the reference pulse is measured by an f-2f interferometer. The error signal is used to feedback to move grating in the stretcher to stabilize its CEP. The experiment result is shown in Fig. 3. Single-shot CEP fluctuations of reference and 10 Hz pulses are monitored by two out-of-loop f-2f interferometers. By stabilizing CEP of reference pulses, long-term single-shot CEP of 10 Hz amplified pulse is stabilized to 700 mrad (rms). The slow drifting of 10 Hz CEP, as shown in Fig. 3(a), is caused by its energy fluctuation. Since energy fluctuation will only results in measurement error [7], real CEP stability should be better. Short term CEP stability of 10 Hz pulse is given by Fig. 3(b). Single-shot CEP fluctuation of 558 mrad (rms) is obtained.

In conclusion, we stabilized CEP of a 10 Hz laser using a collinearly propagate high repetition rate reference pulse which is orthogonally polarized. In an out-of-loop measurement, 10 Hz laser pulse CEP is stabilized to 700 mrad and 558 mrad in a long and short term, respectively. This method can employ high repetition rate reference pulse to increase sampling and feedback frequency, such as tens of kHz, to improve the CEP stability. Without loss of generality, this method can be applied for CEP stabilization of low repetition rate/high power fs lasers using high damage threshold gratings which have similar efficiency for different polarizations.

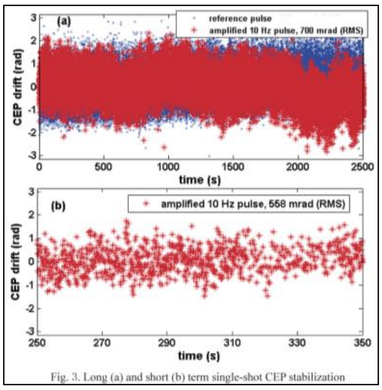

Fig. 3. Long (a) and short (b) term single-shot CEP stabilization

[References]

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