Stabilizing the Carrier-envelope Phase of a 30 fs, 1 kHz, 6 mJ Ti: sapphire Regenerative Amplifier

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Abstract: Carrier-envelope phase stabilization of a two-stage chirped pulse amplifier laser system with regenerative amplification as the preamplifier is demonstrated with a 90 mrad rms error for a locking period of 4.5 h.

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1. Introduction

Single attosecond nonlinear and pump-probe experiments require high energy laser system that has long term carrier-envelope (CE) phase stabilization [1]. Regenerative amplification is an attractive choice for such laser system because of its excellent beam profile, pointing stability, power stability, and extraction efficiency. It has been commonly used as the preamplifier for high-energy femtosecond laser systems. However, CE phase stabilization has been demonstrated only on multipass lasers [2, 3]. Although the CE phase evolution after regenerative amplification has been explored to some extent [4], the CE phase drift caused by the amplification stage has not been corrected. Furthermore, no high-field CE phase-dependent experiments have been demonstrated with a regenerative amplifier. Here we report CE phase stabilization and control of the Manhattan Attosecond Radiation Source (MARS) regenerative amplification laser system and unambiguously confirm its stability by measurement of the CE phase dependence of the high-order harmonic spectrum generated by double optical gating (DOG) [5].

2. Experimental Setup and Results

The layout of the MARS laser system is presented in Figure 1. It consists of a commercially available Ti:sapphire Coherent Legend Elite Duo (Coherent, Santa Clara, California, USA) chirped pulse amplifier (CPA) that operates at 1 kHz, seeded by a Rainbow oscillator (Femtolasers, Vienna, Austria). The CE offset frequency (f_{CEO}) of the oscillator is stabilized using the monolithic CE phase-stabilization scheme [6]. We studied the temperature dependence of the carrier-envelope offset frequency and implement temperature feedback control on the oscillator. With the assistance of the temperature feedback control, f_{CEO} of this oscillator can be locked for more than 12 hours on a daily basis as shown in Fig. 2, which is 3-4 times more than the longer than the typical phase stabilization time with only pump power modulation.

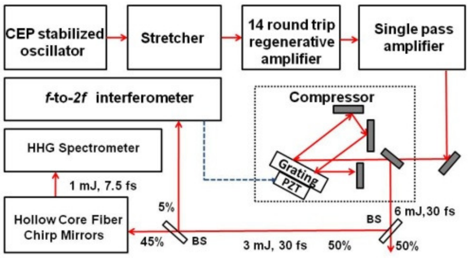

Fig. 1. Layout of the MARS laser system. BS: beam splitter

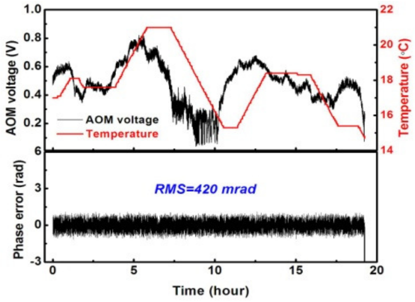

Fig. 2. (a) 20 h CEP stabilization achieved by the double feedback control; the black curve shows the AOM driving voltage; the red curve shows the chiller temperature; (b) Phase error during the of CEP stabilization.

During the CE phase stabilization process, we found that the CE phase of the final output laser pulse from this laser system is sensitive to mechanical vibration and acoustic noise. However, by moving the pump laser further away from the amplifier, padding the laser cover with sound absorption materials, and improving the stability of the optical mounts in the stretcher and compressor, the CE phase stability was achieved. The rms error of the locked CE

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phase was measured to be 90 mrads over a period of 4.5 h with a 50ms spectrometer integration time as shown in Fig. 3.

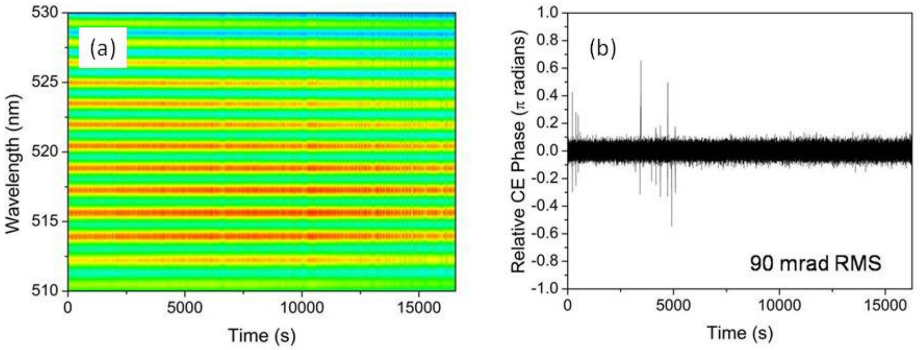

Fig. 3. Long-term CE phase stabilization: (a) f -to- 2f interference fringes, (b) retrieved CE phase from the fringes, which has a 90 mrad rms averaged over 50 laser shots.

To unambiguously confirm the CE phase stabilization of the MARS laser system, the dependence of the high-order harmonic spectrum generated in argon from DOG was measured with an extreme ultraviolet transmission grating spectrometer. A 1 mJ, 7.5 fs short pulse was generated from MARS laser system using a neon filled hollow-core. The short pulse was then focused on an argon gas cell to generate the high-order harmonics. When the CE phase was scanned linearly from 0 to 8π, the harmonic spectra varied with a 2π periodicity as shown in Fig. 4, which is consistent with the 2π periodicity of the electric field generated by DOG. The total time to perform the CE phase scan was 30 min.

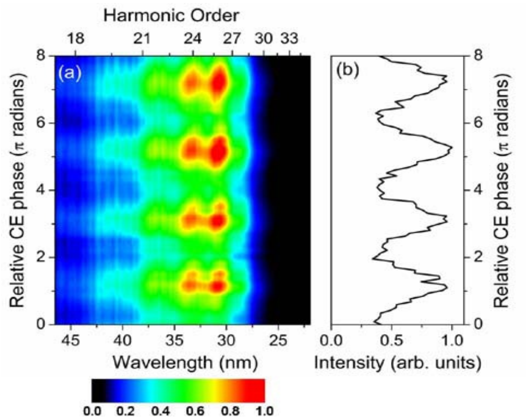

Fig. 4. (a) DOG harmonic spectra taken with the CE phase scanned from 0 to 8π. (b) Line out of the normalized integrated spectrum. The integration range is from 48 to 20nm. The 2π periodicity is consistent with the asymmetric electric field of DOG.

3. Conclusions

In conclusion, we studied the temperature dependence of the carrier-envelope offset frequency of a femtosecond laser oscillator and improved the oscillator long-term CEP stabilization to more than 12 hours in daily bases. We also demonstrated the CE phase stabilization of a 6 mJ, 30 fs, 1 kHz regenerative amplifier with a 90 mrad rms over a period of 4.5 h. The DOG spectral dependence on the CE phase unambiguously confirms the stability. This paves the way for the realization of high-power CE phase stabilized lasers and high-flux single-isolated attosecond pulse generation, which are critical steps toward the study of nonlinear physics and pump probe experiments with single attosecond pulses.

4. References

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