Single Shot Stereo-ATI (above threshold ionization) Phase Meter

Ultraschnelle Nanophotonik (Prof. Kling)

The electric field of a laser pulse, which can be considered as a sine-like electromagnetic wave modulated by an envelope function $E_0(t)$, can be written as $E(t) = E_0(t)\cos(\omega t + \phi_{ce})$, where $\omega$ is the frequency of the carrier wave and $\phi_{ce}$ is the carrier–envelope phase (CEP). The significance of the CEP $\phi_{ce}$, or rather the rate of its variation $d\phi_{ce}/dt$, was first recognized and exploited in frequency metrology. Known as the offset frequency, $d\phi_{ce}/dt$ is the offset of the frequency modes of a short-pulse laser from integer multiples of the pulse repetition rate. Stabilization of this offset frequency led to a revolution in frequency metrology and its pioneers, T. W. Hänsch and J. L. Hall, were awarded for their contributions with the Nobel Prize in 2005.

For few-cycle laser pulses, the pulse envelope changes appreciably within one optical cycle; therefore, the CEP effectively determines the temporal evolution of the underlying electric field (see Fig. 1). This is of great significance, as most strong-field laser–matter interactions depend on the electric field rather than the intensity envelope of the pulse. Changes in the CEP shift the position of the cycle maximum within the pulse envelope, which strongly affects the temporal shape of the electric field. Extension of waveform control to multi-terawatt few-cycle lasers is expected to open the door to a plethora of new phenomena. One of the most intriguing applications is the generation of isolated attosecond bursts with keV photon energies. Obviously, these applications are limited by our ability to control the carrier envelope phase.

Several techniques exploiting various phase-sensitive phenomena were shown to be able to retrieve the CEP in proof-of-principle experiments. All of these methods need a large number of laser shots for a single phase measurement, thus fluctuations of the CEP are averaged out. It also implies the need to stabilize the CEP of the laser pulses, which, as a rule, is rather complex. Typically, the rate of change of the CEP is detected with a so-called $f$-to-$2f$ interferometer, and the CEP drift is actively corrected for with a control loop. This is a way to stabilize the phase of intense few-cycle pulses. As an alternative, recent efforts using quantum interference in photocurrents or linear optical interferometry have been developed and can potentially be used to derive the evolution of the CEP. All of these

Fig. 1. Illustration of the electric field for a few-cycle pulse. The electric field oscillations for a given pulse envelope $f(t)$ are plotted for two different carrier envelope phases $\phi_{ce} = 0$ and $\pi/2$, as indicated.
techniques cannot detect the actual value of the CEP but only its relative change, and furthermore, they all rely on active stabilization of the CEP, which is difficult to achieve for long periods of time.

Recently the ability to measure, in real time, the CEP for every single-shot using the strong-field phenomena of above-threshold ionization (ATI) of xenon gas has been demonstrated. The stereo-ATI carrier–envelope phase meter (CEPM) implementing this technique facilitates CEP data tagging, i.e. measuring the CEP for each laser shot in parallel to another event-mode CEP-dependent measurement. This allows one to probe CEP-dependent processes without CEP locking, facilitating the study of low probability CEP-dependent phenomena. Moreover, the carrier–envelope phase meter (CEPM) represents a powerful, real-time diagnostic tool with sub-cycle sensitivity, which is crucial for easy and reliable tuning and monitoring of intense, ultrashort, Ti:sapphire sources, for instance, when trying to generate isolated attosecond pulses in the XUV.

The goal of the present experiment is to characterize the CEP and duration of light pulses generated by a state-of-the-art few cycle laser system with the use of a stereo-ATI phase meter. The experiment provides many insights into various aspects of ultrafast laser science and the atomic physics in strong laser fields.

**Literature**


