EPJ Web of Conferences **41**, 02011 (2013)
DOI: 10.1051/epjconf/20134102011

Carrier envelope phase effects in strong field ionization of xenon with few-cycle 1.8 μm laser pulses

B. E. Schmidt[1], M. Möller[2], A. M. Sayler[2], A. D. Shiner[3], G. Vampa[3], F. Légaré[1], D. M. Villeneuve[3], G. G. Paulus[2], and P. B. Corkum[3]

[1]Institut National de la Recherche Scientifique Centre Énergie Matériaux et Télécommunications, 1650 Boulevard Lionel-Boulet, Varennes, QC J3X1S2, Canada
[2]Institut für Optik und Quantenelektronik, Max-Wien-Platz 1, 07743 Jena, Germany
[3]Joint Laboratory for Atto-Second Science, University of Ottawa/NRC, 100 Sussex Dive, Ottawa, K1A 0R6, Canada

Abstract. Interferometrically CEP controlled few-cycle IR pulses revealed a strong influence on both, directly ionized and rescattered electrons in xenon for pulse durations from 2 to 5 cycles.

1 Introduction

Practically all strong-field laser–matter experiments are sensitive to the electric field rather than the intensity envelope of the laser pulse. The carrier envelope phase (CEP) of few-cycle laser pulses is commonly controlled by varying the amount glass dispersion in the beam which changes the ratio of group delay and phase delay of broadband fs pulses and thus the peak of the electric field (traveling with phase velocity) relative to the pulse envelope (traveling with group velocity). We present a simple, wavelength and bandwidth independent method for CEP control if passive CEP stabilization is employed with an optical parametric amplifier (OPA). Stereo above threshold ionization (ATI) is sensitive to this absolute phase because the peak electric-field strength (and thus the vector potential which accelerates the ionized electron) is different for positive and negative directions in the plane of polarization. This causes the number of electrons emitted in both directions to be anticorrelated, being a signature of the absolute CEP.

2 Experimental Setup

A white light seeded optical parametric amplifier is utilized in which offers the possibility of passive CEP stabilization. Passive CEP stabilization is carried out through difference frequency generation (DFG) between arm 1 in which a white light continuum (blue line, φ_{wl}) is generated in a Sapphire window and the remaining 800 nm pulses of arm 2 (φ_{pump}) in a BBO crystal, as shown in figure 1.

The relative phase shifting between white light and pump beam prior to their DFG results in CEP controlled Idler pulses. The phase shifter of arm 1 (sketched green in Figure 1) consists of a piezo driven mirror which shifts the relative phase between both 800 nm beams by adding $\Delta\varphi$ to arm 1. Continuum generation takes place after phase shifting the 800 nm beam and since self-phase modulation preserves the CEP of its driving field, this phase offset Δφ is transferred to the continuum. Thus, it is transferred to the phase of the Idler pulse in the DFG process:

$$\varphi_{\mathrm{Idler}} = \varphi_{\mathrm{pump}} - (\varphi_{\mathrm{wl}} + \Delta\varphi) - \pi/2 = \mathit{const.} - \Delta\varphi \qquad (1)$$

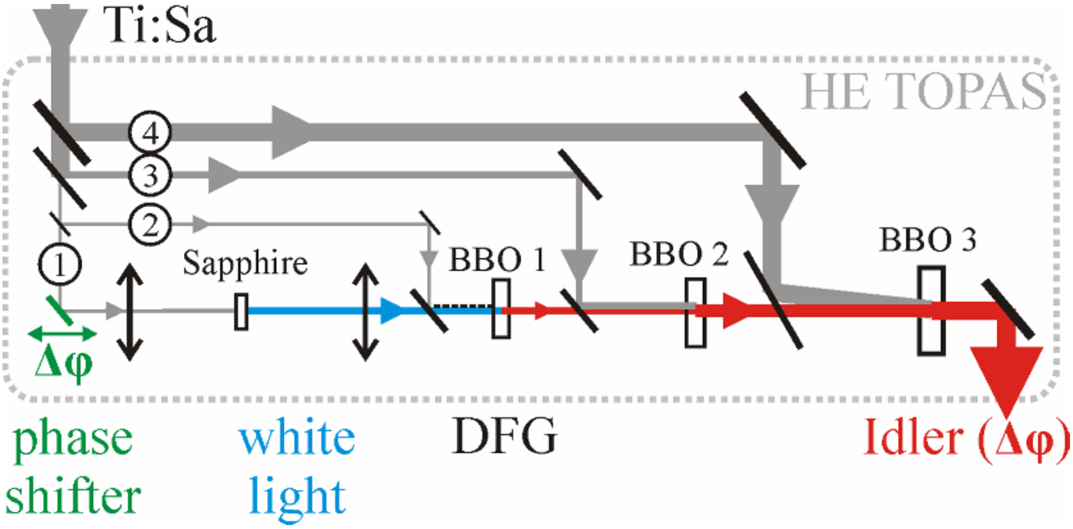

Fig. 1. Experimental setup for interferometrically CEP controlled high energy IR pulses based on passive CEP stabilization via difference frequency generation (DFG). The phase shift (Δφ) of the 800 nm beam in arm 1 is preserved during self-phase modulation in the Sapphire window. This phase shift is transferred to the Idler in the DFG process and maintained in the subsequent amplification stages.

Since this approach rest upon sifting two 800 nm beam with respect two each other, it is independent of the wavelength chosen for subsequent DFG and the bandwidth employed [2]. Subsequent to the OPA, pulse compression is carried out with a hollow core fiber setup to reach two cycle pulses at 1.8µm wavelength [1].

The stereo above threshild ionization ATI measurement apparatus basically consists of two electron time of flight tubes with multi channel plates placed symmetrically around the focused laser beam. It detects electron kinetic energy spectra parallel to the laser polarization axis as described in Ref [3].

3 Results

Figure 2 shows such kinetic electron spectra on a semi-logarithmic scale obtained with two different pulse durations. All curves are normalized to their maximum around 20 eV. 4.5 cycle (27 fs) pulses yielded the curves of figure 2(a) showing the characteristic high energy plateau ranging from about 50 eV to 200 eV kinetic energy. The red and black curves show the spectra for left and right detector, respectively. The order of magnitude higher signal for direct extends from 0 to about 53 eV and was recorded with pulse energy of 120 µJ. Spectra of figure 2(b) are taken with a 14 fs pulse duration which is half compared to the one of figure 2(a). Therefore the input energy was reduced to 66 µJ to achieve comparable intensity in both cases. A prove that intensities were very similar in both cases is given by the similar extension of the direct electron spectrum, 53 eV in (a) and 60 eV in (b). However, the integrated signal of rescattered electrons (for energies higher than 60 ev) relative to the amount of direct electrons is much lower for the 2.4 cycle pulse. This trend of reduced rescattered electron signal was verified in the range from 2 to 5 cycles of the driving laser. Noticibly, a strong CEP dependence was observed not only for the shortest pulse duration but also for relatively long pulses of 5 cycles.

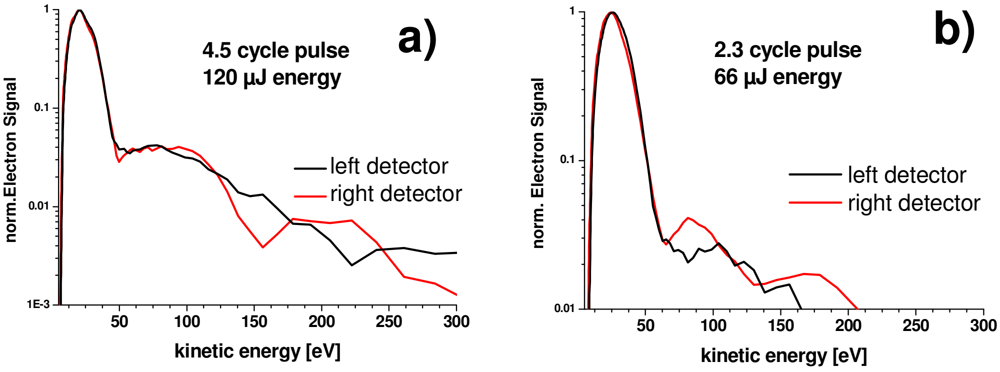

Fig. 2. Experimental setup for interferometrically CEP controlled high energy IR pulses based on passive CEP stabilization via difference frequency generation (DFG). The phase shift ($\Delta\varphi$) of the 800 nm beam in arm 1 is preserved during self-phase modulation in the Sapphire window. This phase shift is transferred to the Idler in the DFG process and maintained in the subsequent amplification stages.

In addition to the cycle dependent yield of rescattered electrons, we observed a very pronounced CEP dependence for the direct electrons which is characterized by the asymmetry parameter A = (left-right)/(left + right). An asymmetry parameter of 60% was reached for certain parts in the direct electron spectrum.

Finally we recorded a CEP dependence over 8 hours and found the passive CEP stabilization of the few-cycle pulses to be extremely stable over such a long time scale without any further feedback stabilization.

References

1. B. E. Schmidt, P. Béjot, M. Giguère, A. D. Shiner, C. Trallero-Herrero, É. Bisson, J. Kasparian, J-P. Wolf, D. M. Villeneuve, J-C. Kieffer, P. B. Corkum, F. Légaré, APL **96**, 121109 (2010)
2. B. E. Schmidt, A. D. Shiner, M. Giguère, P. Lassonde, C. A. Trallero-Herrero, J.-C. Kieffer, P. B. Corkum, D. M. Villeneuve, F. Légaré, J. Phys. B **45,** 074008 (2012)
3. A. M. Sayler, OE **19,** 4464 (2011)