Generation of high-flux 50-attosecond 'water window' X-ray by a high-energy infrared two-color waveform synthesizer

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Isolated attosecond pulse (IAP) is significant for studying ultrafast dynamics. Up to now, pulse duration of IAPs obtained based on Ti:sapphire laser systems (laser wavelength near 0.8 μm) has been reached to ~ 67 as by high-order harmonic generation (HHG). But the photon energy of these IAPs are below 100 eV. Because fundamental absorption edges lie in the soft X-ray region which has photon energies above 200 eV, IAP with photon energies over 200 eV is significant for applications. Furthermore, the temporal chirps of the IAPs need to be carefully compensated to get a short IAP, which make the experiment even more difficult. Very recently, IAP with photon energy barely reached 'water window' region (284-543 eV) has been reported, after chirp compensation, the pulse duration of IAP was ~ 53 as [1]. However, the photon flux of these IAPs was low and difficult to be used for applications.

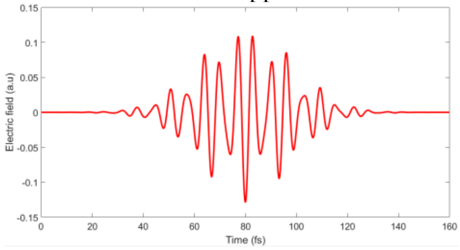

Fig. 1. Electric field of the two-color infrared synthesizer.

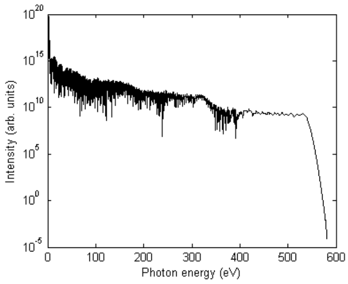

Fig. 2. Spectrum obtained by the infrared two-color waveform synthesizer through HHG.

In this work, we theoretically demonstrate a high-energy 50-as IAP generation in the 'water window' region by combining a dual-chirped optical parametric amplification (DC-OPA) [2] and a waveform synthesizer [3]. There are several critical advantages of our method compared with reported works. First, our DC-OPA provides 1-2 orders higher driving laser energy in infrared wavelength region. Thus, we are expectable to obtain much higher photon flux of the IAP. Second, due to longer driving laser wavelength, the temporal chirp of generated IAP is much reduced that we can obtain very short IAP even without chirp compensation, which greatly reduced experimental difficulty. Third, by combining two-color waveform synthesizer, we can use multicycle laser pulses rather than single-cycle or two-cycle lasers, which makes experiment easier.

In our two-color synthesizer, the wavelength of the main pulse is 1950 nm (generated by our DC-OPA), with its pulse duration of 30 fs and pulse energy of 100 mJ. The control pulse at 1350 nm was also generated by our DC-OPA with a pulse energy of ~ 10 mJ a pulse duration of ~ 30 fs. The synthesized electric field waveform is shown in Fig. 1. The second highest peak is ~ 0.848 times the highest electric peak, which is similar to a 1.5-cycle pulse at 0.8 μm. The generated HHG spectrum in Ne gas is shown in Fig. 2. By selecting the spectrum between 464-542 eV in the 'water window' region, an IAP with a pulse duration of ~ 50 as is obtained even without chirp compensation, as shown in Fig. 3. By employing a loose focusing method for HHG, we can expect several orders stronger IAP than reported work by our high-energy two-color synthesizer.

In conclusion, a strong IAP in the 'water window' region can be produced by a high-energy IR two-color waveform synthesizer according to our simulations. The strong IAP will be very useful for ultrafast dynamics and biological studies.

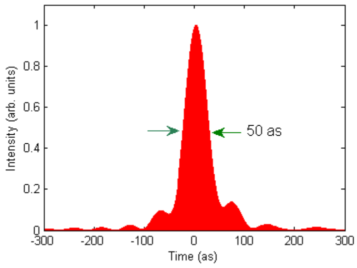

Fig. 3. IAP after Fourier-transform. Atto-chirp was not compensated.

References

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3) E. Takahashi *et al.*, Nat. Commun. **4**: 2691 (2013).