High order harmonic generation with mid-infrared driven pulses

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Abstract: We report on coherent water-window radiation by high-order harmonic generation in a gas cell with midinfrared femtosecnd pulses . With optimized parmeters, photon energy upto ~420 eV could be observed.

High-order harmonic generation (HHG) has been studied intensively since its discovery nearly two decades ago [1]. One of the attractions of HHG is generation of highly coherent light source in water window region. The main drawbacks of 800 nm pump laser for generating the coherent X-ray in water window lies in the fact that high peak intensity laser pulses must be used in order to provide sufficiently high ponderomotive energies to the ionized electrons, which could lead to highly ionization of the generating medium and destroying the whole process. It has been proposed that employing mid-infrared laser pulses could bypass the problem [2]. Recently, coherent water window X-ray has been demonstrated by HHG with a gas jet using a home-built high-energy midinfrared pump laser operating at 10 Hz repetition rate and 1550 nm wavelength [3-4]. In this report, we demonstrate the generation of the water window X-ray at 1 kHz repetition rate in a 4-mm long gas cell using a commercially available optical parametric amplifier (OPA) which could deliver wavelength tunable mid-infrared femtosecond pulses.

In this experiment, midinfrared pulses of 1500 nm carrier wavelength, maximum pulse energy of ~1.6 mJ, pulse duration of ~50fs, and M^2 of ~1.3 are produced by OPA system (HE-TOPAS, Light Conversion Inc.). With fused silica lens with a focal length of ~15cm, the infrared beams is focused into a 4 mm long gas cell filled with neon gas. A flat-field grating spectrometer equipped with a soft-X-ray CCD (Princeton Instruments, 1340×400 imaging array PI:SX 400) is used for measurement of the HHG spectra. The spectrometer consists of a spherical concave gold mirror and a flat field grating (Hitachi, 001-0266, 1200 grooves/mm). In order to block the low-order harmonics and the residual infrared driving pulses, a 150nm thick aluminium foil was placed at the entrance of the spectrometer.

Fig. 1 shows the HHG spectra obtained at ~800 nm, ~1300 nm and ~1500 nm wavelengths in neon gas at nearly constant focal intensity of ~6.0×10^{14} W/cm^2. With the 800 nm driving pulse, the highest cutoff energy achieved is only ~135eV. And with the 1300 nm driving pulse, the harmonic spectrum in water window can be merely observed. In the case of using the 1500 nm driving pulse, the cutoff is greatly extended to ~420eV. Therefore, the cutoff energy roughly obeys the wavelength scaling law of HHG [5]

$$E_{\text{cutoff}} = \text{h}\omega_{\max} = I_{\text{p}} + 3.17U_{\text{p}} \qquad (1)$$

, where I_P denotes the binding energy of the target atom and ponderomotive energy U_P is proportional to square of the driven wavelength.

The dip around the carbon K-edge (284eV) should be caused by a thin layer of pump oil absorbed on the optical components of the spectrometer or on the soft X-ray CCD, as had been pointed out in Ref. [6].

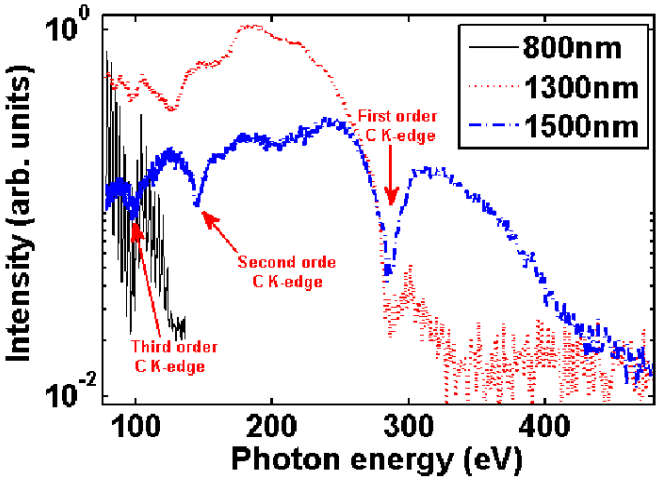

Figure 1. Normalized HHG spectra optimized at different wavelengths of the driving pulses. Black solid curve: 800 nm; red dotted curve: 1300 nm; and blue dashed-dotted curve: 1500 nm. The intensity of the laser beams is fixed at ~6.0×10^{14} *W/cm²* for the three wavelengths.

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