High flux table-top ultrafast soft X-ray source generated by high harmonic generation

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Abstract: Intense, few-cycle infrared laser pulses centered at 1.8 μm wavelength, coupled to a new gas cell design, are employed to drive high harmonic generation with high flux down to the soft X-ray regime.
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Generation of ultrafast soft X-ray pulses is a major challenge for conventional laboratories. The spectral range of 100 eV to 1 keV is highly attractive for new scientific applications including the water window spectral range (280-540eV) for probing ultrafast chemical reaction in the liquid phase [1] and the study of ultrafast demagnetization at the L-edges of 3d transition metals composing magnetic materials [2].

In order to study those ultrafast phenomena, there is a need to develop femtosecond to attosecond X-ray pulses in the sub-keV spectral range. Using the process of high harmonic generation (HHG) enables generation of such energetic photons. Intense laser sources in the IR are necessary to reach the soft X-ray spectral range as the HHG cut-off scales with $I\lambda^2$ [3]. However, in the limit of the single atom response, increasing the laser wavelength leads to a significant decrease of the HHG flux [4]. To compensate, one has to increase the number of emitters with high ionization potential [5] and to reduce the laser pulse duration to have less ionization events prior the peak of the electric filed [6]. At the advanced laser light source (ALLS), we have addressed this challenge by:

(i) Increasing the number of emitters by designing a new interaction chamber, which combines the advantages of the pulse valve (high density at minimum gas load), and the gas cell (long interaction length).

(ii) Developing an IR optical parametric amplifier (OPA) delivering 20 mJ Signal (1.4 μm) plus Idler (1.8 μm), with a pulse duration near 30 fs (5 cycles at 1.8 μm). This system utilizes amplified Ti:Sa pulses to pump a white light seeded OPA with three amplification stages.

The setup delivers 7 mJ Idler pulses on target which enables HHG in neon and helium.

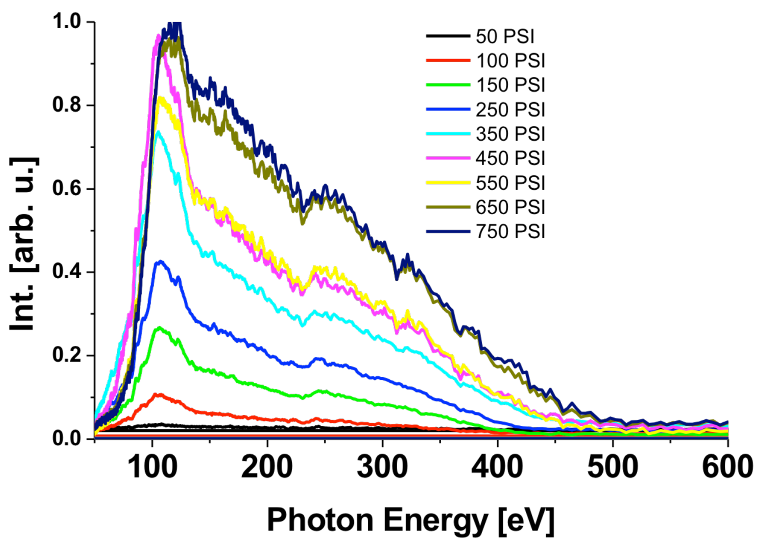

Fig. 1. Harmonic spectra in He for different backing pressure of our pulsed gas cell.

Figure 1 shows a pressure dependence of the HHG process in an extended gas medium of about 8mm length. Each spectrum was recorded within 1000 laser shots (10 seconds at 100Hz repetition rate) which makes our approach promising for future use as a table-top X-ray source for time resolved investigations. From the curves of figure 1, one can see the saturation of the HHG intensity around 650 psi (≈ 45 bars) of backing pressure in our gas cell. Investigation of different lengths of the cell has also been performed from 4 mm up to 12 mm showing a maximum around 8mm. Theory is currently under way to gain insight in the interaction mechanisms and propagation dynamics occurring at such high pressure at intensities around 10^{15} W/cm^2.

Finally, we measured the absolute XUV flux with a calibrated X-ray CCD camera to be around 2.10^5 photons/shot between 280 and 500 eV (≈10nJ). This value is not comparable to FEL sources but is acceptable in order to produce results in pump-probe experiment in an acceptable period of time. Another impressive result is the capability to record data showing the carbon K-edge at 280 eV in a single shot manner. The X-Ray beam is also extremely well collimated (See fig. 2:less than 0.1 mrad, 300 µm FWHM at 1.2 m of the generation area) making this table-top beamline ideal for a number of applications. This source could be advantageously compared to the capillaries approach [5].

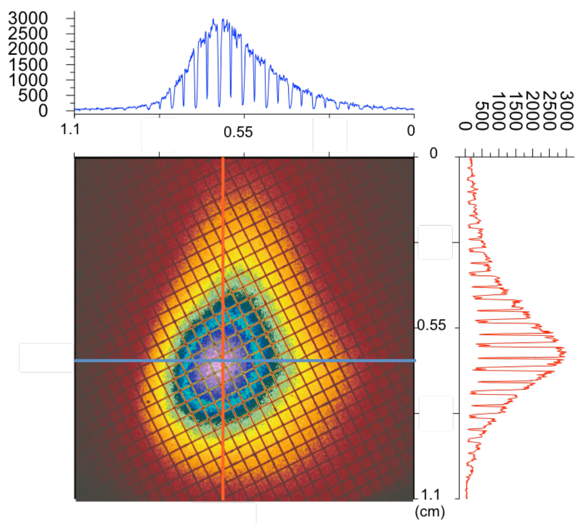

Fig. 2: Beam profile of the X-Ray beam

This easy-to-operate and reliable setup is an excellent alternative to synchrotron and FEL facilities in a conventional laboratory with several advantages like easier access, good temporal resolution, excellent beam properties and sufficient flux to perform X-Ray pump-probe spectroscopy.

As a next step down the road, we will improve the energy of our actual 2 cycles 1.8 µm setup [7] to be able to generate isolated attosecond pulses up to the keV spectral range.

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