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Microscale Diffraction Measurements with a High Harmonic Soft X-Ray Source

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Abstract: High harmonic generation in a gas filled capillary provides a high spatial coherence, collimated, soft x-ray source. We present simple diffraction measurements and theoretical simulations that demonstrate this coherence.

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We use high harmonic generation (HHG) in an Ar filled capillary to produce a coherent [1] beam of soft x-rays. The driving E-field is obtained from a Ti:Sapphire chirped pulsed amplifier system which is capable of providing $\sim$30 fs pulses at 1 kHz with an energy of close to 1 mJ. In this configuration we observe generation of odd harmonics of the driving field up to the 31^{st} harmonic ($\sim$25 nm).

In this work we present the results of a series of simple diffraction experiments carried out with our coherent soft x-ray source [2]. The basic setup used in each of these experiments is largely the same. The soft x-ray beam exits the HHG capillary co-linear with the driving laser. A 200 nm thick Al foil filter, positioned in the beam 50 cm from the exit of the capillary, blocks the laser whilst transmitting approximately 10% of the x-rays [3]. Spatial detection of the x-ray beam is carried out by a CCD camera positioned $\sim$1 m after the Al foil. X-ray spectra are obtained using a grazing-incidence spectrometer. The diffracting object is inserted into the beam and the diffraction pattern is observed on the CCD camera.

For the first of our diffraction experiments we selected a 200 nm thick Al foil filter supported on a square Ni wire grid. This was inserted into the beam at the filter position (50 cm from the capillary) and acts both as the filter and as the diffraction target. The grid is constructed from 18 μm diameter Ni wires, crossing at 90°, which define 340 μm square apertures. As can be seen in figs. 1 a (no grid) and 1 b (with grid) the Ni wire mesh provides a microscale regular pattern that diffracts the x-ray beam. Figs. 1d and 1e show enlarged views of one mesh cell recorded for capillary Ar pressures of 120 mbar and 60 mbar respectively. As is evident from these figures the diffraction pattern changes considerably as a function of pressure. This is because different harmonics are generated preferentially at different pressures, see fig. 1c, as a result of phase matching conditions [4]. In fact using this technique we have

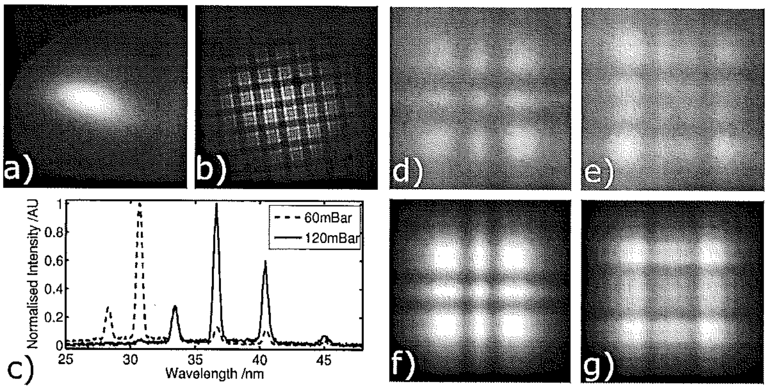

Fig. 1. X-ray output spots: a) no grid. b) with grid. c) X-ray spectra recorded at Ar pressures of 60 mbar (dashed) and 120 mbar (solid). Ni grid diffraction patterns: d) 120 mbar Ar gas (experiment). e) 60 mbar Ar gas (experiment). f) 120 mbar Ar gas (theory). g) 60 mbar Ar gas (theory).

been able to observe wavelength variation spatially across the x-ray beam. Figs. 1f and 1g show the results of Fresnel diffraction calculations performed to verify these results. Contributions from each harmonic are summed together according to their relative spectral intensities at the appropriate pressure. Figs. 1d and 1f and figs. 1e and 1g are found to be in good agreement.

Using an unsupported Al foil and positioning a 10 μm diameter pinhole into the beam (1 m from the source and 0.3 m to the detector) we observe the diffraction pattern this generates, see fig. 2a. Diffraction through a circular aperture can also be modelled by numerically integrating the Huygens-Fresnel diffraction equation [5]. Contributions from all positions inside the aperture are summed at every pixel position on the CCD camera. There is good agreement between the measured and theoretically calculated patterns as is shown in fig. 2c.

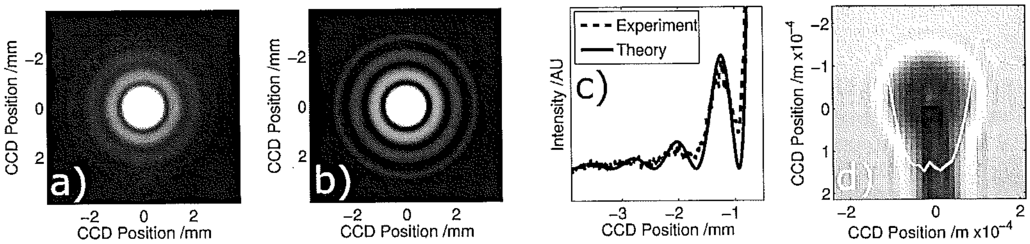

Fig. 2. Measured a) and Calculated b) diffraction patterns due to a 10 μm pinhole 1 m from the source and 0.3 m from the detector. c) Cross sections of a) (dashed) and b) (solid). d) Diffraction from an approximately spherical obstruction.

The diffraction target in fig. 2d was created by heating and pulling an optical fibre into a long thin taper. A fusion splicer was then used to melt the end of the taper into an approximately spherical bead. In this example the diameter of the spherical part is $\sim$ 120 μm and the shank is $\sim$ 50 μm wide. The target is positioned $\sim$ 0.08 m from the camera and $\sim$ 1 m from the source. Upon close inspection of fig. 2d the expected Fresnel bright spot is evident. Most of the intensity in this spot is confined to a single pixel region 13 μm square).

To conclude, we have demonstrated our ability to image the diffraction patterns of micro scale objects using an HHG soft x-ray source. We have also performed theoretical calculations of these diffraction patterns and found good agreement with the experimental results. These basic diffraction measurements provide an elegant and simple means of testing the spatial coherence of our x-ray beam under normal laser operating conditions, without any concessions to improve coherence, they also enable us to study the spatio-spectral variation of the x-rays. As shown in figs. 1d and e the frequency agility of our source[2] allows us to study diffraction as a function of wavelength. Future experiments could employ this technique to extract additional information about the sample. In the case of the circular aperture the intensity at the centre of the diffracted spot can be enhanced, in theory by a factor of 4, relative to the incident beam. This effect could be used to intensify our x-ray beam prior to irradiating a sample. The spherical obstruction acts as a single-zone amplitude zone-plate, and brings the beam to a focus like spot. The supporting fibre and any deviations from sphericality have the effect of blurring the spot to a larger size. However in this crude experiment we were still able to produce a spot of $<$ 6.5 μm radius. In future experiments this spot could be scanned over a sample.

This work represents a 'stepping stone' towards our aim of conducting x-ray scattering experiments on much smaller samples. HHG sources such as this have the potential to bring frequency-agility, and sub-few-fs time resolution, to the imaging of nano-scale objects, in a region of the spectrum that has as yet received relatively little study. This technology is therefore sure to become an important tool in the future of fields such as nano-fabricated devices and single molecule imaging as well as opening up entirely new areas of science in the x-ray and attosecond regimes.

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