# Interferometry in the XUV spectral range

# using laser-generated high-order harmonics

D. Hemmers, G. Pretzler, University of Düsseldorf, Germany, (September 2010)

## Application Note

### Introduction

Coherence properties of light fields provide a powerful tool to gain insight into the generation process characteristic for a specific light source. While spatial coherence properties allow, amongst others, to draw conclusions about the size of the emitting area, temporal coherence carries information about temporal details of the generating process.
The spectral range of interest for lasergenerated high-order harmonics is the XUV spectral region. In this range it is generally difficult to setup interferometers of e.g. Michelson or Mach-Zehnder type to determine the coherence length for a large set of harmonics due the lack of efficient beam splitters as well as the lack of broadband highreflective mirrors. Furthermore, a high degree of mechanical stability must be ensured to avoid mechanical vibrations on the scale of the given wavelength in the case single-shot experiments are not possible.
We developed a device using a combination of a transmission grating and a rotatable double pinhole acting as an interferometer which is mechanically robust, free of adjustments, and works for multiple wavelengths simultaneously. We applied this interferometer to measure the coherence length of high-order harmonics and to determine the optical properties of a beryllium foil.

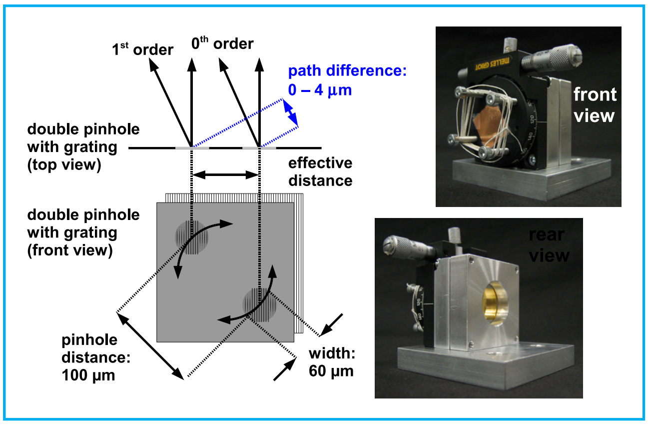


Figure 2: Setup of and photographs the XUV interferometer. A rotatable double pinhole mask is mounted in front of a transmission grating with free-standing goldbars.

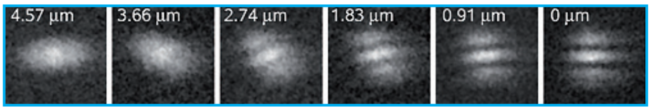


Figure 3: Typical interferograms of H35 for different rotation angles of the pinholes. The figures denote the path difference of the two beams.

### Setup

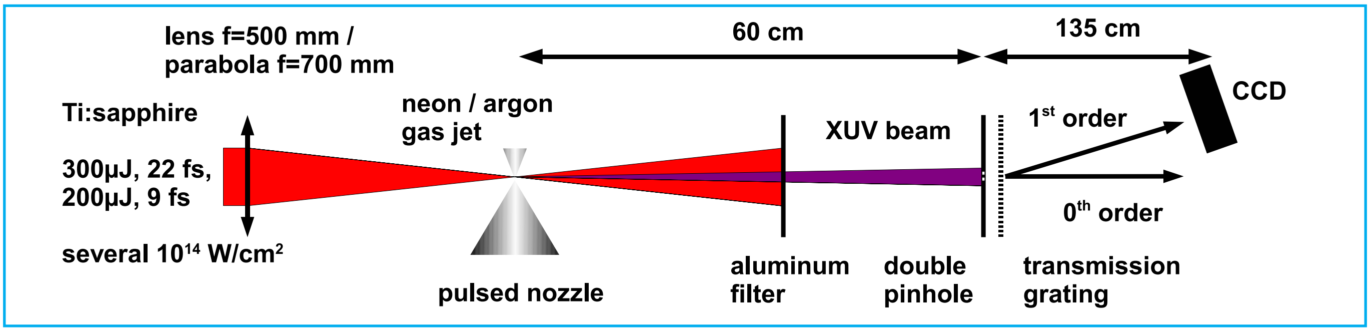


Figure 1: Setup of the XUV light source: high-order harmonics of a titanium sapphire laser are generated by focussing the laser beam into a neon gas jet.

In the experiments high-order harmonics of a titanium-sapphire laser (800 nm, 300 µJ, 22 fs) were used as the light source. The laser beam is loosely focussed into a pulsed neon gas jet as shown in fig. 1. Due to the high intensity (several $10^{14}$W/cm$^2$) and the non-linearity of the gas odd harmonics of the fundamental frequency up to the 47$^{th}$ order are generated. The laser light is subsequently blocked by two aluminum filters. The interferometer is placed in the remaining XUV beam. The resulting interferograms are recorded by an Andor X-ray CCD detector (iKon-L DO936N-MW-BN) with 2048 × 2048 pixels which is cooled down to -65 °C thermoelectrically to allow for long exposure times of up to 600 s.

### XUV Interferometer

The interferometer developed for the experiments consists of a rotatable double pinhole mask (pinhole diameter 60 µm, distance 100 µm) which is mounted in front of a transmission grating with free-standing gold bars (2000 lines/mm), fig. 2. The double pinhole serves as a beamsplitter and generates two beams which are subsequently dispersed by the grating. Thereby in the first diffraction order a path difference is introduced between the two beams which depends on the orientation of the pinholes with respect to the grating lines. While in the case of parallel orientation the path difference vanishes it becomes maximal in the case of perpendicular orientation (4 µm for our geometry depending on the pinhole distance, the grating constant, and the wavelength of the radiation considered). Thus, by rotating the pinholes the path difference between the two beams can be varied continuously and the contrast of the interference fringes formed at the detector can be determined as a function of path difference. In the case the spectrum of the light source consists of discrete lines as with gas harmonics each wavelength generates its own interference pattern well separated from the others so that this procedure allows to record the interference patterns for all wavelengths simultaneously.

### Results

Typical interference patterns for a single selected wavelength (H35, l = 22.6 nm) obtained upon rotation of the pinholes are shown in fig. 3. The observed contrast of the interference fringes decreases from a maximum value at parallel orientation (path difference 0) to almost zero for perpendicular orientation (path difference 4.57 µm). The path difference at which the fringe contrast has dropped to 50% of is maximal value defines the coherence length of the radiation. By an appropriate fitting procedure this can be determined from the set of interference patterns shown in fig. 3 to amount to 1.5 µm in this specific case.

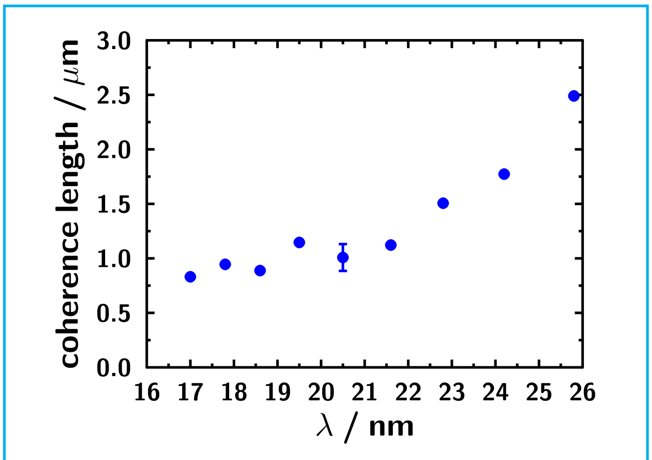


Figure 4: Coherence lengths of harmonics H45 to H31.

In fig. 4 the coherence lengths for harmon ics H45 to H31 determined by this procedure are shown. The coherence length drops from 2.5 µm for the longest wavelength to below 1.0 µm for the shortest wavelength. This is caused by the fact that higher harmonics are generated only during the most intense laser cycles while lower orders can be generated over a longer period of time.

### Interferometric determination of material constants

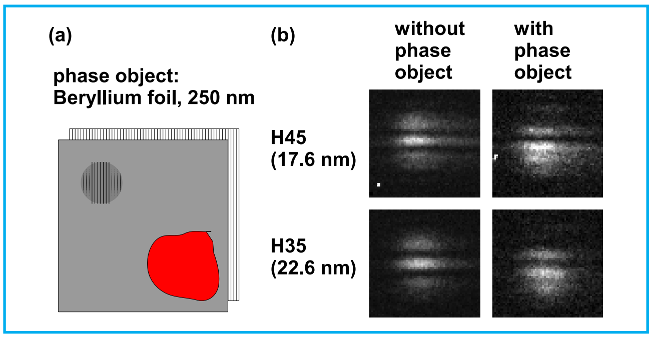


Figure 5: Interferometry of a thin beryllium foil inserted into one of the two beams (a). The interference fringes (b) exhibit a clear shift which allows the determination of the index of refraction.

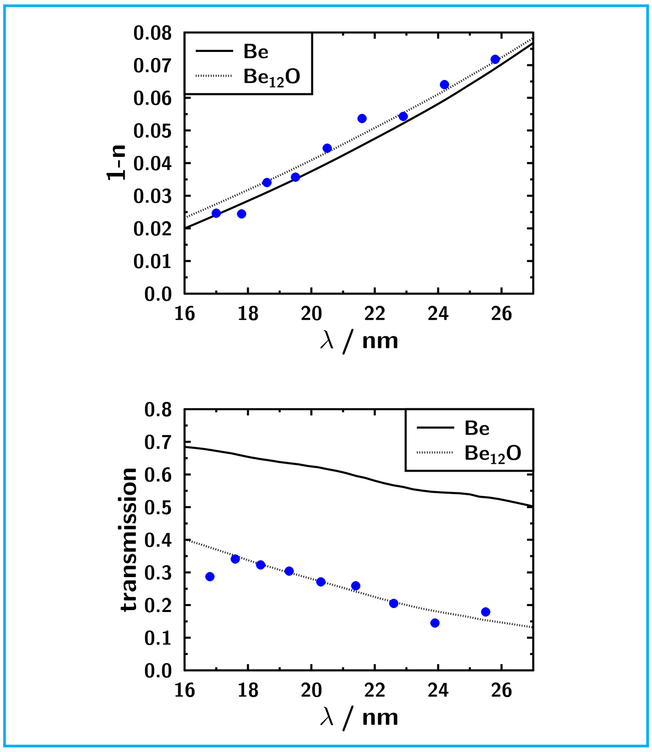


Figure 6: Index of refraction (upper part) and transmission (lower part) of the beryllium foil compared with data from [2].

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The interferometer has been used to determine the optical properties of beryllium. For this purpose a thin beryllium foil (thickness 250 nm) was placed in front of one of the two pinholes, fig. 5a, and the corresponding interference patterns for each harmonic were recorded and compared with those obtained without a phase object, fig. 5b. As result the interference fringes exhibit a clear shift from which the index of refraction of the foil can be determined, fig. 6. Further, the intensity in the interference patterns is reduced so that from the same measurement the transmission of the foil can be deduced, fig. 6. Compared with the data given in the literature [2] the index of refraction agrees very well whereas there is a significant discrepancy for the transmission data. However, as we did not take any precautions concerning the probe preparation it is very likely that the surface of the foil is oxidized leading to a reduced transmission. Assuming an appropriate oxygen content the agreement of the transmission data as well as the refractive index with the measurement is satisfying.

**References**

[1] D. Hemmers, G. Pretzler, Appl. Phys. B 95, 667 (2009)
[2] B. L. Henke, E. M. Gullikson, J. C. Davis, At. Data Nucl. Data Tables 54, 181 (1993)

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