XUV Interferometry using Thin-Film Beam Splitters at 13.5 nm Wavelength

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Application Note

Motivation

Interferometry using XUV and soft x-ray wavelengths is capable to resolve phase objects, e.g. laser produced plasmas, at a nanometer scale [1, 2]. XUV and soft x-ray radiation is particularly suited to investigate high density plasmas that are generated in inertial confinement fusion and laser-particle acceleration experiments. Due to their high plasma frequency such plasmas absorb lower frequency radiation, i.e. visible radiation. In contrast, XUV and soft x-ray radiation is transmitted experiencing a phase shift due to the additional optical path caused by the plasma.

Accordingly, the electron density can be deduced from this phase shift. This calls for an interferometric investigation of such plasmas using small-bandwidth XUV and soft x-ray radiation. The free-electron laser FLASH at DESY (Hamburg, Germany) provides intense 13.5 nm radiation in combination with ultra-short pulse duration of tens of femtoseconds. This makes it an ideal tool to study the dynamics of laser-produced plasmas with femtosecond resolution. However, an interferometric setup can even provide the electron density as a function of time and space when performing a pump probe experiment. Such capabilities of measurements attract also increasing interest for experimentalists at high-intensity laser facilities.

Prove-of-principle Experimental Setup

The experimental setup for a demonstrative experiment as sketched in Fig.1 uses monochromatized XUV radiation from the DORIS BW3 XUV beam line at DESY (Hamburg, Germany). At our design wavelength of 13.5 nm (92 eV), the BW3 beam line at DORIS provides about 1012 photons per second in the monochromatic beam. The bandwidth is 0.2 eV (open monochromator slit). The radiation is slightly diverging (≤ 1°) into the experimental chamber after passing through the fixed beam line focal point, where a slit can be introduced. Hence, the wave fronts will be spherical. The XUV radiation is then impinging onto a newly developed and characterized thin-film beam splitter, provided by the IOF Jena (see Fig. 2). They are the world-leading experts in multilayer and thin-film coating technology. The beam splitter consists of a silicon nitride membrane with a few Mo/Si layers deposited on it, such that an equal ratio of reflectivity and transmission of about 20 % is obtained. The open aperture of the beam splitter is 4x4mm².

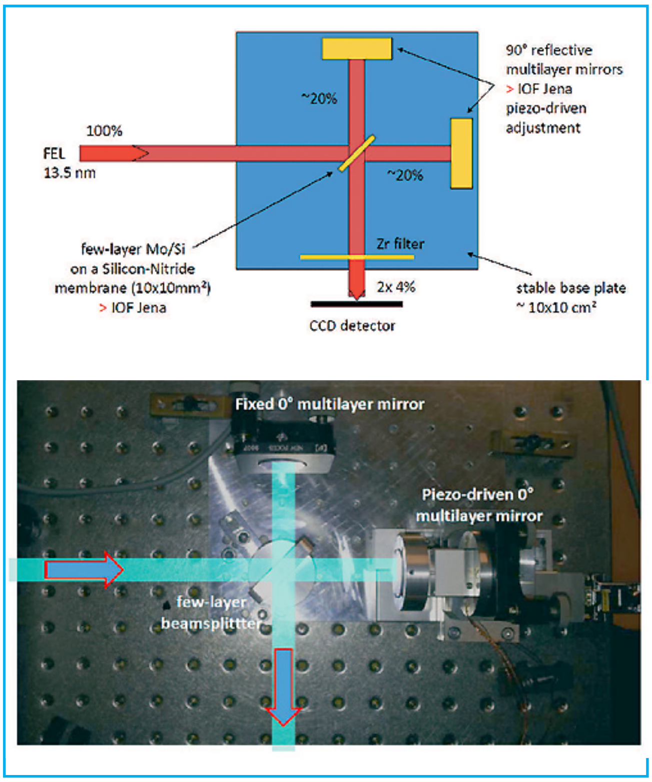

Figure 1: Experimental Setup. Left: Schematics. Right: Photograph of Michelson-type assembly.

We realize a Michelson-type interferometer setup where the beams are back-reflected by normal-incidence multilayer mirrors (sub-nm surface roughness, reflectivity 60% at 13.5 nm). While one of these mirrors is pre-aligned with sufficient precision, the mirror in the reference arm is mounted on a piezo-driven stage (see right part of Fig. 2). This stage can be translated in beam direction. Tip and tilt are also piezo-driven, allowing for in-vacuum fine adjustment. The rays are recombined in the same beam splitter and observed by a Peltier-cooled Andor iKon-L CCD detector.

This CCD camera offers a large chip area (2048x2048 pixels) with various pixel-binning, region-of-interest, and full-vertical-binning options. The overall transmission of the interferometer is about 8 %, which leads to more than 10^{10} photons per second detected by the CCD. Due to mechanical fluctuations and vibrations of the interferometer setup, a read-out time as fast as possible was set (1 msec) to minimize blurring of the fringe pattern, while the CCD was cooled to -40 °C to

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keep a flat background. In order to reduce background from stray light, a thin Zr filter (transmission 50%) could be introduced in the beam path. The Andor SOLIS software allows for several data acquisition modes such as raw counts, background-corrected counts, and e.g. "transmission %". We recorded fringe patterns in the latter mode, which means that besides a background correction, we recorded a reference image with no fringes, by which the afterwards recorded fringe pattern was divided. By this procedure, constructive and destructive interference will modify the 100% value up and down respectively, while any structures or brightness variations of the beam profile are normalized.

We investigate the (temporal) coherence length lc, which is given by the Wiener-Chintschin-theorem in case of Gaussian-like spectra. It is dominated by the synchrotron spectrum and is expected to be in the order of lc = 7 μm.

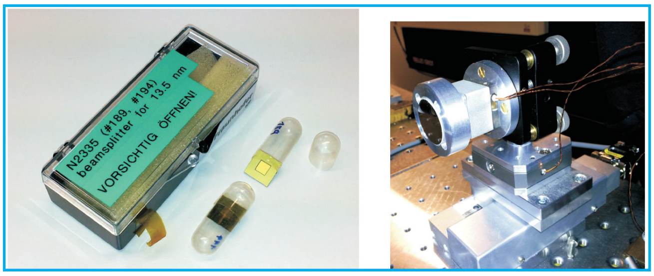

Figure 2: Left: The two identical XUV thin-film beam splitters, provided by the IOF Jena. Right: The translation and tip/tilt piezo stage.

Finally, a few 100 nm thin metal foil from B, C, Al or Zr could be introduced in one of the interferometer arms, introducing a phase shift due to its refractive index. With known foil thickness, the real part of the refractive index could be measured directly. This is in contrast to the usual practice, where the absorption of the sample is measured over a broad spectral range, and Kramers-Kronig relations are employed to recalculate the real part from these data.

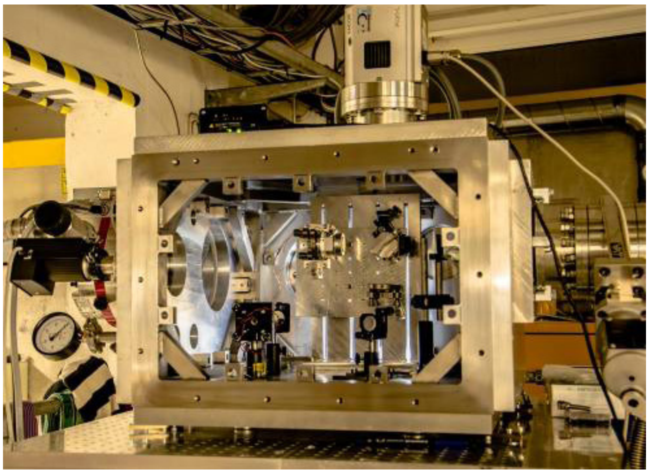

Figure 3: Setup of the XUV Michelson Interfermeter at DESY DORIS BW3 beamline. The Andor iKon-L large-area CCD detector is installed on top of the vacuum chamber.

References

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