Small angle scattering using XUV light from high-order harmonic generation

Ch. Weier, R. Adam, C. M. Schneider, Peter Grünberg Institute, Forschungszentrum Jülich GmbH, Germany (October 2014)

Application Note

Introduction

Recent progress in development of laser-based extreme ultraviolet (XUV) light (30-250 eV) and soft X-ray (250–10.000 eV) sources has triggered an increasing interest in imaging of nanometer-sized structures on pico- and femtosecond time scales. Scattering and imaging techniques, including coherent X-ray diffraction [1], coherent diffractive imaging [2], holography [3], ptychography [4], or X-ray photon correlation spectroscopy [5] became feasible due the increased coherence of the available light sources. In addition to an excellent lateral- and time-resolution, these experiments provide the benefit of element selectivity by using photons with energies fitting the absorption edges of chosen elements. For the soft X-ray spectral range, large experimental facilities like synchrotrons or free-electron lasers are needed, while XUV light can be efficiently produced in a standard laboratory using laser-based high-order harmonic generation (HHG). These light sources are driven by femtosecond laser pulses; therefore, they provide highly desirable time resolution required for studies of ultrafast charge and spin dynamics.

In our project, we investigated samples consisting of nanometer-sized grains synthesized by oxidation of Fe and FePd thin films. The average arrangement of these grains was studied using small angle scattering (SAS) of laser-generated XUV radiation. The focus of our studies was the feasibility of SAS as well as the influence of the XUV beam parameters (including the photon energy, beam diameter, and coherence) on the scattering pattern.

Experimental setup

Figure 1 shows our experimental setup. The XUV light is generated by focusing ultrashort laser pulses (1.57 eV, 2 mJ per pulse at 3 kHz, pulse duration 35 fs) into a glass capillary filled with argon gas. The outgoing XUV radiation is separated from the fundamental laser light using two 150 nm thick aluminum foils acting as a visible light filter. Due to the high absorption of XUV in air all components after the capillary source are mounted inside vacuum (10^{-5} mbar). After passing the Al filters, the XUV beam is reflected from a pair of Bragg mirrors designed as monochromator, selecting one harmonic order at 43eV from the broad XUV spectrum (20–50 eV). After passing through the thin FePd and Fe films, prepared on top of 50 nm thin Si_3N_4 membranes, the direct beam is blocked by a metallic wire and the scattered XUV light is recorded by charge coupled device (CCD) camera (Newton DO920P-BN with 1024 x 255 x 26 µm² pixels from Andor Technology) located 7 cm away from the sample.

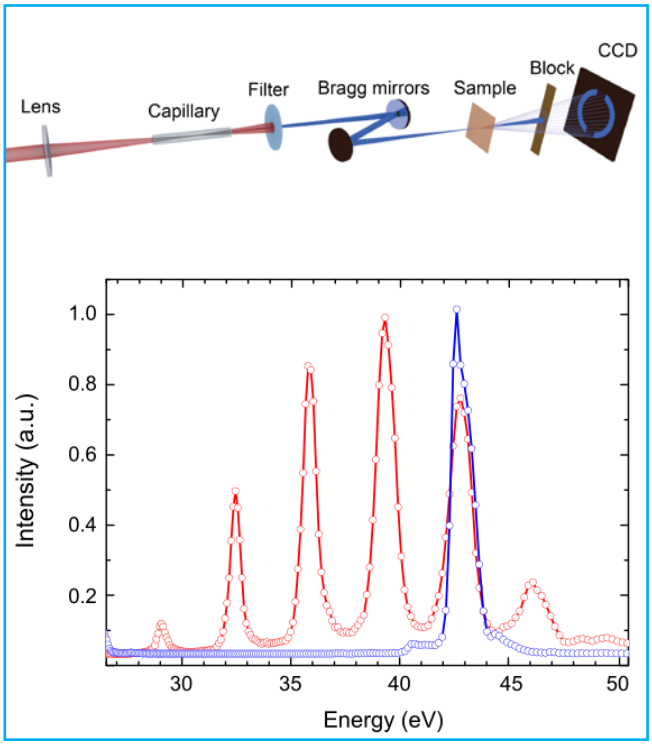

Fig.1 Schematics of a resonant magnetic scattering experiment using high-order laser harmonics (top) and a comparison of the full XUV spectrum (red) and the monochromatized spectrum (blue) measured with the bragg mirror pair (below).

Results

Figure 2 shows the observed SAS images after temporally integrating the scattering signal for 15 minutes. The scattering pattern from the FePd and Fe grains are given in (a) and (b), respectively. The image in (b) has been mirrored for a better comparison. The wavelength of the XUV radiation of 28.9 nm (corresponding to photon energy of 42.9 eV) is small enough to image the nanometer-sized randomly oriented grains, resulting in scattering rings with varying diameter and width for the individual samples. Furthermore, both images reveal a substructure in the scattering image, known as a speckle pattern. The visibility of speckles in our images is a consequence of the illumination with coherent light and allows evaluation of the longitudinal and transverse coherence properties of the XUV light source. According to our results, the contrast of the speckle

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pattern, defined by the ratio of variance and mean of the speckle intensity, is limited by the longitudinal coherence length, related to the monochromacy of the source. The visibility of such speckle patterns gives the possibility to investigate dynamical changes of structure or magnetism, as it is accomplished in photon correlation spectroscopy experiments.

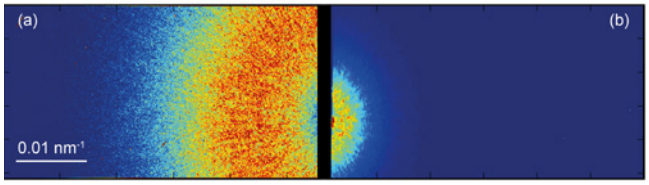

Fig.2. Scattering images from FePd and Fe nanometer-sized grains are shown in (a) and (b), respectively. The image in (b) has been mirrored for a better comparison. Both images are temporal integrations over an exposure time of 15 minutes. The CCD camera was cooled to -70 °C.

The scattering images from both samples can be radially integrated, yielding an intensity curve, which can be plotted against the momentum transfer vector Q = kout-kin, where kout and kin denote the wave vector of the outgoing and incoming light. The integrated intensity curves are shown in Fig. 3, where the blue (black) curve results from the radial integration of FePd (Fe) sample. The strong difference in the position and width of the scattering peak has its origin in the individual average grain diameter and size distribution for the particular material. We note that the SAS measurements employing laser based XUV source in combination with the sensitive CCD camera provide extremely convenient laboratory tool for fast structural analysis of the synthesized films.

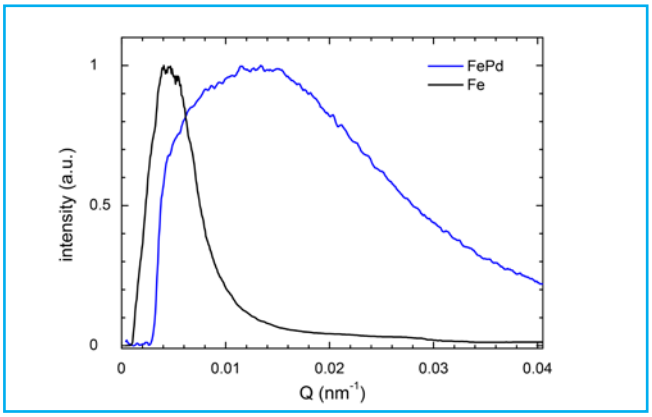

Fig.3. Radial integrated intensity of the scattering images displayed in Fig.3. The scattering curves are normalized to their maximum intensities.

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Conclusion

Our experiments demonstrate that the XUV light scattering is suitable and sensitive tool to investigate morphology of Fe and FePd thin films on the nanometer length scales using higher harmonics of a femtosecond-pulsed laser. Focusing the laser light into argon gas, bright XUV radiation can be generated and intense scattering images can be recorded within a few minutes employing low noise CCD camera. Radial integrations of the SAS images allow the analysis of structural properties of the sample with nanometer precision and high sensitivity. Furthermore, the detected speckle patterns can be used for the characterization of coherence properties of the generated XUV radiation, opening the door for further applications in the XUV spectral range.

References

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Contact

Christian Weier
Peter Grünberg Institut (PGI-6 "Electronic Properties")
Forschungszentrum Jülich GmbH
Jülich Aachen Research Alliance (JARA)
52425 Jülich
Germany
Phone: +49 2461 61 2695
E-Mail: c.weier@fz-juelich.de
Web: http://www.fz-juelich.de/pgi/pgi-6/EN/Home/home_node.html

Dr. Roman Adam
Peter Grünberg Institut (PGI-6 "Electronic Properties")
Forschungszentrum Jülich GmbH
Jülich Aachen Research Alliance (JARA)
52425 Jülich
Germany
Phone: +49 2461 61 2620
E-Mail: r.adam@fz-juelich.de
Web: http://www.fz-juelich.de/pgi/pgi-6/EN/Home/home_node.html