Compact EUV Source and Optics System for Metrology and Material Interaction Studies

Laser-Laboratorium Göttingen e.V.

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INTRODUCTION

The precise characterization of EUV source parameters and optical components is a key issue for the succesful implementation of EUV lithography systems. Metrology tools for comprehensive characterization of EUV radiation and related optical components as well as sensoric devices are developed at Laser-Laboratorium Goettingen, utilizing a table-top laser-induced source for the generation of 13.5nm radiation. The emission characteristics of this source are monitored by the help of various diagnostic tools, including pinhole cameras, a spectrometer and a Hartmann wavefront sensor sensibilized for 13.5nm radiation. For the generation of a micro focus of high energy densities an EUV-Schwarzschild objective was developed and adapted to the source. The setup produces a 30µm spot with energy densities up to 70mJ/cm^2. We present first applications of this system, demonstrating its potenial for high-resolution modification and structuring of surfaces, such as the direct photo-induced ablation of PMMA and the generation of color centres in LiF.

EUV SOURCE

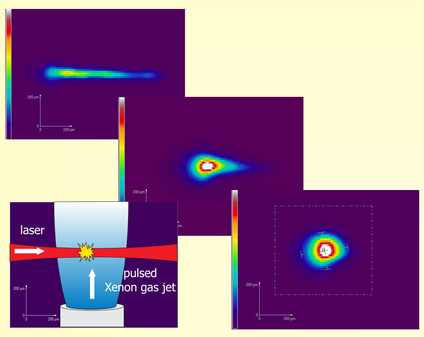
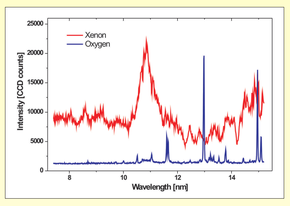


Fig. 1: EUV plasma monitored with pinhole camera for different positions of the laser focus.



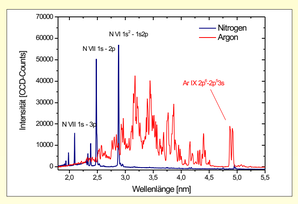


Fig. 2: Emission spectra of the laser plasma source for different target gases. Left: EUV spectral range; bottom: XUV spectral range.

Specifications of laser-based EUV source:

- wavelength (Xe target):	7 - 20nm
- pulse length:	6ns
- pulse energy:	4mJ / 4π sr / 2% BW
- plasma shape:	spherical, 300µm 10% FWHM
- pulse-to-pulse-stability:	10%
- positional stability:	10%
- repetition rate:	1 - 10Hz
- conversion efficiency (Xe):	0.5% (4)

EXPERIMENTAL SETUP

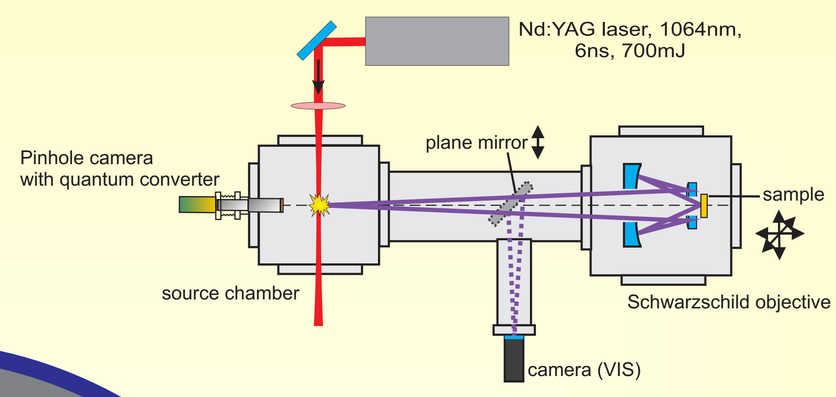


Fig. 3: Experimental setup of EUV source and adapted Schwarzschild objective for generating a microfocus with EUV energy densities up tp 70mJ/cm^2. The sample is mounted on a piezo driven translation stage, allowing scanning EUV irradiation. A CCD-camera for the visible spectral range was integrated for sample positioning and on-line monitoring of radiation induced effects.

SCHWARZSCHILD OBJECTIVE

Specifications:

- demagnification:	9.8x
- numerical aperture:	0.44
- distance source-image:	520mm
- energy density:	approx. 70mJ/cm^2

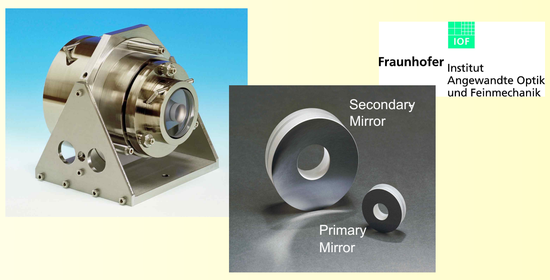


Fig. 6: Photo of the Schwarzschild objective, consisting of two annular spherical mirror substrates. The Mo/Si multilayers (R~68%) were deposited by magnetron sputtering at the Fraunhofer Institut Jena (IOF).

METROLOGY

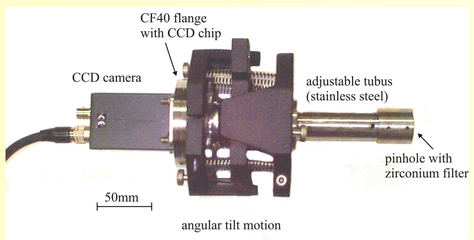


Fig. 4: Photograph of EUV pinhole camera, consisting of a 30µm pinhole, a Zr filter and a CCD chip with EUV-VIS quantum converter.

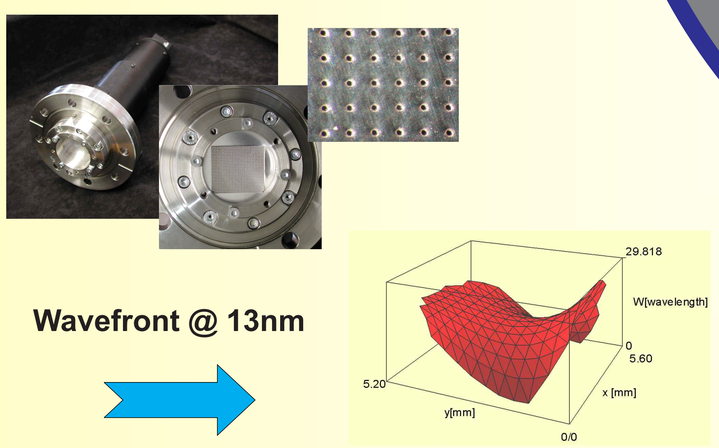


Fig. 5: Hartmann wavefront sensor for the EUV spectral range. The sensor consists of an array of pinholes, positioned in front of a zirconium covered EUV-Vis quantum converter plate. This plate is imaged onto a CCD chip. The resulting image of microfoci can be evaluated by a special software, yielding the wavefront of the incoming EUV radiation.

MATERIAL SCIENCE

Irradiation of PMMA/MA Copolymer

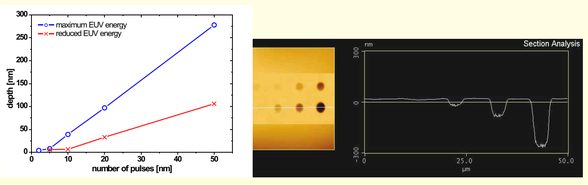


Fig. 7: Depth of structures in PMMA/MA copolymere for different numbers of pulses and different energy densities. In both cases the depth increases linearly with the number of EUV pulses. The picture on the right shows AFM measurement of irradiated spots.

Direct Ablation of PMMA

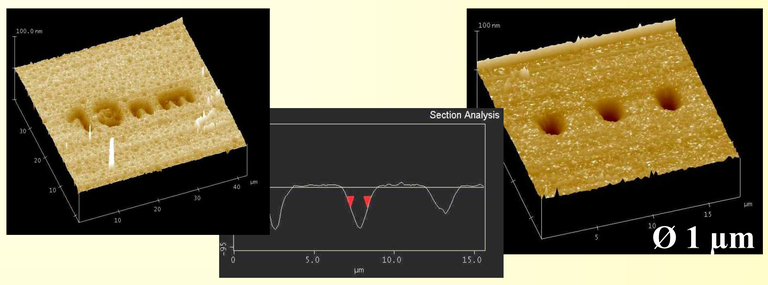


Fig. 8: Direct structuring of PMMA by EUV-induced photo-ablation. The 1 µm spot on the sample is generated by a 10x demagnified imgaging of an 10 µm pinhole placed close to the plasma. Each site was irradiated with 100 EUV pulses at an energy density of approx. 25 mJ/cm^2. The depth of the structures is about 20 nm.

Generation of Color Centers in LiF

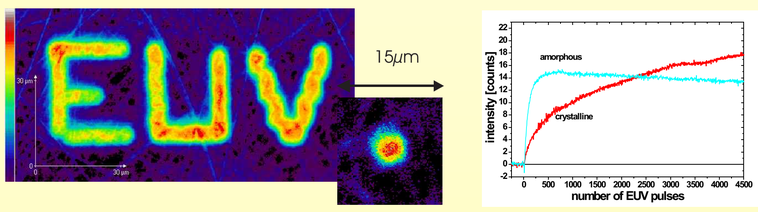


Fig. 9: Direct writing of color centers in lithium fluoride crystals by imaging an EUV illuminated 50µm pinhole onto a LiF sample. Letters were written by raster-scanning the sample; each point was exposed to 10 EUV pulses with an energy density of approx. 25mJ/cm^2. The spot on the right was generated by a single EUV pulse only. The color centers are visualized by a laser scanning microscope in fluorescence mode. The diagram on the right shows the increase of fluorescence intensity with cumulative number of EUV pulses in case of an amorphous and a crystalline LiF sample.

Structuring of In/C_{60} Nanocomposites

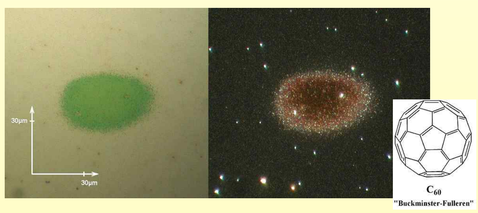


Fig. 10: Bright field micrographs in reflection (left) and transmission (right) of an In/C_{60} multilayer surface, exposed to a single EUV pulse. The sample was provided by L. Juha (Prague Institute of Physics).

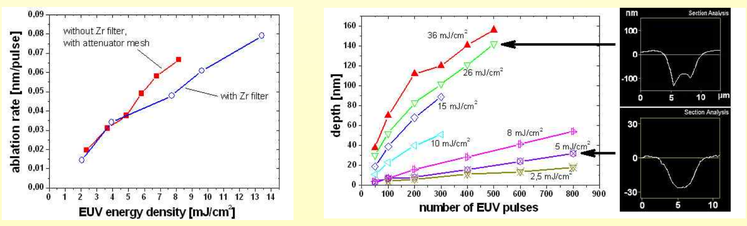


Fig. 11: The diagram on the left shows the ablation rate of PMMA as a function of the EUV energy density. To block all out-of band radiation the experiment was also carried out with an additional Zr-filter. In both cases the ablation rate increases linearly with the energy density showing no threshold level for ablation. Furthermore, the ablation depth versus the number of pulses for different EUV energy densities was determined (right). Below 10mJ/cm^2 the depth is nearly proportional to the number of pulses. Above this value distortions of the ablation crater at higher pulse numbers impede the exact evaluation (right).

CONCLUSION

A table-top EUV source for metrology and material interacation studies was developed. For the comprehensive characterization of the EUV source emission properties a pinhole camera and a Hartmann wavefront sensor were developed.

In order to generate a micro focus of high energy density at 13.5nm a modified Schwarzschild objective was developed within the BMBF project KOMPASS. By adapting the objective to the table-top EUV source a 30µm focus with an energy density of approx. 70 mJ/cm^2 was generated. The interaction of 13.5nm radiation with different materials was investigated.

In case of PMMA direct EUV-induced photo ablation was observed and ablation rates as a function of the applied EUV fluence were determined.

[1] C. Peth, S. Kranzusch, K. Mann, W. Viöl: Characterization of gas targets for laser produced extreme ultraviolet plasmas with a Hartmann-Shack sensor, Rev. Sci. Instr. **75** 3288 (2004)

[2] F. Barkusky, C. Peth, K. Mann, T. Feigl, N. Kaiser: Formation and direct writing of color centers in LiF using a laser-induced extreme ultraviolet plasma in combination with a Schwarzschild objective, Rev. Sci. Instr. **76,** 105102 (2005)

[3] F. Barkusky, C. Peth, A. Bayer, K. Mann: Ablation of PMMA using focused extreme ultraviolet radiation from a table-top laser-induced plasma source, to be published.

ACKNOWLEDGEMENT

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