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

C. Peth, F. Barkusky, A. Bayer, J. Dette, A. Kamin, H. Toettger, and K. Mann
Laser-Laboratorium Goettingen e.V., Hans-Adolf-Krebs-Weg 1, D-37077 Goettingen, Germany, kmann@llg.gwdg.de
www.llg.gwdg.de

INTRODUCTION
The precise characterization of EUV source parameters and optical components is a key issue for the success of an energy density of EUV lithography systems. Metrology tools for comprehensive characterization of EUV radiation and related optical components and 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. 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/um². We present first applications of this system, demonstrating its potential 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.

Specifications of laser-based EUV source:
- wavelength (the largest): 7 – 20nm
- pulse length: 6ns
- pulse energy: 4mJ/4µs or 2% BW
- plasma shape: spherical, 300µm ± 10% FWHM
- pulse-to-pulse-stability: ± 10%
- positional stability: ± 10µm
- repetition rate: 1 – 10kHz
- conversion efficiency (Sr): 0.5% (4e)

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

Fig. 3: Experimental setup of EUV source and adapted Schwarzschild objective for generating a microfocus with EUV energy densities up to 70mJ/um². 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.

EVALUATION
Fig. 7: Depth of structures in PMMA/MA Copolymer 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.

Fig. 8: Direct structuring of PMMA by EUV-induced photo-ablation. The 1µm spot on the sample is generated by a 10x demagnified imaging 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/um². The depth of the structures is about 20nm.

SCHWARZSCHILD OBJECTIVE
Specifications:
- demagnification: 9x
- numerical aperture: 0.44
- distance source-image: 520mm
- energy density: approx. 70mJ/cm²

Fig. 6: Photo of the Schwarzschild objective, consisting of two annular spherical mirror substrates. The McStI multilayers (6-16%) were deposited by magnetron sputtering at the Fraunhofer Institut IZM/I0F.

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 8mJ energy density. A few µm in size. The spot on the right was generated by a single EUV pulse only. The color centers are visualized by a fluorescence microscope, in the picture 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.

Fig. 10: Bright field micrographs in reflection (left) and transmission (right) of an InC₆ nanocomposite, exposed to a single EUV pulse. The sample was provided by L. Juhn (Puegues Institute of Physics).

STRUCTURING OF INC₆ NANOCOMPOSITES
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 performed using a single EUV pulse. The ablation depth 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/um² the depth is proportional to the number of pulses. Above this value the ablation rate of the crater increases faster pulses numbers increases the exact.

MATERIAL SCIENCE
Direct Ablation of PMMA

Fig. 1: 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.

METROLOGY

Fig. 4: Wavefront @ 13nm

CONCLUSION
A table-top EUV source for metrology and material interaction studies was developed. For the comprehensive characterization of 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/um² was generated. The interaction of 13.5nm radiation with different materials was investigated. In case of PMMA direct EUV-induced photoablation was observed and ablation rates as a function of the applied EUV fluence were determined.


ACKNOWLEDGEMENT
The authors like to thank the German Bundesministerium für Bildung und Forschung for financial support within the project “KOMPASS”