Preparation and characterization of multilayers for EUV applications

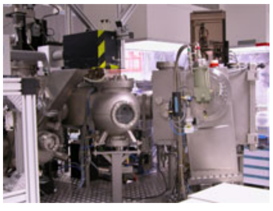
Stefan Braun*, Thomas Foltyn, Wolfgang Friedrich, Maik Menzel, Stefan Schädlich, and Andreas Leson

IWS Dresden, Fraunhofer-Institut für Werkstoff- und Strahltechnik, Winterbergstr. 28, D-01277 Dresden, Germany
* e-mail: stefan.braun@iws.fraunhofer.de, phone: +49.351.2583.432, fax: +49.351.2583.314

Multilayer fabrication

Nanometer multilayers with single layer thicknesses in the range between 0.5 nm and 20 nm are synthesized using UHV thin film deposition techniques like sputtering or pulse laser deposition (PLD). For EUV multilayers, the magnetron sputter deposition (MSD) is applied to produce multilayers with outstanding specifications:

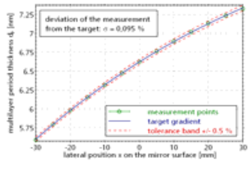
- layer thickness uniformity: ≥ 99.9 %
- run-to-run reproducibility: 99.8 % - 99.9 %
- layer microroughness (rms): 0.15 nm – 0.25 nm
- EUV reflectance: R = 69.5 % - 70.1 % (λ = 13.5 nm, α = 1.5 °)



Photograph of the thin film deposition machine "UHV cluster tool" combining two deposition chambers, the handling system, one sample magazine and the load-lock. In both deposition chambers, MSD and PLD, up to four materials can be used in the multilayer period. The typical substrate size is ∅ = 150 mm, the maximum size can be up to ∅ = 250 mm.

In order to fulfill the BRAGG condition for multilayers, precise thickness gradients have to be deposited on curved substrates (spherical, aspherical, convex, concave). With MSD, we apply two techniques to fabricate such gradients:

- one-dim. gradients: suitable velocity profiles of the substrate motion
- two-dim. gradients: application of transmission masks



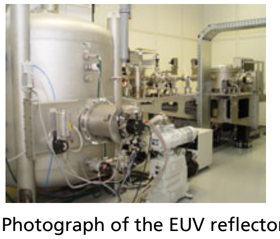
Typical precision of layer thickness gradients obtained using transmission masks. For one-dimensional gradients deposited with special velocity profiles of the substrate motion the precision is typically by a factor of 2 better.

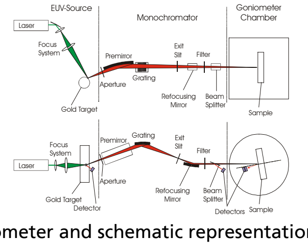
see also *T. Foltyn, S. Braun, M. Moss, A. Leson: "Deposition of multilayer mirrors with arbitrary period thickness distributions", Proc. of SPIE 5193 (2003) 124*

EUV reflectometry

The development of EUV reflective coatings requires the direct feedback of the optical behavior (lateral information about EUV peak positions, reflectance, FWHM). Therefore, IWS together with a number of other partners (Carl Zeiss, PTB, Bestec, MBI, AIS) has build a laboratory EUV reflectometer consisting of a laser pulse plasma source, a grid monochromator and a large goniometer chamber with following characteristics:

- wavelength range: 10 nm ≤ λ ≤ 16 nm
- maximum sample size: ∅ = 500 mm, thickness = 200 mm
- maximum sample weight: m = 30 kg
- reproducibility:
  - reflectance R: 99.8 %
  - peak position (wavelength λ): 99.98 %





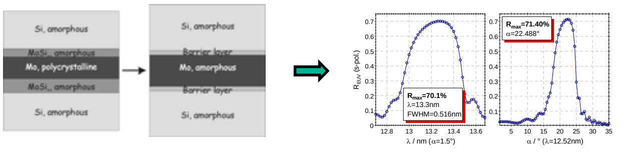
Photograph of the EUV reflectometer and schematic representation of the beam path (front and top view).

see also *L. van Loyen et al.: "New laboratory EUV reflectometer for large optics using a laser plasma source", Proc. of SPIE 5038 (2003) 12*

Barrier layers in Mo/Si multilayers

EUV reflective coatings consist of Mo/Si multilayers with single layer thicknesses of ~ 3 nm (Mo) and ~ 4 nm (Si). On the interfaces between two adjacent layers interdiffusion of both materials occurs, which reduces the optical contrast and the EUV reflectance. In order to diminish the interface diffusion we developed tiny barrier layers. The modified multilayer system with up to four layers per period results in significant improvements compared to the standard system:

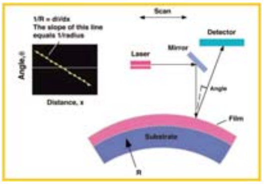
- higher EUV reflectance
- improved thermal stability
- improved long-term stability



see also *S. Braun, H. Mai, M. Moss, R. Scholz, A. Leson: "Mo/Si multilayers with different barrier layers for applications as EUV mirrors", Japanese journal of applied physics 41 (2002) 4074-4081* and *S. Braun, H. Mai, M. Moss, R. Scholz, A. Leson: "Microstructure of Mo/Si multilayers with barrier layers", Proc. of SPIE 4782 (2002) 185-195*

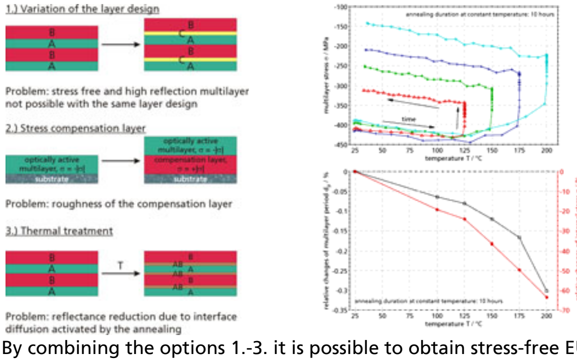
Internal stress of EUV multilayer mirrors

The internal stress of EUV multilayers can be determined by measuring the wafer curvature before and after deposition of the coating and applying Stoney's equation.



The laser scanning method is used to measure the wafer curvature. With the commercial tool FLX-2320 (KLA-Tencor) sample annealing up to temperatures of 500 °C and in-situ stress measurements are possible.

EUV multilayer mirrors produced by MSD and optimized for high reflectance exhibit compressive stress in the order of -420… -390 MPa. Particularly the application as reflective layers on micromechanical mirrors or for EUV projection optics requires a significant stress reduction to avoid the deformation of the mirror surface. In order to reduce the stress, three strategies have been used to solve the problem:



By combining the options 1.-3. it is possible to obtain stress-free EUV multilayers with reflectances R > 69.5 %. However, it has to be considered that the annealing results in a period thickness contraction connected with a corresponding EUV peak shift.

Acknowledgments

The developments presented on this poster have been supported by the BMBF, the Carl Zeiss SMT AG and the Fraunhofer-Gesellschaft. We would like to thank F. Scholze (Physikalisch-Technische Bundesanstalt PTB/BESSY2 Berlin) for numerous EUV reflectance measurements.

IWS
Fraunhofer Institut Werkstoff- und Strahltechnik