Mo/Si-multilayers for EUV applications prepared by Pulsed Laser Deposition (PLD)

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Abstract

In the past the successful application of PLD for X-ray multilayer synthesis has already been demonstrated for C-spacer systems. Recently the method has been tested also for Mo/Si layer stacks. An UHV-coating machine has been used to prepare X-ray mirrors on 4" substrates. The ablation of both, Mo and Si targets, was carried out by Nd:YAG laser radiation using the third harmonic (λ=355nm) with a pulse energy E_P= 550mJ and a pulse width τ=4...6ns. Multilayers of 10...50 periods have been synthesized.
Soft X-ray measurements in the EUV-range at near normal incidence show reflectivities R_s of typically 60%. From HRTEM a high stack regularity and minimum interface roughness can be deduced. In contrast to conventional technologies (coating by sputtering or e^--beam evaporation) the formation of a $MoSi_x$-interface layer happens only for deposition of Mo on Si. Extremely sharp interface transitions from one individual layer to the other are observed and the total period is represented by a three-layer system. From TEM results a structure model for PLD-prepared Mo/Si-multilayers has been deduced. The optical parameters of the layers were adapted by reflectivity curve fitting, so that the measurements in the EUV-range can be explained. Using this model predictions of the ratio of the number of atoms N_{Si}/N_{Mo} for the total stack were made and are in good agreement with results of RBS measurements.
The application of the multilayers as X-ray optics requires an excellent homogeneity of the layer thickness across the entire mirror. It can be shown, that PLD is able to realize film uniformities with a standard deviation of the period thickness of <0.5%. This was confirmed by Cu-K_α-reflectometry and by near normal incidence measurements in the EUV range on 4" samples.

Multilayer preparation

Large area pulsed laser deposition (PLD) [1] enables thin film synthesis with high reproducibility. A schema of the PLD principle is shown in figure 1.

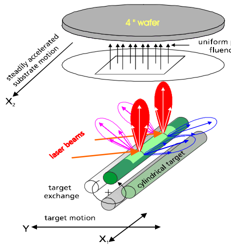

Fig. 1: Principle of thin film depositition by large area PLD method.

HRTEM investigations

Conclusions from HRTEM investigation (Fig. 2):
- very good regularity of the multilayer stack
- extremely smooth interfaces between the different layers
- different interfaces Mo on Si and Si on Mo, for Mo on Si formation of transition layers with sharp interfaces to adjacent layers
- in contrast to sputtered (Fig. 4 and 5) or e-beam evaporated Mo/Si multilayers having polycrystalline Mo-layers no lattice fringes are found, all individual layers are amorphous

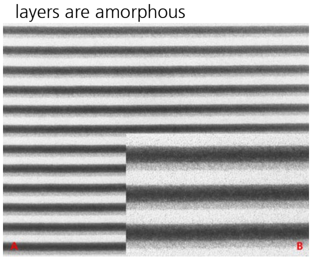

Fig. 2: **A**: HRTEM cross section of a **PLD-prepared** Mo/Si multilayer. Coating direction: from bottom to top.
B: Magnified representation of three periods of the stack showing atomically flat interfaces.

Fig. 3: Structure model of PLD-prepared Mo/Si multilayers.

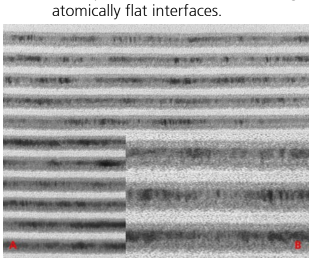

Fig. 4: **A**: HRTEM cross section of an **ion beam sputtered** Mo/Si multilayer.
B: Magnified representation:
- 2 transition layers with different thickness and increased roughness compared to the PLD-multilayer
- strong texture of the Mo crystallites parallel to the layers

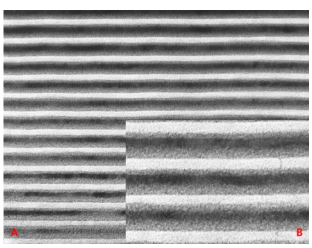

Fig. 5: **A**: HRTEM cross section of a **magnetron sputtered** Mo/Si multilayer.
B: Magnified representation:
- similar layer stack morphology to the ion beam sputtered multilayers
- weak texture of the Mo crystallites

On the basis of HRTEM results a structure model for PLD-prepared Mo/Si multilayers is proposed:
- multilayer period consists of three layers
- absorber and its supporting spacer are separated by an amorphous interlayer
- a $MoSi_2$-composition is suggested for this interlayer

By variation of Si and Mo contents of absorber and spacer, resp. , the model was adapted to the measured data of Cu-Kα- and EUV-reflectivities. The best fitting result is shown in Figure 3.

EUV reflectivity measurements

Measurement of absolute reflectivity as a function of EUV wavelength and angle of incidence α was made using synchrotron radiation from BESSY (PTB, [2]).
Main results of the measurements:
- Reflectivities R_s of 60% can be observed at different substrate types (ULE, zerodur, silicon, sapphire) at the Si-L-edge (photon energy = 99eV), Fig. 6
- Near normal reflectivities (α=1.5°) at λ=13nm are typically 2% lower compared to the values obtained at 99eV (corresponds to λ=12.52nm), Fig. 7

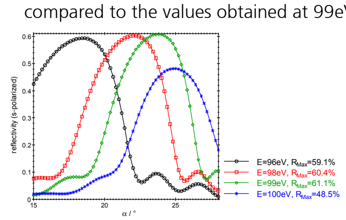

Fig. 6: EUV reflectivity of sample V414 as function of angle of incidence α.

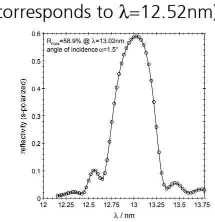

Fig. 7: Near normal incidence EUV reflectivity of sample V539 as a function of the wavelength.

Coating uniformity

Determination of the coating uniformity by Cu-Kα- and EUV-reflectometry. With both methods relative standard deviations of period thickness <0.5% were observed (Figures 8-10).

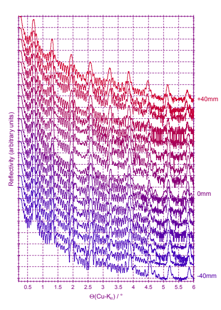

Fig. 8: Cu-Kα reflectographs of a 10-period Mo/Si multilayer (V628) at different sample positions (4" substrate).

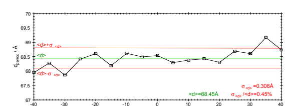

Fig. 9: Period thickness as function of sample position of multilayer V628.

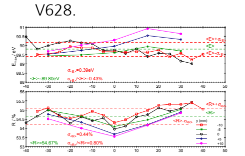

Fig. 10: EUV-peak positions and reflectivities as function of sample position (50 period multilayer, plane 4" substrate).

Acknowledgment

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References

[1] R. Dietsch, T. Holz, H. Mai, P. Panzner, S. Völlmar, Optical and Quantum Electronics, **27**, (1995), 1385
[2] D. Fuchs, M. Krumrey, P. Müller, F. Scholze, G. Ulm, Rev. Sci. Instrum. **66** (2), (1995), 2248

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