Characterization of Mo/Si soft X-ray multilayer mirrors by grazing-incidence small-angle X-ray scattering


Institute of Physics, Slovak Academy of Sciences, Dubravska cesta 9, 84511 Bratislava, Slovakia
1Erich Schmid Institute for Materials Science, Austrian Academy of Sciences, Jahnstrasse 12, A-8700 Leoben, Austria
2Materials Center Leoben Forschung GmbH, Roseggerstraße 12, A-8700 Leoben, Austria
3HASYLAB / DESY, Notkestr. 86, 22603 Hamburg, Germany
4IMRAM, Tohoku University, 2-1-1 Katahira, Aobaku, Sendai 980-8577, Japan
5Fakultät für Physik, Universität Bielefeld, Postfach 100131, 33501 Bielefeld, Germany

Multilayer interface characterization plays a key role in the development of soft- and hard-X-ray mirrors suitable for synchrotron radiation, free-electron laser and novel compact micro-spot X-ray sources. The imperfection of multilayer interfaces leads to an enhanced off-specular scattering of X-ray radiation, which results in a decreased mirror reflectivity. An invasive inspection of multilayer interfaces can provide transmission electron microscopy. However, the sample preparation is time-consuming and in some cases can add artificial information due to sample milling, thinning and gluing techniques. The pioneering works of Salditt et al. [1, 2] have shown the possibility of multilayer interfaces inspection by monitoring the non-coplanar diffusely scattered X-ray radiation incident at small angle at the mirror surface.

We have used grazing-incidence small-angle X-ray scattering (GISAXS) at BW4 beamline (HASYLAB) in experimental geometry suitable for inspection of diffusely scattered radiation from the Mo/Si mirrors. We discuss here the Mo/Si mirror deposited by e-beam evaporation combined with ion beam polishing. An exhaustive analysis of Mo/Si multilayer mirrors fabricated by various deposition techniques is given in Ref. 3. The Fig. 1a shows the X-ray reflectivity of a selected mirror. The average thickness and net roughness of spacer and absorber layers and their standard deviations were determined by fitting procedure based on the Parrat formalism. The differential cross-section for the scattered radiation by a multilayer stack was simulated within the Born approximation (BA). The BA approximation is valid as the incident and exit angles were larger than the critical angle for total reflection. For the lateral correlation functions we used a model developed by Sinha et al [4]. The vertical correlation length was defined according to the model of Ming et al. [5]. The recorded GISAXS pattern shows the first three Bragg sheets in Fig. 1b. The visibility of Bragg sheets is proportional to the net roughness of the multilayer interfaces and to the vertical correlation length. The extension of the Bragg sheets along q_y direction in the reciprocal space is proportional to the power spectra density of interface roughness. The width of Bragg sheets (FWHM) as a function of q_y is plotted in Fig. 1c. The width of the Bragg sheets is inversely proportional to the number of effectively correlated layers N_eff. The GISAXS measurements allow evaluation of the vertical correlation length which is dependent on the spatial frequency. The higher spatial frequencies of roughness do not replicate well within the multilayer stack when compared to the lower ones. This has been observed for most multilayer mirrors and is a natural consequence of Edwards and Wilkinson [6] growth model. For comparison, similar measurements (shown in Fig. 1c) were done at a table-top SAXS system (Nanostar, Bruker) and will not be discussed here. The simulation of the intensity decay of the 2nd Bragg sheet and the measured data are shown in Fig. 1d. Assuming identical autocorrelation function for all interfaces we can obtain average lateral correlation length (ξ = 1.4 nm) and average Hurst parameter (H = 0.3). These parameters are hardly accessible in co-planar measurements of diffusely scattered X-ray radiation because of a limited accessible range of lateral frequencies of roughness. Moreover, the simulations of experimental data demonstrate an unambiguous determination of statistical properties of the interfaces.
Figure 1: The Mo/Si multilayer deposited by e-beam evaporation combined with ion beam polishing. (a) X-ray reflectivity (b) GISAXS pattern (c) FWHM of the 2nd Bragg sheet measured by synchrotron and Nanostar (d) The intensity decay of the 2nd Bragg sheet.

References