E.3: Development of high-quality X-ray multilayer mirror for hard X-ray applications

X-ray multilayer (ML) optics plays a vital role to manipulate X-rays for frontier scientific and technological applications. It acts as a notch filter passing a narrow band of energies. ML mirror is advantageous compared to diffractive crystal optics because of greater flux and design flexibility. In addition, ML mirrors allow a variety of optical configuration by tailoring reflective responses using a figured surface. The objective of the present work is to develop high-quality X-ray ML mirrors for high-throughput and high-resolution applications in the hard X-ray energy range (10–20 keV). Indigenous development of such precision optics is essential for HBSRS (Indus-3) beamlines to deliver diffraction-limited, coherence-preserving X-ray beams. The major challenge in fabricating these mirrors lies in achieving nanometer-scale layer thicknesses with angstrom-level precision and atomically smooth interfaces across hundreds of layer pairs.

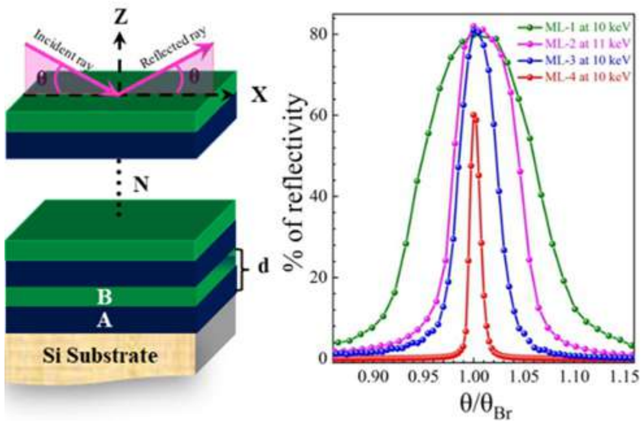
Mo/Si and W/B_4C ML mirrors have been successfully developed with low achievable interface roughness (~0.21–0.24 nm) and thickness errors below 0.2%, suitable for high-performance X-ray applications. Under optimized deposition conditions, Mo/Si ML mirrors are designed for high-flux applications, whereas W/B_4C ML mirrors are optimized for moderate- to high-resolution applications. All MLs are deposited using magnetron sputtering with carefully tuned periodicities and number of layer pairs to optimize for either high photon flux or high spectral resolution.

Fabricated structural parameters of ML Mirrors: Mo/Si MLs (ML-1 and ML-2) have periods (d) of 9.43 and 6.53 nm, layer pairs (N) of 60 and 50, and roughness (σ) of 0.24 and 0.21 nm, respectively. W/B_4C MLs (ML-3 and ML-4) have d = 3.74 and 1.85 nm, N = 50 and 400, and σ = 0.24 and 0.27 nm, respectively.

A systematic investigation of the structure, stress and optical property correlation is carried out for hard x-ray application. Optical performance, measured using Indus-2 in the 10–20 keV range, shows that Mo/Si MLs exhibit high measured reflectivity (R_m80–92%) and excellent integrated reflectivity, suitable for high-flux applications. In contrast, W/B_4C MLs with shorter periods provide high-resolution performance with relative energy resolution (ΔE/E) down to ~1.2%. The results indicate high quality of fabricated ML mirrors.
A representative measured first-order Bragg reflectivity (R) profiles of MLs are shown in Fig. E.3.1, with the results as follows:

ML-1: $R_m \approx 82\%$, $\Delta E/E \approx 11.9\%$ at 10 keV
ML-2: $R_m \approx 81\%$, $\Delta E/E \approx 6.8\%$ at 11 keV
ML-3: $R_m \approx 81\%$, $\Delta E/E \approx 4.1\%$ at 10 keV
ML-4: $R_m \approx 60\%$, $\Delta E/E \approx 1.2\%$ at 10 keV

ML-1 and ML-2 show excellent agreement with the theoretical reflectivity, R_T (R_m/R_T> 0.93) up to 18 keV, with a sharp drop at 20 keV due to the absorption edge. ML-3 shows reasonable agreement, with R_m/R_T ranging from 0.91 to 0.97 across 10–20 keV. In contrast, ML-4 exhibits significantly reduced values (0.75 at 10 keV and 0.55 at 14 keV), mainly due to enhanced interdiffusion in the ultra-short period structure.



(a) (b)

Fig. E.3.1: (a) Schematic of a ML structure. (b) Measured reflectivity data using Indus-2 of first order Bragg peak for four MLs, normalized to Bragg angle.

The results are comparable to current international benchmarks for similar multilayer X-ray optics. The study demonstrates that Mo/Si systems are well suited for high-flux applications, while W/B_4C systems provide high-resolution performance, addressing different requirements in hard X-ray optics. These outcomes offer valuable insights for optimizing the design of multilayer-based synchrotron mirrors and monochromators for future Indus-3 applications.

For further details please see: Mollick Faiyaz, Nayak Maheswar et al., "Structure, stress, and optical property correlations in nano-structured Mo/Si and W/B_4C multilayer mirrors for hard x-tray applications", *J. Appl. Phys. 138, 175303 (2025).*

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