A.6: Development of multilayer mirror for soft gamma-ray spectroscopy

X-ray multilayer (ML) optics plays a vital role to manipulate x-rays for frontier scientific and technological applications, such as for synchrotrons and astronomy. Recently, more attention was drawn towards finding a possible way to reflect shorter wavelengths down to soft gamma rays (~100 keV to 400 keV) with high efficiency. Advancement of ML fabrication techniques enables the production of such optics. ML mirror based soft gamma-ray spectroscopy finds potential application in gamma-ray astronomy and nuclear technology. ML mirror operates in glancing incidence configuration (few mrad - several mrad) to reflect such high energy soft gamma-rays. A meter long ML mirror is required, generally by arranging small ML mirrors in a cascading manner, to operate at such shallow angles. 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 configurations by tailoring reflective responses using a figured surface.

A high reflectivity in such high energy soft gamma ray region requires the ML mirror to have periodicity in the range 1 to 2 nm, number of layer pairs ~400 and atomic smooth interfaces (with minimal intermixing) with rms roughness of ~0.1 to 0.3 nm. By precisely optimizing the sputtering process parameters, it was found that the required parameters of the ML mirror for such high energy applications are possible with W/B_4C material combination. W/B_4C ML mirrors with N=400 and varying periodicity in the range from 1.53 to 1.86 nm, with rms roughness in the range of 0.28 to 0.27 nm were fabricated, which are required for such high energy optics.

Figure A.6.1 shows structural study of W/B_4C MLs. In Figure A.6.1(a), the experimentally measured x-ray reflectivity (XRR) spectra is shown from 10 keV to 20 keV for W/B_4C ML with d = 1.86 nm and N=400. Well defined Bragg peaks at different energies indicate a good quality of fabricated ML mirrors with average rms interface roughness of ~0.27 nm. Figure A.6.1(b) shows cross-sectional TEM image of ML with d=1.55 nm and N=400. It indicates good quality of periodic structure. The rms interface roughness of ML with d=1.55 nm is 0.28 nm (obtained using XRR).

Figure A.6.2 shows optical performance of the ML mirrors. At 10 keV, measured reflectivity around the first order Bragg peak for two ML mirrors (d=1.86 nm and 1.55 nm) are shown in Figure A.6.2(a). At 10 keV, significantly high reflectivity of ~64% (theoretical 82%) with energy resolution ΔE =132 eV is measured for ML with d=1.86 nm. The ML with d=1.55 nm, has a measured reflectivity of 39% with ΔE = 75 eV at 10 keV.

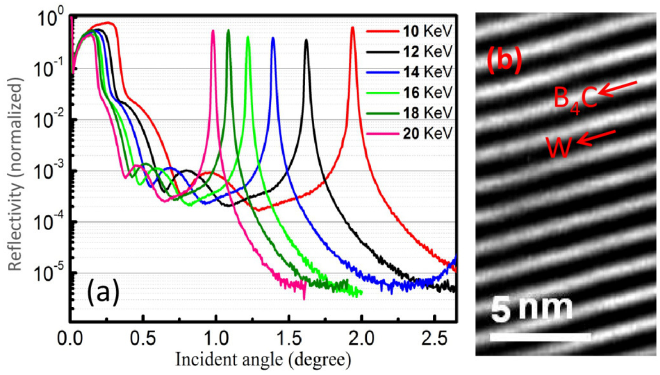

Fig. A.6.1: Structural characterization of W/B_4C ML mirrors. (a) Measured reflectivity profiles of ML mirror (periodicity d = 1.86 nm and number of layer pairs N =400) in the energy range from 10 to 20 keV using BL-16 at Indus-2 synchrotron, and (b) cross-sectional TEM image of other ML with d=1.55 nm and N=400.

Considering the measured structural parameters of the ML mirror, the expected reflectivity spectrum at 100 keV from ML mirror with d=1.86 nm is extrapolated, and is shown in Figure A.6.2(b). The calculation was done with an angular step size of 0.002°. The expected reflectivity at 1st order Bragg peak is ~80% at an incident angle of ~0.193°. Thus, the good agreement between measured and predicted hard x-rays optical properties as well as predicted soft gamma-ray reflectivities, makes a strong case supporting W/B_4C as one of a prospective material of choice for such optics.

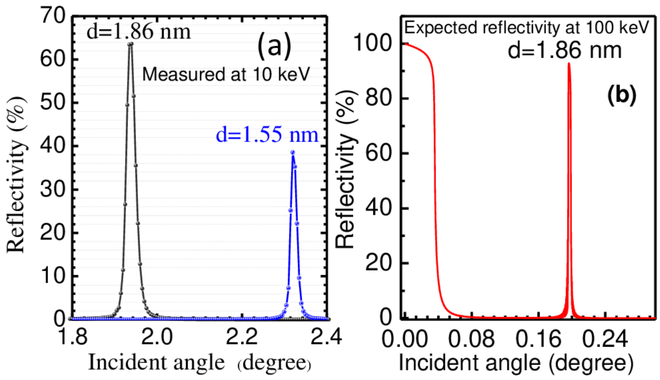

Fig. A.6.2: Optical performance of W/B_4C ML mirror. (a) Measured 1st order Bragg peak reflectivity (linear scale) of two MLs with d=1.86 nm and 1.55 nm at 10 keV, and (b) expected calculated reflectivity spectra at 100 keV considering measured structural parameters of the ML mirror with d=1.86 nm.

Reported by:
Maheswar Nayak (mnayak@rrcat.gov.in)