A.7: Studies on low-Z/low-Z multilayers using synchrotron based soft x-ray reflectivity

X-ray multilayer (ML) optics is very popular for synchrotron applications as it bridges gap between crystal monochromator and total reflection mirrors. In x-ray multilayers, typically a high-Z metallic element is used as the scatterer and a low-Z element is used as the spacer layer. This combination of high-Z /low-Z puts a limit on the maximum number of layers which can contribute to reflectivity due to high absorption in the high-Z layer. However, increased number of layer pairs is important to improve the resolution and reflectivity. One way of increasing number of layer pairs is to use multilayer made of low-Z/low-Z elements having low absorption. These low electron density contrast (EDC) structures have potential to produce both high reflectivity and strong spectral filtering. These can be used as mirrors, monochromators, beam splitters etc., and their high thermal stability makes them ideal to study interaction of high intense radiation with matter.

At ISUD, RRCAT, we have a program on the development of low-Z/low-Z multilayers. The two important parameters, namely interface structure and composition of the layers, influence the properties (like Bragg peak width, peak and integrated reflectivity) of ML structure. It is important to derive these parameters of nanometer scale length MLs, so that the ML preparation techniques can be optimized to yield better performance. Hard x-ray reflectivity (HXRR) provides interface information with sub-nm accuracy. Sensitivity in the HXRR depends on EDC of the constituent materials. In the case of MLs containing low-Z/low-Z elements, the electron densities in the two layers are very similar, resulting in low contrast. Hence, HXRR measurements performed at a single wavelength can provide only limited structural information in the small EDC systems. The HXRR measurements are more sensitive to structural parameters and are less sensitive to the compositional/ optical changes of the layers. In contrast, soft x-ray reflectivity measurements performed near the absorption edges, referred to as resonant soft x-ray reflectivity (RSXR), are more sensitive to the compositional/ optical changes in the layers. One can infer the complete information about ML structures and their performance by combining both techniques of HXRR, cross-sectional TEM, and RSXR. These aspects are shown with an example of 10-period C/B_4C multilayer, which is a low EDC combination.

When electromagnetic radiation is incident on a medium, the electrons in the atom start oscillating. In a multi-element system, the total scattering is the sum of scattering from both resonant and non-resonant atoms. These interactions cause large change in the refractive index near the absorption edges and cause strong modulation in the reflectivity profile. Analysis of the reflectivity profile near the absorption edges gives the variation of the number density of the resonating atoms perpendicular to the material surface. The optical constants of such a multi-element layer can be written as

$$\delta = 2.7007 \times 10^{-4} \lambda^2 \rho \frac{\sum_j X_j \left(f^0_{NR,j} + f'_{R,j}(\lambda) \right)}{\sum_j X_j \mu_j}$$

$$\beta = 2.7007 \times 10^{-4} \lambda^2 \rho \frac{\sum_j X_j f''_{R,j}(\lambda)}{\sum_j X_j \mu_j}$$

Here λ is the incident wavelength [nm], ρ is the density [g/cm^3], X_j is the atomic fraction of j atoms, and μ_j is the atomic weight of j atoms [g/mol]. $f^{o}_{NR,j}$ gives the scattering from the electrons in the atom, $f'_{R,j}$ and $f''_{R,j}$ are the resonance and absorption corrections to the atomic scattering factor arising from anomalous dispersion respectively.

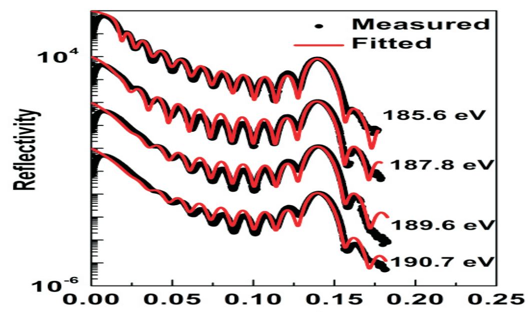

Fig. A.7.1: The measured and simulated RSXR profiles of the C/B_4C ML, in the vicinity of B K-edge.

The experimental and simulated RSXR curves of C/B_4C ML as a function of scattering vector in the vicinity of B K-edge, are shown in Fig. A.7.1. The free parameters in simulating RSXR profile are individual layer thickness, interface roughness/width, and the optical constants. To reduce the number of free parameters in simulating RSXR profile, structural parameters obtained from HXRR and cross-sectional TEM were used. The compositional changes cause significant variation in optical constants of buried layers in the soft x-ray region. For example, when the composition of boron carbide with B_4C stoichiometry changes to 90 at.% B and 10 at.% C, δ changes from -0.00237 to -0.00556 (more than 200% increase) and β changes from 0.00117 to 0.00115 (more than 60% decrease) at 187.8 eV energy. Such a large change in optical constants can influence the performance of the mirror significantly. In this study, presence of excess C into the boron carbide layer was established.

(For more details, please refer to *P.N. Rao et al., J. Appl. Phys. 119, 245301 (2016)*)

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