Simultaneous analysis of Grazing Incidence X-ray reflectivity and X-ray standing wave data from periodic multilayer systems

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Structural analysis of periodic multilayers with small period thickness (~4 nm) is a challenging task, especially when thicknesses of intermixed interfaces become comparable to individual layer thicknesses. In general, angular dependent X-ray fluorescence measurements, excited by the X-ray standing wave (XSW) that is formed in the Bragg reflection conditions, can provide information about the in-depth distribution of atoms in a multilayer. The atomic depth profiles in periodic multilayer structures can be obtained with high resolution by simultaneously analyzing the fluorescence data from XSW experiments, together with the analysis of grazing incidence X-ray reflectivity (GI-XRR) experiments. As a first step, the electron density distribution in the multilayer period is obtained by fitting of GI-XRR data. Next, the electromagnetic wave distribution in the multilayer is calculated based on the reconstructed electron density profile which is then used to calculate fluorescence yield from specific materials in x-ray standing wave experiments. The traditional data analysis approach is the simultaneous fit of these two sets of data and it depends on two distributions: the atomic distribution and the electron density distribution. In case of unknown atomic intermixture, there may not be a clear connection between these two distributions leading to fit of non physical parameters.

Our new approach is that the atomic profile can be *directly calculated* by combining measured fluorescence yields from specific atoms with the averaged electromagnetic field distribution in a multilayer period. Calculations involve solving the system of linear analytical equations using the technique of ill-posed [1] problems. The averaged electromagnetic wave distribution in a period is calculated based on the summation of field distributions in each period of the multilayer, as obtained from GI-XRR analysis. Obtained atomic distribution automatically describes accurately measured XSW data. Additional advantage of this approach is that fitting only GI-XRR data is significantly faster than the traditional simultaneous fit of GI-XRR and XSW data. Uniqueness of obtained results can be checked by comparing of obtained atomic distribution profiles to electron density profiles.

The atomic profile reconstruction method described here has been applied to the analysis of short period (d = 3.4nm) La/B_4C and LaN/B_4C multilayers considered for application in 6.x nm projection lithography. Optimization of multilayer optical performance requires accurate determination of the multilayer structure. Reconstructed electron density profiles of both multilayers were comparable and didn't explain increased at-wavelength reflectivity of LaN-based mirror with respect to La-based. However, when the GI-XRR analysis was combined with XSW analysis according to our new approach, the distribution of La showed that La atoms are more localised in LaN-based multilayer, while in La-based multilayer La atoms are even present in the position of B_4C layer, hinting at significant intermixture. This clearly shows that nitridation of La prevent its diffusion into B4C layer, increasing multilayer optical contrast and as the result increasing at-wavelength reflectivity.

References

1. A. N. Tikhonov and V. Y. Arsenin, Solutions of ill posed problem, V H Winston & Sons, 1977.