Interfacial structure and lateral correlations in neutron supermirrors

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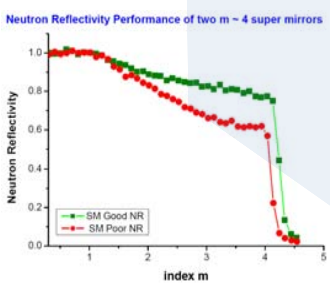
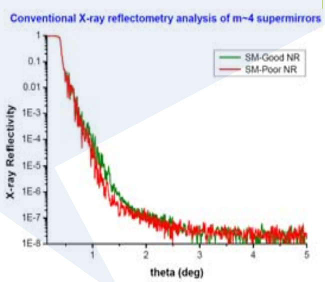
The reflectivity performance of a neutron supermirror is critically dependent on the interfacial roughness and the lateral roughness correlations. We examine a pair of supermirrors that showed good and poor neutron reflectivities by x-ray reflectivity from early layers of growth and demonstrate that the strong in-plane correlations begun in the early growth has deteriorated the total reflectivity.

Motivation

Neutron supermirrors (SM) are typically fabricated using a depth-graded layer sequence suggested by Hayter-Mook by repeating Ni and Ti bilayers. Typically thin bilayers are deposited first followed by layers with gradually increasing thickness, as calculated by the depth gradation, in order to suppress the roughness development at the early stages of the growth. The quality of the supermirrors or the interfaces can be judged from a neutron reflectivity (NR) performance after all the layers are deposited, however, it is important to learn the properties of the interior layers to understand the physical reasons for their performance as well as for quality control research.



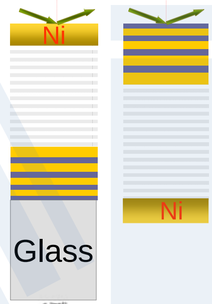


The figures depict the conventional neutron (left) and x-ray (right) reflectivities of two m~4 SMs that were grown side by side on different glass substrates. The mirrors differ in NR by 20%. The interface information from conventional x-ray reflectivity is marred by the large surface roughness and the limited penetration depth. Nevertheless, it appears that the surface roughness of both supermirrors are qualitatively identical.

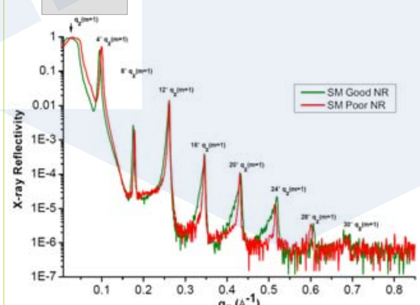
Questions

- Could the interface properties of the interior layers of the two SMs differ in the two cases?
- How can the interface properties of the initial layers be revealed?
- Do any roughness correlations exist and how do they affect the reflectivity?

Back face reflectometry



By virtue of the depth-gradation of the bilayers, they behave like a super-lattice with a slowly varying periodicity and giving rise to Bragg reflections of higher orders as shown in figure below.

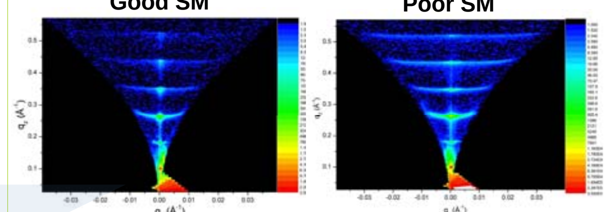


Bragg-reflections originating from bi-layer motifs with slowly varying thickness give rise to closely spaced intensity maxima along the specular ridge and the sharper the interfaces are, the more slowly the intensity decays. For the SM with good NR, the Bragg-peaks are broad and give rise to intensity distribution along the specular ridge

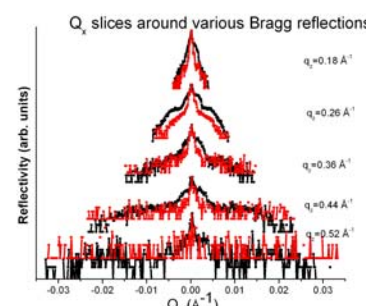
- What is happening in the poor SM?

Off-specular reflectivity

- Reciprocal space maps of the good and poor SMs show interface correlations evident from Resonant Diffuse Scattering (RDS) sheets
- Prominent RDS-sheets along q_x at constant q_z Bragg positions in poor SM indicates a strong interface roughness correlation
- The intensity is spread mostly around the q_z Bragg spot in the good supermirror case – rather sharp interfaces



Lateral correlation lengths



Diffuse scattering intensity has a broad shoulder for the poor SM case (black) compared to the good one (red) and the correlation lengths estimated are:

ξ_{good} = 4703 ± 1500 Å ξ_{poor} = 1964 ± 748 Å

Conclusion

We have shown that the interface properties of the very first layers of depth-graded multilayers (e.g. neutron & x-ray supermirrors) can be studied post-situ by means of back-face x-ray specular and off-specular reflectometry. In the SM we investigated, the neutron reflectivity performance is found to be directly related to the strong lateral correlation of the roughness rather than the actual roughness itself.

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