A study on reflectivity limit of neutron supermirror

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Multilayer mirror is one of the most important devices for slow neutron experiments. A multilayer with small d-spacing and supermirror with large-m are desirable to enlarge utilization efficiency for neutron scattering experiments. Here m is a maximum critical angle of the mirror in unit of critical angle of nickel and Q of nickel ($m = 1$) is 0.215 nm^{-1}. It is also very important to fabricate high reflectivity supermirror even in low-m. Ion beam sputtering (IBS) technique enables us to fabricate smooth layer structure with sharp edge. Indeed, we have succeeded in fabricating $m > 5$ supermirrors and very small d-spacing multilayer using ion beam sputtering (IBS) technique, and neutron optics group in JAEA has installed a large IBS machine and is producing supermirror for J-PARC project. In these reports, the effect of interface roughness and intermixing at each layer boundary in multilayer seems to be less than surface of substrate even in $m > 5$ supermirrors. In our previous result, the measured reflectivities were well reproduced by the simple interface roughness model given in Debye-Waller factor. The surface roughness of ordinary substrate, for example commercial silicon wafer and float glass, is almost larger than 0.4 nm in rms (root-mean-square). The supermirrors were deposited on silicon wafer using IBS instrument installed in the Kyoto University Research Reactor Institute (KURRI).The deposition rates of NiC and Ti were determined by X-ray and neutron reflectometry. The real and imaginary nuclear potential values of NiC were estimated to be 230 and 0.063 neV, respectively. Those of Ti were -51 and 0.038 neV, respectively. The deposition rates of NiC and Ti were estimated to be 0.0315 and 0.037 nm/s, respectively. We have fabricated $m = 2.9$ NiC/Ti supermirror on ordinary silicon wafers in which surface roughness are about 0.4 nm by ion beam sputtering technique. As shown in the inset of Fig.1, the measured reflectivity at $m < 2.8$ was much better than the expected theoretical lines with σ=0.3 and 0.4nm. It was well reproduced by the theoretical line with ideal smooth layer structure in which surface and interface roughness is nothing or very little ($\sigma < 0.1$). In case of IBS technique, supermirror reflectivity is not restricted with in the simple surface roughness model. We realized almost theoretical reflectivity limit of $m = 2.9$ NiC/Ti supermirror by ion beam sputtering technique. It is effective for high reflectivity low-m supermirror deposited on an ordinary substrate to increase the number of layer. It is also useful for realization of small d-spacing monochromator with high reflectivity although we have to estimate the effect of interface roughness with more realistic model.

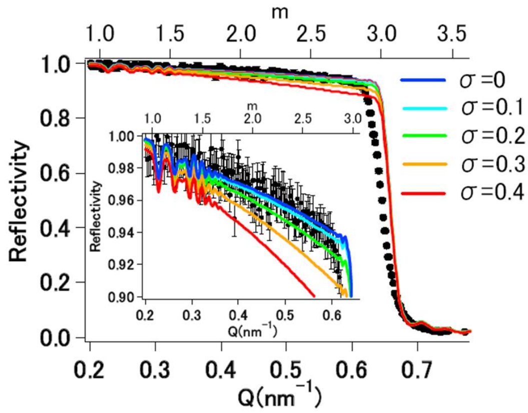

Fig. 1. Measured reflectivity of m=3 supermirror in which number of layers is 650. The solid lines indicate theoretical ones with σ=0, 0.1, 0.2, 0.3 and 0.4 nm. The inset is enlarged at high reflectivity (R$\geq$ 0.9).