Development of very small *d*-spacing multilayer neutron mirrors

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Neutron optical devices are very significant to progress neutron instrumentation and neutron science. Neutron multilayer mirror, e.g., supermirror, is one of most important key devices. It is still important to develop smaller *d*-spacing with higher reflectivity and wider bandwidth like supermirror. In this study, we report a successful result of very small *d*-spacing multilayer neutron mirrors in which average thickness of one layer is approximately 1 nm. The multilayer coating was conducted with ion beam sputtering machine at the KURNS (KUR-IBS) [1]. Figure 1 shows the photograph of configuration of mirror substrates in the KUR-IBS. Figure 2 shows reflectivity profiles of neutrons by a NiC/Ti(C) multilayer neutron mirror deposited on a silicon wafer (U0) placed at center of the substrate disk holder shown in Fig.1. Here the effective number of layers is 3360 and the half of the layers were very thin carbon interlayers. The thickness of carbon interlayer is constant and approximately a few sub-nanometers. In the point of view of the reflectivity performance, the effective number of periodic layers is 1680. The designed *d*-spacings are gradually changing from 2 nm to 2.2 nm. The measurement of the multilayer mirrors was conducted by neutron reflectometer at C3-1-2 (MINE) port at JRR-3. The measured average *d*-spacing and reflectivity at the peak position were estimated to be 2.03 nm and 1.4%, respectively. In even ideal case (surface roughness is zero), the reflectivity is approximately 8 %. The effect of surface and interface roughness was approximately estimated to be less than 0.4 nm(rms) that is same with surface roughness of silicon wafer. The average wavelength of incident monochromatic neutron beam 0.88 nm is relatively long and it is easy to estimate the performance of stacking mirrors. As shown in Fig.3, we observed that measured neutron reflectivities were increased by number of the stacking mirrors.

[1] M.Hino, et al., Nucl. Instr. and Meth., 797(2015) 265.

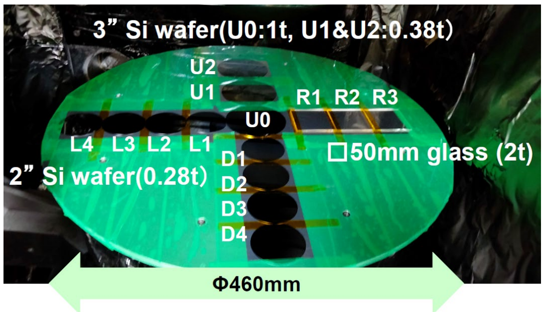

Fig. 1. The photograph of silicon wafers and glass plates placed on the substrate disk holder in diameter of 460 mm in the KUR-IBS.

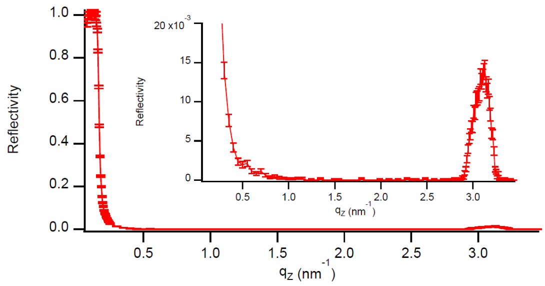

Fig. 2. The measured neutron reflectivity of the multilayer deposited on 3 inch silicon wafer (U0) placed at center of the substrate disk holder. The inserted figure shows the enlarged view.

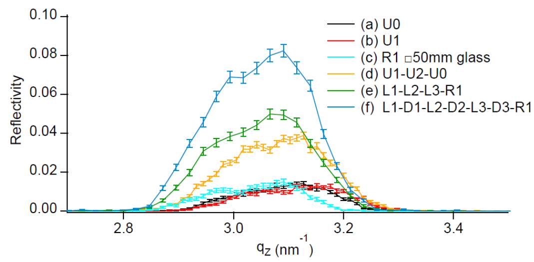

Fig. 3. The measured neutron reflectivities (a), (b) and (c) are those by single multilayer mirror of U0, U1 and R1 position, respectively. The reflectivities (d), (e) and (f) are those by triple (U1-U2-U0), quadruple(L1-L2-L3-R1) and septuple(L1-D1-L2-D2-L3-D3-R1) mirrors, respectively.