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X-ray reflectivity studies on single-crystal molybdenum mirror

Mari MIZUSAWA and Kenji SAKURAI*
National Institute for Materials Science, Sengen, Tsukuba, Ibaraki 305-0047, Japan

Introduction

So far, flat and smooth mirror surfaces have been obtained mainly for glass and silicon. Although coating metals on such mirror-polished substrates is the usual procedure for industrial applications, probably the only exception at the moment is a single-crystal metallic molybdenum mirror [1,2]. In the present report, X-ray reflectivity data [3] are discussed.

Experimental

The sample measured in the present study was a single-crystal molybdenum mirror (Nippon Mining, SN 01076), which was prepared by the secondary recrystallization method [1]. The diameter was 25.0 mm and the thickness 5.0 mm. The surface roughness measured by a mechanical stylus profiler was around 1 nm. The orientation of the surface is approximately 18~20 deg. distant from (200) plane. X-ray reflectivity measurements were carried out with 16.0 keV X-rays. The beam size was 0.05×1.0mm.

Results and Discussion

Figure 1 shows the experimental specular reflectivity, which were obtained through θ/2θ scan at grazing incidence. As X-ray reflectivity is influenced by not only roughness in the nm scale but also the degree of flatness in the μm scale, the divergence of the reflected beam was examined. The reflectivity below the critical angle (3.7 mrad) was 82 % as shown in Fig.1, but it reached around 95~96 % when the receiving slit was removed. The data show oscillations at ~5 mrad and also at ~20 mrad, suggesting the existence of thin surface layers, which are probably formed due to near surface damage during polishing. A fitting based on the layered model concludes that the 3-layered model is most likely; the top surface roughness is 0.7 nm rms, and the layer thickness and density of each layers are 2.20 nm and 2.91 g/cm^3 (28.5% of bulk molybdenum) for the upper layer, and 4.15 nm and 8.58 g/cm^3 (84% of bulk molybdenum) for the second layer. The corresponding density profile is given as an inset of Fig.1.

Measurements of non-specular reflectivity were also attempted in the present study. It has been found that non-specular scattering is quite strong in the whole angular range, which is not usually expected for a very smooth surface. In particular, the intensity becomes 2~5 % of the specular peak (8.75 mrad) at near specular condition (8.0~9.5 mrad). Yoneda peaks (3.7 mrad and 13.8 mrad) are 2.2% and 0.54%, respectively. A numerical calculation indicates that both features can be explained for quite a large correlation length (> 3μm) and small Hurst parameter (0.2~0.3) with moderate roughness (~1.0 nm rms) [3]. Those values could be concerned with

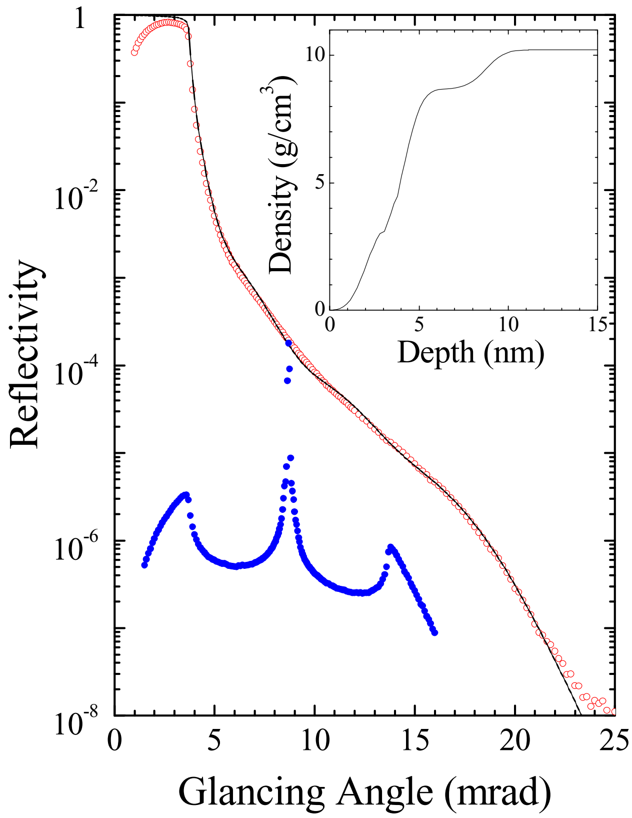

Fig.1 Specular (red open circle) and non-specular reflectivity (rocking scan, blue closed circle) for single crystal Mo mirror. The fitted curve for specular reflection is shown as solid line. The inset indicates the surface density profile proposed in this study.

the domain structure of the single-crystal formed through the recrystallization process, i.e., a domain size larger than 3μm, and ~1.0 nm rms roughness in the domain, and somewhat jagged morphologies due to near surface damage and also some sub-domain structures between domains. The authors would like to thank Prof. Y. Hiraoka of Okayama Science University for his valuable discussions, and Prof. S. Kishimoto for his kind assistance during the experiment.

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*sakurai@yuhgiri.nims.go.jp