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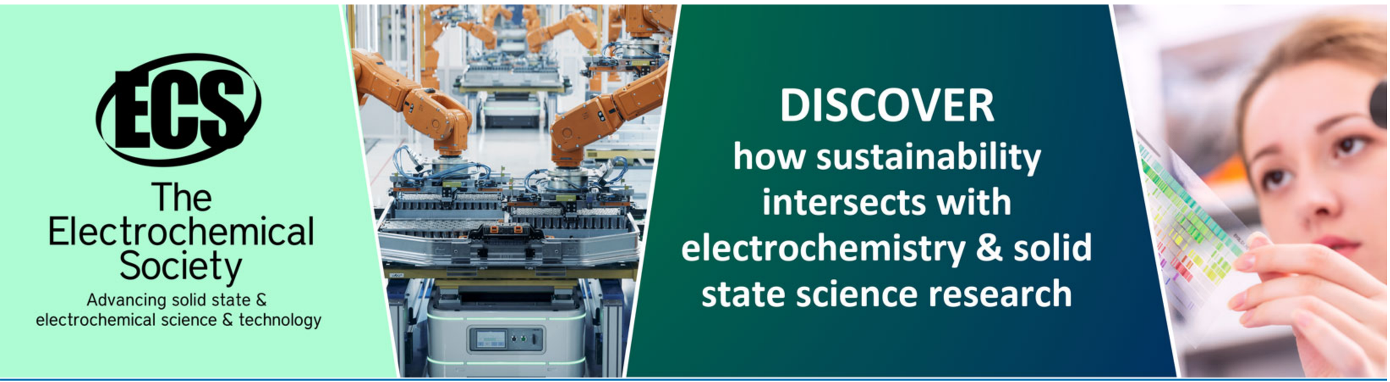

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Mo/Si and $MoSi_2$/Si nanostructures for multilayer Laue lens

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Abstract. To develop a multilayer Laue lens (MLL), we fabricated depth-graded Mo/Si and $MoSi_2$/Si multilayers with each boundary according to the Fresnel zone configuration. The multilayers were deposited by magnetron sputtering. From the result of SEM image analysis of the multilayer cross sections, $MoSi_2$/Si multilayer had smaller layer-thickness errors than Mo/Si multilayer. In addition, from the result of the focusing test by using 20-keV X-rays, the measured beam size of $MoSi_2$/Si MLL had a small blurring from the diffraction limited beam size. These results suggest that $MoSi_2$/Si multilayer is better suited than Mo/Si multilayer for use as an MLL in hard x-ray nanofocusing.

1. Introduction

Nanometer-sized x-ray beams are desired for x-ray microanalysis and x-ray microscopy at a nanometer scale. For this purpose, development of x-ray optical devices is advancing rapidly in recent years. Focused spot sizes of a few tens of nanometers have been obtained using Kirkpatrick-Baez mirrors [1,2], compound refractive lenses [3], Fresnel zone plates [4-6], and multilayer Laue lens (MLL) [7-9]. MLL was pioneered by the APS group. The MLL consists of multilayer structures and uses the Bragg diffraction effect to improve spatial resolution and diffraction efficiency; thus, this technique appears promising with regard to the achievement of a 1-nm focus with very high diffraction efficiency, even in the hard x-ray region [10]. Their MLL is composed of WSi_2 and Si layers [8]. We recently designed and fabricated an MLL by magnetron sputtering, using Mo/Si and $MoSi_2$/Si as the multilayer materials by their superior properties of high diffraction efficiency. In particular, $MoSi_2$/Si is a likely candidate for good multilayer system because of its excellent thermal properties and sharp interfaces between the Mo-silicide layers and the Si layers [11]. In this paper, we report results of SEM image analysis of these multilayer nanostructures and those of the focusing test for hard x-ray nanofocusing.

2. Fabrication

A magnetron sputtering system was used to fabricate the Mo/Si and $MoSi_2$/Si depth-graded multilayers [12] with each boundary r_n according to the Fresnel zone configuration which is given by $r_n^2 = nf\lambda + n^2\lambda^2/4$, where λ is the wavelength and f is the focal length. The outermost zones were deposited first onto the flat Si substrate to get smooth interfaces around the thinner layer thickness,

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that is, the layers increased in layer-thickness from the bottom to the surface of these multilayers. In the Mo/Si ($MoSi_2$/Si) multilayer, the minimum layer thickness was designed to be 15 nm (10 nm), while the maximum thickness was designed to be 83 nm (100 nm). The total multilayer thickness was 4.2 μm (4.6 μm), and the number of layers was 165 (248). The focal length was designed to be 2.4 mm (1.6 mm) for an x-ray energy of 20 keV. The multilayers were subsequently sectioned and polished to appropriate depth.

3. Characterization by SEM observations

Figure 1 and figure 2 show the cross sectional SEM images of Mo/Si and $MoSi_2$/Si MLL structures and the measured values of layer thickness versus layer numbers. Each layer thickness was measured by SEM image analysis to compare with the designed layer thickness. The difference from the designed layer thickness was 9.2% RMS in Mo/Si multilayer and 4.0% RMS in $MoSi_2$/Si multilayer. $MoSi_2$/Si multilayer has a smaller layer-thickness error than Mo/Si multilayer in spite of the thinner design thickness. The large layer-thickness disturbance in the Mo/Si multilayer is mainly due to the large interdiffusion and aggregation between the Mo-layers and Si-layers. The shaper interface in $MoSi_2$/Si multilayer is mainly owing to the non-reactive nature of $MoSi_2$ with Si.

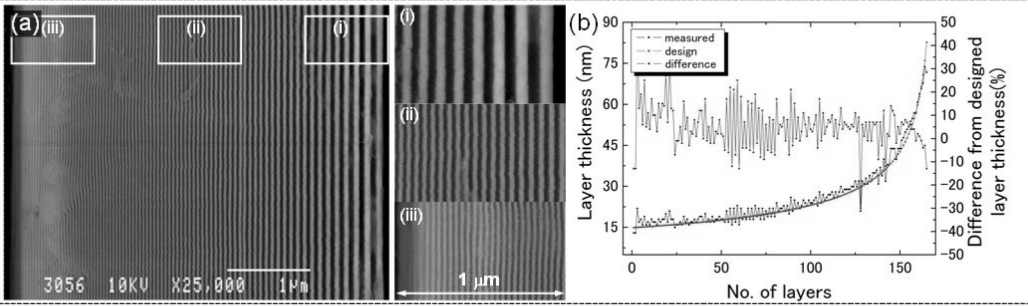

Figure 1. (a) Cross sectional SEM image of a Mo/Si MLL structure. (b) Measured layer thicknesses as a function of layer number obtained from the SEM image. Right vertical axis indicates a difference from a designed layer thickness. RMS value of the difference was 9.2%.

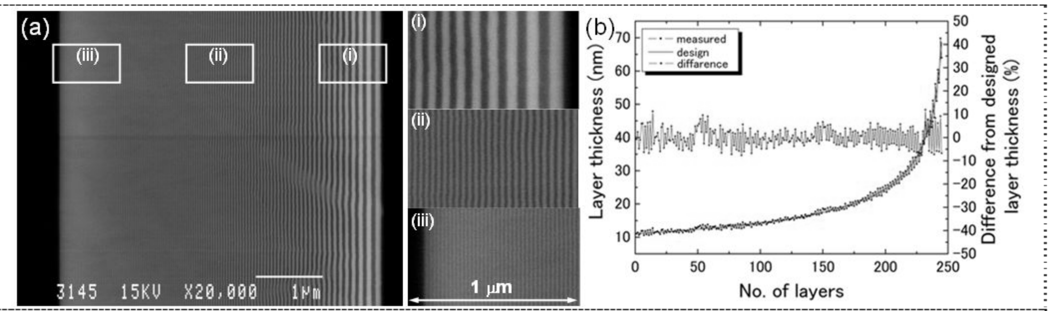

Figure 2. (a) Cross sectional SEM image of a $MoSi_2$/Si MLL structure. (b) Measured layer thicknesses as a function of layer number obtained from the SEM image. Right vertical axis indicates a difference from a designed layer thickness. RMS value of the difference was 4.0%.

Focusing test was performed at Hyogo-ID beamline (BL24XU) [13] of synchrotron radiation facility SPring-8 with 20-keV x-rays. The obtained beam sizes were 50.2 ± 3.9 nm and 28.2 ± 2.7 nm in the full width at half maximum, while the diffraction limited sizes are 36 nm and 22 nm for the Mo/Si and $MoSi_2$/Si MLL, respectively. Ten measurements were performed in order to confirm the

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reproducibility. The measured beam size of $MoSi_2$/Si MLL had a small blurring from the diffraction limited beam size in comparison with Mo/Si MLL.

4. Conclusion

To develop an MLL, we fabricated Mo/Si and $MoSi_2$/Si depth-graded multilayers with each boundary according to the Fresnel zone configuration. The multilayers were deposited by a magnetron sputtering. From the result of SEM image analysis of the multilayer cross sections, $MoSi_2$/Si multilayer had smaller layer-thickness errors than Mo/Si multilayer. In addition, from the result of the focusing test by using synchrotron radiation, the measured beam size of $MoSi_2$/Si MLL had a small blurring from the diffraction limited beam size. These results suggest that $MoSi_2$/Si multilayer is better suited than Mo/Si multilayer for use as an MLL in hard x-ray nanofocusing.

Acknowledgments

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