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Analysis of X-ray reflectivity from sputtered carbon thin films (1) Consideration of density gradient

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Introduction

X-ray reflectivity is a feasible routine tool to evaluate the structure of thin films along the depth, i.e., layer thickness and interface roughness [1]. Usually, analysis is automatically performed based on fitting to the Parratt's model [2]. Recently, however, it was ascertained that taking into account the gradient of the density is sometimes significant [3]. In this report, X-ray reflectivity from a carbon thin film sputtered on a Si wafer will be discussed.

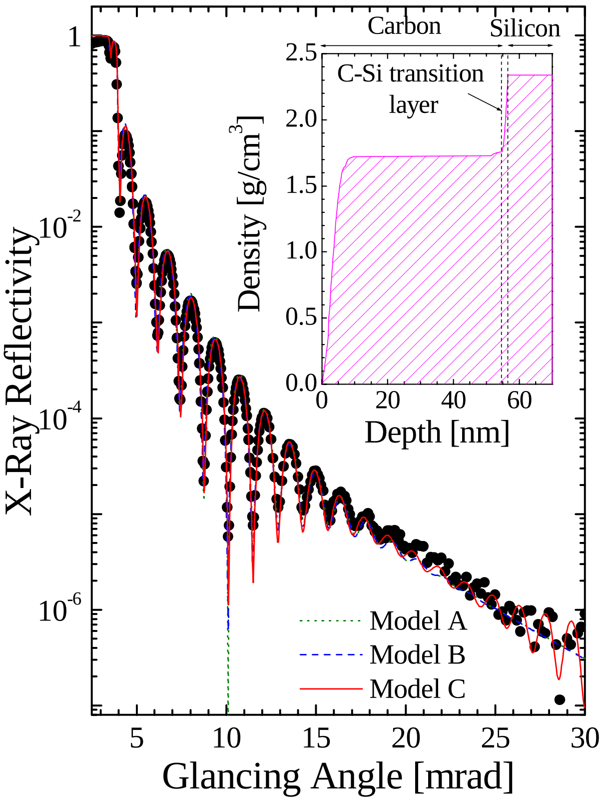
Results

The measured sample is a carbon thin film prepared by RF sputtering (200W, Ar pressure 1.0Pa, flow rate 10ccm). The substrate is a silicon wafer, which was kept at room temperature during the deposition. The deposition rate and time were ca. 0.9 nm/min and 1 h, respectively. Figure 1 shows the experimental reflectivity for 8.04 keV X-rays, which were obtained through θ/2θ scan at grazing incidence. Judging from the critical angle (3.85 mrad), it was found that the density of the carbon layer is very low (at least lower than 1.8 g/cm^3), probably due to the porous structure.

Data Analysis

Three different models were considered in the present study. We started with a very simple structure, a uniform carbon layer on a silicon substrate (Model A). The best fit was obtained when the layer thickness was assumed as 53.0 nm. As shown in Fig.1, the amplitude of the interference oscillation is not well reproduced, particularly in the high-angle region (16~30 mrad). Therefore, we improved the model and introduced an intermediate layer between the carbon layer and the substrate (Model B). The parameters obtained are listed in Table 1. Figure 1 indicates that the degree of fitting was improved by Model B, but it is not still perfect. In addition, one may wonder why the density value for the intermediate layer is very low in spite of the fairly different chemical composition.

The final model assumes some gradient in the density between the carbon layer and the silicon substrate (Model C, as shown in the inset of Fig.1). It was confirmed that the fitting is almost satisfactory. The results suggest that there exists a transition region (1.17 nm) between the carbon layer and silicon substrate. This could correspond to some instability in the growth of the carbon layer at the beginning of sputtering. The deposition could gradually stabilize by forming such a thin layer. The density gradient is not exactly linear, and the density of the bottom part of the carbon layer is slightly higher (1.85 g/cm^3) than that of the uniform region (1.73 g/cm^3). The total carbon layer thickness is 55.4 nm, but the uniform region is 41.8 nm. The authors would like to thank Dr. S. Takahashi (NIMS) for preparing samples.



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	Layer No.,	Thickness	Roughness	Density 3
Model A	1 C	53.0	1.8	1.74
	2 Si	-	0.5	2.34
Model B	1 C	50.0	1.8	1.70
	2 C-50%Si	3.0	1.2	1.73
	3 Si	-	0.5	2.34

Table 1 (top) Parameters obtained for Models A and B to explain the experimental X-ray reflectivity shown in Fig.1.

Figure 1 (left) X-ray reflectivity of carbon thin film sputtered on a silicon substrate. Closed circle, experimental data. Dotted, dashed and solid lines are calculation based on Models A, B and C, respectively. Density profile assumed for Model C is shown as an inset.