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Effect of ion irradiation on the evolution of Pt film morphology

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Abstract

Atomic force microscopy (AFM) and X-ray diffraction (XRD) analysis have been used to characterize ion-irradiated-and-annealed surface structures of Pt thin films deposited on SiO_2 glass substrates. The surface morphology of the Pt films is found to be strongly dependent on ion irradiation conditions. A Pt film composed of grains of approximately 1 μm diameter with a smooth surface is successfully prepared by an appropriate combination of ion irradiation and annealing. The Pt film shows a preferential (1 1 1) orientation parallel to the substrate surface.

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Keywords: Platinum film; Silica glass substrate; Single-crystalline film; AFM; Ion irradiation; Large grain

1. Introduction

The particular properties of thin-film materials show up most clearly when the film is single crystalline. Epitaxial film growth on a single-crystal substrate [1–5] is one of the most advisable means of depositing single-crystalline films. For practical reasons, however, thin-film growth on amorphous substrates has also been studied: Potassium lithium niobate thin films with a *c*-axis orientation have been prepared on a glass substrate by optimizing their sputtering parameters [6]. Hontsu et al. have shown the effect of an amorphous AlO_x buffer layer on the growth of *c*-axis-oriented $YBa_2Cu_3O_{7-y}$ thin films on an amorphous substrate [7]. Adapting such a buffer layer is one means of depositing high-quality thin films on amorphous SiO_2. Generally speaking, a single-crystalline buffer layer is most desirable because it can be expected to function as a single-crystal substrate for the deposition of high-quality thin films. From an application viewpoint, film deposition on an amorphous oxide layer, such as SiO_2, will become more frequent because the vertically integrated architecture, the so-called stacked structure, will be the basis of next-generation Si integration technology [8]. To fabricate this structure, a single-crystalline buffer layer will first be deposited

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on amorphous SiO_2 for the subsequent deposition of high-quality thin films on it. The two-dimensional size of crystallites in the buffer layer must be about 500 nm to make the layer suitable for application to stacked-structure CMOS devices.

The object of this work is to develop a deposition method for single-crystalline films on an amorphous SiO_2 layer. Here, we show preliminary results of the deposition and ion-beam modification for growing a single-crystal-like Pt film on a SiO_2 glass substrate. Pt metal was selected as the film material because of its high melting point and stability in oxidizing atmosphere required for the deposition of additional oxide films.

There are many reports on the deposition of Pt films [9–17]. Wei et al. have reported Pt film deposition on silica glass substrates by the MBE method [17]. The surface of the film produced was 1.25 nm in roughness (root mean square, RMS) and consisted of Pt grains of approximately 200 nm diameter. The ion-beam modification of the Pt film surface has also been examined [18,19]. Balaji et al. have fabricated a Pt film approximately 30 nm in grain size and less than 1 nm in roughness [19].

2. Experiment

The initial Pt films were prepared by rf magnetron sputtering. The polished SiO_2 glass substrates were cleaned in ethanol solution with an ultrasonic cleaner, heated at 1300 K for 1 h in oxygen atmosphere, and placed in a sputtering chamber. The surface roughness (RMS) of the substrates was less than 2 nm. Pt films, 200 nm in thickness, were deposited on the SiO_2 glass substrates at a substrate temperature of 873 K [3]. Film thickness was monitored by a quartz thickness monitor near the sample position and calibrated by 2 MeV He^+ RBS and the RUMP simulation code [20]. Ion irradiation and the subsequent annealing were performed with the as-deposited Pt films. Ar^+, Si^+ and/or Cu^+ ions with energies from 45 to 750 keV were irradiated onto the films at a fluence of 1×10^{20} ions/m^2. The ion-irradiated films were subsequently annealed for 1 h at temperatures from 773 to 1173 K in oxygen atmosphere. For comparison, the as-deposited films were annealed under the same conditions. The crystallographic properties of the prepared films were studied by X-ray diffraction (XRD) (RINT2100 + MPA2000, Rigaku Co., Japan) analysis, and their surface morphologies by atomic-force microscopy (AFM) in the noncontact mode (SPA400, SII, Japan). Grain size was calculated as the diameter of a circle with the same area as the grain area.

3. Results and discussion

Fig. 1 shows the annealing temperature effect on the as-deposited Pt films' morphology. The grain size and surface roughness of the as-deposited Pt films were about 60 and 15 nm, respectively. There was no substantial effect of the annealing on the Pt grain growth up to 1023 K despite surface smoothening. At 1173 K, the Pt grains have grown to a size of about 200 nm by annealing, whereas the roughness of the surface has increased to 15 nm due to the growth of deep troughs. Prolonged annealing had little effect on grain size and roughness. Fig. 2 shows the effect of Ar^+ ion irradiation and annealing on the Pt films' morphology. The Pt films (200 nm in thickness) were irradiated with Ar^+ ions 50, 180 or 750 keV in energy at a fluence of 1.0×10^{20} ions/m^2. The irradiated films were then annealed at 1023 K. As mentioned above, the thickness of

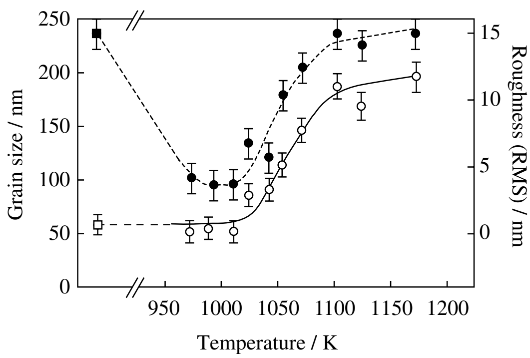

Fig. 1. Effect of annealing temperature on morphology of as-deposited Pt films. The open circles indicate the grain size, the solid ones the roughness (RMS). The values for the initial film are presented by squares.