ROLE OF SURFACE TOPOGRAPHY ON ANGULAR DISTRIBUTION OF SPUTTERED Cd ATOMS*

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ABSTRACT

The angular distributions of sputtered Cd atoms were measured with 27 keV Ar^+ ion bombardment at normal incidence for different target temperatures by using collector technique and RBS analysis. After the sputtering experiment the surface structures were observed using scanning electron microscope. For all samples the angular distributions are over–cosine. But the exponent n from fits of $\cos^n\theta$ to experimental angular distributions changes with target temperature. A simple model is proposed to explain the relation between shape of angular distribution and topography of sputtered surface.

Keywords: Sputtering Angular distribution Topography

1 INTRODUCTION

The linear collision–cascade theory of sputtering predicts that the angular distribution of sputtered atoms have a cosine dependence. Taking into account the depth dependence of the energy deposition distribution near the surface in Falcone and Sigmund theory[1], they have an over–cosine angular distribution, i.e., enhanced emission in small polar angles compare to the cosine distribution. The theory predicts that the over–cosine distribution of sputtered atoms is due to the ejection of recoil atom at deeper layer. For a relatively higher energy ion, angular distribution shows a strong over–cosine distribution.

Yamamura *et al.* investigated the influence of the ion–beam induced surface topography upon the angular distribution of sputtered atoms[2], and found that average lattice constant of surface atoms became larger due to surface roughness induced by the ion beam. This effect will influence the degree of over–cosine character in the angular distribution of sputtered atoms. Rodelsperger *et al.*[3] performed measurements of angular distributions on Au and Cu targets, *etc.*, and discussed the influence of

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topography on the angular distributions of sputtered atoms. Yasuhiro Nagai *et al.*[4] reported that the angular distributions of Ni and Fe atoms sputtered from the Fe–Ni alloy target change as the ion incident angle increases. From a simple model analysis, this phenomenon was caused by surface topography combined with oblique ion incidence. More recent experimental results[5] showed influence of the surface topography of irradiated Fe–W(25 wt%) alloy target on the sputtered atom angular distributions of the individual elements, the shape difference between the Fe angular distribution(over–cosine) and W one (cosine–like) linked up with the composition difference between the pit areas (enriched Fe) and the matrix areas (enriched W) on the sputtered surface. It showed that the sputtered surface micro–topography may be one of major causes of the deviation of the angular distribution of individual elements.

In order to get more information of the ion induced surface topography influence on the pattern of angular distribution, angular distributions of sputtered cadmium atoms were measured at different target temperatures. At the same time, sputtered surface were examined for each sample at different temperatures by SEM and the correlation between surface topography and shape of the angular distribution were discussed.

2 EXPERIMENTAL AND RESULTS

In this experiment, the results of the angular distributions of atoms sputtered from pure elemental cadmium(99.99 %) are reported. The configuration of the present experiment is very similar to that used in previous work for sample temperature control[6]. The measurements reported in this work pertain to sputtering of Cd samples bombarded by 27 keV Ar^+ ions at normal incidence. The sample temperature was kept at 25, 80 or 150 ℃ as measured with a thermocouple attached to the sample heating stage. At 150 ℃, corresponding to about 0.47 of the melting temperature of cadmium, the evaporation from the target can be neglected for the sputtering measurements. The sputtered material was collected on pure Al foil mounted around the target on a cylindrical cup with a radius of 3.0 cm. The bombardmental Ar^+ beam current was about 0.7 μA and the total dose all was 1.4×10^{18} ions/cm^2 for three samples. After irradiation the density of sputtered atoms on a collector was analyzed by RBS using 2.0 MeV He^+ ion.

Fig.1 shows the angular distributions of the sputtered atoms for different sample temperatures. This polar plot shows the relative sputtering yield of cadmium as a function of atom ejection angle θ relative to the sample surface normal. The origin of the plot is located at the center of the sample surface, and the axis of $\theta = 0°$ is oriented on the enter line of the bombarding ion beam. The angle of 90° represents the horizon of the sample. No atom ejection data could be taken near the axis of

$\theta \approx 0°$, since the shroud cut away to allow the passage of the ion beam. For comparison, a plot of the ejection pattern with a cosine distribution is also shown in Fig.1.

The comparison of the measured angular distribution curves with the isotopic cosine distribution shows that the angular distributions of sputtered Cd atoms at higher temperature is closer to a cosine distribution than that at room temperature. In other words, if it is assumed that the angular distributions can be fitted by $\cos^n\theta$, as in Ref.[7], the value of exponent n_T for elevated temperature sample is smaller than the n_{25} i.e. $n_{150}=2.32< n_{80}=6.85< n_{25}=8.90$.

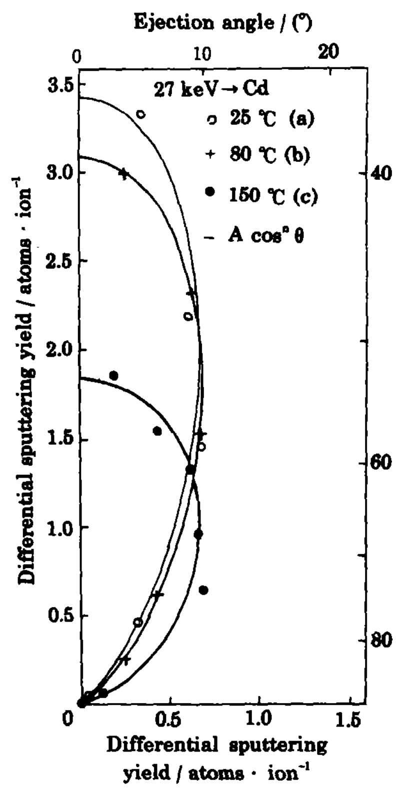


Fig.1 Angular distributions from Cd samples bombarded (normal incidence) with 27 keV Ar^+ at different sample temperatures

In order to understand the role of surface topography on the formation of the pattern of angular distribution the examination of the bombarded surface for each sample of sputtering was carried out using a S-570 model scanning electron microscope. The result is shown in Fig.2. When a sample is sputtered at room-temperature, the sputtered surface exhibits honeycomb type structure with deeper etch pit and few voids (Fig.2a), the sputtering of smaple with same dose (1.4×10^{18} ions/cm^2) at 150 ℃ can lead to a lot of large or little rock-like structure with shallow etch gully on the sputtered surface (shown in Fig.2c). But, it can be seen that for sputtered surface of sample B at 80 ℃ a quite different feature appears to sputtered surface of samples A at 25 ℃ and C at 150 ℃. Two textures which characterize the feature of the sputtered surface are the rock-like structure and peach-like cone groups which were scattered on the matrix of the rock-like structure as in Fig.2b.

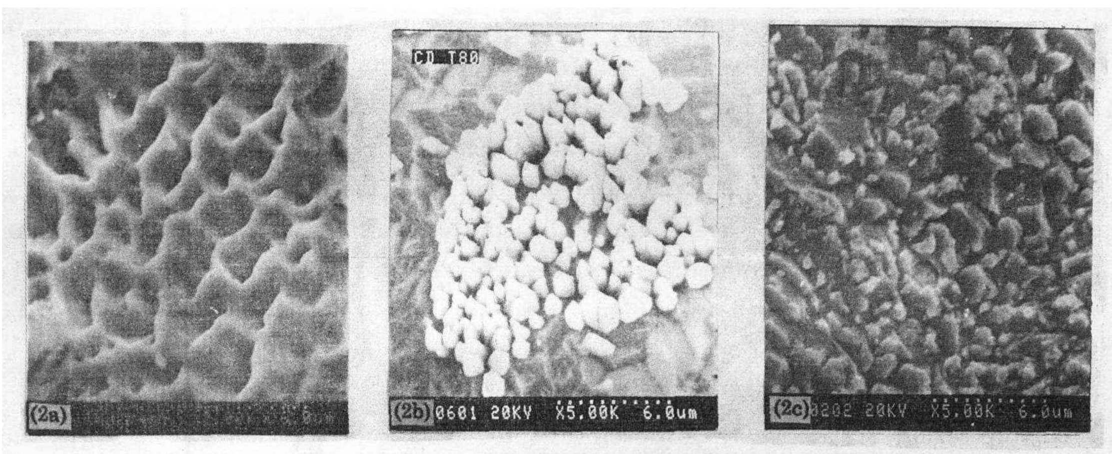
3 DISCUSSION

In order to discuss the relation between shape of angular distributions and topography of sputtered surface, we assume that the differential sputtering yield from bombarded surface with micro topography consisting of two parts, as following:

$$y(\theta) = y_N(\theta) + y_o(\theta) \tag{1}$$

where y_N and y_o are the sputtering yields of normal and oblique incidence of ion beam respectively.

For a faceted surface the sputtering yield will therefore be a function of angles ϕ, the incidence angle of ions, with the different facets, developed during ion bombardment. So the total differential sputtering yield $y(\theta)$ will be the sum of all local differential sputtering yields.



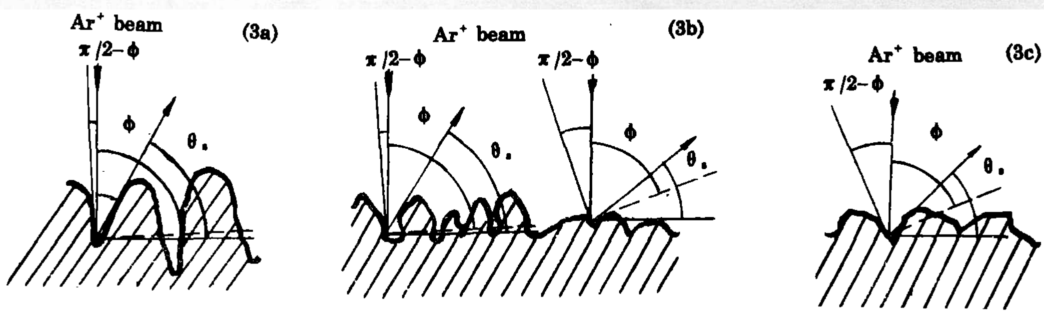


Fig.2, 3 SEM image of Cd surface (2) and the models of sputtered atoms ejection from different textured surface (3) with 27 keV Ar^+ ions bombardment at same condition and different temperatures

(a) 25 ℃, (b) 80 ℃, (c) 150 ℃. θ_s is shadowing angle, $\alpha = 90^\circ - \phi$

At our experiment condition, bombardmental ions were normal incidence upon the surface of honeycomb pit bottoms and voids on the sputtered surface [$y_N(\theta)$], and oblique incidence on the inside wall of honeycomb pits (see Fig.3a), peach-like cone sides (see Fig.3b) and plane surface of polyhedron of rock-like grains (see Fig.3c) with different angle of incidence [$y_o(\theta)$]. For normal incidence of ion, a cosine distribution will be expected. For oblique incidence of ion beam, Marsh *et al.*[8] found a dependence of the sputtering yield on the angle of incidence, ϕ, given by

$$Y(\phi)/Y(\phi=0)=[1+6.66(\phi/90)^2]\cos\phi \quad (2)$$

where ϕ is measured from the surface normal. At the same time, the results indicating preferred forward emission of the sputtering atoms under an oblique angle of incidence were reported. In this case, the shadowing effect for the sputtered atoms is even more effective. Thus the shape of the angular distribution of the sputtered atoms from a target surface can then be obtained if the microscopic surface roughness with a shadowing effect is taken into account, as in Fig.3. Indeed, when an ion beam is directed normal to a featured surface, it will hit an individual microscopic facet (the inside wall of honeycomb pit, peach-like cone side and plane surface of polyhedron of rock-like grain, *etc.*) at an oblique angle. Two competing effects then coexist: a yield increase by an enhanced effective projective incidence angle [see Eq.(2)], and a yield reduction by recapture of obliquely ejected atoms by neighboring convex. It is thus clear that because of the particular geometry of the honeycomb pits and peach-like cones or rock-like grains, as in Fig.3, the sputtered atoms ejected at small polar angles (θ) escape easily from surface, while at large polar angles part of the obliquely emitted atoms gets trapped in the pit inside or forest of cones and grains. This explains the tendency of the over-cosine distribution or even Gaussian-like distribution of the sputtered atoms from surface covered with cones, grains or pits. From the discussion above, the differential sputtering yield $y(\theta)$ defined in Eq.(1) also may be written:

$$y(\theta) \approx \text{cosine} + \text{Gaussian-like} \quad (3)$$

This relation is very similar to what proposed by Hung for sputtering of a textured surface[9]. Summing up all that has been said the following results can be found:

a. It is a cosine-like distribution for the emission of sputtered atoms from void regions. b. According to both of the shadowing effect (the shadowing angle θ_S, defined in Fig.3) and resputtering (on the pit side and pedal region of the peach-like cone) of ejected atoms and reflected ions, the angular distribution pattern from the honeycomb pit bottom and pedal region of the peach-like cone may be changed into a Gaussian-like distribution. At room temperature (25 ℃) condition, therefore, the angular distribution of Gaussian-like pattern with a little modification in the large polar angle ($\theta > 45° \approx \theta_S$) is attributed to the featured surface (Fig.2a) due to ion sputtering. c. When a target is sputtered at higher temperature the Gaussian-like shape of angular distribution is also obtained. However, the extent of preferential ejection of sputtered atoms at small polar angle ($\theta < 45°$) is decreased, and the intensity is increased in the interval of the ejection angle from 45 to 90° , because the etch pits has been changed into unregular size rock-like grains (150 ℃) and peach–like cones on the matrix of which possess various shadowing angle respectively. Thus, this result can be expressed as: The exponents n_{150} and n_{80} for elevated temperature Cd samples are smaller than the n_{25} for room temperature, $n_{150} < n_{80} < n_{25}$. The comparison of this result with the experimental data in this work shows qualitative agreement.

4 CONCLUSIONS

In summary, the present work allows for the following conclusions to be drawn:

a. The investigation of the correlation of the topography on bombarded surface and the angular distribution of sputtered atoms seems to support the suggestion that the surface micro topography is of great importance to the formation of the pattern of angular distribution, except the contribution of the near–surface recoil atoms motion within collision cascade. b. The topography of the sputtered surface can be significantly changed through controlling sample temperature during sputtering. From the technology point of view, the operation which associates ion bombarding with controlling sample temperature may used as a new means for surface modification of material.

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