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Angular distributions of particles sputtered from multicomponent targets with gas cluster ions

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ABSTRACT

The experimental angular distributions of atoms sputtered from polycrystalline W, Cd and Ni based alloys with 10 keV Ar cluster ions are presented. RBS was used to analyze a material deposited on a collector. It has been found that the mechanism of sputtering, connected with elastic properties of materials, has a significant influence on the angular distributions of sputtered components. The effect of non-stoichiometric sputtering at different emission angles has been found for the alloys under cluster ion bombardment. Substantial smoothing of the surface relief was observed for all targets irradiated with cluster ions.

1. Introduction

During last two decades the interaction of gas cluster ion beams with solids has been under extensive study. Cluster ions have been widely used for precise surface polishing, ultra-shallow implantation, ion-assisted deposition of thin films, probing in SIMS technique etc. Different aspects of cluster ions interaction with solids were investigated [1–4]. At the same time, mechanisms of the gas cluster ion interaction with solids are not entirely understood. Meanwhile, an angular distribution of emitted particles is very sensitive to sputtering mechanisms. Nevertheless, only one experimental work [5], in which the angular distribution of metal (Cu) atoms sputtered with inert gas (Ar) cluster ions was measured, has been reported. The main part of sputtered atoms has been found to be ejected under cluster ion bombardment along lateral directions. This work and some molecular dynamics simulations [6] support the conclusion that the lateral angular distribution is characteristic feature of inert gas cluster sputtering. Besides, there is one more paper [7] where the angular distribution of W and Au under bombardment of $(SF_6)_n$ cluster ions were investigated but this is not our case as SF_6 is chemically active substance.

However, strong emission of target material along the surface normal was revealed recently in the case of Mo sputtering by 10 keV argon cluster ions [8]. A new sputtering mechanism connected with elastic properties of targets has been suggested in this study.

In the present work investigations of this mechanism were prolonged on the case of Cd, W, and alloys: NiMoRe and NiPd bombarded with 10 keV argon cluster ions.

2. Experiment

Sputtering experiments were carried out using a gas cluster ion accelerator [9]. A schematic diagram of the experiments is shown in Fig. 1. Argon cluster ions with energy of 10 keV and mean size 2000 atoms per cluster bombarded polycrystalline targets along the normal to the surface. Ions with masses in the range from monomers to clusters with a relative size of up to 5000 atoms per unit electron charge e were measured in the beam using a time-of-flight technique, and the maximum in the mass spectrum of cluster ions was observed to be 800 at/e. A magnetic mass-filter was installed before the collimating system to remove light ions (less than 80 at/e) from the beam. The background pressure in the target chamber which was evacuated with a turbo molecular pump was 1.5×10^{-4} Pa. The ion beam diameter was 1.3 mm, and fluences of bombarding ions were as in the work [5].

Polycrystalline targets (Cd, W, NiMoRe (86–10.5–3.5), and NiPd (50–50)) with purity of 99.99 at.% were used in these experiments. The samples were cut out as plates with dimensions 10×10 mm and thickness from 0.3 to 2 mm. The top side of each sample was mechanically polished and cleaned in organic solvents before irradiation.

A collector technique was used to measure angular distributions of sputtered material. A semi-cylindrical collector with radius

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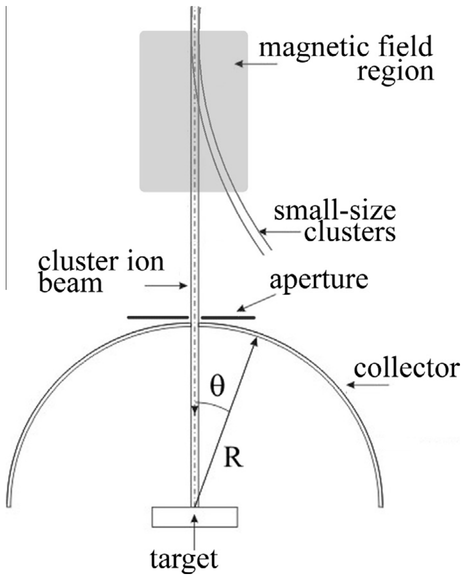

Fig. 1. Schematic diagram of the sputtering experiment.

15 mm was made of 0.1 mm-thick high purity Al foil. The material deposited on the collector was analyzed using Rutherford backscattering spectroscopy (RBS) with 1.7 MeV He^{+} ion beam with a rectangular cross-section of 1×2 mm^2.

Surface topography of the samples before and after bombardment were studied using a Solver P47-PRO atomic-force microscope (AFM) for which the lateral resolution was 15 nm.

3. Results and discussion

In our recent work [8] significant yield of sputtered material was observed along the normal to the sample surface when Mo was used as the target. The experimental angular distribution material sputtered from molybdenum was shown in this study to be well described by the expression:

$$Y(\theta) = Y_L \cos^{\alpha}(\theta - \theta_{max}) + Y_0 \cos^{\beta}(\theta) \quad (1)$$

where Y_L – the value of the lateral yield at emission angle $\theta = \theta_{max}$ (θ_{max} – corresponds the maximum of the lateral yield), Y_0 – sputtering yield at $\theta = 0°$, α and β – fitting parameters. Values of α and β could be extracted from the best fitting of expression (1) to experimental results.

Thus, the first term in expression (1) describes the lateral sputtering [5] while second one is connected with elastic properties of the sputtered metal: the contribution of this mechanism to the sputtered flux is greater than the higher modulus of elasticity of the irradiated material [8].

Some physical properties of all targets used in this study and in [8] are given in the Table 1. It is seen from this table that W has the highest modulus of elasticity. Therefore one might expect that the new mechanism revealed in [8] have to be more pronounced in case of W sputtering compare to Mo.

Table 1
Physical characteristics of targets used in the experiments.

Target	Surface binding energy (eV)	Modulus of elasticity (10^{11} N/m^2)	Atomic mass (a.m.u)
Ni	4.44	1.86	59
Mo	6.82	2.72	96
Pd	3.89	1.81	106
Cd	1.16	1.16	112
Re	8.03	3.72	186
W	8.66	3.23	184

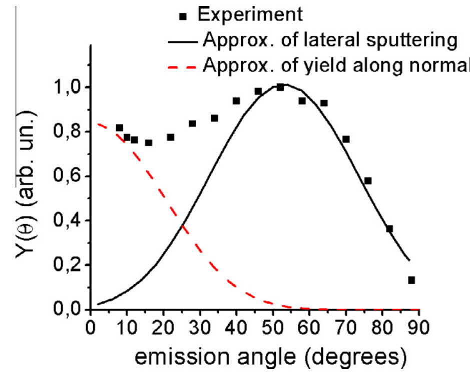

Fig. 2. The angular distribution of atoms, sputtered from W by 10 keV Ar cluster ions.

Fig. 2 shows the angular distribution of W atoms sputtered with 10 keV Ar cluster ions. The maximum yield of sputtered particles normalized to 1 at the angle $\theta_{max} = 55°$. It is seen from Fig. 2 that experimental results can be approximated well by expression (1) using a next procedure. First, experimental results were approximated by the first term of expression (1) at large emission angles $\theta \geqslant 60°$ (the solid line in Fig. 2). The best fit was found for $\theta_{max} = 55°$. Then this part sputtered flux was extracted from the experimental angular distributions. The resulting distribution (dashed line) as is seen in Fig. 2 can be well approximated by the second term of the expressions (1) with $\beta = 8$. The approximation parameters of the experimental angular distributions of atoms sputtered from Mo and W are listed in Table 2.

As the table shows, the contribution of the mechanism associated with the elastic properties of the target material is lower in the case of W sputtering compared to Mo.

In order to understand the reasons for this contradiction let us consider the mechanism responsible for the pronounced emission of atoms along the surface normal suggested in [8]. At the earliest stage of cluster interaction with target the collision frontal atoms of a cluster slow down, interacting with atoms of the target surface. Due to momentum transfer from cluster atoms to target atoms, the cluster ion puts pressure on the surface, causing compression of the target in direction of its motion. The value of this pressure (or stress) was estimated in [8] to be up to 10 Mbar. The next stage of the process is the collapse (or atomisation) of the bombarding cluster as well as the target in the region bombarded by the cluster. Ion-atom and atom–atom collisions develop according to the scenario described in the computer MD calculations [6]. At some moment, the elastic compression of the target begins to relax and creates movement of target atoms to the surface. As the result, emission of target atoms occurs near the surface normal. The contribution of this mechanism increases with increase of the elasticity modulus of the target material [8]. Apparently, the contribution of this mechanism also depends to a great extent on the value of the pressure created at the target surface. Therefore, one of the key points of the considered mechanism is

Table 2
Parameters of expression (1) for different targets. Parameters for Mo are from [8].

Target		Y_0/Y_L	α	θ_{max} (°)	β
Mo		1.13	4	50	12
W		0.83	8	55	8
NiPd	Ni	1.11	4	50	4
NiPd	Pd	0.96	6	64	5