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CHANGE IN THE CATHODE SPUTTERING COEFFICIENT AS A FUNCTION OF THE ANGLE OF INCIDENCE OF IONS ON A TARGET

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At the present time there is no unified, consistent theory of cathode sputtering. To elucidate the nature of this complex phenomenon, it is important to know the angular regularities of the process of target destruction. However, the influence of the angle of incidence of ions on the magnitude of cathode sputtering has been little studied. For ions of low energies, qualitative results are given in works ([1]-[3]). Quantitative measurements of sputtering under the action of ions with energies of tens of kiloelectronvolts are found only in papers ([4], [5]). But they were carried out for a relatively small interval of angles (from 0 to 50°), and the authors themselves regard them as unsuccessful because of the large convergence of the ion beam. For grazing angles of incidence (close to 90°), no measurements of the cathode sputtering coefficient had been made.

This paper presents the results of an investigation of the magnitude of cathode sputtering of polycrystalline copper samples by argon ions with an energy of 27 keV over a wide interval of beam incidence angles (from 0 to 84°). The experiments were carried out with argon ions, since under their action intense sputtering occurs and the surface of the target is not contaminated. The samples for sputtering were made from copper with a minimum content of impurities (M-0000) and from ordinary technical sheet copper of grade M-1. To clean the surface and remove stresses caused by rolling, the samples were annealed in a vacuum furnace at a temperature of 750–800° for 3-4 hr. With such treatment, recrystallization of copper occurs and the crystals increase somewhat in size ([6]).

The experiments were carried out on an apparatus of the type of a large mass spectrometer with double focusing of the ion beam in a sector magnetic field ([7]). The current density on the target was 1-2 mA/cm^2. The target was placed near the focus of the ion beam inside a sphere maintained at the temperature of liquid nitrogen. The gas pressure in the target region during the measurements was $1\text{-}2 \cdot 10^{-7}$ mm Hg. The inaccuracy in determining the angle of incidence of ions on the target at grazing incidence (80-84°) did not exceed $±$1°. The target was mounted on a massive electrode, whose temperature during the experiment did not exceed 150-200°. A special system of diaphragms with a combination of retarding potentials ensured correct measurement of the ion current to the sputtered specimen. The sputtering coefficient was calculated from the loss in weight of the specimen, the ion-current strength, and the irradiation time. Preliminary measurements showed that successive sputtering of one and the same specimen leads to a monotonic increase in the sputtering coefficient, and only after sufficiently strong destruction of the surface does the coefficient become constant; therefore such an increase in the coefficient cannot be explained by surface contamination.

Typical curves for the case of perpendicular incidence of ions on the target are shown in Fig. 1. Along the horizontal axis is plotted the product of the ion-current strength by the irradiation duration; along the vertical axis, the sputtering coefficient. It is seen that the increase in the sputtering coefficient for technical copper is 25% (1), and for copper with a small impurity content 15% (2). This increase is far beyond the limits of the accuracy of the measurements and the reproducibility of the results, which in any case is not lower than 5%. Examining the sputtered samples under a microscope, one can see,

that the sputtering coefficient increases as the surface is destroyed and individual grains of the target material are exposed. Consequently, it is necessary to distinguish between the sputtering coefficient of a "smooth" and that of a "destroyed" polycrystalline surface. This, apparently, also explains the discrepancy between the sputtering coefficients of copper by argon ions at normal ion incidence, reported in the recently published paper by Yonts et al. (8), and the results of (4). The increase in the sputtering coefficient as the surface is destroyed can be explained by the fact that the regions along the cleavage lines of the crystals are destroyed first; as a result, the angle of incidence of the ions on individual elements of the target surface changes.

Fig. 1

The dependence of the sputtering coefficient on the angle of incidence of the ions is shown in Fig. 2 (curve 1). The same figure also gives the product of the sputtering coefficient by the cosine of the ion incidence angle (curve 2). It is seen that the sputtering coefficient, for incidence angles up to approximately 70°, increases in inverse proportion to the cosine of the angle.

Fig. 2

With a further increase in the angle, the growth of the coefficient slows down, and then its value begins to decrease.

As special measurements have shown, the decrease in sputtering is accompanied by the appearance of fast reflected particles. They leave the target at an angle close to grazing. These fast particles are concentrated within a small solid angle and produce noticeable destruction of the surface of the sphere surrounding the target at the place where they strike. To estimate the fraction of energy carried away by reflected particles, the sphere had a special electrode equipped with a thermocouple. Its temperature calibration as a function of the supplied energy was carried out using a direct ion beam. The measurements showed that at an incidence angle of 70°, where no deviation of the cathode sputtering coefficient from the cosine law is yet observed, the loss of energy due to reflected particles is zero within the accuracy of the measurements. For an incidence angle of 78° this fraction of the energy is about 6%. With a further increase of the angle it increases (at 82°, 17%; at 84°, 22%). Although this qualitatively agrees with the decrease in the sputtering coefficient, it cannot quantitatively explain its decrease. For example, at an incidence angle of 78° the fraction of energy carried away by reflected particles is only 6%, whereas the deviation of the sputtering value from the cosine law is 40%. Consequently, the decrease in the cathode sputtering coefficient for grazing angles of incidence is explained not only by energetic factors, but also by other factors that require special study.

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Note: Figure translations are in progress. See original paper for figures.