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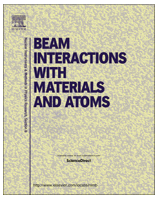

Features of angular dependence of secondary electron emission from metal single crystals

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ABSTRACT

The dependence of secondary electron emission coefficient σ on the angle α of primary electron incidence onto single crystals of metals with different crystalline lattice has been studied for undisturbed surface and for disturbed one by sputtering. We used the single crystals of Cu (fcc), Mo (bcc), Zn (hcp) and Ni_4Mo (tetragonal lattice). It was shown that the coefficient σ is smaller for the disturbed surface, than for initial one due to absorption of secondary and scattered electrons by the lateral surfaces of hills and cones which are formed as a result of sputtering. For the initial surfaces (of Cu, Mo and Ni_4Mo) the maxima of σ(α) in the low-index directions of the crystal lattice arise as a result of primary and secondary electron scattering on the atoms in open channels. At the same time, for the preliminary highly oxidized single crystal surface (of Zn) the minimum of σ in the direction of open channel was observed. The last can be explained by a reduction of work function of surface, and increase in penetration depth of electrons in open channel and by a rise of electron-phonon interaction. Angular dependences of secondary electron emission for a sputtered surface have a more complicated structure with the additional maxima and minima caused by interaction of secondary and scattered electrons with a cone-shaped relief.

1. Introduction

In recent years there has been great interest in the processes of charged particle interaction with surfaces and, in particular, in secondary electron emission [1,2]. A study of secondary electron emission is important not only for obtaining fundamental knowledge, but also for practical applications. Secondary electron emission is widely applied, for example, in electronic multipliers, in various electron-beam and high-frequency devices in the spectroscopic analysis of a solid body and it occurs during electron-beam melting and welding [3–5].

In the research field of secondary electron emission much attention is paid to interaction of electrons with single crystals. Very interesting phenomena, such as the anisotropic nature of secondary and scattered electrons, has been found [6,7]. The secondary emission coefficient σ (number of emitted electrons per incident electron) of metal single crystals was measured as a function of the angle α between a primary electron beam and the normal to the crystal face. The σ(α) dependences show small maxima and fine structure of the σ(α) curves arises. These maxima occur whenever the primary beam falls along one of the low-index axes of the crystal. The magnitudes of these maxima vary with the energy of the incident electrons, but their angular position does not change.

Further the fine structure of angular distribution of secondary electrons for the single crystals of metals and semiconductors has been obtained [8–14]. It was shown that anisotropy of the σ (α) dependence is defined by two factors. First, the intensity of secondary electron emission from the single crystal surface depends on the orientation of primary electron beam relative to the crystal axes (anisotropy *of excitation* of secondary electrons). Second, the anisotropy in angular distributions of secondary electron exit takes place (anisotropy *of emission* of secondary electrons).

The characteristic dependence of secondary electron emission from the (001) face of copper single crystal, obtained in [8], is shown in Fig. 1. Appearance of such thin structure of the σ(α) curve was explained as follows. In case of movement of electrons along open channels increases the number of elastic scattered and truly secondary electrons. Such explanation will be coordinated with the diffraction theory of electron channelling in crystals [4].

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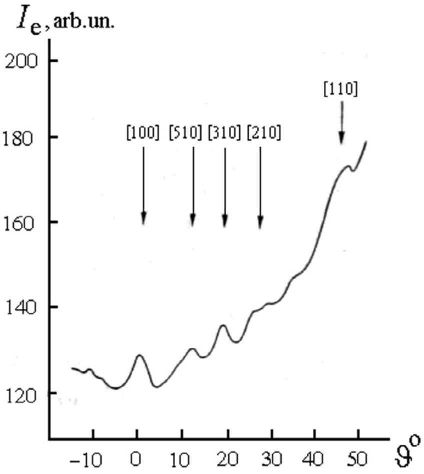

Fig. 1. Angular dependence of secondary electron current from (001) Cu face under rotation of crystal in (010) plain; the primary electron energy $E_p = 14$ keV.

It was of interest to study how changes the anisotropy of angular dependence of secondary electron emission after ion-irradiation of a single crystal surface of metals with different crystal lattice. Such study are fulfilled in this work for Cu (fcc), Mo (bcc), Zn (hcp) and Ni_4Mo (tetragonal lattice) single crystals.

2. Experimental

The ion irradiation of the single crystals was carried out using the system shown schematically in Fig. 2. The improved von Ardenne ion source allowed well-focused beams of argon ions with a current density of 1 mA/cm^2 at the energy $E_0 = 10$ keV to be obtained. The ion beam, after acceleration and focusing by a single electrostatic lens, passed through a hole in a quartz screen and bombarded the sample on the area with diameter of 2 mm. The dose of irradiation was measured by current integrator. A glass collector, on which the sputtered particles were collected, was placed parallel to the studied surface in front of the sample in the distance of 15 mm. Sputtered particles produced by normal or inclined incidence of the ion beam were deposited on this collector. The collector was used to determine the orientation of single crystal samples using the sputtered spot patterns.

For studying the secondary electron emission the LEO 14XX (VP) scanning electron microscope was used. We use a passing of 1 nA current through a crystal. Some times we measured also back-scattered and secondary electrons using a Faraday cup. The energies of primary electrons are: 20 keV for irradiation of Cu, Mo, and Ni_4Mo, and 10 keV for Zn.

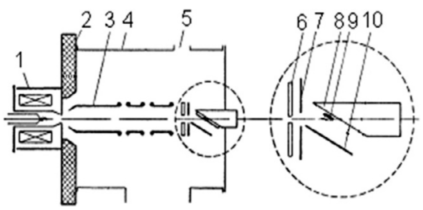

Fig. 2. Sputtering system. 1 – ion source, 2 – insulator, 3 – electrostatic lens, 4 – container, 5 – window, 6 – quartz screen, 7 and 10 – glass collectors, 8 – holder, 9 – specimen.

The topography of the surface has been studied by the scanning LEO-1455 (Carl Zeiss) electron microscope and by the atomic force microscope FemtoScan Online.

3. Results and discussion

The angular dependence of secondary electron emission coefficient $\sigma(\alpha)$ for Cu, Mo, Ni_4Mo and Zn single crystal faces before and after ion irradiation and their surface structure are presented in the next sections.

3.1. Cu (001) face, fcc lattice

The initial structure of (001) Cu face and the structure after ion bombardment by 10 keV argon ions with a dose of 10^{21} ion/cm^2 are shown in Fig. 3a and b. Hills and pyramids, of maximum height up to 20 μm, were formed at the ion-irradiated surface (Fig. 3b). The appearance an accurate sputtered spot pattern on a glass collector (Fig. 3c) shows that this rough surface with hills and pyramids has the single crystal structure with the same crystallographic orientation as the main surface. It coincides with results of our earlier studies [15–17] of growth of cones on the single crystals of metals and semiconductors under sputtering.

The secondary electron emission coefficient σ for the Cu (001) face versus the angle α of primary electrons in the (110) plane for the undisturbed surface and for a previously ion-irradiated surface is shown in Fig. 4. The main features of these curves are as follows.

1. There are clear maxima on the $\sigma(\alpha)$ curve, close to $\alpha = 19$, 35 and 55°, which arise in the close-packed [114], [112] and [111] directions, respectively, for the undisturbed surface. They appear due to the scattering of primary and secondary electrons on the atoms in open channels. This picture is similar to the one, which is shown in Fig. 1.
2. The $\sigma(\alpha)$ dependence changes for the ion-irradiated surface with highly developed surface roughness with single crystal cones and hills: the additional maxima on the $\sigma(\alpha)$ curve arise. There are two reasons for this: first, the primary electrons can arrive at the lateral faces of cones and hills at the angles, which may coincide with the angles of open channels. Second, the rise of σ with an increase of primary electron angles of incidence plays a role: the secondary electron emission can increase when the primary electrons strike the sides of hills and cones under the larger angles α.
3. The secondary electron emission is lower for the modified surface than for the initial one owing to absorption of secondary and scattered electrons on the lateral faces of hills on the ion-irradiated surface.

The reduction of the secondary electron emission due to surface roughness (with triangular grooves) was also obtained by computer simulations in Ref. [18] and explained as follows. An initial electron hits the surface of triangular grooves (cones) at different angles and produces secondary electrons. Depending on the emission angles, some of the secondary electrons can escape the groove and move away from the surface. Other secondary electrons would hit an inner side of the groove. With some probability they will be absorbed, or they can generate further secondary electrons (which are *second generation* secondaries). The process may repeat several times until the energy of higher generations becomes too low and they are absorbed by the surface.

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