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SPUTTERING OF GOLD BY URANIUM IONS WITH UNILAC ENERGIES

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The sputtering yield of solid foils by uranium ions in the energy range 1.25–5.5 MeV/u was investigated. The experimental results are different from those predicted by existent theories. A modified cascade mechanism of sputtering for the pair U–Au is proposed.

The sputtering yield of gold foils by uranium ions in the energy range between 1.25 and 5.5 MeV/u was investigated experimentally in connection with the need for acceleration and storage of high-intensity heavy ion beams in ring machines[1]. There is some concern that beam instability might be induced by avalanche effects if the sputtering yield at medium and high ion energies were high (>20 atoms/ion)[1]. A theory of high energy sputtering was published recently[2]. According to this theory the sputtering yield for the pair U–Au should be very large (a few hundred atoms/ion) due to inelastic interaction of high-energy ions with matter. Also, sputtering yield should increase when inelastic energy losses of heavy ions increase. The experimental results obtained by us, however, are different from the predictions of both the high-energy sputtering theory[2] and the better-established cascade theory[3]. We propose a possible mechanism of sputtering for the pair U–Au.

In order to obtain data on the energy dependence of the sputtering yield we employed a collection method based on a special target that consisted of many alternating layers of gold, carbon and aluminum foils. The carbon foils collect the sputtered gold atoms. The aluminum foils are used for changing the uranium ion energy. Gold foils with thickness of 0.4 μm were warmed in a vacuum oven at a temperature of 350°C during four hours to provide a gross grain structure. Sputtering yields strongly depend on the grain size[4]. This special target structure allowed us to take data of the relative sputtering yield of Au foils by U ions having different energies simultaneously. The quantity of sputtered gold on carbon collectors was determined by activation analysis. The results of one target stack are shown in Figure 1. The yields were measured for the forward ("transmission") and backward sputtering. As may be seen in Figure 1, the yields are not significantly different. The dependence of the sputtering yield on the U ion energy, as shown in Figure 1, is not in agreement with the high-energy sputtering theory[2]. While the cascade mechanism[3] predicts a functional behavior similar to Figure 1, the experimental results are much higher than those predicted by this theory.

The absolute sputtering yield of Au with a clean surface by U ions was measured. The surface of the gold was cleaned by heating. The sputtering yield is equal to 12 ± 2 atoms/ion at U-ion energy of 5.5 MeV/u. This value is too large as compared with the cascade mechanism, which predicts $\leqslant 1$ atom/ion for this ion energy. We have tried, therefore, to give a different interpretation to our experimental result.

According to one model[2], a heavy ion crossing the gold foil creates hot cylindrical region around its trajectory, with electron temperature of 20 to 25 eV. At the same time the metal atoms are cold. It is necessary to notice that the binding energy of atoms in metal is zero if the electron temperature is more than some critical electron temperature. This temperature is ≈ 4 eV for gold. Following the model[2], one can show that the cooling time of the hot cylindrical region from the initial temperature down to 4 eV is $\geqslant 10^{-13}$s for the U-Au pair at beam energies $\geqslant 2$ MeV/u. The initial radius of the hot region is ≈ 25 Å, and the initial electron temperature is ≈ 15 eV. For comparison, the time of transform of the hot electron energy into phonon energy is $\approx 10^{-12}$ s. The model[2] predicts acceleration of surface atoms by

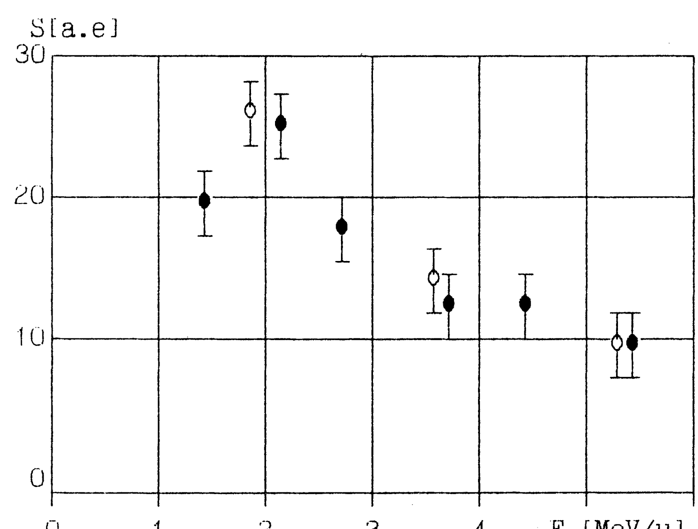

FIGURE 1 The dependence of sputtering yield S of gold foils on energy E of incident uranium ions for one target. The notation [a,e] are arbitrary; the many-layered target was not heating properly, so the surfaces of the gold foils were not quite clean. ● = backward, ○ = transmission.

an electrical double layer that appears on the materials surface due to high electron temperature and pressure. Our results show that this mechanism must not be so important in our case.

Our experimental results are consistent with a cascade mechanism[3], but under conditions where the electron system in the metal has a high temperature and the binding potential of the atoms in the metal is below V_0, the binding potential of cold matter. In this case the surface atom with energy $\leqslant eV_0$ have a finite probability of leaving the metal. The time of 10^{-13}s is enough for this. Accordingly the sputtering yield should be higher than given by the cascade theory of cold metal. For checking our hypothesis we have to extend our experimental investigation of uranium ion energy region below 1.25 MeV/u, in order to reach the energy region where the cascade mechanism of cold metal is applicable. We plan to measure angular distributions of the ejected atoms as well.

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