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INTERACTION OF SLOW POSITIVE RUBIDIUM AND CESIUM IONS WITH THE SURFACE OF MOLYBDENUM

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Secondary ion emission from molybdenum bombarded with Cs^+ and Rb^+ ions with energies $U = 10 - 250$ eV, was studied. It was found that: 1) scattering of primary ions cannot be accounted for by the theory of pair collisions of elastic spheres; 2) at $U < 40$ eV the effect of atomic bonds in the lattice becomes so strong that the mass of the primary ion ceases to be important; 3) considerable penetration of the molybdenum lattice by primary ions begins at $U > 80$ eV; 4) the assumption that the primary ion interacts with the lattice as a whole agrees better with experiment than the assumption that the effective cross section varies with the energy U; 5) when there is an adsorbed film on the target, the secondary emission consists mainly of sputtered adsorbed atoms.

THE problem of secondary ion emission in bombardment with fast ions has been studied quite extensively.[1-4] It has been found that scattering of fast primary ions is described satisfactorily by the theory of pair collisions of elastic hard spheres (incident ions and lattice atoms).[1-3] The energy distribution of scattered ions has been found to be a single-valued function of W/U, where W is the secondary ion energy, and U is the primary ion energy.

Several workers[3,5] have reported that lattice bonds begin to affect results at low incident ion energies. No detailed analysis of changes in the scattered-ion energy spectrum with variations of U has yet been published. No data are available on the interaction of slow ions with adsorbed atoms. These two problems were studied by the author and are reported here.

The work was carried out using an instrument similar to that described earlier.[4] Several modifications were made to accomodate slow ions: the Cs^+ or Rb^+ beams had densities j up to 10^{-6} A/cm^2 with an energy scatter of ~ 1 eV. The ion beams were analyzed by mass spectroscopy and found to contain no other ions in detectable concentrations. During ion bombardment the residual gas pressure in the apparatus, measured with an ionization gauge, was $p_0 = (3 - 9) \times 10^{-8}$ mm Hg. The adsorption pressure p_a on the target measured by the flash method,[6] was even lower: for example, it was found that $p_a = 2 \times 10^{-8}$ mm Hg when $p_0 = 8 \times 10^{-8}$ mm Hg. The necessary corrections were made to the curves representing the secondary current i as a function of the retarding potential V_2; these curves were obtained in the same way as in the earlier work.[4] The curves were not differentiated since they gave the energy spectra quite clearly.

1. Scattering of ions was studied using a heated molybdenum target. It was found that at $U > 80$ eV and $V_2 = 3 - 4$ V, the retardation curves $i(V_2)$ had characteristic kinks,[4] while below $U = 80$ eV they were smoother. The kinks were partly due to the presence (among the scattered ions) of ions produced at the surface by ionization of Cs or Rb atoms formed from primary ions which penetrated deep into molybdenum. Considerable penetration of the primary ions into the target occurred at $U > 80$ eV.

To obtain information on the deviation of the interaction of the primary ion with the lattice from the law of elastic collision of two spheres, dependences of eV_2/U on U were plotted for different values of i/i_0, where i_0 is the current at $V_2 = 0$. These data are given in Figs. 1a and 1b. To avoid the effect of surface ionization, these dependences were plotted by extrapolating to $V_2 = 0$ the right-hand parts ($V_2 > 3 - 4$ V) of the corrected retardation curves, $i(V_2)$. This extrapolation procedure did not alter greatly the eV_2/U values, as is seen when the upper two curves in Fig. 1b are compared. The ratio eV_2/U was not constant at the primary energies used ($U = 10 - 250$ eV); this may indicate that lattice bonds in molybdenum affect the results even at $U \approx 250$ eV.

The energy $U \approx 80$ eV divides two qualitatively

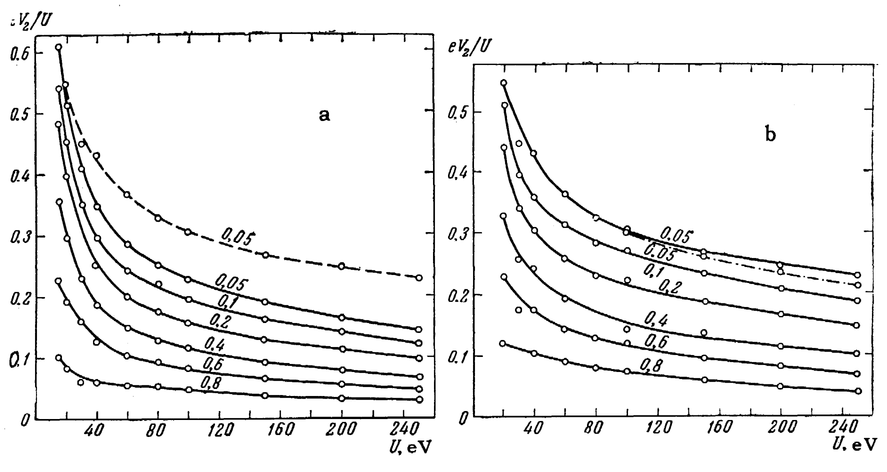

FIG. 1. Dependence of the ratio eV$_2$/U on the energy of primary ions: a) Cs$^+$ ions (target temperature T = 1450°K); b) Rb$^+$ ions (T = 1400°K). The numbers by the curves give the values of i/i_0. Fig. 1a includes also a dashed curve which represents Rb$^+$ ions at $i/i_0 = 0.05$. The chain curve in Fig. 1b represents results which are not corrected for thermal ionization.

different regions (Figs. 1a and 1b), in agreement with the assumption that considerable penetration of the molybdenum target begins at U ≈ 80 eV. Wehner[7] found that this energy is close to the threshold of sputtering of molybdenum.

The ratio of the slope tangents of the curves in Fig. 1 to the magnitude of eV$_2$/U rises with increase of i/i_0. This indicates that lattice bonds affect the yield of slow ions more strongly than that of fast ions.

A qualitative theoretical analysis showed that the curves of Fig. 1 contradict directly the assumption that there is pair interaction of ions with lattice atoms and that the effective scattering cross section varies with U.

Comparison of the results obtained for Cs$^+$ and Rb$^+$ (cf. the top two curves in Fig. 1a) indicates that at U < 40 eV the curves of Fig. 1 are very similar for both incident ions. This means that at U < 40 eV the lattice bonds affect the result so strongly that the mass of the incident ion ceases to be important: the primary ion interacts with a large number of lattice atoms whose total mass is considerably greater than the mass of one primary ion.

Figure 2 gives the scattering coefficient K for Cs$^+$ and Rb$^+$ ions as a function of the primary energy (curves 3 and 4); these curves are not corrected for surface ionization. Curve 3′ was derived from curve 3 by subtracting the current representing surface ionization. Curves 3 and 4 are qualitatively similar to the curves representing scattering of K$^+$ and Na$^+$ on W and of Cs$^+$ on Ni.[5]

2. The current i was also measured as a function of the time t elapsed after interrupting the heat supply to the target (T = 1800° K), for different densities of the primary-ion current j. When j was varied and the pressure p_0 kept constant, the dependence of i on t was practically unaffected. This means that the secondary emission coefficient changed with time due to contamination of the target surface by the bombarding ions and was not greatly affected by the adsorption of residual gases, in spite of the fact that the flux of residual-gas atoms was comparable with the flux of bombarding ions.

With increase of t the secondary-ion retardation curves changed their shape and, eventually, at sufficiently large values of t when i reached a stable value, the curves became identical, within the experimental error, for Rb$^+$ (Fig. 3) and Cs$^+$ ions. These curves were not affected when the primary-ion beam density was varied within wide limits: for example, from 3 × 10^{-6} to 3 × 10^{-8} A/cm^2 at U = 100 eV.

Figure 2 also gives the dependence of the ion emission coefficient on U for cold targets covered with layers of Cs or Rb (curves 1 and 2). These curves differ quite considerably from those representing scattering of the primary ions by the lattice

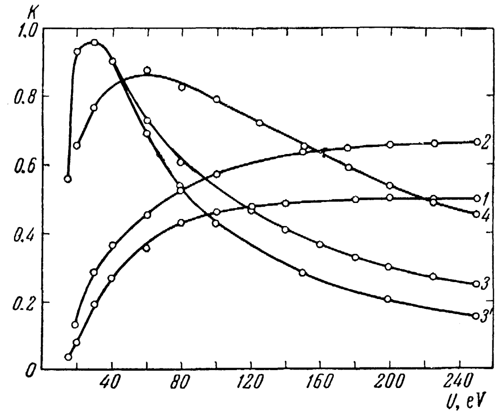

FIG. 2. Dependence of the secondary-ion emission coefficients K on the primary-ion energy U: 1) Cs$^+$ ions, T = 293°K; 2) Rb$^+$ ions, T = 293°K; 3) Cs$^+$ ions, T = 1450°K; 4) Rb$^+$ ions, T = 1400°K; 3′) was obtained from curve 3 by correcting for surface ionization.

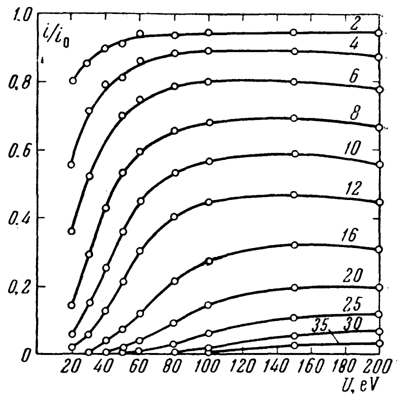

FIG. 3. Corrected current-voltage characteristics (retardation curves) of secondary rubidium ions ($T = 293$°K). The numbers by the curves give V_2 in volts.

(curves 3 and 4), but they are similar to the energy dependences of the sputtering coefficients of alkali metal targets.[8] The natural assumption is that when adsorbed layers of Cs or Rb atoms are present on the target, scattering of primary ions is replaced by sputtering and ionization of the adsorbed atoms. The saturation shown by curves 1 and 2 of Fig. 2 indicates the beginning of deep penetration of the bombarding ions into the target.

Other explanations are also possible:

1) a loose layer of adsorbed atoms is formed on the target surface and ions are scattered from this layer in a different way than from the target lattice itself;

2) when the primary-ion energy is varied, variation of the layer work function produces a dependence of the degree of ionization of scattered ions on the primary energy U.

The first possibility is not very likely because curves similar to 1 and 2 in Fig. 2 and to those in Fig. 3 are obtained on formation of adsorbed primary-ion layers of one or two atomic thicknesses. Moreover it would be unlikely that the energy spectra obtained for elastic scattering of Rb$^+$ on molybdenum should differ from the spectra obtained on scattering from adsorbed Rb atoms which have masses very close to those of molybdenum (compare Figs. 1b and 3).

To eliminate the second possibility a technique similar to the flash method was used: the target was heated for 10 sec at 1800° K. At the end of this heating period ion bombardment was started and continued for a time Δt at room temperature; then the target was heated again to 1800° K. Since both Cs and Rb are almost completely ionized on molybdenum, the current in the target circuit, i_f, should be proportional to the number of sorbed Cs or Rb atoms. For $\Delta t < 80-100$ sec the dependences $i_f(\Delta t)$ were different for different values of U. For $\Delta t > 80-100$ sec and $U < 100$ eV, the dependence $i_f(\Delta t)$ and, consequently, the extent to which the target was covered by the adsorbed material, θ, were almost independent of the energy U in spite of the increase of the primary beam intensity with increase of U. This may have been due to intensification of sputtering of the sorbed layer on increase of U. At $U > 100$ eV the number of adsorbed atoms vaporized by flash heating began to increase considerably with increase of U because of increasing penetration of the primary ions into the target proper.

Since θ was independent of U at $U < 100$ eV, we can reject the second possibility which suggested variation of the target work function with U. The assumption of sputtering of adsorbed atoms was also confirmed by the changes of the retardation curves on variation of U (Fig. 3): at $U < 80$ eV these curves were broadened almost proportionally to the primary-ion energy, but at $U > 80$ eV the retardation curves were practically unaffected by U. A similar saturation of the mean energy of sputtered atoms on increase of the energy of bombarding ions was found by Wehner.[9]

Thus all the data indicate that when adsorbed layers are present on the target surface, sputtered adsorbed atoms are the main component of the secondary emission.

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