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Abstract

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ON SOME PROPERTIES OF SECONDARY ION-NEUTRAL EMISSION

When the surface of a solid is bombarded by positive ions, a number of phenomena arise, among which neutralization occupies an important place. In the few works carried out up to the present time ($^{1-3}$), the neutralized part of the primary-ion beam is calculated as the difference between the current of primary ions and the current of secondary ion emission. However, in order to clarify the question of the energy balance in the interaction of ions with the surfaces of solids, it is more important to determine what part of the primary ions, after neutralization at the surface, leaves the surface carrying away part of its initial energy. In addition, it is of great interest to determine the energy spectrum of the particles leaving the target in the form of neutral atoms. In view of this, we set ourselves the task of obtaining at least the most preliminary direct data on this little-studied phenomenon by direct measurements of the number of neutral atoms leaving the target and of determining what is common in the behavior of the neutral and ionic components of secondary emission.

It seemed to us most convenient, for detecting and investigating the composition of the neutralized particles leaving the bombarded target, to place a metallic surface in their path and to use the phenomena of surface ionization and secondary ion emission for detecting the neutral component of secondary emission.

Moreover, this method makes it possible simultaneously to study certain phenomena that occur in the interaction of neutral atoms with a metallic surface. The need to pose this latter problem also matured long ago, but, owing to the difficulties of obtaining fast neutral atoms, this direction has not received proper development. Thus, in the existing works the interaction of fast (i.e., velocities exceeding thermal ones) neutral atoms of alkali metals with a metallic surface has appeared as a side effect, or else it was of interest primarily from the standpoint of the ejection of secondary electrons by atoms ($^{4-6}$). Other aspects of the collision process have not yet been elucidated.

In the present work a T-shaped glass apparatus with two Ta targets was used, each surrounded by its own collector K_1 and K_2 and by a guard cylinder. The first target (M_1) had dimensions $30 \times 7 \times 0.015$ mm and the second (M_2) $30 \times 5 \times 0.015$ mm. The first target was bombarded by ions obtained by surface ionization of an alkali-halide salt in an ion source with a cylindrical capacitor

Fig. 1

Figure 1: Fig. 1

(7). In the space between the two targets the charged particles were reliably deflected in the field of a plane capacitor, and thus only neutral particles leaving the surface of the first target could reach the second target.

The secondary currents to collector K_1 were measured with a galvanometer of sensitivity $1 \cdot 10^{-9}$ A/mm; by means of a switch it was possible to measure the current to target M_1, the current to K_1, and the total current. The secondary currents to collector K_2 were measured with an electrometer of sensitivity $1 \cdot 10^{-13}$ A/mm.

The apparatus was evacuated by two oil-vapor diffusion pumps and was equipped with liquid-nitrogen traps. The residual pressure in the apparatus with the heated source was $3 \div 4 \cdot 10^{-7}$ mm Hg. During the measurements the pressure was $1 \div 3 \cdot 10^{-6}$ mm. Before each series of measurements the targets were heated for 6-8 h to 2500° K. When measuring individual points of the curves, the targets were briefly heated to 2000° K, after which the temperature for targets M_1 and M_2 was lowered, respectively, to 1200 and 950° K.

One of the important features of secondary ion-ion emission is the presence of limiting energies (7-9) in the scattered ion, indicating an individual elastic collision of the incident ion with an atom of the target, with preservation of the ion charge. It may be assumed that elastic collisions of the primary ion incident on the target with individual atoms of the target will also occur, in part, with electron capture. Consequently, the particles constituting the neutral component of the secondary emission must have energies from zero up to the same limiting values as those possessed by the secondary scattered ions. When such a flux of neutral atoms strikes the surface of the second target, at high temperatures there will occur phenomena of surface ionization and secondary emission, which can be detected by measuring the currents to the collector surrounding target M_2.

Fig. 1

Figure 1 shows delay curves of the secondary currents appearing when target M_2 is bombarded by the neutral component of the secondary emission from target M_1, bombarded by Na^+ ions with energies of 100 eV (1) and 200 eV (2). Along the abscissa are plotted the voltages between target M_2 and its collector K_2, and along the ordinate—the current of positive ions to the collector in arbitrary units. As is seen from Fig. 1, the secondary particles from M_2, caused by bombardment by neutral atoms coming from M_1, possess considerable energies. Saturation of the currents at collector K_2 when the first target is bombarded by ions with energy E_0 equal to 100 and 200 eV occurs at positive potentials of collector K_2 of 60 and 100 V.

The presence of secondary ions with such large energies can be explained only by assuming, first, that the neutral atoms bombarding M_2 possess large energies. That is, the neutral component of the secondary emission during bombardment of target M_1 by ions, just as the secondary ions, contains scattered neutral atoms leaving the surface, apparently by elastic collisions with individual atoms of target M_1. The limiting energies of such neutral atoms, under the assumption of elastic collisions, can be found, as is known (^{7}), from the relation

$$E = E_0 \frac{m_1 - m_2}{m_1 + m_2}, \tag{1}$$

where m_1 is the mass of the target atoms, m_2 is the mass of the ions bombarding target M_1. Secondly, these neutral atoms, in turn striking target M_2, leave it in the form of positive ions, also retaining a considerable fraction of the energy of the neutral atoms incident on target M_2. Assuming that elastic collisions also occur in the latter case, and taking that the initial energy of the particles incident on target M_2 is equal to the limiting energy of the particles leaving the surface of target M_1, the limiting energies of these ions can be calculated from relation (1).

When M_1 (Ta) is bombarded by Na ions, for example with energy $E_0 = 100$ eV, for the limiting energies of the secondary ions leaving target M_1, from relation (1) we obtain the value $E = 77$ eV. Then, assuming that target M_2 is bombarded by neutral atoms with maximum energy

77 eV, for the limiting energies of the secondary ions leaving target M_2, we obtain the value $E = 59$ eV. As can be seen from Fig. 1, this value is close to the saturation value of the currents to collector K_2.

A comparison was also made of the energy distribution of the secondary ions when M_2 was bombarded by the neutral component of the secondary emission from the first target, with the energy distribution of the secondary ions when target M_2 was bombarded by the ionic component of the secondary emission from the first target. For this purpose, after removing the voltage from the plates of the plane capacitor and applying a small ion-accelerating voltage between the targets, all secondary particles from target M_1—the ionic and neutral components of the secondary emission—were directed onto target M_2. Moreover, owing to the presence of a small ion-accelerating voltage, and at low energies of the ions bombarding the first target, the ionic current to target M_2 was several times greater than the neutral component, and therefore the influence of the presence of the neutral component could be neglected. The experiment showed that the energy distribution of the secondary ions when target M_2 was bombarded by secondary ions coming from target M_1 is close to the distribution of the secondary ions obtained when M_2 was bombarded by the neutral component alone.

Fig. 2

Fig. 2

Figure 2: Fig. 2

The presence of considerable energy in the scattered neutral atoms can also be judged from the appearance of secondary emission of negative particles, which is produced by neutral atoms falling on the cold, contaminated surface of target M_2. Figure 2 shows the curves obtained when the neutral component bombarded the clean (1) and contaminated (2) surface of target M_2. The curves were obtained when target M_1 was bombarded by Na ions with an energy of 600 eV. As can be seen from the figure, when the clean surface of M_2 is bombarded, there is no emission of negative particles; only scattering of the neutral component in the form of positive ions takes place. When the contaminated surface of target M_2 is bombarded, the neutral component causes secondary emission of negative particles. Evidently, the appearance of secondary emission of negative particles can be caused only by particles possessing considerable energies.

Thus, when solids are bombarded by ions, elastic scattering of the primary ions from individual atoms of the target occurs both in the form of positive ions and in the form of neutral atoms, and, as experiment shows, the energy distributions of the scattered ions and neutral atoms do not differ substantially from one another.

It also follows from the experimental results that, when a target is bombarded by neutral atoms, emission in the form of positive ions is observed, whose limiting energy coincides with the calculated value computed on the assumption of the presence of elastic collisions of the bombarding particles with individual atoms of the target.

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