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Abstract

Full Text

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INVESTIGATION OF THE COMPLETE ENERGY SPECTRUM OF SECONDARY ELECTRONS OF Sn AND In IN THE SOLID AND LIQUID STATES*

Introduction. Investigation of the complete energy spectrum of the secondary electrons of certain low-melting metals under electron bombardment in the solid and liquid states is of interest for understanding the mechanism of excitation of secondary electrons by primary bombarding electrons. This is especially interesting for clarifying the dependence of characteristic losses on the aggregate state of the metal, which, as far as we know, has not yet been studied. In several works ([1–5]), the dependence of the secondary-electron emission coefficient for Pb, Sn, Bi, Ge, Hg, Cu, Ga on the aggregate state was studied, but under different experimental conditions, and the results prove to be not only different but often contradictory. Therefore, in the present work we report a simultaneous study of the current-voltage characteristic and of the complete energy spectrum of the secondary electrons of Sn and In in the solid and liquid states, using an instrument with good resolving power, and recording these dependences by the high-speed oscillographic method ([6,7]) at primary-electron energies of 100–1000 eV.

Fig. 1. Schematic diagram of the apparatus. 1 —filament; 2 —electrostatic lenses; 3 —cylindrical condenser; 4 —protective shield; 5 —electron collector; 6 —grid; 7 —target; 8 —scraper; 9 —protective cylinder of the analyzer; 10, 11 — electrostatic analyzer

Apparatus and method of measurements. The apparatus in which the measurements of the integral and differential spectra of secondary electrons of Sn (purity 99.999%) and In (99.999%) were carried out is shown in Fig. 1. It consists of an electron source 1, a collector 3, and an analyzer of secondary electrons 10, 11, as well as an electron multiplier with a gain coefficient of the order of 10^4. All parts of the apparatus are made of red copper. Pumping was carried out in parallel by two mercury-vapor pumps. The working vacuum in the apparatus was $1–5 \cdot 10^{-7}$ mm Hg (a description of the remaining parts of

Fig. 2. Current–voltage characteristic of secondary electrons at a primary energy of 250 eV for pure Sn

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the apparatus is given in detail in ([6])). The apparatus in Fig. 1 differs from

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of the target device described in works ([6],[7]), adapted in the present case for work with a liquid metal. It consisted of a porcelain cylinder with an internal diameter of 10 mm, into which the substance under study was placed, and a piston machined from stainless steel, with a spherically concave tip. The piston could be raised or lowered inside the cylinder by a special threaded hinge device controlled from outside by a magnet. Melting was carried out by passing direct current through a spiral wound on the porcelain cylinder. To avoid charging the surface of the cylinder, a tube made of tantalum foil was placed over it. All the indicated parts of the target were arranged so that they disturbed as little as possible the uniformity of the field in the space between the target 7 and the analyzer 10, 11. In addition, a magnetically controlled device was used, by means of which it was possible to remove the contaminated surface film of the metal under study in the liquid state. The moment of melting or solidification could be observed by viewing the surface of the target through a special window in the receiving part of the instrument.

Fig. 2. Current–voltage characteristic of secondary electrons at a primary energy of 250 eV for pure Sn

The first measurements of electron emission from solid tin revealed a noticeable increase in the number of slow secondary electrons as the temperature was raised up to red heat. However, after repeated meltings and heatings of the molten metal to a high temperature in a high vacuum, and after removal of the surface film, the results became independent of temperature.

A substantial difference of the method employed is that the current–voltage characteristic and the complete spectrum of secondary electrons are recorded simultaneously on the screens of two oscillographs ([6],[7]). The use of such a method makes it possible to observe visually the change in the values of the coefficients and of the differential spectra of secondary electrons during the melting and solidification of the material under study under the same experimental conditions.

In the present work this was carried out in the following way. The target is bombarded by a beam of primary electrons of a specified energy. At the same time, on the screens of two oscillographs, by the method described in work ([6]), the integral and differential spectra of secondary electrons are obtained. By switching on the furnace filament, heating of the metal under study begins.

This process continues until the substance being studied has completely melted. After this, by means of a scraper, the surface film of the metal is repeatedly cleaned off under the stationary regime of the other experimental conditions. Then the furnace filament is switched off. For a long time after this, visual observation and photographing of the current–voltage characteristics and of the differential spectrum of secondary electrons continue, until the investigated material solidifies and cools completely.

Results of the measurements. Figure 2 shows an oscillogram of the current-voltage characteristic of secondary electrons during bombardment of molten tin, cleaned of surface contaminants, at a primary-electron energy of 250 eV. Observations over 30–35 min after the target filament was switched off show that, at a constant value of the primary-electron current, the pattern remains unchanged within the experimental error of 2–3%, despite the fact that during this time the molten tin has passed into the solid state. Investigations were also carried out of the dependence of the secondary-electron-emission coefficient on the energy of the primary electrons in the range 100–1000 eV for a solid and a molten target. The difference in the dependences of the secondary-electron-emission coefficients on the ener-

primary electrons for a solid and a molten target, which was found in [1] for tin, was not observed in our experiments.

Figure 3 shows an oscillogram of the complete energy spectrum of secondary electrons at a primary-electron energy of 250 eV from the clean surface of liquid tin.

Fig. 3. Complete energy spectrum of secondary electrons from clean liquid tin at a primary-electron energy of 250 eV.

It should be noted that the fine structure in the high-energy part of the spectrum appears after cleaning the tin surface with a scraper and does not change appreciably for a long time (10–15 min) after the transition to the solid state. This shows that, before removal of the film of surface contaminants, the molten surface still remains dirty, despite the preliminary heat treatment. The remaining part of the curve of the secondary-electron energy distribution does not change appreciably after cleaning the surface. It should be noted that the sharpness of the peaks of the characteristic losses, both here and in previous studies [6, 7], depends on the cleanliness of the bombarded surface of the metal under study.

Figure 4 shows an oscillogram of the high-energy part of the secondary-electron spectrum on an enlarged scale. From Figs. 3 and 4 it is clearly seen that there are three peaks of characteristic losses at energies of 10, 18, and 32 eV. The loss peaks at 10 and 18 eV agree satisfactorily with analogous peaks found in [8] by the method of transmission of a beam of fast electrons through thin films. It was established that the positions of the characteristic-loss peaks do not depend on the melting of the substance under study or on the energy of the primary electrons in the investigated region.

Discussion of the results. Analysis of the results obtained by us for tin and indium in two aggregate states leads to the conclusion that, upon melting, the character of the complete energy spectrum of secondary electrons does not change. Within the limits of the experimental error (1–2%), the coefficient of secondary electron emission upon melting, obtained from measurements of the integral curve of secondary electron emission, also does not change. Brüche [4] came to the same conclusion for Pb, Bi, Hg, and Ga, as did the authors of [5] for Hg; they likewise investigated changes in the secondary-electron emission coefficient with changes in the aggregate state of the metal under study. Since, upon melting, the mean distances between atoms in a metal—which to a considerable extent determine its energy structure—do not change greatly, it follows that the secondary-emission properties of the substance under study and the character of the energy distribution of secondary electrons should not change greatly either.

Fig. 4. High-energy part of the complete spectrum shown in Fig. 3.

Considering the results of [2, 3], where a number of elements (Cu, Ge, Sn and In, Pb) were studied in the solid and liquid states, it is difficult to agree with the conclusion that, upon melting, the emission of slow secondary electrons is in some incomprehensible way "facilitated" for some metals (for example,

Sn) and "deteriorates" for other metals (In and Pb). In addition, the nature of the change he observed in the position of the maximum in the spectrum of Sn ([2]) with increasing energy of the primary electrons remains unclear. If this maximum is a peak of inelastically reflected electrons, then it should not shift relative to the peak of elastically reflected electrons when the energy of the primary electrons is increased. In the present experiments no such phenomena were observed.

Thus, the results we have obtained for the values of the coefficients and for the complete energy spectrum of secondary electrons indicate that melting of metals does not substantially affect the secondary-emission properties of the substance under study. In this they confirm the fact that the complete spectrum of secondary electrons is determined by the energy structure of the metal ([7]) and therefore does not depend on the aggregate state of the substance under study.

It should be noted that melting has no substantial influence on the position of the maxima of the characteristic losses in tin, which has been found for the first time in the present work. Friedman ([9]) arrived at an analogous theoretical conclusion by comparing the characteristic losses in amorphous layers with the losses in crystalline layers.

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REFERENCES

[1] P. M. Morozov, ZhETF, **11**, 411 (1941).
[2] V. G. Bolshov, V. K. Seleznev, ZhTF, **24**, 1657 (1956).
[3] V. G. Bolshov, V. V. Zarubin, *Physics of the Solid State*, **1**, 462 (1959).
[4] J. Brophy, Phys. Rev., **83**, 534 (1951).
[5] Yu. M. Kushnir, V. I. Milyutin, V. P. Goncharov, ZhTF, **9**, 1589 (1959).
[6] U. A. Arifov, A. Kh. Kasymov, *Radio Engineering and Electronics*, **8**, 138 (1963).
[7] U. A. Arifov, A. Kh. Kasymov, *Proceedings of the Academy of Sciences of the Uzbek SSR, Series of Physical and Mathematical Sciences*, **92** (1963).
[8] L. Marton, L. B. Leder, Phys. Rev., **94**, 203 (1954).
[9] G. Friedman, UFN, **62**, 427 (1957).

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