Secondary Emission from Films of Platinum on Aluminum

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Experimental results for secondary emission from films of platinum on aluminum indicate a direct proportionality between the primary energy (up to 800 electron volts) and the maximum depth from which the secondaries come. The depths of origin of secondaries as indicated by these studies are not out of line with those which would be expected on the basis of existing theories. The maximum depth within the target influencing the secondary emission increases more rapidly for primary energies above 800 electron volts than for those below.

INTRODUCTION

HASTINGS[1] in an interesting paper has recently discussed experiments giving rather definite information concerning the depth of origin of secondaries of various energies in films of silver on platinum. In brief his conclusions are that the secondaries of low energy originate within 15 atomic layers for primaries of 20 ev and within 30 atomic layers for primaries of 50 ev. His results for higher energy primaries are considerably less definite, although he cites evidence that for primaries of 250 ev appreciable emission comes from a depth greater than 150 atomic layers. In this paper the writer presents results for platinum films on aluminum, which, perhaps because of the great dissimilarity between platinum and aluminum, are definite even at primary energies higher than those used by Hastings.

Previously the writer has reported[2–5] some of the more pronounced features of secondary emission from complex targets. In 1934 he[2,3] presented results for secondary emission as a function of primary energy for platinum films of various thicknesses upon aluminum. These results were somewhat qualitative, since no effort was made to measure the thicknesses of the various films, but they showed that for low primary energies the secondary emission was characteristic of the superficial layer, while for primary energies of more than an electron kilovolt, and increasing with the film thickness, the secondary emission was influenced by the aluminum. Results in many ways the converse of those for platinum on aluminum were obtained from films of sodium condensed on tantalum.[4] In this case the films were measured by the microtitration of the sodium, and the results showed definitely that the thickness of the films used ranged up to 300 atomic layers. In 1937 at Montana State College the writer repeated measurements of secondary emission from films of platinum on aluminum, and these results, because they may be of interest both for comparison with those of Hastings and for consideration in connection with current theories, are presented at this time.

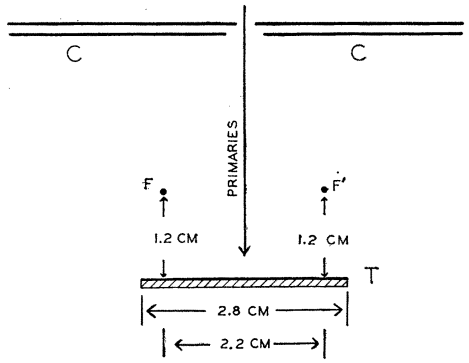

FIG. 1. Geometry of apparatus.

EXPERIMENTAL METHODS

The metal parts of the experimental tube, the essential features of which are shown schematically in Fig. 1, were sealed into a Pyrex glass envelope, and the tube was evacuated by a single stage mercury diffusion pump backed by a Cenco Hyvac. The mercury vapor was condensed in re-entrant type cold traps filled with a slush of dry ice and acetone. Two of these

[1] A. E. Hastings, Phys. Rev. **57**, 695 (1940).
[2] P. L. Copeland, Phys. Rev. **46**, 167 (1934).
[3] P. L. Copeland, Phys. Rev. **48**, 96 (1935).
[4] P. L. Copeland, Phys. Rev. **53**, 328 (1938).
[5] P. L. Copeland, Phys. Rev. **55**, 1270 (1939).

traps in series were placed between the experimental tube and the diffusion pump. Only the first trap was cooled during the first stages of the evacuation, during which the experimental tube was placed in an electric furnace and baked for several hours at temperatures around 475°C. The connecting tubing, including the second trap, was thoroughly torched during the baking process. The furnace was then removed and slush was added to the second trap. The experimental tube was left on the pumps throughout the observations, and the pressure in the tube, too low to be read on the McLeod guage, was certainly less than 10^{-6} mm Hg.

Details of the geometry at the target are shown in Fig. 1. Here T is a plate of commercial aluminum which serves as a target. Two platinum filaments, F and F', of approximately 10 mils diameter are placed in front of the target as shown. The geometry is selected so that when equal amounts of platinum are evaporated from the two filaments, a nearly uniform film is deposited on the face of the target. The diaphragms are cut so that only the secondaries emitted by the target reach the collector, C, and in this apparatus the ratio of the number of secondaries to the number of primaries is obtained for various primary energies in the usual manner.

For evaporating the platinum, the filaments are heated by passing a current through the two in parallel. Readings of the heating current and the potential difference across the filaments were made on meters accurate to one-half of one percent in the range used. For convenience the thinnest films were obtained at one evaporation rate, and the thicker films at an evaporation rate, which, from data on the vapor pressure of platinum as a function of temperature, was estimated to be 4.5 times as great as the first. The procedure, as in the previous work,[3] was to put on a film and measure the secondary emission as a function of primary energy, and then to add to the film and again measure the secondary emission. In the end the amount of platinum lost from the filaments was easily determined by weighing measured lengths of the middle sections

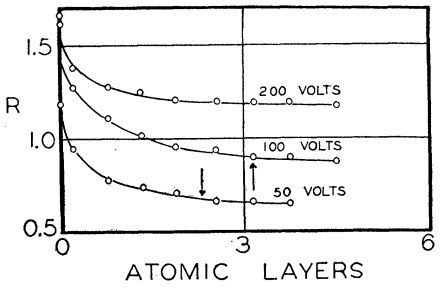

FIG. 2. Secondary emission as a function of film thickness for low primary energies.

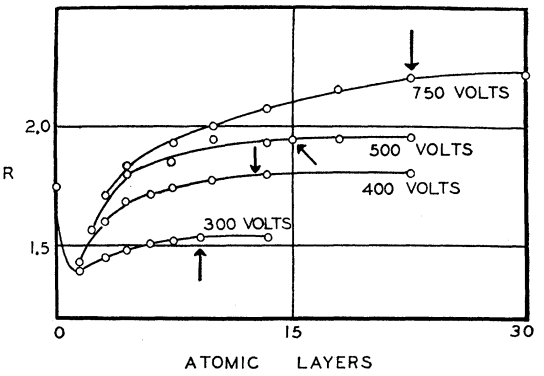

FIG. 3. Secondary emission as a function of film thickness for intermediate primary energies.

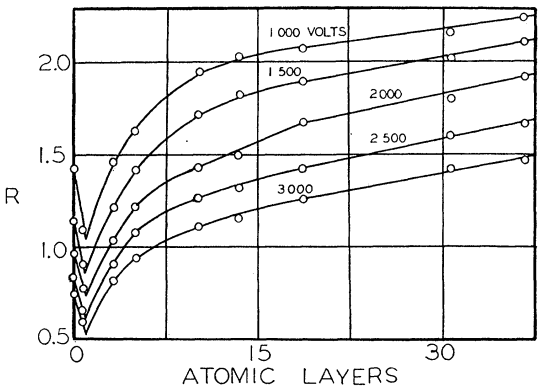

FIG. 4. Secondary emission as a function of film thickness for primaries of high energy.

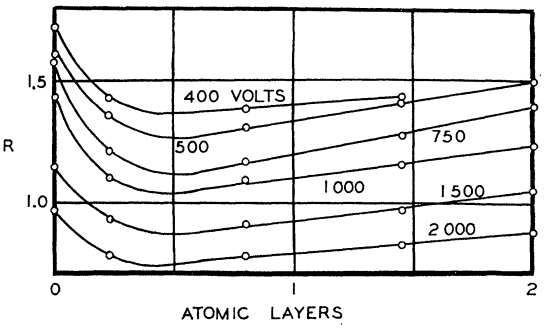

FIG. 5. Secondary emission of thin films.

on a good chemical balance. From these data and the geometry, the density of the films in micrograms per square centimeter was computed. In the accompanying graphs these data are interpreted in terms of atomic layers on the assumption that an atomic layer of platinum weighs 0.53 micrograms per square centimeter.

Results

The data are analyzed in Figs. 2, 3, 4 and 5 by plotting the secondary emission ratio, R, against the thickness of the film. For the lower primary energies such data are shown in Fig. 2. As shown here for primary energies of 50 volts, 100 volts and 200 volts, the addition of platinum causes the secondary emission to decrease continuously and to approach that characteristic of thick platinum films. For primary energies greater than 200 volts, the secondary emission at first decreases and then increases. Such data are shown in Figs. 3 and 4, where to prevent confusion in Fig. 3 those obtained for very thin films are omitted, but all of the omitted points are plotted on a larger scale in Fig. 5.

In many particulars the variations of secondary emission for platinum on aluminum are the converse of those for silver on platinum as shown by Hastings[1] as would be expected on the basis of the writer's previous work on complex targets[2,3] showing both types of behavior. In particular it is of interest to notice that, whereas for primaries of high energy Hastings shows the secondary emission increasing to a maximum at one atomic layer and then decreasing, the results in Figs. 3 and 4 show the secondary emission decreasing to a pronounced minimum and then increasing. The detailed plots of Fig. 5 are interesting in this connection, since smoothly drawn curves put the minima very close to half-coverage. This seems low, but is not unreasonable. There is evidence for believing the maximum of thermionic emission from thoriated tungsten occurs at about three-quarters of full coverage.[6]

The rise in the secondary emission for the thicker films of platinum with primaries of high energy, as shown in Figs. 3, 4, and 5, may be due in part to the relatively great scattering of primaries in platinum. If the primaries have the

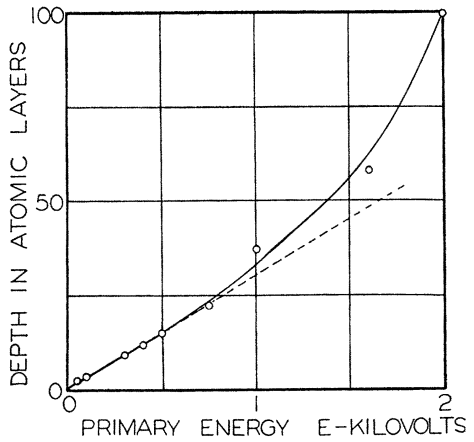

FIG. 6. Maximum depth of origin of secondaries as a function of primary energy.

low energies represented in Fig. 2, the increased scattering is ineffective in the production of more secondaries. The relatively large change in secondary emission for the thin films in all graphs would naturally be interpreted as meaning that most of the secondaries originate very near the surface. The arrows in Figs. 2 and 3 indicate the points at which the secondary emission is estimated to cease varying with film thickness. The flatness of the curve obtained at 200 ev primary energy would seem to be due to the fact that it is the borderline between the two types of curves; it probably should not be taken to indicate that secondaries arise only in the first three atomic layers. The curves in Fig. 4 fail to become flat in the region shown. Here the primary energies at which properties of the aluminum appear were determined as in previous work[3] from breaks in the plots of secondary emission against primary energy. In this work the results are definite at all primary energies, and they provide rather definite evidence that the maximum depth of origin of appreciable secondary emission is at first proportional to the primary energy as shown in Fig. 6. The reason for the departure from the proportionality at the high primary energies is probably that penetration of high energy primaries becomes proportional to the square of the energy.[7] The proportionality itself has a rather simple interpretation in the light of existing theories.

[6] W. B. Nottingham, Phys. Rev. **49**, 78 (1936).

[7] H. M. Terrill, Phys. Rev. **22**, 101 (1923); **24**, 616 (1924).

Frohlich[8] applied wave mechanics to the problem of secondary emission, and concluded that if absorption of the secondaries within the metal were neglected, the secondary emission should increase with the square root of the primary energy, while the energy of the excited secondaries would be small (about 25 ev) and approximately independent of the primary energy. Wooldridge[9] has recently shown that correcting certain errors in Frohlich's work one concludes that if primaries of energy $\hbar^2K^2/2m$ and of momentum $\hbar K$ are incident on a metal, the rate of production of secondaries is independent of the energy of the primaries and that the average energy given by the primary to the secondary is $(\hbar^2/2m)(2\pi/a)^2$ where a is the lattice spacing. For primaries of several hundred electron volts the production of secondaries accounts for practically the full loss of energy by the primaries. According to Wooldridge's picture "in a distance less than the mean free path of the secondaries, the primaries may lose so much energy that they can produce no more secondaries." This theory is capable of explaining observations of secondary emission which at low energies are almost proportional to the primary energy. This theory also indicates that the depth to which the primaries penetrate without losing the ability excite secondaries is proportional to the primary energy. Hence the proportionality between depth of origin of secondaries and primary energy would be expected.

Reliability of the Data

The proportionality of the abscissas to film thickness is more certain than the correctness of the exact numerical values of the abscissas. The individual evaporation periods were from 10 to 20 minutes and they could therefore be determined with high precision. The change in evaporation rate was made after a film of 12.3 atomic layers had been deposited. The curves show no tendency toward irregularity at this point, which fact would appear to confirm the conversion factor relating the two evaporation rates. No hot spots developed on the filaments, and at the end of the run both platinum filaments appeared to be uniform. The apparatus was designed to minimize non-uniformity of evaporation near the experimental region, and an effort was made to detect any non-uniformity that might have developed. Each of the platinum filaments was approximately 15 cm long, and only the central length of 5 cm was weighed after the evaporation of the platinum. Finally as a check on the uniformity of these 5 cm sections, a section of 2 cm length was removed from the center of each of these and these sections were carefully weighed separately on a balance of sensitivity 20 divisions per milligram with a set of weights on which the corrections indicated by a National Bureau of Standards certificate were made. This work indicated a uniform loss of platinum over the 5 cm lengths, hence confirming the assumption on which the computations of film thickness were based.

This investigation was a part of the work undertaken under a grant-in-aid by the National Research Council in 1936. The writer is glad to acknowledge his indebtedness for this assistance. The writer also takes this opportunity to express his appreciation to Dr. J. C. Turnbull, who was associated with him at the beginning of such studies, for suggestions concerning the analysis of data obtained in such experiments.

[8] H. Frohlich, Ann. d. Physik **13**, 229 (1932).
[9] D. E. Wooldridge, Phys. Rev. **56**, 562 (1939).