SECONDARY ELECTRON CURRENT AS A FUNCTION OF CRYSTAL STRUCTURE

By H. E. Farnsworth

Abstract

A summary is given of results formerly obtained which indicate that the breaks in the low voltage region of the secondary electron curve of a metal are characteristic of the arrangement of the atoms at the metal surface, and not of the structure of the atoms themselves. Further evidence in support of this view is as follows: The secondary electron curve for phosphor bronze containing 95.4 percent copper does not show the characteristics of the curve formerly obtained for copper. The curve for targets cut from a single crystal of copper is distinctly different from that previously obtained for a large number of targets taken from copper sheet. Changing the angle of incidence of a copper target from 0° to 45° causes the changes in slope to be much less prominent, and changes the relative positions of some of the breaks.

THE fact that, after a metal target has been properly heat treated in a vacuum, its secondary electron curve (secondary current as a function of primary voltage) shows breaks which appear to be characteristic of the particular metal has led several experimenters[1–3] to attempt a correlation with soft x-ray and optical levels of the atom. The attempts have been far from successful and many of the results indicate no correlation. Krefft[3] has recently reported a correlation for a primary voltage of 70.5 volts in the case of tungsten while at about 1200°K. The writer has previously taken the view that the maxima and minima in the low voltage region of the secondary electron curves for copper and iron are due to inelastic collisions between the incident electrons and the atoms of the metal, although certain results have indicated that these changes in slope are in some way dependent upon the arrangement of the atoms at the surface of the metal. The purpose of this paper is to give further results which it is believed, together with previous observations, furnish convincing evidence that sudden changes in slope of the secondary electron curves in the region investigated (0–40 volts) and for the metal studied are due to the arrangement of the atoms at the surface of the metal and not to the structure of the atoms themselves.

The results previously given elsewhere[4] are briefly summarized here:

1. The temperature at which a copper target has previously been heated, rather than time of heating, appears to be the determining factor which causes the appearance of the various sudden changes in slope in the secondary electron curve for copper.

2. After this curve has been obtained for a copper target, the subsequent exposure of the target to dry air over a considerable range of pressure does not alter the general shape of the curve.

[1] Stuhlman, Science **56,** 344 (1922); Phys. Rev. **25,** 234 (1925).
[2] Petry, Phys. Rev. **26,** 346 (1925).
[3] H. E. Krefft, Phys. Rev. **29,** 908 (1927).
[4] H. E. Farnsworth, Phys. Rev. **25,** 41 (1925); **31,** 405 (1928).

3. The above curve for a copper film deposited by evaporation is considerably different from that for mass metal previously heated. After heating the deposited film, the curve obtained is similar to that for mass metal.

4. After heating a copper target at a temperature near the melting point, the breaks in the curve are less sharp than after heating at a somewhat lower temperature.

5. Measurements of energy distribution of secondary electrons from copper and iron show no such distribution as might be expected to result from atomic inelastic collisions.

Further observations[5] which furnish additional evidence of the influence of surface structure are given in Figs. 1 and 2. If the secondary electron characteristics are an atomic property, they should be observable even

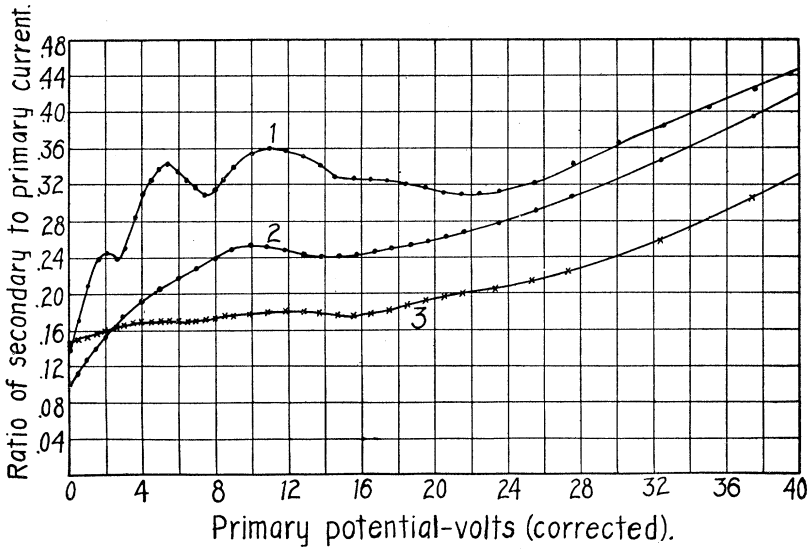

Fig. 1. Secondary electron curves. Curve 1 is for sheet copper. Curve 2 is for sheet phosphor bronze. Curve 3 is for copper cut from a single crystal. All curves were taken subsequent to red-heat treatment of the targets in a vacuum.

though the target contains atoms of other metallic elements, but, if they are a function of the atomic arrangement, the presence of other atoms should produce considerable changes in these characteristics.

Experimental results for a phosphor bronze target containing 95.4 percent copper, 4.5 percent tin and 0.1 percent phosphorus, indicate that structure is the determining factor as is shown by a comparison of curves 1 and 2 in Fig. 1. The positions of the breaks in the curve for copper do not check with any of those in the curve for phosphor bronze. Curve 2 was obtained for 2 different targets taken from the same sheet of metal. Curve 3 is for a Cu target cut from a single crystal in the form of a bar of rectangular cross-

[5] These results were obtained with the tube shown in Fig. 1, Phys. Rev. **31**, 406 (1928).

section. Curves similar to curve 1, Fig. 1, have been obtained for a large number of targets taken from commercial sheet copper as well as from chemically pure sheet copper. Curve 3 was obtained for two different targets cut from the same piece. Precautions were taken not to contaminate the surfaces of the targets before inserting them in the tube, and the surface layers were removed by prolonged heating at red heat while in a vacuum. Since the targets cut from the single crystal were of very pure copper, the only possible reason for the difference between the curves for this and other specimens appears to be a different orientation of the surface crystals. No special attempt was made to keep from breaking the crystals in the targets which were cut from the single crystal, so that they contained a large number of small crystals when placed in the tube. However, these crystals probably retained a certain preferred orientation.

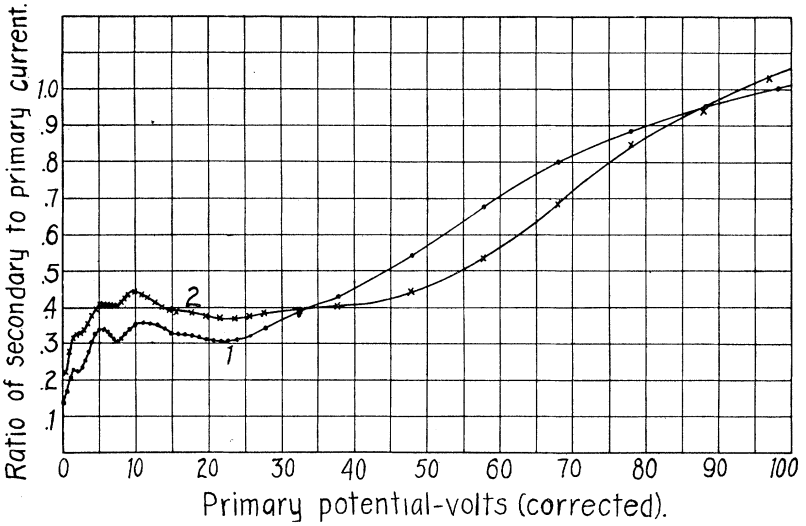

Fig. 2. Secondary electron curves. Curve 1 is for a sheet copper target at normal incidence. Curve 2 is for the same target at 45° incidence.

In looking over the results obtained for copper several years ago, it was found that among a large number of targets tried, there were two for which a curve similar to curve 1, Fig. 1, could not be obtained. The curves for these two targets showed a broad maximum and minimum at about 8 and 14 volts, respectively. At the time these curves were obtained it was thought that they were due to contamination of the metal surface so were not reported. It now seems more probable that they were due to a particular preferred orientation of the surface crystals.

Fig. 2 shows the effect of changing the angle of incidence on the secondary electron curve of a copper target. For the lower primary voltages, where reflected electrons are predominant, the secondary current is increased when the angle of incidence is changed from 0° to 45° with the normal. At some-

what higher primary voltages, where emitted electrons are predominant, the secondary current is decreased by this change. At still higher primary voltages the secondary currents become equal for the two angles of incidence. Thus one effect of increasing the angle of incidence from 0° to 45° is to increase the reflection and decrease the emission for the lower primary voltages. This increase of angle of incidence also causes the changes in slope of the curve to be much less prominent and also changes the relative positions of some of the breaks. However, since the two curves are still similar it appears that a rotation of all of the surface crystals does not produce entirely different characteristics. The distribution in the number of different crystal faces which are exposed may be the determining factor.

In conclusion, a large number of different observations have shown that the secondary electron characteristics of copper, in the low voltage region, are a function of the arrangement of the atoms at the surface of the metal, and are not directly dependent upon the structure of the atoms themselves. This undoubtedly is true for other metals as well as for copper.*

I am indebted to Professor F. G. Keyes for obtaining the copper crystal from which some of the targets were cut.

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* *Note added to page proof:* Since this paper was first written, detailed reports of Krefft's results have appeared (Ann. d. Physik **84,** 639 (1927)); Phys. Rev. **31,** 199 (1928); Jour. Frank. Inst. **204,** 537 (1927). Krefft attributes the differences between his results and those of other observers on tungsten to a more complete elimination of gas from the metal in his experiments. This explanation for all of the differences appears doubtful in view of the present results of the writer which show that structure is a determining factor for copper in the low voltage region. It is impossible to state that this is also true for much higher voltages and for all metals, but in view of the possibility it is obvious that further experiments on critical potentials of metals by the secondary electron method will be of little value unless the metal studied is in the form of a single crystal with known orientation with respect to the incident electron beam. Horton, Davies, and Andrews, (Nature **121,** 192 (1928)) have recently suggested that some of the critical potentials for soft X-ray excitation may also be characteristic of the arrangement of atoms at the surface of the metal.