Photoelectric Effect of Aluminum Films Evaporated in Vacuum

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Sensitivity curves of aluminum films deposited by evaporation in vacuum have been determined. A new threshold value of 2830A and a selective maximum around 2700A have been found. The cell has the form of a horn, absorbing all the incident light. Charcoal was used for producing high vacuum and for giving off gases that influence the position and inclination of the sensitivity curves.

THE photoelectric effect of aluminum surfaces has been repeatedly studied. For the threshold of the sensitivity, values lying between 5000A[2] and 3342A[3] have been observed. The general trend in successive investigations, as the technique for obtaining good vacua and outgassed surfaces improved, has been to displace the threshold to the violet. The work reported in this paper follows that general trend. We find a long wave-length limit for aluminum films distilled in vacuum at 2830A, 500A below the smallest value previously found.

APPARATUS

The cell used is illustrated schematically in Fig. 1. It consists of a Pyrex tube of 25 mm diameter in the form of a horn. At one end it is closed by a quartz plate P sealed with Apiezon wax, in the other it contains a 6-turn coil of 40-mil tungsten wire, supported by two insulated tungsten leads. The electrode K provides contact with the internal surface of the horn and the well-insulated and appropriately bent tungsten wire A is used as anode. The cell is open to a side tube C, which contains charcoal. It is connected to the pumping system through the stopcock B and the liquid-air trap D. For the stopcock B Apiezon wax was used instead of grease.

The cell was prepared in the following way. First the tungsten coil, with its glass seal, but detached from the cell, was loaded with small pieces of aluminum wire and attached to contacts inside a vacuum bell jar, in order to melt the aluminum, outgas it partially and clean it from its thick coat of oxide. Then well-washed and vacuum-cleaned charcoal was placed in the side tube C, the window P put in position and the coil E attached to the cell. The system was then connected to a Hypervac mechanical oil pump through the liquid-air trap D. A small cylindrical furnace kept the charcoal at red heat during evacuation. After pumping thus for 48 hours the stopcock B was closed, the cell separated from the trap D, and the charcoal allowed to cool down and subsequently immersed in liquid air, while a glow discharge was passed between the electrodes K and A in order to outgas partially their surfaces. A small potential difference was applied to the terminals of the coil E so as to keep it at dull red heat without producing evaporation of aluminum. The cell was covered with asbestos, leaving the window and the stopcock B unenclosed. After 2 hours of this treatment the asbestos insulation was removed, and the electrical connections were interrupted in order to let the glass cool down. Once this was done, a potential difference of 7 volts was applied to the tungsten filament for 16 seconds and a thin clean bright reflecting aluminum film was deposited on the glass walls of the cell. As the distilling aluminum travels in straight lines and condenses totally upon the first impact against the walls, if the vacuum is good, the quartz window and the electrode seal A remain free from metal. The amount of aluminum in the tungsten filament allows the deposition of successive layers when desired. The cell was then ready for use.

An atmospheric-pressure quartz-mercury arc served as light source. Its radiation was resolved by a Müller-Hilger double quartz monochromator. The horn-shape of the cell insured the

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[2] R. Pohl and Peter Pringsheim, Verh. d. D. Phys. Ges. **16**, 336 (1914).

[3] S. C. Roy, Proc. Roy. Soc. **A112**, 599 (1926).

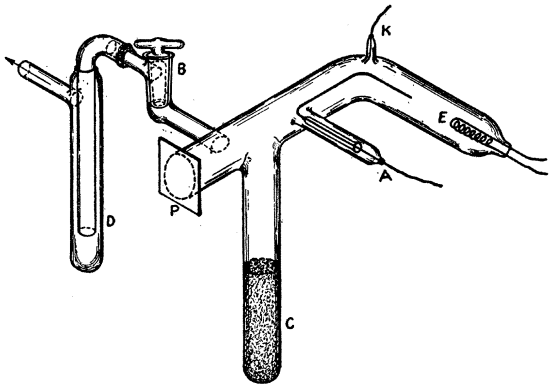

FIG. 1. Photoelectric cell.

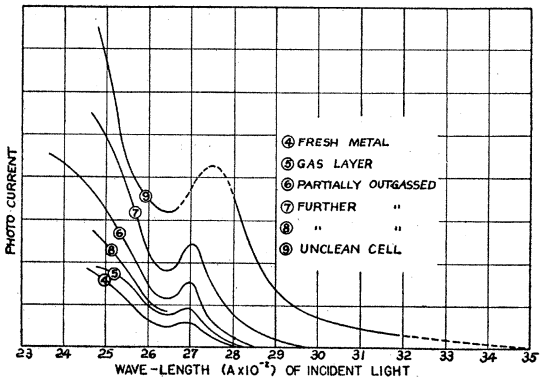

FIG. 2. Characteristic of cell containing evaporated aluminum film.

total absorption of the light that reached it through the window.

The photoelectric current was read on a string electrometer with a microscope. The intensity distribution of the light entering the cell was determined with a vacuum thermocouple connected to a galvanometer.

EXPERIMENTAL PROCEDURE AND RESULTS

The first measurements were made with a cell that had not been properly outgassed. Curve 9 of Fig. 2 represents the sensitivity function obtained in that case. The rest of the curves of Figs. 2 and 3 were determined with a better cleaned and outgassed cell. Curve 4 (Fig. 2) is characteristic of a freshly distilled aluminum film while the charcoal was in liquid air. The threshold lies at about 2830A and a zone of selectivity is noticeable at about 2700A.

The charcoal was then allowed to warm up to room temperature, to give off residual gas that would form layers on the aluminum surface. Curve 5 was then obtained. The cell was subsequently "outgassed" by placing the charcoal back in liquid air while 4 volts were applied to the tungsten coil for 2 minutes, heating the cell up to 100–200°C. Curve 6 gives the results then obtained. The repetition of the same brief treatment yielded curve 7, displaced further in the same direction as the previous ones had been. The application of 4 volts on the coil for 10 minutes produced a retrogression of the sensitivity to the values represented by curve 8.

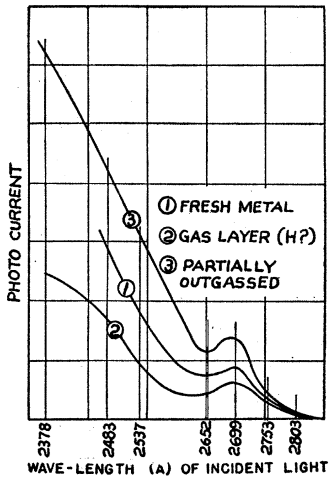

FIG. 3. Characteristic of cell containing evaporated aluminum film.

This effect may be due to further "outgassing" of the surface or to the slow distillation of fresh aluminum, forming a thin new layer on top of the old film.

If a new thick deposit was formed and the operation of warming up the charcoal and then "outgassing" in steps was repeated, the results obtained did in general not reproduce the previous ones, with the sole exception of the curve characteristic of the fresh film distilled in good vacuum. There were nevertheless two types of behavior to be noticed. In some cases the sensitivity curve would suffer displacements more or less parallel to itself, as in Fig. 2, while in others the threshold value would remain the same while the sensitivity in the further ultra-

violet would increase or decrease in amounts practically proportional to the distance from the long wave-length limit, as in Fig. 3. This irregular behavior suggests that the gases given off by the charcoal when allowed to warm up had different composition in different cases.[4]

The selective maximum at about 2700A was present in all the measured curves, indicating a certain independence of the nature and thickness of the gas layers.

Discussion

The metal used for loading the tungsten coil was commercial "pure" aluminum, containing, besides hydrogen and air, small amounts of Fe, Zn, Ga, Ni, Cu, Si, Mg and Sn, as determined by a qualitative spectroscopic analysis.[5] The iron is present in the evaporated film to the extent of 0.2 percent by weight. To these we have to add the minute quantities of tungsten evaporated together with the aluminum. The threshold value 2830A obtained for fresh aluminum films cannot be thus considered as characteristic of pure aluminum, without further evidence. But it suggests that all the values determined previously, and lying between 3342 and 5000A, were affected by the presence of small or large amounts of aluminum oxide on the surface.

[4] Compare Joh. Kluge, Ann. d. Physik **82**, 432 (1927); R. J. Cashman and W. S. Huxford, Phys. Rev. **48**, 734 (1935).

[5] E. Gaviola and John Strong, Phys. Rev. **48**, 136 (1935).

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An Abnormal Electrical Conductivity in Powdered Tellurium

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It was found that tellurium powder under a pressure of 1000 kg/cm² had about ten times greater specific electrical conductivity than that of a single crystal of tellurium under the same pressure. An investigation was made of the influence of the electrodes, particle size, condition of the surface of the powder and the medium surrounding the particles. This anomalous conductivity was most pronounced in the purest tellurium (specific conductivity of 2.5 ohm^{-1} cm^{-1}) and it gradually disappeared in tellurium powders containing impurities (the addition of which increases the conductivity of the massive metal). The abnormal conductivity probably existed in impure tellurium but was simply masked by the normal increase in conductivity with pressure observed for conducting particles. Momentarily passing an electric current through the powder under pressure caused its volume to diminish; but, also the electrical conductivity was greatly decreased and, in the case of pure tellurium, it became almost the same as that of the massive metal. Under a hydrostatic pressure of 20,000 kg/cm² massive tellurium increases its electrical conductivity more than a hundred times and the rate of increase rises rapidly with pressure. This suggests that the anomalous conductivity of tellurium powder might be due to local pressures between particles that are greatly in excess of the average pressure that was measured. However, this explanation does not account entirely for the observed magnitude of the anomalous conductivity. It seems necessary to assume that (1) the conductivity of tellurium increases even much more for a nonuniform pressure than for a hydrostatic pressure, or (2) very sharp points occur between particles which produce strong enough electric fields to liberate electrons.

Introduction

THE electrical properties of tellurium, which appear so anomalous compared to those of conducting metals, can be attributed to its small free electron density. While there is approximately one free electron per atom in conducting metals, there is probably only one free electron per million tellurium atoms. Phenomena of small absolute magnitude which would be masked in ordinary metals may be observed in tellurium, where the background of free electrons is small, and they present anomalies by comparison with conducting metals. On this basis is found an explanation for the abnormally high Wiedemann-Franz ratio of tellurium, for its anomalous