

I. PHYSICAL ELECTRONICS

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RESEARCH OBJECTIVES

The study of those properties of electrons that are not specifically associated with individual atoms forms the basis of the science of physical electronics. Examples of investigations carried out under this program include:

1. conductive and photoconductive properties of semiconductors with special attention to boundary discontinuities that occur at surfaces: (a) between the solid and its surroundings, (b) between semiconductors of different impurity content, and (c) between semiconductors and metallic contacts;
2. thermionic emission from pure materials – tungsten and complex composite surfaces, for example – including, specifically, the oxide cathode;
3. photoelectric emission from insulators and semiconductors and from pure surfaces;
4. strong field emission from single crystals and a detailed analysis of the field emission dependence on crystallographic direction and temperature;
5. properties of low-pressure gaseous discharges.

The center of interest of this group is changing from the investigation of emission properties of solids to a greater emphasis on the electronic conduction properties of semiconductors. Present studies include Hall-effect measurements in photoconductive films of lead sulfide, photoconduction as a function of light intensity with single crystals of germanium, and the rectifying properties of junctions as a function of the temperature, applied voltage, and physical composition.

The oxide-coated cathode is economically the most important thermionic emitter at the present time. The availability of new experimental data acquired both in this and other research laboratories has made it possible to formulate a unified theory to explain the conductivity and the emission properties of these cathodes. This theory will serve as a guide to further experimental researches that are planned as an important part of our future program.

W. B. Nottingham

A. ELECTRON EMISSION PROBLEMS

1. Thermionic Emission from a Planar Molybdenum Crystal

The primary purpose of this research is to investigate the existence in thermionic emission of a hypothesized internal reflection of slow electrons from the surface of the metal, by which means the emission current is reduced below the theoretically predicted value. This hypothesis was advanced by Nottingham (1) on the basis of emission studies in tungsten, and further evidence supporting it was found by Hutson (2). The reflection coefficient appears to follow the empirical relation

$$R = e^{-\frac{V}{0.191}}$$

where V is the initial kinetic energy of emission in electron volts with respect to the vacuum level.

A recent experiment by Shelton (3), in which tantalum was used, showed no evidence

(I. PHYSICAL ELECTRONICS)

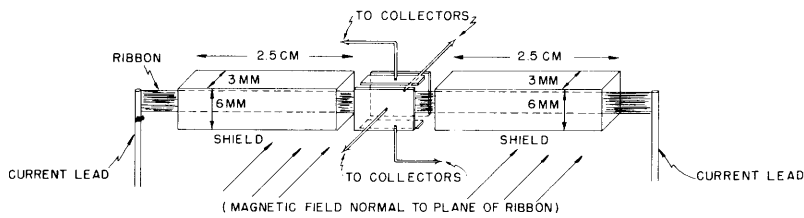


Fig. I-1. Filament and collector plates.

of such reflection, however. In Shelton's research, two single crystals of tantalum, grown in thin ribbon, were used as the emitter and collector in an ideal retarding potential experiment. To collimate the electron beam, a strong magnetic field was directed normal to the surface of both emitter and collector. It has been suggested by Nottingham that the absence of a reflection effect in this case may be attributable to the strong magnetic field, which, by altering the velocity distribution of electrons within the metal, would enable electrons that would otherwise be reflected to escape.

It was originally planned to apply Shelton's procedure to molybdenum, as described in the Quarterly Progress Report of Oct. 15, 1956, page 1, to determine the emission constant A and work-function ϕ , as well as the presence or absence of a reflection effect, in that metal. However, it now seems more advantageous to first investigate the effect of the magnetic field. For this purpose the following experiment has been devised.

The total emission current from a short length of molybdenum ribbon will be measured, both with and without a magnetic field, for various field strengths. Since it will also be of interest to compare the emission from opposite faces of the ribbon, after various types of current treatment, there will be two insulated collector plates, one on each side of the ribbon, and two additional plates, one above and one below the ribbon, to insure that the total emission current will be collected. The filament and collectors are shown schematically in Fig. I-1. The two shields, maintained at the same potential as the collector plates, act as guard rings to avoid fringing of the electric field in the central region. Only the current from this region will be sampled.

The sample to be used is a ribbon (dimensions, 7 cm by 3 mm by 1 mil) which contains several large single crystals along its length. This was the best sample grown during several trials in the period covered by the last report.

The experimental tube is now under construction.

J. Greenburg

References

1. W. B. Nottingham, Phys. Rev. 49, 78 (1936).
2. A. R. Hutson, Phys. Rev. 98, 889 (1955).
3. H. Shelton, Ph.D. Thesis, Department of Physics, M.I.T., May 1956, p. 73.

B. PHYSICAL ELECTRONICS IN THE SOLID STATE

1. Hall Effect in Lead-Sulfide Films

The measurement of the Hall effect in chemically deposited lead-sulfide films is nearing completion. Five samples were investigated and all were found to be N-type as determined by the sign of the Hall voltage. Measurements of Hall voltages for film temperatures of 325°K down to 175°K were carried out on illuminated and unilluminated samples. Linearity between Hall voltage and both applied longitudinal electric field and magnet field (0-10,000 gauss) was found throughout the temperature range and for all light intensities.

These experimental results are in good agreement with an elementary theory of uniform semiconductors that involve carriers of one sign. This theory also predicts that Hall voltage will be proportional to the average drift velocity of the carriers and will be independent of the number of carriers.

At several temperatures, with the effective applied voltage constant, i. e., with the internal field constant, the Hall voltage and the conduction current of two samples were measured as a function of the sample illumination. It was found that the Hall voltage remained constant within a ± 3 per cent experimental error for all light intensities. The increase of conduction current resulting from illumination was greater than the dark-current value by a factor of ten. In the light of the simple theory this is certainly consistent with the idea that illumination primarily increases the number of mobile carriers and has a relatively small effect on their mobility.

The details of this work will be published in a technical report.

D. H. Dickey

2. Surface States on Semiconductors

An experimental tube, now nearing completion, was designed to measure the photoconductivity of a germanium sample versus light intensity and the related changes, if any, that occur in the contact potential of the sample. It is desired to correlate the changes of the germanium surface to changes in the photoconductive characteristics of the sample. The contact potential will be determined by plotting the current of electrons directed at the sample versus the retarding voltage applied between the sample and the electron emitter; changes in the contact potential (such as those caused by changing the ambient) will shift the current plot along the voltage scale. The tube design has recently been modified to include electrostatic shields around the lead-in wires connected to the sample in order to reduce the disturbing effects of current leakage and polarization of the tube glass. This should extend the useful range of the electron retardation plots down to very small currents and increase the accuracy of measurement of contact potential changes.

E. Ahilea

(I. PHYSICAL ELECTRONICS)

3. Temperature Dependence of the Resistance of Germanium P-N Junctions

At sufficiently low voltages, a p-n junction ceases to rectify and becomes, essentially, an ohmic conductor. Theory indicates that, in this region, the dependence of the resistance on the temperature should yield information on the height of the potential barrier at the junction and on its temperature dependence. The work has been plagued by instrumental difficulties, largely because of the low voltages involved, and any results are inconclusive. The major difficulties (principally, thermal emf's and non-linear circuit contacts) have been overcome, and we hope that data on barrier heights of junctions formed of germanium with various impurity concentrations will be available shortly.

J. F. Campbell, Jr.

C. EXPERIMENTAL TECHNIQUES

1. Spectral Emissivity of Tungsten

In the Quarterly Progress Report of October 15, 1956, page 3, an experiment designed to measure the spectral emissivity of tungsten was summarized in detail. The spectral emissivity of tungsten was measured in the temperature interval 1600-2400°K and the wavelength interval 3000-8000 Å. The data are being analyzed. Inspection of the data reveals that the present emissivity values are slightly lower than the values of other observers. This can be attributed to the correction for scattered light, which has been made in the present experiment, and as far as is known to the author, has not been made by any other observer.

We plan to measure the variation of the light emitted by a tungsten radiator as a function of viewing angle and direction of polarization.

2. High-Vacuum Studies

In the Quarterly Progress Report of April 15, 1956, page 6, a theory was proposed which enables the measurement of some of the important ionization gauge parameters from a study of the equilibrium pressure versus the (electron current)⁻¹ curve for a sealed-off gauge. A special vacuum-jacketed ionization gauge for testing this theory was discussed in the Quarterly Progress Report of July 15, 1956, page 3.

The observed equilibrium pressure versus (electron current)⁻¹ for this vacuum-jacketed gauge is shown in Fig. I-2. According to the present theory, this curve should be a straight line with a slope that is determined by the ratio of the effective permeation rate to the clean-up rate and with an intercept that measures the apparent X-ray limit of the gauge. (The effective permeation rate is a combination of glass-wall permeation and the back-flux of previously cleaned-up gas that is again given off.)

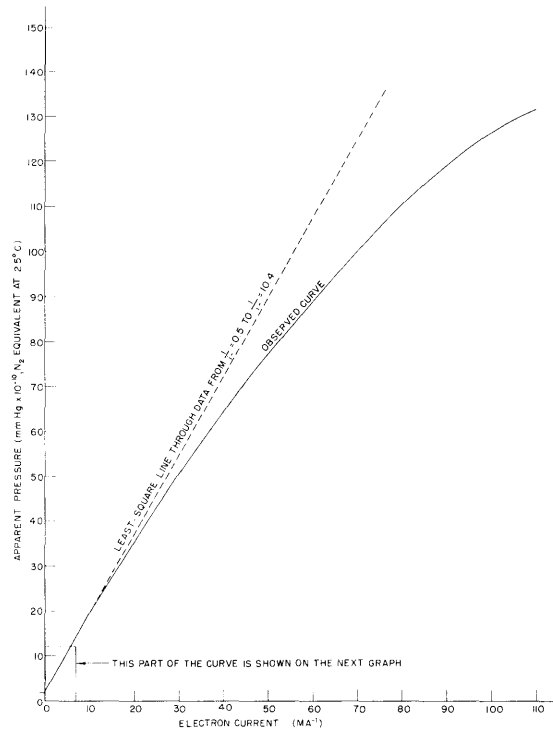


Fig. I-2. Equilibrium characteristic of modified Bayard-Alpert ionization gauge ($J_{\text{electron}} = 100$ volts); high-pressure portion.

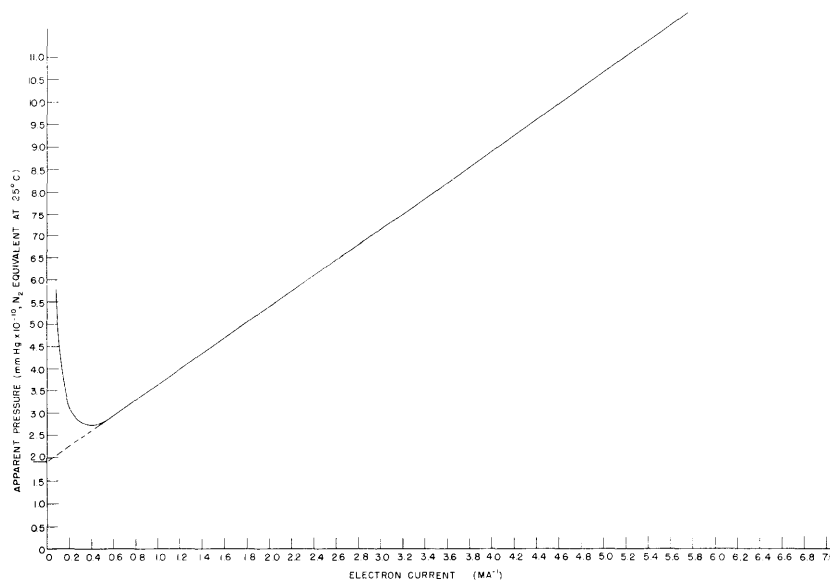


Fig. I-3. Equilibrium characteristic of modified Bayard-Alpert ionization gauge.

(I. PHYSICAL ELECTRONICS)

It is apparent that in the range 0.1-1.6 ma of electron current, the experiment justifies the theory, and the X-ray limit appears to be 1.9×10^{-10} mm Hg, N₂ equivalent (5.7×10^{-9} amp of X-ray current per amp of electron current). The systematic departure from linearity at low electron currents is thought to be caused by the decreased back-flux of gas from the metal portions of the tube (i. e., more effective trapping of cleaned-up gas), since at low electron currents these metallic portions receive less radiant energy from the electron emitter and are, consequently, at a lower temperature. The vacuum jacket prevents permeation of gas through the parts of the glass envelope that are susceptible to such temperature variations.

The details of the equilibrium curve at high electron currents are shown in Fig. I-3. The departure from linearity at large electron currents might be attributed to the on-set of space charge which changes the clean-up rate and/or the gauge constant, or it might be attributed to the liberation of gas from the electron collector which is caused by the heating effect of the collected electrons. The clean-up rate is being measured as a function of electron current to determine whether or not this effect will explain the departure from linearity. It is also hoped that the comparison of the present data with similar data that will be taken at a larger electron-acceleration voltage will show which of the two mechanisms is responsible.

R. D. Larrabee