I. PHYSICAL ELECTRONICS

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A. ELECTRON-EMISSION PROBLEMS

1. Thermionic Work Function and Conductivity of Oxide-Coated Cathodes

This research has been completed and it will be the subject of a journal article. Some of the results are summarized below.

The electronic energy level structure of a (Ba,Sr)O coated cathode has been studied as the activation state of the cathode was varied. These states included (1) the freshly converted inactive condition, (2) several intermediate stages,(3) the well-activated state with ion gauge inoperative, and (4) the well-activated state with the ion gauge running. The vacuum conditions were monitored throughout this study by means of an ion gauge. Time effects and activation changes occurring during the taking of all data were carefully recorded.

Conductivity measurements were taken with an embedded probe and across a two-piece base metal sleeve. This allowed a comparison of three methods of measuring conductivity. Circuits were designed that were capable of detecting much smaller absolute conductivity values than had been reported previously. Thermionic emission, photoelectric emission, and conductivity measurements have been studied within the temperature range of 295°K to 1050°K.

The vacuum conditions were found to be most favorable when the ion gauge was operating after the getter had been flashed. The indications were that dissociated molecules or ionized molecules or atoms react more rapidly with the getter. The electron emission from the oxide cathode was much higher under these favorable vacuum conditions. In contrast to this observation, the conductivity activation energy values did not depend so much on vacuum conditions. The increased electron emission from the oxide appeared to be due to a change in the oxide surface. This showed up as a decrease of 0.3 volt in the electron affinity. These results do not conform with the Loosjes-Vink theory (1). Under similar vacuum conditions the electron affinity remained constant as the cathode activation varied.

Photoelectric emission from the oxide increased with temperature, although the logarithm of the photoelectric current divided by the square of the temperature decreased with increasing temperature.

A comparison of the gap and probe conductivity measurements indicated that the gap was not as well activated as the rest of the cathode. It is possible to explain Mutter's (2) anomalous results on this basis. Results of gap conductivity measurements lend support to a semiconductor theory based on prominent lattice scattering at the lower temperatures.

The movement of ions within the oxide was detected at all temperatures at which probe current-voltage curves were taken. Although the time effects associated with these changes in the physical structure offered some evidence in favor of an electrolytic explanation of the low-temperature conductivity, in general these observed results favor an electronic conduction theory in which ion movement alters the barriers.

The semiconductor model most capable of explaining all of the observed results was one having two donor levels in the active state located at 0.4 ev and 2.2 ev below the conduction band. These levels were explained on the basis of a colloidal theory for the oxide in which an excess amount of barium existed. The electron affinity for both the active and inactive states was 1.1 volts. In the completely inactive state the forbidden band was found to be 4.2 ev wide. These results compare favorably with optical measurements as well as with results obtained from thermionic and conductivity data.

One other semiconductor model considered as a possible explanation for the results found here and elsewhere has an inactive state characterized by an equal number of donors and acceptors, with the donors 0.4 ev below the conduction band and the acceptors 2.2 ev below the conduction band. The acceptors would be occupied and the donors unoccupied in the inactive state. In the active state the number of donors would increase and exceed the number of acceptors. Some donors would be occupied and the acceptors would remain constant in number. This picture could explain the Vink (1) curves without assuming any pore conduction at high temperatures. However, this model does not explain the results of this research found in the inactive state of the cathode.

References

1. H. J. Vink, R. Loosjes: Philips Research Reports 4, 449, 1949
2. W. E. Mutter: Doctoral thesis, M.I.T., 1949

R. T. Watson

2. Magnetic Velocity Analyzer Investigation of Thermionic Emission from Tungsten

Experiments have been carried out on a "dummy" tube in order to answer some of the questions arising in the design of the final tube. These questions are:

(1) Is it possible to obtain a very high vacuum in a tube whose electron-receiving metal parts have not been heated during the final exhaust of the tube? The criterion of a high vacuum in this case is the stability over long periods of time of the thermionic emission from a tungsten filament whose temperature is about 1400°K.

(2) How close may glass insulating beads be mounted to a structure that must be outgassed at a high temperature without being injured by the outgassing process?

(3) What type of gettering is most effective in maintaining the desired high vacuum?

The "dummy" tube consists of a large pyrex envelope containing a 0.003-inch tungsten filament. Surrounding the filament is a cylindrical tantalum anode 1.5 inches in diameter and 2.5 inches long. A side tube for getter and a Bayard-Alpert ionization gauge are appended to the main envelope.

The vacuum processing was carried out on one of the Research Laboratory of Electronics oil diffusion pump systems. After the tube had been sealed on the system and given a preliminary bakeout, all metal parts were thoroughly outgassed. In particular, the tantalum anode was heated to a temperature of 2100°K by r-f induction. During this heating, two glass beads on 0.040-inch tungsten wire, which were welded at distances of 1/8 inch and 3/8 inch from the anode, were observed. The closest bead softened and was considerably deformed; the other bead appeared to remain unharmed. This provided a conclusive answer to question two.

Next, the tube was returned to atmospheric pressure for a day. At this time, a 0.010-inch tantalum filament was mounted on a two-lead press in the getter side-tube. The remaining vacuum processing consisted of cycles of oven-baking at 450°K and outgassing of all metal parts with the exception of the anode. During the seal-off a vacuum of better than 10^{-7} mm Hg was maintained.

After the tube had been sealed off, the Bayard-Alpert gauge indicated a pressure of 3×10^{-9} mm; the operation of the gauge served to "clean up" the tube. Evaporation of tantalum in the getter side tube did not change the observable pressure. After the gauge had been operating for a week, flash-filament data (1) indicated that the time taken for a clean surface to adsorb a monolayer of gas was of the order of two days. This corresponds to a pressure of condensable gas of about 10^{-11} mm. It is believed that the higher pressure read by the gauge was partly due to the "reverse photoeffect" (2) as the gauge was not the best Bayard-Alpert design.

Operation of the filament of the main tube indicated that the pressure was not at a satisfactorily low value; the emission dropped by a factor of two in twelve hours operation at 1400°K.

The use of batalum and KIC getters in obtaining stability of thermionic emission is now being studied.

References

1. W. B. Nottingham: Quarterly Progress Report, Research Laboratory of Electronics, M.I.T. p. 4, Oct. 15, 1948; p. 8, April 15, 1948
2. Final Report, Research Laboratory of Electronics, M.I.T. p. 16, June 30, 1946

A. R. Hutson

3. Photoelectric Emission

A new experimental tube has been constructed to determine whether or not the high contamination rate previously reported could be reduced. A getter of tantalum wire was employed in this tube. The getter is fired by evaporating tantalum to the wall of the tube at intervals of three to four days. It is found that by following this procedure the pressure may be held at 4×10^{-9} mm Hg. The photoelectric emission produced by the mercury 2537 A spectral line from the molybdenum decreases by a factor of two in 3 1/2 hours. This decrease in emission corresponds to an increase in the work function of about 0.10 ev. The final value of the work function remains steady at 4.55 ev and is extremely reproducible. This work function is considerably higher than that found by previous researchers; we consider it to be reliable because the molybdenum cathode was outgassed at higher temperatures (2300°K) than previously reported and was maintained under better vacuum conditions. The low work function may be characteristic of a high degree of surface contamination as is shown by the results published in the Quarterly Progress Report, January 15, 1951.

Germanium has been evaporated on the molybdenum surface to a thickness of about 150 A. Both the distribution in spectral energies (Fowler plot) and the distribution in total energies (retarding potential plot) of the photoelectrons have been taken. The distribution in spectral energies increases as $(h\nu - 4.55)^2$ for molybdenum for $h\nu$ greater than the work function 4.55, where $h\nu$ is the photon energy expression in electron volts. It is found empirically for germanium that the distribution in spectral energies varies as $(h\nu - 4.75)^4$. The number "4.75" probably represents the energy required to remove an electron from the highest occupied energy level in the semiconductor to infinity.

The photoelectric current as a function of the retarding potential was taken for both the molybdenum and the germanium surface for a photon energy of 5.42 ev. It was found that the cutoff potential shifted by 0.07 ev when the semiconductor was deposited on the molybdenum surface. This shift corresponds to a forbidden energy gap of 0.14 ev for germanium. The saturation point of the retarding potential plot corresponds to the contact potential difference between the cathode and anode. Subtracting the work function of the anode from this saturation value of potential yields 4.75 ev which we shall call the work function of the germanium.

The correspondence between the work function value, found from the retarding potential plot, and the threshold value, found from the Fowler plot, seems to indicate that surface states exist on the germanium. However, it must be postulated that only the low energy photons near threshold give rise to photoelectric emission from surface states and that the high energy photons interact only with electrons in the filled band. In order to check this hypothesis more thoroughly, a retarding potential plot will be taken in the vicinity of the thresholds to determine whether or not the cutoff potential is shifted toward that value for the molybdenum substratum.

H. S. Jarrett

4. Photoelectric Study of Surface States on Insulators

A photoelectric study of surface states on insulators has been undertaken. Previous work by D. Jeffries (Master's thesis, Department of Physics, M.I.T., 1950) on the photoelectric emission from quartz seems to show that this emission arises from the surface states, and that it offers a good method for the study of these electronic energy levels. It is planned to refine and extend the study.

Two considerations arise: First, one must be assured that the photocurrent being measured arises from the surface of the insulator, i.e. that any spurious currents are eliminated. Second, provision must be made to assure a clean surface, or it must be shown that contamination does not affect the results of the experiment.

A tube has been designed with these two objects in mind. Careful shielding with separate leads to the several parts of the shield allow potentials within the tube to be varied, and will permit the elimination and/or the identification of the spurious currents. In order to eliminate contamination, provision has been made for the condensation of new material on the surface of the crystal from an evaporator after the tube has been pumped. It is also planned to investigate any dependence of the photoelectric threshold on the crystallographic direction of the surface being studied. Construction of the experimental tube is under way.

R. Noyce

5. The Influence of Electric Field and Temperature on Field Emission from Tungsten

The quantitative studies reported by M. K. Wilkinson (Quarterly Progress Report, Oct. 15, 1950) applied to a smooth surface of a single crystal of tungsten. The measurements were made by observing photometrically the light pattern created by the bombardment of a phosphor by the field emission electrons. Wilkinson and others have found that if the point under observation is held at a high temperature while a strong electric field is applied, the emission pattern changes, becoming far more complex and yet holding practically perfect crystallographic symmetry. The present study is designed to obtain more quantitative information concerning this effect when studies are being made under the most favorable vacuum conditions and with electric fields rather better determined than is usually the case. The tube to be used has the phosphor deposited on "conducting glass" and therefore the removal of excess charge from the phosphor is accomplished by conductivity instead of secondary emission.

T. F. Wichmann, W. E. Spicer

B. STUDIES WITH GAS DISCHARGE

1. Probe Measurements in a Low-Pressure Mercury Arc

Langmuir probe studies of the electron densities and energy distributions in a mercury arc are being made in the pressure range of 1.75 μ to 35 μ. The pool type mercury arc has a vertical and horizontal section. In the vertical section the arc is maintained constant, and halfway along this part of the tube there is a side arm 48 cm long and 5.25 cm in diameter that thus forms a "T". At the opening of the side arm there is a "double-grid" structure with staggered slots and bars arranged so that straight line trajectories between the two tube sections are impossible. The studies of plasma conditions reported here apply to the discharges in this side arm. With a current of 2.5 amp in the vertical section a good plasma can be maintained in the side arm with currents between 0.1 amp and 5.0 amp. Exact limits have not been established. To ensure uniformity of mercury pressure the tube is completely immersed in a thermostated water bath when measurements are being made.

The probes themselves are all tantalum disks, 0.345 cm in diameter, and except for the current collecting surface, are completely surrounded by tantalum shields whose potentials may be controlled independently of the probe potential. Two of the probes, identified as the "front" and "rear" probes, are fixed at the plasma axis, with their axes perpendicular to the plasma axis, and are accurate in measuring energy distributions since they suffer from no drift-current effects. A third probe set is similar, but has in addition a separate surface with its axis parallel to that of the plasma and facing the grids. For the determination of the radial variation of potential and charge density in the plasma, the tube has been equipped with a probe which can be moved from the tube wall to the axis as desired and a sixth probe is fixed at the tube wall.

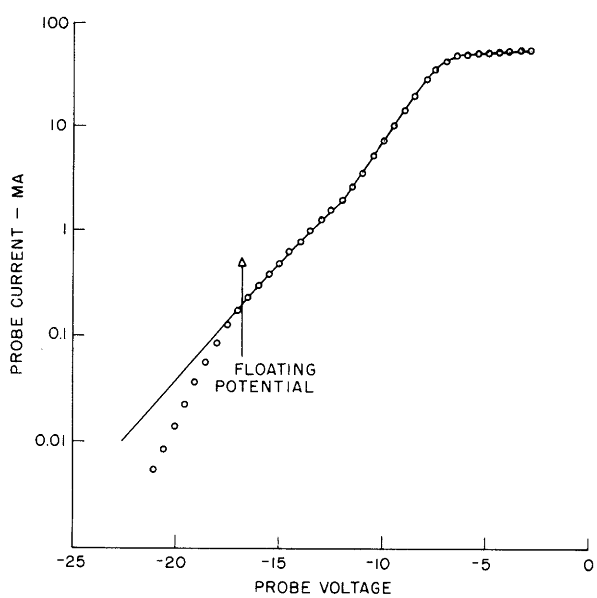

Fig. I-1 Probe curve; bath temperature 30°C.

Thus far, measurements have been made with the various probes at bath temperatures of 22°C, 30°C, and 40°C (calculated mercury pressures of 1.75 μ, 3.4 μ, and 7.6 μ). A run has been made with one of the probes with a bath temperature of 50°C (16 μ pressure).

Since mercury atoms condensing on a tantalum probe change its work function and therefore its contact potential relative to the anode, the probes are flashed red-hot before every reading in order to clean their surfaces. Since flash currents were in the neighborhood of 100 mils (3 percent of plasma current), equilibrium conditions in the plasma should not have been disturbed appreciably. The main plasma was monitored with an oscilloscope at all times.

When the probe is made quite negative it draws only ion current; this current is extrapolated to more positive regions, where the electron current is found by adding the estimated ion current to the magnitude of the probe current. The ion saturation curve was usually almost a straight line, so a straight line extrapolation was employed. Following this determination of the electron current the log of current is plotted against probe voltage. For a Maxwellian energy distribution this plot yields a straight line.

At pressures of 1.75 μ and 3.4 μ, all probe curves departed from the Maxwellian straight line by (1) dipping down at voltages below the floating potential; (2) bending at voltages above the floating potential. The first effect comes from a depletion of high-energy electrons, probably due to inelastic collisions. The bends were found to occur at lower voltages for higher pressures and in general fell 3 to 9 volts above the floating potential. The front probe, only 8.3 cm from the twin grids, had the most pronounced bend in its curve, and the rear probe the least. (See Fig. I-1.) Tests made at 7.6 μ pressure continued to show bends in the front and anode-facing probes, but the rear probe had none.

The ion and electron densities and effective plasma resistance increased with pressure; and the electron temperature, found roughly from the average slope of the probe curves, decreased with increasing pressure as expected.

J. M. Bailey

C. EXPERIMENTAL TECHNIQUES

1. Ionization Gauge Studies

Experiments continue in order to establish ranges in the design parameters of the Bayard-Alpert gauge for the maintenance of high sensitivity consistent with ease of production. Parameters under investigation include the spacing between the electron emitting filaments and the electron collecting grid. Also, attention has been given to the grid wire size and the number of turns per inch of the electron collector. Considerable variation in these parameters can be made without more than a twenty or thirty percent change in sensitivity. Details of these studies will be reported when they are available.

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