I. PHYSICAL ELECTRONICS

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A. ELECTRON-EMISSION PROBLEMS

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

Measurements of thermionic emission and conductivity as functions of the cathode state of activation will be taken to determine the location of the energy levels of the oxide coating. To check a discrepancy in the deactivated state in which the thermionic work function is reported less than the conductivity activation energy, several methods of measuring conductivity are being used in the same tube. It is hoped that using a MgO ceramic to support the split base metal will enable conductivity measurements below room temperature.

A probe wire loop of 0.0005-in. platinum wire has been welded successfully. Nickel sleeves now fit well onto the MgO ceramic and are ready for coating. The glass envelope has been baked and carefully cleaned to prevent electrical leakage. If no trouble occurs in winding the probe wire, the tube will soon be assembled.

The thermocouple was calibrated in an atmosphere of nitrogen and is to be recalibrated in vacuum to make sure that the tungsten and nickel were not contaminated.

The measuring circuits are set up and in working order. Results are expected in the near future.

R. T. Watson

2. Thermionic Emission from Ultrafine-Grain Oxide-Coated Filaments

The tube for making velocity distribution measurements is now virtually completed. This tube has an emitter consisting of a polished tungsten filament of a diameter of about 4 mils, coated cataphoretically with barium and strontium oxides to an overall diameter of 5 mils. So that the temperature over the coated portion of the wire will be uniform, the distance from the upper end of the coating to the upper supporting spring is over 15 cm. The corresponding distance at the lower end is small but the filament runs to the center of a hairpin which is brought up to temperature by an added heating current. Two potential leads serve to measure the voltage drop across the central section of the filament. By this means the temperature of the emitter can be calculated from its resistance.

In measurements of this sort it is particularly important to have the anode clean. During the activation of an oxide-coated cathode contaminating materials are given off.

For this reason it was necessary to construct the tube with two anodes. During activation the main anode is slid out of the way and the current is collected by an auxiliary anode. At this time the open end of the main anode is protected by a hinged baffle. After activation the baffle can be swung open and the measuring anode is allowed to slide into position.

The main anode consists of a collector and two guard rings mounted rigidly to three quartz rods. To reduce leakage currents over the surface of the quartz, each of the three quartz rods is protected by two evaporation shields.

The getter to be used will consist of pellets from a batalum getter mounted in four tantalum holders. The getter bulb is constructed so that the barium emitted during firing cannot reach the main portion of the tube by rectilinear motion.

All the metal structure of the tube is of pre-outgassed tungsten or tantalum. Insofar as possible these parts can also be outgassed again after assembly in the tube.

The measuring circuit to be used is that described by Nottingham (1). The filament is heated by pulses; the thermionic measurements are made between the pulses.

It is expected that this tube will be completed and measurements started by the middle of March.

C. P. Hadley

Reference

(1) W. B. Nottingham: Phys. Rev. 49, 78 (1936).

3. Deterioration of Oxide-Coated Cathodes under Low Duty-Factor Operation

The ageing program described in previous Progress Reports has been carried to 3441 hours with the following results:

a. Interface resistance

Eleven tubes have developed interface resistance. All are from panels III and IV and have drawn no emission current throughout life. Seven are from panel III and four from panel IV. Figure I-1 is a graph representing the survival of tubes from these panels against interface resistance, where every tube showing a detectable resistance is regarded as a failure.

b. Pulsed emission

There has been only a slight decrease in the average pulsed emission for each panel from that at 1557 hours (reported in the last Quarterly Progress Report). If an emission of less than 0.05 amp is taken to indicate a failure, four tubes, all from panels I and II, must be considered failures.

(1) Pulse shapes

The increase in emission current during a 1-msec pulse reported for the majority

of the tubes of panels III and IV in the last Quarterly Progress Report is now shown by only a small number of these tubes. The remainder show either constant emission current during the pulse, or a slight decrease. All tubes of panels I and II show a constant emission during the pulse.

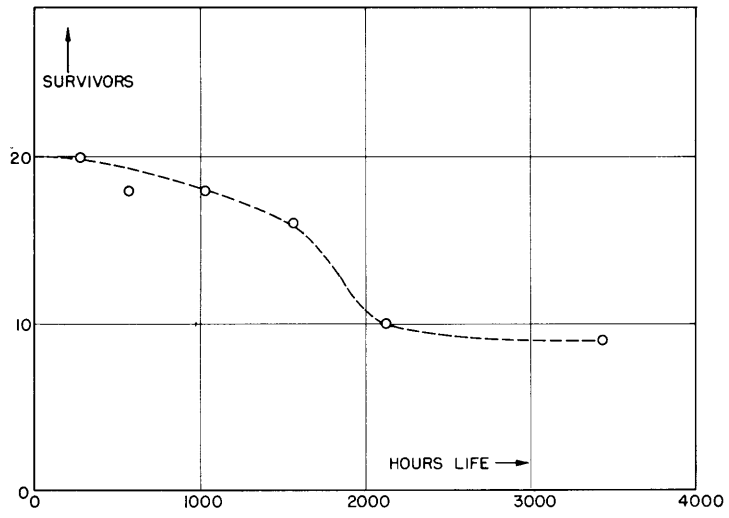

Fig. I-1 Survival against interface, panels III and IV.

c. D-C emission

The average low field, low temperature d-c emission for each panel has decreased only slightly from that at 1557 hours. If an emission less than 3 μa is taken to indicate a failure, five tubes must be considered failures. Four of them are from panels I and II, and are considered failures from the pulsed-emission standpoint as well. One is from panel III and also exhibits an interface resistance.

The life test described in these reports is very nearly complete. It is planned to make one further series of emission and resistance tests at about 4000 hours' life, and then to subject the tubes to spectro-chemical analysis and x-ray tests to determine impurity content and the nature of the interface compound, if possible.

Work is under way in the construction of a tube in which the interface voltage drop may be measured for currents in both directions in order to obtain a clearer idea of the energy level structure of the cathode at the interface.

Plans are also being made to conduct accelerated life tests of purified diodes containing a single reducing agent of high purity. J. F. Waymouth, Jr.

4. Purified Standard Diodes

Standard diodes N-5 and N-7 have now been aged 3441 hours, with the following results:

a. Interface resistance

Neither tube shows an interface resistance.

b. Pulsed emission

	2116 hrs	3441 hrs
N-5	0.20 amp	0.09
N-7	0.26	0.09

Up to 2116 hours, these tubes both have decidedly better pulsed emission than similar diodes with No. 699 nickel cathode cores aged under the same conditions. At 3441 hours, they have approximately the same emission as the 699 diodes.

c. D-C emission

	2116 hrs	3441 hrs
N-5	64 μa	52 μa
N-7	<0.01	<0.01

It was remarked in the last Quarterly Progress Report that N-7 (which had aged delivering no emission current) was believed to have a high cathode coating resistance. This hypothesis was made in order to explain why this tube could have a good pulsed emission and an extremely poor d-c emission. To obtain an idea of the mechanism of the effect, volt-ampere characteristics of both N-5 and N-7 were taken at 2116 hours' life; they are plotted in Fig. I-2. The characteristic for N-5 serves to establish the space-charge line. As may be seen, the characteristic for N-7 appears to deviate from the space-charge line at the origin.

Since the pulsed emission from N-7 is better than that from N-5, this deviation was assigned to coating resistance, rather than emission saturation. The current in the inter-electrode space is felt to be space-charge limited, so that by far the large majority of the applied potential appears across the cathode coating. The observed characteristics are believed to be those of the coating itself.

Bearing in mind that this cathode was activated by doping with methane gas, we may explain this volt-ampere characteristic by the assumption that only the surfaces of the (BaSr)O grains contain an appreciable number of activation centers, while the interiors of the grains are more nearly intrinsic semiconductors. A one-dimensional model of a coating of this sort would have an energy level structure as in Fig. I-3. The regions where the density of activation centers is high will also have a high density of electrons in the conduction band. The intrinsic regions will have practically no electrons in the conduction band. There exist, therefore, reservoirs of electrons separated by potential barriers.

When a field is applied and the energy levels are tipped, the barriers are effectively reduced in height. Since the current over a barrier of height Φ electron volts above the Fermi level varies as $\exp(-e\Phi/kT)$, the current increases faster than the first power of

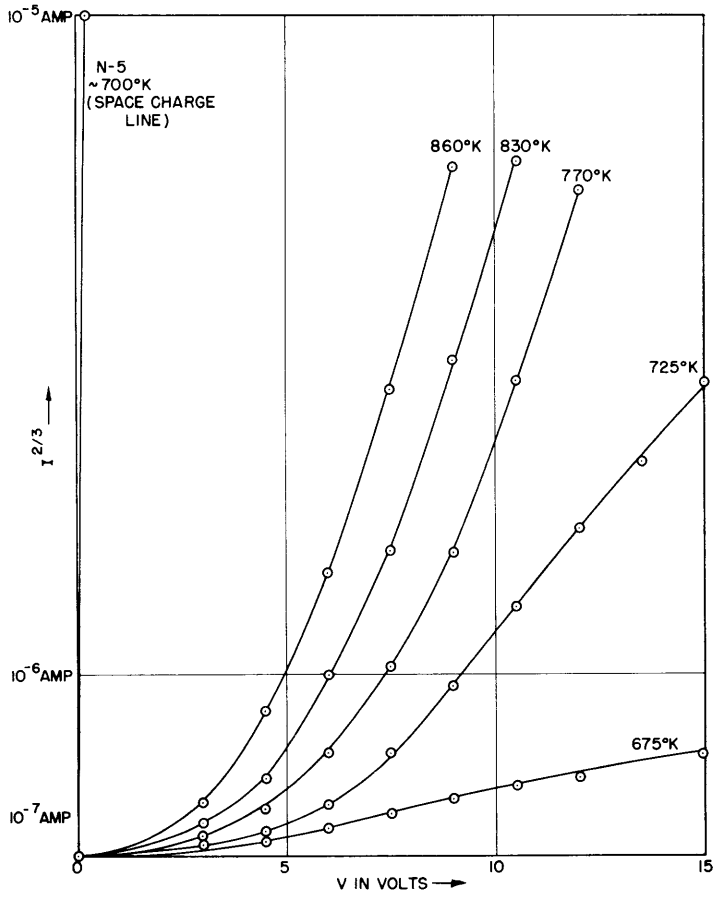

Fig. I-2 Volt-ampere characteristics.

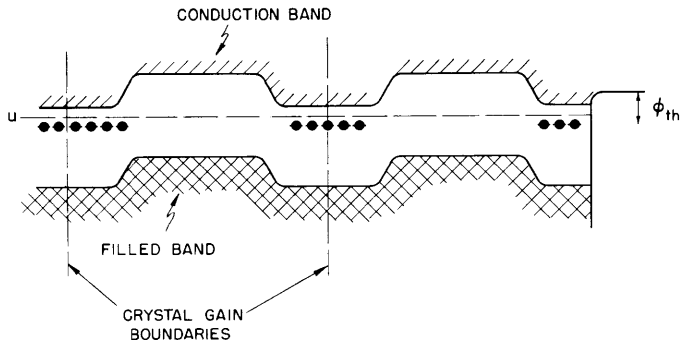

Fig. I-3 Proposed energy band structure for N-7 cathode.

the potential difference across the coating, as in Fig. I-2. Furthermore, the presence of activation centers near the grain surfaces leads to a normal work function and satisfactory emission, if sufficient voltage is applied to the tube that the inter-electrode space current is not space-charge limited, and saturation emission current can be drawn.

J. F. Waymouth, Jr.

5. Determination of the Field-Emission Properties of Single Tungsten Crystals by a Photometric Method

The second experimental tube has been completed and found to be satisfactory. In the construction of this tube several procedures were followed which differed from those used for the first tube. In place of zinc sulphide, willemite was used for the phosphor, and another coating technique was employed. It was found that the method of washing the phosphor on the bulb from a solution of acetone and collodion (described in a previous Progress Report) frequently gave coatings which were so thick that they cracked when baked. Attempts were made to discover a more satisfactory method. It was found that excellent uniform coatings could be obtained by washing the inside surface of the glass envelope with a binder and then blowing the dry willemite on this surface when the binder became tacky. The binder which proved the most satisfactory was a solution of acetone, phosphoric acid, and acetic acid in the ratio: 5 cc acetone, 1 cc phosphoric acid, 3 drops acetic acid. Very little difficulty was experienced in reproducing excellent coatings by this method but when the envelope was baked at about 350°C, the phosphor became spotty and discolored. This difficulty was found to be due to nonuniformity of the binder. Extreme precaution must be taken to use only as much binder as necessary and to wash this binder very uniformly over the surface to be coated.

As stated in the last Quarterly Progress Report, the anode structure in this tube was constructed of tungsten springs. This type of anode eliminated the problem of insufficient collection of secondary electrons which was experienced in the first tube.

The same vacuum techniques which were used for the first tube were repeated in processing the second. While the tube was on the vacuum system, several cycles were performed, in which the metal parts were outgassed, followed by a high temperature bake. An ionization gauge was sealed off the vacuum system with the experimental tube, and the operation of this gauge served to clean up the residual gases. The data taken on this tube substantiate data on the first tube and indicate that a very good vacuum can be obtained in this manner. The field-emission pattern of clean tungsten has been observed on this tube and found to be reasonably stable for periods of about an hour. Previous experimenters in field emission found that even with the best vacuum techniques known at that time, patterns of clean tungsten could be held stable for only a few minutes.

The photometric equipment required to photometer the field-emission pattern and measure relative currents along the various crystallographic directions has been put in operating condition. Other experimental apparatus is now being assembled and it is hoped that photometric data will be available for the next Quarterly Progress Report.

M. K. Wilkinson

6. Photoelectric Emission

Construction of the equipment to measure the energy distribution of the photoelectrons from germanium deposited on molybdenum is continuing. The germanium will be deposited on the spherical molybdenum cathodes in thin layers and the photoelectric emission of each successive layer will be measured to determine the transition from a Fermi metal to a semiconductor.

Since extremely good vacuums and clean cathodes are needed in the study of surface phenomena, the usual getter, which may contaminate the surface, will be replaced by an ionization gauge which will tend to clean up the residual gases after seal-off.

A Compton electrometer will be used in an attempt to measure photoelectric currents that are lower than those allowed by the vacuum tube electrometer. Construction of ultraviolet sources, radiation detectors and other allied equipment is being continued.

H. S. Jarrett

7. Effect of Impurity Surface States on the Photoelectric Threshold in Semiconductors

Experimental apparatus is in the process of construction at present. The tube on which measurements will be taken consists of a central section to which three side tubes are attached radially. The latter contain respectively a retarding anode, an oven and an ionization gauge. The pyrex envelope of the central section terminates in a 60°-cone on the bottom, within which rests snugly a cone-shaped tantalum platform. A stainless steel holder rests on the platform and can be rotated magnetically about the axis of the cone. A germanium slug is clamped in the holder in such a fashion that by rotating the holder one can move the slug in front of any one of the side tubes. The side tube containing the retarding anode has a quartz window for the admission of ultraviolet light which passes through a small hole in the anode to strike the germanium. The anode and its guard ring are tantalum electroplated with platinum in order to minimize photoelectric emission from the anode. The oven is a resistance-heated tantalum cylinder containing aluminum. Aluminum vapor effuses from an 18-mil hole and must pass through a 7-mm hole in the side tube in order to enter the main section and deposit on the germanium slug. Aluminum vapor is quickly removed from circulation in the side tube by immersing the tube in liquid air. To insure that none of the Al atoms striking the germanium are reflected, the slug is kept at a very low temperature during deposition. This result is accomplished by immersing the cone of the main section in liquid air. The ionization gauge is constructed so that it may also serve as an electron gun for heating the germanium slug. The tube is constructed so that metallic parts (except for the oven and the slug) may be induction-heated for outgassing purposes after final assembly in the tube.

The germanium slug is formed by vacuum melting in a quartz crucible. An estimate of the purity of the germanium can be made if the variation of electrical conductivity

with temperature is known. The slug prepared appears to have an impurity content of less than one part in 10^9. The impurity is probably zinc.

In general, calculations can be made of the effect of certain types of surface impurity atoms on the electronic energy-band structure of a semiconductor. Such calculations are based on a theorem discovered by Wannier (1), which gives a method of treating perturbing potentials in periodic lattices. The importance and scope of the theorem has only recently been realized (2). The general theorem holds exactly for a constant perturbing potential, and approximately for a perturbing potential which does not change appreciably over a range of several lattice distances. In the important special case of symmetrical periodic lattice potentials (a class which includes most elemental semiconductors such as germanium), it can be shown that the theorem holds exactly for a perturbing potential which varies linearly with position, and approximately for a perturbing potential which varies in a nearly linear manner over a range of several lattice distances. The perturbing potential resulting from surface states varies quite rapidly near the surface, but in the first approximation may be considered to vary linearly over small distances so that Wannier's theorem is still applicable.

R. H. Parmenter

References

(1) G. H. Wannier: Phys. Rev. 52, 191 (1937).

(2) J. C. Slater: Technical Report No. 113, Research Laboratory of Electronics, M. I. T. (1949); Phys. Rev. 76, 1592 (1949).

B. STUDIES WITH GASEOUS DISCHARGE

1. Investigation of Low-Pressure Mercury Arcs

As described in the last Quarterly Progress Report, non-Maxwellian distributions of electron energies are observed at the center of the plasma of a low-pressure mercury arc. The distribution exhibits a depletion of high energy electrons when compared with an ideal Maxwellian distribution. It is felt that this depletion results from inelastic collisions of electrons with the tube walls since there seems to be a close correlation between the wall potential and the potential at which the depletion sets in.

In order to investigate this hypothesis further a plane probe surrounded by a guard ring has been mounted in the wall of the tube. Diametrically opposite this wall probe has been placed a multiple-section coaxial tantalum probe, the center of which is a 20-mil wire extending to the middle of the tube. Surrounding this wire are four successively larger cylinders, each with successively less length exposed. The net result is that each cylinder acts as a guard ring for the cylinders inside it and at the same time serves as a collector for taking probe measurements. From this arrangement one will

be able to obtain the radial distribution of plasma potential and electron energies.

The mercury tube containing these probes is L-shaped as previously described. In order to lessen the chance of electrons reaching the probes directly from the cathode, the cathode side of the L has been doubled in length over the previous tube. Processing of the new tube has almost been completed, and it is anticipated that measurements will be taken in the near future.

R. M. Howe

C. EXPERIMENTAL TECHNIQUES

1. Spectral Emissivity of Tungsten

The production of an experimental tube for this project has required the development of new techniques unfamiliar to the personnel working on the problem of designing and constructing the specimen tube to be used for this investigation. One of the greatest difficulties has been that of welding the thin-wall tungsten tube to suitably shaped tungsten rods which serve to support the specimen and conduct the high current to it. The method of arc welding in an atmosphere of hydrogen has been used and sufficient skill developed so that the welds which we are now able to produce are satisfactory. Another problem that gave trouble relates to the evaporation of copper or copper oxide from the water-cooled supporting electrodes used as integral parts of the metal-to-glass seals by means of which the electric current is delivered to the specimen. Although final tests have not been completed there is hope that the method now to be tried, of covering all the surface of copper with a heavy nickel plating, will eliminate this copper evaporation difficulty.

W. B. Nottingham, L. E. Sprague, H. R. Phillipp, J. R. Stevenson

2. Ionization Gauge Study

Studies that have been made of the development of gas within a highly evacuated sealed-off ionization gauge indicated that helium from the atmosphere can diffuse through pyrex glass and build up a measurable helium pressure within a very few hours' time. With this result in mind it is thought that a vacuum leak detector might be developed by using a large area thin-wall pyrex surface to separate the ionization gauge from the evacuated region which is being investigated. A leak in that region would be discovered by permitting a flow of helium through the leak after which a fraction of this helium would be selectively transmitted through the thin wall of the pyrex separator. Calculations indicate that this method of leak detection has a chance of being successful. Based on this possible chance of success preparations are being made for a quantitative test of the usefulness of this technique.

W. B. Nottingham, L. E. Sprague, G. C. Bell, Jr.

3. An Electronic Circuit for the Operation of an Ionization Gauge

Although specialized circuits for use in connection with ionization gauges have been developed, none of the published circuits fill all of the needs that have to be satisfied in the use of this instrument. The most important of these needs are:

a. Self-contained circuits by means of which all of the elements of an ionization gauge can be thoroughly outgassed simultaneously (including the ion collector plate which may require as much as three or four hundred watts of heating power to bring it up to a suitable temperature).

b. A collector current measuring circuit capable of detecting a current as small as 10^{-11} amp and capable of the measurement of currents with satisfactory accuracy at 10^{-9} amp.

c. A suitable circuit for integrating the quantity of current received on the collector during and immediately following the flashing of an auxiliary filament with a sensitivity such that a charge accumulation of 10^{-10} coulomb can be measured.

d. Adjustments available so that operating parameters can be controlled to give electron energies from 10 volts to 700 volts, and collector potentials from -10 to -400 volts.

e. Circuits for automatic regulation of the electron current at chosen values over a very wide range.

f. Circuits and relays for the automatic removal of power to the ionization gauge in case of accidental failure in the vacuum system.

A circuit arrangement has been designed to accomplish these and other objectives. The equipment is now being constructed, and in case the preliminary tests are satisfactory the laboratory model of the system will be built and put into actual service.

W. B. Nottingham, L. E. Sprague, W. S. Attridge, J. B. Thomas