I. PHYSICAL ELECTRONICS

Prof. W. B. Nottingham	W. E. Mutter
C. P. Hadley	L. E. Sprague
R. M. Howe	R. T. Watson
H. S. Jarrett	J. F. Waymouth, Jr.
L. D. McGlauchlin	M. K. Wilkinson

A. ELECTRON-EMISSION PROBLEMS

1. Work Functions and Electrical Conductivity of Oxide-Coated Cathodes

This research has been completed, and it will be the subject of a technical report now in preparation. Some of the results are summarized below.

The thermionic and photoelectric work functions as well as the electrical conductivity of the coating have been measured for a single (Ba, Sr)O cathode in five distinct physical states of activation. A new cathode design involving a two-piece base metal sleeve permitted electrical conductivity measurements to be made without the use of fine wire probes and allowed the use of a coating of normal thickness. Agreement of conductivity measurements made with the specimen in vacuum and in a pressure of 760 mm of helium, where the mean free path of low-energy electrons is not more than 10^{-4} cm, showed that the observed conductivity takes place through the volume of the (Ba, Sr)O crystals, and not by thermionic emission through the pores of the coating or by emission from one section of the cathode to the other.

Surface treatments, such as the evaporation of barium (with barium oxide) on to the surface of the cathode in either the activated or deactivated state, produced only small changes in either the conductivity activation energy or in the absolute value of the conductivity at a given temperature. After heating the cathode for several minutes in a low pressure of oxygen, the conductivity activation energy increased from 1.2 ev to 3.4 ev; and it appeared that in this state the (Ba, Sr)O was behaving almost as an intrinsic semiconductor. From this observation the forbidden band is estimated to be at least 6.8 ev wide.

Conductivity measurements were made over a temperature range of 300°K to 1172°K. This covers lower temperatures than have previously been reported in the literature. Plots of the logarithm of the conductivity against reciprocal temperature yielded two separate straight lines of different slopes with a new "break" in the neighborhood of 600°K. In the low-temperature range the slopes correspond to approximately 0.1 ev. Since the

electron donor-centers in the alkaline earth oxides (be they interstitial barium or vacant negative ion sites with trapped electrons) would be expected to have two electrons associated with them, it is suggested that the slope in the low-temperature range may be connected with the thermal excitation energy of the first electron from such a center.

The thermionic work function near zero field was found to be 1.40 ev for the well activated cathode and 2.36 ev after the oxygen deactivation. Evaporation of barium (with barium oxide) reduced both of these work functions by about 0.25 ev and put the cathode in a thermodynamically unstable state so that heating to temperatures as low as 500°K caused the work functions to revert gradually to their former values. It is believed that the dipole moment of the adsorbed barium atoms lowers the electron affinity of the crystals and brings about the reduction in work function.

A Fowler analysis of the photoelectric emission from the active cathode yielded a photoelectric work function of 1.39 ev in close agreement with the thermionic work function for this state. The first barium evaporation reduced this to 1.27 ev. After a second evaporation, the photoelectric data seemed to be best fitted by two separate Fowler theoretical curves which gave work functions of 1.54 and 2.08 ev. It appeared that some kind of composite surface was present, but no suggestion is offered as to its nature. After oxygen deactivation no photocurrents could be observed, but it is estimated that the work function was greater than 3.5 ev.

From simple semiconductor theory, neglecting the possibility of surface states, one expects the following relations to hold:

$$\varphi_{th} = V + \frac{1}{2} E \tag{1}$$

$$\varphi_{ph} = V + E \tag{2}$$

$$- k \frac{d(\log \sigma)}{d(1/T)} = \frac{1}{2} E \tag{3}$$

where φ_{th} and φ_{ph} are the thermionic and photoelectric work functions respectively, V is the electron affinity of the oxide, σ is the conductivity, E is energy gap between the impurity levels and the bottom of the conduction band, and k is Boltzmann's constant. We do not find these relations verified for any of the physical states of the cathode studied. The work here indicates that the photoelectric work function may have values ranging from those equal to the thermionic work function to those considerably over one volt greater, depending on the physical condition of the cathode. It is possible that with the cathode in a suitable state,

fortuitous verification of the simple relations may be found; and this possibility together with the fact that the results obtained depend so markedly on the state of activation of the cathode may explain some of the discrepancies in the experimental results of previous investigations of these cathode properties and their interrelations. From the radical changes in the shapes of the Fowler plots as material is evaporated on to the surface of the cathode, it is fairly certain that the photoelectric work function depends largely on the distribution of surface states of the oxide, and not on the volume properties alone as Eq. (2) would imply. W. E. Mutter

2. Determination of the Thermionic-Emission Properties of Single Tungsten Crystals by a Photometric Method

Study on this project has been discontinued for the time being. Definite plans are under way for its re-establishment.

W. B. Nottingham

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

A technique has been developed by which uniform coatings of phosphor may be obtained on the inner surface of spherical glass envelopes. It is anticipated that the phosphor to be used in this experimental problem will be zinc sulphide, silver activated, since it possesses secondary emission properties such that high potentials may be employed to attain the high electric fields required. Attempts to obtain a uniform coating by spraying the zinc sulphide from a diatol solution with a nitrocellulose binder were not successful. This method has been used for willemite, but willemite forms a suspension in diatol whereas zinc sulphide does not. Dusting dry zinc sulphide powder on the inner glass walls which had previously been rinsed with a solution of potassium silicate also failed to give a uniform coating.

The method which has been developed is satisfactory for coating the inside of a standard one-liter pyrex round-bottom flask (5-inch diameter), from which the glass envelope of the experimental tube will be made. When the flask has been thoroughly cleaned, seven grams of zinc sulphide are placed in it. Fifty cubic centimeters of a solution consisting of 89 percent acetone and 11 percent collodion, U.S.P., are then poured in, and the flask is moved continually to prevent the zinc sulphide from settling. When almost all of the acetone has evaporated, the mixture becomes very tacky and starts to stick to the glass envelope. By carefully turning the

flask manually, the mixture is allowed to flow over the entire inner surface and a very uniform coating can be obtained. This procedure is made somewhat easier by shining the light from a 150-watt projector spot lamp on the outside of the flask so that the mixture dries out more quickly as it sticks to the inner surface.

A vacuum system for this project has been completed, and the first experimental tube is now under construction. Work will soon be started to determine the type of point filaments and the proper vacuum techniques required to give stable field-emission patterns. M. K. Wilkinson

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

In line with the objectives of this research as outlined in the Progress Report of July 15, 1949, the following advances have been made.

A considerable amount of 5-mil tungsten wire has been polished using techniques developed by this group.

Some experimenting has been done on coating glass cylinders with phosphor. A coating of the desired physical characteristics has been produced, and it is intended to complete a projection tube for the qualitative determination of the influence of the crystal structure of the base metal.

A method has been developed for coating tungsten wires cataphoretically with equimolar barium and strontium carbonates. The procedure followed is an extension of that used by the Raytheon Company of Waltham. The particle size of the cataphoretic suspension is of the order of 3 microns.

In order to determine proper activation schedules for such wires, a tube has been constructed which contains four filaments and a common anode. The filaments used are of 5-mil tungsten, re-crystallized by heating in a vacuum, and coated with various thicknesses of carbonates. Preliminary measurements have been made on several filaments. The maximum emission obtained was of the order expected for a well-activated cathode. The temperature required for activation, however, was lower than that usually quoted.

C. P. Hadley

5. Investigation of Certain Properties of Oxide-Coated Cathodes Using Radioactive-Tracer Techniques

Because of a wide interest in the possible application of the radioactive-tracer technique to a study of oxide-coated cathodes, it was thought worthwhile to conduct a survey in this field. A brief resumé of what has been uncovered is presented here.

From the possibilities considered, the following methods were classified as diffusion experiments:

(1) Uniformly mix some radioactive Ba (or Sr) in the form of $BaCO_3$ into the coating, and study the final radioactive distribution resulting from the various variables (activation, age, applied field and temperature).

(2) Place thin radioactive layers of $BaCO_3$ at various depths of the coating and observe the outcome.

(3) Sandwich a cylindrical radioactive ring of oxide on a base metal between two larger non-radioactive cylindrical rings. Record diffusion into the inactive rings.

(4) Proceed as in (3), but let the radioactive ring be a surface layer for observation of surface migration.

(5) Using a base metal containing radioactive Ti^{51} impurities (72-day half-life), study the interface formation of $BaTiO_4$ as a function of activation, and see if the conductivity variation has any correlation.

Since there is no radioactive oxygen available of half-life over 100 seconds, the oxygen atoms or ions cannot be tagged. Sr^{90}, having a 25-year half-life, is quite useful; while Ba^{140}, with a 12.5-day half-life, would have to be used in relatively short experiments.

A difficulty to be overcome is the fact that the maximum coating thickness, being about 0.003 inch, is not suited for accurate or consistent slicing for detection purposes. Also, absorption in the coating would be negligible for the emitted radiation. However, if the coating could be sliced as a wedge – with zero thickness at one edge and 100 percent thickness at the opposite edge – one photographic emulsion could detect the emission at all thicknesses.

A new method for measuring excess Ba is under consideration. Here radioactive I^{131} (8-day half-life) would be admitted to the cathode tube. The iodine would react with Ba but not with BaO. The counting rate from the final coating products should tell the amount of free Ba present. It is hoped that this method will be more precise than the water vapor procedure.

Single crystals of BaO have been produced at Cornell. If slight impurities of radioactive Pb or Po were mixed into these crystals, emission patterns on photographic emulsions would reveal the grain boundaries of the crystals. The crystals could then be oriented and studied as functions of these boundaries. If free radioactive Ba were permitted to diffuse into such a BaO crystal, it might be possible to show from photographic emulsions whether the diffusion was through the lattice or was interstitial.

An evaporation experiment is contemplated in which a tube contains a pure Ba (or Sr) source, a pure BaO (or SrO) source, several receivers and an anode. In this case the effect of small or large quantities of Ba at the interface, in the volume of the coating or at the coating surface, can be investigated. Radioactive Ba can be used here to give accurately the quantities of materials evaporated.

If a counter could be built into the tube without destroying the desired vacuum, it would widen considerably the possibilities of this experiment. Otherwise, the tube would have to be cracked open for counting and results would have to be extrapolated back. The other main problem connected with this last experiment is in obtaining pure Ba, Sr, BaO and SrO sources.

The results of this survey have not revealed to us the one main branch on which our efforts should be concentrated. The exact nature of the problem to be attacked during the next quarter is still to be determined.

R. T. Watson

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

The purpose of this research program is to study more thoroughly the problem of deterioration of oxide-coated cathodes under the conditions of low emission-current duty-factor, with the intention of obtaining a more complete understanding of this phenomenon in particular, and of oxide-coated cathodes in general.

Through the assistance of Mr. James Cardell of Raytheon, fifty QT 179 C standard diodes were obtained from the Raytheon Manufacturing Co., Newton, Mass. under their ONR Contract N7 onr-389 (1). The cathode sleeves were of 699 nickel alloy, while the remainder of the elements were constructed of materials containing a minimum of reducing-agent impurities. The 699 alloy was chosen since previous work indicates that high percentages of Si and other reducing agents contribute materially toward rapid deterioration (2).

An ageing panel was constructed so that these tubes could be aged as follows: (E_f = 7.0 volts, Groups I – IV).

Groups I and II	(I_b = 30 ma)	20 tubes
Group III	anodes grounded	10 tubes
Group IV	110 volts d-c on anodes	10 tubes
In reserve		10 tubes

At various stages during life these tubes are to be tested as follows:

(1) Interface resistance
(2) Emission current for 1-msec pulses
(3) D-C emission current

The interface resistance is to be measured by a method developed by Mr. H. B. Frost, of the Project Whirlwind Division of the M.I.T. Servomechanisms Laboratory. This method makes use of the fact that the cathode interface behaves like a parallel RC combination: as a constant current flows through it, the potential across it builds up according to the law

$$V = -IR_i e^{-t/R_i C_i} + R_i I \quad .$$

The diode under test is pulsed at constant current (obtained by means of a pulser whose internal resistance is high in comparison to the diode plate resistance) and the potential across it is observed by means of a synchroscope. At constant current, the potential between anode and cathode surface remains constant, and the potential that develops across the interface during the 2 1/2-μsec pulse appears as an increase in the potential across the tube. Thus, for a constant current pulse, the observed potential across the tube is as follows:

The purpose of the 1-msec pulse emission test is to observe the pulsed emission from the cathode, and also to observe any emission decay that may take place. The pulse-repetition frequency in this case is about one pulse per second.

The usual standard diode emission test is employed to check the d-c emission from these cathodes. (E_f = 1.75 volts a-c, E_b = 4.5 volts d-c). It is hoped that by means of d-c and pulsed-emission tests additional information may be obtained as to what happens when a cathode develops a high-resistance interface.

To date the tubes have been carried through an ageing period of 284 hours. The results of the above tests before and after this ageing period are given below.

(1) Interface resistance: No tubes have shown interface resistance

as yet.

(2) Pulse emission: (4.5 volts E_f, 250 volts E_b). Deviations indicated are "standard deviation of the mean," and represent the interval within which an additional measurement of ten tubes having the same history would have a 67.5 percent probability of being found.

Group	Emission at Zero Hours	Emission at 284 Hours
I	0.21 ± 0.01 amp	0.17 ± 0.01 amp
II	0.23 ± 0.01	0.17 ± 0.01
III	0.24 ± 0.03	0.22 ± 0.01
IV	0.24 ± 0.02	0.23 ± 0.01

(3) D-C emission:

Group	Zero Hours		284 Hours			
			Before pulse test		After pulse test	
	Fil power input(ω)	Emission μa	Fil power input	Emission μa	Fil power input	Emission μa
I	0.268 ± 0.002	31.0 ± 5.4	0.260 ± 0.002	8.58 ± 1.29	0.260 ± 0.002	8.53 ± 0.94
II	0.268 ± 0.002	31.5 ± 2.8	0.261 ± 0.001	11.4 ± 3.47	0.260 ± 0.001	10.4 ± 3.09
III	0.268 ± 0.002	38.5 ± 10.5	0.263 ± 0.001	16.9 ± 2.65	0.263 ± 0.001	26.5 ± 3.82
IV	0.268 ± 0.002	38.7 ± 3.6	0.265 ± 0.001	24.2 ± 3.3	0.263 ± 0.001	31.1 ± 2.75

Attention is called to two points. First, the decrease in filament power input at 1.75 volts which indicates an increase in filament resistance upon ageing (probably due to the ageing at 7.0 volts rather than the rated 6.3 volts); second, the increase in average emission current for III and IV caused by the pulse test. For groups I and II, which had aged under continuous conduction, no such increase is observed.

It has been verified from the ten tubes held in reserve that the variation in emission current due to slight changes in filament power input in the region of 0.268 watt may be expressed as

$$\frac{di}{i} = 6.5 \frac{dP}{P} \quad .$$

Since the changes in power input shown above are in the region of two to four percent, it may be seen that serious errors could be made if the decrease in emission from this cause is ignored. In the calculation of

i/i_o for the purposes of statistical comparison, due note will be taken of this effect.

It is probably too early as yet to attempt to reach any conclusions concerning this data. The tubes have been returned to the ageing panel for further ageing.

7. Activated Diodes

Several unprocessed standard diodes (great care having been taken to eliminate reducing-agent impurities from the tube structure) were obtained from Raytheon Manufacturing Co., through the courtesy of Mr. James Cardell. W. B. Nottingham and L. E. Sprague attempted to activate them.

It was found that despite the most stringent processing schedules, it was impossible to activate the cathodes satisfactorily unless a reducing agent such as methane were admitted to the system. Two tubes were processed with methane and were placed on life test, as follows:

Tube N-5	I_b = 12 ma
Tube N-7	Anode grounded

To date, they have aged 284 hours with the following results:

(1) Interface resistance: None

(2) Pulse emission test (E_f = 4.5 volts, E_b = 250 volts, 1-msec pulse, PRF = 1/sec):

Tube	Emission at zero	Emission at 284 hours
N-5	0.47 amp	0.51 amp
N-7	0.41	0.23

(3) D-C emission test (E_f = 1.75 volts, E_b = 4.5 volts)

Tube	Emission at zero	Emission at 284 hours	
		Before pulse test	After pulse test
N-5	92 μa	26 μa	108 μa
N-7	190	0.05	0.08

Note the marked decrease in d-c emission for tube N-7; it is accompanied by a slight decrease in pulsed emission. Note also the marked increase in d-c emission caused by the pulse test for tube N-5. The tubes have been returned to the ageing panel for further ageing.

J. F. Waymouth, Jr.

8. Studies of Photoelectric Emission

No work has been done on this project during the summer. The study will be continued with the opening of the fall term. H. S. Jarrett

B. STUDIES WITH GASEOUS DISCHARGE

1. Investigation of Low-Pressure Mercury Arcs

The design and construction of a mercury arc tube has been completed. In order to study the random current to drift current ratio a plain probe has been provided which can be rotated so that its normal may be set parallel to the axis of the tube or perpendicular to the axis of the tube. A second plain probe is provided with a tungsten heater and with suitable guard rings, so that accurate probe measurements may be made and the influence of the temperature of the probe determined. R. M. Howe

C. EXPERIMENTAL TECHNIQUES

1. Spectral Emissivity of Tantalum

In the July 15, 1949 Progress Report preliminary results on the spectral emissivity of tantalum were presented in spite of the fact that additional data-taking was planned at that time. A new determination of the spectral emissivity of tantalum is now completed. The most recent data were taken using the same method and tantalum sample in the tube originally designed by W. B. Nottingham and constructed by W. E. Mutter. A different tube orientation with respect to the monochromator allows the electronic measuring instrument to view the source from a better angle. This arrangement causes the electronic photometer to "see" more nearly black-body radiation from the hole in the hollow tantalum cylinder which functions as a comparison black body. The order of taking the separate readings has also been changed so as to minimize the error resulting from changes in the temperature of the black-body source and the tantalum surface, and a correction has been applied for the scattered light entering the system. This correction was not applied to the results previously reported for tantalum.

Polaroid filters were inserted in the optical system, and, although the system was found to discriminate against light of certain polarizations, this effect is found not to affect the measured emissivity. Measurements at several wavelengths and temperatures yield the same emissivity value regardless of the angular setting of a polaroid polarizing filter in the system.

It was feared that scattered light in the blue region of the visible

was being passed by the monochromator when it was adjusted to transmit light having a wavelength of 700 mμ. In order to determine the magnitude of this possible error a color filter was inserted in the system and further measurements were made at 700 mμ and for several temperatures. The results were the same as those without the filter and it is therefore believed that only small amounts of light of undesired wavelength are transmitted by the monochromator.

Graphical analysis of these latest results yields a very simple empirical equation which is a good representation of the new observed data covering the range in temperature of 1640°K to 2120°K and the range in wavelength of 450 mμ to 700 mμ. The equation found is the following:

$$E = 0.295 + \frac{78.7 - 10^{-2} \times T}{\lambda} \quad ,$$

where E is the spectral emissivity; T, the temperature in degrees Kelvin; and λ is the wavelength in mμ.

A comparison between this latest equation and the earlier one shows that our new results correspond to emissivity values about ten percent lower.

W. B. Nottingham, L. Sprague, L. D. McGlauchlin

2. Ionization Gauge and High-Vacuum Studies

Some of the sealed-off ionization gauges used in this investigation have been maintained with the filament in continuous operation during the summer, in order to investigate the build-up of gas pressure which takes place. A determination of these gas pressures has not yet been made.

W. B. Nottingham, L. Sprague

References

(1) Standard Materials Testing Tubes QT 179 C (Purified Diode) Contract No. N7 onr-389; Raytheon Manufacturing Co., Newton, Mass.

(2) Report on "Special Problem in Electronics", J. F. Waymouth, June 1949.

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