

I. PHYSICAL ELECTRONICS

Prof. W. B. Nottingham
Dr. H. A. Gebbie
E. Ahilea

S. Aisenberg
D. H. Dickey
W. J. Lange

R. D. Larrabee
H. Shelton
L. E. Sprague

A. ELECTRON EMISSION PROBLEMS

1. Importance of Porosity in Maintaining High-Current Density from Oxide Cathodes

A reanalysis of some of the problems of thermionic emission in the presence of space charge is being carried on at present. This study shows that many of the properties of oxide cathodes, including the determination of emission constants and the temperature coefficient of the true work-function, can be discovered from an analysis of data taken at normal operating temperatures and lower, and with applied fields never in excess of 5 volts. Some of the details of these studies will be summarized from time to time. One result involves the concept that surface porosity of an oxide cathode might very well be taken advantage of by its specific and artificial introduction into the cathode surface. A brief summary of the reasoning behind this thought is given.

The low value of the true work-function of the oxide-coated cathode structure accounts for the very high electron emission obtainable at low operating temperatures. The actual value of the true work-function should be defined as the difference in energy between that of the Fermi level just inside the surface and the energy of an electron just outside the surface. The presence of polarizable barium atoms on the surface can contribute to the lowering of the electron affinity of the surface. The presence of excess barium just inside the surface is the dominating factor that establishes the location and the temperature dependence of the Fermi level with respect to the conduction band of the oxide. The emission of electrons constitutes a current flow and therefore creates in the interior of the oxide an electric field in a direction that drives the excess barium away from the surface into the interior of the cathode. This migration lowers the Fermi level with respect to the conduction band and therefore increases the true work-function. A limitation on the emission current density results indirectly from the fact that the concentration gradient of barium atoms combined with thermal diffusion must finally offset the drift under the influence of the internal electric field near the surface.

The practical difficulties of obtaining high-current density from oxide-coated surfaces can be minimized by taking advantage of the surface porosity to obtain a higher electron emission density from the pore itself than is demanded from the internal electron-emitting surfaces that bound the pore and supply electrons to it.

Fowler (1) derived the basic equations for the electron atmosphere in a pillbox-like cavity by giving proper consideration to the combined influences of the Boltzmann density relation for charged particles in a potential field and Poisson's equation.

(I. PHYSICAL ELECTRONICS)

Re-examination of this problem yields certain practical results that are summarized here. They serve as a guide in the development of cathode structures capable of high electron emission density which are not subject to the same deterioration in emission properties expected from a nonporous structure.

A calculation based on kinetic theory gives a relation between the concentration of electrons n_e needed at a given temperature, and the maximum current density. This equation is

$$n_e = 4 \times 10^{13} \frac{i}{T^{1/2}} \quad (1)$$

The current density i is expressed in amperes per square centimeter, the temperature T in degrees Kelvin, and the concentration n_e as electrons per cubic centimeter. The concentration of electrons at the center of a cavity is directly proportional to the temperature and inversely proportional to the square of the smallest dimension of the cavity. The expression can be worked out exactly for the pillbox structure for which the thickness of the pillbox is w and the other dimensions large compared with w . The expression for the maximum attainable electron density in this cavity is

$$n_{e(\max)} = 9.4 \times 10^2 \frac{T}{w^2} \quad (2)$$

In this expression, w is the cavity dimension in centimeters. These equations may be equated and solved for w to obtain

$$w = 5 \times 10^{-6} \frac{T^{3/4}}{i^{1/2}} \quad (3)$$

This equation serves to establish the order of magnitude of the pore dimension. For example, if the order of current density required is 25 amp/cm², and the temperature T is 1060°K, the value of w is approximately 2×10^{-4} cm. The depth of the pore should be as great as it is physically possible to make it.

If one could conceive a practical method of creating a uniform "honeycomb" structure of open pores each having a diameter of the order of 10^{-3} cm with good-conducting, very thin, separation walls, an electron source would be created that should be capable of high emission current density for the effective emitting surface itself and at the same time not require such a high emission current density from the actual internal oxide surfaces themselves. This construction would reduce the tendency of the cathode to destroy its efficiency because of the impurity migration accompanying a high electron emission.

W. B. Nottingham

Reference

1. R. H. Fowler, Statistical Mechanics (Cambridge University Press, London, 1936), Second Edition, p. 368.

(I. PHYSICAL ELECTRONICS)

2. Reflection of Slow Electrons at a Metal Surface

An experimental tube has been designed for a study of reflection of slow electrons at a single-crystal tantalum surface. Since the energy resolution of the apparatus is limited by the geometry, the tube components must be made and aligned precisely. Since the experiment must be carried out in high vacuum the tube has to be capable of vacuum-processing. The tube parts are now nearly complete.

A satisfactory single crystal of tantalum, which is to be the target, has not yet been prepared. Although crystals of sufficient size are obtained the surfaces are speckled with microscopic pits. The pits seem to develop, after heating, from imperfections in the commercial tantalum.

W. J. Lange

B. PHYSICAL ELECTRONICS IN THE SOLID STATE

1. Studies of Surface Phenomena in Germanium

Very little information on the properties of germanium surfaces free from contaminants is available. The fundamental information that is lacking is quantitative data on energy levels associated with the surface. These will be important in determining such quantities as contact potential, surface recombination velocity, and the "field effect." The object of the present research is to try to use measurements of these quantities, singly or in combination, for surfaces on germanium crystals which have been treated and maintained in high-vacuum conditions, in order to get information on surface states. In general, pressures of less than 10^{-9} mm Hg will be necessary if contamination is to be slow enough for results to be meaningful.

Apparatus has been set up to produce and measure the required low pressures, and some preliminary work has been done on measuring contact potentials. These were derived from diode characteristics in the retarding region with etched surfaces of germanium as anodes. Preliminary measurements of the "field effect" have also been made.

H. A. Gebbie

C. GAS DISCHARGES

1. Ion Generation and Electron Energy Distributions

A basic problem in the theory of gas discharges is the determination of the relative importance of cumulative ionization (multiple-collision ionization) as compared to direct ionization (single-collision ionization).

In order to determine whether or not direct ionization is sufficient to account for the observed ion generation in the positive column, and in order to calculate certain arc

(I. PHYSICAL ELECTRONICS)

characteristics, the theory of ion generation has been subjected to some refinement. The ion generation $G(n_-)$ is the number of singly charged positive ions produced per unit volume per unit time as a function of the electron density n_- (and the distribution function), and may be broken into two parts: $G(n_-) = G_d(n_-) + G_c(n_-)$, where $G_d(n_-)$ is attributable to direct ionization and $G_c(n_-)$ is attributable to cumulative ionization. The direct ionization component can then be given by the usual form:

$$G_d(n_-) = \int_0^{\infty} v P_i(E) f(E) dE$$

where $v = (2E/m)^{1/2}$ is the random electron velocity, $P_i(E)$ is the probability of ionization in ions per centimeter of path for an electron of energy E , and $f(E)$ is the distribution function for the electron energies. This expression for $G_d(n_-)$ contains the implicit assumption that P_i is independent of the electron density. Previous investigators have used a linear approximation

$$P_i = \alpha [E - eV_i], \quad eV_i < E < 2 eV_i$$

plus the assumption of a Maxwell-Boltzmann (M-B) electron energy distribution.

Langmuir probe measurements in the plasma of a mercury arc indicate that a depleted M-B distribution actually exists and lead one to suspect that the actual electron energy distribution is closer to the Druyvesteyn distribution (D-D)

$$f(E) dE = (n_-) D \exp\left(-0.547 \frac{E^2}{\bar{E}^2}\right) dE$$

where \bar{E} is the average electron energy. Using this distribution function and retaining, for the present, the linear approximation for P_i , one obtains $G_d(n_-)$ in terms of incomplete gamma functions and it reduces to an expression involving the error function

$$G_d(n_-) = (\text{constant}) (n_-) \alpha \bar{E}^3 \left[1 - \text{erf}\left((0.547)^{1/2} \frac{e V_i}{\bar{E}}\right) \right]$$

The next step in the refinement of the theory involves an improvement over the linear approximation for P_i . Certain theoretical considerations, plus inspection of the experimental curves, lead one to suspect that the curve can be represented by

$$P_i = g \frac{\ln(\gamma E)}{E}$$

where g and γ are constants of the gas. Using this expression, one can even represent the definite fine structure in P_i . If one considers the detailed measurement of P_i for

mercury made by Nottingham and rectifies the data by proper change of variables, a number of straight-line sections result, which verifies the representation given above and indicates that the composite P_i consists of a sum of the terms given above.

With the improved representation

$$P_i = \sum_k g_k \frac{\ln(\gamma_k E)}{E}$$

plus the M-B distribution, the ion generation can be specified in terms of a set of logarithmic integrals. On the other hand, by using the improved representation for P_i plus the Druyvesteyn distribution, the ion generation can be expressed in terms of an integral that has not yet been reduced to a previously tabulated form. It may be necessary to evaluate the integral by numerical means.

The theory of the Langmuir probe has been extended to the case of a Druyvesteyn distribution in order to permit one to test for both a Druyvesteyn and an M-B distribution. For the former, the electron particle current density Γ_{+x} to a plane probe with a retarding potential ΔV (with respect to the plasma potential) has been calculated to be

$$\Gamma_{+x} = (n_-) \bar{E}^{1/2} \left(\frac{\pi}{8m \Gamma(3/4) \Gamma(5/4)} \right)^{1/2} \left(\frac{1}{\pi^{1/2}} e^{-x^2} - x[1 - \text{erf}(x)] \right)$$

$$x = \frac{\Gamma(5/4)}{\Gamma(3/4)} \frac{e \Delta V}{\bar{E}} = (0.547)^{1/2} \frac{e \Delta V}{\bar{E}}$$

where e and m are the electron charge and mass, n_- is the electron density, and $\Gamma(3/4)$ and $\Gamma(5/4)$ are complete gamma functions. The value of Γ_{+x} for zero retarding field (random particle current density) is only 3 per cent larger than that for the M-B distribution of the same electron density and same average electron energy \bar{E} . Proper rectification of the Langmuir probe data will permit a test for a Druyvesteyn distribution.

Work is also being continued on the solution of the nonlinear ambipolar diffusion equation for both direct and cumulative ionization.

S. Aisenberg

D. EXPERIMENTAL TECHNIQUES

1. High Vacuum Studies: The MassITron

The MassITron, a small, low-resolution mass spectrometer utilizing cycloidal paths, which was designed for use as a vacuum gauge has been tested, and its performance and several interesting results are now known. Its desirable features have been found to be,

(I. PHYSICAL ELECTRONICS)

as was anticipated, high efficiency, with about the same gauge constant as that of conventional ion gauges, and perfect shielding, which eliminates spurious currents such as those caused by soft x-rays in ion gauges and hence easily allows measurement of pressures as low as 10^{-11} mm Hg. Very satisfactory operation is obtained by using a permanent magnet, although the mass range and the resolution are improved by using an electromagnet with its greater and more uniform field.

An analysis of the gases in a sealed-off pyrex tube with tungsten and tantalum parts illustrates the value of this instrument. The important gases studied are: hydrogen, helium, nitrogen, oxygen, water vapor, carbon monoxide, and carbon dioxide. Hydrogen, for instance, exists as H_2 and is emitted when the filament is first heated and absorbed at high temperatures. Helium is highly insensitive to filament flashing, but slowly cleans up with electron current. Nitrogen adsorbs on clean filaments and flashes off easily. It cleans up rapidly with electron current and leaves the space for a long period after a clean filament is cooled. Oxygen is almost missing and is found as O^+ ions. Water vapor is missing in an operating sealed-off tube. When N_2 is temporarily cleaned from the space, the 28 peak consists of CO and is identified by the fact that about 10 per cent as much C^+ is simultaneously detected. These observations were taken with a total pressure between 5×10^{-8} and 1×10^{-9} mm Hg.

H. Shelton

2. The Spectral Emissivity of Tungsten

An experiment designed to measure the spectral emissivity of tungsten as a function of wavelength and temperature is in progress. Basically, a direct-comparison method is being used: the radiant intensity (at a particular wavelength selected by a monochromator) from the tungsten source is compared with that from an approximating black body at the source temperature by means of a photomultiplier. The vacuum tube containing the tungsten source - black body combination and all auxiliary equipment has been constructed.

R. D. Larrabee

3. Cleanup of Helium in Ionization Gauges

In measuring the character of the cleanup of helium in the Bayard-Alpert ionization gauge, it has been found that there are small variations that cannot be explained by a simple theory. In order to measure these variations, it was decided that an electron current regulator was needed. One that cut the effect of line voltage fluctuations on the electron current by a factor of 50 was designed and constructed. The electron current is so stable that it is possible to use recording equipment to read the ion current continuously during a cleanup experiment. To check for slow drifts in the equipment, hourly checks can be made and recorded by means of electrical timers. During a permeation

(I. PHYSICAL ELECTRONICS)

run the electron current regulator is especially useful. Readings may be taken automatically, as desired, between the limits of once a day to once an hour. The time required to take a reading is about 3 seconds. This is made possible by the fact that transients in the regulator and the associated equipment die out rapidly. This fast measuring time is about one-thirtieth of the previous measuring time. In addition to producing much less cleanup during a permeation run, because of necessary measurements, this equipment reads continuously (night and day), thus giving all needed data. The temperature of the air surrounding the ion gauge is automatically regulated.

Special gears for the Brown recorder are being built. These gears will allow a chart speed appropriate for these measurements, that is, about one foot per day.

D. H. Dickey

4. Ionization Gauge Studies

Now that a satisfactory ionization gauge control circuit has been designed, constructed, and is in use, work is being continued on the ionization gauge itself. It has been noticed that supposedly identical Bayard-Alpert (B-A) ionization gauges have gauge constants that sometimes differ by 30 per cent or more. The gauge constant K (defined by $PK = i_+/i_-$, where P is the pressure in millimeters of mercury, i_+ is the ion current, and i_- is the electron current) is determined in part by the gauge geometry. Construction of gauges with reproducible gauge constants is desired.

In order to determine how critical the various constructional and operational details of the gauge are, a set of measurements was made in which the relative gauge constants for the two filaments in the same gauge were determined as a function of electron current i_- . This was done by operating both filaments (of a sealed-off B-A ion gauge) at a temperature suitable for electron emission. One filament "A" was at -108 volts with respect to the electron collector and the other filament "B" was at the electron collector potential. After measurements were made with this arrangement of potentials, the connections were changed so that "B" emitted the electrons instead of "A." The emission currents are kept equal to each other by means of an electronic emission current regulator that was specially designed and constructed. The ratio of the gauge sensitivities for filaments "A" and "B," $K(A)/K(B)$, is given by the ratio of the corresponding ion currents read from a recorder chart connected to the ion control circuit. The change in filaments is made so quickly that the pressure change is found to be negligible. The results for three different gauges (B-A with screen grid and closed ends on electron collector grid) are given in Fig. I-1. It can be seen that not only do the relative gauge constants differ but the difference is a function of the electron current i_- , thus indicating that the gauge constant is not really constant. Visual inspection of the three gauges shows that gauge No. 1 has an almost axial ion collector, gauge No. 2 has an ion collector tilted off the axis, and gauge No. 3 has an ion collector that is extremely tilted.

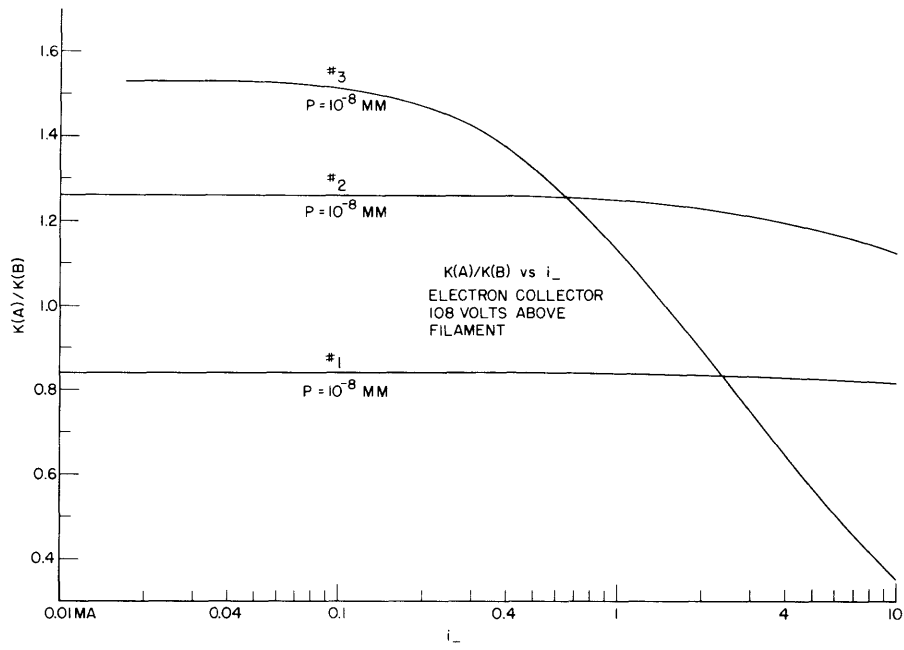


Fig. I-1

Ratio of gauge constants for two filaments in the same gauge.

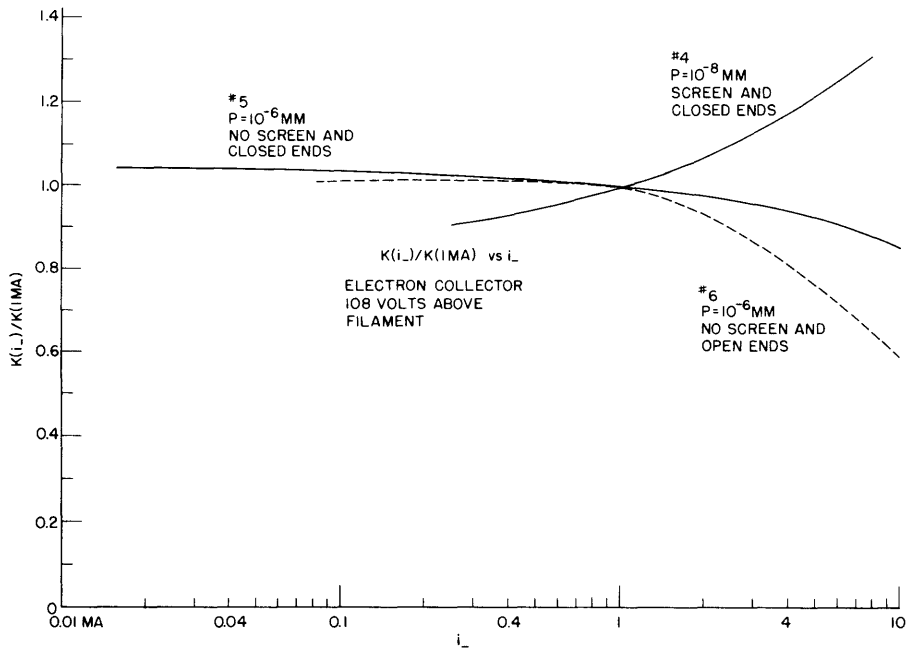


Fig. I-2

Variation of gauge constant with electron current.

(I. PHYSICAL ELECTRONICS)

There appears to be no correlation between filament orientation and gauge-constant variation. This indicates that the gauge constant is very dependent upon the orientation of the ion collector. Measurements will be made upon a gauge with a movable ion collector in order to verify these observations.

The problem of the variable gauge constant was investigated in more detail. By quickly changing the emission current of one filament from a particular current to a standard current (with an emission current regulator stable to a fraction of a per cent) and by measuring the ion currents with a chart recorder, the gauge constant can be measured as a function of the electron current, and is expressed relative to the constant at the standard current, $K(i_e)/K(1 \text{ ma})$. The results for three gauges are given in Fig. I-2. Gauge No. 4 is a B-A gauge with screen and closed ends. Gauge No. 5 has closed ends and no screen. Gauge No. 6 has open ends and no screen. It can be seen that at 1 ma, or less, the dependence upon the current is essentially negligible, indicating that the gauge should probably be operated at currents below 1 ma. This dependence at higher currents is probably caused by space charge modifying the electron and ion orbits.

S. Aisenberg