

## I. PHYSICAL ELECTRONICS

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### A. VACUUM STUDIES

#### 1. DESIGN PARAMETERS INFLUENCE ON BAYARD-ALPERT SENSITIVITY

The Bayard-Alpert concept of using an ion collector of small area centrally located within a cylindrical electron collector was incorporated into an ionization gauge configuration that has been described in detail by the author (1). The significant differences between this gauge and others commonly used are: (a) A gridlike screen with an independent electrical connection is placed outside of the conventional structure in order to minimize the influence of the glass wall on the electron trajectories. (b) Fine wire screens connected to the electron collector close the cylindrical open ends and thus prevent the escape of ions produced within the ionization space. Without the closed ends these ions are subject to fields that accelerate them out to the negatively charged glass walls. (c) Two independent filaments placed on opposite sides of the electron collector and between it and the outside screen were available for use as electron emitters. The experiments reported here relate specifically to the quantitative evaluation of the gain in sensitivity provided by the covers on the electron collector. A second parameter, which was found to be far more critical than previously anticipated, was the spacing between the electron-emitter filament and the electron collector.

##### a. Description of the Experimental Method

Three of the tubes were connected to a 3-spoke manifold. Each spoke was approximately 4 inches long and had 5/8 inch inside diameter, and their orientation placed them 120° apart, since they connected with the central pumping lead and through this to the liquid air trap and mercury diffusion pumps. In the high-pressure range, the pressure of the nitrogen used for tube calibration and evaluation was determined by a McLeod gauge operated as described previously by Nottingham and Torney (2). This method of operation provides a means of determining the location of the "effective top" of the closed capillary, and shows that accuracy can be obtained only after the experimenter has established that his method of operation is consistent with Boyle's law by taking a set of readings with different degrees of compression of the trapped-off gas.

The circuit arrangement provides for the measurement of the electron emission from the filament instead of after the electron's arrival at the electron collector. The advantage of this method of operation is that it distinguishes between emitted electrons and those generated as a result of the ionization. Under low-pressure conditions, the difference in method is not significant, but under high-pressure conditions it is very important because it is not possible to correct the measured current to the electron

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collector for the ionization, since it is possible for ions that are produced to be neutralized at the glass wall and not be measured at the ion-collecting electrode. The ion currents that flowed to the small wire ion collector and also those that flowed to the outside shield grid were measured by suitably calibrated electrometer circuits. The electron emission currents were generally observed by means of calibrated dc meters. Most measurements were started with very low electron emission currents so that gas clean-up could be avoided. Check points were taken frequently, and especially after the application of the highest electron emission currents, so that the gas clean-up that did take place would be evaluated.

### b. Experimental Results

It is to be noted that three filament spacings have been studied, generally with two spacings in each envelope. Two significant results came from this study. First, the spacing factor is relatively unimportant at pressures in excess of  $10^{-3}$  Torr. In the range of pressures less than  $10^{-5}$  the sensitivity changes by approximately a factor of 2 within the range of spacing of 1 mm-3 mm. In these gauges most of the ions produced are either collected at the normal ion collector, or at the outside screen. It is interesting to note that over the entire range of study the total number of ions produced was practically independent of the filament location. Therefore it is evident that the increased sensitivity results at the filament-to-electron collector of greater distance because of the more favorable delivery of the ions to the normal ion collector.

A second parameter investigated depended on three gauges with different degrees of end covering on the electron-collecting, cylindrical-grid structure. One tube was very completely shielded by the "standard" grid structure that had been found desirable by previous studies. The second tube had a single ring of 20-mil wire that had one-quarter of the diameter of the electron collector itself. This was supported by two cross wires. The third tube had an open-cylinder electron collector. In the high-pressure range the open-ended tube was seen to be 20 per cent less sensitive than the ones with grid covering; whereas the two grid-covered tubes were only slightly different in sensitivity. In the low-pressure range below  $10^{-5}$  Torr, the sensitivities normalized with respect to the covered electron collector that was taken as 100 per cent were approximately 80 per cent for the partially covered, and 50 per cent for the open-ended structure. This result is in good agreement with the determination reported previously (2) and is applicable specifically to the Westinghouse gauge Type WL-5966.

In the previous study (2) the ion current delivered to the normal ion collector as a function of the electron current used to produce the ions showed a nonlinearity in the high-pressure range ( $10^{-4}$  Torr, or more); this demonstrated the need for using electron currents as small as 10  $\mu$ amp, in order to avoid the nonlinear relation. At that time, we thought that recombination within the ionization region could account for the

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nonlinearity. The present studies indicate clearly that that interpretation is not valid. The fact that the nonlinearity observed with nitrogen and argon was so similar, and that some nonlinearity existed even for helium, made further study desirable. The current collected on the small wire ion collector as a function of the electron current is linear only for very small electron current. The measured ion current to the outside screen shows nonlinearity, in that it first starts out to be linearly related to the electron current and then the ion arrival rate increases superlinearly with the electron current. The most significant point is that the sum of the two ion currents measured at the normal collector and the screen shows an accurately linear relation even up to high electron currents.

It is these results that suggest that an ionization gauge that has an outside ion collector such as the ones used for this study, as well as the NRC gauge Type 551, should be operated in the high-pressure range by connecting both of these ion collectors to the recording meter to give a calibrated gauge constant as a function of pressure. With calibration data such as these available, a pressure determination can be made by plotting calibration data which includes the nonlinear relation between  $(i_{2+}/i_-)$  and pressure. With this curve available, any observed value of the ion current-electron current ratio serves to establish the corresponding pressure by the location of a point on the calibration curve. In this curve the ion current  $(i_{2+})$  is the sum of the currents collected on the small wire collector and the outside screen.

### c. Conclusion

The location of the electron-emitting filament in a gauge structure of the type described here is especially critical if the gauge is to be used in the ultrahigh vacuum range. At a spacing of approximately 3 mm, the maximum sensitivity is approached. Capping of the electron collector by a grid structure further increases sensitivity. Such increases are advantageous in the ultrahigh vacuum range because true gauge sensitivity tends to offset the interference caused in the ultimate vacuum range by the x-ray production of electrons at the ion collector. An outside screen serves a multiplicity of purposes. (a) It establishes more definitely the electron trajectories and minimizes the effects of the glass wall. (b) It is advantageous to use it with the normal collector as an ion collector for pressure measurements in the higher pressure range in which x-ray effects are unimportant. (c) Gauges of the Bayard-Alpert type, which are useful as nude gauges for large-volume vacuum systems, can be operated more reliably on the basis of previously determined calibrations by the stabilization of the local electric fields and the control of the electron and ion trajectories.

W. B. Nottingham

(References on following page)

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### References

1. W. B. Nottingham, Vacuum Symposium Transactions, 1954, p. 76.
2. W. B. Nottingham and F. L. Torney, Jr., A Detailed Examination of the Principles of Ion Gauge Calibration, American Vacuum Society Meeting, Cleveland, Ohio, Oct. 12, 1960; Technical Report 379, Research Laboratory of Electronics, M.I.T., Oct. 25, 1960.

### 2. STUDY OF EMISSION-CURRENT-DEPENDENT NONLINEARITIES IN THE BAYARD-ALPERT TYPE OF IONIZATION GAUGE

Studies have been conducted previously on ionization gauges of the Bayard-Alpert type with a view toward improving the accuracy, reproducibility of measurement, and standardization of construction of these pressure-measuring devices. In the course of such studies, it was found that the gauge sensitivity was not independent of filament emission current, as would be expected from simple ionization-gauge theory. A substantial loss of ions was observed. On the basis of the evidence then available, the explanation offered was that of an electron-ion recombination loss. Lack of conclusive evidence as to the nature of this loss mechanism led to the present study. The results indicate that the recombination hypothesis is no longer acceptable; the ions not collected at the ion collector are collected at the outer screen that is used as a shield. An explanation is offered in terms of a build-up of positive ion space charge, which crowds out many of the ions produced.

The results of this study will be found in the author's Bachelor of Science thesis, with the title given above, submitted to the Department of Physics, M.I.T., May 12, 1961.

J. J. Pergola

## B. SEMICONDUCTOR DIODES

### 1. THE VOLTAGE-CURRENT CHARACTERISTIC OF GERMANIUM DIODES

This report is a summary of a Bachelor of Science thesis under this title, submitted by the author to the Department of Physics, M.I.T., May 18, 1961.

Germanium junction diodes have been studied in an attempt to find an empirical formula relating their current dependence on voltage and temperature. Voltage-current characteristics have been obtained for four diodes over a range of temperatures. The diodes used were constructed so as to attempt to obtain a diode whose characteristics depend as much as possible on the transmission of carriers across the p-n junction, and as little possible on surface effects.

The four diodes were of the same manufacture and showed similar properties. The empirical formula for the "current-voltage" observations which best fits the data is

$I = I_s(\exp(qV-IR/NkT)-1)$ , where  $R$  is a very small resistance that is several per cent of the junction resistance, and  $N$  is a temperature-dependent constant.

The zero-field conductivity was obtained as a function of temperature, but no simple formula fits the results for the temperature range studied.

G. L. Withbroe

### C. THERMIONIC EMISSION

#### 1. THERMIONIC EMISSION FROM SINGLE-CRYSTAL TUNGSTEN AS A FUNCTION OF CRYSTALLOGRAPHIC DIRECTION

A novel apparatus for measuring the thermionic emission from a single-crystal tungsten filament as a function of crystallographic direction has been designed, constructed, and successfully tested. This apparatus allows the observation of thermionic emission current from  $360^\circ$  of the filament by means of a rotatable slit. This is unlike previous devices, which only permitted viewing the crystal from a little more than  $180^\circ$ . The data from this apparatus are in good agreement with those of Smith (1), who used the rotating-filament technique to observe the emission from only  $240^\circ$ . This same apparatus can be used to take data from the single-crystal filament with adsorbed cesium present. Preliminary cesium measurements were undertaken, but results were not obtained on account of a fatigue crack in the rotating-slit mechanism.

Details of the apparatus can be found in the author's Bachelor of Science thesis, with the title given above, submitted to the Department of Physics, M.I.T., May 20, 1961.

S. N. Salomon

#### References

1. G. F. Smith, Phys. Rev. 94, 295 (1954).

#### 2. PULSED PROBE MEASUREMENTS IN A CESIUM-PLASMA THERMIONIC DIODE

Apparatus for these measurements is now being assembled. The diode is of cylindrical geometry, and consists of a massive nickel anode and a tungsten ribbon filament. The tube envelope is of Pyrex, and tungsten press leads are used throughout. The filament will be heated by half-wave rectified alternating current, and the entire probe characteristic will be displayed on an oscilloscope screen during the off half-cycle of the filament heating current.

The mean filament-to-anode distance is large enough to be equivalent to approximately 400 electronic mean-free paths at a cesium reservoir temperature of  $300^\circ\text{C}$ . Thus, the above-mentioned, relatively low, operating temperature and the speed with

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which the oscilloscope displays can be recorded photographically serve to minimize the demands put upon the materials in the tube envelope because of high-temperature operation in the presence of cesium vapor.

P. J. Shaver