I. PHYSICAL ELECTRONICS

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A. ELECTRON EMISSION AND CESIUM PLASMA

1. THERMIONIC ENERGY CONVERTERS

Thermionic diodes containing cesium vapor ionized by contact with the heated surface of the diode are of increasing interest as their potentialities become established. Many calculations demand a knowledge of the vapor pressure of the cesium or of its mean-free path or both. To satisfy this demand as well as is possible with our present limited knowledge of the actual characteristics of cesium, the following equations have been worked out:

$$p = 2.45 \times 10^8 \, T_{Cs}^{-1/2} \, e^{-8910/T_{Cs}} \text{ mm}$$

$$p = 2.45 \times 10^8 \, T_{Cs}^{-1/2} \times 10^{-3870/T_{Cs}} \text{ mm}$$

$$\lambda_c = 1.38 \times 10^{-13} \, T_g^{1/2} \times 10^{3670/T_{Cs}} \text{ m}$$

$$\lambda_c = 1.38 \times 10^{-11} \, T_g^{1/2} \times 10^{3670/T_{Cs}} \text{ cm}$$

where p is the pressure in millimeters; T_{Cs} is the cesium condensation temperature in °K; T_g is the average temperature of cesium gas in °K; and λ_c is the mean-free path.

The numerical results represented by these equations have been incorporated in a nomographic chart (Fig. I-1) prepared by J. H. Hufford, Class of '63, M.I.T. The columns at the right give a one-to-one correspondence between pressure and cesium temperature. This is the pressure in equilibrium with liquid cesium at the temperature specified. If the temperature of the gas in some part of the diode is different from the temperature of the cesium reservoir, the mean-free path will be slightly greater if the temperature in the diode is greater than the cesium temperature. The chart also serves to show how much change takes place in the mean-free path, and of course it can be used to estimate the mean-free path in the immediate neighborhood of the cesium surface by setting a straightedge, or alignment thread, at the cesium temperature point on the T_g scale. It is hoped that this chart will be found useful for quick estimations of the pressure-temperature mean-free-path relations.

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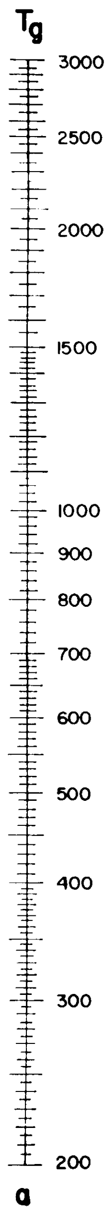

$$p = 2.45 \times 10^{8}\, T_{Cs}^{-1/2}\, e^{-\frac{8910}{T_{Cs}}} \quad \text{mm}$$

$$p = 2.45 \times 10^{8}\, T_{Cs}^{-1/2}\, 10^{-\frac{3870}{T_{Cs}}} \quad \text{mm}$$

$$\lambda_c = 1.38 \times 10^{-13}\, T_g^{1/2}\, 10^{\frac{3670}{T_{Cs}}} \quad \text{m}$$

p = pressure in mm

T_{Cs} = cesium condensation temperature °K

T_g = average temperature of cesium gas °K

λ_c = mean-free path in meters

Use scales a, b and c for high temperature.

Use scales a, d and e for low temperature.

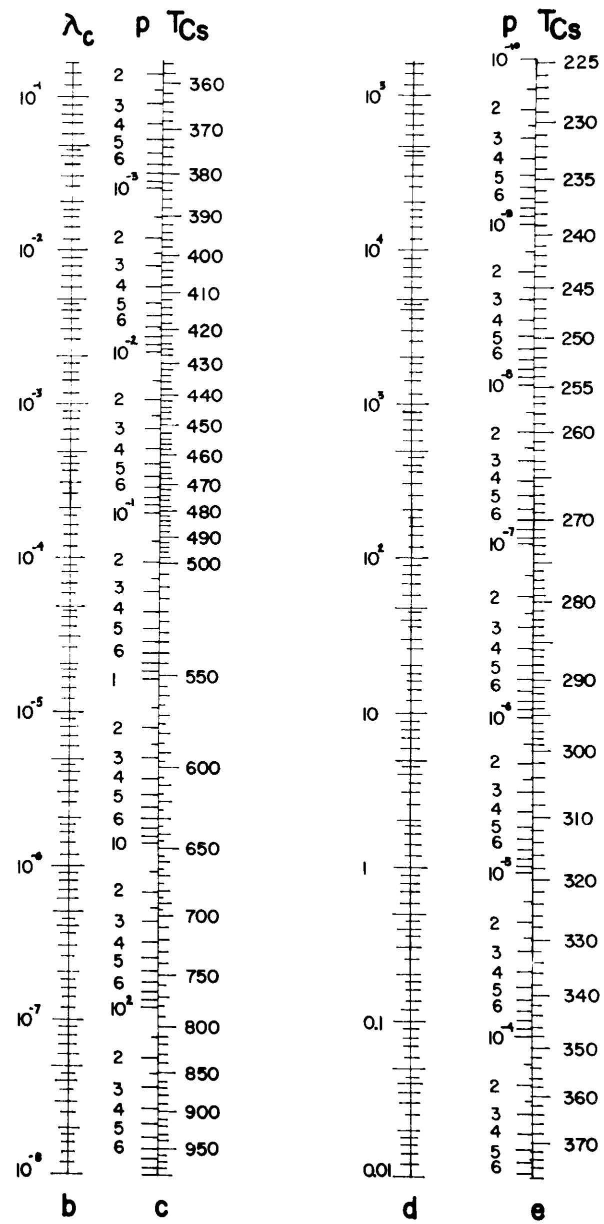

Fig. I-1. Temperature-pressure mean-free-path relations for cesium.

B. PHYSICAL ELECTRONICS IN THE SOLID STATE

1. CHARACTERISTICS OF SEMICONDUCTOR JUNCTIONS

In Quarterly Progress Report No. 57, measurements were reported on two type 1N670 diffused silicon diodes. The analysis of these data is essentially complete.

In Fig. I-2 is shown a semilogarithmic plot of the forward part of the characteristic of one of the diodes at several temperatures from 20°C to 140°C. The slight bend in the characteristic was previously mentioned in connection with other diodes that were studied (1). In order to understand the reason for this bend, measurements were made of the ac forward conductance of the diodes as a function of applied voltage. The results (Fig. I-3) show that the conductance at higher forward voltages is about what would be expected from the measured dc conductance, calculated as dI/dV. This is represented

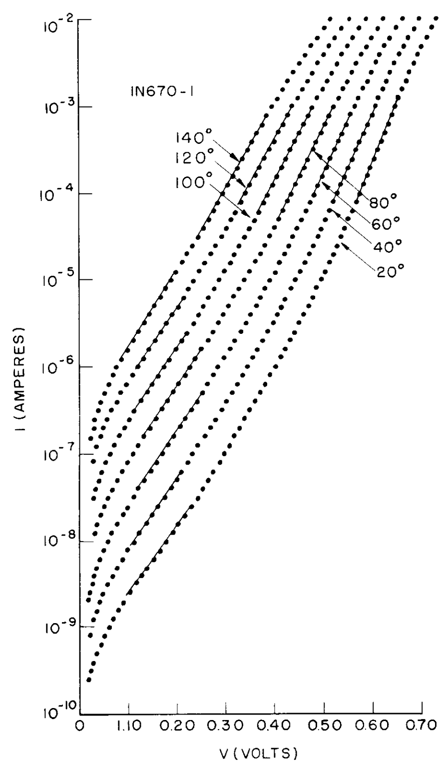

Fig. I-2. Forward characteristic of diode 1N670-1.

by the solid line in the upper end of the curve. At smaller applied voltages the conductance is always larger than would be expected from the dc characteristic. This is the behavior expected from a surface channel viewed as a lossy transmission line.

On the basis of this evidence that a surface channel existed and was responsible for

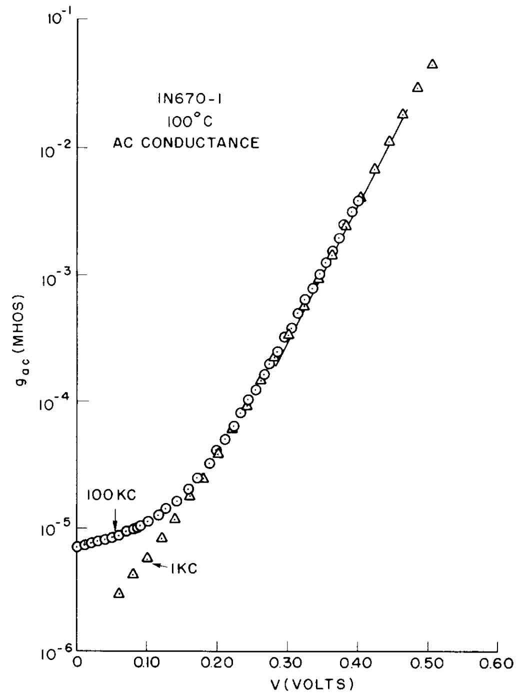

Fig. I-3. Forward ac conductance (diode 1N670-1).

part of the forward current, we made an analysis of the forward characteristic, using the theory of Cutler and Bath (2). This analysis shows that the part of the current from the channel should be

$$I_c = I_{c_o}\left[\exp(V/V_T) - \frac{V}{V_T} - 1\right]^{1/2}$$

where $V_T = q/kT$. By assuming another current component, I_u, given by

$$I_u = I_{u_o}\left[\exp(V/nV_T)-1\right]$$

a three-point fit was made to the forward characteristic. Reconstruction of the entire forward characteristic after the determination of I_{c_o}, I_{u_o}, and n produced an excellent fit to the entire forward characteristic below 10^{-3} ampere. Furthermore, comparison of the constants determined here with the measured low-voltage dc conductance, g_o, through the relation $I'_{c_o} = 2V_T g_c$ shows excellent agreement. This relation follows from consideration of the channel as a transmission line. Here g_c is the conductance of the channel alone. This is calculated from the observed conductance by subtracting from g_o a reasonable (but small) estimate of the conductance of I_u.

In Fig. I-4 is shown a plot of I_{u_o}, I_{c_o}, I'_{c_o} and the reverse current at three different voltages. We see the general trend of agreement between I_{c_o} and I'_{c_o}. In addition, the temperature variation of the reverse current is similar – a fact that shows that it, too, arises from a surface channel. The other current component, I_u, displays a completely different temperature behavior. This component is thought to be a combination of diffusion and space-charge recombination currents.

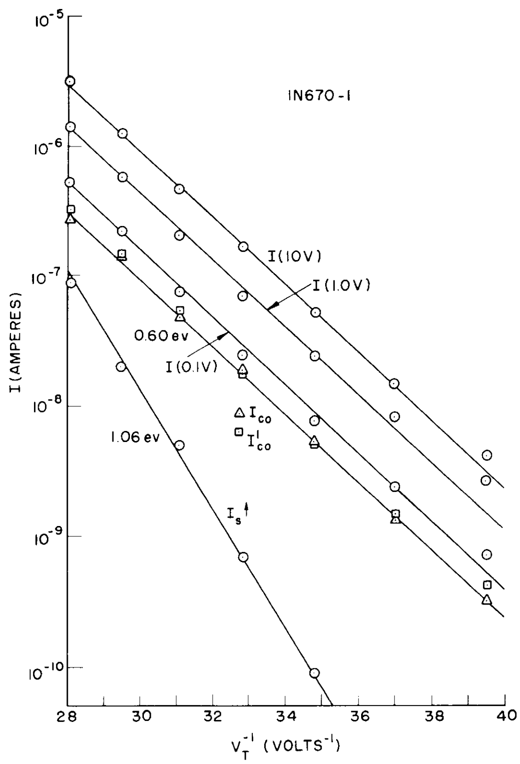

Fig. I-4. Temperature dependence of current components.

The diode on which data have been presented here shows behavior that is completely consistent with conventional channel behavior. Another diode, quite similar in construction, shows incomplete agreement with the channel picture. In contrast with diode 1N670-1, which showed a reverse current that always increased with time after application of a reverse bias, this diode (1N670-2) shows a reverse current that decreases with time. This observation indicates that the density of slow surface states must be changing, probably as the result of migration of ions along the surface of the diode. A rough calculation shows that the mobilities required for this behavior are in the range of 10^{-3} to 10^{-4} cm^2/volt-sec, which suggests the presence of a surface film of water. This is unlikely, however, because diodes that have been freshly evacuated also show the downward creep of current with time.

More complete results of this study are presented in a Ph.D. thesis, Department of Physics, M.I.T. (1960).

J. F. Campbell, Jr.

References

1. J. F. Campbell, Jr., Characteristics of semiconductor junctions, Quarterly Progress Report No. 55, Research Laboratory of Electronics, M.I.T., Oct. 15, 1959, pp. 1-3.

2. M. Cutler and H. M. Bath, Surface leakage current in silicon fused junction diodes, Proc. IRE 45, 39-43 (1957).