power dissipated, using increments of power proportional to the increments of temperature used in laying out the isothermal characteristics. The desired thermal equilibrium characteristic can now be drawn through the intersection points of the isothermal characteristics and their respective hyperbolas.

It can be seen that this thermal equilibrium characteristic qualitatively resembles the measured characteristic of Fig. 1. If one increases the ambient temperature, i.e., starts out along a higher temperature isothermal characteristic, it is easy to see that the temperature dependence found is also qualitatively that shown in Fig. 1.

Preliminary experiments[4] with very short pulses have shown the isothermal characteristics to be nearly straight lines out to voltages of more than twice the dc characteristic breakdown voltage. These isothermal or pulse characteristics also coincide with the dc characteristic at the low voltages.

The theory of Aigrain[3] explains the relatively large currents found at low voltages in some point contact characteristics by assuming that the rectifying barrier is not on the surface, but lies some distance below it. In such a case there is a surface layer of relatively high conductivity allowing the current lines to spread out and use a much larger area of the barrier than would be the case if the barrier were immediately beneath the point contact. This model, when considered in connection with the effects of heating, would require that the surface layer immediately beneath the point would be heated first as the current is increased. If the bulk resistivity of this layer is considerably below the intrinsic resistivity at the ambient temperature, its resistance should increase until the intrinsic range is reached at some elevated temperature. This behavior would result in the thermal equilibrium curve showing a greater resistance than the ambient isothermal curve for a small range of intermediate currents. Such a behavior has been found[5] for contacts which show relatively high currents at low voltages.

The physical assumption of Aigrain seems to be capable of explaining the observed behavior in this case even though such an assumption seems impossible for very high inverse resistances, since in such cases it requires surface layers of thickness considerably less than the mean free path of a current carrier in germanium.

[1] S. Benzer, J. Appl. Phys. **20**, 804 (1949).
[2] Torrey and Whitmer, *Crystal Rectifiers* (McGraw-Hill Book Company, Inc., New York, 1948), p. 78.
[3] P. Aigrain, Compt. rend. **230**, 62 (1950).
[4] A. I. Bennett and L. P. Hunter, Phys. Rev., following letter.
[5] Figure 1 of reference 4.

Pulse Measurement of the Inverse Voltage Characteristic of Germanium Point Contacts

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THE inverse voltage characteristics of point contacts on *n*-type germanium were measured using short pulses in order to eliminate heating effects. It was found necessary to use pulses of less than 0.5 μsec in order to eliminate these effects in most cases. The resulting isothermal characteristic curves were nearly straight lines out to voltages of more than twice the dc inverse breakdown voltage.

The germanium crystals used were single crystals lapped to a thickness of about 0.015 in and soldered to a relatively large copper block. The crystal and the copper block were both maintained in the temperature bath. Because of the thinness of the crystal and the large area in contact with the copper, it is felt that the crystal remained very nearly at bath temperature. The measurements were made with a basic oscilloscope, consisting only of a cathode ray tube and power supply. The crystal and probe assembly was hung on the deflection plate connections so that there was no more than two inches of line connecting the assembly with the deflection plates themselves. This arrangement eliminated most of the reactive effects, and the small amount of reactance remaining was tuned out with a variable condenser across the current measuring resistor.

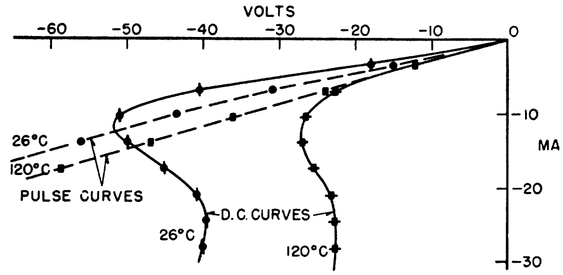

FIG. 1. Pulsed and dc inverse characteristics.

In order to get stable and reproducible operation, the point contacts were formed by momentarily running them at a high inverse current (several times the current used in the measurements). This resulted in lower resistance contacts than would otherwise have been obtained.

A typical set of results are shown in Fig. 1. It should be noted that at room temperature the dc or thermal equilibrium curve lies above the pulse or isothermal curve for intermediate values of current. However, when the temperature is raised, it is seen that this effect disappears near that temperature where the bulk resistivity reaches a maximum just before the intrinsic range is reached.

We will consider first the nearly linear isothermal characteristics in terms of the theory of Aigrain.[1] For moderate voltages Aigrain gives the formula

$$V=(Ri_s/2\pi)[1-(i/i_s)+(i/i_s)\ln(i/i_s)] \tag{1}$$

for the inverse voltage characteristic neglecting thermal effects. Since $i_s\sim10^{-7}$ amp, and since $i\sim10^{-3}$ amp, the unity in Eq. (1) can be neglected and this becomes

$$V=(Ri/2\pi)[\ln(i/i_s)-1]. \tag{2}$$

Since the ratio $i/i_s>10^4$, the logarithm is nearly constant, so that we have essentially a linear characteristic of slope $R[\ln(i/i_s)-1]/2\pi$. The temperature dependance should be that of R, which in turn is that of the bulk resistivity of the surface layer. The temperature dependence of i_s is that of the intrinsic conductivity so that, unless the logarithm were quite large, it would contribute to the over-all temperature dependence. In the case of the results shown in Fig. 1, the temperature is uniform for the pulse curves but not for the dc curves. This means that in the low current region of the dc curve we might expect the Aigrain surface layer to heat up immediately beneath the probe, while the temperature of the barrier is not appreciably increased above ambient. If this is the case, we should expect the dc curve to exhibit somewhat higher resistance values at low currents than the pulsed curve for the same low ambient temperature, since at moderately low temperatures the resistivity of the surface layer should have a positive temperature coefficient. As the ambient temperature of the pulsed curves is increased, however, we need not necessarily expect their resistance to increase even at first, since in this case the temperature of the barrier region and the surface layer are the same and the temperature dependence of R may be balanced or overcome by the temperature dependence of i_s.

In conclusion it would seem that since there are two regions at different temperatures represented by two temperature dependent constants (i_s and R), it is very difficult to generate the thermal equilibrium curve (dc characteristic) quantitatively from the isothermal curves (pulsed chtracteristics) by the method of Hunter.[2] It does appear, however, that qualitatively such a relation exists between the two sets of curves, and that back voltage breakdown is really a self-heating effect.

[1] P. Aigrain, Compt. rend. **230**, 62, 194 (1950).
[2] L. P. Hunter, Phys. Rev., preceding letter.