surface and heated for three hours at 918°C at a residual gas pressure of 5×10^{-5} mm mercury. It was found that during the vacuum heating radioactive copper was collected on a cold finger in the vacuum system indicating that copper had evaporated from the germanium. From the change in sample surface count before and after the vacuum heating and from the amount of copper collected on the cold finger, it is estimated that at least 96 percent of the copper was evaporated from the germanium during the vacuum heating. Hall measurements made on the sample show that after the initial heat treatment in helium, the density of added acceptors was $n_A=1.43\times10^{16}/\mathrm{cm}^3$, and after the vacuum heat treatment the remaining density of acceptors was $n_A=3.4\times10^{14}/\mathrm{cm}^3$.

The evaporation of copper during the vacuum heating corresponds within experimental error to the loss of acceptors as given by Hall measurements.

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Diode Characteristic of a Hollow Cathode*

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If a current is drawn from an aperture of a hollow cathode, the inside surface of which is coated with Ba−Sr oxide emitting material, a diode characteristic is obtained which does not resemble the typical Child-Langmuir characteristic.

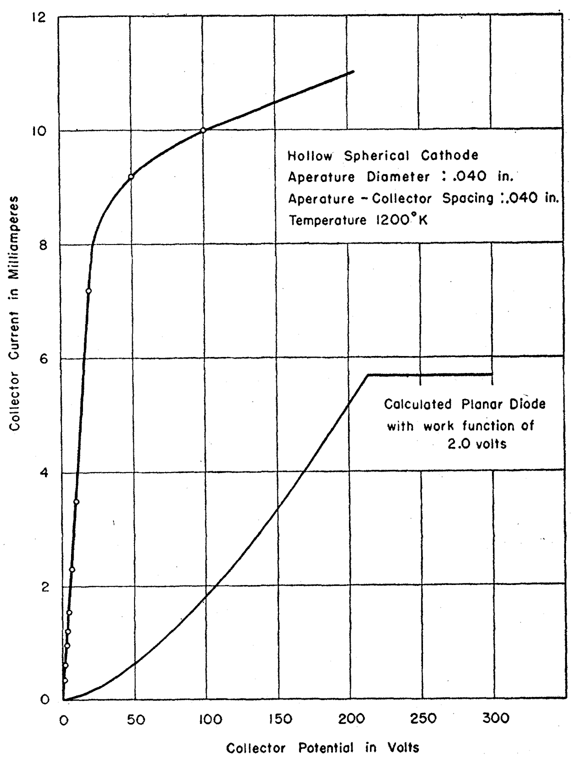

Fig. 1. Comparison of the measured current-voltage characteristic obtained through the aperture of a hollow cathode with the computed characteristic of a planar diode with a cathode area equal to the aperture area.

In Fig. 1 the diode characteristic is plotted for a hollow cathode arrangement in which the current from an aperture of one millimeter diameter is collected by an anode spaced one millimeter distant. This is compared with the curve one would expect from an equivalent planar diode, i.e., one with the same emitting material, with a cathode area equal to the aperture area, and with the same cathode-anode spacing.

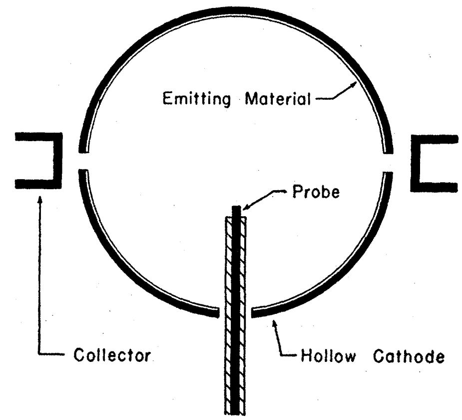

Fig. 2. Schematic diagram of the experimental arrangement used for the study of the characteristic of a spherical hollow cathode.

Three typical features of this characteristic are of particular interest:

(1) The rapid increase of current even if small positive potentials are applied to the collector electrode.

(2) Over the entire potential range higher currents were obtained than are to be expected from the equivalent planar diode.

(3) At potentials above which the planar diode exhibits saturation, the current in this structure continues to increase at a considerable rate.

Figure 2 shows schematically the experimental arrangement being used in these studies. The spherical hollow cathode is heated uniformly and indirectly by a larger concentric heater sphere (not shown in Fig. 2). For purposes of comparison two apertures with their corresponding collector electrodes are provided. Since particular care was taken to avoid spurious effects of any kind, the collector electrodes are water-cooled to eliminate the possibility of thermionic currents in the inverse direction. The inverse impedance under operating conditions is found to be very large indeed; it is of the order of 3×10^8 ohms.

A probe which can be inserted or withdrawn during operation allows the study of the conditions inside of the sphere.

These experiments are a phase of a general study of electron gases in equilibrium[1,2] and will be reported in greater detail in a later article.

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A Tentative Theory of Metallic Whisker Growth*

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Peach's[1] very pretty explanation of the formation of metallic whiskers[2] seems to be ruled out by the observation[3] that they grow at the root. The growth seems to be influenced[4] by the atmosphere over the surface. The energy required to form a fresh surface may be more than repaid if it is attacked avidly enough by the atmosphere; there is then an effective negative surface tension $-\gamma$. We might have perhaps $\gamma b^2 \sim 1$ *ev* (b = lattice constant). The ratio γ/μ (μ = shear modulus) would then be about 1A. The surface tension forces on a small hump on the surface [Fig. 1(a)] obviously have the right character (a central pull

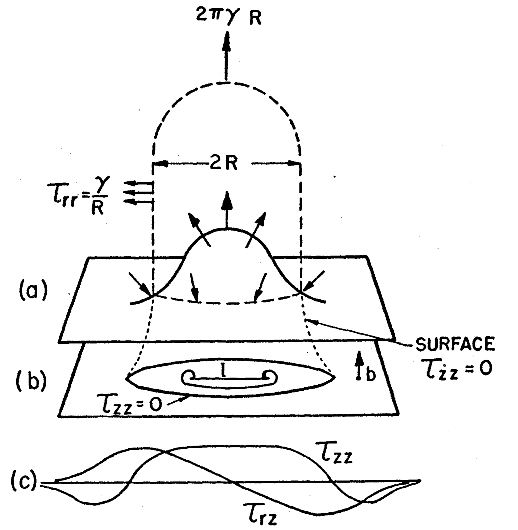

FIG. 1. Model for whisker growth.

surrounded by a restraining pressure) to "wire-draw" it into a whisker according to intuitive ideas of plastic flow. For the observed whisker size ($R \sim 10^{-4}$ cm) the stress of order γ/R in and just below the hump might exceed the actual yield stress, though not the theoretical yield stress ($\sim \mu/20$). However, on this small scale one must consider in detail how flow is catalyzed by dislocation.

The model of Fig. 1 lends itself to rough calculations. A Frank-Read source of length l and vertical Burgers vector b lies in a horizontal plane (b) at a depth of order l below the hump. The stress τ_{zz} [Fig. 1 (c)] makes the source emit a dislocation loop by "climb." The loop expands in the plane (b) until it reaches a radius where $\tau_{zz}=0$. Here the stress τ_{rz} assisted by image forces makes the loop glide vertically, so adding one atomic layer to the base of the hump. When by repetition of this a reasonable whisker has grown, τ_{zz} will be $2\gamma/R$ in the whisker and about γ/R at the source. To operate the source, τ_{zz} must be at least $\mu b/l$. With $\gamma/\mu \sim 1\text{A} \sim b$, this will be so if $R \sim l$. The stress at the source ultimately falls off both for $R \gg l$ and $R \ll l$ if the source depth stays constant. The whisker radius is thus tied to the length of a Frank-Read source, which is usually supposed to be about one micron. The surface $\tau_{zz}=0$ forms a "stress funnel" which guides each loop more or less unerringly to break surface at the base of the whisker, and so keeps its diameter constant. If the motion of the source is not to be stopped by the back-pressure of the vacancies it emits, there must be suitable sinks for them. It can be shown that surface tension changes the volume of a body of any shape with compressibility χ by $\frac{2}{3}\gamma\chi$ times its surface area. For a macroscopic specimen the corresponding mean pressure, $\frac{2}{3}\gamma \times$ (surface/volume) would fall far short of the value required to make Frank-Read sources in the interior act as the necessary sinks. However, it should not be hard to find them at the surface. Frank[5] has shown that even with positive surface tension it may be energetically an advantage for a dislocation reaching the surface to develop a hollow core. Or again, if we had a depression instead of a hump in Fig. 1 the source would work in reverse, absorbing vacancies and deepening the depression.

We may use a calculation of Mott's[6] to find the rate of growth. He showed that, if a cube has normal stresses P on one pair of opposite faces and $-P$ on another pair, a volume $V \sim NbD(Pb^3/kT)$ of material is transferred from one pair of faces to the other in unit time if there are N points on dislocations which can absorb or emit vacancies and the coefficient of self-diffusion is D. Our case is analogous. P is γ/R times a factor κ depending on the detailed stress-distribution, including a possible stress concentration if successive loops help one another. N is about l/b, the number of lattice sites per loop, times the fraction β (perhaps $\ll 1$) of them which can emit or absorb vacancies times n, the number of loops in transit between source and surface at one time. The rate of change of the whisker length h will thus be

$$\dot{h} = V/\pi R^2 \sim \kappa\beta n D(b/l^2)(\gamma b^2/kT).$$

With the value of D for tin at room temperature,[7] we can get a growth rate of a millimeter or a centimeter per year with $\kappa\beta n \sim 100$ or 1000. The small number of accidental coincidences of sources and suitable surface irregularities may be enough to account for the number of whiskers per unit area. If not, we might suppose that the sources build their own humps by operating initially without stress as the result of a subsaturation of vacancies due to a change of temperature.

Many variations of this model are possible. The transfer of loops to the surface might occur by the formation and joining up of secondary loops in a vertical plane as in "prismatic punching,"[8] where the stress distribution is similar. The whiskers might then be prismatic. Professor Seitz (to whom the writer is indebted for helpful discussions) has suggested a mechanism involving a spiral prismatic dislocation,[9] which is the internal counterpart of spiral growth on the surface and which leaves a screw dislocation along the axis of the whisker.

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Oxygen-Induced Surface Conductivity on Germanium

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MOTT has suggested[1] that oxygen may introduce acceptor energy levels on a germanium surface. The present note reports mainly on gas adsorption and resulting surface electrical conductance at a temperature of 197°K.

A very thin high-resistivity (40 ohm-cm at room temperature) n-type single crystal rectangular bridge of germanium was assembled for electrical measurements in a high vacuum system. The voltage probes are germanium and an integral part of the single crystal and are separated by 0.5 cm. The crystal width is 0.2 cm and the thickness about 0.004 cm, made purposely thin to amplify any surface changes. The surface was prepared by etching with an etchant of HF, HNO_3, and H_2O, and then rinsing with H_2O.

The residual gas pressure was reduced to about 5×10^{-8} mm Hg after pumping for 20 hours, and after heating the experimental tube containing the Ge to about 450°C for one half-hour. This treatment decreased the germanium conductance by a factor of two, representing a decrease in conductance of 4×10^{-6} mho. If one assumes a surface carrier mobility of 1000 cm²/volt sec this represents a decrease of 4×10^{10} carriers per cm² of surface. A different carrier concentration will correspond to a different mobility. The germanium was heated to near its melting point for a short period of time (seconds) and then quenched rapidly by radiation