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Electrical Properties of Germanium at Very Low Temperatures

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HUNG[1] found that there is a change in the activation energy of the carrier current in germanium in the region of helium temperatures and later this was verified by experiments[2,3]. But until the present time there has not appeared a satisfactory theoretical clarification. It seems to be proper at this time then to study the properties of germanium at very much lower temperatures.

We obtained very low temperatures by the adiabatic demagnetization of iron-ammonium alum. The apparatus allowed us to cool the germaium sample to 0.15° K. The temperature of the sample was controlled by a calibrated carbon thermometer, with an accuracy of 5×10^{-3}° K. The electrical conductor for measuring the resistance was passed into the dewar to the sample through an evacuated steel tube, and covered with polystyrene washers. The conductor is cooled to helium temperatures by means of a quartz rod and to very low temperatures by means of a block of alum. This made possible the attainment of very low temperatures in a matter of a few hours, so that we could carry on the experiments at a temperature that remained relatively stable.

The thermal and electrical contacts to the sample of germanium were made using springs tightly enveloping the sample, the ends of which were electrolytically covered with copper. The electrical resistance of the sample was measured with an electrometer with a reversable connection and with a current sensitivity equal to 1×10^{-14} A.

For measurements in the region of hydrogen and helium temperatures, the apparatus was filled with atmospheric helium. For measurements at very low temperatures, several centimeters of gaseous helium were put in at room temperature by which the isothermal magnetization was hastened. The adiabatic demagnetization depends on the adsorption of the gaseous helium over the surface of the cooled salt.

Several samples of germanium were studied having a specific resistance of the orderof 1 ohm-cm at room temperature. The samples were prepared in the Institute of the Metallurgical Academy of Sciences, USSR, and in the semiconductor section of Moscow State University.

The temperature dependence of the specific resistance of the sample is shown in Fig. 1. The resistance of the sample was measured at a gradient of 50-100 mv/cm. At this voltage the resistance for all practical purposes still does not depend on the field. The effect of geometry on the resistance was studied. To clarify the role of the contacts, the space between them was variedfor one of the samples from 15.8 to 8 mm at a constant cross section area of about 0.25 cm^2. Within the limits of the accuracy of the experiment (around 20%) the calculated specific resistances were equal. There is the same degree of accuracy in the results for samples subjected to these different surface treatments: 1. polishing, 2. dipping in a boiling mixture of hydrochloric and nitric acids. The results did not change when the ends of the sample were coated with copper by means of electrolysis.

We have shown two sets of curves on Fig. 1. One of these curves corresponds to the resistance of the samples in the region of hydrogen and helium temperatures, the other, in the region of helium and very low temperatures. The results of the measurements allow us to make some conclusions on the existence in the region of temperature from 0.15 to 1°K of an energy of activation smaller than in the region of temperature between 1.6 and 4.2° K. The small amount of activation energy of the current carrier in the region of helium and very low

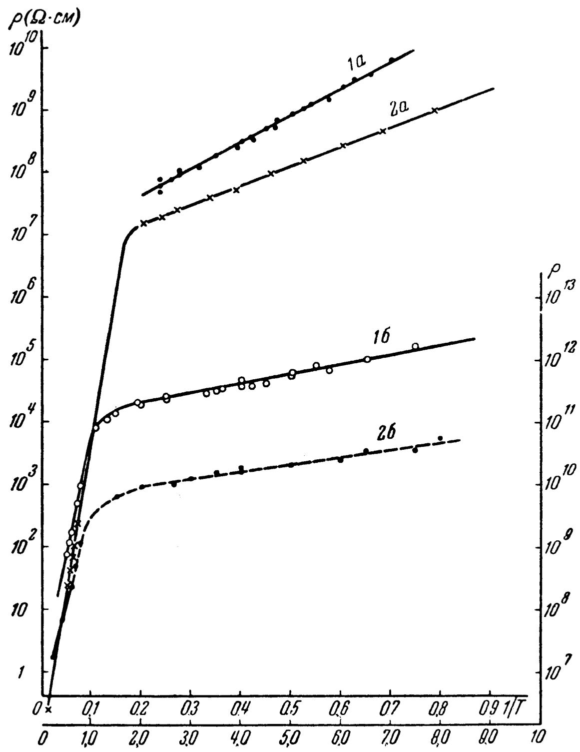

FIG. 1. ρ (ohm-cm) *vs.* $1/T$ (left scale), ρ *vs* $1/T$ (right scale). The dependence of resistance on the temperature: *1a, 2a,* in the region of hydrogen and helium temperatures (left scale), *1b, 2b,* in the region of helium and very low temperatures (right scale).

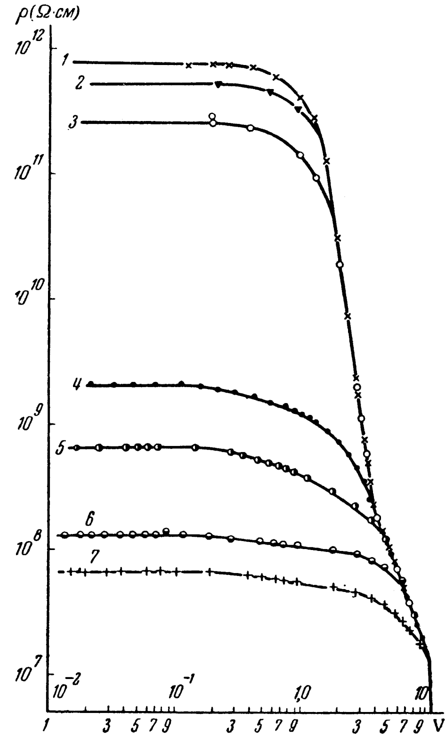

FIG. 2. $\rho(\Omega \cdot \mathrm{cm})$ *vs.* V. The dependence of the resistance on the external electrical field: (v/cm): *1*--0.15; *2*--0.2; *3*--0.4; *4*--1.77; *5*--2.23; *6*--3.12; *7*--4.2° K; (V_{cr} = 11 v/cm).

temperatures makes germanium sensitive to a very small surface effect. Thus, for example, room temperature radiation lessens the resistance of the sample by a factor of ten. This circumstance led to the necessity of shielding the sample with a baffle at the temperature of liquid helium.

We know[4] that the presence of comparatively small electrical fields also leads to an increase of conductivity. Figure 2 shows curves taken at various temperatures between 0.15 and 4.2° K and the dependence of the sample resistance on the electrical field. The results for the samples exposed to various surface treatments are self-consistent. Changing the linear dimensions of the sample displaces all the curves so that the ratio of V_{cr} to the dimensions of the sample remains constant.

With an external voltage differing from the "critical" by only 10-15%, a thermometer fastened to a lower part of the sample, i.e., on the side opposite from the coolant, did not show more than a 0.1° K rise. The application of a "critical" field led to an instantaneous heating of the sample to the temperature of the outer bath, i.e., to 1.7-1.8° K. On the curves of Fig. 2 in the region of voltage lower than the critical we can see two different slopes, one of which is inherent in the curve in the region of very low temperatures; the other, in all curves in all temperature intervals from 0.15-4.2° K.

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