Effect of illumination on the surface conductivity of germanium

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Illumination of a germanium surface produced by cleavage in liquid helium leads to an irreversible increase of electrical conductivity. The possible causes of this effect and of the temperature hysteresis of surface conductivity observed by us earlier[1] are discussed.

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We have detected earlier[1] that the surface of germanium produced by cleavage in liquid helium has electrical conductivity in the SHF range. It turned out that this conductivity can be increased substantially if the sample is heated to ~40 K after cleavage and then cooled again to 4.2 K. We shall call this effect temperature hysteresis of the surface conductivity (TH). Analogous qualitative results were obtained by Vul *et al.*[2] in measurements with direct current. They also noticed a correlation between the quality of surface and its conductivity immediately after cleavage. It turned out that only the rough surface had a noticeable conductivity, whereas the mirror-smooth surface (111) had no conductivity immediately after cleavage. After heating a high conductivity was established, regardless of the quality of cleavage.[2]

In this paper we investigate the effect of illumination on the surface conductivity in the SHF range ($\sim 10^{10}$ Hz) and with direct current. In both cases the sample was exposed to white light from a miniature electric bulb. We used *p*-Ge samples with an acceptor concentration of $\sim 10^{13}$ cm^{-3}. Typical curves obtained by measurements are shown in Figs. 1 and 2. The main results of measurements are as follows: 1) after exposure to a light pulse the direct-current pulses are not "remembered"; 2) the TH

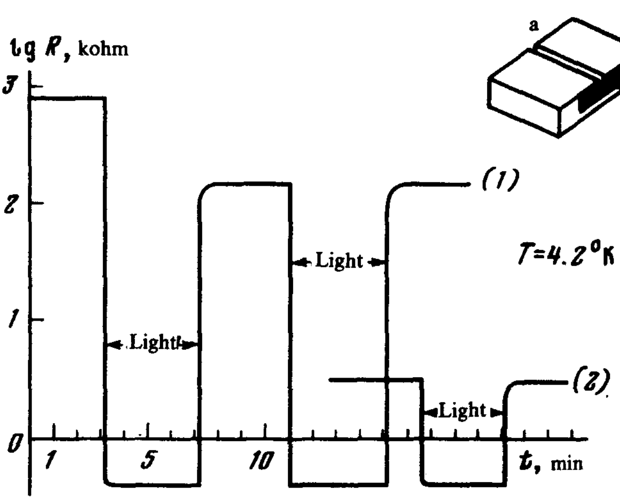

FIG. 1. Effect of illumination on the surface conductivity of germanium with direct current. 1, The measurements performed at $T = 4.2$ K immediately after cleavage of the sample; 2, the measurements performed at $T = 4.2$ K after heating the sample to 40 K. The sample is shown in the upper right-hand corner: a) profile; b) indium contact.

remains after illumination of the surface; 3) both illumination and heating account for a much stronger change in conductivity with direct current than in the SHF range.

The latter case is apparently attributable to surface inhomogeneity. On the surface there are both defective regions (DR) having a high conductivity and ordinary regions (OR) with a low conductivity.[2] The conductivity with direct current is determined by the charge flow along the DR from contact to contact; the various DR in this case can be divided by potential barriers, which produces a high resistance on the

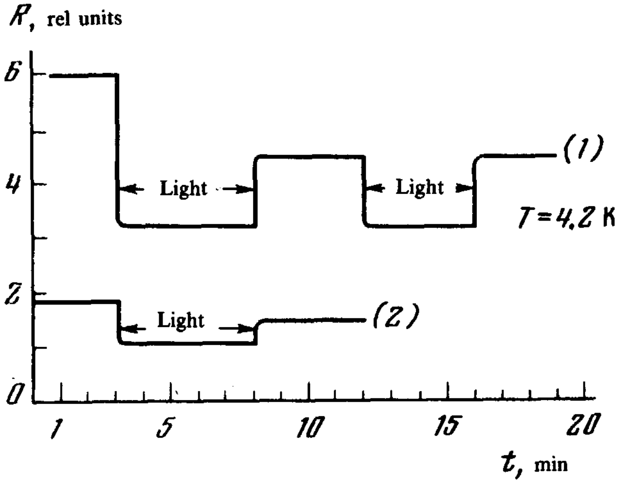

FIG. 2. Effect of illumination of the SHF surface conductivity of germanium. 1, The measurements performed at $T = 4.2$ K immediately after cleavage of the sample; 2, the measurements performed at $T = 4.2$ K after heating the sample to 40 K.

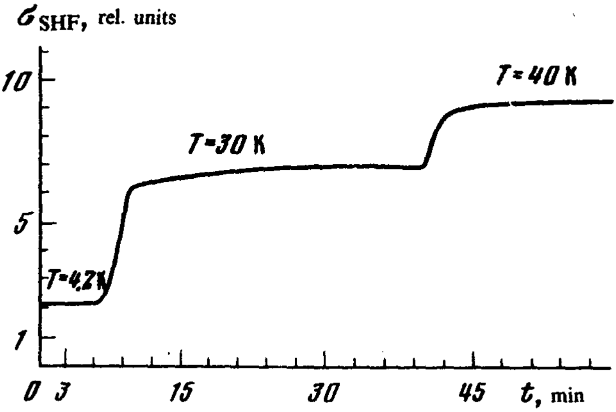

FIG. 3. Time dependence of the SHF conductivity for different temperatures.

surface with direct current. The conductivity in the SHF range is determined by all DR on the surface, irrespective of the location. We can expect, therefore, that a change in the state of the OR will manifest itself stronger in the measurements with direct current than in the SHF range; we can see from our data that illumination and heating change primarily the conductivity of the OR. The surface conductivity of germanium produced by cleavage is attributed to the presence of holes in the valence band near the surface. The holes, however, are produced because a fraction of electrons from the valence band migrate to the surface levels[2-4] (the electron mobility in the surface levels is usually disregarded[3]). The illumination effect in such a model can be accounted for by the unfilled surface levels which are separated from the crystal volume by a sufficiently high potential barrier. The barrier can account for the TH. If we assume that the unfilled surface levels lie near the valence-band ceiling, then a thermodynamically stable filling of these levels should occur at sufficiently high temperatures. Upon cooling, a fraction of the electrons should remain in the surface levels, since these levels are presumably located near the valence-band ceiling. This explanation of the TH, however, has some difficulties. First, the reason the illumination accounts for a much weaker change in the surface conductivity than heating is not understood. We performed, moreover, the following additional measurements in the SHF range. We used very pure n-Ge samples ($n \sim 10^{11}$ cm^{-3}) whose bulk conductivity can be ignored. After cleavage the sample was quickly (~ 3 min) heated to 30 K. As a result, the surface conductivity increased irreversibly without reaching a maximum value. The sample was subsequently kept at this temperature for a long time. It turned out that its electrical conductivity changed very little during holding time and was comparable to the total measurement error. A fast heating of the sample from 30 to 40 K again increased its conductivity, and exposure at 40 K further increased it negligibly. These data are shown in Fig. 3. In this connection, we can propose the following TH model. The (111) surface produced by cleavage in liquid helium has free energy levels that lie above the valence-band ceiling; hence, they remain unfilled in the equilibrium state. These levels are separated from the volume states by the barrier, which accounts for the illumination effect. An irreversible rearrangement of the atomic-crystal structure of the surface occurs in the temperature region above 25 K. (A similar irreversible rearrangement occurs in germanium in the temperature range 100–150° C.[5]) We can assume that the new surface structure corresponds to the unpopulated levels lying near the valence-band ceiling, whose population is not related to overcoming the barrier, and the holes that remain in the valence band determine the surface conductivity. As for the fact that the electrical conductivity changes primarily due to heating and increases very little with time as a result of isothermal exposure, we can attribute this to thermoelastic equilibrium achieved due to rearrangement of the atomic-crystal structure of the surface. Such equilibrium and an incomplete transformation can be frequently observed at low-temperature, martensitic-type phase transformations.[6]

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