UHF conductivity of Ge surfaces produced by cleavage

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Ge samples containing new surfaces obtained by cleavage in liquid helium have a noticeable conductivity in the UHF range. In a number of cases this surface conductivity may greatly exceed the volume conductivity. The temperature dependence of the surface conductivity is investigated.

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The important progress of recent years in the investigating the physical properties of the surface of solids in many respects is connected with the advances in the experimental methods of producing and investigating atomically pure surfaces. In addition to cleavage of a crystal in a deep vacuum, one of these methods can be used to cleave a crystal in an inert medium at low temperature.

Specifically, crystal cleavage in liquid nitrogen has been used to investigate the electrical properties of germanium with direct current.[1-3]

We have investigated the variation of the conductivity of Ge due to formation of a new surface on a cleaved crystal immersed in liquid helium. To avoid problems connected with establishing contacts, the experiments were conducted in the ultrahigh frequency range. The results of the measurements presented below show that the surface in germanium greatly increases the UHF absorption.

The samples in question were placed into a cylindrical cavity in which the E_{010} vibration was excited at a frequency of 9500 MHz. The samples were in the shape of a parallelepiped with dimensions $3\times3\times4$ mm. The samples were cleaved by a sapphire rod which was introduced through the hole in the cavity wall. Usually the samples broke up into several parts due to cleavage. We measured the width of the resonance curve of the cavity together with the sample (original and cleaved), and then subtracted from it the width of the resonance curve of the empty cavity. The value of Δf

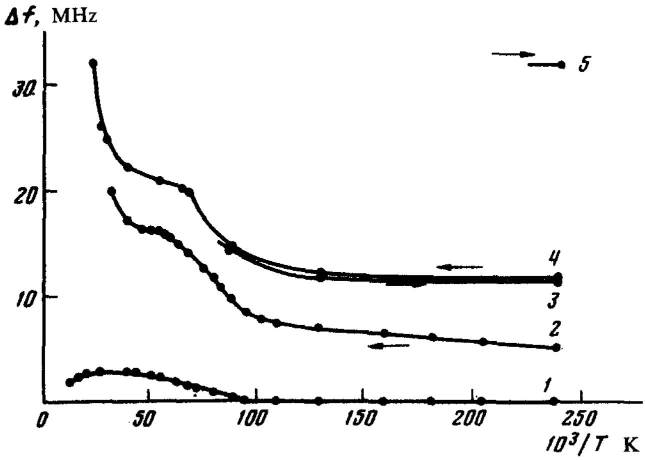

FIG. 1. Data for the *n*-Ge sample with a small-donor concentration of 10^{11} cm^{-3}: 1—original sample before cleavage; 2—heating after cleavage; 3—subsequent heating; 4—second heating; 5—the value of Δf obtained after cooling from 40 K.

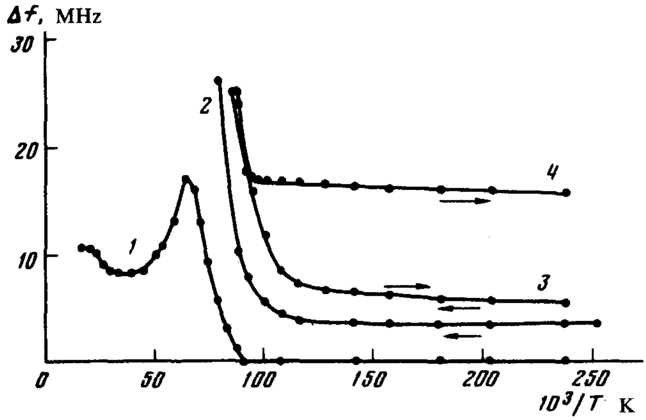

FIG. 2. Data for the *n*-Ge sample with a small-donor concentration of 5×10^{13} cm^{-3}: 1—original sample before cleavage; 2—heating after cleavage; 3—cooling after heating to 25 K; 4—cooling after heating to 50 K.

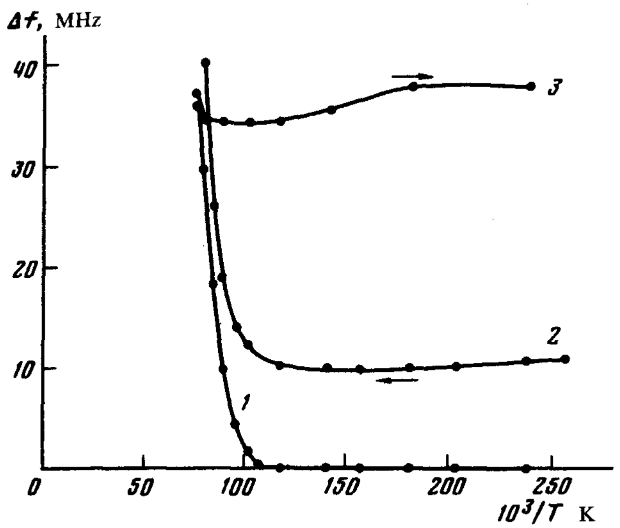

FIG. 3. Data for the *p*-Ge sample with a small-acceptor concentration of $\sim10^{13}$ cm^{-3}: 1—original sample before cleavage; 2—heating after cleavage; 3—cooling after heating to 30 K.

obtained in this way is determined by the UHF power losses in the bulk and on the surface of the sample and hence can be used as the measure of its electrical conductivity.

The measurements were conducted in the following order. First, we measured the temperature dependence of Δf for the original sample in the range 4.2–50 K; we found that for all the investigated samples Δf was practically 0 at $T < 10$ K. Then we filled the cavity with liquid helium and the sample was cleaved. After cleavage the width of the resonance curve increased sharply, which indicated the onset of conductivity. The conductivity did not change if the liquid helium was evaporated at a constant temperature of the cavity and the sample remained in the gaseous helium.

We investigated Ge samples of a differing degree of alloying: n-Ge with a donor concentration (antimony) of 10^{11} cm^{-3} and 5×10^{13} cm^{-3}, and p-Ge with an acceptor concentration (gallium) of $\sim10^{13}$ cm^{-3}. Our results (Figs. 1–3) first of all show that, as a result of formation of a new surface, the conductivity of all the Ge samples increases greatly, irrespective of alloying. At $T < 10$ K the usual bulk conductivity is very small for all the Ge samples. We shall arbitrarily call the UHF conductivity observed by us surface conductivity. Its temperature dependence turns out to be rather complex. If the temperature of the newly cleaved samples is increased from 4.2 K to approximately 10 K, then their surface conductivity will remain almost the same (Figs. 1–3). If also does not change as a result of cooling from 4.2 to 1.4 K. However, as a result of further heating in a gaseous helium atmosphere from 10 K and higher, the surface conductivity of the Ge samples increases further. But if the sample is cooled after being heated to 30–40 K, then its surface conductivity first decreases and then levels off, but the points will not lie on the curve obtained through heating, i.e., temperature hysteresis occurs. After the sample is cooled from a certain temperature, the surface conductivity again becomes temperature independent but it is now much higher than it was at the same temperature before the heating (hysteresis). All these data for Ge samples of different levels of alloying are presented in Figs. 1–3. After the removal of vacuum from the system, the samples immediately lost their high conductivity, and the conductivity and its temperature dependence for all the samples coincided with the values that were obtained before cleavage.

The purpose of this paper is to report an observation that UHF conductivity does increase due to cleavage of germanium, and that the conductivity has an anomalous temperature dependence. The available experimental data are insufficient to determine confidently the mechanism of the observed conductivity. It is most likely that the conductivity is attributable to the inversion layer near the surface, which is formed due to capture of electrons from the valence band to the surface states.[4]

[1]G.A. Katrich and O.G. Sarbeĭ, Fiz. Tverd. Tela **5**, 3321 (1963) [Sov. Phys. Solid State **5**, 2432 (1963)].
[2]G.A. Katrich, O.G. Sarbeĭ, and D.T. Tarashchenko, Fiz. Tverd. Tela 7, 1352 (1965) [Sov. Phys. Solid State 7, 1091 (1965)].
[3]F. Proix and P. Handler, Surf. Scil. **5**, 81 (1966).
[4]D.R. Palmer, S.R. Morrison, and C.E. Dauenbaugh, Phys. Rev. **129**, 608 (1963).