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ELECTRICAL CONDUCTIVITY OF GERMANIUM CLEAN SURFACE

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Clean surfaces on p- and n-type Ge were obtained by cleavage of the crystals in liquid helium. In all samples after annealing the surface conductivity was of p-type and reached the limiting value $\sigma_m \simeq 4.10^{-4}\ \Omega^{-1}$, with hole's concentration $n_s \simeq (6 \sim 10).10^{12}$ cm^{-2} and mobility μ_m=400-250 cm^2/v.sec The phenomena are similar to the investigated early on the grain boundary interfaces in bycrystels of Ge [1].

Clean surfaces were prepared by cleavage of crystals in liquid helium so far as helium has high chemical inertness and all impurities in it are frozen and fallen out.
The device for cleavage and sample were placed in a hermetic helium cryostat. The samples of (1-4) mm thick and of 1 cm^2 in square were cut from orientated in [111] direction bars of n- and p-type Ge with different concentration of impurities $10^{13} \lesssim N_i \lesssim 5.10^{15}$ cm^{-3}. The contacts of different geometry were formed by alloying of Indium on both sides of Ge plates. For the Hall-effect measurements the distance L between contacts was nearly 6-8 mm, the width of conducting area S $\sim$ (1÷2) mm, and the contacts were located as shown in Fig.1. Only two contacts have been used for the J-V measurements, and the values of L and S were varied from 1 to 7 mm. Typical dependence of current on applyed voltage at T=4,2°K is shown in Fig. (1). As is seen from these data, the conduction was diminished after cleavage, as the cross section of the sample was reduced. Therefore, the surface conduction immediately after cleavage, was very small in comparison with bulk germanium conduction, $\sigma \simeq 10^{-9}\ \Omega^{-1}$ at this temperature. But after intermediate heating of the sample surface conduction greatly increased.

At similar conditions a strong increasing of ultrahigh frequence's absorbtion was observed in paper [2].

As is seen from Fig. 2, the values of σ_i, measured at T=4,2°K, strongly depended on temperature T_i and duration t of intermediate heating in helium vapour.

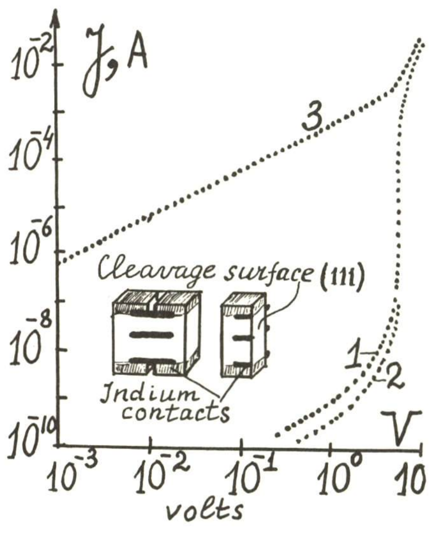

Fig.1 Typical $J=f(V)$ on sample with L $\approx$ S = 4 mm, at T = 4.2°K

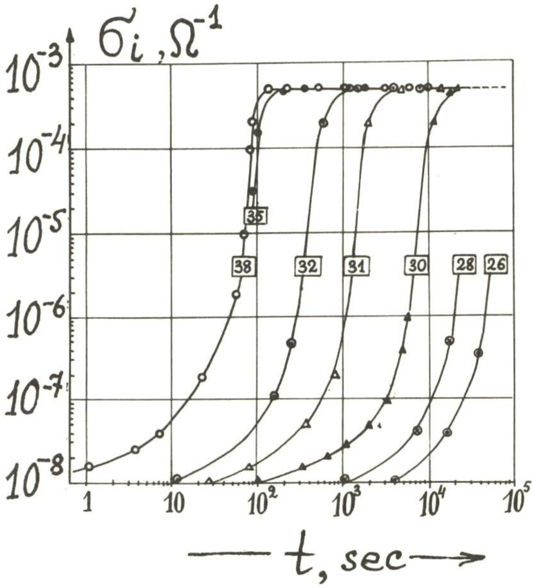

Fig. 2 The values of σ_i at T_0=4,2°K depending on duration of intermediate heating at T_i: o- (40-38): ● -35: ⊙-32; Δ-31; ▲ -30; ⊗ -28; ⊙-26, °K.

The conductivity σ_i increased up to the limiting value $\sigma_m \approx 4.10^{-4}\ \Omega^{-1}$ irrespective to the intermediate heating temperature T_i . But the duration of heating required to achieve the value σ_m increased abruptly with the decreasing of T_i . The duration t was about several hours at $T_i \sim 30°$ and only a few minutes at $T_i \sim 40$°K. If T_i was greater than 50°K, a contamination of surface by gaseous impurities took place, and the surface conductivity decreased appreciable.

But in cases $T_i \lesssim$ 40°K the limiting surface conductivity σ_m remained practically constant during prolonged heating up to ten hours.

The value

$$\sigma_m = 4.10^{-4}\ \Omega^{-1}\ (\pm 30\%) \qquad (1)$$

is nearly the same for all samples of n - and p-type germamium with various bulk impurity concentrations. This limiting conductivity does not depend on temperature of crystals T_0 over the range of measurement $1,5 \leqslant T_0 \leqslant 40$°K, and does not change in electrical fields up to twice overlow temperature breakdownfields in bulk germanium.

The Hall-effect measurements have shown that the surface conductivity σ_m in all cases is due to the motion of holes. For each sample the Hall-coefficient R remained constant in the measurement limits $10^{-6} \leqslant J \leqslant 10^{-3}$ A, and $100 \leqslant H \leqslant 7000$ Oe, but for different samples it varied by about 2 times,

$$n_s = (6 - 10) \cdot 10^{12}\, cm^{-2}. \qquad (2)$$

The values of Hall mobility

$$\mu_m = R\sigma_m = (400 - 250)\ cm^2/V \cdot sec. \qquad (3)$$

These data (1,2,3) are similar to the observed in bicrystals of Ge at the grain boundary interfaces [1]. Conducting layer of holes adjacent to the surface may be considered as degenerated two dimentional gas with scattering of holes mainly on charged centers N_i. The experimental data of Hall mobility, for various samples shown on Fig. 3, were compared with two-dimensional mobility, calculated according to [3].

$$\mu = \frac{\varkappa h \sqrt{n_s}}{2\sqrt{2\pi}\, e m N_i} \cdot \left(\tan^{-1} \frac{\varkappa h^2 n_s}{4\pi e^2 m \sqrt{N_i}} \right)^{-1}, \qquad (4)$$

where κ - dielectric constant, h -Planck's constant,
m - holes effective mass, e - elementary charge

For the first approximation it was assured that $N_i = n_s$ and that near surface $K = 16$ and $m \simeq 0.4 m_0$ as in the bulk Ge. In this case the calculated values of μ are about two times smaller than the measured ones, what may be considered as a quite satisfactory agreement.

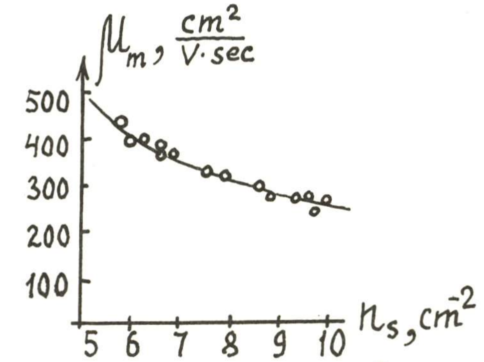

Fig. 3 Dependence $\mu_m = f(n_s)$
o - experimental data
— - twice value of , calculated according to eq. (4)

If intermediate heating is carried out at T_i << 40°K and for a short period, then annealing process is incomplete, and conductivity σ_i does not attain the value σ_m. These intermediate values of σ_i in liquid helium also remain unchanged for many hours.
The Hall measurements on surface with conductivity

$$0.1\sigma_m < \sigma_i < \sigma_m$$

have shown that the concentration of holes in this case also equal to (2). The dependence of surface conductivity and hole mobility upon the duration of the intermediate heating are shown on Fig. (4). As it is seen from these data, the intermediate heating call into play an increase of mobility, probably connected with annealing of structure defects, arising due to cleavage at low temperatures.

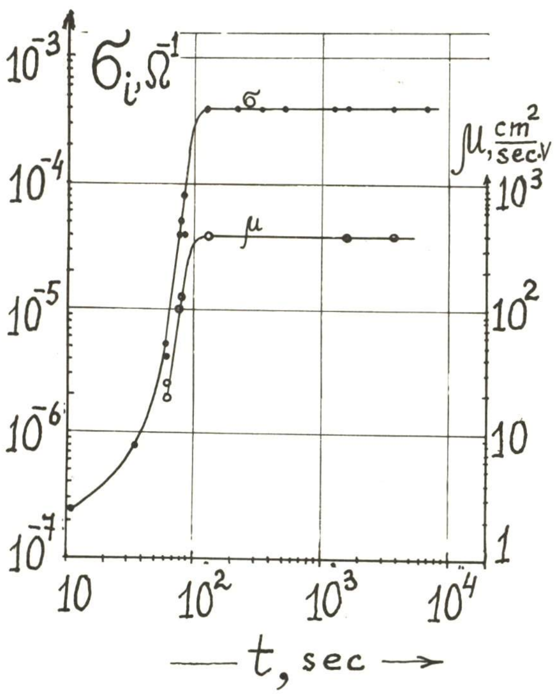

Fig. 4 The value of σ_i and μ_i at T_o=4,2°K depending on duration of heating at T_i =40°K

Immediately after cleavage in liquid helium the negligible surface conductivity took place on the samples with specular cleavage surface. In case of rough surface, having a great number of different defects, an appreciable surface conductivity σ_s arised immediately after cleavage. Depending on the type of surface defects the values σ_s varied between $(10^{-8} - 10^{-5})$ Ω^{-1}.
On certain defective surfaces the conductivity in liquid helium σ_s spontaneously slightly increased after cleavage. On all samples with defective surfaces, significant residual photoconductivity was observed after visible light illumination. Following heating up to $T_i \approx 40$°K caused the increasing of surface conductivity σ_s to the limiting value of (1), the same as on the sample with specular surface.

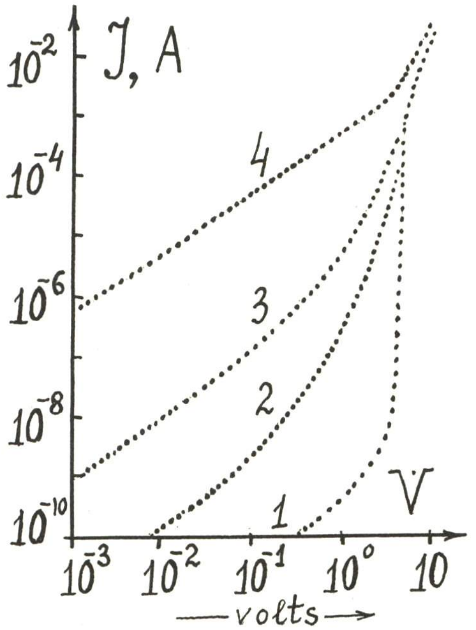

Fig.5 Typical $J = f(V)$ curves at T = 4,2 K on the sample with L ≈ S = 4 mm and rough surface after cleavage.
1) before cleavage
2,3,4) after following action:
2) cleavage, 3) illumination,
4) heating

The observed phenomena can be explained by assuming that during the cleavage of a crystal in liquid helium the electrons transfer from the bulk valence band to the freshly formed surface, and by losing E_b energy they are coptured there, probably, on the dangling bonds.

This process continues till the crystal surface gets filled with a such large number of negative charges, that further transfer of electrons can not occur due to repulsion. The electrons on the surface and the holes near it form a double layer. Calculation of its energy in Thomas-Fermi approximation leads to the conclusion that the effective width of the double layer is about 35 A° and the bonds energy E_b per electron is about 0.1 ev.

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2) Ju.A. Osipian et al:Sov. JETP Ltr. 30 (1979) 253.
3) S. Kawaji, Y. Kawaguchi: J. Phys. Soc. Japan Suppl 21 (1966) 366.