Possible mechanism of carrier scattering in germanium with point defects

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(Submitted March 25, 1974)
ZhETF Pis. Red. **19**, 575–579 (May 5, 1974)

We consider a new mechanism of carrier scattering by elastic-deformation regions in semiconductors. This scattering mechanism explains, in particular, the sharp decrease of the electron mobility in n-Ge when point defects of a definite type are introduced.

The strong decrease of the conduction-electron mobility when n-Ge is bombarded by electrons or γ quanta of energy ~1 MeV was noted even in the first papers on radiation defects in this material.[1,2] These results were qualitatively interpreted on the basis of the mechanism of scattering by ionized centers. No quantitative estimates could be made, since the changes of the total concentration of the charged centers were not determined in[1,2]; in particular, the concentration of the shallow donor states of the impurity atoms was assumed to be constant in the group. In[3,4] it is shown that when n-Ge is bombarded with γ quanta, the interaction of the primary defects with the impurity atoms of group V causes the latter to lose their electric activity, namely, the concentration N_D of the shallow donor states of the impurity atoms of group V, decreases and there are no electrically-active shallow donors in the bombarded material after the $n \rightarrow p$ conversion. It turned out, furthermore, that the change ΔN_D of this concentration was in all cases larger than the total number ΔN_A of the deep acceptor centers produced by bombardment ($\Delta N_D > \Delta N_A$). This change of the charged-center concentration should have led to an increase in the carrier mobility in the impurity-scattering region. This, however, is not observed. To the contrary, the mobility decreases with increasing irradiation dose; at large values of the integral dose, a decrease of the mobility becomes noticeable even at room temperature (Fig. 1).

An investigation of the formation and annealing of defects in n-Ge has enabled us to establish that such a strong scattering of electrons is connected with radiation

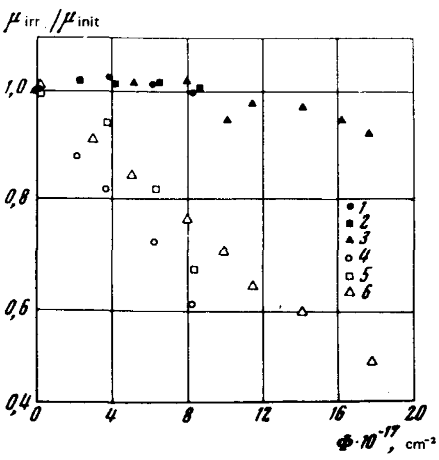

FIG. 1. Dependence of the Hall mobility of the electrons on the integral dose of γ radiation at 290 °K (1—Ge: P, 2—Ge: Sb, 3—Ge: Bi) and at 77 °K (4—Ge: P, 5—Ge: Sb, 6—Ge: Bi).

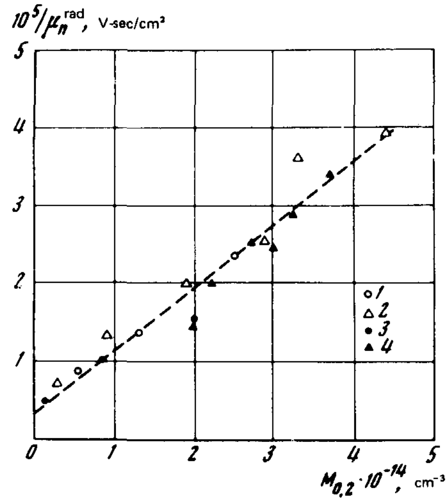

FIG. 2. Dependence of partial scattering of electrons by radiation defects on the concentration of the $E_c - 0.2$ eV acceptor centers, which is altered by γ radiation (1—Ge: P, 2—Ge: Bi) and by annealing (3—Ge: P, 4—Ge: Bi).

centers having acceptor states $E_c - 0.2$ eV. Figure 2 shows the dependence of the partial scattering of the electrons by the radiation defects at 77 °K on the concentration $M_{0.2}$, which is altered either by irradiation or by annealing.[1)]

It is shown in[5] that the $E_c - 0.2$ eV acceptor levels apparently belong to interstitial impurity atoms of group V; it is necessary here to consider not only isolated interstitial positions (tetrahedral or hexagonal), but also "bound" configurations (dumbbell-type or at the middle of the bond between two regular germanium atoms, see[6]).

An estimate of the cross section for scattering by the $E_c - 0.2$ eV centers shows that this cross section σ exceeds the cross section σ_i for scattering by an ionized center (determined from the Brooks-Herring formula at $Z = 1$[7]) by a factor not less than 16 ($\sigma \gtrsim 16\,\sigma_i$). If we disregard the improbable $Z > 3$, but take into consideration the scattering-center configuration noted above, then it is natural to attribute the observed decrease of mobility to the considerable elastic deformations of the crystal lattice around these centers.

In light of the foregoing, we consider an ultimate electron scattering mechanism, determined by an elastic interaction $U(r) = C_0(\alpha/r)^3$ with a static defect (scattering by the region of the elastic deformation around a point defect). Here $C_0 \sim M\omega_D^2 a^2[(\Delta V)_d/a^3][(\Delta V)_e/a^3]$ [M is

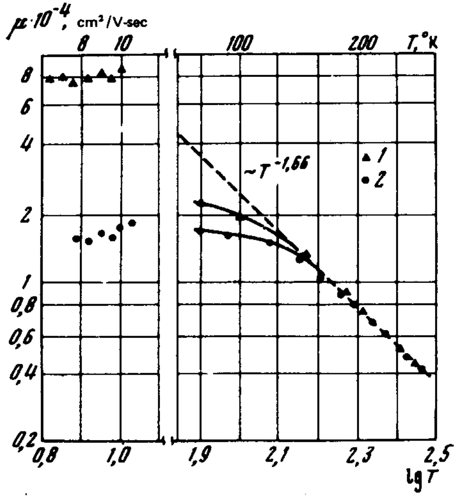

FIG. 3. Temperature dependences of the mobility of electrons in germanium: 1—prior to bombardment ($N_D = 2.1\times10^{15}$ cm^{-3}, $k = N_A/N < 0.05$); 2—after γ bombardment with $\Phi = 6.8\times10^{17}$ quanta/cm^2 ($N_D = 1.2\times10^{15}$ cm^{-3}, $k = 0.15$). For the initial material, *the values of the mobility in the entire temperature* interval agree with the calculated data.[7,10]

the cell mass, $(\Delta V)_d$ and $(\Delta V)_e$ are the total changes in the crystal volume following elastic deformation by a defect and an electron, respectively].[8] Assuming, as usual, that this interaction is appreciable within a radius r_0 on the order of several times a, we can approximately consider the corresponding scattering as Born scattering [even though $|U|_{max} \equiv |U(a)| = |C_0|$ can become somewhat larger than $\hbar^2/m^*a^2$, the order of magnitude estimate of the scattering cross section σ_{el} should not be significantly altered]. Then

$$\sigma_{el} \sim \sigma^{\circ}_{el} \equiv 4\pi\left(\frac{2m^*}{\hbar^2}\right)^2 \left| \int U(r) r^2 dr \, \frac{\sin|k-k'|r}{|k-k'|r} \right|^2$$

$$\approx 4\pi(\pi^2 a)^2\left(\frac{C_0}{E_0}\right)^2 \qquad \text{for } E_0 = \hbar^2/m^* a^2.$$

Comparing σ^0_{el} with the Brooks-Herring scattering cross section σ_i, we can easily verify that at reasonable values of C_0 the ratio σ_{el}^0/σ_i can be of the order of unity or even larger (of the order of 10). Thus, in the case of interest to us ($m^* \approx 0.2m_0$, $a \approx 3$ Å, $E_0 \approx 1$ eV, $\sigma_i \approx 10^{-12}$ cm^2) we have $\sigma_{el}^0/\sigma_i \approx 10$ if $|C_0| \approx 10$ eV. This is possible only if $[|(\Delta V)_d|/a^3][|(\Delta V)_e|/a^3] \approx 1$, which is perfectly realistic. We can note in this connection that this estimate of $[|(\Delta V)_d|/a^3][|(\Delta V)_e|/a^3]$ does not contradict at any rate the estimates obtained for the crystal elastic deformation in investigations of EPR in irradiated n-Ge.[9] We note that under the action of the proposed scattering mechanism the electron mobility should not depend noticeably on the temperature; this is indeed in the experiment (Fig. 3).

We can thus assume that in our case the proposed elastic-scattering mechanism can explain the decrease of the electron mobility in irradiated n-Ge both qualitatively and in order of magnitude. We note that this mechanism, which previously has apparently not been discussed, can be the dominant one at low temperatures also in other cases.

1)The concentration $M_{0,2}$ of these centers is approximately equal to the concentration ΔN_A of acceptors of radiative origin, so that these centers are singly-charged.[3]

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