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Electron Mobility in Plastically Deformed Germanium

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A plastic deformation influences strongly the electrical properties of semiconductor single crystals. If the dislocations, generated by plastic deformation, have an edge component, they introduce acceptor centres along the dislocation line which capture electrons from the conduction band of an n-type semiconductor (1). The dislocation line becomes negatively charged, and a space charge is formed around it. The resulting potential field scatters the conduction electrons and so reduces the electron mobility. The effect of dislocations on the electron mobility in n-type germanium was examined experimentally in (2 to 4), and theoretically in (5) and (6).

The screened potential of a negatively charged dislocation line at a great distance from the line is according to (7)

$$U(r) = - \frac{ef}{2\pi\varepsilon a} K_o\left(\frac{r}{\lambda_D}\right), \qquad (1)$$

where a is the distance between the acceptor centres along the dislocation line, f is the occupation rate of these acceptor sites, and λ_D the Debye screening length:

$$\lambda_D = \left(\frac{\varepsilon kT}{e^2 n}\right)^{1/2} .$$

Knowing the scattering potential we determined with the Born approximation the scattering cross section. Thus the relaxation time perpendicular to the system of parallel dislocations has been deduced as follows:

$$\tau_{disl} = \frac{8\varepsilon^2 m^2 \left(\frac{\hbar^2}{4m^2\lambda_D^2} + v_\perp^2\right)^{3/2}}{N_{disl}\ e^4 f^2\ \lambda_D} ,$$

where $v_\perp$ is the component of electron velocity perpendicular to the dislocations. Averaging with the equilibrium distribution function, the mobility is

$$\mu_{disl} = \frac{30(2\pi)^{1/2}\varepsilon^2 a^2 (kT)^{3/2}}{N_{disl}\, e^3 f^2\, \lambda_D\, m^{1/2}} . \qquad (2)$$

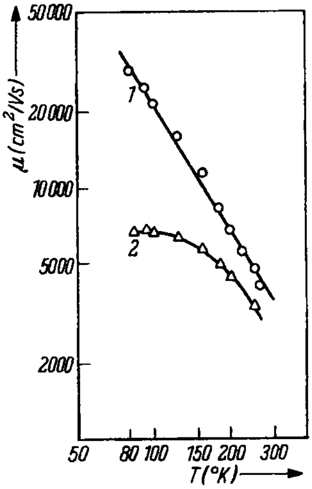
Equation (2) is slightly different from the corresponding expression given in (6), based on a potential function different from (1). Equation (2) indicates a stronger scattering than the corresponding expression in (6). At about 100 °K it gives a mobility which is more than one order of magnitude smaller than that obtained from the expression in (8). This high mobility is due to the scattering effect of the mechanical deformation field around the dislocation line. Since the reciprocal values of the relaxation times resulting from different physical mechanisms are additive, the scattering caused by the charge of dislocations in n-type semiconductors gives the dominant effect below room temperature.

We measured the electron mobility on plastically deformed germanium single crystals between 80 and 300 °K. n-type high-purity germanium single crystals with a room temperature resistivity of 25 Ωcm and a dislocation density of 4×10^3 cm^{-2} were bent about the [112] axis at 730 °C in a H_2 stream by graphite shapes with a known curvature. The samples were plated with tin in order to prevent contaminations during the heat treatment (9). According to our measurements the heat treatment alone did not produce acceptor centres, the electron concentration and mobility remained unchanged.

The electron mobility was determined from the conductivity and the Hall coefficient. The ratio of Hall mobility to conduction mobility was taken to be $3\pi/8$. The magnetic field was normal to the axis of bending i.e. to the direction of the dislocations, and the current perpendicular to both. Typical results of the measurements on non-deformed and deformed samples are plotted in Fig. 1.

The mobility measured on deformed samples is the compo-

Fig. 1. Electron mobility vs. temperature in non-deformed and plastically deformed germanium single crystals
Curve 1: unbent crystal;
curve 2: bent crystal, bending axis [112], bending radius 50 mm



sition of the scattering effects of electrons by acoustic phonons and by dislocations. The resulting mobility in the usual approximation is

$$\mu_{def}^{-1} = \mu_{disl}^{-1} + \mu_{lattice}^{-1}.$$

From the results of the measurements at 100 °K we find μ_{disl} = 9600 cm²/Vs. At the same time we obtain μ_{disl} = 15000 cm²/Vs from equation (2) with $\varepsilon/\varepsilon_0 = 16$, $m = 0.3\ m_{el}$, $a = 3.46\times10^{-8}$ cm, $n = 2.1\times10^{13}$ cm^{-3} (from Hall measurements on deformed crystals), $N_d = 6.53\times10^{13}$ cm^{-3} (from Hall measurements on non-deformed crystals), and N_{disl} = $= 5\times10^{6}$ cm^{-2} (from the bending radius).

Thus the agreement between the experimental and theoretical results is acceptable.

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