Anomalously high scattering of electrons in plastically deformed *n*-silicon

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The change of the electron mobility $\mu_n(T)$ in n-type silicon with density $n = (3\text{–}4)\times 10^{15}$ cm^{-3} was investigated as a function of the density of the dislocations introduced by uniaxial compression at 600 °C. A sharp decrease of $\mu_n(T)$ was observed in samples with dislocation density $N_{\text{dis}} \geq 2\times 10^8$ cm^{-2}. The change of the scattering action of the dislocation following aging and annealing of the samples confirms the important role played by the state of the atmosphere of deep centers at the dislocations.

There are known investigations[1–6] of the influence of dislocations on the energy spectrum of n-type germanium and silicon, and where acceptor action of the dislocations was observed. To preserve the type of conductivity of high-resistance samples after dislocations and to obtain the ionization energy of the acceptor dislocation centers, the authors of[1–6] investigated a crystal with electron density $n \approx 10^{14}$ cm^{-3} at a dislocation density $N_{\text{dis}} = 10^6 – 10^7$ cm^2, inasmuch as a dislocation density $N_{\text{dis}} > 10^8$ n-type crystals become p-type. We have therefore investigated the scattering action of the dislocations in silican samples with electron density $n = (3–4)\times 10^{15}$ cm^{-3}, in which the carrier density changes insignificantly at dislocation densities $\geqslant 2\times 10^8$ cm^{-2}. To increase the dislocation density, the samples were plastically deformed for 40–50 minutes by uniaxial compression along the [110] direction at 600 °C in vacuum. The outer surface of the samples, with dimensions 3×3.5×20 mm was polished prior to the deformation with silicon-carbide powder. Cooling from the deformation temperature was by turning off an inertialless heater and throwing the sample after 2–3 minutes onto a stainless-steel plate. After removal of the surface layer, two samples were cut from the deformed crystal, with dimensions 1×3×10 mm, for measurements of the electric conductivity and the Hall effect. The measurements were performed by a null method at a current $I = 1$ mA in a magnetic field $H = 10$ kOe, and the Hall factor was assumed equal to unity. The temperature dependence and the magnitude of the carrier density in the deformed samples remained practically constant in the entire range of dislocation densities from 10^7 to 2.5×10^8 cm^{-2}. The dislocation density after etching in a chrome etchant (1 part HF + 2 parts 30% solution of CrO_3) to pit dimensions less than 1 μ was determined by averaging over many fields, with an error $\pm 5\times 10^6$ cm^{-2}.

The temperature dependence of the electron mobility $\mu_n(T)$ for different dislocation densities is shown in Fig.

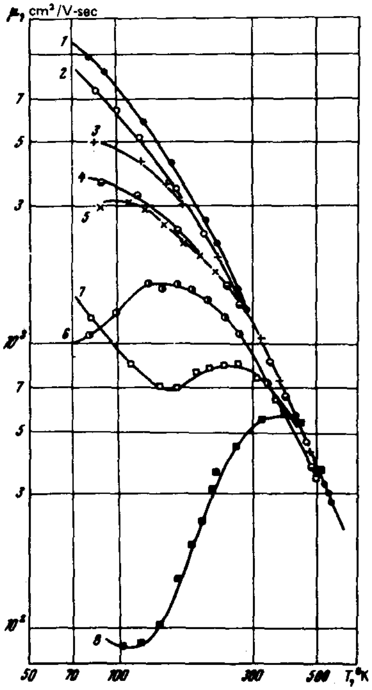

FIG. 1. Temperature dependence of the electron mobility in a control sample (1) and in deformed samples (2–8) with the following dislocation densities: 1–10^4, 2–3.5×10^7, 3–8×10^7, 4–10^8, 5–1.5×10^8, 6–2×10^8, 7–2.25×10^8, 8–2.5×10^8 cm^{-2}.

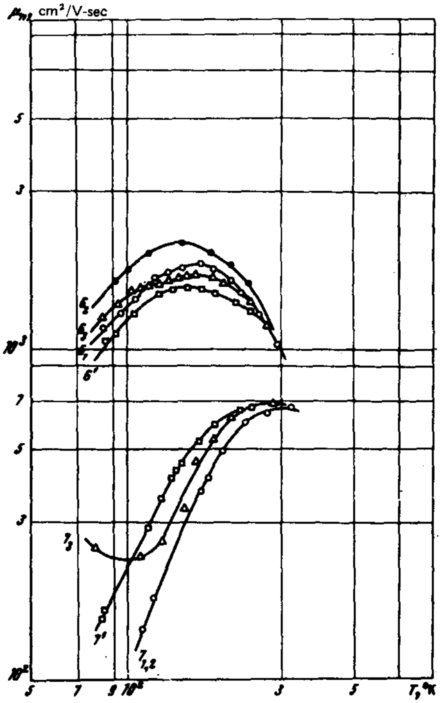

FIG. 2. Variation of $\mu_n(T)$ in natural aging after deformation (6' and 7'; $T = 20$ °C, 7 months), after annealing at 200 °C (6_1—15 min, 6_2—50 min, and $7_{1,2}$—30—20 min), and after annealing at 400 °C for 30 min (6_3 and 7_3).

1, from which it is seen that the scattering decreases sharply at $N_{\text{dis}} \geqslant 2\times10^8$ cm^{-2} in the temperature region $T\sim100-150$ °K. The carrier mobility in this region has a clearly pronounced minimum analogous to that observed in p-type germanium at 16 °K and $N_{\text{dis}} \approx 10^7$ cm^{-2}.[7]

The temperature at which the minimum of the mobility was observed correlates with temperature at which the deep centers observed in deformed samples are filled with electrons.[6] Such a tremendous scattering of the electrons could be ensured by charged impurty centers at concentrations $\geqslant 10^{17}$ cm^{-3}. In our case the scattering is from charged cylindrical region surrounding the dislocations.

The character of $\mu_n(T)$ changes radically with increasing dislocation density above $\geqslant 2\times10^8$ cm^{-2} (curves 6 and 7, Fig. 1). Natural aging for seven months at room temperature did not change the $\mu_n(T)$ dependences of samples 5 and 6 (curve 6'), whereas in samples of type 7 the scattering continues to increase sharply in the low temperature region (curve 7'). The different behavior of the samples 6 and 7 is also manifest after low-temperature annealing at 200 °C for 15—50 minutes. In sample 6', the mobility begins to increase after 15 minutes of annealing (curve 6_1), and further after 50 minutes of annealing (curve 6_2). In sample 7', after annealing at 200 °C (20—30 min), the process of further decrease of mobility continues and terminates (curve $7_{1,2}$), i.e., natural aging at room temperature was not completed in 7 months. Finally, annealing at 400 °C (40 min) leads to changes that are different in samples 6 and 7 (curves 6_3 and 7_3). The increase of the scattering action of the dislocations upon aging is apparently connected with the increase of the concentration of the complexes—the trapping centers for electrons in the Cottrell atmosphere produced when deformed samples are cooled and aged, but which are destroyed at 200 °C in samples of type 6 and at 400 °C in samples of type 7. The A and E centers and transitions of impurity interstitial atoms to dislocations could take part in the indicated processes, as well as the reir distribution among the sites, interstices, and second phases.

The described phenomenon cannot be understood within the framework of existing concepts and theories, and requires further study.

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