Influence of spin state of dislocations on the conductivity of silicon crystals

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We have observed a decrease of the conductivity of silicon crystals following saturation of the dislocation EPR signal. At helium temperatures, the effect is proportional to $T^{-0.75}$. The observed phenomenon is attributed to the dependence of the interaction of the free carriers with the dislocations on the spin state of the dislocation and of the carriers themselves.

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We have previously observed electron spin resonance on a system of dislocations introduced by plastic deformation in pure silicon in which there was no measurable concentration of paramagnetic centers prior to the deformation.[1] Subsequently, a singularity was observed in the vicinity of 50 °K on the temperature dependence of the characteristics of the dislocation EPR signal. The presence of this dependence was connected, hypothetically, with a magnetic phase transition in the dislocation spin system.[2] In a recent study[3] of the temperature dependence of the Hall mobility of the carriers in silicon, a minimum of the mobility was observed in the same temperature interval. In light of the earlier results, this minimum could be attributed to an abrupt increase of the scattering by fluctuations of the magnetic moment of the dislocation spin system in the region of the phase transition. This raised the question of whether it is possible to observe directly in experiment the contribution made to the carrier scattering by the state of the spin dislocation system. This

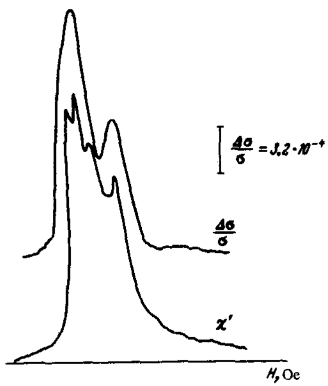

FIG. 1. Plot of the $\Delta\sigma/\sigma$ spectrum and of the EPR signal (χ') from the dislocations. $T = 1.4$ °K, σ of sample $\sim 10^{-9}$ Ω^{-1} cm^{-1}. Abscissas—magnetic field. The g-factor is ~ 2.0. The line width is ~ 25 Oe.

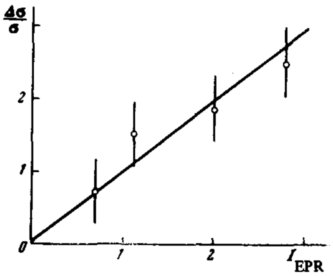

FIG. 2. Dependence of the $\Delta\sigma/\sigma$ signal (in arbitrary units) on the dislocation density. $T=1.4$ °K.

was attempted by us, and the results are reported in this communication. The magnetic state of the dislocations was varied by saturating the dislocation EPR signal with a microwave field.[4–9] We investigated p-Si samples measuring $2\times2.5\times8$ mm, deformed at 700 °C by the procedure described in[1,2]. The concentration of the electrically-active impurities in the sample did not exceed $10^{12}-10^{13}$ cm^{-3}. The investigated sample was placed on the bottom of a rectangular resonator (H_{102}). The measurements were performed at 9200 MHz in the interval 4.2–1.4 °K. The external field H_0 was applied perpendicular both to the microwave field H_1 and to the direct current flowing through the sample. Since the carrier density at these temperatures is low (the resistance is $10^{12}-10^{13}$ Ω), weak infrared illumination was used to produce a certain number of carriers in the sample. To this end, a miniature incandescent lamp was placed in the resonator and was energized with 5–10% of its nominal voltage. The radiation from the lamp corresponded to black-body radiation with the maximum at wavelengths 3–4 μ. A filter was placed in front of the lamp, in the form of a silicon plate ~2 mm thick that absorbed the short-wave part of the radiation. The resistivity of the samples, in the employed range of additional illuminations and temperatures, ranged from 2×10^8 to 10^{10} Ω-cm, and the carrier density did not exceed 10^8 cm^{-3}. A current $10^{-9}-10^{-10}$ A was made to flow through the sample. The voltage on the potential contacts and the current through the sample were measured with an electrometer having an input resistance 10^{14} Ω. The measurements were performed in the following manner: the magnetic field was swept slowly in the range 3060–3260 Oe. At each value of the field (in steps of 0.2 Oe), we measured the conductivity of the sample with the microwave power turned on and off, and obtained the difference between these values of $\Delta\sigma$. We then plotted the quantity $\Delta\sigma/\sigma$ against the "static" magnetic field. The measurement procedure was fully automatized by connecting the electrometer to a computer. This procedure made it possible to overcome the difficulties connected with separating $\Delta\sigma/\sigma$ against the background of the strong magnetoresistance of the sample, and also connected with the drifts, and to improve the signal/noise ratio as a result of computer averaging of a large number of measurements. The main result reported in the present paper is that when the dislocation spin system goes through resonance there is observed a distinct growth of the electric resistance, and the form of the change of $\Delta\sigma/\sigma$ when the magnetic field is swept coincides with the line shape of the dislocation EPR signal.

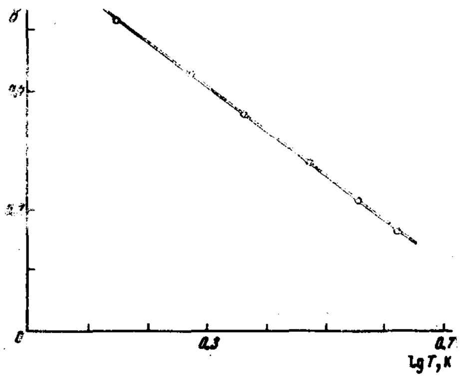

FIG. 3. Dependence of the quantity $\delta=\log(\Delta\sigma/\sigma)+3$ on $\log T$ (in °K). The slope of the curve corresponds to $\Delta\sigma/\sigma\sim T^{-0.75}$.

These data are shown in Fig. 1. The $\Delta\sigma/\sigma$ spectrum is broadened in comparison with the EPR spectrum (χ'), since it was recorded at a microwave power corresponding to saturation of the spin system. Figure 2 shows the dependence of $\Delta\sigma/\sigma$ on the EPR signal intensity for four samples of different dislocation-spin concentration. Figure 3 shows the dependence of the effect on the temperature. It turns out that in the region 1.4–4.2 °K we have $\Delta\sigma/\sigma\sim T^{-0.75}$ for the dislocations. In the case of carrier interaction with paramagnetic centers, we can expect $\Delta\sigma/\sigma\sim T^{-2}$, since the interaction cross section contains the product of the spin polarizations for the centers and for the carriers.[9] Thus, the weak dependence of $\Delta\sigma/\sigma(T)$ in the case of dislocations can be connected with the ordering of the spins on the dislocations. We propose to study this question in greater detail in the future.

We note in conclusion that heating of the carriers by the microwave power (at powers not exceeding 10^{-2} W) is negligibly small, and in addition, this heating leads to an increase of the conductivity of the samples, whereas a decrease of the conductivity is observed on going through the dislocation resonance.

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