Anomalous anisotropy of electron mobility in plastically deformed silicon with low dislocation density

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A new mechanism is observed for the onset of anisotropy of the electric conductivity of semiconductors. It is due to the change of the state of the impurity in the internal volume of the crystal adjacent to that part of the slip plane which is swept by the dislocation in the course of the plastic deformation.

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Investigations[1,2] of plastically deformed silicon single crystals have revealed distinct traces left by moving dislocations. When viewed in a transmission electron microscope, they were observed on the strongly-doped silicon surface crossed by a dislocation line, in the form of dark tracks made up of microscopic segregations of a new phase. This phase was produced because

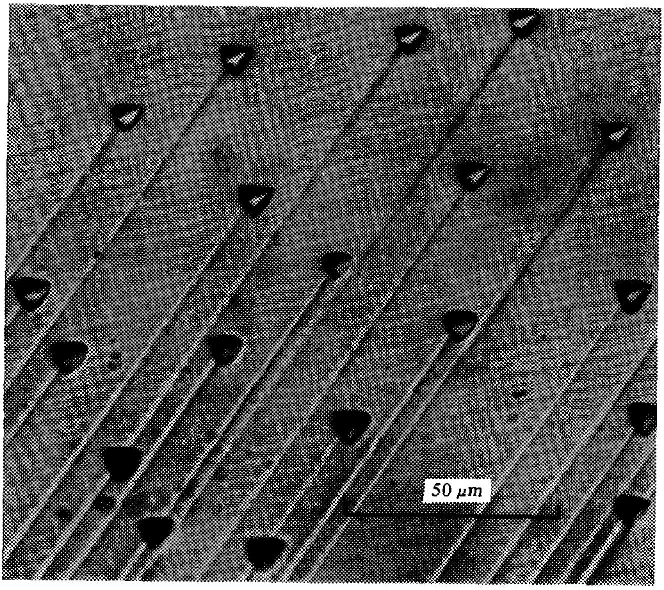

FIG. 1. Selective chemical etching of a silicon surface. Etch pits on the dislocations and tracks along the slip planes are seen.

the dislocation moving through the crystal attracts to itself from the ambient impurities that are carried out to the surface by channel diffusion, and favorable conditions are produced under the surface oxide film for the phase transition.

Selective chemical etching also reveals traces along the slip plane behind the etch pits (Fig. 1). Investigations have shown that in this case the crystal inhomogeneities are observed in the sections swept by the dislocation not only on the outer surface of the sample. Successive polishing of the crystal by etching revealed traces on all the planes crossed by the dislocation line and located at arbitrary depth below the surface of the initial deformed sample. This indicates that not only the dislocation core and its immediate surrounding, but the entire plane swept by the dislocation line produces in the chemical potential a change strong enough to be revealed by selective etching. In this experiment the slip plane assumes a new role of a two-dimensional defect made up of an assembly of point defects: electron microscopy does not reveal behind the moving dislocation either small dislocation loops or stacking faults. These point defects are complexes based on impurity atoms, since the vacancies and the interstitial host atoms are in no position whatever to produce an ordered two-dimensional stable system that does not decay even after many hours' heating at temperatures up to 600°C. These complexes can be produced because in a real crystal a moving dislocation, by stimulating diffusion, increases the effective concentration of the impurities in local sections along the slip plane, and the process of the breaking and restructuring of the atomic bonds as the dislocation moves facilitates chemical reactions with formation of new stable compounds made up of the impurity atoms and the host material.

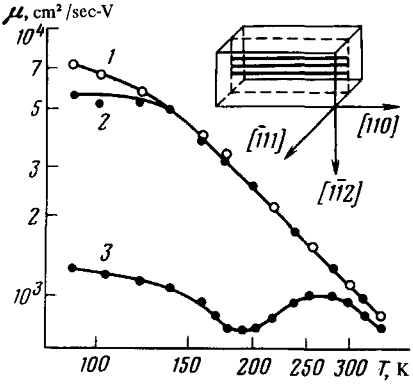

FIG. 2. Temperature dependence of the electron mobility in plastically deformed silicon. The current lines are directed perpendicular (3) to the slip plane or parallel to it (1, 2—along and across the dislocations, respectively). The upper right corner shows a diagram of the sample, and the positions of the dislocations and of the acting slip plane.

This effect, heretofore not taken into account, can also determine the unusual change in the physical properties of the crystal following plastic deformation, such as its electric conductivity. By using the special plastic deformation methods described in[3], we have introduced in a silicon crystal, at 600—650°C, straight-line parallel randomly disposed 60° dislocations. We cut from the crystal samples in which the shear formation took place practically along only one slip system, as could be easily monitored by the etch pattern (Fig. 1). We determined next the temperature dependence of the concentration n of the electrons and their mobilities μ along and across the acting slip plane. The electric conductivity was measured by the method of[4].

Figure 2 shows the results for one of the samples. The crystal was plastically deformed for five hours at 620°C to a relatively low dislocation density ($N_d = 3\times10^5$ cm^{-2}), at which the known[5] mechanism whereby the dislocations influence n and μ should not produce any appreciable effect. Indeed, the electron density in this sample, following the plastic deformation, hardly differed from the initial value ($n_0 = 4\times10^{13}$ cm^{-3}), in agreement with the results of[6]. The values of the carrier mobilities in the case when the current lines were directed along the dislocation lines or perpendicular to them, but parallel to the slip plane (Fig. 2, curves 1 and 2), were also practically the same as in the initial crystal. If, however, the current lines were perpendicular to the acting dislocation slip plane, an excessively large scattering of the carriers was observed and caused anomalously small values of μ (Fig. 2, curve 3). The magnitude of the effect depended on the heat-treatment temperature and on the impurity composition of the crystal. The anomaly vanished when the deformation temperature exceeded 700°C. The effect was likewise not observed in n-Si samples obtained by slag melting, in which the content of the oxygen and of other uncontrollable impurities was much lower than in the described crystals, which were grown by the usual Czochralski method.

Thus, the reported investigations show convincingly that dislocation motion can lead to formation of a stable aggregate of point defects disposed along the slip plane; these aggregates can govern decisively the changes of the physical properties of the crystals.

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