Photoelectret effect on dislocations in silicon

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It has been observed that dislocations introduced into silicon single crystals by plastic deformation increase by 14 orders of magnitude the relaxation time of the spatially inhomogeneous charge distribution produced in the illuminated sample under the influence of an external electric field.

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No one has studied as yet the influence of dislocations on the formation, in an electric field, of a polarized state of nonmetallic crystals which are enriched by nonequilibrium carriers by illumination, nor was their depolarization after the removal of the light and field studied. Yet such investigations are of fundamental interest not only because charge transport over a one-dimensional dislocation band[1] can serve as an additional hitherto unaccounted-for method of depolarization of the sample and cause appreciable changes in the characteristic of the photoelectret state, on which some valuable technical applications are based.[2,3] The field of elastic micro-stresses and the broken covalent band in the dislocation core produce in the forbidden band of the crystal both systems of one-dimensional bands and of levels.[4,5] Some of them may be connected with singular sections on the dislocation lines (kinks, steps, etc.) and point defects released on the dislocation and causing both their own electron structure and that of the dislocation.[6] What are the parameters and the nature of the local centers, and what are the characteristics of the one-dimensional bands and the regularities of the specific conductivity along them? The methods traditionally used to investigate crystals with dislocations[7] are not in position[8] to answer these questions, and this has stimulated active search for new methods.[1,9,10] Contactless methods of investigating the photoelectret effect in materials with unusually low conductivity, the possibility of obtaining a broad spectrum of characteristics of each of the centers that determines it, can uncover prospects for the solution of most important problems in the analysis of the nature of the electric activity of dislocations in semiconductors.

We have detected a possibility of producing a photoelectret state in a silicon single cystal via dislocations introduced by plastic deformation. The initial samples were doped with phosphorus to a concentration 4×10^{13} cm^{-3}. The photoelectret effect was investigated in a vacuum cryostat at 90 K. Samples of thickness 0.4 mm were placed between semitransparent electrodes to which 300 V were applied. To eliminate effects of injection, extraction, etc., insulating mica liners 20–30 μm thick were placed between the sample and the electrodes. The measurement system made it possible to register both the total charge and the current flowing in the electrode circuit when the light and the electric fields were turned on and off.

The electric field separates the light-induced (as well as the equilibrium) carriers, and the regions of the crystal near the electrodes become enriched with carriers of

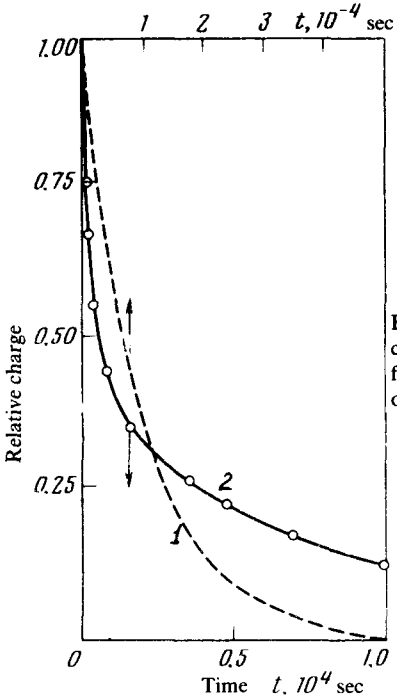

FIG. 1. Relaxation of the internal polarization in an initial silicon sample (1) and after plastic deformation (2). Q_0 is the charge flowing in the electrode circuit in the course of photopolarization of the sample.

opposite sign. In the initial samples, as well as in control dislocation-free samples subjected to the same heat treatment as the deformed samples, this spatially inhomogeneous charge distribution relaxed rapidly after the field was turned off, within a time $\tau_{init} \sim 10^{-4}$ sec (curve 1). This time was determined mainly by the relaxation of the measurement system, inasmuch as estimates show that the Maxwellian relaxation time for the initial sample is much shorter ($\tau_M = \epsilon/4\pi\sigma \approx 10^{-10}$ sec).

The dislocations introduced in the course of plastic deformation at 650 °C increase by many orders of magnitude the relaxation time of the spatially inhomogeneous distribution of the charge on the crystal. For example, in a sample with dislocation density $\sim 10^9$ cm^{-2} the charge was decreased by one half after turning on the light and the field within a time $t \gtrsim 10^3$ sec, i.e., the photoelectret state was produced (curve 2). In the plastically deformed silicon this state is due to capture of carriers by the dislocation centers in the regions next to the contacts. In samples with dislocation density exceeding 10^7 cm^{-2} there were not enough such centers to bind the entire excess charge. The value of this photoelectret charge, measured by the photodepolarization method,[2,3] was $(3–5)\times 10^{-9}$ Coulomb/cm^2. With decreasing dislocation density its value decreased. In darkness, the photoelectret charge at $t \gtrsim 10^3$ sec decreased like $Q \sim \exp(-t/\tau_{def})$, where $\tau_{def} \approx 10^4$ sec. If we equate this value to the Maxwellian relaxation time, we obtain for the electric conductivity of the plastically deformed silicon $\sigma \approx 10^{-16}$ $(\Omega\ \text{cm})^{-1}$. The darkness discharge in deformed crystals can be due, besides the usually considered mechanisms such as thermal release of a bound charge[2,3] also by conductivity along the dislocations. Further investigations of the anisotropy of the effect using samples with parallel dislocations of the same type, as well as of the

spectral dependence of the polarization and depolarization currents in a wide range of temperatures, will reveal the mechanisms that determine the destruction of the photopolarization, the contribution made to this process by the conductivity along the dislocations, and the nature of the dislocation centers that determine the photoelectret effect in silicon.

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