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INVESTIGATION OF LOCAL CHANGES OF THE ELECTRIC PROPERTIES OF SILICON UNDER THE INFLUENCE OF INDIVIDUAL DISLOCATIONS

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Most investigations [1 - 3] of the influence of dislocations on the electric properties of semiconductors have been performed on samples with large dislocation density (10^5 - 10^8 cm^{-2}). The most widely used methods for measuring the characteristics of the electronic subsystem of the crystal (the Hall effect, the attenuation photoconductivity, etc.) make it possible to determine their averaged changes due to the complicated dislocation structure. In such investigations, it is difficult to separate the contribution of any concrete type of dislocation.

Recently, methods were proposed [4 - 6] of investigating local changes of the electric properties of semiconductors under the influence of individual dislocations. We present here the results of an investigation of the characteristic of a metal-silicon microcontact at the place where an isolated 60° or screw dislocation emerges to the surface, and also the conductivity along these dislocations. Naturally, dislocations of this type differ significantly in their influence on the energy spectrum of the electrons of the semiconductor. Around each of them there exists a unique microstress field that leads to an energy-band bending determined by the different constants of the deformation potential. In addition, in the core of the 60° dislocation there is a chain of broken unsaturated bonds, which can ensure the appearance of additional acceptor levels in the forbidden band.

The investigations were performed with silicon single crystals containing no growth dislocations, both n-type (resistivity $\rho \sim 120$ ohm-cm) and p-type ($\rho \sim 70$ ohm-cm). Single isolated dislocations were introduced into the crystal by the four-point-bending method [7, 8] at a temperature 500°C. We report here measurements of two n-Si samples, one containing linear 60° dislocations whose ends emerge on two opposite (110) faces of a crystal 2 mm thick, and the other containing dislocation half-loops whose ends emerged on the (100) surface and had a screw and a 60° orientation. The samples were mounted between two coaxial microscopes, which make it possible to observe the placement of tungsten microprobes in etch pits on the dislocations. The diameters of the sharpened microprobe was 0.5 - 1 μ. The measurements were made on freshly-etched surfaces.

The results shown in Figs. 1 and 2 make it possible to compare the current-voltage characteristics obtained with the aid of an ohmic gold contact and tungsten microprobes mounted on the dislocation-free sections of the surface and at the points of emergence of the 60° and screw dislocations (Fig. 1), or else with the aid of tungsten microprobes (Fig. 2). Curve 4 of Fig. 1 indicates that appreciable rectification occurs in n-type silicon in the metal-semiconductor contact at the point of emergence of the 60° dislocation on the surface: the forward and inverse currents of the characteristic differ by a factor of 100. The volume current-voltage characteristic (curve 2, Fig. 1) is somewhat nonlinear, symmetrical, and the corresponding currents are large and comparable in magnitude with the forward currents of a dislocation diode.

When current was passed through a 60° dislocation and two tungsten microprobes were used, an approximately symmetrical characteristic was observed

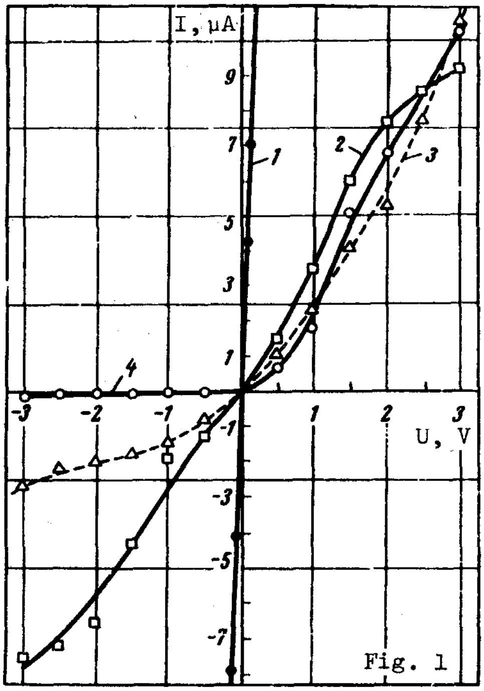

Fig. 1

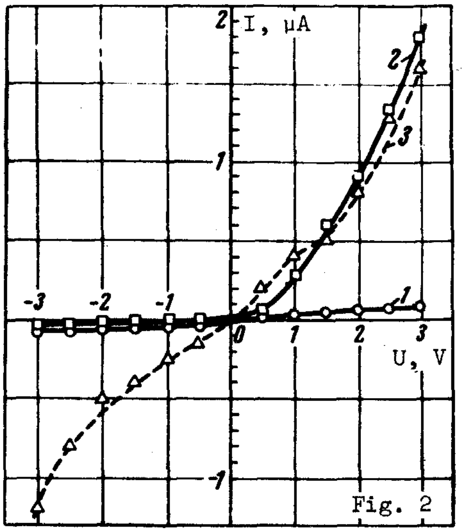

Fig. 2

Fig. 1. Current-voltage characteristics of an n-type silicon crystal with dislocations, obtained with the aid of a microprobe and a welded gold contact. The current was passed through the volume of the crystal: 1 - through a pair of gold contacts welded to dislocation-free sections of the sample; 2 - through a probe mounted on a dislocation-free section of the surface and one of the gold contacts; 3 - through a probe mounted in an etch pit on a screw dislocation and a gold contact; 4 - through a probe mounted in an etch pit on a 60° dislocation and a gold contact.

Fig. 2. Current-voltage characteristics of an n-type silicon crystal with dislocations, obtained with the aid of two tungsten microprobes. The current was made to pass: 1 - along a 60° dislocation with the microprobes mounted in etch pits on opposite ends of the dislocation; 2 - through microprobes mounted in etch pits on a 60° dislocation and on a dislocation-free section of the crystal; 3 - through the volume of the crystal via probes placed on dislocation-free sections of the surface.

(curve 1, Fig. 2). The values of the forward and inverse currents were very small and corresponded to the inverse branch of the characteristic (curve 2) obtained when one of the probes was set on a dislocation-free section of the surface. It can be concluded from this that the current flowing along a 60° dislocation is determined by the action of the two surface diodes connected opposite to each other.

The observed effect may be due to the fact that the 60° dislocation is itself charged because of the acceptor levels bound to it, and in addition causes a redistribution of the charge of the surface states, causing in turn a blocking bending of the bands, leading to the appearance of a local barrier (or inverse) layer at the surface of the sample. It should be emphasized that in the described case the processes occur not in the volume of the crystal (as in investigations of the changes of the microscopic electric characteristics of a semiconductor under the influence of the dislocations), but in the surface layer. This indeed determines the form of the characteristic (curve 2, Fig. 2).

In investigations of screw dislocations in n-Si (curve 3, Fig. 1), and also of both types of dislocations in p-Si, no appreciable change in the characteristics of the metal-semiconductor microcontact was observed under the influence of the dislocations. In the latter case the contact was strongly rectifying also on the dislocation-free surface. A similar situation occurred in the first investigation [4] of the diode properties of dislocations in n-Ge, for which the inverse currents on the volt-ampere characteristics, of a contact mounted on either a dislocation-free surface or in etch pits on edge and screw dislocations, were the same.

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OBSERVATION OF EXCITED STATES AND EXPERIMENTAL DETERMINATION OF THE BINDING ENERGY OF AN INDIRECT EXCITON IN GERMANIUM

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We have investigated the exciton structure of the indirect-absorption edge in germanium by using the method of differentiating the spectrum with respect to the wavelength. As is well known, an analysis of the unusual indirect-absorption spectra calls for a numerical resolution of the experimental curve into components, and this naturally does not make it possible to separate reliably and to identify the weak singularities of the spectrum. In our case, the use of a highly-sensitive differential method has made it possible not only to observe the transition to the ground state of the exciton with participation of all four crystal phonons (TA, LA, LO, and TO), but also to observe transitions to the excited state with n = 2. As a result we have obtained, for the first time, the value of the exciton Rydberg constant and determined the binding energy of the lowest level of the indirect exciton in germanium, $E_{ex} = 0.0036 - 0.0003$ eV.

Indirect transitions to the exciton states with participation of phonons, as is well known, become manifest in the spectra in the form of absorption bands. For allowed transitions, the exciton band takes the form [1 - 3]