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INFLUENCE OF THE CLUSTERS OF IMPURIENT NICKEL ATOMS ON THE CRYSTALLINE SILICON STRUCTURE

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Abstract. The effect of clusters of nickel impurity atoms on the structure of single-crystal silicon is considered. Using the electron probe microanalysis method, the typical properties of dislocation lines formed around clusters of nickel impurity atoms in silicon are studied.

Keywords: impurity, nickel, diffusion, accumulation, nanoinclusions, microinclusions, dislocation lines.

One of the important objects of research on the influence of clusters of impurity atoms on the properties of semiconductor silicon is mechanical interactions between impurity microinclusions and the surrounding crystal structure. It is known that the formation of impurity accumulations in the bulk of semiconductor single crystals is accompanied by deformation of the surrounding crystal structure [1-4]. Depending on the size and internal energy of the resulting impurity micro- and nanoinclusions, the deformation of the crystal lattice can lead to a significant change in the electrophysical parameters of the semiconductor material.

Provided that the crystals under consideration contain impurities, either specially introduced, so-called dopants, or uncontrollable, microscopic inhomogeneity in the distribution of these impurities causes local changes in the crystal lattice parameter, leading to the formation of dislocations [5]. It is known that silicon with a cubic diamond structure is extremely brittle at room temperature, but at temperatures of ~0.6-Tₘ (Tₘ is the melting point of silicon) it becomes plastic. When the crystal is of high quality, i.e. with a low dislocation density is subjected to compression or tension at an elevated temperature (T>1023 K), at the initial stages of deformation, a noticeable drop in the stress of the plastic flow of the dislocation is observed.

In carrying out the research, we used n-Si <Ni> samples, which were made on the basis of SEP monocrystalline silicon, with a resistivity ρ=5 Ohm-cm. Diffusion of nickel in silicon was carried out at T=1523 K for t=2 hours. The cooling rate of the samples after diffusion annealing was υcool=100 K/s. All samples were prepared in the form of a rectangular parallelepiped with dimensions of 8×4×2 mm. Structural studies were carried out by electron probe microanalysis using a Superprobe JXA-8800R setup, designed for the local determination of the morphological parameters of impurity atomic clusters in the bulk of the samples and various defects formed in the structure of the matrix material, in which the wavelengths and intensity of the excited X-ray radiation, which occurs along with other types of radiation when an electron beam interacts with an object. In this case, the depth of excitation of the samples was ~ 20 μm.

The results of structural studies in n-Si<Ni> samples showed that, upon diffusion doping, accumulations of impurity atoms of various sizes and shapes are formed in the bulk of the samples.
As it turned out, the resulting impurity nanoinclusions of nickel with sizes up to $d=700$-$800$ nm, having a lenticular shape, have a significant mechanical effect on the surrounding crystalline structure of silicon, as a result of which dislocation lines are formed. In fig. 1 shows a typical picture of the formed dislocation lines, the length of which reaches $\sim 2 \ \mu m$. As can be seen, they are formed practically around each impurity nanoinclusion.

Fig. 1. Typical pattern of dislocation lines formed around lenticular nickel nanoinclusions in silicon

And sometimes in some regions of the matrix structure surrounding such microinclusions, microcracks are observed, and this confirms the fact that between the nanoinclusion – crystal structure boundaries there is a region of high elastic stresses, which is characteristic of thermodynamically nonequilibrium impurity clusters.

Microprobe analyzes of the crystal structure around relatively large microinclusions ($d \geq 1 \cdot 10^{-6} \ \text{m}$), with a spherical shape in n-Si $<\text{Ni}>$ samples showed that such microinclusions do not have significant mechanical effects on the surrounding crystalline structure of silicon (Fig. 2).

Fig. 2. A micrograph of the surrounding structure around spherical nickel microinclusions in silicon.
In a micrograph obtained with an electron probe microanalyzer, one can see that around relatively large microinclusions of nickel in silicon in the crystal structure, no significant damage is observed.

Thus, impurity nanoinclusions of nickel, with lenticular shapes, significantly affect the surrounding crystalline structure of silicon. The dimensions of dislocation lines formed around nickel nanoinclusions and their density mainly depend on the size and shape of nanoinclusions. In contrast, impurity microinclusions of nickel with a spherical shape do not lead to deformation of the surrounding crystal structure.

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