

Decay of Impurity Nano-inclusions of Cobalt in Silicon under the Influence of Thermal Annealing

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Abstract

The influence of a thermoannealing on electrical conduction of silicon monocrystals doped by cobalt has been studied. Also, analysis of sequence of the impurity nano-inclusion's disintegration under influence of thermoannealing has been carried out by the method of electron-probe microanalysis.

Keywords: Impurity nano-inclusions; Electron probe microanalysis; Thermal annealing; Decay of impurity nano-inclusions

Introduction

As is known, impurity clusters significantly affect the electro-physical properties of silicon single crystals. Particular attention is drawn to the behavior of impurity nanotriations under the influence of external influences. The state and behavior of impurity atoms of transition metals under the influence of thermal annealing (TA) is of great interest from the point of view of controlling the electrophysical properties of silicon single crystals. In this connection, the effect of TA on the electrical conductivity of silicon doped with cobalt, as well as the kinetics of the decay of impurity nano-inclusions of cobalt under the influence of TO, were investigated in this paper [1].

Materials and Methods

The studies were carried out with n-Si <Co> samples, which were obtained on the basis of the initial single-crystal silicon of the electronic conductivity of the KEF brand, with a specific resistance $\rho=20 \Omega \cdot \text{cm}$. The diffusion temperature of cobalt in silicon was 1523 K. The temperature in the furnace was measured with the help of a thermo-electronically active power of a platinum-platinum-rhodium thermocouple. The cooling rate of samples of n-Si <Co> after diffusion with cooling rate 10 K/s. All samples were $8 \times 4 \times 2$ mm in the form of a parallelepiped. Samples were subjected to isothermal treatment at temperatures of 373-1273 K in a time interval of 5-60 minutes followed by sharp quenching. After each annealing step, the electrical properties of the samples were investigated. In order to clarify the nature of the effect of heat treatment, control specimens without a dopant were studied and subjected to annealing under the same conditions. Structural analysis of the impurity nano-inclusions was carried out using the Superprobe JXA-8800R electron probe microanalyzer [2].

The results of investigations of the dependence of the value of ρ on the annealing time in samples of n-Si <Co> with specific resistivity $\rho=9 \times 10^3 \Omega \cdot \text{cm}$ showed that at TA in the temperature range 373-573 K no significant changes occur (curve 1 in Figure 1). At subsequent TA, at 623-1073 K for 5-20 minutes, an increase in the value of ρ (curves 2-4 in Figure 1) is observed in samples of n-Si <Co>. With increasing annealing time, the curves pass through a maximum, and then the value of ρ of the samples decreases. Dependences of ρ on the annealing time in n-Si <Co> samples show a tendency according to which the maximum happens earlier with an increase in the TA temperature, and the rate of decrease of the curves increases [3].

This character of the dependence of samples on the TA time can be explained by the consequence of two processes. At the initial stages

of thermal annealing at $T \geq 673$ K, the impurity atoms located at the lattice sites become interstices, leaving vacancies. With increasing temperature and time of TA, such a transition of impurity atoms increases. Consequently, the resistivity of the samples increases. In the second stage, impurity microinclusions disintegrate, as a result the released impurity atoms pass into the free lattice sites, so if in the electroactive state [4].

For subsequent TA, at $T=1173$ K, a sharp decrease in the value of n samples of n-Si <Co> is observed for 10 minutes, the value of the resistivity of the samples approaches the initial value (curve 5 in Figure 1).

Discussion

To elucidate the nature of this change in the electrical conductivity

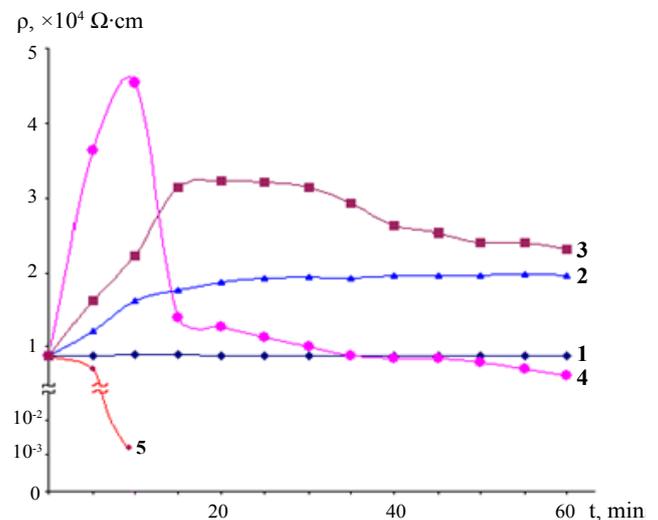


Figure 1: Dependence of the value of ρ on the annealing time in samples of n-Si <Co> at TA: (1) 473 K; (2) 623 K; (3) 873 K; (4) 1073 K; (5) 1173 K.

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of the samples under the influence of TA, complex microstructural analyzes of impurity nano-inclusions in n-Si <Co> samples were carried out using an electron probe microanalyzer before and after the TA [5].

The results of microstructural studies of Si <Co> samples under the influence of TA at temperatures $T < 673$ K for 30-40 minutes show a decrease in the density of impurity nano-inclusions of cobalt. It was found out that in the process of thermal annealing a partial decomposition of nano-inclusions takes place with sizes up to ~ 500 nm, having needle-shaped, disk-like, plate-shaped forms.

Under the influence of TA, at $T = 1173$ K, decay of larger impurity microinclusions (~ 800 nm) with spherical forms is observed. Figure 2 shows micrographs of a sample of n-Si <Co> before and after TA. As can be seen, small nano-inclusions in samples of Si <Co> after TA practically disappear; under the influence of thermal annealing, their complete decay occurs.

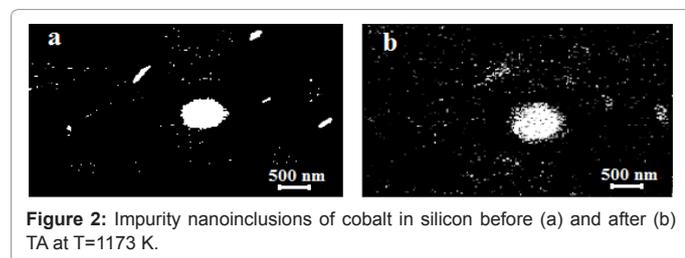


Figure 2: Impurity nano-inclusions of cobalt in silicon before (a) and after (b) TA at $T = 1173$ K.

Conclusion

Thus, on the basis of the obtained experimental results, two stages can be distinguished in the kinetics of the change in the electrical properties of silicon with impurity nano-inclusions. At the first stage of the TA, the impurity atoms located at the lattice sites are transferred to the interstices, leaving vacancies. In the second stage, impurity nano-inclusions disintegrate, as a result of which the released impurity atoms pass into the free lattice sites, i.e. in the electroactive state, which leads to a sharp decrease in the value of the resistivity.

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