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Effect of Different Types of Radiation and Heat Treatment on the Electrophysical Properties of Silicon Structures

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Abstract: *The purpose of this article is to discuss the influence of various types of radiation, heat treatment on the electrical properties of silicon structures doped with transition elements: analysis and discussion of scientific papers on this topic, comparison and generalization of their data.*

Keywords: *Silicon structures, photosensitivity, thermal sensitivity, deformation sensitivity and radiation resistance, parameters and properties of a doped crystal, diffusion, recombination properties of silicon, doping with transition elements, thermal defect formation, CVC and CVC structures, nanocluster structures on recrystallized nanocrystalline silicon, ion doping, studies of the effect of gamma radiation on the properties of porous silicon, etc.*

This work is a continuation of a series of studies of the effect of various types of radiation and heat treatment on the electrical properties of silicon structures doped with transition elements [1–3].

In modern solid-state electronics, the control of electrophysical parameters of semiconductors using doping processes using impurities that form deep energy levels is one of the most promising ways to control material properties. Depending on the type of impurity (donor, acceptor, or amphoteric), the parameters and properties of the doped crystal change, which leads to the development of such important properties as photosensitivity, thermal sensitivity, deformation sensitivity, and radiation resistance. Indeed, in the production of doped semiconductor crystals, dopants with a high propagation velocity are mainly used, which select electronic levels in the passband of the crystal. Such impurities, which form the identified defect centers in the silicon crystal lattice, usually have low solubility, a low concentration of electrically active, and a strong tendency to form complexes with uncontrolled technical impurities [4].

In silicon, an indirect gap semiconductor, radiation defects determine the kinetics of the generation-recombination process. Therefore, in many practical cases, proton and α-irradiation is used for local (in area and depth) modulation of the lifetime of carriers in semiconductor structures. Knowledge of the main parameters of radiation defects and their distribution inside the crystal is an important condition for choosing the irradiation regime in order to achieve the required properties of the device. For this reason, radiation defects in photoionized silicon have become the subject of numerous studies.

The purpose of this article is to discuss the effect of various types of radiation and heat treatment on the electrical properties of silicon structures doped with transition elements: analysis and discussion of scientific papers on this topic, comparison and generalization of their data.

The lifetime of charge carriers is most sensitive to irradiation. This parameter of semiconductors changes even at low irradiation doses so that other electrophysical parameters of the irradiated material practically do not change. It is usually believed that such changes are due to the formation of recombination centers during irradiation [5]. Studying the effect of transmitted radiation on the recombination properties of silicon doped with transition elements (nickel, cobalt, and manganese) [6], the authors found that the presence of such impurities to a certain extent increases the radiation resistance of silicon compared to control silicon.

The study by A. Kurbanov, Sh. Makhkamov and others on the change in the lifetime of carriers in rapidly and slowly cooled samples showed that the probability of the formation of impurity pairs in compounds like [CI-OI] and SiOn with n>2 increased. These electrically inert defects reduce the oxygen concentration between sites, which in turn gradually increases the efficiency of formation of K-centers [divacancy-oxygen-carbon] in doped p-type silicon [7].

The article [8] presents the results of a study of rare-earth elements for thermal defect formation in n-type silicon, methods of neutron activation analysis, IR spectroscopy, and isothermal relaxation of the capacitance. It was found that in Sm, Gd and Yb impurities, an increase in the resistance of samples during heat treatment was revealed, thereby increasing the value of τННЗ compared to the control ones by 2–4 times, and the suppression of thermal defects can be the purification of the Si volume from uncontrolled fast-diffusing impurities, their gettering with Sm impurities , Gd, and Yb or the formation of REE+acceptor defect complexes, as well as the active interaction of REE with oxygen in Si. As a result of studies of IR absorption in Si<РЗЭ> , it was found that the effective interaction of REE with oxygen in Si begins with NREE concentrations NРЗЭ ≥ 5·1017 $см^{-3}$ as well as their silicides, acting as sinks for uncontrolled and technological impurities.

M. N. Alikulov studied the effect of heat treatment and radiation on the electrical properties of silicon doped with platinum [9], obtaining new characteristics for the manufacture of semiconductor devices based on silicon, including various thermal and radiation treatments with a change in its electrical properties and the dependence of the cooling rate after diffusion in silicon. The behavior of platinum impurities and the effect of their alloys with platinum, Si, Re, and Ce have been studied. It was found that among the most promising options for managing costs, silicon is one of the legal impurities. In order to characterize the interaction of impurity atoms with primary radiation and thermal defects, the concentration-dependent kinetics of pyrolysis of platinum centers in p-type silicon was also set as a problem.

Comprehensive studies carried out by the authors of [10] using three independent XRD methods, ultrasoft X-ray emission spectroscopy and Raman spectroscopy SIPOS (oxygen-doped semi-insulating polycrystalline silicon, SIPOS) showed that the layers obtained by the LP CVD method at a temperature of 625 °C and SiH4 silane consumption of 8 l/h with the addition of N2O as an oxygen source at different values of γ N2O/SiH4 0.15 have a complex phase composition consisting of silicon nanocrystals embedded in amorphous clusters of a matrix of silicon and silicon-oxygen. An increase in the oxygen content in SIPOS layers to a maximum value at γ=0.15 leads to a decrease in the size of nanocrystals from ~75 nm (at γ 0) to 2–5 nm (at γ 0.15) embedded in an amorphous silicon matrix.

Analysis of the scientific literature on the development of problems affecting the structure of its silicon and changing the electrical properties, such as radiation, heat treatment, doping, conclusion to conclusions:

- defect engineering plays an important role in this problem and originates in the study of defect formation processes during irradiation of solids with accelerated particles. The study of the processes of defect formation during irradiation led to the idea of developing methods for the controlled introduction of defects into solids and modification of their structural, electrical, and optical properties. This direction was put into practice with the development of ion implantation technology, a process that, in addition to introducing electrically active impurities, led to the appearance of many types of radiation defects.

A study of the evolution of defect systems by annealing after ion implantation revealed the existence of defect complexes emitting light in the infrared (IR) region, including telecommunication wavelengths; promising methods for controlling the process of degradation of the electrophysical parameters of silicon are heat treatment and alloying with rare earth elements (REE) and transition metals. However, it should be emphasized that rare earth elements do not exhibit electrical activity when introduced into single crystals; do not form electrically active complexes;

In undoped a-Si:H films, nanocrystals are formed at a laser irradiation energy density of 80 mJ/cm2, and the volume fraction of the crystalline phase reaches more than 20%. On the contrary, in films doped with boron, crystallization first begins at 110 mJ/cm2, and the volume fraction of the crystalline phase does not exceed 10%. This suggests that the presence of boron affects the mechanism of laser crystallization. At the same time, the low volume fraction of the crystalline phase (<10%) during femtosecond laser crystallization of boron-doped amorphous silicon indicates the possibility of obtaining materials with potential applications in solar energy [11, 12].

Thus, the influence of structural defects and impurities in silicon on the electrical properties of p-n structures and methods for applying defect removal have been studied and analyzed, which showed the need to use the gettering method in the production of semiconductor devices and integrated circuits. The application of the principle of removing structural defects in silicon in mass production can improve the internal functional properties of semiconductor devices and integrated circuits and increase their reliability.

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