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ELECTROPHYSICAL PROPERTIES OF n-Si<Pd>, IRRADIATED WITH GAMMA-RAYS

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In the context of the rapid advancement of modern microelectronics and semiconductor technology, an important scientific and technical challenge remains the comprehensive investigation of novel materials and their properties. Among them, silicon-based structures represent the most extensively utilized semiconductor materials in industry. Through doping with various elements, the electronic and electrophysical characteristics of silicon can be deliberately modified to achieve the desired properties. One dopant that has attracted particular attention is palladium (Pd), as its incorporation into the silicon crystal lattice significantly alters the electronic states and defect structure of the material [1,2].
The aim of this work is to study the influence of gamma radiation on the electrical properties of n-Si and n-Si<Pd> single crystals using impedance spectroscopy.
This article examines how the electrophysical properties of palladium-doped silicon structures change under the influence of gamma radiation. The results of the study open up new possibilities for increasing the radiation resistance of semiconductor materials and developing modified structures suitable for use in space technologies and devices operating under nuclear radiation conditions.
The objects of study were n-type silicon wafers with specific resistivity of 40 Ω•cm (KEF-40). The wafers were cut from silicon ingots grown by the Czochralski method. Doping with palladium was carried out by the diffusion method, with palladium atoms deposited on the silicon surface in evacuated quartz ampoules at temperature of 1200 ℃ for 3 hours.
After cleaning, both the original and doped samples were irradiated with gamma rays of 1.25 MeV energy at a total dose of 1×10^7 rad at a temperature of 30 ± 2 ℃.
The electrical properties of the silicon samples were studied at room temperature (300 K) using an Ellins P-45X impedance meter in the frequency range of 1 Hz to 0.5 MHz with an excitation signal voltage of 10 mV.
Fig. 1 shows the impedance hodographs of an undoped n-Si sample before and after irradiation (hereinafter referred to as "initial"). The impedance spectrum (Fig. 1a) is in the resistance range of 18.5 kΩ ÷ 127.7 kΩ and has a semicircle shape, which is typical for the electrode reaction.

Fig. 1. Hodographs of the initial n-Si sample: before (a) and after (b) irradiation. The green line is the best fit curve

The hodographs of the irradiated sample (Fig. 1 b) have a similar shape and are in the range of 17 kΩ ÷ 247.3 kΩ. It can be seen that irradiation in this case led to an increase (almost 2 times) in the resistance of the sample, presumably due to the formation of radiation defects in the crystal lattice [3]. The most significant factor of radiation exposure is radiation defect formation, in particular, the formation of vacancies. Such defects primarily include oxygen vacancies Oi - vacancy V (A-center), divacancies (V-V) and the phosphorus complex PS (at the site) - vacancy V (E-center) [4].
Interesting results were obtained in doped and irradiated samples (Fig. 3 and Fig. 4). After doping silicon samples with palladium atoms, the electrical resistance increases to 137.2 kOhm (1200 0C).
In the work [5] it was shown that electrically active palladium exists in silicon in the form of two independent species. The first, designated Pd1, is amphoteric and has an acceptor level 0.22 ± 0.01 below the conduction band edge, as well as a donor level 0.33 ± 0.01 eV above the valence band edge. The second species, designated Pd2, has only an acceptor level 0.32 ± 0.1 eV above the valence band edge. The ratio of Pd1 to Pd2 embedded in silicon varies from 40 to 5 for diffusion temperatures from 900 to 1200 ℃, respectively.
According to [6], at doping temperatures above 1150 ℃, palladium attains sufficient mobility to diffuse into the silicon crystal lattice and form more stable configurations. Under such conditions, complexes that are energetically close to the equilibrium state are formed, thereby reducing the concentration of deep traps and recombination centers. This process has a beneficial effect on the electrical conductivity of the material, as the number of defects hindering charge carrier transport decreases. Consequently, precise temperature

control during palladium doping represents a crucial factor for optimizing the structural and electrophysical properties of the resulting semiconductor.

Fig. 2. Hodographs of n-Si samples doped with Pd at 1200 0C degree: before (a) and after (b) irradiation. The green line is the best fit curve.

Irradiation of the original and doped samples with gamma quanta leads to a change in electrical resistance. The resistance of the original sample increases after irradiation (almost 2 times) and we wrote about this above(Fig.1b). But, in the doped samples, we obtained other results (fig. 2b), i.e. irradiation with gamma quanta leads to a decrease in electrical resistance in the doped samples (at 1200 ℃ - 87.1 kOhm).
In palladium (Pd)-doped silicon samples, γ-irradiation leads to a decrease in electrical resistance, which differs from the behavior observed in pure silicon. This effect may be explained by several mechanisms. First, we assumed, that γ-irradiation may destroy Pd–V (palladium–vacancy) complexes or transform them into electrically neutral states, thereby eliminating their ability to capture charge carriers. In addition, under high irradiation doses, the traps may become filled with electrons, rendering them less active and diminishing their influence on conductivity[7].
Second, we expect, that γ-irradiation can alter the energy position of trap levels within the silicon band gap. If these levels are shifted closer to either the conduction or valence band, their carrier capture efficiency decreases. This facilitates the transport of electrons and holes, which in turn reduces the overall resistance of the material. Thus, γ-irradiation in Pd-doped silicon structures can improve the electrical properties by modifying the defect structure[8].
Electrochemical impedance spectroscopy revealed that doping n-Si samples with Pd atoms results in an increase in their electrical resistance. Gamma irradiation with an energy of 1.25 MeV at a total dose of 1×10^7 rad caused a nearly twofold increase in the electrical resistance of the original silicon samples. In contrast, for the doped n-Si<Pd> samples, irradiation led to a noticeable decrease in electrical resistance.

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