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THE EFFECT OF ACCELERATED PROTONS ON THE ELECTROPHYSICAL PARAMETERS OF THERMISTORS BASED ON N-SI<NI> AND N-SI<CU>

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Annotation

Modification of semiconductors by proton beams, which is carried out by controlled introduction of radiation defects into the semiconductor, is analyzed. The effect of accelerated protons on the electrophysical parameters of silicon doped with Ni and Cu impurities is shown.

Keywords: silicon, doping, accelerated proton, temperature sensitivity coefficient, resistivity, electrostatic generator, EG-2 accelerator.

Currently, a lot of research is being conducted on technological methods for creating highly efficient thermistors with maximum stability and stable parameters based on semiconductor materials. Modification of semiconductor materials, i.e. directed modification of their properties by beams of light ions, in particular protons, is one of the most promising and rapidly developing physical and technological methods in recent years. Unlike an impurity atom (impurity defect), which, as a rule, is a defect in the composition of a semiconductor, a radiation defect (vacancy, interstitial atom, divacancy, etc.), as a rule, is a defect in the structure of a semiconductor material. However, the nature of the influence of both composition defects and structural defects on the properties of a semiconductor is similar [1].

Today, in order to increase the sensitivity and stabilize the parameters that are the main characteristics of thermistors, it is necessary to study new physical phenomena observed in semiconductor materials. As the analysis of scientific literature shows, the properties of thermistors created on the basis of silicon doped with foreign atoms have been studied sufficiently, and increasing their efficiency and stability of parameters is one of the most pressing problems today.

The use of modern technological methods for obtaining materials with specified electrophysical parameters due to the introduction of impurities into silicon, creating deep energy levels, allowed us to obtain completely new semiconductor materials with high sensitivity. In [2], the influence of heat treatment and electrophysical parameters of silicon doped with Ni atom was reported. In order to increase the sensitivity of silicon-based thermistors and improve the stability of their electrophysical parameters, scientific studies were conducted to study the effect of accelerated protons on silicon after doping with Ni premium atoms. As a result of the effect of the radiation flux on silicon, various radiation defects arise, i.e. neutral and charged complex and point defects, vacancies and nodes between atoms, the concentration of which increases in proportion to the amount of radiation [3]. Under the influence of radiation, due to an increase in the concentration of defects, the lifetime of non-basic charge carriers is shortened and the electrophysical properties of the semiconductor material are significantly changed [4]. The maximum radiation resistance depends on the type and concentration of impurities in the semiconductor material. It is possible to increase the radiation resistance of the material by finding a unique design solution. As is known, the formation of defects is accompanied by the appearance of local energy levels in the affected area of the semiconductor. Defects either serve as suppliers or traps of electrons (donors or acceptors), or are centers of radiation (nonradiative) recombination of nonequilibrium charge carriers. Controlled introduction of radiation defects in combination with heat treatment makes it possible to achieve a wide range of changes in the electrophysical characteristics of a semiconductor, such as electrical conductivity, type of conductivity, concentration, mobility and service life of charge carriers. To date, the use of transmutation formation of impurities in semiconductors under the action of irradiation with light ions [1], processes stimulated by protons, and the introduction of hydrogen atoms to modify the properties of semiconductors is presented in the literature in the most detail.

One of the ways to increase the radiation resistance of silicon-based thermistors is to choose a starting material with a certain resistivity, which significantly depends on the purity (technical integrity) of the material, i.e. the concentration of uncontrolled impurity atoms remaining in the crystal during alloying [5,6]. At the same time, the presence of residual oxygen and carbon atoms in the volume of monocrystalline silicon is very dangerous. Because they are activated by radiation and form recombination centers with high efficiency, which significantly reduces the service life of non-primary charge carriers.

The initial monocrystalline silicon used to create thermistors with stable electrical parameters is grown in vacuum or in an inert gas atmosphere at a residual pressure R = 10-5 - 10-6 mmHg with the possibility of achieving maximum technological purity. In monocrystalline silicon materials obtained by these methods, the concentration of residual oxygen and carbon atoms decreases from 20 to 100 times, which, in turn, causes an increase in the diffusion length of charge carriers. The study used KEF-130 silicon wafers with a diameter of 42 mm grown by the Chokhralsky method. In the initial samples, the concentration of boron atoms was 1013 cm-3, the concentration of residual oxygen atoms was 2 ÷ 1017 cm-3, the concentration of residual carbon atoms was 3.2 ÷ 1016 cm-3. Thermistors created on the basis of silicon material ligated with input nickel or copper atoms were placed in an EG-2 irradiation chamber (electrostatic generator) for irradiation with accelerated protons with an energy of 350-650 keV for various time intervals (from 15 to 75 minutes). To place the samples in the irradiation drum shown in Figure 1 and check whether the incoming proton beam hits the surface of the sensors, a quartz mirror is placed in one probe of the irradiation drum, and then the sensors are placed in the remaining 15 probes.

Acetone or industrial alcohol was used to remove any impurities deposited on the top of the irradiation drum during installation.

Preparation for training is completed by closing the upper part of the chamber, after which the process of creating a vacuum in the chamber is started.

In the chamber, the vacuum reaches 10-6÷10-7 mmHg. The Faraday cup is used to count the number of protons falling on the samples parallel to the back wall of the irradiation drum (Fig. 1).

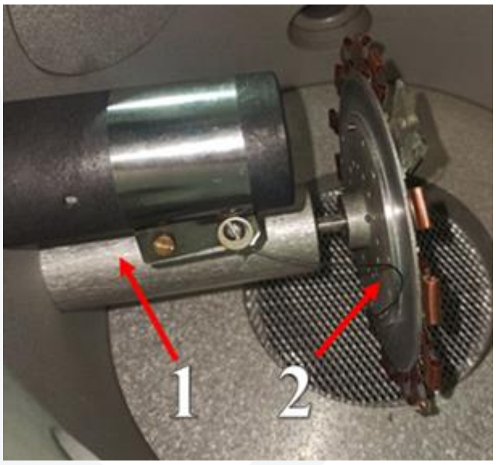

Figure 1. 1- Faraday cup, 2- irradiation drum

During irradiation, the number of protons corresponding to the surface of each sample was determined as follows:

$$I_{imp} = \frac{I_{int}}{t} \cdot \frac{1}{100} \ [\text{mkA/sec}]; \quad N_p = I_{imp} \cdot t = \frac{I_{imp}}{1{,}6 \cdot 10^{-19}} \cdot t$$

in this expression, I_{int} is the charge value in the integrator (mkA), is the current value corresponding to one pulse in the integrator, N_p is the number of protons corresponding to the sample surface, t is the irradiation time.

Table 1 shows the results of proton exposure to thermistors made on the basis of Si<Ni> and Si<Cu> samples without an external sealing coating, and Table 2 with an external sealing coating (Np is the number of protons on the surface of the thermistor, t is the exposure time, ρ, β, the coefficients of relative resistance and sensitivity to irradiation and ρ^*, β^* after irradiation).

Table 1

Type of thermistor	N_p, 10^{16}	t, min.	Before irradiation		After irradiation	
			ρ, Ohm	β, K	ρ^*, Ohm	β^*, K
Si<Ni>	0,2	15	$3\cdot10^4$	8170	$3\cdot10^4$	8190
	0,3	30	$3\cdot10^4$	8130	$3\cdot10^4$	8207
	0,6	45	$3\cdot10^4$	8250	$3\cdot10^4$	8290
	1,2	60	$3\cdot10^4$	8290	$3\cdot10^4$	8299
	4.2	75	$3\cdot10^4$	8190	$3\cdot10^4$	8241
Si<Cu>	0,2	15	$1{,}5\cdot10^4$	6863	$1{,}5\cdot10^4$	6890
	0,4	30	$1{,}5\cdot10^4$	6871	$1{,}5\cdot10^4$	6882
	0,6	45	$1{,}5\cdot10^4$	6910	$1{,}5\cdot10^4$	6933
	1,3	60	$1{,}5\cdot10^4$	6839	$1{,}5\cdot10^4$	6839
	4.1	75	$1{,}5\cdot10^4$	6908	$1{,}5\cdot10^4$	6912

Table 2

Type of thermistor	N_p, 10^{16}	t, min.	Before irradiation		After irradiation	
			ρ, Ohm	β, K	ρ^*, Ом	β^*, K
Si<Ni>	0,2	15	$3\cdot10^4$	8170	$3\cdot10^4$	8171
	0,3	30	$3\cdot10^4$	8130	$3\cdot10^4$	8132
	0,6	45	$3\cdot10^4$	8250	$3\cdot10^4$	8251
	1,2	60	$3\cdot10^4$	8290	$3\cdot10^4$	8290
	4.2	75	$3\cdot10^4$	8190	$3\cdot10^4$	8195
Si<Cu>	0,2	15	$1{,}5\cdot10^4$	6863	$1{,}5\cdot10^4$	6863
	0,4	30	$1{,}5\cdot10^4$	6871	$1{,}5\cdot10^4$	6872
	0,6	45	$1{,}5\cdot10^4$	6910	$1{,}5\cdot10^4$	6911
	1,3	60	$1{,}5\cdot10^4$	6839	$1{,}5\cdot10^4$	6838
	4.1	75	$1{,}5\cdot10^4$	6908	$1{,}5\cdot10^4$	6905

Thermistors based on silicon doped with Ni and Cu atoms, after irradiation with accelerated protons, were re-examined for the coefficient of β-temperature sensitivity. As can be seen from the tables, accelerated protons did not affect the internal structure of thermistors, since the path of a proton in silicon at these energies is several microns (8-12 microns).

Consequently, the parameters of the thermistors have not changed. According to the results of the experiments, the radiation resistance of the created thermistors was determined in comparison with existing thermistors created and used in industry. This, in turn, distinguishes the stability of the operating parameters to external factors, stability, accuracy and repeatability of the parameters, the ability to work with low power consumption, small dimensions and the absence of the need to use additional electrical amplification circuits.

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