**УДК 621.315.592**

# INFLUENCE OF TEMPERATURE ON PHOTORESISTORS OBTAINED ON THE BASIS OF COMPENSATED SILICON

***Sh.Makhkamov, Sh.A. Makhmudov, A.A. Sulaimonov, A.K. Rafikov***
*Institute of Nuclear Physics of the AS Uz, 100214, Uzbekistan, e-mail: makhmudov@inp.uz*

*An experimental study of the kinetics of photoconductivity of a resistor by impurity centers based on compensated silicon has been carried out. The parameters characteristic of the control silicon with radiation impurities are investigated. The electrical resistances of irradiated $n^+$-$n$-$n^+$ - structures are changed on temperature for silicon with different initial samples.*

***Key words:*** *semiconductor, photoconductivity, resistance, radiation technology, concentration of charge carriers.*

# ВПЛИВ ТЕМПЕРАТУРИ НА ФОТОРЕЗИСТОРИ, ОТРИМАНІ НА ОСНОВІ КОМПЕНСОВАНОГО КРЕМНІЮ

***Ш. Махкамов, Ш.А. Махмудов, А.А. Сулаймонов, А.К. Рафіків***
*Інститут ядерної фізики АН РУз, Ташкент, 100214, Узбекистан, e-mail: makhmudov@inp.uz*

*Проведено експериментальне дослідження кінетики фотопровідності резистора домішковими центрами на основі компенсованого кремнію. Досліджено параметри,* *характерні для контрольного кремнію з радіаційними домішками. Змінено електроопору опромінених $n^+$-n-$n^+$ - структур від температури для кремнію з різними вихідними зразками.*

***Ключові слова:*** *напівпровідник, фотопровідність, опір, радіаційні технології, концентрація носіїв заряду.*

**ORCID:** 0000-0003-0182-3917.

Recently, to teach photoresistors, it has been proposed to use compensated silicon with impurity defects that create deep energy levels (DE) [1]. However, obtaining a large amount of compensated material with identical photoelectric and electrophysical characteristics for the manufacture of photoresistors by the thermal diffusion method is difficult.

In this regard, in this work, the production of a compensated material is solved by the method of radiation technology (by irradiating a silicon single crystal with fast neutrons), which makes it possible to purposefully change the photoelectric parameters of silicon. The use of radiation methods for technological purposes involves the control of the composition of the resulting defects, on the one hand, and the search for ways to optimize the radiation technological process, on the other.

The aim of this work is to study the possibility of obtaining a photoresistor based on n-silicon, compensated by radiation defects, with electrophysical characteristics.

Research methods: methods of radiation defects in the reactor flow of fast neutrons; electrical methods for measuring the resistance of a resistor as a function of temperature; measuring the concentration of charge carriers; measuring the resistivity of silicon by the Hall method.

It is known that during radiation treatment, compensating radiation defects are formed in the volume of a silicon single crystal and the degree of compensation of the crystal is determined by the concentration of charge carriers in the initial material and the irradiation fluence, while the higher the concentration of the main charge carriers, the longer the neutron irradiation time (at a constant neutron flux density) [2].

On the other hand, when irradiating silicon with neutrons, to reduce the residual activity, it is necessary to use monocrystalline silicon with a minimum concentration of major charge carriers. In this regard, we used n-type monocrystalline silicon with a resistivity of 120 - 180 Ohm×cm, in which the Fermi level at room temperature is located in the region $E_c$ - (0.32 ÷ 0.36) eV from the bottom of the conduction band.

Further, the electrophysical parameters were measured by the photoconductivity decay method, and the effect of high-temperature treatment on the NDS recombination properties was studied as a function of the boron concentration. Annealing of radiation defects (RD) was carried out at a temperature of ~900 °C in air, for ~30 minutes, followed by slow cooling (8 ÷ 15) deg/min. To clarify the nominal value of the mobility of the majority charge carriers, isothermal annealing was carried out at a temperature of ~900 °C.

The photoelectric parameters of the compensated samples were monitored on the basis of a change in the ratio - $R_T/R_C$, where $R_T$ is the dark resistance, Ohm; $R_C$ - light resistance, Ohm. Light resistance was measured at illumination E = 200 lux.

Thus, as a result of the study of radiation-compensated silicon, the possibility of creating photosensors with identical characteristics, operating in the temperature range from 30 ÷ 100 °C, was revealed.

The prepared samples ($n^+$-$n$-$n^+$ - structures) were placed in a quartz ampoule and sealed, subjected to neutron irradiation in the channel of an atomic reactor (at a fast neutron intensity $\varphi$ = (3÷4) $\cdot 10^{12}$ $cm^{-2} \cdot s^{-1}$) until full compensation the majority of charge carriers by acceptor radiation defects. Dark resistance was controlled by measuring the temperature dependence in the range 30÷100 °C. The results are shown in Fig. 1 and 2.

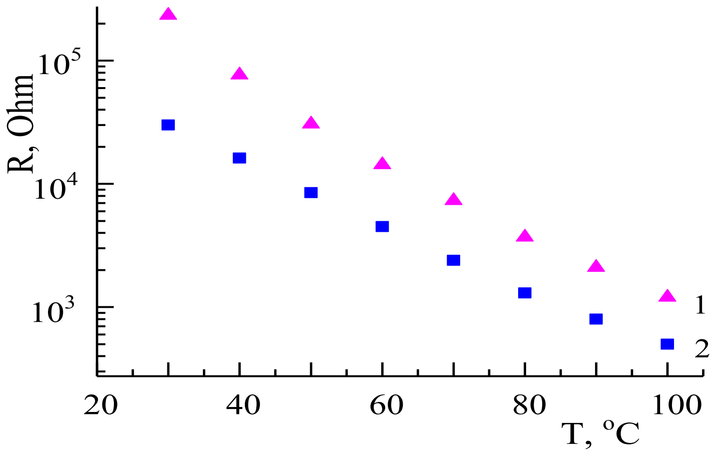


Fig. 1. Dependence of the resistance of photoresistors ($n^+$-$n$-$n^+$ - structure) on temperature: 1– in the dark; 2– under illumination (E = 200 lux)

As can be seen from fig. 2, the values of $R_t$ practically reach their maximum value after the irradiation time t = 60 s. It should be noted that at a fast neutron fluence of $2 \cdot 10^{14}$ $cm^{-2}$, the values of $R_T$ of resistors with a specific resistance of (120 ÷ 180) Ohm·cm are compared (Fig. 2). In these samples, the

Fermi level is located below $E_c$-0.50 eV, and the resulting levels $E_c$-0.18 and $E_c$-0.39 eV are completely ionized as the fast neutron fluence increases due to the shift of the Fermi level towards the middle of the band gap. The level $E_c$-0.40 eV, associated with the *phosphorus* + *vacancy* (E-center) defect and having a low concentration ($<10^{12}$ cm$^{-3}$), is also ionized after irradiation, that is, it practically does not affect the electrophysical properties of silicon. Therefore, it can be assumed that in the compensation of the initial donor impurity of phosphorus, mainly, only the acceptor level of divacancy, $E_c$-0.54 eV, is involved.

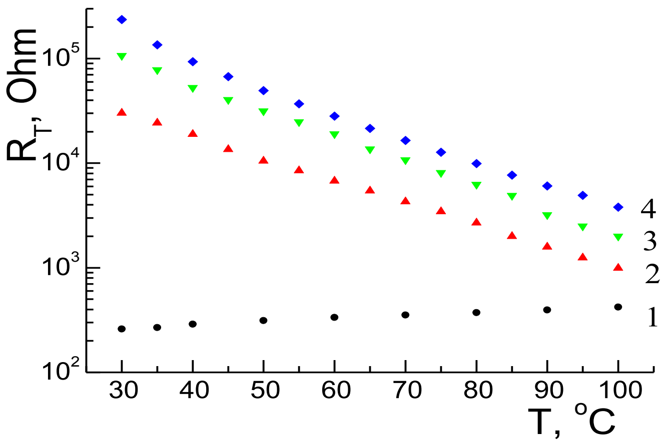


Fig. 2. Change in the electrical resistance of the $n^+$-$n$-$n^+$ -structure ($\rho_0$ = 180 Ohm·cm) depending on temperature before (1) and after irradiation with fast neutron fluences (cm$^{-2}$): 2 – $5{\cdot}10^{13}$; 3 – $8{\cdot}10^{13}$; 4 – $2{\cdot}10^{14}$

To stabilize the photoelectric parameters of the irradiated sample, thermal annealing was carried out at a temperature of

220 °C for 20 min. The results of measuring $R_T/R_C$ versus the annealing temperature are given in Table 1. As can be seen from the table, after heat treatment, the multiplicity of changes in electrical resistance increases and increases by almost an order of magnitude (~10 times).

Table 1

The multiplicity of the change in the ratio $R_T/R_C$ in the samples $\rho_o$ = 180 Ohm·cm after irradiation with fast neutron fluences ~ $2\cdot10^{14}$ cm$^{-2}$ before and after thermal annealing at ~ 220°C for ~20 min

| | The multiplicity of change in the ratio $R_T/R_C$ | | | |
|---|---|---|---|---|
| Before thermal annealing | 1,14 | 1,1 | 1,1 | 1,2 |
| After thermal annealing | 11,2 | 9,7 | 11,1 | 12 |

In fig. 3 shows the relative change in the electrical resistance of irradiated (fast neutron fluence ~ $2\cdot10^{14}$ cm$^{-2}$) $n^+$-$n$-$n^+$ - structures (obtained on the basis of $\rho_o$ = 180 Ohm·cm) at illumination ~ 200 lux depending on temperature – T. dependence is described by the following expression:

$$(R_T-R_C)/R_T = \exp(-670 / T)$$

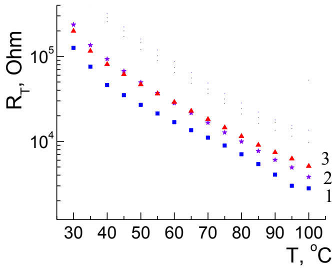


Fig. 3. Change in the electrical resistance of the irradiated $n^+$-$n$-$n^+$ - structures on temperature for silicon with different initial $\rho_0$ (Ohm·cm): 1–120; 2-180

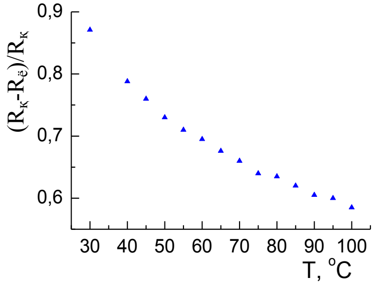


Fig. 4. Relative change in the electrical resistance of photoresistors ($n^+$-$n$-$n^+$ - structures) depending on temperature at illumination E = 200 lux

As a result of the study of radiation-compensated silicon, the possibility of creating photo- and thermal sensors with identical characteristics, operating in the temperature range from 30 ÷ 100 °C, was revealed.

A photoresistor based on silicon, compensated for by radiation defects, is capable of operating up to a temperature of ~100 °C as photosensors (see fig. 4).

Thus, as a result of the study of radiation compensated silicon, the possibility of creating photosensors with identical characteristics, operating in the temperature range from 20 ÷ 100 °C, was revealed.

**References:**

1. M.Yu. Tashmetov, Sh.A. Makhmudov, A.A. Sulaimonov, A.K. Rafikov, B. Zh. Abduraimov, "Photosensors based on neutron doped silicon" // International Scientific Journal "Heliotechnika" Tashkent, 2018, V. 6, p. 61–63.

2.M.Yu. Tashmetov, Sh.A. Makhmudov, A.A. Sulaymonov, B. Zh. Abdurayimov, A. K. Rafikov. Photosensors Based on Neutron Doped Silicon // Applied Solar Energy, 2019, Vol. 55, No. 1, p. 71–73.

3. M. Karimov et all. Compensated silicon based photoresistor with radiation defects // Conference dedicated to the 80th anniversary of Academician MS Saidov. Tashkent, November 24 25, 2010, S. 221–222.