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Radiation resistance of nickel-doped silicon solar cells

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The influence of nickel doping on the radiation resistance of silicon solar cells in the range of γ-irradiation doses of 10^5-10^8 rad was studied. It is shown that diffusion doping of silicon with impurity nickel atoms increases the radiation resistance of the parameters of silicon solar cells. It is assumed that the reason for the increase in the radiation resistance of such solar cells is the existence of clusters of impurity nickel atoms, which serve as sinks for radiation defects.

Keywords: silicon, γ-irradiation, nickel, cluster, solar cell.

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1. Introduction

High radiation susceptibility of single-crystal silicon and silicon devices is the reason why the issues of radiation impact on physical properties of materials, characteristics, reliability and stable operation of space semiconductor electronic devices have become so challenging in recent time. In view of this, it has become necessary to predict the behavior of semiconductor devices in radiation fields and to develop and make high radiation hardness electronic devices.

Radiation impact efficiency depends to a great extent on the quality of raw materials, type of doping and $p-n$-junction structure [1,2]. It should be noted that the presence of impurity atoms within the crystal leads not only to formation of new defects, but also has a significant impact on the radiation defect (RD) generation rates [3–7]. The role of impurity atoms in radiation exposure of samples is mainly determined by the diffusion coefficient, solubility and impurity atom state (including charge state) in the silicon lattice.

It is reported in [8–11] that formation of nickel impurity atom clusters in the silicon lattice is observed in nikel-doped silicon samples. By controlling the nickel diffusion conditions (temperature, cooling time and rate), radiation stability of silicon may be changed [12–14]. The increase in concentration of the introduced impurity nickel atoms results in the improvement of radiation stability $\mathrm{Si}\langle\mathrm{Ni}\rangle$ [13].

It is reported in [14–19] that doping of silicon SC with impurity nickel atoms ensures the improvement of SC performance. However, radiation hardness of such SCs has not been studied.

The purpose of this research was to investigate the radiation hardness of silicon solar cells (SC) doped with nickel by diffucsion method.

2. Experimental

To investigate the impact of γ-radiation on SC parameters, p-type silicon wafers with a thickness of $d = 380\,\mu$m and specific resistance of $\rho = 0.5\,\Omega \cdot$ cm (KDB-0.5).

Then, these samples were used to produce SCs without impurity nickel atoms (group I) and SCs nickel-doped achieve $p-n$-junction (group II).

To prepare group II SCs, a 1 mkm pure nickel layer was applied to the silicon wafers by vacuum evaporation method and nickel diffusion was carried out at $T = 800$, 1000 and 1200°C during $t = 30$, 10, 3 min. Then $p-n$ junction was produced by phosphorus diffusion towards the „nickel“ side of the wafer at $T = 1000$°C during $t = 30$ min. After the diffusion, additional thermal annealing was carried out at the optimum temperature [16] $T = 750-800$°C during $t = 30$ min.

Group I SCs were made in the same way, but without evaporation and nickel diffusion.

After each process stage, the surface was cleaned and chemically treated (using 10% HCl, then 10% HF) to remove residual nickel and silicon oxide from the SC surface. There was no antireflection coating on the SC surface.

After achievement of ohmic contacts, SC volt-ampere response and main parameters were measured — no-load voltage V_{oc}, short circuit current density J_{sc} (Table) — for all samples in the same conditions.

To define the radiation hardness criteria for SCs, irradiation experiments were carried out in the dose range from $\Phi = 10^5$ to 10^8 rad. SC irradiation by γ-quanta was carried out in stages: $\Phi = 10^5$, 10^6, 10^7, $5 \cdot 10^7$, 10^8 rad using Co^{60} (~ 1.17 MeV) isotope at $T_{\mathrm{rad}} = 300$ K. After each γ-quanta irradiation stage, the main parameters of SC were measured. $V_{\mathrm{oc.0}}$ and $V_{\mathrm{oc.\Phi}}$ — SC no-load voltage before and after

Average values of SC parameters

Group	I	II (1200)	II (1000)	II (800)
J_{sc}, mA/cm^2	32	33	36	38.5
V_{oc}, mV	590	590	590	605

Note. Group II (1200), II (1000), II (800) SCs nickel doped at $T = 1200$, 1000, 800°C respectively.

γ-irradiation and $J_{sc.0}$ and $J_{sc.\Phi}$ — SC short circuit current density before and after γ-irradiation were measured.

The experiments have shown that the silicon SC performance decrease with the increase in γ-irradiation dose. The effect of γ-radiation on silicon SCs becomes perceivable, when the irradiation dose exceeds $\Phi = 10^6$ rad. It has been found that the short circuit current was most susceptible to γ-irradiation.

Fig. 1 shows $J_{sc.\Phi}/J_{sc.0}$ — short circuit current density vs. γ-irradiation dose. At γ-irradiation dose of $\Phi = 10^8$ rad, the short circuit current density of group I SC decreased by 41.3%. At the same time, short circuit current density of group II (800) SC decreased by 26.9%, and of group II (1000) and II (1200) SC decreased by 31% and 28.3%, respectively.

Fig. 2 shows $V_{oc/\Phi}/V_{oc.0}$ — no-load voltages vs. γ-irradiation dose. At γ-irradiation dose of $\Phi = 10^8$ rad, no-load voltages of group II (800), II (1000) and II (1200) SCs decrease by 10.5%, 12.9% and 7.96%, respectively. No-load voltage of group I SC decreased by 18.2% (Fig. 2).

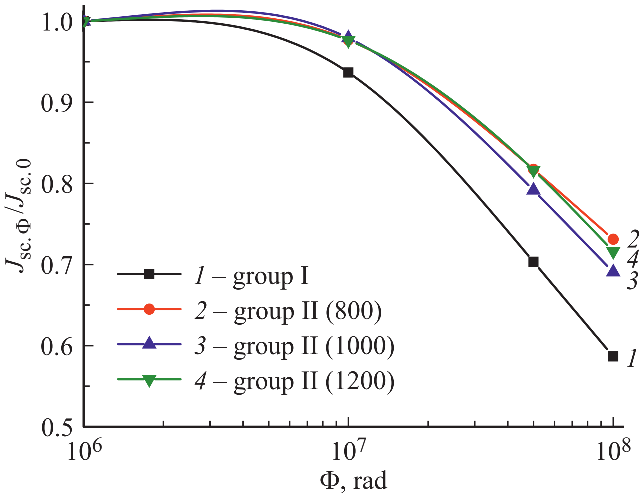

Figure 1. Relative variation of SC short circuit current density vs. γ-irradiation dose.

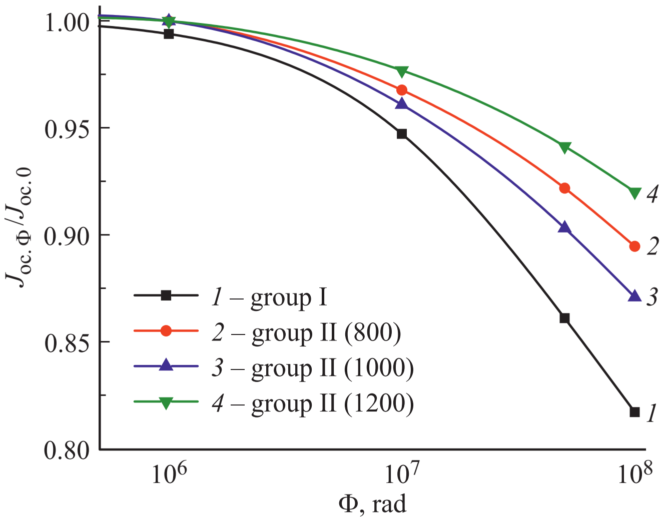

Figure 2. SC relative no-load voltage variation vs. γ-irradiation dose.

3. Discussion

It is known that irradiation with γ-quanta produces point radiation defects in silicon — mixed silicon atoms from lattice points and free vacancies having rather high diffusion coefficient and low migration energies [2,20]. As a result, they migrate within the silicon crystal and interact with each other and with doping and background impurity atoms in silicon.

The investigations of irradiation effect on group II sample properties (Fig. 1 and 2) show that irradiation leads to the difference in electrical properties of SCs compared with group I samples. When group II samples are exposed to γ-quanta radiation, the changes in their properties are much lower that in the properties of group I samples. This means that the nickel impurity atoms influence the radiation defect formation process. At the same time, the radiation stability of group II SC properties gets much better with the increase in the nickel diffusion temperature. Given that nickel solubility is increased with the increase in the diffusion temperature [21,22], it is fair to say that the radiation stability of group II SCs depends on the concentration of nickel atoms introduced during diffusion.

Nickel atom impurities are mainly located in interstices and have a rather high diffusion coefficient [21,22], and also are intensively interacting with oxygen atoms [23,24]. There is high probability that the radiation defects occurring during the irradiation process will meet nickel atoms. interstitial electrically neutral nickel atoms that may exist in the form of clusters probably serve as the main centers of trapping and annihilation of vacancies and interstitial silicon atoms [8–11].

4. Conclusion

The experiments have shown that nickel doping improves radiation hardness of silicon SCs and SC radiation hardness increases with the increase in the nickel atom concentration. It is supposed that in nickel-doped SCs irradiated with γ-quanta, the initial radiation defects are neutralized by the nickel atom clusters.

The following conclusions may be drawn from the findings:

– nickel atom doping improves the radiation hardness of silicon SCs for short circuit current up to 15% and for no-load voltage up to 10% versus control ($\Phi = 10^8$ rad).

– positive effect of nickel atoms depends on the nickel diffusion temperature and achieves the maximum at 1200°C.

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Conflict of interest

The authors declare that they have no conflict of interest.

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