

PROCEDURE OF NANODIMENSIONAL AMORPHOUS-MICROCRYSTALLINE STRUCTURE FORMATION BY RADIATION IN SINGLE CRYSTAL SILICON

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Quantum structures with enhanced electric conductivity have been formed in a single-crystal silicon matrix. An array of quantum filaments improves the collection of low-mobility charge carriers in the emitter structure of the $c-Si(p, n)$ photoconverter. Experimental results of applying radiation technologies for creation of that sort of structures are presented.

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1. INTRODUCTION

The processes of radiation disordering of structure in $c-Si$ materials are determined by the electronic subsystem excitation and the energy transfer to lattice atoms for producing amorphous phases in single crystal silicon. The disordering of structure on its irradiation with ions is governed by the dependence of inelastic (ionization) losses (dE/dx) on the energy, mass and charge state of ions as well as on the structural and thermophysical characteristics of the material. The reason is that at inelastic processes the melting covers the whole structure rather than the area of separate atoms. For inelastic scattering channels the ionization losses in the material are well approximated by the Bethe-Bloch equation

$$-\left(\frac{dE}{dx}\right)_e = \frac{4\pi Z^2 e^4}{mv^2} AN \ln\left(\frac{2mv^2}{j}\right), \quad (1)$$

where A is the atomic number of the target, N is the number of atoms in the unit volume, m is the ion mass, v is the ion velocity, j is the ionization potential, e is the electron charge. A strong dependence of (dE/dx) on the charge of the ion incident on the target is observed. The multicharged ions give rise to light and heavy uranium fission products with the following averaged characteristics: masses 95 ± 2 and 138.5 ± 1.5 amu, energies 99 ± 1 and 67 ± 1 MeV, initial velocities $1.41 \cdot 10^9$ and $0.97 \cdot 10^9$ cm/s and nuclear charges $Z_i = 38.6$ and 53.4 charge units for light and heavy fragments, respectively [1]. The crystal structure is sputtered due to ionization losses of decelerated uranium fission fragments [2].

In the low energy range (~ 100 keV) it is the elastic losses due to ion scattering by solid body atoms

that are dominant, while at high energies (several tens of MeV) inelastic processes prevail over nuclear ones, and $|dE/dx|_e > |dE/dx|_n$. In inelastic interaction of the ion with lattice electrons its motion gets decelerated, though its trajectory remains unaffected. But elastic collisions of the ion with atoms not only substantially reduce the ion energy, but also may be the reason for the change in the direction of its travel.

For high-speed ions of kinetic energy higher than 1 MeV/nucleon the intensity of energy release to the electronic subsystem is 10^3 to 10^4 times higher than the energy release to the nuclear subsystem and can make up a few MeV/ μm . A high energy release to the electronic subsystem increases the role of electron excitations in the generation of structure defects for intense sputtering of material, and causes local melting, amorphization, latent track formation, shock wave generation and material damage. The relaxation of strong electron excitations is the principal parameter that is responsible for the nature of track regions. With occurrence of high temperatures in these domains the "thermal wedge" model is used to describe the track formation, while with charge accumulation in dielectric materials the mechanism of "Coulomb explosion" is used for the description.

The energy dissipation by primary and secondary electrons and the energy exchange through electron-electron collisions takes place within $10^{-16} \dots 10^{-13}$ s. The electron-phonon interaction occurs during a few Debye periods $10^{-13} \dots 10^{-12}$ s. The velocity of energy transmission for the two processes is given by

$$\left(\frac{dE}{dt}\right)_{e-e} / \left(\frac{dE}{dt}\right)_{e-ph} \sim \frac{\varepsilon}{k_B T} \frac{\tau_{e-ph}}{\tau_{e-e}} \gg 1, \quad (2)$$

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where ε is the value of the energy exceeding the energy of electron excitation, k_B is the Boltzmann constant, T is the temperature. The part of energy transferred in a time of collision ($\varepsilon \gg k_B T$) is greater at the ($e^- - e^-$) interaction than at the ($e^- - ph$) interaction.

The measure of stopping power of the material in the interaction of fast electrons with a solid is the energy loss by the fast particle over the unit path $-(dE/dx)$. In accordance with the Bohr theory, this parameter is given by

$$-\frac{dE}{dt} = \frac{2\pi n q^4}{E} \ln \left(\frac{4E}{j} \right), \quad (3)$$

where E and q are, respectively, the energy and charge of electrons; n is the concentration of atomic electrons in the material, J is the ionization potential of the material ($J = 13.5 \cdot Z$, where Z is the effective atomic number of the material).

The trajectory of electron motion is chaotic in character and is markedly distinct from the straight line. The energy release of "hot" atoms occurs in macrodefect nanostructures and the atoms can attain the vaporization temperature, because $t_{e-ph}(T) \sim 1/N_e$. To obtain an amorphous phase in the ($c - Si$) structure, its cooling time must be $\sim 10^{-11} s$. The rise in the temperature of atoms at interstitial sites with a loss of long range ordering can be provided by hydrogenation of the structure. The crystal structure fragmentation by electrons presents interest from the viewpoint of amorphous phase creation in the bulk of the crystalline matrix. Until recently, the amorphous phase has been obtained only on the crystal surface by the methods of silicone glow-discharge decomposition, RF discharge sputtering of the silicon structure, or chemical vapor deposition.

A combined radiation processing of $c - Si$ material by electrons and fission fragments of heavy elements gives rise to the amorphous phase in a single crystal structure. As a result of partial annealing, a transport channel for charge carriers is formed, which consists of randomly oriented micro- and nano-crystallites with a developed network of phase boundaries. At the boundaries, there arise surface levels, which provide the energy band bending necessary for the formation of regions with an increased concentration of $p-$ or $n-$ type charge carriers in single crystal chains. The use of these structures improves the collection of low-mobility charge carriers (holes) from the emitter structure of the $c - Si$ photoconverter. The energy band diagrams of $p-$ and $n-$ type $c - Si$ semiconductors are shown in Fig.1 [3]. The mechanism of direct defect production by particles (e^- , γ , n^0 , ^{238}U ions, ^{238}U photo-fission fragments) in the formation of nanodimensional ($a - Si$) structures in the ($c - Si$) semiconductor bulk is realized during atomic displacement from crystal lattice sites to the interstitial sites.

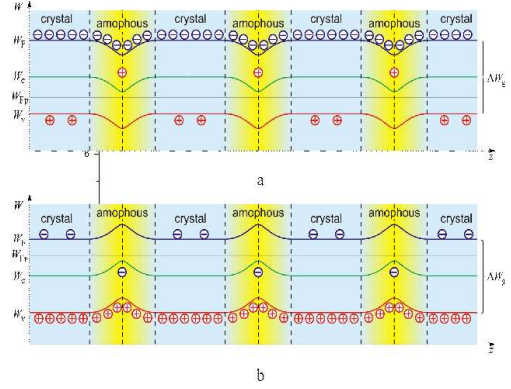


Fig.1. Energy band deformation in the region of latent tracks in $p-$ and $n-$ type $c - Si$ semiconductors (a) and (b), respectively

The expression for the threshold displacement energy (E_d) of the primary knocked-on atom (PKA) is written as

$$E_d = \frac{2(E_{min} + 2m_0c^2)}{Mc^2} \cdot E_{min}, \quad (4)$$

where m_0 is the rest mass of electron, M is the nuclear mass of atom of the irradiated material, c is the light velocity, E_{min} is the minimum energy of bombarding electrons.

For silicon, we have $E_d = 12.9 eV$ at the minimum energy of bombarding electrons $E_{min} \sim 140 keV$. If silicon is irradiated with electrons of energy up to $10 MeV$, there occur the processes showing an intense energy exchange with crystal electrons (excitation of electron shells and ionization of atoms, excitation of oscillations in the crystal lattice). Specific electron energy losses per unit length of the material in the $1 \leq E_0 \leq 10 MeV$ range are determined from the following expression

$$\frac{1}{\rho} \frac{\partial E}{\partial x} = \frac{2MeV}{g/cm^2}, \quad (5)$$

where ρ is the density of the absorbing material.

In the case of silicon irradiation with electrons of energy $E_0 \geq 10 MeV$, elastic collisions become to prevail over inelastic ones, and the energy transferred for atomic displacement increases; but as this takes place, the differential scattering cross-section decreases (see Fig.2). To make up for the decrease, it is necessary to increase the irradiation dose by using the accelerators with the energy $E_0 \geq 10 MeV$ and an intense electron beam. The threshold energy for cascade atomic-displacement processes makes $E_{dr} \sim 5 keV$, this corresponding to a bombarding electron energy of $\sim 10 MeV$.

The crystal structure fragmentation presents interest from the viewpoint of amorphous phase formation in the crystal matrix bulk, where a high energy density level is required for crystal structure melting. A high level of defect formation with introduction of radiation processes makes it possible to reduce substantially the energy losses in atomic bindings,

this being necessary for producing amorphous phases deeply in a single crystal silicon. The dislocation model of boundary structure between the fragments (see Table 1) points to the presence of a great number of broken and unsaturated spin bonds of atoms.

Table 1. Classification of nanosystem objects

Phase state	Diameter, nm	Number of atoms
Unit atoms	0.1 ... 0.3	1 ... 10
Clusters	0.3 ... 10	10...10 ⁶
Nanoparticles	10 ... 100	10 ⁶ ...10 ⁹
Compact substance	> 100	> 10 ⁹

Under gamma irradiation ($E_\gamma > 0.5 \text{ MeV}$), there arise point defects, namely, vacancies and interstitial atoms. The initiation of displacements as a result of direct collisions of γ -quanta with the atoms is next to improbable. As γ -quanta are absorbed, we can observe the occurrence of the Compton effect, the production of e^-e^+ -pairs and the photoeffect. The Compton effect cross section $\delta_p \sim Z$ of the irradiated material (Z defines the number of electrons involved in scattering) is typical for the photons of energy $E_\gamma = (1...2) \text{ MeV}$. The Compton effect leads to the appearance of sufficiently energetic electrons in the whole crystal bulk, which are capable of causing displacements. The cross section for electron-positron pair production $\delta_p \sim Z^2$ increases from zero at $E_\gamma = 2m_0c^2 = 1.02 \text{ MeV}$ up to significant values ($\delta_p \approx 10...24 \text{ cm}^2$) for the atoms with a mean Z value at the γ -quantum energy $E_\gamma = 5 \text{ MeV}$. The photoeffect is realized at $E_\gamma < 1 \text{ MeV}$ in the interaction with K -, L -, M -shells of substance atoms, resulting in photoelectron production.

The cross section of K -electron emission (δ) is the highest at E_γ equal to the K -electron energy, and then monotonically decreases by the $\delta \sim E$ law as E_γ increases. A uniform production of point defects in the crystal bulk specifies the main advantage of γ -quantum irradiation over irradiation with an accelerated electron beam.

Under neutron irradiation of Si material, there arise comparatively small amounts of vacancies capable of migrating over great distances. A local concentration of arising Frenkel (interstitial-vacancy) pairs may be rather high even with due regard for their annihilation. Divacancies localized in a small volume are interacting between themselves without moving away from each other too far. The divacancy concentration in disordered regions can make $\sim 10^{20} \text{ cm}^{-3}$, but these regions being even $\sim 100 \text{ \AA}$ in size, remain crystalline. The change in the main properties of Si semiconductors during their irradiation with heavy particles in comparison with the case of irradiation with gamma-quanta that are incapable of imparting high energy to the material atoms, is to a great extent determined by complex

structural damages such as disordered regions. So, at radiation processing of semiconducting crystalline materials by high energy particles γ -quanta give rise there to point defects only, while electrons of energy $E_0 \geq 10 \text{ MeV}$, neutrons and ions give rise to disordered structures at the expense of cascade processes [2]. The process of direct defect production by ^{238}U fission fragments during formation of nanodimensional ($a-Si$) structures in the bulk of the ($c-Si$) semiconductor is realized through atomic displacements from crystal lattice sites to the interstitial sites.

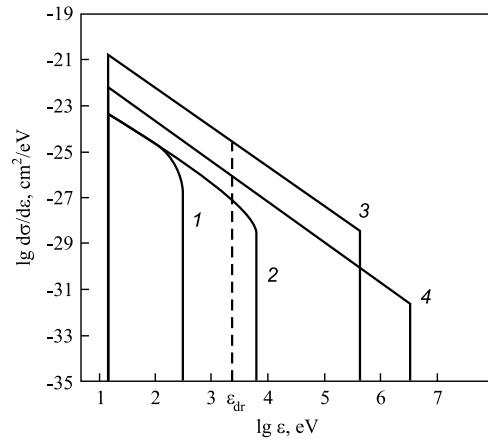
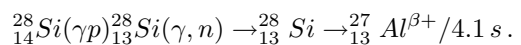


Fig. 2. Differential cross section of energy transfer for atomic displacement in the lattice of silicon irradiated with electrons of energies 1 MeV (1) and 10 MeV (2), and also to protons of the same energies (curves 3 and 4, respectively)

The interaction of gamma-quanta with the nuclei of substance results in the occurrence of nuclear reactions accompanied by knocking-out of one or several particles (neutrons, protons, etc.) and in the appearance of residual nuclei, which are lighter than the nuclei of initial materials (transmutation method). Two characteristic features of photonuclear reactions specify the possibility of doping the material by means of gamma-radiation:



The first feature consists in the presence of the peak, the so-called giant dipole resonance, in the effective nuclear disintegration cross section (σ) as a function of γ -quantum energy (E_γ). This peak is observed at the γ -quantum energy lower than 30 MeV , and its resonance energy (E_{res}) decreases with an increasing mass number of the nuclei A : $E_{res} \approx 75A^{-1/3} \text{ MeV}$, and $E_\gamma \approx 0.7E_e$. The cross section (σ) value at $E = E_{res}$ makes $\sim 50 \text{ mBarn}$ for silicon. These cross-section values appear sufficient for creating the required concentrations of impurity atoms by irradiating materials with γ -quanta of energies $E_\gamma \sim 15...30 \text{ MeV}$. Electron accelerators with energy up to 35 MeV can be used as a γ -source.

The second peculiarity of photonuclear reactions is that in the region of the dipole resonance there predominate the reactions with knocking-out of only

one nucleon (neutron or proton), the cross-section of which is more than order of magnitude higher than the cross sections of all the rest reaction channels. Correspondingly, as a result of nuclear reactions at γ -quantum energies between 15 and 30 MeV, one can observe mainly the residual nuclei, the mass numbers of which are a unity less than the mass numbers of the initial nuclei ($A - 1$). The composition of the impurity introduced is presented in Table 2. The possi-

bilities of transmutation of $Si < Al >$ atoms in the bulk of Si semiconductor as concerns the uniformity of their distribution ($\sim 3\%$) surpass all traditional techniques of metallurgical alloying.

It can be seen from Table 2 that in silicon the impurity Al (element of group III) arises, the atoms of which form small acceptor levels in the forbidden zone of Si semiconductor.

Table 2. Characteristics of photonuclear reactions in silicon

Isotope	Content, %	Type of reaction			
		(γ, n)		(γ, p)	
		Threshold, MeV	Reaction products	Threshold, MeV	Reaction products
^{28}Si	92.2	17.18	$^{27}Si \rightarrow ^{27}Al$ $T_{1/2} = 4.2$ s	11.58	^{27}Al
^{29}Si	4.7	8.48	^{28}Si	12.33	$^{28}Al \rightarrow ^{28}Si$ $T_{1/2} = 2.31$ min
^{30}Si	3.1	10.61	^{29}Si	13.51	$^{29}Al \rightarrow ^{29}Si$ $T_{1/2} = 6.6$ min

The number of aluminum impurity atoms, N_{Al} , produced as a result of silicon irradiation with bremsstrahlung quanta can be determined by the following expression

$$N_{Al} = J_e K_{trans} t, \quad (6)$$

where J_e is the accelerated electron flux, K_{trans} is the transmutation coefficient equal to the probability of impurity atom production calculated per incident electron, t is the exposure time.

The transmutation coefficient K_{trans} is essentially dependent on the electron energy, the target design and on the exposure geometry, and is determined from the expression

$$K_{trans} \sim \sum n_i A^{\frac{4}{3}}, \quad (7)$$

where n_i is the i -th isotope concentration, A is the mass number of Al atom.

Besides, it follows from Table 2 that among the basic reaction products there exist unstable nuclei. The radioactivity of silicon crystals is mainly specified by the $^{27}Si_{14}$, $^{28}Al_{13}$, $^{29}Al_{13}$ nuclei with the half-life period of no more than 10 min, and the time of activity decay in these crystals will make a few hours.

Note that in the radiative capture of neutrons (primary channel of nuclear reactions at neutron doping) residual nuclei with the mass numbers $A + 1$ are produced. It is these differences in the mass numbers of final nuclei that determine different composition of chemical impurities introduced into semiconductor materials as the last ones are irradiated with neutrons and γ -quanta.

The X-tomography can be used for the analysis of the amorphous phase only on condition that the following defects are eliminated in the initial crystals.

- 1. Schottky defects - by annealing the crystal at around its melting temperature (for silicon T_{melt} is $1420^\circ C$).

- 2. Point defects - after elimination of Schottky defects the annealing temperature must be reduced down to intermediate values.

- 3. Dislocations - should be brought out to the surface layer of the crystal on annealing at about the melting temperature with the following etch removal of the surface layer and neutralization of the remaining defects in the process of hydrogenation.

In the presence of nonremovable defects, a "halo" of the amorphous phase is concealed in the lattice in the range of Bragg angles.

The number of nuclear fission fragments Y introduced into the Si semiconductor is given by the expression

$$Y = \frac{1}{2} n_n \int_{E_{\gamma,th}}^{E_{\gamma,max}} 2\sigma(E_\gamma) f(E_{\gamma,max}, E_\gamma) dE_\gamma, \quad (8)$$

where $\sigma(E_\gamma)$ is the ^{238}U fission cross section versus the γ -quantum energy E_γ , n_n is the number of ^{238}U nuclei per cm^2 , $f(E_{\gamma,max}, E_\gamma)$ is the transformed spectrum of bremsstrahlung γ -quanta, $E_{\gamma,th} = 5$ MeV is the threshold of the ^{238}U photofission reaction, $E_{\gamma,max}$ is the highest γ -quantum energy in the radiation spectrum; $1/2$ is the coefficient that takes into account the direction of nuclear fragment emission, as in the photofission of ^{238}U nuclei in the giant resonance region the angular distribution of light and heavy fragments remains practically isotropic; the factor 2 represents the number of nuclear fission fragments. The yield of fission products from a uranium layer of thickness $\delta \sim 1 \mu g/cm^2$ is equal to $Y = 5.4 \cdot 10^6$ fragments $\cdot cm^{-2}h^{-1}$ at a γ -quantum energy corresponding to the highest electron energy on the converter, i.e., 12 MeV.

2. QUANTUM STRUCTURES IN THE $C - Si$ SEMICONDUCTOR BULK

The state of $c - Si$ structures showing quantum dimensional effects (variations in the occurrence depth of quantum filaments and their resistivity) is determined by condensation processes and the level of structure fragmentation by high-energy electrons. In the radiation zones of electron accelerators KUT-1 (12 MeV), EPOS (26 MeV) with the cutoff of electrons from the γ -quantum flux, but with the uranium target inserted, or under irradiation with γ -quanta and accompanied by electrons coming from the converter and with the uranium target in the photon beam the energy isolation will cease to increase thus providing the formation of long quantum structures. With the cutoff of electrons the depth of amorphous structures will be limited. The γ -quantum energy spectrum in the radiation zone of the accelerator KUT-2 is shown in Fig.3. The electric and structural characteristics of quantum filaments are given in Figs.4 and 5.

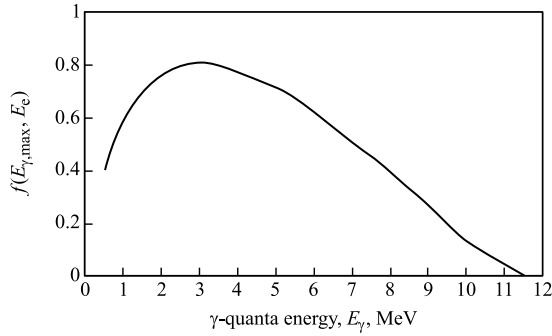


Fig.3. gamma-quantum spectrum after electron beam scanning at the accelerator KUT-1

For a detailed analysis of the radiation zone geometry at the accelerator KUT-1, the Geant program has been used to calculate the influence of the particle scatterer, which is placed behind the converter and at 1 mm ahead of the set of Si crystals.

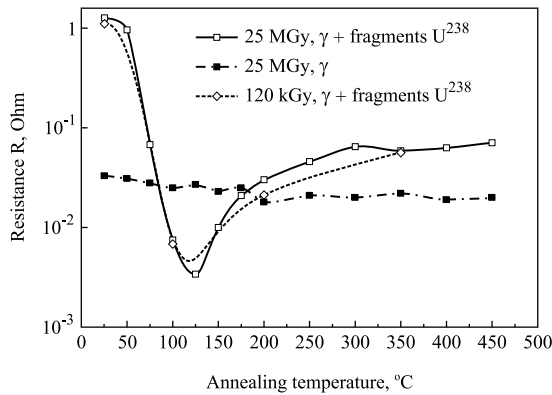


Fig.4. Quantum structure formation at the electron accelerator KUT-1

The secondary electrons are the sources of radiation defects in the bulk of the $c - Si$ crystal that cause a rise in electrical resistivity.

With installation of the aluminum cutter of electrons from the converter, a spectrum of secondary electrons was obtained (see Fig.6).

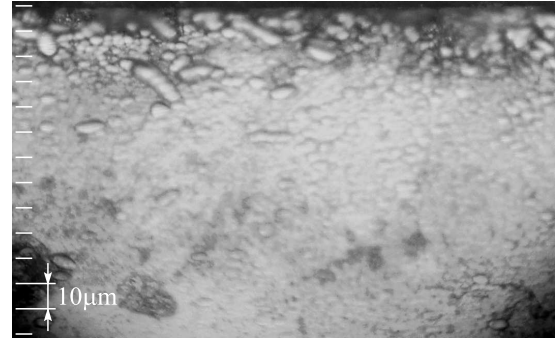


Fig.5. Microphotograph of the cross section of the ($c - Si$) semiconductor sample after its exposure to uranium fission fragments at the electron accelerator KUT-1 and a subsequent electrochemical etching

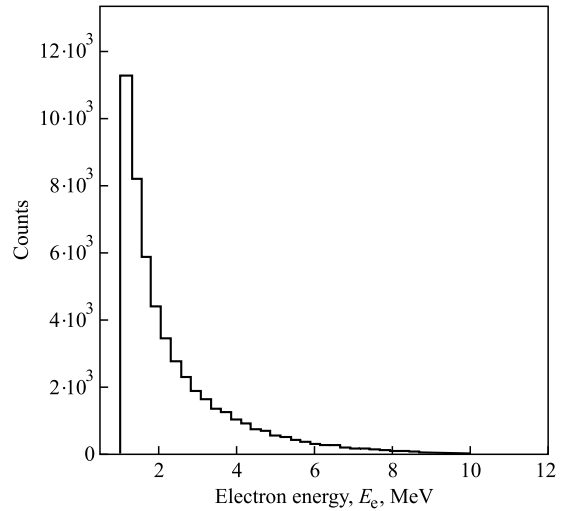


Fig.6. Secondary electron energy spectrum with a 2 mm thick aluminum scatterer at the electron accelerator KUT-1

To increase the length of conducting quantum filaments in the $c - Si$ crystal, it is necessary to reduce the energy losses by conduction electrons during atomic structure melting due to additional atomic bond breakings by electrons throughout the crystal volume. Figure 7 shows the crystal surface condition after irradiation with 12 MeV electrons to a dose of $6 \cdot 10^{15} e^- / cm^2$ at a beam fluence of $2 \mu A / cm^2$ and a subsequent electrochemical etching. The lattice disordering ceases throughout the entire crystal bulk as soon as electrons are removed, wholly or partly, from the γ -quantum flux. However, this will stop the increase in the energy isolation, and the length of conducting quantum filaments will be limited (see Fig.8). With reduction in the time of conducting quantum structure production in a single crystal silicon it is necessary that the uranium photofission cross section should be increased at the expense of increasing the γ -quantum energy. To increase the quantum filament length in the $c - Si$ crystal matrix, it is essential to reduce the energy losses

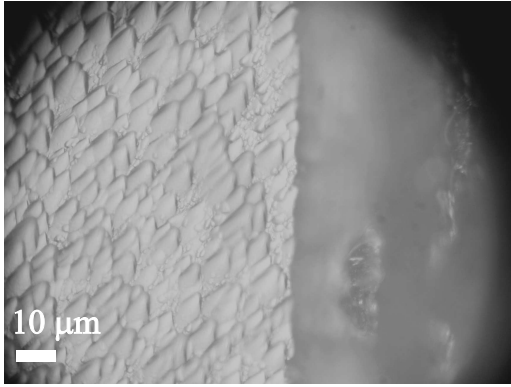


Fig.7. Atomic structure disordering by electrons on the silicon surface

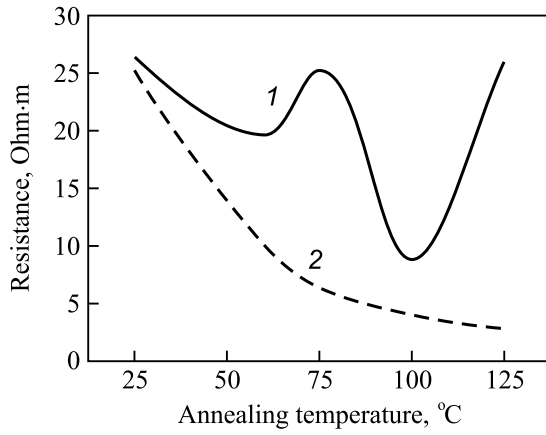


Fig.8. Sample resistance as a function of annealing temperature. 1 - crystal entry side irradiated with uranium fragments and electrons; 2 - crystal exit side for electrons

in inelastic processes of energy transfer from ions (uranium fragments) to crystal lattice atoms. Since the formation of conducting single-crystal structures occurs in amorphous phases produced during crystal structure melting, the dissipation of the major portion of energy transferred to the crystal bulk through atomic (spin) bonds limits the depth of amorphous phase formation. The atomic bonds break down in the bulk during crystal irradiation with the electron beam, and this leads to an increase in the energy isolation, and as a consequence, to a growing length of quantum filaments. The boundary conditions of variable-length quantum filament production are determined by the electron exposure dose. To increase the uranium photofission cross-section (see Figs.9 and 10) due to increasing the γ -quantum energy and the presence of electrons of energy ≤ 10 MeV in the γ -quantum flux (electrons causing the $c-Si$ material structure fragmentation), the 26 MeV electron accelerator "EPOS" is used for amorphous structure production operations. The resulting uranium nuclear fragments are divided into "light" and "heavy" fragments of masses 95 ± 2 and 138.5 ± 1.5 amu, with distribution widths 7.5 and 6.6 amu, respectively,

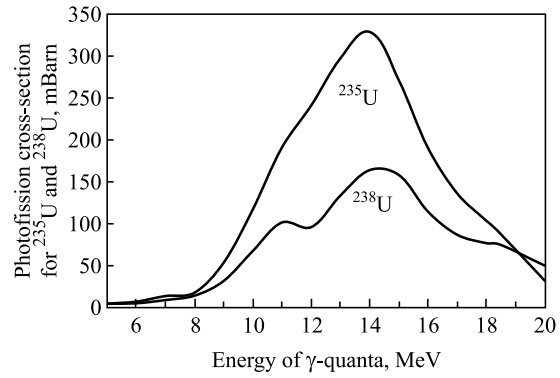


Fig.9. Energy dependence of uranium photofission cross section in the giant resonance region

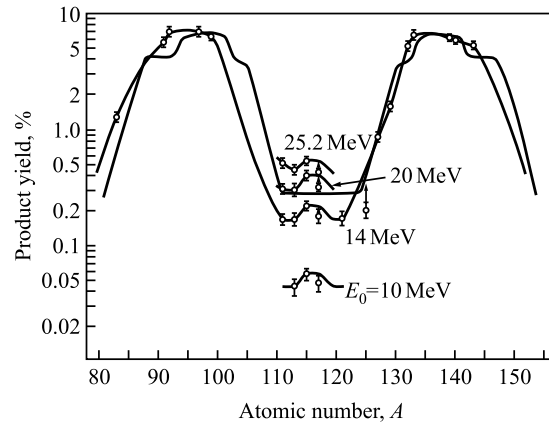


Fig.10. Total yields of ^{235}U , ^{238}U photofission products versus uranium mass numbers A

and with different percentage yields ($Y, \%$) of fission products [4].

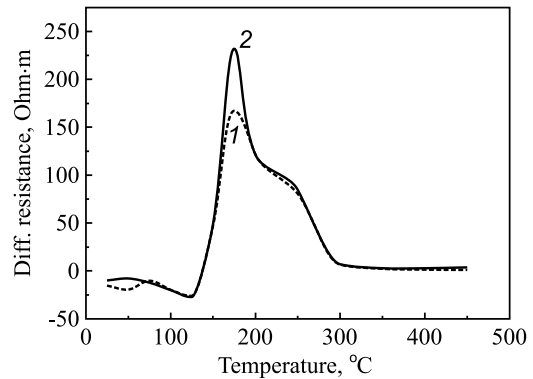
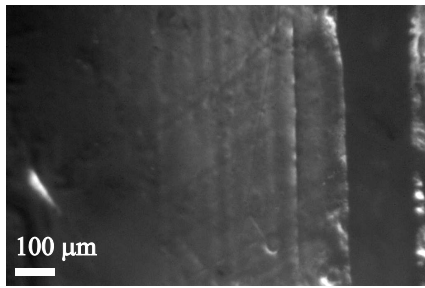
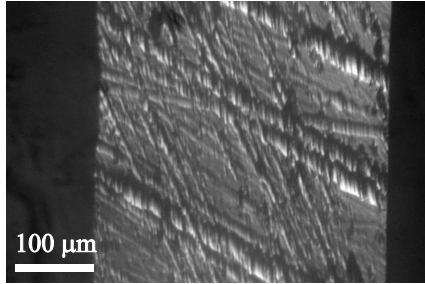


Fig.11. Difference between resistivities of two samples versus annealing temperature. 1 - crystal entry side irradiated with uranium fragments and electrons; 2 - crystal exit side for electrons

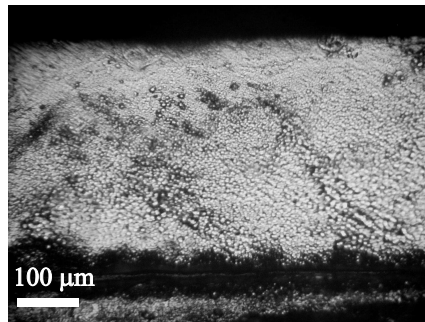
As high-energy electrons and secondary particles of photonuclear reactions come to initiate the cascade processes of defect formation, the energy isolation of atoms by conductivity electrons is created, this providing the amorphous phase formation in the ($c-Si$) crystal throughout its depth. The possibility of point defect annealing in the silicon matrix is provided by the process of matrix hydrogenation.



a



b



c

Fig.12. Microphotographs of (*c* – *Si*) semiconductor cuts before (*a*) and after (*b*, *c*) irradiation

On crystal structure annealing after the process of hydrogenation at the temperature $T = 100^{\circ}\text{C}$ to 125°C conducting quantum filaments are introduced throughout the all crystal depth. Depending on the radiation dose, the filament density can satisfy the principle of wave-corpuscule dualism described by the de Broglie equation. Such a solution of the *c* – *Si* crystal structure modification will make it possible to increase both the diffusion length of minor photocurrent carriers and the efficiency of solar-to-electric energy photoconverters.

The *c* – *Si* crystal structure after its exposure to electrons and uranium nuclear fission fragments to a dose of 1800 Mrad (100 hours) at the electron accelerator "EPOS" and a subsequent electrochemical etching is shown in Fig.12. Figure 13 (*a* and *b*) illustrates the difference between the resistivities of the sample irradiated with electrons, gamma-quanta and uranium nuclear fission fragments, and of the sample irradiated with electrons and gamma-quanta versus the annealing temperature. Irradiation runs were performed at the

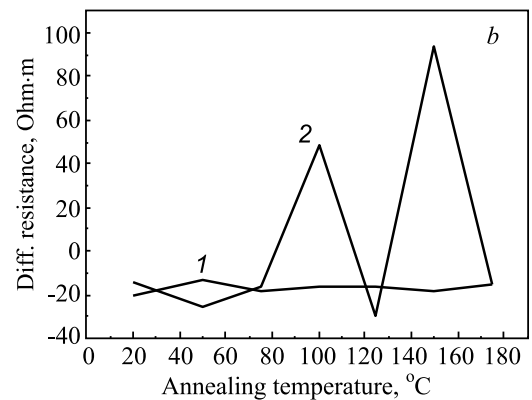
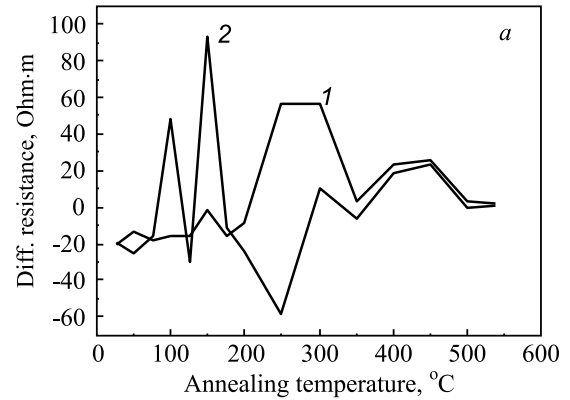


Fig.13. Difference between resistivities of two samples versus annealing temperature. 1 - crystal entry side irradiated with uranium fragments and electrons; 2 - crystal exit side for electrons

accelerator "EPOS" to a dose of 3600 Mrad (200 hours). Quantum filaments show a considerably higher electric conductivity than the *c* – *Si* crystal matrix, therefore they can be used as contact chains for collection of charge carriers at the photoconverter electrodes.

3. THE CONCLUSION

The regions of quantum structures in the (*c* – *Si*) semiconductor are formed owing to irradiation of single-crystal silicon with electrons and ^{238}U photofission fragments, followed by hydrogenation and annealing with the result that a charge-carrier transport channel is built up from randomly oriented micro- and nano-crystallites with a developed network of phase boundaries. Two technological processes must be carried out: 1 - to realize multicharged ion production on the basis of nuclear photofission of uranium, 2 - to provide atomic bond breakings in the *Si* structure to reduce dissipation of energy released by multicharged ions to the crystal bulk.

References

1. S.V. Chuklyaev, Yu.N. Pepelyshev. Time resolution of a vacuum fission chamber (in Russian)// *Pribory i Tekhnika Eksperimenta*. 2003, N6, p.23-28.
2. A.N. Dovbnya, V.P. Yefimov. Radiation Technologies in Formation of the Condensed State of Atomic Structure in Crystal Materials (Physical Methodology for Radiation Process Development) // *Telecommunications and Radio Engineering*. 2008, v.67, p.1805-1826.
3. A.N. Dovbnya, V.P. Yefimov. The Structures for Controlling Charge Carriers in Silicon Photocells// *Telecommunications and Radio Engineering*. 2008, v.66, p.1-18.
4. M.Ya. Kondratenko, K.A. Petrzhak. Yields of ^{235}U photofission fragments // *Atomnaya Energiya*. 1967, N6, p.556-561 (in Russian).

МЕТОДИКА ФОРМИРОВАНИЯ НАНОРАЗМЕРНЫХ АМОРФНО-МИКРОКРИСТАЛЛИЧЕСКИХ СТРУКТУР В МОНОКРИСТАЛЛИЧЕСКОМ КРЕМНИИ ИЗЛУЧЕНИЕМ

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Сформированы в монокристаллической матрице кремния квантовые структуры с повышенной удельной электрической проводимостью. Массив квантовых нитей улучшает выведение носителей заряда с малой подвижностью из объема эмиттерной структуры $c-Si(p, n)$ -фотопреобразователя. Приведены экспериментальные результаты применения радиационных технологий для создания таких структур.

МЕТОДИКА ФОРМУВАННЯ НАНОРОЗМІРНИХ АМОРФНО-МІКРОКРИСТАЛЕВИХ СТРУКТУР В МОНОКРИСТАЛІЧНОМУ КРЕМНІЇ ВИПРОМІНЮВАННЯМ

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Сформовані в монокристалічній матриці кремнію квантові структури з підвищеною питомою електричною провідністю. Массив квантових ниток покращує виведення носіїв заряду з малою рухливістю з об'єму емітерної структури $c-Si(p, n)$ -фотопреобразователя. Приведено експериментальні результати застосування радіаційних технологій для створення таких структур.