

# AN INFLUENCE OF GAMMA-IRRADIATION AND $^{238}\text{U}$ FRAGMENTS ON SINGLE-CRYSTAL SILICON PROPERTIES

A.N. Dovbnya, V.P. Yefimov, G.D. Pugachev, V.S. Dyomin, N.A. Dovbnya, J.E. Gordienko<sup>1</sup>,  
B.G. Borodin<sup>1</sup>, S.V. Babychenko<sup>1</sup>, T.A. Semenets<sup>1</sup>

NSC KIPT, Kharkov, Ukraine

<sup>1</sup>Kharkov National University of Radioelectronics, Kharkov, Ukraine

E-mail: yefimov@kipt.kharkov.ua

In the paper the processes of accumulation of radiation defects, formed by fragments of  $^{238}\text{U}$  nucleus fission, for forming of amorphous phases in the bulk of single-crystal silicon and the influence of the temperature annealing of defects on the properties of disordered structures are investigated.

PACS: 61.82. Fk

## I. RADIATION MODIFICATION OF (C-SI)-SEMICONDUCTOR

The experiment was carried out on a scanning beam of  $\gamma$ -quanta of the linear technological accelerator with a maximal energy of the scanning beam of 12 MeV convertible electrons. The object of research was a series of two samples of the (c-Si)-crystal, cut out from the wafer-plate of a 396  $\mu\text{m}$  thickness irradiated simultaneously with  $\gamma$ -quanta of bremsstrahlung radiation spectrum, the absorbed doze being 0.12 MGr. The absorbed doze power in the site of the silicon assembly location was 8 kGr/h. Before one of the samples the target of  $^{238}\text{U}$  salts was mounted for creation of nucleus photofission fragments formed under action of  $\gamma$ -quanta. The schematic representation of the experiment is given in Fig.1.

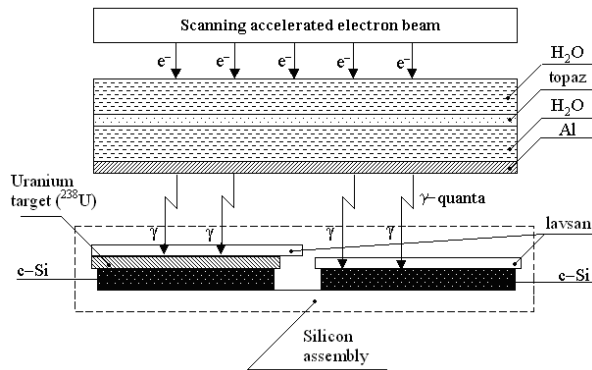


Fig.1. The schematic representation of irradiation of the silicon assembly irradiation with  $\gamma$ -quanta at the linear technological electron accelerator (KUT-1)

The number of nucleus fission fragments implanted into the semiconductor, under conditions of this experiment, is determined from the expression

$$Y = n_a \int_{E_{\gamma \text{ thres}}}^{E_{\gamma \text{ max}}} \sigma(E_{\gamma}) f(E_{\gamma \text{ max}}, E_{\gamma}) dE_{\gamma}, \quad (1)$$

where  $\sigma(E_{\gamma})$  – the cross-section of  $^{238}\text{U}$  nucleus fission as a function of  $\gamma$ -quanta energy ( $E_{\gamma}$ ),  $n_a$  – the number of  $^{238}\text{U}$  nucleus per  $\text{cm}^2$ ,  $f(E_{\gamma \text{ max}}, E_{\gamma})$  – the transformed spectrum of bremsstrahlung  $\gamma$ -quanta,  $E_{\gamma \text{ thres}} = 5 \text{ MeV}$  – threshold of reaction of division the nucleus  $^{238}\text{U}$ ,  $E_{\gamma \text{ max}}$  – maximal energy of  $\gamma$ -quanta in the radiation spectrum.

For the  $^{238}\text{U}$  target of a thickness  $\delta \sim 1 \mu\text{g}/\text{cm}^2$ , calculated by the program "GEANT", the value of  $Y$  was  $5.4 \cdot 10^6$  fragments / $\text{cm}^2 \cdot \text{h}$  [1].

## 2. PROCESS OF DEFECT ACCUMULATION IN THE SILICON STRUCTURE

To describe the process of semiconductor structure disordering we introduced the function of state [2] characterizing a nonannealed part of defects and normalizing the initial defect concentration to unit

$$f = \frac{t_{\text{an}}^{-1} - t_0^{-1}}{t_{\text{ir}}^{-1} - t_0^{-1}}, \quad (2)$$

where  $t_0$ ,  $t_{\text{ir}}$ ,  $t_{\text{an}}$  are the values of lifetime of charge carriers in the samples before irradiation, after irradiation and after annealing, respectively. At  $t_{\text{an}} = t_0$  the value of the function  $f=0$  corresponds to the full annealing of radiation defects. At  $t_{\text{an}} = t_{\text{ir}}$  the function  $f=1$ , that means the absence of radiation defect annealing.

The lifetime of charge carriers was measured by the phase method [3] with the help of light-emitting diodes having a maximum of spectral radiation distribution on the wavelength of 0.55  $\mu\text{m}$ . Thus, the depth of photoabsorption does not exceed the depth ( $\sim 10 \mu\text{m}$ ) of  $^{238}\text{U}$  fragments penetration into the (c-Si)-structure of the semiconductor. The crystal was placed in the cut of the resonator actuated by the microwave oscillator at the frequency of 37500 MHz and was illuminated with the light-emitting diode supplied from the low-frequency harmonic signal generator. The photoconductivity signal was detected by the microwave diode, amplified by the selective amplifier and was recorded directly with the help of the synchronous detector.

The lifetime is determined from the relationship

$$\text{tg} \varphi = \omega \tau_f, \quad (3)$$

where  $\varphi$  is the angle of phase shift between photocurrent and the light signal, arising due to the photoconductivity process persistence,  $\omega$  is the frequency of the low-frequency generator.

The phase method was used to record the decrease in the charge carrier lifetime ( $\tau_f$ ) from 28.6  $\mu\text{s}$  down to 19.4  $\mu\text{s}$  on the side of the sample under irradiation with  $\gamma$ -quanta implantation of  $^{238}\text{U}$  fragments. The values of the function of state, calculated by the experimental

results of measurements of the charge carrier lifetime in the sample irradiated only with  $\gamma$ -quanta (designated by circles) and in the sample irradiated with  $\gamma$ -quanta with implantation of  $^{238}\text{U}$  fragments (designated by squares),

as a function of annealing temperature are given in Fig.2. From various characters of functional dependences of structures states it follows that, in the region of fragment implantation in the semiconductor, the process of defect accumulation is observed.

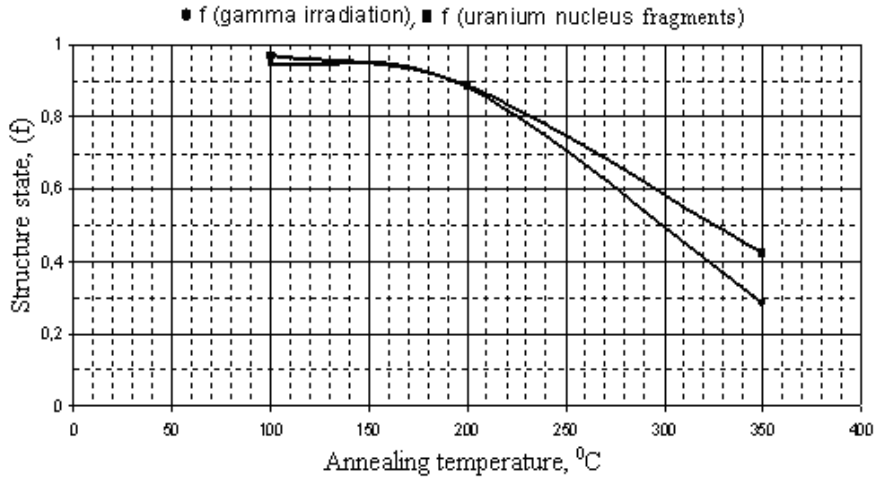


Fig.2. Functions  $f(\gamma)$  and  $f(\gamma + ^{238}\text{U}$  fragments) versus annealing temperature

The defect accumulation will grow with the increase in the irradiation doze, energy and  $\gamma$ -quanta beam fluency on the uranium target. The temperature treatment of the semiconductor by annealing of radiation defects enables to receive the values of the structure states of the function  $f \rightarrow 1$  for uranium nucleus fission fragments and of the function  $f \rightarrow 0$  for point defects from gamma radiation.

### 3. CONDUCTIVITY OF THE STRUCTURE BY THE DAMAGES CREATED BY $^{238}\text{U}$ FRAGMENTS

By breakdown of large complexes of disordered structures along the tracks of heavy particles,

elementary defects are liberated and microcrystalline structures with a grain size of some nanometers are formed, resulting in the formation of conducting layers. The conductivity dominates in such structures and is defined by overlapping of separate disordered areas [4]. Experimental results on annealing of the sample structure after treatment it by  $\gamma$ -irradiation and  $^{238}\text{U}$  fragments are given in Fig.3. The resistivity ( $\rho$ ) of a sample was determined by the 4 probe technique and estimated from the relationship

$$\rho = \frac{\pi}{\ln 2} \cdot \frac{U_{2-3}}{I_{1-4}}, \quad (4)$$

where  $U_{2-3}$  is the voltage,  $I_{1-4}$  is the current in the circuit between corresponding probes.

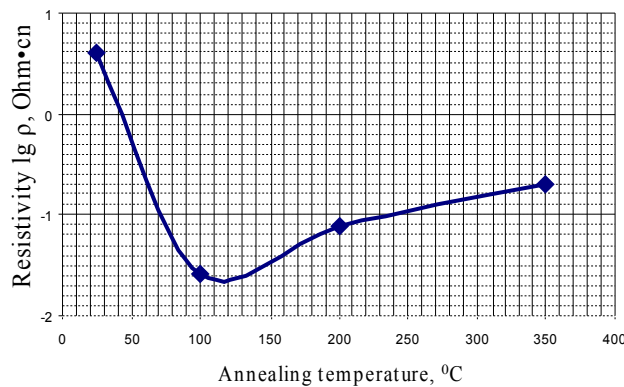


Fig.3. Resistivity of the sample irradiated with  $\gamma$ -quanta by a doze of 120 kGr with implantation of  $^{238}\text{U}$  fragments as a function of the annealing temperature

### 4. CONCLUSIONS

In the sample irradiated with  $\gamma$ -quanta and under implantation of  $^{238}\text{U}$  fragments the process of radiation defect accumulation takes place. For creation of amorphous phases in the structure of lateral formations in the (c-Si)-semiconductor the irradiation doze should be increased up to  $\sim 8$  MGr at an electron energy of 12 MeV.

The increase in the conductivity by the structure damages along the tracks of uranium nucleus fragments at low annealing temperature ( $\sim 100^\circ\text{C}$ ) can be used for the output of charge carriers with a weak mobility from the semiconductor bulk. Thus, the single-crystal structure of a silicon matrix will be used as the transport environment for the charge carriers being very mobile.

## REFERENCES

1. A.N. Dovbnaya, V.P. Yefimov, G.D. Pugachev et al. Forming of disordered structures and their transformation into the amorphous phase in the bulk of the (c-Si)-semiconductor by the nucleus fragments being formed under  $\gamma$ -quanta irradiation of fissile materials // *Novye technologii*. 2005, №1-2 (7-8), p.11-16 (in Russian).
2. I.D. Konozenko, A.K. Semenyuk, V.I. Khivrich. *Radiation effects in silicon*. Kiev: "Naukova dumka", 1974 (in Russian).
3. Yu.E. Gordienko, B.G. Borodin, A.A. Ryabukhin. Photomodulating diagnostics of semiconductor structures // *Radiotekhnika*. 1999, v.111, p.7-13 (in Russian).
4. L.V. Lezhejko, N.B. Pridachin, L.S. Smirnov. On the conductivity in semiconductors by the damages created by bombardment with heavy particles // *Fizika Tech. Phys.* 1972, v.6, №5, p.899-902 (in Russian).

### ВОЗДЕЙСТВИЕ $\gamma$ - ОБЛУЧЕНИЯ И ОСКОЛКОВ ЯДЕР $^{238}\text{U}$ НА СВОЙСТВА МОНОКРИСТАЛЛИЧЕСКОГО КРЕМНИЯ

*А.Н. Довбня, В.П. Ефимов, Г.Д. Пугачев, В.С. Демин, Н.А. Довбня, Ю.Е. Гордиенко, Б.Г. Бородин, С.В. Бабыченко, Т.А. Семенец*

Исследуются процессы накопления радиационных дефектов, образованных осколками деления ядер  $^{238}\text{U}$ , для формирования аморфных фаз в объеме монокристаллического кремния и влияния температуры отжига дефектов на свойства разупорядоченных структур.

### ВПЛИВ $\gamma$ - ОПРОМІНЕННЯ ТА ОСКОЛКІВ ЯДЕР $^{238}\text{U}$ НА ВЛАСТИВОСТІ МОНОКРИСТАЛІЧНОГО КРЕМНІЮ

*А.М. Довбня, В.П. Єфімов, Г.Д. Пугачьов, В.С. Дьомін, Н.А. Довбня, Ю.О. Гордієнко, Б.Г. Бородін, С.В. Бабиченко, Т.А. Семенець*

Досліджуються процеси накопичення радіаційних дефектів, утворених осколками ділення ядер  $^{238}\text{U}$ , для формування аморфних фаз в об'ємі монокристалічного кремнію та впливу температури віджига дефектів на властивості розупорядкованих структур.