SECTION 3. COMPUTER SIMULATION IN MICRO- AND NANOELECTRONICS

INVESTIGATION OF THE RADIATIONS EFFECT ON THE ELECTRICAL CHARACTERISTICS OF A JUNCTION FIELD-EFFECT TRANSISTOR

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I. INTRODUCTION

The influence of penetrating radiation is appeared in radiation effects in semiconductors and structures with p-n junctions. These are mainly radiation effects: discompositios effects, atomic transmutations, ionization effects [1,2].

The discompositions effects lead to the formation of radiation defects in the crystal. A radiation defect can arise if the incident energy is sufficient for the displacement of atom from the lattice site to the interstitial site.

Impurity composition of the semiconductor, the form of exposure effect, thermal stability and ability to influence the electrical and optical properties of a semiconductor and semiconductor devices determine the occurrence of a specific type of radiation defect [3]. Radiation defects manifest themselves in semiconductors as recombination centers, changing the charge minority carrier lifetime, as trapping centers, reducing the concentration majority carriers, and as scattering centres, reducing mobility [1]. Atomic transmutation and ionization effects are not considered in this paper.

In addition to the negative impact, penetrating radiations can serve as an effective technological tool which allows obtaining qualitative semiconductor materials, significantly improve and reduce the cost manufacture of many types of semiconductor devices, and improve their quality [4, 5]. In the technological manufacturing processes semiconductor devices perspective use of most types of penetrating radiations: high-energy electrons, gamma quantums, neutrons, protons, alpha rays, etc.

All these listed factors make modeling of electrical characteristics taking into account the effect of different types of radiation an actual task aimed at improving the operating characteristics of IC.

II. STRUCTURE OF P-JFET

JFET belong to the category of normally open field-effect transistors, in which the conducting channel and, consequently, the current in the channel, close to the maximum, exist at zero gate voltage (VG = 0 V). These JFET are called depleted-type devices, since when the voltage is applied to the gate, the channel is depleted by electrical current carriers and the current in the channel decreases. Device structure of the p-JFET is shown in Fig. 1. Substrate of the hole type conductivity, doped boron with concentration of $1.35{\cdot}10^{15}$ cm^{-3}, crystallographic orientation (111).

In the modeling of the operation-routing sequence for the formation of the device structure p-channel JFET, 14 stages are conventionally allocated: setting the parameters of the substrate and selecting computation grid, sequential formation of regions of the n+-buried layer, p+-buried layer, epitaxial layer, oxide isolation process, p-channel areas, n-collector, p+-collector, p-base, opening of the areas under the contacts (together with oxidation of the substrate surface), formation of regions n+-gate, p+-emitter, n+-emitter, 1st level of metal interconnections. To form the structure, 11 operations of photolithography are necessary.

The conditions for the application of the JFET imply the need to study the effect of penetrating radiations over a wide temperature range (from 383 K to 163 K). To obtain adequate results, it is necessary to correct the coefficients of the Klassen mobility model used in the simulation. The results of simulation electrical characteristics showed an acceptable agreement with the experimental data in the temperature range from 383 K to 223 K. Pinch-off voltage at 303 K is 1,31 V (measured at 1,29 V), the drain current is 3.9 mA (3.4 mA), for temperatures 383 K and 223 K the magnitude of these characteristics is 1.49 V (1.43 V) and 2.85 mA (2.7 mA), 1.17 V (1.15 V) and 4.58 mA (2.68 mA), respectively.

III. RESULTS

The influence of the flow of electrons, neutrons and protons on the electrical performance of the device structure of p-channel JFET is simulated.

As shown in [6], there is a combination of fluence values and particle energy at which the effect is equal. It is assumed that the fluence of electrons F_E with an energy E_E = 4 MeV will cause in the IC the same displacements of atom as fluence of neutrons F_N = 0,302 FE with an energy E_N = 1,5 MeV or fluence F_P = 1,1·10-4 F_E with an energy E_P = 2,0 MeV. Results of the effects fluence of electrons $F_E = 6 \cdot 10^{14}$ cm^{-2} with an energy E_E = 4 MeV and the corresponding fluences of neutrons and protons at a temperature 303 K and gate voltage V_G = 0 V is showned on the Fig. 2.

As can be seen from the figure, the effect of penetrating radiation with the parameters described above introduces almost identical degradation changes in the device structure. Thus, the drain current I_D of the p-channel JFET under the influence of the fluence of electrons $F_E = 6 \cdot 10^{14}$ cm^{-2} with an energy of EE = 4 MeV decreases by 5.68 % with respect to the drain current of the JFET without exposure of penetrating radiation (I_D = 3,70 mA to I_D = 3.49 mA). For a fluence of neutrons $F_N = 2 \cdot 10^{14}$ cm^{-2} with an energy E_N = 1,5 MeV, the change in the drain current is 4,59 % (drain current value I_D = 3,53 mA). For a fluence of protons $F_P = 6{,}6 \cdot 10^{10}$ cm^{-2} with an energy E_P = 2 MeV, the change in the drain current is 4,87 % (drain current value I_D = 3,52 mA).

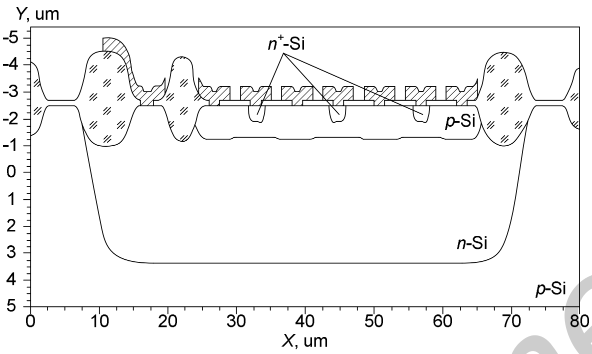

Figure 1 – Device structure of p-channel JFET

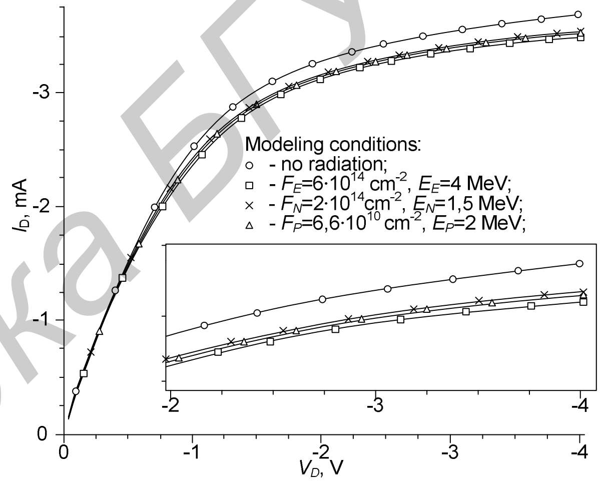

Figure 2 – Dependence of the drain current on the drain voltage V_D when exposed to various types of penetrating radiations at a temperature 303 K

Figure 3 shows dependency graphs of the drain current on the change in the fluence of electrons F_E with energy E_E = 4 MeV for different temperatures. The drain current is expressed in relative units. The value of the drain current without exposure to penetrating radiation is assumed per unit.

As can be seen from the figure, the influence of the fluence of electrons on the drain current for different temperatures differs. Thus, for a temperature of T = 383 K of the fluence of electrons F+ = $2 \cdot 10^{15}$ cm^{-2}, the drain current is 88.15 % of the value without influence, with the fluence F+ = $6 \cdot 10^{15}$ cm^{-2} this value is 67.45 %. For a temperature of 223 K, the drain current is 78.93 % and 45.03 % of the value without exposure for fluences $F_E = 2 \cdot 10^{15}$ cm^{-2} and $F_E = 6 \cdot 10^{15}$ cm^{-2}, respectively. With a further decrease temperature to a value of 163 K, the drain current decreases by 25.7 % and 74.3 %.

Thus, it is seen that with increasing temperature the influence effect of the electrons flux increases. First of all, this is due to the partial recovery of the crystal structure of silicon at higher temperatures.

Figure 4 shows dependency graphs of the drain current on the change in the fluence of neutrons FN with an energy E_N = 1,5 MeV for different temperatures.

Analysis of simulation results shows that impact of influence of the neutrons flux with decreasing temperature also increases. Thus, for a temperature of T = 383 K of the fluence of neutrons $F_N = 1 \cdot 10^{14}$ cm^{-2}, the drain current is 86.75 % of the value without influence, with the fluence of FN = $2 \cdot 10^{15}$ cm^{-2}, this value is 74.79 %. At a temperature of 223 K, the drain current is 76.5 % and 56.52 % of the value without influence for fluences $F_N = 1 \cdot 10^{15}$ cm^{-2} and $F_N = 2 \cdot 10^{15}$ cm^{-2}, respectively; at T = 163 K, 71.36 % and 48.31 %.

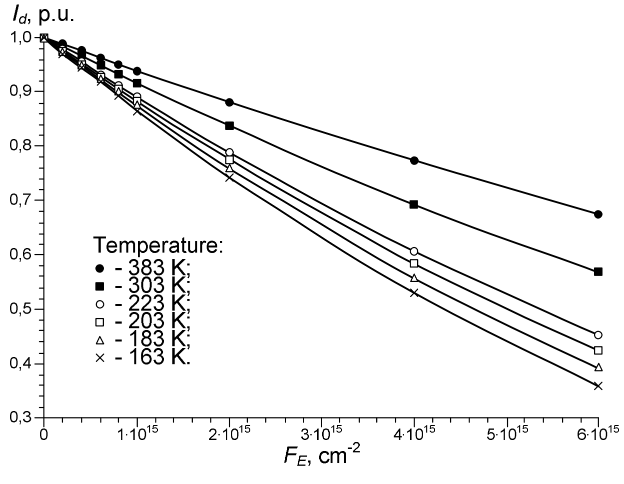

Figure 3 – Dependence of the drain current on the change in the fluence of electrons F_E with energy E_E = 4 MeV for different temperatures

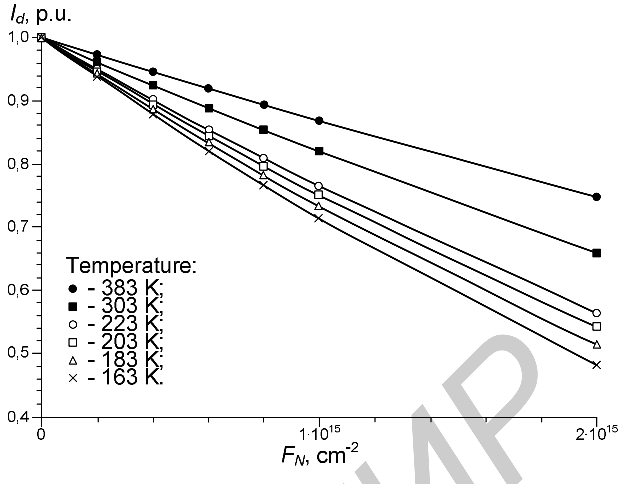

Figure 4 – Dependence of the drain current on the change in the fluence of neutrons F_N with an energy E_N = 1,5 MeV for different temperatures

Figure 5 shows dependency graphs of the drain current on the change in the fluence of protons F_P with an energy E_P = 2 MeV for different temperatures.

As can be seen from the presented graphs, the influences of the protons flux analogous to those considered earlier. For a temperature of T = 383 K of the fluence of protons $F_P = 6 \cdot 10^{11}$ cm^{-2}, the drain current is 74.04 % of the value without influence, at a temperature of 223 K it is 55.31 %.

Figure 6 shows the results of simulation of the dynamic characteristics for device structure of a p-channel JFET under the action different fluence of electrons with an energy of E_E = 4 MeV at a drain voltage V_D = -4 V for a temperature of T = 303 K. Positive impulse of voltage (V_G = 2 V) width of 3 μs is served on the gate. The width of leading and trailing edges is 1 μs.

It is seen from the figure that under the influences of the electrons flux with an energy of E_E = 4 MeV up to fluences value to the point $F_E = 2 \cdot 10^{15}$ cm^{-2}, the dependence of the width of leading and trailing edges is practically equal. With a further increase in the fluence, the change in the width of trailing edge continues to decrease linearly to 375 ns (a change is 13.1 % of the value without influence) at $F_E = 6 \cdot 10^{15}$ cm^{-2}. The dependence of the width of leading edge becomes nonlinear in this case (decreases by 5.7 % to a value of 410 ns). The analytic data can be explained by the difference in the effect of the drain current on the charge and discharge of capacitors when the transistor is switched.

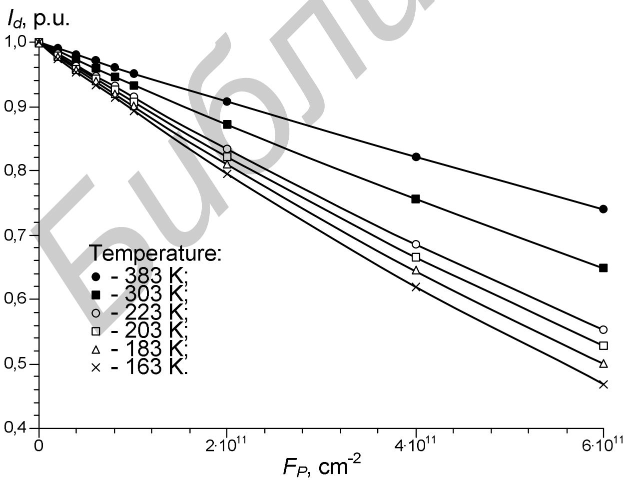

Figure 5 – Dependence of the drain current on the change in the fluence of protons FP with an energy E_P = 2 MeV for different temperatures

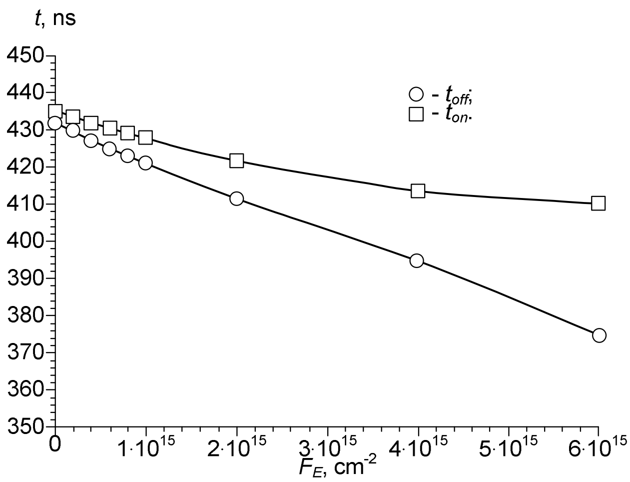

Figure 6 – Dependence of width of the leading and trailing edges on the fluence of electrons F_E with an energy E_E = 4 MeV

Similar patterns are observed for neutrons and protons fluxes. So for a neutrons flux with an energy of E_N = 1,5 MeV, the fluence value, at which the dependence of the width of leading edge ceases to be linear, is $F_N = 8 \cdot 10^{14}$ cm^{-2}. For the protons flux with an energy of E_P = 2 MeV, the fluence value is $F_P = 2 \cdot 10^{11}$ cm^{-2}.

IV. CONCLUSIONS

The results of modeling electrical characteristics of the device structure p-channel JFET showed acceptable agreement with the experimental data in the temperature range from 383 K to 223 K. The pinch-off voltage at 303 K is 1,31 V (measured at 1,29 V), the drain current is 3,9 mA (3,4 mA), for temperatures 383 K and 223 K the value of these characteristics is 1,49 V (1,43 V) and 2,85 mA (2,7 mA), 1,17 V (1,15 V) and 4,58 mA (2,68 mA), respectively.

Through a series of computer experiments, the assumption [6] of the equality of degradation effect introduced by electrons fluxes, neutrons and protons with a fluences F_E with an energy of E_E = 4 MeV, $F_N = 0{,}302 \cdot F_E$ with an energy of EN = 1,5 MeV or a fluence $F_P = 1.1 \cdot 10^{-4} \cdot$FE with an energy E_P = 2 MeV was checked.

Dependence of the degradation effect of influence particle flux on temperature is shown. For the considered device structure of the p-channel JFET, it has been established that, with decreasing temperature, the effect of the influence of electrons flux increases.

The results of the effect of particle flux on the width of leading and trailing edges when switching the device structure of p-channel JFET were given. The values of the fluences of electrons, neutrons and protons for which the change in the width of leading edge ceases to be linear ($F_E = 2 \cdot 10^{15}$ cm^{-2}, $F_N = 8 \cdot 10^{14}$ cm^{-2}, $F_P = 2 \cdot 10^{11}$ cm^{-2}) are determined.

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OPTIMIZATION OF STRUCTURAL AND TECHNOLOGICAL PARAMETERS OF JUNCTION FIELD-EFFECT TRANSISTOR WITH INCREASED RADIATION HARDNESS

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I. INTRODUCTION

The solution of process tasks [1] in creating a microelectronic radiation-hardened hardware components and the development of «special» circuity engineering [2] in recent years is given increased attention. Synthesis of high-quality analog ICs, that are low-sensitivity to the effects of penetrating radiation, is advisable to perform on bipolar transistors (BT) and junction field-effect transistors (JFET) with a large boundary frequency [3, 4]. The results of the investigation radiation hardness of ABMK version 1_2, (JSC