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RADIATION IMMUNITY OF THE PLANAR n-p-n-TRANSISTORS

Influence of streams of electrons, neutrons and γ—quantum is investigational on the amplification factor of bipolar planar-epitaxial transistors. It is shown that a preliminary thermal-electric-train allows to increase of radiation immunity in 2—3 times.

1. INTRODUCTION

The action of radiation around to solids brings to the origin of a number of effects: excitation of atoms and their ionization, nuclear transmutation birth of pair, is an electron-positron, displacement of atoms from the knots of crystalline grate in interstice space and other The change of electrophysics properties of silicon under the action of radiation (this, as a rule, compensation of conductivity [1]) associates both with the process of origin of initially-stable defects (divacancies, tetravacancies and other is similar defects) and second — as a result of quasi-chemical reactions (complexes of vacancies with admixtures by the alloying and concomitant admixtures of oxygen, carbon and other[2]). In particular, in *n*-Si, alloyed phosphorus, non-equilibrium vacancies, entering into the quasi-chemical reaction with alloying (phosphorus) or with base-line (oxygen, carbon) admixtures, and also between itself, form the second radiation defects[3].

Most effectively the reactions take place in the conditions of irradiation of γ—quantum Co^{60}, by electrons with energy 1 MeV, low-energy protons and other by particles energy of which in order of size is comparable with energy of origin of defects (by different estimations she makes for silicon 145-250 keV).

In scientific literature in detail all sides of work of bipolar transistors are lighted up at the irradiation. It is shown that none of parameters characteristic for them remains here unchanging. Nevertheless, distinctions appear substantial in the change of properties at the irradiation of alloyed transistors and structures got a diffusive method, in particular, planar-epitaxial transistors.

In the real work the comparative change of amplifying properties of the planar transistors of the same type is considered at influence of radiation by fast electrons, γ—quantum, fast neutrons.

2. METHOD OF EXPERIMENT

The experimental samples silicon *n-p-n*-transistors were made on planar-epitaxial technology. Specific resistance of initial epitaxial film $\rho = 0.5\ \Omega\cdot$cm. Before the leadthrough of thermal operations silicon epitaxial structures 15KEP was processed by boiling 5 min. in solution of $H_2O + H_2OH + H_2O_2$ (4:1:1). Then conducted oxidization of standards in a stove at $T=(1200\pm3)^0C$. Thickness of the growth layer SiO_2 it was 0.6 μ. This layer served as a mask at diffusion of the boron. After creation of oxyde masking film photolithography was conducted for diffusion of the coniferous boron (base). Boron spin-on was carried out at $T=940^0C$ in the atmosphere of argon for the receipt of sheet resistivity $R_s=60\ \Omega/\square$. For forming of base layer with the necessary distributing of concentration of dopant the drivi-in of dopant of the boron was conducted at $T=1150^0C$. Concentration of alloying dopant in a base $\sim1.5\cdot10^{18}$ cm^{-2}, depth of diffusive transition was ~3.5 μ. Photolithography was further conducted under the emitter of transistor. The region of emitter was created by diffusion of phosphorus from PCl_3 at $T=1050^0C$ in the atmosphere of oxygen. Depth of emitter diffusion was 2-3 μ. The thickness of base made ~1.5 μ. For forming of contact in area of base and emitter photolithography was conducted under the contacts. After it on the plate of silicon by cathode-ray evaporation coating the layer of aluminium in thick 1.5 μ. After lithography on metallization aluminium was firing at $T=550^0C$ in the atmosphere of argon during 15 min. The got structures were pressurized in a glass-to-metal corps.

The irradiation of structures was made by the stream of fast electrons Fe on the linear accelerating "Electronics" as ELU-4. Energy of electrons 5.0 MeV, current of irradiation 0.1-1.0 mA. The irradiation of samples was made at $T=60^0C$.

The irradiation by the streams of neutrons F_n with E=1.5 MeV was made in the horizontal channel of reactor of BBP-M. The thermal-neutron were chopped off by a cadmium filter. The fluence was 10^{11}-10^{15} $n\cdot cm^{-2}$.

The irradiation of γ—quantum was made from the source of Co^{60}. Intensity of γ—quantum (dose of D_γ) was 3500 R/s, middle energy of quantum — 1.25 MeV. The temperature of samples in the process of irradiation changed in an interval (293-330) ^0C.

Alloying of single-crystals planar-epitaxial of silicon by the ions of the boron with energy 30-100 keV to the doses 10^{14}-10^{18} $i\cdot cm^{-2}$ it was conducted on the accelerating setting "Vesuvius-1A" with the division on the masses.

3. RESULTS AND DISCUSSION

On descriptions of semiconductor elements determination of maximum streams is the practical purpose of any research of influencing of radiations at which an element falls out. There is a research task also development of technological methods of increase of these maximum values.

Amplifying properties of transistor are characterized by h_{21e}, the transfer coefficient of current h_{21e} equal to attitude of change of output current toward the change of entrance in a scheme common-emitter ($h_{21e}=I_c/I_b$). In this case we examine a transfer coefficient exactly h_{21e}, as it answers most amplification factor of power of transistor. As is generally known, it concernes by efficiency of emitter, coefficient of transfer and efficiency of collector.

In a scheme common-emitter h_{21e} measured a transfer (strengthening) current h_{21e} at tension on a collector $U_c = 3\,\mathrm{V}$ and current of collector $I_c = 3$ A. Temperature of measurings $T = 293\,\mathrm{K}$. Measurings were conducted for three parties of transistors (for three types of transfer got out with the identical value h_{21e}, each of which was exposed to the rays by a certain stream in a range 10^{12} - $10^{15}\,\mathrm{cm}^{-2}$, whereupon extracted a transistor from the chamber of irradiation and measured the value h_{21e}.

It was studied to dependence of mobility (fig.1), time of life of charge curriers (fig.2), and also specific resistance of collector, base and emitter (fig.3) from a radiation stream.

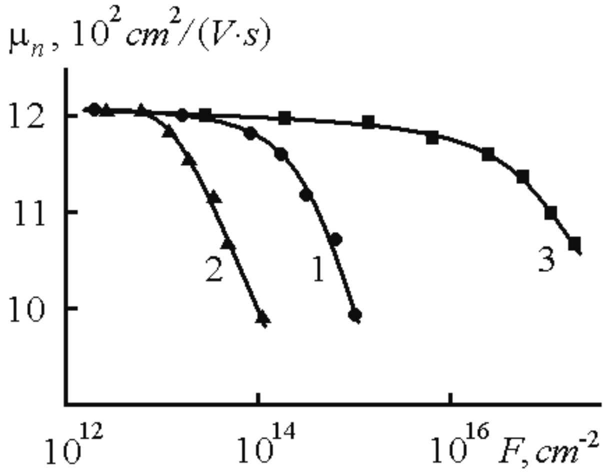

Fig. 1. Dependence of mobility of electrons in epitaxial layer of silicon with ρ = 0.5 Ω·cm from the stream of electrons (1), fast neutrons (2) and γ—quantum (3)

The slump of mobility and of life time of charge curriers under the action of radiation decreases length of diffusion $L_{n,p}$, and accordingly the transfer coefficient of current of transistor, as $h_{21e} \sim L_{n,p}/w^2$. At the same time the thickness of base *w* changes at the irradiation. The growth of specific resistance of collector, base and emitter (fig. 3) corresponds to decreases of concentration of charge curriers in a semiconductor at the irradiation [1]. It results in displacement of collector deep into semiconductor, i.e. increase *w*. It is special shows up in structures with a thin base, as in our case ($w \approx 1.5$ μ).

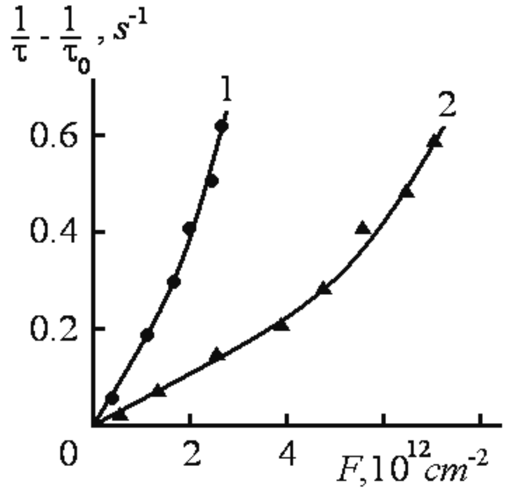

Fig. 2. Change of life time of electrons in the *p*-base (1) and holes in the *n*-collector (2)

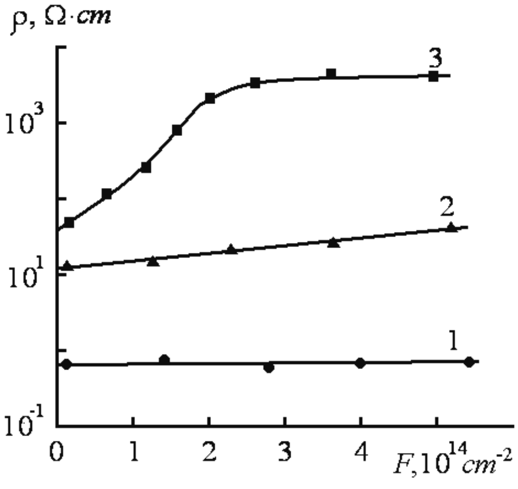

Fig. 3. Change of specific resistance collector, base and emitter at the irradiation by neutrons: 1— *n*-collector (ρ = 10 Ω · cm), 2 — *p*-base (ρ = 10^{-2} Ω · cm), 3 — *n*-emitter (ρ = 10^{-3} Ω · cm)

On a fig. 4 dependence of the transfer coefficient of current h_{21e} of planar transistors is shown on the stream of electrons, neutrons and γ—quantum. It ensues from the graphs, that thresholds values of radiation streams which the sharp decreasing of strengthening of transistor is after, make accordingly: for the stream of electrons $5\cdot10^{14}$ $e\cdot cm^{-2}$, for the neutrons of 10^{13} n cm^{-2}, for γ—quantum 10^{6} R. Physical reason of decreasing h_{21e} under the action of radiation is the origin of defects in the crystalline structure of semiconductor, which shunt emitter *p-n*-junctions and reduce its coefficient of injection, and also decreasing of life time of charge curriers in the base of transistor.

The graphs of fig. 4 correlates with the dependencis of pictures 1, 2 and 3. It ensues from these dataes, that with the increase of maximum frequency of transistors their radiation immunity is increased. We will remind, that maximum decreased is frequency on which the transfer coefficient of current h_{21e} diminishes in $\sqrt{2}$ one times. In the scheme of including common-emitter maximum frequency concernes by effective time of life of transmitters of charge (inversely proportional). At planar, i.e. diffusive transistor of *n-p-n*-type maximum frequency higher, than at driveable, therefore and radiation immunity higher.

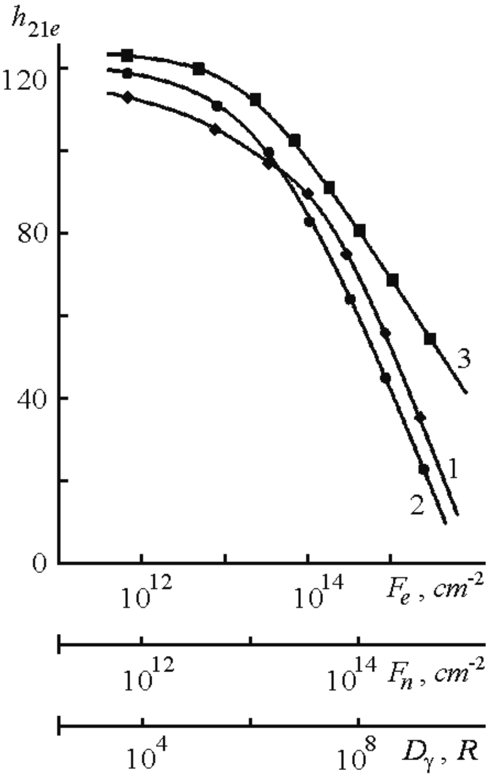

Fig. 4. Influencing of streams of electrons, neutrons and γ—quantum on the transfer coefficient of current h_{21e}

For the increase of radiation immunity of transistors we used the method of thermal-electric-train (TET). Co-operation of radiation streams with a semiconductor it is possible to examine by consisting of two stages. On the first stage (at small energies of stream) a radiation operates on technological defects appearing in material at creation of transistor, and on the second (at large energies) the own defects of crystalline structure are created. The creature of method consists of that at ТЭТ technological defects and parameters of transistor collapse at the small streams of radiation does not change.

Experimental verification of method of TET was carried out as follows. Transistors were heated to 125^0 C and was simultaneously exposed to periodic electric influence with power in 2.5 time greater, than passport maximal power. Self-control was conducted at maximal influence about 5 min. with a period 20 min. Research of influencing of radiation streams on the parameters of transistors, that after TET during 40—60 hours thresholds values of radiation streams resulting in the sharp decreased h_{21e}, is increased more than in 2 times. The got results talk about the change of terms of second radiation residual damage as a result preliminary thermal and TET treatments of transistors structures.

As the structure of investigational transistors does not differ from transistors in the integrated circuits, phototransistors and etc, the considered method of increase of radiation immunity is applicable to these semiconductor devices.

4. CONCLUSIONS

The thresholds streams of electrons, neutrons, γ—quantum for *a* planar *n-p-n*-transistor make $5 \cdot 10^{14}$ *e* cm^{-2}, 10^{13} *n* cm^{-2} and 10^{6} *R*, accordingly. For the increase of radiation immunity of transistors the method of thermal-electric-train can be used.

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Abstract

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РАДИАЦИОННАЯ СТОЙКОСТЬ ПЛАНАРНЫХ n-p-n-ТРАНЗИСТОРОВ

Резюме

Исследовалось влияние потоков электронов, нейтронов и γ-квантов на коэффициент усиления биполярных планарно-эпитаксиальных транзисторов. Показано, что предварительная электротермотренировка позволяет увеличить радиационную устойчивость приборов в 2 раза.

Ключевые слова: нейтроны, радиационная стойкость, транзистор.

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РАДІАЦІЙНА СТІЙКІСТЬ ПЛАНАРНИХ n-p-n -ТРАНЗИСТОРІВ

Резюме

Досліджувався вплив потоків електронів, нейтронів і γ –квантів на коефіцієнт підсилення біполярних планарно-епітаксійних транзисторів. Показано, що попереднє електротермотренування дозволяє підвищити радіаційну стійкість приладів в 2 рази.

Ключові слова: нейтрони, радіаційна стійкість, транзистори.