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Investigation of the Irradiation Influence with High-energy Electrons on the Electrical Parameters of the IGBT-transistors

V.N. Murashev, M.P. Konovalov, S.A. Legotin, S.I. Didenko, O.I. Rabinovich, A.A. Krasnov, K.A. Kuzmina

National University of Science and Technology 'MISiS' "Moscow Institute of Steel and Alloys", 4, Leninskiy prosp., 119040 Moscow, Russian Federation

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The results of studies of the effectiveness of the radiation method for control the characteristics of the IGBT transistors are shown. Experimental results on the effect of irradiation with high-energy electrons with an energy of 6 MeV for dynamic and static parameters of the IGBT transistors of company International Rectifier IRGB14C40L are discussed.

Keywords: IGBT-transistors, Irradiation, Systems, Radioisotope.

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1. INTRODUCTION

Bipolar transistor with insulated gate (IGBT) – is a "workhorse" of modern power electronics. IGBT is a combination of functionally-integrated power semiconductor device and is classified as bipolar field devices and is designed to work in a key mode.

A combination of two devices in one structure allowed to combine together the advantages of bipolar and field transistors:

– Ease of operation of MOS transistors;

– Low conduction losses that typical of bipolar transistors.

Today IGBT-transistors are produced by dozens of companies (International Rectifier, Semikron, Infineon Technologies, ON Semiconductor, Fairchild Semiconductor, Ixys, STMicroelectronics, Mitsubishi and others.).

Working to improve the IGBT transistor intensive course and scope of these devices is expanding rapidly.

The main field of application of these transistors – is frequency control of asynchronous electric drives designed for automatic frequency control of a broad class of machines and mechanisms in various fields utilities, industrial and special production: pumps, fans, compressors, drive, conveyors, hoists, centrifuges, saws and others. Frequency selection control in electric is determined by the dynamic losses IGBT transistors with increasing frequency the power loss increases when switching and the crystal is heated above the allowable temperature. In this regard, the developers of IGBT transistors understand a problem to minimize as far as possible the dynamic power losses which are determined mainly by the time off.

Congenital defect of IGBT transistor is the presence of the "tail" of the residual collector current when turning off the transistor due to the finite lifetime of the minority carriers in the base of the power transistor p-n-p. When the collector current decreases large power loss occurs due to the fact that the IGBT transistor at this time has a relatively high voltage. Therefore it is extremely important to reduce the length of the "tail" of the collector current. Since the IGBT transistor is off with a broken base, then speeding up the turn-off time schematics methods cannot be achieved [1-4]. Continuous improvement of designs and IGBT technology have led to the creation of transistors with operating frequencies of 100 kHz or more.

To reduce the lifetime of minority carriers in the n-region and to improve the performance of devices irradiation with high-energy particles was used.

A number of foreign companies (e.g. "Mitsubishi", etc.) uses the method of proton irradiation, allowing without change in the lifetime of the charge carriers in the bulk of the epitaxial n-layer locally to reduce its buffer n^{+} layer [5]. This allows increasing the speed of devices at relatively low voltage collector-emitter saturation. This technology, firstly, require expensive equipment, and secondly, it leads to doping of the n-region by shallow donors (hydrogen), which at integral large flows may reduce the breakdown voltage of the device. A much more efficient and economical result is the usage of radiation processes using high-energy electrons. Advantages of this type of radiation treatment following [6-8]:

– High uniformity generation of primary displacements in the entire volume of the crystals and structures;

– No significant displacement cascade processes of formed areas of disorder;

– Complete absence of induced radioactivity and the introduction of additional chemical contaminants through photonuclear reactions;

– The speed of the process;

– Ease of use and ease of electron accelerators, the ability to handle large batches of structures without vacuum (in the air), the low cost and high efficiency of the process of radiation treatment.

2. EXPERIMENTAL PROCEDURES

The testing IGBT transistors of the company International Rectifier type IRGB14C40L were irradiated with high-energy electrons with $E = 6$ MeV in the range of the integral fluxes $F = (1\text{-}20)\cdot 10^{14}$ cm^{-2}.

During irradiation the test IGBT transistor it is a significant reduction in the time off, due to the decrease of the lifetime of minority carriers in the base of the power *n*- vertical *p-n-p* transistor due to the introduction of deep radiation centers of different physical nature.

The processed averaged (10 samples) results of measurements off time for the IGBT transistor IRGB14C40L at various integrated fluxes of high-energy electrons are shown in Fig. 1.

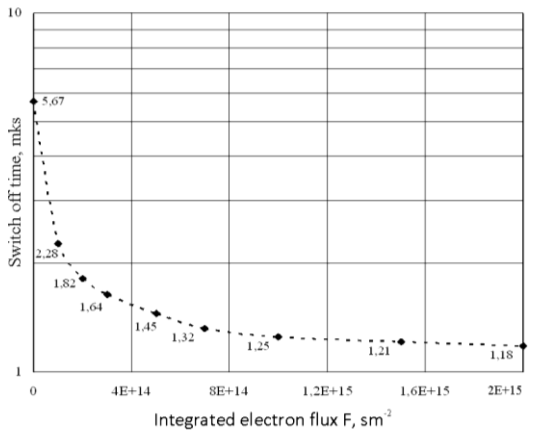

Fig. 1 – The dependence of the turn-off time of the IGBT IRGB14C40L ion integral flux of electrons

Due to the unavailability of basic n-region it was not possible to get X-ray diffraction structure spectra to determine the electrophysical parameters prevailing in her radiation centers. However, based on published data, as well as some experimental work in the nature of the radiation centers of the n-silicon [6-7], we can conclude that, apparently, they are centers (V·P), (C·V·O), (V·V) and others involving vacancies and residual impurities (oxygen, carbon).

Along with a reduction in off time and increasing operating frequency during irradiation it is deterioration (increase) in the main static parameter IGBT transistors - voltage collector-emitter saturation. The dependence of the saturation voltage collector-emitter of the IGBT IRGB14C40L RTP modes is shown in Fig. 2.

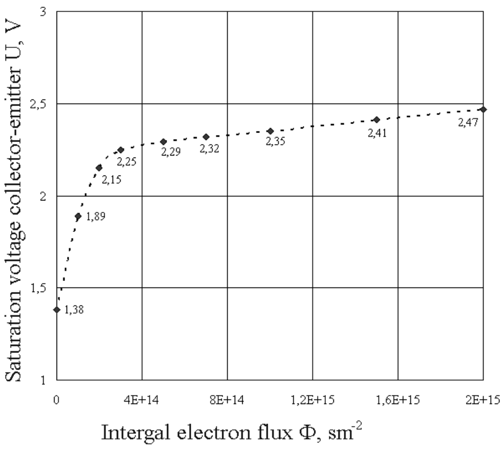

Fig. 2 – The dependence of the saturation voltage for collector-emitter voltage of the IGBT IRGB14C40L integral flux of electrons

In general, the value of the voltage collector-emitter saturation in the IGBT transistor is determined by the following components: the bias voltage of the collector *p-n* junction (it is usually 0.7÷0.9 B, at which there is a noticeable hole injection from the p^+ collector), the voltage drop across the resistance modulating *n-* base and voltage drop across the MOSFET structure.

The magnitude of the voltage drop across the MOS structure is determined by the resistance of the channel MOS structure and resistance low modulated area between MOS elements of cells.

Upon irradiation of IGBT transistors it is compensated the main dopant in the *p*-layer and the *n*-epitaxial layer radiative centers, resulting in an increased resistivity of these areas, which leads to an increase in the voltage drop in these regions. The main contribution to the increase in voltage collector-emitter saturation voltage drop makes for a sufficiently thick epitaxial *n*-layer.

IGBT control part is a field effect transistor with an induced *n*-channel. Unlike bipolar devices operating on the principles of current-carrying minority carriers and changing parameters under irradiation mainly due to the introduction of deep radiation centers in the volume of the device structure, MOS devices operate on the principle of current transport by the majority carriers in the surface layer of the silicon and the mechanism of degradation of their parameters, the main of which is the threshold voltage of the gate-emitter, under the irradiation is mostly superficial “charge” in nature.

Range in the threshold gate-emitter voltage (decrease) of IGBT transistors during irradiation with high-energy electrons is mainly due to the accumulation of positive charge in the dielectric volume and an increase in the density of surface states at the Si-SiO_2. This contributes to the induction of electrons in the channel of the device at lower gate voltages. Dependence of the threshold voltage of the gate-emitter investigated the IGBT depending on the integral flux of electrons is shown in Fig. 3.

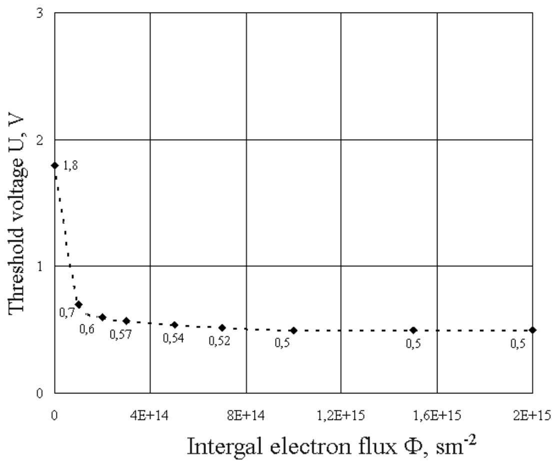

Fig. 3 – The dependence of the threshold voltage of the gate-emitter voltage of the IGBT IRGB14C40L on integral flux of electrons

3. RESULTS AND DISCUSSION

One of the most important characteristics of the IGBT transistor, used in power converter circuits, is the ability to block high voltages. In order to exploit the IGBT transistor live off, the shutter must be closed to the emitter. This prevents surface inversion layer formed under the gate. When voltage is applied to the collector, IGBT transistor can withstand a lot of stress, because the transition p^-n^- becomes reverse biased. The depletion layer extends from the transition in both directions. Thus space charge region (SCR) *p*-layer should not interlock with the n + emitter region, and in *n*-layer - a p^+ collector region.

When the boundary SCR, passing through *n*-layer reaches the high doped n^+ buffer layer further extension of the SCR becomes impossible, begins to grow, the electric field in the *n*-layer and can occur avalanche breakdown. The permissible operating voltage of IGBT transistor (not leading to a breakdown) determined by the size of *n*-drift layer and its doping. Thus, by varying the concentration of the dopant in this layer, it is possible to control the value of the breakdown voltage. When radiation treatment by compensating dopant layer n^- administered radiation centers the electrical resistivity of the area increases and, consequently, the breakdown voltage.

The dependence of the breakdown voltage of the collector-emitter investigated the IGBT depending on the integral flux of electrons is shown in Fig. 4. From this dependence it is seen that irradiation of the breakdown voltage of the collector-emitter voltage increases on average by 15 %.

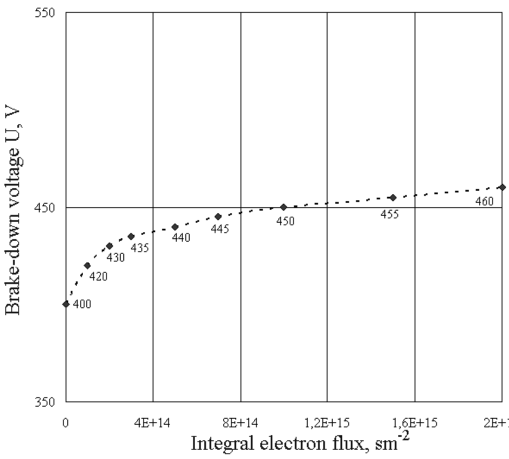

Fig. 3 – The dependence of the breakdown voltage of the collector-emitter voltage of the IGBT IRGB14C40L on integral flux of electrons

The experimental results to change the main static and dynamic parameters of the IGBT IRGB14C40L by irradiation with high-energy electrons allow to conclude that the use of the radiation method allows efficiently to manage the electrical characteristics of the transistors of this type, to get the optimal combination of static and dynamic parameters, depending on the requirements of development of electronic equipment.

Operation of irradiation with high-energy electrons should be carried out directly in the manufacturing process flow of IGBT transistor. After, radiation (before putting in a crystal coverage) it is necessary to carry out thermal annealing for adging unstable radiation centers and to provide the optimal balance between time off and voltage collector-emitter saturation.

To select the optimal mode of operation of the radiation process (irradiation and subsequent thermal annealing) to obtain the best combination of complex electrical parameters of the IGBT it is necessary to analyze the power dissipation for operating the IGBT transistor under operating conditions (optimal regimes will be those that provide a minimum power dissipation).

4. SUMMARY

Optimal modes of radiation process will provide a more comfortable mode of IGBT by the minimum value (compared to the original device) power dissipation and a significant improvement in a number of electrical parameters with a slight increase of static parameters that determine the direct loss.

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