THE PROTON FLUX INFLUENCE ON ELECTRICAL CHARACTERISTICS OF A DUAL-CHANNEL HEMT BASED ON GaAs

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I. INTRODUCTION

The Element base of modern objects of space and nuclear technology is exposed to ionizing radiation, the main of which are gamma rays (γ), neutron (n), electron (e) and proton (p) radiation. Alfa-particles (α), fission fragments Fp and other particles from a nuclear reactor or nuclear explosion zone can also influence the degradation of performance characteristics. However, their influence is not so significant (for example, neutrinos, mesons, etc.).

When a particle flux affects microelectronic device structure, two main mechanisms are possible: ionization and damages caused as a result of elastic scattering of primary particles and fragments formed in nuclear reactions (inelastic scattering) of incident protons or neutrons on target's nucleuses. Ionization is not considered in this work. The magnitude of the manifestation of displacement effects depends on the type of particles radiation, the total dose, radiation flux and energy, ambient temperature, operating voltage, the state of the device at the moment of irradiation. These problems complicate testing, increase the complexity of using theoretical calculations to predict radiation effects, increase the time of designing device structures and require a significant number of test samples.

II. RESULTS

A typical device structure of a dual-channel GaAs-based high electron mobility field effect transistor (HEMT) is shown in figure 1. Cut-off voltage and maximum drain current for the resulting structure at ambient temperature T = 303 K are equal to V_{TH} = -0.9 V and I_{Dmax} = 1.7 mA (at drain voltage V_D = 0.1 V and gate V_G = 1 V) respectively.

The formation of bulk defects in semiconductor device structure is proportional to non-ionizing energy loss (NIEL) - total kinetic energy transferred to the lattice atoms. Parameter NIEL can be used to the extrapolation of device parameters degradation measured for particle with given energy to other energies ("NIEL scaling"). The Radiation Fluence Model is used in microelectronics TCAD software packages to describe the impact of particle flux on material characteristics, which makes it possible to predict the rate of defect generation.

According to the model the total density of defect states depends on the radiation flux, NIEL, damage coefficient and the density of material. The non-ionizing energy losses for GaAs are determined using SR-NIEL project for displacement threshold energy values Ed1 = 9,5 eV [3], Ed2 = 10 eV [4], Ed3 = 21 eV [5] and Ed4 = 25 eV [6]. For the obtained values mean values were determined, which are described by approximating dependence (figure 2). The obtained results fully agree with the data presented in the paper [7]. The total NIEL for GaAs is calculated by summing the contributions of each element weighted by its atomic fraction [8].

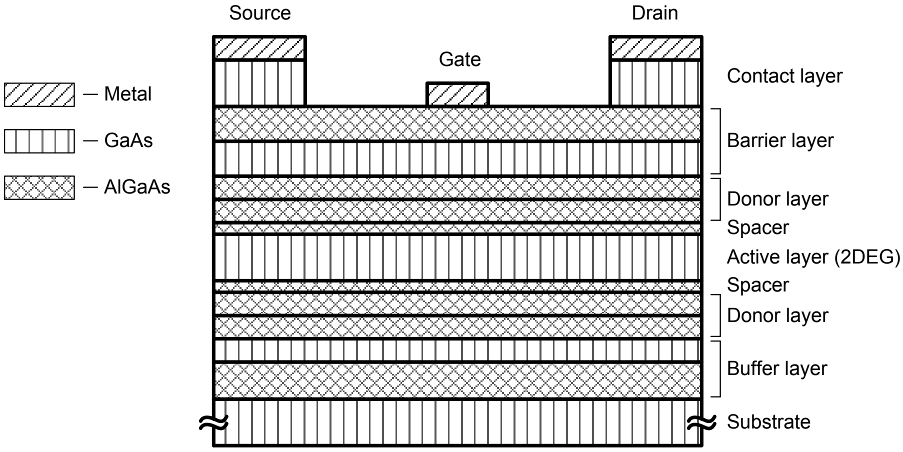

Figure 1. Device structure of a dual-channel GaAs-HEMT

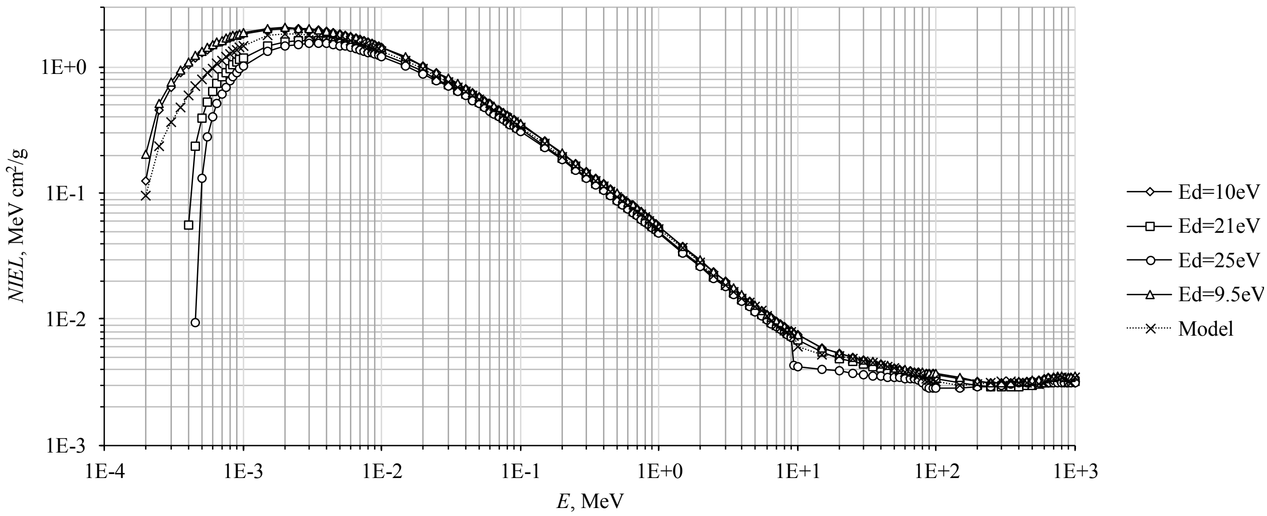

Figure 2. The dependence of non-ionizing energy loss on the proton energy

A simulation of the effect of proton flux on the performance characteristics of a dual-channel GaAs-based HEMT device structure was carried out. The results obtained are in agreement with theoretical data for the flux of protons with energies E_p from 0.1 to 10 keV at temperature T = 303.

III. CONCLUSIONS

The model of the dependence of NIEL on the proton energy with different values of threshold energy of defect formation for GaAs and AlGaAs, that are described in the literature and comply with the latest theoretical and experimental data, has been developed.

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REFERENCES

[1] V.M. Kulakov, E.A. Ladygin, V.I. SHahovcov, "Dejstvie pronikayushchej radiacii na izdeliya elektronnoj tekhniki", Sov. Radio, C. 224, 1980. [in Russian]

[2] http://www.sr-niel.org/index.php.

[3] E. Mansouri, "Studies on Radiation-induced Defects in InP/InAsP Nanowire-based Quantum Disc-in-wire Photodetectors", Halmstad University, P. 48, 2018.

[4] D. Pons, P.M. Mooney, J.C. Bourgoin, "Energy Dependence of Deep Level Introduction in Electron Irradiated GaAs", J. Appl. Phys, Vol. 51, pp. 2038-2042, 1980.

[5] E.E. Allam [et al.] "Gamma and Electron NIEL Dependence of Irradiated GaAs", NSREC, P. 7, 2016.

[6] C. Claeys, E. Simoen, "Radiation effects in Advanced Semiconductor Materials and Devices", Springer, P. 404, 2002.

[7] N.J. Chen, "Computational simulation of threshold displacement energies of GaAs", J. Materials Research, Vol. 32, Issue 8, pp. 1555–1562, 2017.

[8] J.F. Ziegler, J. P. Biersack, U. Littmark, “The Stopping and Range of Ions in Solids”, Pergamon, P. 321, 1985.