SMALL-DOSE EFFECTS ON ELECTRICAL CHARACTERISTICS OF AlGaN/GaN MICROWAVE TRANSISTORS

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Effect of small dose gamma-irradiation on electrical characteristics of AlGaN/GaN high electron mobility transistors has been investigated. Decreasing of the leakage current and its noise has been registered after dose of $1x10^6$ Rad. As-grown heterostructures used in further for the device fabrication have been examined after the same radiation treatment. The small dose radiation results are explained within a model that takes into account relaxation of elastic strains and structural-impurity ordering occurring in the barrier layer under irradiation.

Introduction

Microwave transistors manufactured on the basis of AlGaN/GaN heterostrustures demand for improvement of material characteristics to attain high power and high-speed operation. Today, GaN-based High Electron Mobility Transistors (HEMTs) possess still comparative high level of leakage current due to large dislocation density and material layers imperfections [1-3]. To decrease the leakage current an intermediate dielectric or ferroelectric layers have been grown before metalization to the barrier region [4, 5]. However, these layers result in lowering of the operating frequency due to an increase of the device capacitance. In this contribution we report an investigation of structural, transport and noise properties of HEMTs irradiated by gamma-quanta. At a certain dose of gamma irradiation an improvement of barrier properties of the transistors was revealed. The origin of observed effects is discussed.

Experimental details

The investigated structures are high performance AlGaN/GaN HEMT devices grown by organic metallic vapour phase epitaxy on sapphire substrates. Each structure consists of the following layers: a nucleation AlN layer, an undoped GaN buffer layer and an AlGaN (33% Al) undoped barrier layer. The devices with several gate lengths (150-350 nm) and widths (100-400 μm) were investigated. Detailed description of the structures preparation as well as characterization of materials and devices studied have been reported elsewhere [6, 7].

The transistor dc characteristics were investigated with a HP4145B Semiconductor Parameter Analyzer operated in transistor mode. The noise spectra were measured in the frequency range from 1 Hz to 100 kHz by HP35670A Dynamic Signal Analyzer using a low-noise preamplifier ITHACO1201. All measurements have been carried out at room temperature.

Structural characterisation of the heterostructures has been performed by x-ray diffraction (XRD) and secondary ion mass spectroscopy (SIMS).

The gamma irradiation was provided by ^{60}Co gamma rays at room temperature with doses in the range of 10^4-10^9 Rad and flux of 10^2 Rad/s. The gamma quanta average energy was about 1.2 MeV.

Results and discussion

Recently [6, 7], we have reported about enhanced radiation hardness of GaN-based HEMTs that has good prospects in exploitation of the devices in radiation environment. Moreover, an improvement of the principal parameters of the HEMTs, such as the saturation current and transconductance, was registered after a dose of $1x10^6$ Rad. It has been assumed the effect is related to relaxation of strains existing in mismatched heterostructures and structural ordering of native defects. To verify this suggestion we performed comparative study of structural and electrical characteristics of AlGaN/GaN HEMTs under small dose irradiation. Simultaneously, as-grown heterostructures used in further for the device fabrication have been examined after the same radiation treatment.

Except above mentioned improvement of the dc parameters of the HEMTs after a low dose irradiation, there were negligible changes in the transfer characteristics. The peak position of the transconductance curve and the threshold voltage show a weak shift (~5%) towards lower (in absolute values; over the whole paper we deal with the gate biased negatively) gate voltages. More remarkable finding is considerable decrease of dispersion of the transfer characteristics measured on set of the transistors patterned on the same wafer (Fig.1). This is consistent with the higher uniformity of the irradiated heterostructure relative to non-radiated one.

To gain insight into structural transformation of the heterostructure during irradiation, x-ray diffraction of the wafers was performed at room temperature.

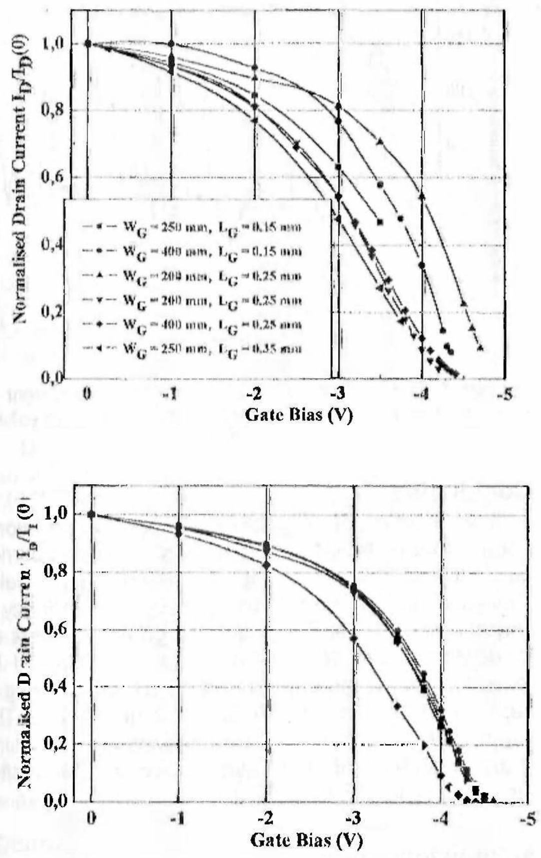

Fig. 1. Normalised transfer characteristics for set of pre-radiated (upper) and irradiated at $1x10^6$ Rad HEMTs. U_{SD} = 100 mV, T =300K

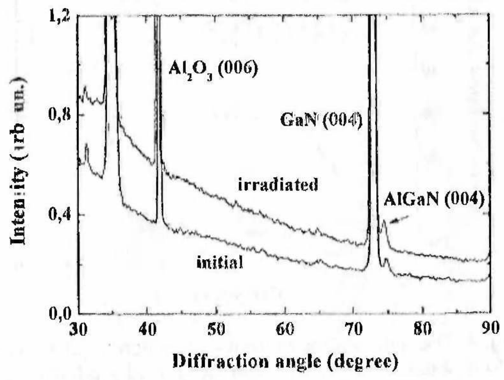

Fig. 2. X-ray diffraction spectra for AlGaN/GaN heterostructure before and after $1x10^6$ Rad irradiation

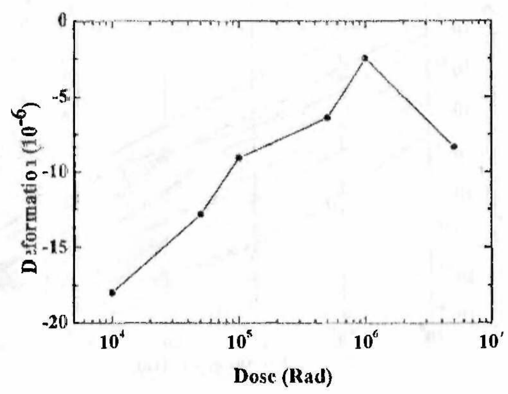

Fig. 3. Dose dependence of elastic strains of the AlGaN layer

Figure 2 shows the x-ray diffraction spectra of the AlGaN/GaN/Al_2O_3 wafer before and after $1x10^6$ Rad dose. It is worth to note the changes occurring with the reflection around the 74^0 (the reflection corresponds to the (004) plane of the AlGaN layer). Although the intensity of the peak is low, it is clearly seen its increasing and shift to lower 2Θ position after irradiation. The later should be considered as a result of strain relaxation in the AlGaN layer. To prove this statement direct measurement of elastic strains existed in the heterostructure has been carried out. An integrated method for measuring of surface curvature, R was used to estimate the elastic strains [8]. The method consists in measurement of angle shift, α, of the diffraction maxima at translation of the sample on certain distance, l. The results of these measurements are presented in Fig.3. Negative sign corresponds to tensile stress in the AlGaN layer. It is clearly seen that strain relaxation does occur up to doses of $1x10^6$ Rad.

Results of structural measurements fairly agree with the electrical behaviour of the transistors. In particular, considerable decrease of leakage current was established after low dose irradiation (Fig.4). The latter is accompanied by a decrease of leakage current noise. Due to its important role in the device performance we paid special attention to these measurements. We concentrated on peculiarities observed in the low frequency generation-recombination (GR) noise that is additional to 1/f noise because it was suggested that the features are connected with current flowing through the AlGaN barrier region and detailed study will allow to investigate microstructure of the barrier layer and processes responsible for leakage current formation. It is necessary to point out that Si_3N_4 passivation of the surface of the devices has been implemented to eliminate the surface leakage. Noise characteristics of the HEMTs were measured in both standard and non-standard set-ups. In the former case the source (or drain) was grounded, the gate bias was supplied by a voltage source with zero impedance, and the noise voltage was taken on ungrounded channel output. In the latter case both source and drain were grounded, the gate bias was supplied via a load resistance, and the noise voltage was taken on the gate output. These measurements were done to separate the contribution of channel current and leakage one. Room temperature noise spectra of the channel current were investigated in the linear regime at different drain and gate voltages.

The noise spectra of leakage current measured for pre-radiated device are shown in Fig.5. The spectra were measured in the regime with grounded source and drain and the noise voltage taken on the gate output. The shape of the spectra resembles that of a Lorentzian expected for GR noise. The temporal

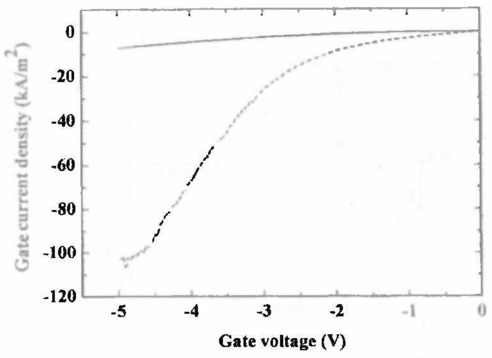

Fig. 4. The gate-source current as function of gate voltage before (dashed curve) and after 1x10^6 Rad irradiation (solid curve) measured at 300 K.

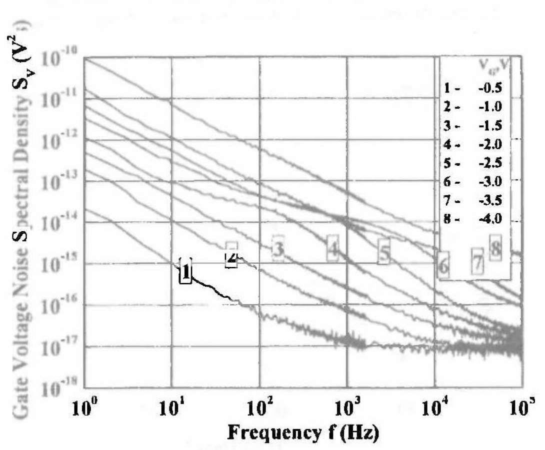

Fig. 5. The noise spectra of leakage current for pre-radiated HEMT measured at 300 K in the regime with grounded source and drain and the noise voltage taken on the gate output. The gate width and length are 250 μm and 0.15 μm respectively.

dependence of leakage current behaves itself like random telegraph signal (RTS) noise. It Is seen in Fig.6 that RTS noise shows a very complex switching behaviour. It should be noted that increasing of the gate voltage gradually transforms frequency of the RTS series. Analysis of the leakage current noise spectra shows that observed RTS noise is caused by fluctuations of charge accumulated on defect centers randomly distributed in the barrier layer. The measurements done on irradiated devices reveal reduced level of the leakage current noise. Its temporal dependence is characterized as more stable and in most cases the RTS noise did not appear. All these findings are consistent also with proposed mechanism of structural-impurity ordering that occurs in the barrier layer at initial irradiation stages.

It should be noted out that level of the channel current noise slightly increases even at small irradiation doses but these changes do not affect seriously on the reliable performance of the AlGaN/GaN HEMTs. The study of radiation effects on the channel current noise is beyond the scope for the present paper. This issue will be addressed in a separate publication.

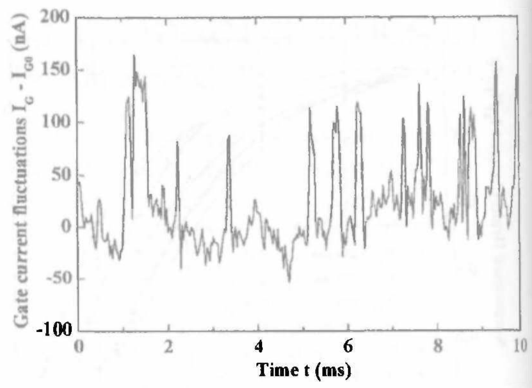

Fig. 6. The temporal dependence of leakage current measured for pre-radiated HEMT at 300 K and gate voltage U_G = -3 V.

Conclusion

Investigation of small dose effects on operational parameters of AlGaN/GaN HEMTs has been carried out. It is shown that transport and noise characteristics of the transistors reveal a tendency to improvement under irradiation by gamma-quanta up to doses of 10^6 Rad. The effect is explained by relaxation of elastic strains and structural ordering of native defects in the AlGaN barrier layer. The suggestion is confirmed by results of structural characterization of as-grown heterostructures after the same radiation treatment.

Acknowledgements

This work is supported by the Office of Naval Research under Grant No. N00014-01-1-0828 (Project Monitor Dr. Colin Wood). A.E.Belyaev acknowledges the Deutsche Forschungsgemeinschaft for research grant.

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