INVESTIGATION OF ELECTRICALLY ACTIVE DEFECTS IN INALGAN/GAN/SIC HEMT

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Abstract *This paper presents results of investigation of electrically active defects in innovative HEMT structures with InAlGaN/GaN barrier by Deep Level Transient Fourier Spectroscopy (DLTFS). The experiments were performed on the barrier structures, InAlGaN/GaN HEMT structures grown on N$^+$ doped SiC substrate with a semi-isolating epitaxial SiC layer and with AlGaN back-barrier between the AIN nucleation layer and the GaN buffer with FAT, GTML and Schottky gate contacts. Parameters of five defects were determined from the measured spectra in FAT structures, six defects in GTML structures and nine defects in Schottky structures. The presence of nitrogen-vacancy, dislocation, nitrogen in off-grid position as well as C/O/H impurities was confirmed in all structures. We assume that the difference in the distribution of defects in the case of GTML structure is the manifestation of edge gate effects.*

Keywords DLTFS, InAlGaN, HEMT, GTML, FAT, Schottky barrier

1. INTRODUCTION

The current research effort is aiming to significantly improve the performance and the cost of GaN-based millimetre wave components and devices. The AlGaN/GaN HEMT with 1×10^{13} cm^{-2} 2DEG carrier density is the standard solution. The changing of the AlGaN/GaN barrier to InAlGaN/GaN has the potential to achieve carrier density up to 2.5×10^{13} cm^{-2} and also higher mobilities. Thanks to InAlGaN/GaN HEMT has higher power densities and thus better power performance than AlGaN/GaN HEMTs [1]. Price reduction can be achieved by changing of SiC semi-insulating substrates to an N$^+$ doped SiC substrate with a semi-insulating epitaxially grown SiC layer. These cheaper N$^+$ doped SiC substrates are usually used by power electronics and LED industries [2]. The insertion of an AlGaN back-barrier structure is one of the solutions for reducing the short-channel effects without needing additional top-barrier scaling, which significantly improves performance [3]. With the usage of the InAlGaN barrier can the structure overcome the high strain state, which is observed in the AlGaN barrier, and alloy disorder scattering issues in InAlN barriers [4].

The DLTFS [5] is one of the most used methods for identification of electrically active defect states and their parameters. These defect states have a crucial influence on the quality of devices. The main aim of this work is to present results of defect analysis, realize on InAlGaN/GaN/SiC heterostructures grown on N-doped SiC substrate with epitaxial growth semi-insulating SiC layer with the use of the DLTFS method.

2. EXPERIMENTAL SETUP

Three types of test barrier structures, a large Schottky diode, a FAT FET (Fat Field Effect Transistor) and a GTML transistor with a gate length of 30 μm were prepared by the MOCVD (Metal Organic Chemical Vapor Deposition) process on a Norstel N^+ doped SiC substrate with a 95.3 μm thick semi-insulating natural high resistivity SiC epi-layer. The epi stack of investigated structures (Fig. 1a) consisted of (from bottom to top): an AlN nucleation layer, an MQW (Multiple Quantum Well) AlGaN/GaN layer, a 0.8 μm GaN buffer layer, a carbon-doped AlGaN back-barrier, a 150 nm GaN channel layer, a 1.2 nm AlN interlayer, and a 6.2 nm InAlGaN top barrier layer. Ohmic contacts were prepared with a TiAlNiAuTiPt stack and were annealed at 850°C (about 0.55 Ω.mm). The gates were the metalized with NiPtAu (a Schottky diode 200×200 μm, a FAT FET, 200×100 μm and a GTML transistor 30×145 μm). The differences in areas are close to the measured values of capacitance (Fig. 1b). The electrical isolation of these devices was realized by Ar implantation. The next stage was the passivation of these two wafers with a bilayer of SiN_X. After locally etched the passivation by RIE (Reactive-Ion Etching) plasma, a TiPtAu stack was deposited for interconnection [2].

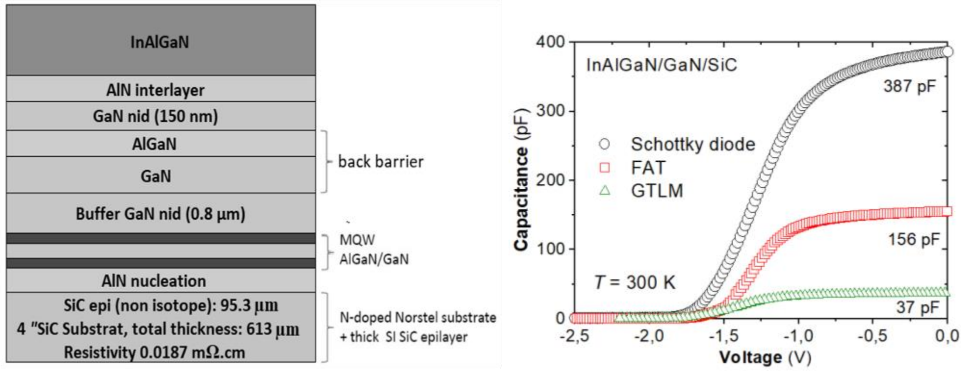

Fig. 1 a) Schematic description of the layer structure of investigated samples, b) Comparison of Schottky diode, FAT FET and GTLM transistor CV characteristics.

All measurements were performed using the measurement system BIO-RAD DL8000 DLTFS at the Institute of Electronics and Photonics. The obtained DLTFS spectra were evaluated by Direct Arrhenius Analysis. The basic parameters of deep energy levels (activation energy ΔE_T (eV) and capture cross-section σ_T (cm^2)) were calculated from obtained Arrhenius plots.

3. RESULTS AND DISCUSSION

Measured DLTFS spectra showed complex defects states, hence the interaction of mutually present deep energy level responses (Fig. 2). The parameters of twenty deep energy levels were identified from measured DLTFS spectra (Fig. 3): nine in Schottky diode, five in FAT FET and six in GTLM transistor. 13 of them were published in [6].

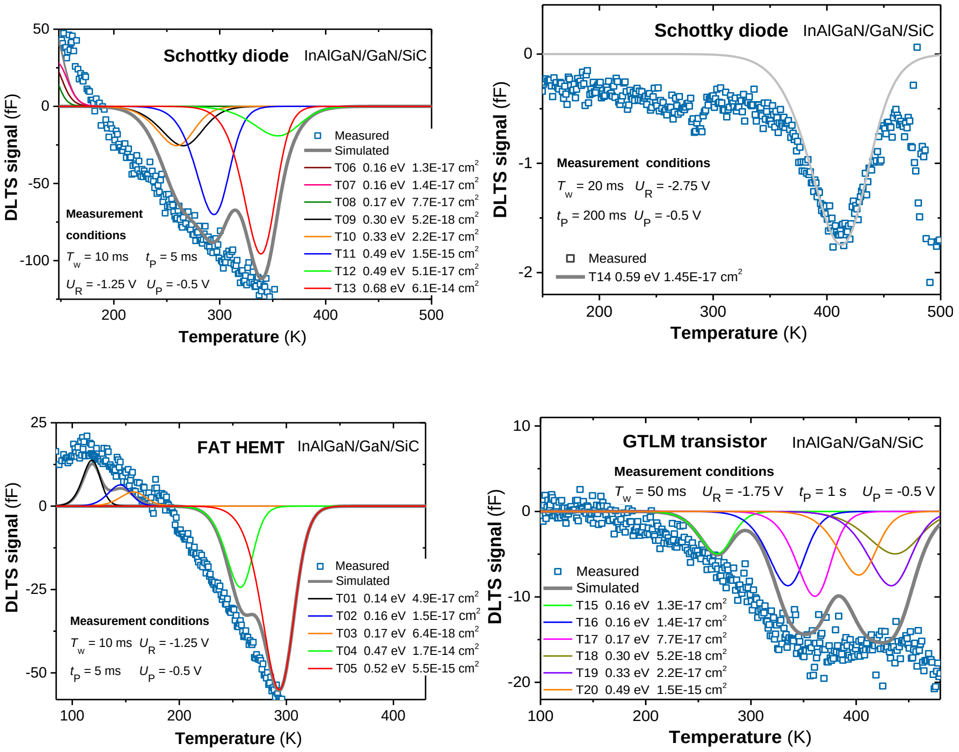

Fig. 2 Deep energy levels identified in Schottky diodes, FAT FET and GTLM transistor (measured DLTFS spectrum, measured parameters, calculated values of activation energy and cross captures and simulated curves for identified deep energy levels).

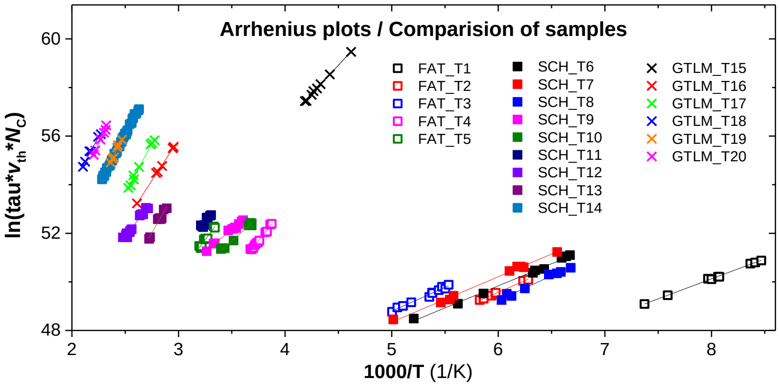

Fig. 3 Arrhenius plots of twenty identified deep energy levels in all three types of InAlGaN/GaN HEMT structures: Schottky diodes, FAT FET and GTLM transistor.

The presence of nitrogen in off-grid position (~0.5 eV) as well as C/O/H impurities (~0.47 eV) was confirmed in all three types of investigated structures. The presence of carbon and hydrogen impurities (~0.14 eV), defects related to dislocation (~0.14 - 0.3 eV) and nitrogen-vacancy (~0.27 eV) was confirmed only in Schottky barrier and FAT structures. We assume that the origin of the difference in the distribution of defects in GTML transistor was from the structure of GTLM itself (e.g. the edge gate effects).

4. CONCLUSION

InAlGaN/GaN HEMT heterostructures have the potential to be the solution to actual challenges like improvement of transistor reliability, decreasing of current leakages and robustness, reducing production costs in the area of RF devices.

This paper present result of a DLTFS study carried out on three types of barrier InAlGaN/GaN HEMT structures (Schottky, FAT and GTLM). We examined twenty deep energy levels, which were identified in the studied barrier structures and confirmed by simulations. Only well-known defects states with low concentration were detected, from which we can characterize the studied samples as HEMT structures with very high quality. The electron like defects did not identify in only one type of investigated barrier structure - in GTLM transistor. We assume that origin of these differences is the type of barrier structure itself (the presence of the edge gate effects). Still, to confirm these assumptions, it is necessary to subject the samples to further studies.

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