DLTFS STUDY OF GAN/ALGAN/GAN/SIC HEMT HETEROSTRUCTURES WITH DIFFERENT LAYER COMPOSITION

J. Drobný[1]*, A. Kopecký[1], A. Kósa[1], P. Benko[1], M. Florovič[1],
J. Kováč, jr.[1], S. L. Delage[2], Ľ. Stuchlíková[1]

[1] Slovak University of Technology, Faculty of Electrical Engineering and Information Technology,
Institute of Electronics and Photonics, Ilkovicova 3, 812 19 Bratislava, Slovakia
[2] III-V Lab, 1 Avenue Augustin Fresnel, 91767 Palaiseau Cedex, France
e-mail: jakub.drobny@stuba.sk

Abstract *The paper introduces a Deep Levels Transient Fourier Spectroscopy study of emission and capture processes of deep levels in three types of AlGaN/GaN/SiC HEMT heterostructures, which differ in type of substrates and by the presence of a back-barrier. Parameters of 11 traps were identified. In all examined structures, the presence of nitrogen interstitial, gallium vacancies and edge dislocation defects were confirmed. The distribution of defects, except for the three above, is not similar and comparable, but lower concentrations of defects indicate a positive effect of the inserted AlGaN back barrier.*

Keywords DLTFS, electrically active defect, ALGAN/GAN/SIC HEMT structures

1. INTRODUCTION

High electron mobility transistors - HEMTs utilizing beneficial properties of AlGaN/GaN heterostructures are continuously of great interest among many researchers and engineers, due to their potential usability in various technologies such as high power and high frequency applications and 5G networks [1]. Ultimate research goal is to improve and reach the highest possible overall performance of these transistor structures, in the millimeter wave technology field, compared to production and packaging costs. The most optimal substrate is considered to be the semi-insulating SiC or silicon carbide that provides not only high thermal conductivity but also valuable electrical properties. More advanced thermal conductivity with a 30% improvement can be reached by epitaxially grown isotope pure SiC layers (with 28Si + 12C isotopes) on SiC substrates [2]. Altogether, the thermal conductivity depends on many factors including the presence of defect states, density of defect states, layer widths and the growth quality [3]. Potential structure strain – 3.5% lattice mismatch between GaN and SiC in AlGaN/GaN HEMT structures – is significantly reduced and compensated by the usage of nucleation layers based on AlN. Moreover, by inserting a back barrier of AlGaN (AlGaN/GaN MQW) between the nucleation layer and GaN, a construction with reduced leakage current can be also achieved. Given this structure set up, and the different lattice parameters of GaN and AlGaN MQM, a higher mechanical stress is more likely, however this unwanted feature can be harnessed to reduce the stress at substrate level [4]. Production low cost solutions of these more complicated structures is a key aspect of commercial use, therefore there is an effort to replace the semi-insulating SiC with a more cost friendly combination, n+ doped SiC substrate with semi-insulated epitaxial layer SiC. These semiconductor layers are already widely known among LED and the other energetics industry solutions.

All the technological processes used to fabricate this semiconductor structure setup are potential sources of electrically active defect states and have a significant impact on quality and electrical properties. Presence of defect states have a disadvantageous influence on generation and recombination of charge carriers, eventually it reduces performance of GaN HEMTs. It is evident that indispensable part of the semiconductor evolution is the investigation and measurement of electrically active defect states, since it has the potential to support the growth process and improve the HEMT quality. In this field the most significant role has the Deep Level Transient Fourier Spectroscopy (DLTFS) method. Focus of this article is to study electrical active defect states in 3 types of AlGaN/GaN/SiC HEMT heterostructures by DLTFS. Comparison and evaluation of defect distributions is oriented on structural differences such as substrate types: semi-insulating SiC, n+ doped SiC with semi-insulating SiC, n+ doped SiC with isotope semi-insulating SiC and the presence of AlGaN back barrier.

2. EXPERIMENT

Three type of test structures (FATs labelled A, B and C) were prepared on a GaN/AlGaN/GaN/SiC structure using conventional HFET processing steps (Fig. 1). Sample A is AlGaN/GaN HEMT structure grown by MOCVD on a reference semi-insulating SiC substrate recommended for RF devices. Sample B is low cost AlGaN/GaN HEMT structure grown on n$^+$ doped SiC substrate with on top natural high resistivity epitaxial SiC. Sample C was grown on substrate consisting of top high resistivity isotope pure epitaxial SiC (^{28}Si + ^{12}C) [5] layer on N$^+$ doped Norstel SiC substrate and furthermore has a MQW AlGaN/GaN back barrier. Ohmic contacts for all samples are done with a TiAlNiAu stack and the gates were then metallised with NiPtAu.

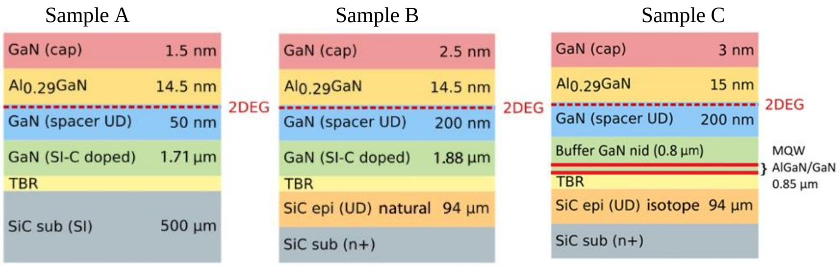

Fig. 1 Samples A, B and C layer description.

Wide variety of DLTFS experiments with electrical excitation were carried out by varying measurement conditions using the BIO-RAD DL 8000 DLTFS system [6].

3. RESULTS AND DISCUSION

Fig. 2a shows typical C-V curves measured on the samples with 2DEG, the sudden fall of capacitance in the range of reverse voltage from -1.8 V to -2.8 V is caused by QW depletion. Leakage current in reverse characteristics, measured on sample C (Fig. 1), is almost one order lower. We attribute this phenomenon to the presence of AlGaN/GaN layers in structure C. DLTFS experiments (Fig. 2) confirmed the presence of many emission and capture processes. Arrhenius plots showed 11 deep energy levels. Defect parameters compared to reference data are presented in Tab. 1. 9 defects T1-T9 were identified in structure C with MQW AlGaN/GaN back barrier.

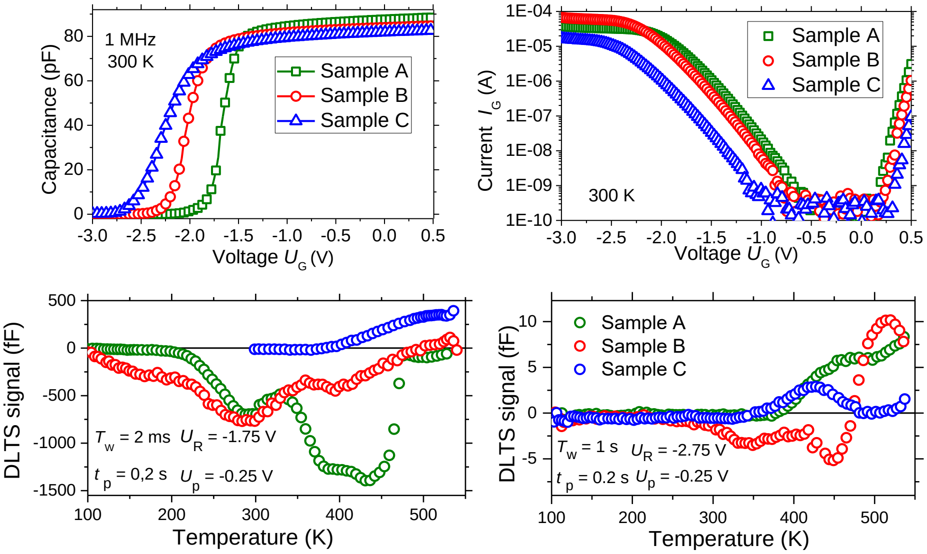

Fig. 2 Compare of C-V, I-V and DLTFS measurements for all three structures.

Tab. 3 Parameters of identified deep energy levels with reference data.

Sample			Trap	Activation energy ΔE_T (eV)	Capture cross section σ_T (cm^2)	Trap type [7], [8]
C			T1	0.49	7.4×10^{-15}	unknown
C	B	A	T2	0.66	6.8×10^{-15}	Nitrogen interstitials
C			T3	0.65	2.9×10^{-16}	unknown
C	B	A	T4	0.85	5.4×10^{-15}	Gallium vacancy
C			T5	0.72	4.2×10^{-17}	unknown
C			T6	0.80	4.0×10^{-17}	unknown
C		A	T7	1.04	3.4×10^{-15}	$(V_{Ga}\text{-}O)^{-2}$
C	B		T8	1.07	4.0×10^{-13}	Carbon interstitial defect
C	B	A	T9	0.92	1.3×10^{-15}	point defects on the edge of dislocation
		A	T10	0.19	2.7×10^{-16}	unknown
		A	T11	0.26	7.2×10^{-15}	AlGaN surface

Three of them T2, T4 and T9, were determined in all types of the measured structures. According to [7] and [8] these levels are most likely to correspond to Nitrogen interstitials (T2), Gallium vacancies (T4) and point defects on the edge of dislocations (T9).

4. CONCLUSION

In the presented experiment we characterized three types of GaN/AlGaN/GaN/SiC HEMT structures (A, B and C) using C-V, I-V and the DLTFS methods. The quality of all three types of structures has not changed even after thermal and voltage stress. The study made possible to confirm the presence of nitrogen interstitial, gallium vacancy and edge dislocation defect states in all investigated structures. The distribution of electrically active defect states in all other cases is not similar and hardly comparable. However, lower defect concentrations indicate a positive effect of the introduced AlGaN back barrier. I-V and DLTFS measurements made possible to identify the potentially best structure setup as sample C, grown on the n + doped substrate with an epitaxial high resistance semi-insulating SiC topcoat and with added AlGaN/GaN MQW back barrier. Such a structure composition indicated a decrease in leakage currents and defect concentrations compared to sample A grown on a semi-insulating SiC substrate and sample B grown on n + doped SiC substrate with an epitaxial SiC topcoat layer.

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