DLTFS STUDY OF EMISSION AND CAPTURE PROCESSES IN INALGAN/GAN HEMT HETEROSTRUCTURES WITH DIFFERENT PASSIVATION SCHEMES

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Abstract *The paper introduces results of a Deep Level Transient Fourier Spectroscopy (DLTFS) study, carried out on InAlGaN/GaN HEMT heterostructures grown on N-doped SiC substrate with semi-insulating epitaxial natural SiC layer and with AlGaN back-barrier between an AlN nucleation layer and a GaN buffer. Authors focused their attention on defect distribution in InAlGaN/GaN HEMT heterostructures with different passivation schemes: a bilayer of SiN_x and a bilayer of SiN_x and Al_2O_3. The results of defect analysis show that the passivation by the SiN_x and Al_2O_3 bilayer significantly reduces the concentration of the hole traps.*

Keywords DLTFS, InAlGaN, HEMT structure, Al_2O_3 and SiN_x bilayer

1. INTRODUCTION

GaN-based high electron mobility transistors (HEMTs) can reach significant performances in terms of high-power dissipation, robustness and maximum operating frequency, due to intrinsic properties of the material [1].

Quaternary barrier InAlGaN/GaN HEMT represent an interesting alternative to InAlN/GaN and AlGaN/GaN HEMTs because of their higher mobility [2] and similar or higher two-dimensional electron gas density [3] in the channel induced by much stronger spontaneous polarization. In spite of the higher performance of InAlGaN/GaN HEMT, the development of the high-quality InAlGaN film is still challenging because of the significant differences in the decomposition temperatures and differences in the lattice constants of the binary compounds (AlN, GaN and InN) [4].

The development of specific surface conditioning (e.g. surface oxidation [5]) and the deposition of passivation dielectric layers (Si_xN_y, SiO_2, etc.) are fundamental to achieve outstanding DC and RF characteristics. SiN_x film was mostly used as surface passivation, since it reduces the response of the surface traps, suppresses the effect of the current slump, increases the current gain cut-off frequency, and improves the device reliability. Electrical active defects have been evidenced in these kinds of devices, but it was difficult to locate them in the structure precisely [6].

This paper aims to report the results of a defect analysis of innovative InAlGaN/GaN HEMT structures with two different passivation schemes: a bilayer of SiN_x + SiN_x and a bilayer of Al_2O_3 + SiN_x. This DLTFS study was performed in order to evaluate and investigate the influence of this difference in HEMT structures on defect distribution.

2. EXPERIMENT

The investigated samples, labelled A and B, are $In_{16.5}AlGa_{83.5}N$/GaN HEMT heterostructures grown on a substrate consisting of the high resistivity epitaxial SiC layer on top of an N^+ doped Norstel SiC substrate. Sample A is passivated by a bilayer of SiN_x + SiN_x, and sample B is passivated by a bilayer of Al_2O_3 + SiN_x (Fig. 1). There is an increased AlGaN back-barrier between the AlN nucleation layer and the GaN buffer layer in both samples to achieve a low leakage current. The structures were prepared by the MOCVD method within the framework of the international cooperation in the III-V Lab in France. The contacts were created by metallization - ohmic TiAlNiAu, Schottky contacts NiPtAu. The barrier character of investigated structures was verified by C-V and I-V measurements (Fig. 2).

Sample	A	B
Thickness (µm)	2,139	2,152
Passivation layer	SiN_x + SiN_x	Al_2O_3 + SiN_x
InAlGaN thickness (nm)	6.2	
AlN interlayer (nm)	1.2	
2DEG density (cm^{-2})	1.40×10^{13}	
GaN buffer	AlGaN BB	
Substrate- SI SiC epiwafer on N+ SiC		

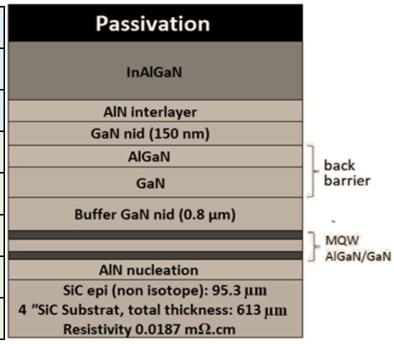

Fig. 1 Description and layer composition of measured samples A and B.

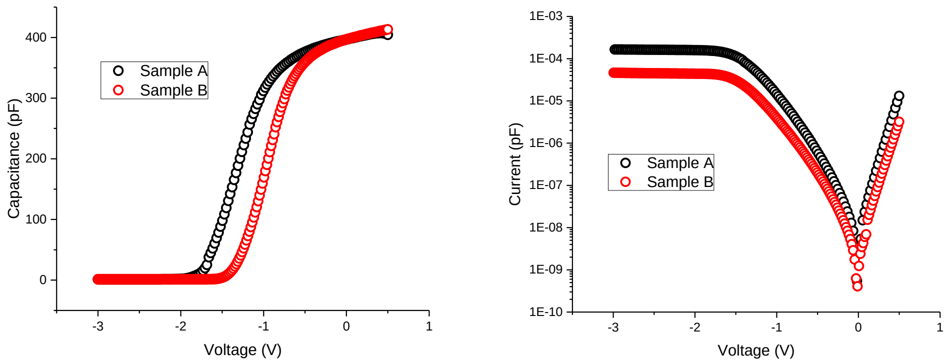

Fig. 2 Measured static characteristics C-V (left) and I-V (right) of samples A and B.

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

DLTFS experiments confirmed the presence of many emission processes in both investigated type of samples. The defects concentrations in the samples A corresponded to up to 100 fF, while in samples B were observed a maximum spectrum of about 15 fF. In sample A with a standard SiN_x + SiN_x bilayer, six-hole traps were detected. In sample B with a bilayer Al_2O_3 + SiN_x six electron traps and four-hole traps were identified. Traps HT2, HT3 and HT4 are present in both samples. Arrhenius plots of identified deep levels are shown in Fig. 3 and all parameters of these levels are listed in Tab. 1. The results were verified by simulations of measured DLTS spectra (Fig. 4).

Tab. 1 Parameters of identified deep levels

Sample	Trap	Type	ΔE (eV)	σ (cm^{-2})	Origin of trap from literature
A	HT1	hole	0.81	1.3×10^{-17}	unknow
A, B	HT2	hole	0.91	7.0×10^{-17}	acceptor complex of Gallium vacation with Oxygen $(V_{Ga}\text{-}O)^{2-}$
A, B	HT3	hole	0.92	4.3×10^{-14}	screw dislocation
A, B	HT4	hole	0.76	2.1×10^{-14}	nitrogen intersticial
A	HT5	hole	0.84	1.8×10^{-14}	dislocation – vacation
A	HT6	hole	0.51	5.4×10^{-18}	nitrogen intersticial
A	HT7	hole	0.52	2.8×10^{-17}	nitrogen intersticial
A	HT8	hole	0.54	7.6×10^{-15}	unknown
B	ET1	electron	0.49	2.8×10^{-17}	C/O/H inpurities
B	ET2	electron	0.83	8.0×10^{-17}	unknown
B	ET3	electron	0.96	9.0×10^{-15}	nitrogen intersticial
B	ET4	electron	0.54	2.0×10^{-17}	unknown
B	ET5	electron	0.74	1.1×10^{-16}	unknown
B	ET6	electron	0.83	3.1×10^{-17}	unknown

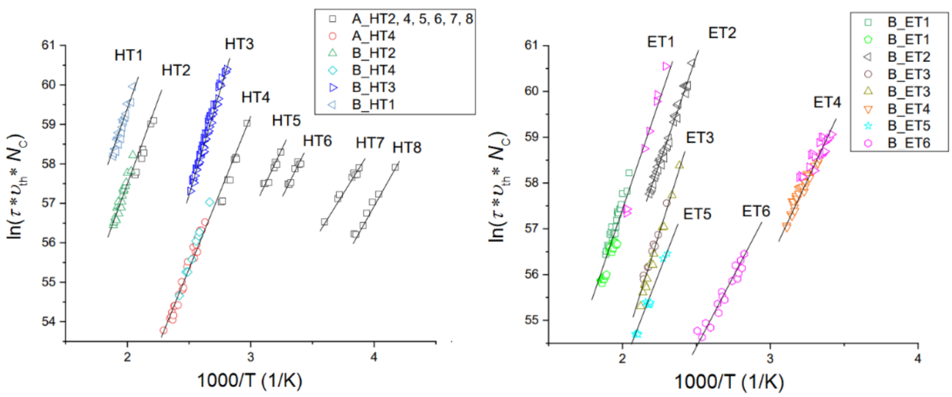

Fig. 3 Arrhenius plots of measured samples - hole trap–s (left), electron trap (right).

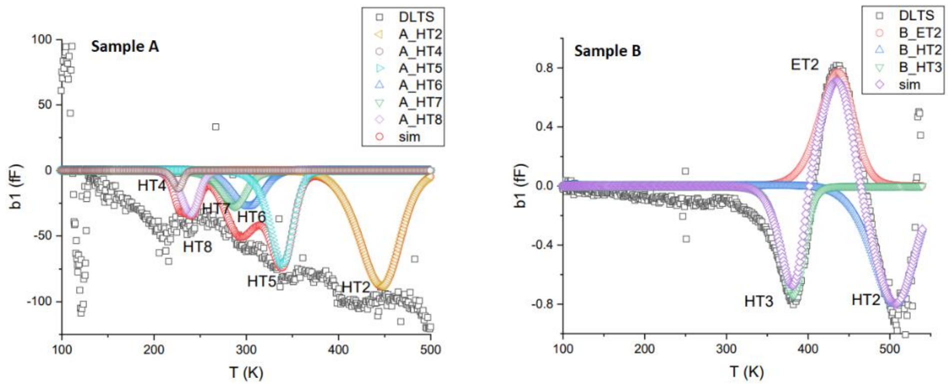

Fig. 4 Simulations of evaluated deep levels in measured DLTFS spectra- Sample A and Sample B.

4. CONCLUSION

The obtained results of defect analysis confirmed the high quality of both types of investigated samples and show that the passivation by the Al_2O_3 + SiN_x bilayer significantly reduces the concentration of hole traps in $In_{16.5}AlGa_{83.5}N$/GaN HEMTs.

Acknowledgement

This work has received funding from the ECSEL JU under grant agreement No 783274, project 5G_GaN2. The JU receives support from the European Union's Horizon 2020 research and innovation programme and France, Germany, Slovakia, Netherlands, Sweden, Italy, Luxembourg, Ireland. This work was also supported by the Slovak Scientific Grant Agency VEGA (contract VEGA 1/0668/17), and by the Slovak Research and Development Agency (project SK-PL-18-0068). Our gratitude goes to the technology teams from III-V Lab and Linköping University for growing and device processing of the structures.

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