CHARACTERIZATION OF AlGaN/GaN HEMT STRUCTURES BY DEEP LEVEL TRANSIENT FOURIER SPECTROSCOPY WITH OPTICAL EXCITATION

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Received 30th April 2016; accepted 15th May 2016

1. Introduction

The advantages of high power and wide-frequency performance GaN devices attracted great attention [1]. GaN based high electron mobility transistors (HEMTs) represent good candidates for next generation microwave end power electronics [2, 3]. Even though strong efforts are being made to improve long-term reliability of HEMTs [4, 5] the dynamic performance of these devices is still affected by the charge trapping phenomena [6].

To quantify bulk traps in GaN, deep level transient spectroscopy (DLTS) has emerged as a powerful tool providing information about the trap densities, their location in the energy gap, and the capture cross section which can indicate the charge state of the trap [7]. GaN compounds measured by standard DLTFS method indicate unclear or complex DLTFS signals. One of the possible solutions how to more exactly determine parameters (activation energy and capture cross sections) of deep energy levels in GaN structures is the utilization of a DLTFS modification, hence DLTFS with optical excitation, which is able to investigate emission and capture processes of minority carriers.

The main idea of this research is to improve the validity of deep levels parameter values in HEMT structures based on GaN by deep level transient Fourier spectroscopy with optical excitation. The aim of this article is to interpret first measurements and results obtained on GaN samples.

2. Experiment

The AlGaN/GaN HEMT structures were grown by low-pressure metalorganic vapour phase epitaxy on 4H-SiC and consisted of 1.5 μm thick GaN buffer Fe doped away from channel followed by 25 nm thick $Al_{0.20}Ga_{0.8}N$ barrier layer (Fig. 1(a)). The AlGaN barrier was intentionally undoped. Nb(20 nm)/Ti(20 nm)/Al(100 nm)/Ni(40 nm)/Au(50 nm) metallic system was used to form alloyed ohmic contacts to the AlGaN/GaN heterostructure. After optimal rapid thermal annealing (RTA) at 850 °C for 35 s in a nitrogen atmosphere the ohmic contacts exhibited low value of contact resistivity. In the next step a MESA isolation was performed using a reactive ion etching (RIE) of AlGaN/GaN in CCl4 plasma gas. The depth of MESA etching was proposed to be about 100 nm. Electron beam evaporated Ni(40 nm)/Au(100 nm) metallic system in combination with a lift-off technique where used to form the Schottky gate interfinger contacts. The expanded contacts consist of Ti(30 nm)/Au(120 nm) [8].

DLTFS measurements were carried out by the measurement system BIORAD DL8000 DLTFS in the experimental laboratory of the Institute of Electronics and Photonics FEI STU in Bratislava. Observed DLTFS spectra indicated complex defect states difficult to evaluate, therefore the utilization of optically excited DLTFS was necessary to ensure more precise analysis by minority carrier excitation. Equipment of illumination, thus the optical source was designed and fabricated at the Institute of Electronics and Photonics. The source was equipped with current adjustment, pulse modulator and an exchangeable cap for LEDs. This tool is directly connected to the DL8000 system. Experiments were realised with two single emitter deep UV LEDs based on AlGaN with typical peak wavelength of 240 nm and 345 nm and with optical output power of 30 -70 μW. As expected, using this proposed analysis complicated measured signals can be evaluated by DLTFS method more precisely [9]. Photon energies were calculated by the equation $\left(E = h\frac{c}{\lambda}\right)$, thus for 240 nm it is 5.166 eV and for 345 nm 3.594 eV. This method is often referred to as minority carrier transient spectroscopy (MCTS) [10–12]. During MCTS measurements, electrons are photogenerated by light exceeding the energy gap and leave the depletion region while the concurrently generated holes are captured by the minority carrier traps from which their emission by thermalization is analyzed [13].

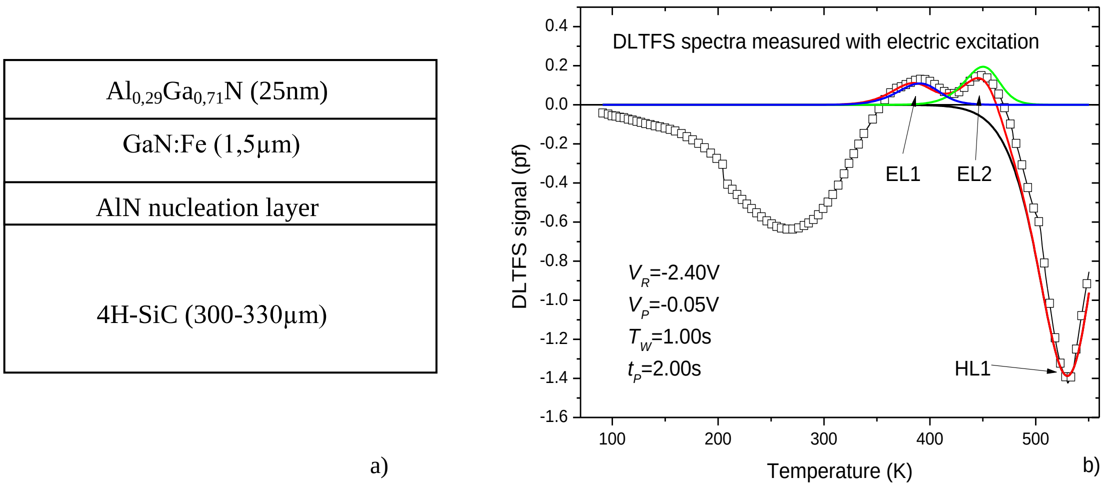

Fig.1: *a) Material composition of investigated sample, b) identified deep energy levels, measured and simulated DLTFS spectra.*

Input parameters of measured DLTFS spectra were carried out from C-V curves (frequency 1MHz at 297±1K) by the measurement system DL8000 and applied for both electric and optic DLTFS measurements in the temperature range 80 - 550 K. Fig. 1 (b) shows DLTFS spectra measured by electrical excitation on GaN structures obtained at applied measurement parameters: pulse width $t_p = 2$ s, period width $T_W = 1$ s, reverse bias voltage $V_R = -2.4$ V and pulse voltage $V_p = -0.05$ V. There were identified three traps by “direct evaluation method – Arrhenius, auto level”, hence deep energy level parameters are calculated directly from measured capacitance transients. EL1 and EL2 assumed to be electron like and one hole like trap labelled HL1 were identified (Tab. 1). Non evaluable signal observed at temperature range 100 K to 360 K indicated a highly complex response, thus several mutually interacting electrically active defects.

Same sample was investigated at identical measurement conditions, but by the application of optical excitation with 240 nm a 345 nm LED illumination (Fig 2 (a, b)). These measurements showed significantly overlapping levels. For these results it is more appropriate to use another conventional DLTS evaluation method called “Maximum analysis”[14]. This method manually defines the time constant τ and can be determined by period width T_w for maximum coefficients. Obtained values are valid only at peak maximums and depend on T_w, T_w/t_0 and the type of coefficient. This value will be calculated numerical by simulation (variation of τ at fix T_w and t_0) and maximum search of the coefficient τ.

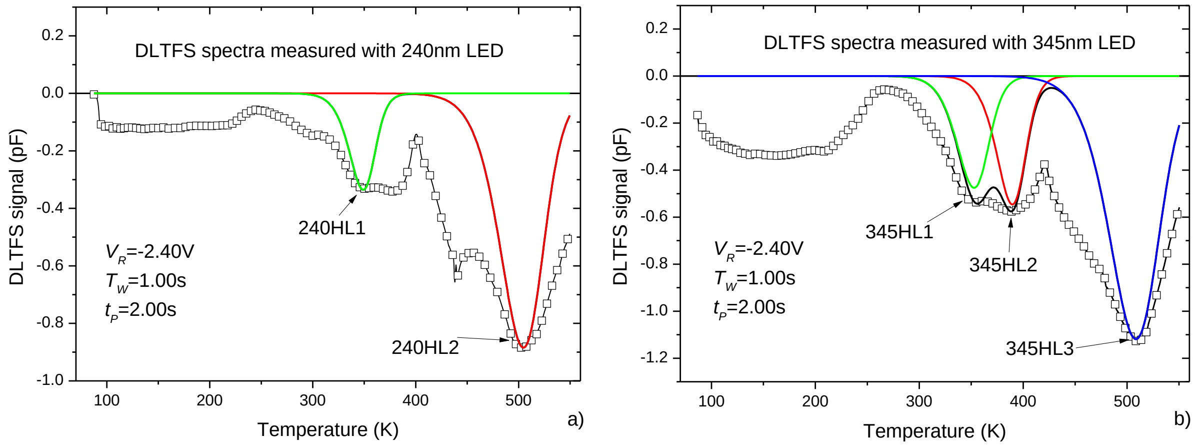

Fig.2: *Identified deep energy levels in by DLTFS spectra measured with optical excitation, measured and simulated DLTFS spectra - peak wavelength with a) 240 nm, b) 345 nm.*

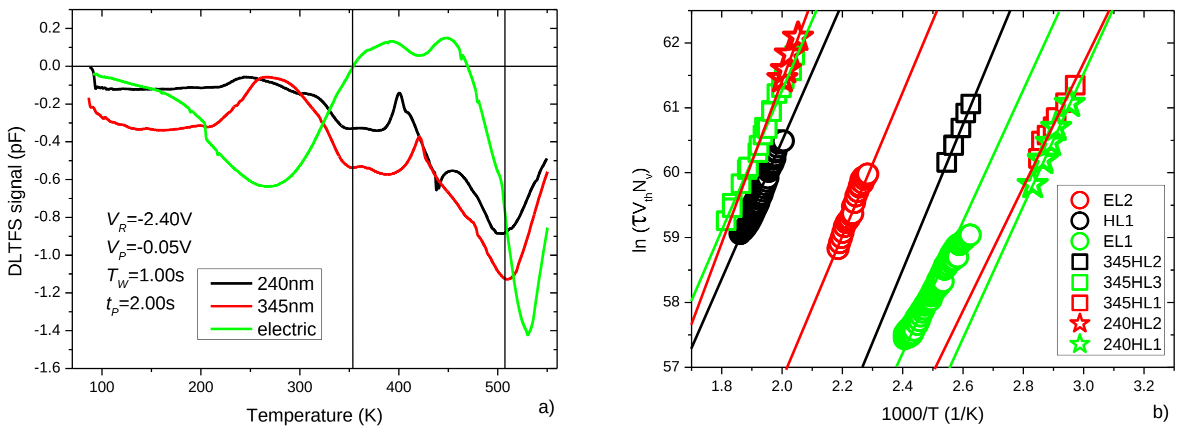

Fig.3: *a) DLTFS spectra measured on investigated structure, b) Arrhenius plots*

Tab. 1. *Deep energy levels parameters and interpretation.*

Trap	Activation energy ΔE_T (eV)	Capture cross section σ_T (cm^2)	Interpretations
240HL1	0.885	4.35×10^{-14}	Nitrogen interstitials [19]
240HL2	1.087	2.50×10^{-16}	Threading dislocations [20]
345HL1	0.727	1.73×10^{-16}	Fe dopant [17]
345HL2	0.990	3.73×10^{-14}	Threading dislocations [20]
345HL3	0.960	1.12×10^{-17}	Gallium vacancy or N interstitials [18]
HL1	0.971	2.18×10^{-17}	Gallium vacancy or N interstitials [18]
EL1	0.683	2.21×10^{-17}	surface [16]

Optical measurements made possible to identify 5 deep levels assumed to be hole like (Tab. 1). DLTFS spectra measured with both LEDs were evaluated by maximum evaluation and Arrhenius regression line calculation (Fig. 3). The linear regression will be done level by level about the data points of the level. There is no mismatch possible, even at an overlapping, if the automatic sorting is successful [15].

3. Conclusion

This work deals with identification of electrical active deep energy levels in AlGaN/GaN HEMT structures by DLTFS methods with electrical and optical excitation. We used two types of evaluation methods suggested by the DL8000 system's analysis software.

Analysis of measured results confirmed three hole like traps and two electron like traps (Tab. 1). All these results and the trap parameters were also verified by DLTFS spectra simulations. DLTFS spectra measured with optical excitation showed similar curves, but the 240HL1 and 345HL1, 240HL2 and 345HL3 are not identical traps considering the activation energy and capture cross section (regression (Fig. 3)). This may be resulted by different wave lengths of illumination used in the experiment. A more detailed analysis on the sample is the objective of further studies.

Acknowledgement

This work has been supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic (Projects VEGA 1/0377/13 and VEGA 1/0739/16). This work was supported by Wroclaw University of Technology statutory grants.

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