INVESTIGATION OF InGaAsN/GaAs HETEROSTRUCTURES BY CAPACITANCE METHODS

Ľubica Stuchlíková[1], Jakub Rybár[1], Arpád Kósa[1], Miroslav Petrus[1], Ladislav Harmatha[1], Beata Ściana[2], Damian Radziewicz[2], Damian Pucicki[2], Marek Tłaczała[2]

[1] Slovak University of Technology, Faculty of electrical engineering and information technology, Institute of electronics and photonics, Ilkovičova 3, 81219 Bratislava, Slovakia

[2] Wrocław University of Technology, Faculty of Microsystem Electronics and Photonics, Janiszewskiego 11/17, 50-372, Wrocław, Poland

E-mail: lubica.stuchlikova@stuba.sk

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1. Introduction

The $In_yGa_{1-y}As_{1-x}N_x$ semiconductor alloys ($A_{III}B_V$-N), have been extensively studied recently, because these alloys are very promising for applications in 1.3 – 1.55 µm lasers and high efficient multijunction solar cells [1]. So, a lot of research efforts are focused on understanding the reasons of the generated defects and optimisation the growth methods.

In this paper the attention is focused on the electrical characterization of the multiple quantum well (MQW) InGaAsN/GaAs heterostructures with the small nitrogen concentration of 0.4 % and 0.43 %, indium content of 13.5 % and 13.0 %, respectively, using deep level transient spectroscopy.

2. Experiment

Two samples labelled as NI59n and NI66n were used in the experiment (samples' parameters are listed in Tab. 1). Both samples are $In_yGa_{1-y}As_{1-x}N_x$ /GaAs - based Schottky heterostructures with triple quantum well. The heterostructures were manufactured at the Wrocław University of Technology using APMOVPE (Atmospheric Pressure Metal Organic Vapour Phase Epitaxy) at different growth conditions [1 - 3]. Schottky contact (area $A = 1.66\times10^{-3}$ cm^2) was made by evaporation of gold to UD GaAs and ohmic contact was made by application of silver paste to the substrate. These processes were carried out at the Institute of electronics and photonics in Bratislava. The main differences of these typical UD $In_yGa_{1-y}As_{1-x}N_x$ triple quantum wells samples are: indium and nitrogen content, thickness of UD GaAs barrier and the absence of GaAs „cap" layer in the case of NI59n sample (Tab. 1).

Tab. 1. *The geometric parameters of the samples.*

Sample	Substrate	UD GaAs buffer	3×UD $In_yGa_{1-y}As_{1-x}N_x$ quantum wells			UD GaAs barrier	UD GaAs "cap"
NI59n	n-GaAs:Si(100)	0.45 µm	17 nm	y=13.5%	x=0.40%	36.0 nm	0 nm
NI66n	n-GaAs:Si(100)	0.45 µm	17 nm	y=13.0%	x=0.43%	22.5 nm	36 nm

All CV (capacitance-voltage) measurements and DLTS (Deep Level Transient Spectroscopy) experiments were carried out using the DLTS measurement system BioRad DL8000, which is equipped with Fourier transform analysis of the measured capacitance transients. Using this analysis complicated measured signals can be evaluated in a better way, which in our measurement system is called Direct auto Arrhenius Multilevel evaluation [4].

3. Results and discussion

CV characteristics in lower temperatures show very fine fluctuations of capacitance in the voltage range around 0 V. Higher temperatures confirm these fluctuations while increasing their amplitude and shifting them to the higher reverse voltage (Fig.1 and Fig.2). The source of the fluctuations is charge carriers emission from quantum wells.

It is important to notice the influence of nitrogen concentration upon the character of the CV curves. Although the nitrogen concentrations are nearly the same (Tab.1.), but even such a small difference of 0.03 % affects the resulting CV curve.

According to the results (Fig. 1 and Fig. 2) the sample NI66n with higher nitrogen concentration of x =0.43% shows smaller fluctuations in the CV curves and the fact is that the decrease in nitrogen concentration results into higher capacitance amplitudes with more significant fluctuations. It is highly probable that this effect is a result of capturing the free carriers emitted from quantum wells by capture centres produced by presence of the nitrogen atoms.

CV characteristics measured on sample NI59n (Fig. 1) at different temperatures are shifted □ 7 pF to lower values of capacity than CV characteristics measured on sample NI66n (Fig. 2). It is possible that this effect was caused by the absence of the „cap“ layer in sample NI59n (Tab. 1).

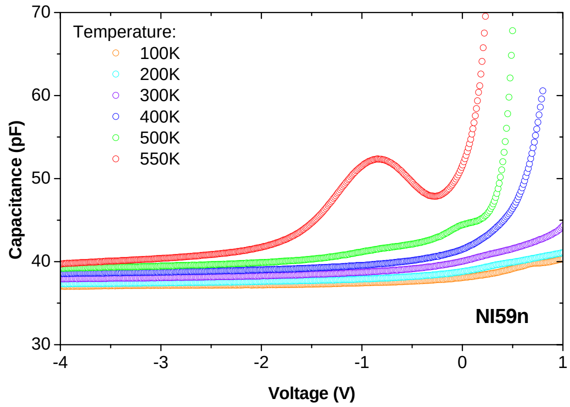

Fig.1: *CV characteristics of NI59n in temperature range 100 – 550 K (x=0.40%).*

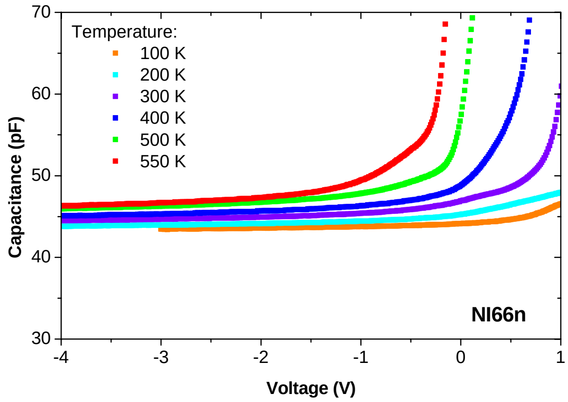

Fig.2: *CV characteristics of NI66n in temperature range 100 – 550 K (x=0.43%).*

By applying the measurement parameters T_W = 15.1 ms, t_p = 3 ms, U_R = -0,5V, U_P =0,05V DLTS spectra were obtained (Fig.3). A peak significant for both samples was identified in temperature range 400 - 420K. It is highly probable that both samples have the similar system of the defects. This statement was verified by results getting from evaluation Direct auto Arrhenius Single level method (Fig. 4). There were identified two energy levels ET1 and ET2 in both samples (Arrhenius plots obtained by Direct auto Arrhenius Single level – fig...). The parameters of these deep levels energy show very big differences (Tab. 2).

It is caused by the presence of more than two deep energy levels situated closely to each other. Therefore DLTS spectra were analyzed by evaluation method available in software for the measurement system BioRad DL8000, called „Direct auto Arrhenius Multi level“ (Fig. 5). This analysis has a decent algorithm that uses Fourier transform and selects only exponential decays of the capacitance transients and removes various factors of non-exponential nature. The result of this analysis is an Arrhenius plot.

The parameters of the identified defects were calculated from the resulting Arrhenius plots. Arrhenius plots and resulting parameters were approximately the same.

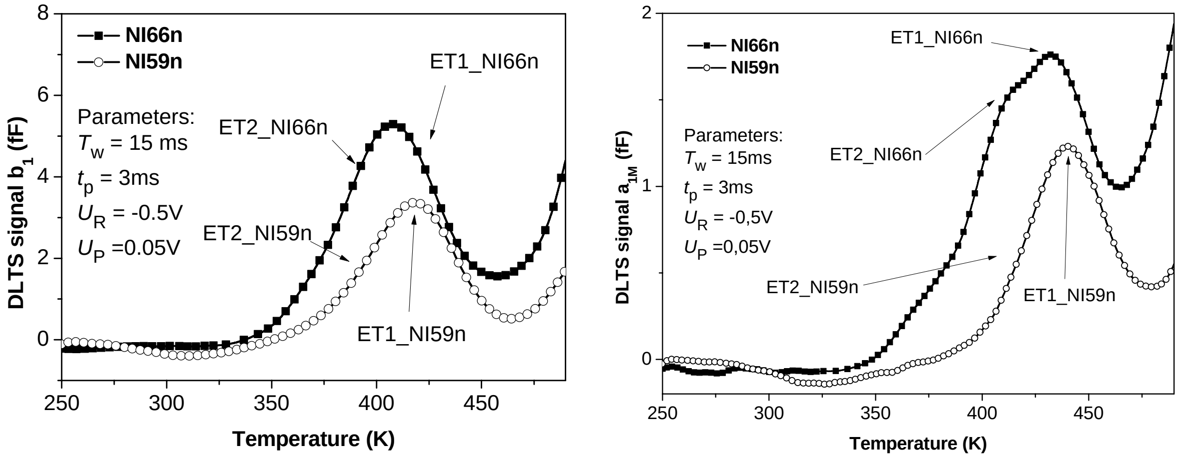

Fig.3: *DLTS spectra measured using parameters T_W=15.1 ms, t_p=3ms, U_R=-0.5V, U_P=0.05V for both samples NI59n and NI66n for correlation functions b_1 and a_{1M}.*

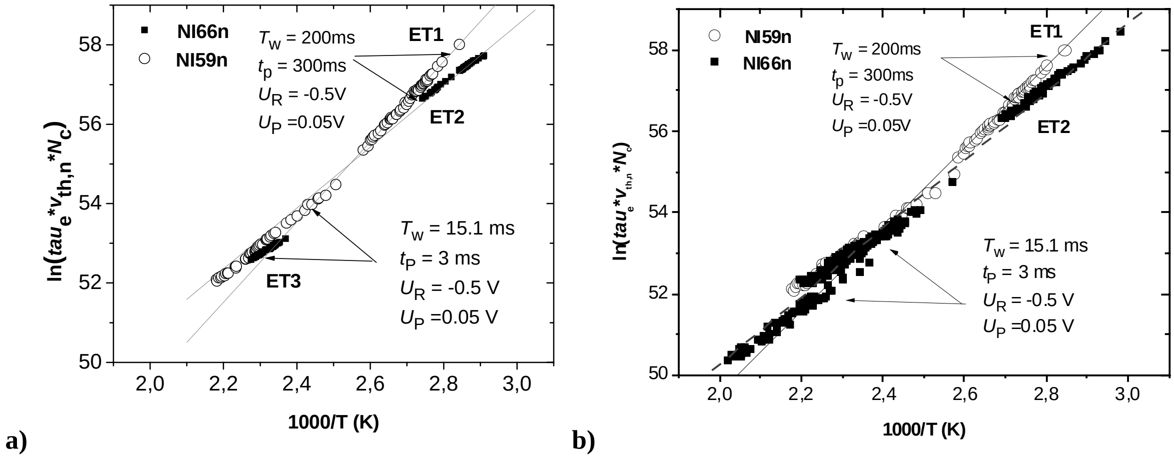

Fig.4: *Comparison of the resultant Arrhenius plots obtained by „Direct auto Arrhenius evaluation" of the samples NI59n and NI66n a) single level and b) multi level method.*

According to results and parameters calculated via several evaluation conditions (Tab. 2.) it is possible to estimate the activation energy of the defect which is approx. E_T = 0.62 eV, value of effective capture cross-section of the defect σ_T is about 10^{-16} cm^2, and defects concentration N_T is about 10^{14} cm^{-3}. This trap is certainly present in both structures.

Due to differences in the values of the deep energy level parameters the capture-emission processes were influenced by the concentration of nitrogen in the measured structures. This is obvious especially in case of evaluation of DLTS spectra of the sample NI66n.

Tab. 2. *Calculated defect parameters.*

Name	Evaluation method	Energy (eV)	Cross-section σ_T (cm^2)	N_T (cm^{-3})
ET1 (NI59n)	Single level	0,650	3,5E-16	3.68E+14
ET1 (NI59n)	Multi level	0.619	1.32E-16	3,88 E+14
ET2 (NI59n)	Single level	0,869	1,81E-13	3,15 E+14
ET2 (NI59n)	Multi level	0,872	1,99E-13	3,16E+14
ET1 (NI66n)	Single level	0,493	6,61E-18	5,17E+14
ET1 (NI66n)	Multi level	0,623	2,94E-16	6,30E+14
ET2 (NI66n)	Single level	0,587	3,23E-17	3,82E+14
ET2 (NI66n)	Multi level	0,647	1,334E-16	3,57E+14

4. Conclusion

According to the results obtained by „Direct auto Arrhenius Multi level“ evaluation of the DLTS spectrum of the all measured samples the identified deep energy level ET1 has following parameters: activation energy $E_T = 0.62$ eV, effective capture cross-section $\sigma_T \sim 10^{-16}$ cm^2 and trap concentration $N_T \sim 10^{14}$ cm^{-3}. The growth was presumably Ga- rich and therefore favouring incorporation of oxygen in As sites near the interface [5]. ET1 probably corresponds to EL3 centres presented in [5]. The parameters of the energy level ET2 in the two presented samples are not the same. This is due to capture emission processes from more than one energy level. This subject is under investigation.

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