DLTFS STUDY OF p-i-n DIODE BASED ON InGaAsN/GaAs MULTI-QUANTUM WELL STRUCTURE

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1. Introduction

Unusual properties of the $In_yGa_{1-y}As_{1-x}N_x$ semiconductor alloys such as a huge and negative band gap bowing coefficient and a large conduction band offset make this semiconductor very promising for applications in high efficient multijunction solar cells [1].

This paper presents DLTS study of the p-i-n structure based on the triple quantum well InGaAsN/GaAs heterostructure and reference p-i-n structure based on the GaAs. Both structures were grown by atmospheric pressure metalorganic vapour phase epitaxy. The principal difference between these two investigated samples is the formation of the triple quantum well InGaAsN/GaAs in one of them. In order to determine the origin of the traps, detected in these samples, we have to compare the DLTFS spectra measured on both structures. This way, it is possible to find out, whether the deep energy levels are caused by emission from quantum well or by presence of material defects in the structure.

2. Experiment

Two types of p-i-n diodes were examined in this experiment - sample labelled NI71n based on InGaAsN/GaAs multi-quantum well structure and reference sample X329 based on GaAs (the samples' parameters are listed in Tab. 1 and in Fig.1). Investigated samples were manufactured at the Wrocław University of Technology using APMOVPE with AIX200 R&D AIXTRON horizontal reactor on (100)-oriented Si-doped n-type GaAs substrates at different growth conditions [2]. $3\times In_yGa_{1-y}As_{1-x}N_x$ quantum wells of p-i-n structure NI71n consist of two sub wells (Tab. 1). The top ohmic contact (area of 2×10^{-2} cm^2) was prepared by AuMn evaporation on p^+GaAs:Zn "cap" layer of p-i-n structure NI71n. The bottom ohmic contact in both structures was created by AuGeNi evaporation.

Tab. 1: *The parameters of the p-i-n diodes structure labelled NI71n and X329.*

Sample	substrate	buffer	buffer	3xUD $In_yGa_{1-y}As_{1-x}N_x$ quantum wells			UD GaAs barrier	UD GaAs	p-GaAs: Zn	p^+GaAs: Zn
				thickness (nm)	y (%)	x (%)				
NI71n	n-GaAs:Si (100)	n^+-GaAs:Si 0.30 µm	UD-GaAs 0.45 µm	8.8 nm 8.8 nm	8.0 17.0	0.47 0.10	22.5 nm	0.45 µm	0.25 µm	"cap" 50 nm
X329	n-GaAs:Si (100)	n^+-GaAs:Si 0.50 µm	-	-	-	-	-	0.9 µm	0.15 µm	40 nm

p-i-n structure NI71n

p^+- GaAs:Zn	”cap”	50.0 nm
p - GaAs:Zn		0.25 μm
UD GaAs		0.45 μm
UD InGaAsN	QW	17.6 nm
UD GaAs	barrier	22.5 nm
UD InGaAsN	QW	17.6 nm
UD GaAs	barrier	22.5 nm
UD InGaAsN	QW	17.6 nm
UD GaAs	buffer	0.45 μm
n^+- GaAs:Si	buffer	0.30 μm
n- GaAs:Si (100)	substrate	

p-i-n structure X329

p^+- GaAs:Zn	”cap”	50.0 nm
p - GaAs:Zn		0.15 μm
UD GaAs	buffer	0.90 μm
n^+-GaAs:Si	buffer	0.50 μm
n- GaAs:Si (100)	substrate	

Fig.1: *Schematic description of the investigated structures.*

The DLTFS (Deep Level Transient Fourier Spectroscopy) measurements in the temperature range from 80 to 550 K were carried out using the BIORAD DL8000 measurement system, which is equipped with the Fourier transform analysis of the measured capacitance transients. During the DLTFS measurements, the reverse bias was set at different voltages and periodically pulsed to fill voltage for the trap filling. The obtained DLTS spectra were evaluated using the Fourier transform analysis by Direct auto Arrhenius Single and Multilevel evaluation.

3. Results and discussion

The evaluation of the measured DLTS spectra had shown the existence of several deep energy levels in the measured structures. Fig. 2 and Fig. 3 depict two measured DLTS spectra under the different measurement conditions with evaluated deep energy levels ET1, HT1, HT4 (a, b, c) and HT1x with their activations energies and positions in the spectra.

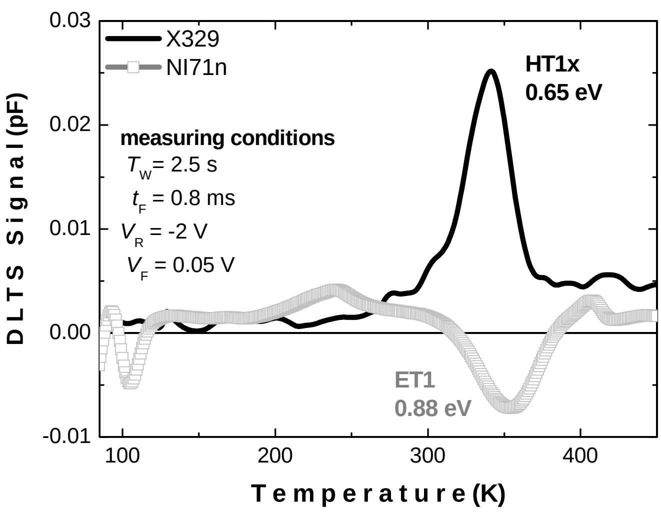

Fig.2: *Compared measured DLTS spectra of the X329 and NI71n samples with evaluated deep energy levels HT1x and ET1, their activation energies and positions in the spectra.*

The parameters of the deep energy level HT1 (Tab. 2) were identified by evaluation with “min. class for evaluation” 40. This hole-like level with rather small activation energy has a very small value of the capture cross-section. If we consider the fact, that one of the most valuable properties of dilute nitride alloys is a discontinuity of the valence band equal to 150 meV we may assume that the level HT1 (0.038 eV) corresponds with the emission related to this discontinuity and with the emission of the holes from the quantum well in the valence band.

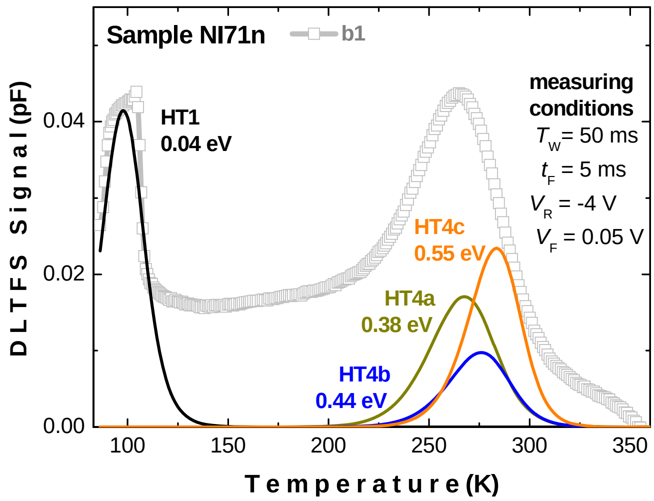

Fig.3: *Measured DLTS spectra of the NI71n sample with evaluated deep energy levels HT1, HT4a, HT4b, HT4c, their activation energies and positions in the spectra.*

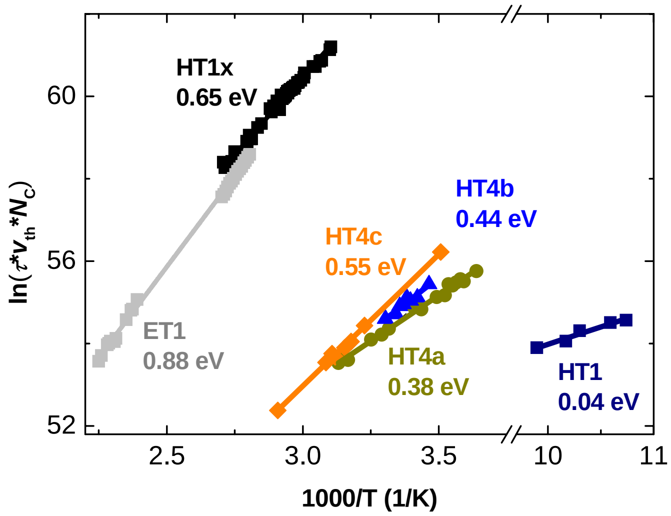

Fig.4: *Arrhenius plot of the evaluated deep energy levels.*

The Arrhenius plot in the Fig.4 shows all the evaluated deep energy levels with their activation energies. Tab. 2 lists the evaluated deep energy levels with their parameters (activation energy ΔE_T, capture cross-section σ_T, and trap concentration N_T), the evaluation method type by which it was evaluated, and the probable origin of the deep energy level.

The deep energy level HT4 was evaluated by the Single level Direct auto Arrhenius evaluation method with the parameters listed in the Tab. 2. After detailed analysis followed by the Multi level Direct auto Arrhenius evaluation with great precision (min. class for evaluation value was 50) it was clear that the HT4 deep energy level in fact represents a summary peak in the DLTS spectra. Thus the three compound deep energy levels HT4a, HT4b, and HT4c were identified with the parameters listed in the Tab. 2. These deep energy levels were identified in the literature as HL8 (0.519 eV) [3] and HM1 (0.550 eV) [4, 5], related to the As_{Ga} defects. The deep energy level HT1x was identified in the literature as the Fe-related defects HC1 with the activation energy of 0.630 eV [4]. The ET1 deep energy level was evaluated with high level of min. class for evaluation (50) and further identified as well-known GaAs defect EL2 (0.831 eV) [6].

Tab. 2: *Calculated deep energy levels parameters*

Trap	Sample	Evaluation method	Evaluation Min. class	Energy ΔE_T (eV)	Cross-section σ_T (cm^2)	Concentration N_T (cm^{-3})	Probable origin of deep energy level
HT1	NI71n	Multi level	40	0.038	1.1E-20	3.4E+13	Peak + emission from QW
HT4	NI71n	Single level	60	0.200	4.7E-21	1.1E+14	Summary peak
HT4a HT4b HT4c	NI71n	Multi level	50	0.382 0.443 0.549	6.1E-18 4.6E-17 2.0E-15	1.0E+14 8.3E+13 2.4E+14	HL8 0.519 eV [3] HM1 0.550 eV [4, 5]
ET1	NI71n	Single level	50	0.877	4.69E-14	7.9E+13	EL2 0.831 eV [6]
HT1x	X329	Single +Multi level	60	0.649	3.6E-17	1.1E+14	HC1 0.630 eV [4]

4. Conclusion

We present the DLTS study of two p-i-n structures; one (NI71n) based on the triple quantum well (MQW) InGaAsN/GaAs heterostructure and the other based on GaAs as the reference sample (X329). A comparison is helpful to see the influence of the MQW, which can be proven by the presence of the trap HT1 (0.038 eV). In both types of the structures electrically active deep energy levels were confirmed. The parameters of the deep energy levels were obtained by two methods of evaluation with high level of precision. The assignment to the previously known defects of the evaluated deep energy levels was suggested. The following deep energy levels were identified: HT1 (0.038 eV) – emission from QW, HT4a, b, c (0.382 eV, 0.443 eV, 0.549 eV) – HL8 [3] and HM1 [4, 5], HT1x (0.649 eV) – HC1 [4], and ET1 (0.877 eV) – EL2 [6]. In order to fully understand the behaviour of the deep levels present in the measured structures further study will follow.

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