THE IMPACT OF INDIUM AND NITROGEN CONCENTRATION ON THE QUALITY OF THE InGaAsN/GaAs HETEROSTRUCTURES

Ľubica Stuchlíková[1], Juraj Jakuš[1], Arpád Kósa[1], Ladislav Harmatha[1], Jaroslav Kováč[1], Beata Ściana[2], Damian Radziewicz[2], Damian Pucicki[2], Wojciech Dawidowski[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

Received 09 May 2014; accepted 25 May 2014

1. Introduction

The unusual physical and electrical properties of InGaAsN semiconductor alloys have made it a good candidate for applications in high-conversion-efficiency multijunction solar cells [1]. Therefore, a lot of research efforts are focused on understanding the reasons of generated defects and the growth methods optimisation [2, 3].

This paper presents the DLTS study of eight types of Schottky diodes based on the triple quantum well InGaAsN/GaAs heterostructures with variant nitrogen and indium concentration.

2. Experiment

All samples are $In_yGa_{1-y}As_{1-x}N_x$/GaAs - based Schottkyheterostructures with triple quantum well. These eighttypes of heterostructures were manufactured at the Wrocław University of Technology using APMOVPE at different growth conditions [4, 5]. Samples' schematic description and geometric parameters are displayed in Tab. 1. All these samples are from set of samples with various ratios of In and N concentrations.Schottky contact (area is A = 1.66×10^{-3} cm^2 all samples except NI70n (5.02×10^{-3} cm^2)) was made by evaporation of gold to UD GaAs and the ohmic contact was created by AuGeNi evaporation. These processes were carried out at the Institute of Electronics and Photonics in Bratislava.

DLTS measurements were realised in the temperature range from 80 to 350K using the BIORAD DL8000 measuring system equipped with Fourier transform analysis of the measured capacitance transients. DLTS spectra were obtained by applying the same measurement parameters at all samples: time periods T_w = 200 ms, 500 ms, 1 s, filling time t_p = 300 ms, filling voltage V_P = 0.05 V and reverse voltage V_R = -0.5 V.These measurements confirmed the existence of many electrically active defects. The parameters (ΔE_T (eV), capture cross-section σ_T (cm^2) and trap concentration N_T (cm^3)) of 16 deep energy levels (T1 – T16) were identified (Tab. 2). All calculated values of deep energy level parameters were verified by tempfitsimulation.Typical DLTS measured spectra on these samples and tempfit of identified defects are shown in Fig. 1.

The hole-like energy levels T1 (0.49 eV), evaluated in the sample I219 eV (Fig. 1a), T12 (0.50 eV)in NI51n(Fig. 1g) and T16 (0.44 eV) in NI49n (Fig. 1h) correspond to the native defect in GaAs - structural imperfection HL8 [7]. The electron-like level T2 (0.53 eV) evaluated in the sample NI60n (Fig. 1b) probably corresponds to the defect EC2 in GaAs [8]. The electron-like level T3 evaluated in the sample NI68n (Fig. 1c) corresponds to the defect

EL11 in GaAs - complex including structural imperfections and an impurity structural imperfection [9]. Electron-like levels T4 (0.22 eV) and T5 (0.26 eV) evaluated in the sample NI68n, T7 (0.26 eV) in the sample N70n (Fig. 1d), T10 (0.25 eV) in NI66n (Fig. 1f), T12 (0.28 eV)in NI51n(Fig. 1g) and T14 (0.10 eV) in NI49n (Fig. 1h) have very small value of the capture cross-section. Therefore it is suggested, that these energy levels do not represent the material defect, but the charge carriers emission of the electrons from the quantum well (QW) [2, 3].

Tab. 1.*Samples' schematic description and geometric parameters.*

Schottky barrier structure			I219	N62n	NI49n	NI51n	NI60n	NI66n	NI68n	NI70n
UD GaAs	"cap"	(nm)	40.0	37.0	46	41.5	38.0	36.0	32.0	33.0
UD GaAs	barrier	(nm)	24.0	26.0	31	30.0	26.0	22.5	27.0	23.8
UD InGaAsN	QW	(nm)	17.0	9.2	14.5	14.5	7.8	17.0	14.0	16.6
UD GaAs	barrier	(nm)	24.0	26.0	31	30.0	26.0	22.5	27.0	23.8
UD InGaAsN	QW	(nm)	17.0	9.2	14.5	14.5	7.8	17.0	14.0	16.6
UD GaAs	barrier	(nm)	24.0	26.0	31	30.0	26.0	22.5	27.0	23.8
UD InGaAsN	QW	(nm)	17.0	9.2	14.5	14.5	7.8	17.0	14.0	16.6
UD GaAs	buffer	(μm)	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
n-GaAs:Si(100) substrate										
3×UD $In_yGa_{1-y}As_{1-x}N_x$ quantum wells		**In** (%)	**15.4**	**0**	**14.5**	**15.8**	**7.5**	**13.0**	**16.0**	**13.3**
		N (%)	**0**	**1.2**	**0.62**	**0.36**	**0.3**	**0.43**	**0.24**	**0.32**

Tab. 2.*Samples' schematic description and geometric parameters.*

Trap	Sample	Energy ΔE_T (eV)	Cross-section σ_T (cm^2)	Concentration N_T (cm^{-3})	Probable origin of deep energy level
T1	I219	0.49	2.6E-17	2.6E+14	HL8 0.519 eV [7]
T2	NI60n	0.54	1.3E-15	5.0E+13	EC2 0.480 eV [8]
T3	NI68n	0.19	4.6E-15	5.6E+15	EL11 0.170 eV [9]
T4	NI68n	0.22	8.8E-20	2.9E+15	emission from QW [2, 3]
T5	NI68n	0.26	1.5E-19	3.3E+15	emission from QW [2, 3]
T6	NI70n	0.05	1.3E-23	6.9E+14	emission from QW [2, 3]
T7	NI70n	0.26	8.8E-20	4.1E+15	emission from QW [2, 3]
T8	NI62	0.38	1.6E-18	1.7E+14	EL16 0.37 eV [10]
T9	NI66n	0.34	6.9E-19	3.8E+13	EL16 0.37 eV [10]
T10	NI66n	0.25	1.8E-19	3.1E+13	emission from QW [2, 3]
T11	NI51n	0.50	1.1E-16	1.5E+14	HL8 0.519 eV [7]
T12	NI51n	0.28	1.5E-20	3.8E+14	emission from QW [2, 3]
T13	NI49n	0.07	8.5E-21	1.2E+14	emission from QW [2, 3]
T14	NI49n	0.10	2.2E-22	6.0E+12	emission from QW [2, 3]
T15	NI49n	0.44	3.9E-18	3.7E13	HL8 0.519 eV [7]

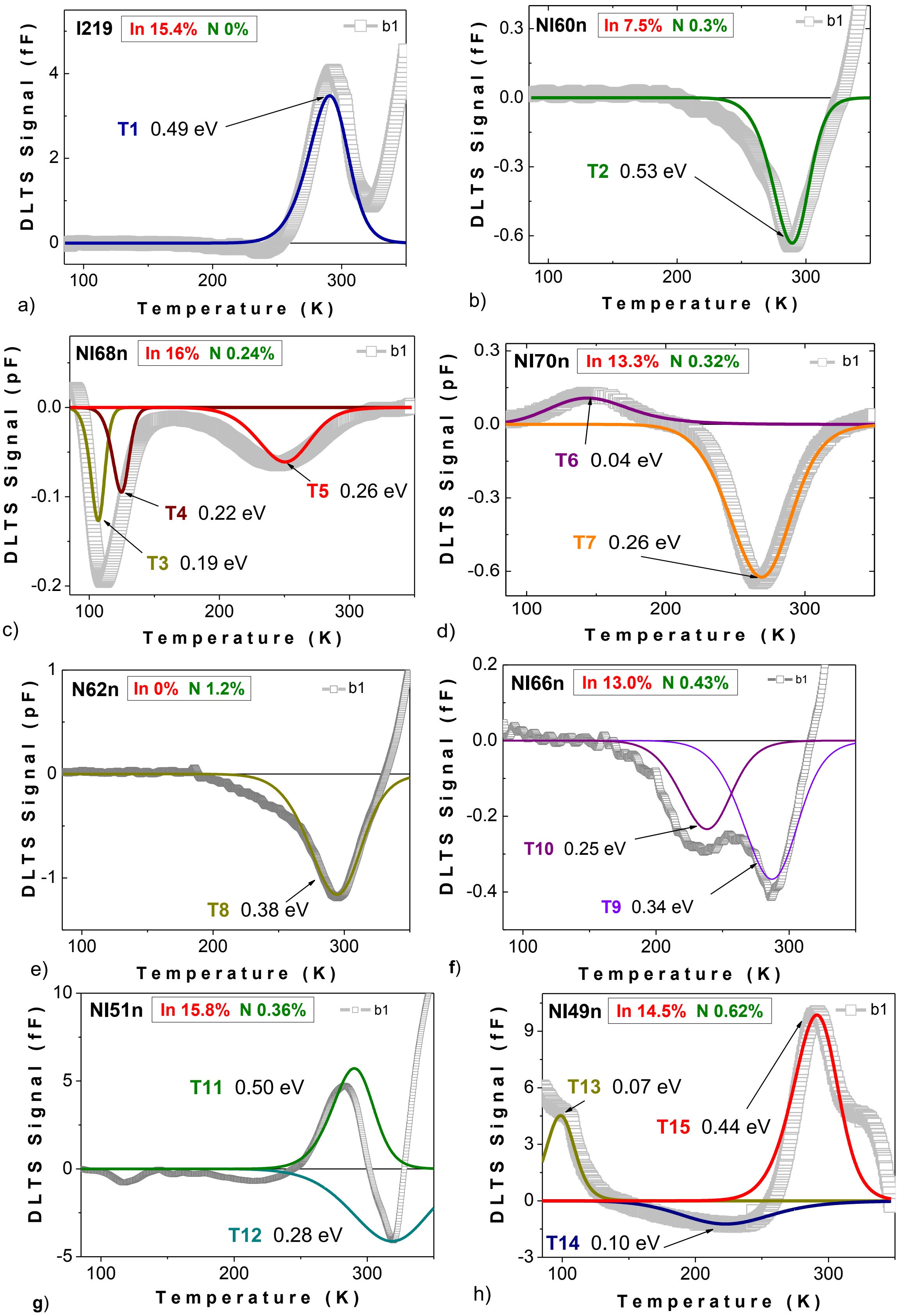

Fig. 1:*DLTS spectra (correlation functions b_1) measured on samples with input measurement parameters: time periods T_w = 200 ms, filling time t_p = 300 ms, filling voltage V_P = 0.05 V and reverse voltage V_R = -0.5 V with evaluated deep energy levelsand tempfit simulation of identified defects.*

In case of the T6 (0.05 eV) in NI70n (Fig. 1d) and T13 (0.07 eV) in NI49n (Fig. 1h) it's the emission of the holes from the QW in the valence band. The emission from quantum wells were detected only in samples with highest concentration of nitrogen and indium at the same time [2, 3, 11].

In sample N62n (Fig. 1e) due to the high nitrogen concentration (1.2%) was evaluated only one trap T8 (0.38 eV), identified as EL16 (0.37 eV) [10]. This trap was identified also on sample NI66n (Fig. 1f) with parameters T9 (0.34 eV).

3. Conclusion

By comparing of eightSchottky heterostructures with triple quantum well (I219, NI51n, NI68n, NI70n, NI49n, NI51n, N62n and NI66n) with different ratios of indium and nitrid concentration was confirmed the conclusion from literature that ratio of indium and nitrid concentration has direct impact on decreasing inner tension in structure and lowering concentration of localized states and defects [1, 2, 3]. Based on analysis of the impact of nitrogen and indium for the presence of electrically active defects in 8 semiconductor heterostructures with quaternary InGaAsN material shows that the best relaxed structure was NI70n having composition of 0.32 % nitrogen and 13.3 % indium.

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 1/0439/13) and by Wrocław University of Technology statutory grant and Slovak-Polish International Cooperation Program no. SK-PL-0005-12.

References:

[1] T. H. Wu, Y. K. Su, R. W. Chuang, C. Y. Huang, H. J. Wu, Y. C. Lin, *J. of Crystal Growth*, 370, 236-239, (2013).

[2] J. F. Chen, J. S. Wang, *J. of Appl. Phys.*, 102, 043705-1- 6, (2007).

[3] J. F. Chen, C. H. Chiang, P. C. Hsieh, J. S. Wang, *J. of Appl. Phys.*, 101, 033702-1-4, (2007).

[4] M. Ch. Hsieh, J. F. Wang, Y. S. Wang, Ch. H. Yang, R. C. C. Chen, Ch. H Chiang, Y. F. Chen, J. F. Chen, *J. of Appl. Phys.*, **110**, 103709-1-9 (2011).

[5] B. Ściana, D. Radziewicz, D. Pucicki, J. Serafińczuk, M. Tlaczala, R. Kudrawiec, J. Kováč, A. Vincze: In: *Proceedings of NAP*, Alushta, Ukraine, 211-217 (2011).

[6] B. Ściana, D. Radziewicz, D. Pucicki, I. Zborowska-Lindert, J. Serafińczuk, M. Tłaczała, M. Latkowska, J. Kováč, R. Srnánek: *Cryst. Res. Technol.*, **47**, 313 - 320 (2012).

[7] G. M. Martin, A. Mitonneau, A. Mircea, *Electron.Lett.*, **13**, 191–193, (1977).

[8] D. L. Partin, J. W. Chen, A. G. Milnes, L. F. Vassamillet, *J. Appl. Phys.*, **50**, 6845-6859, (1974).

[9] P. Blood, J. T. Yarris, *J. Appl. Phys.*, **56**, pp. 993-1007, (1984).

[10] O. Engstrom, M. Kaniewska, *Materials Science and Engineering B*, **138**, pp. 12-15, 2007.

[11] Ľ. Stuchlíková, J. Jakuš, J., Rybár, L. Harmatha, J., Kováč, B. Ściana, D Radziewicz, D. Pucicki, and M. Tłaczała, ADEPT 2013. ISBN 978-80-554-0689-3, 52-55 (2013).