CHARACTERIZATION AND TECHNOLOGY OF ALGAAS/GAAS PHOTOTRANSISTOR WITH DOUBLE DELTA-DOPED BASE

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1. Introduction

Heterojunction bipolar phototransistors (HPTs) have been widely used in the optoelectronic-integrated circuit such as photonic switches and optical amplifiers [1]. They are promising alternative to such devices as PIN and avalanche photodiodes due to a large optical gain and a negligible noise level but they suffer from long response times and a small optical gain, especially at low optical excitation. Different HPT constructions are proposed to solve above problems: a heterojunction phototransistor with a punch-through base [2, 3], a punch-through phototransistor with avalanche enhancement [4, 5] or a guard-ring around active region [6]. One of the methods to improve the phototransistor performance is applying a delta-doped thin base what causes both a higher current gain and a better time response. This work describes the fabrication and measurements of n-p-n AlGaAs/GaAs heterojunction phototransistor with double Zn-delta-doped 50 nm - thick GaAs base region. Parameters of the particular transistor epilayers were optimized by computer simulations using Silvaco Atlas program.

2. Experimental Details

Epitaxial structure of the n-p-n AlGaAs/GaAs HPT was grown by atmospheric pressure metalorganic vapour phase epitaxy (AP MOVPE) on (100)-oriented, undoped and silicon doped GaAs substrates. TMGa, TMAl, AsH_3, SiH_4 and DEZn were used as the growth and dopant precursors. High purity hydrogen was employed as a carrier gas. The following temperatures were applied during growth process: 670 °C (Si-doped 200 nm – thick GaAs subcollector SC, $n=4\times10^{18}$ cm^{-3}), 650 °C (Si-doped 700 nm – thick GaAs collector C, $n=4\times10^{17}$ cm^{-3}, double Zn-delta-doped 50 nm – thick GaAs base B, $p=1\times10^{19}$ cm^{-3}) and 700 °C (Si-doped 350 nm – thick $Al_{0.27}Ga_{0.73}As$ emitter E, $n=3\div4\times10^{17}$ cm^{-3} and Si-doped 80 nm – thick GaAs “cap”, $n=4\times10^{18}$ cm^{-3}). A conventional photolithography and a wet chemical mesa etching were applied to shape the HPT structure, working as a two terminal device without a base bias (“floating” base). The emitter ring contact AuGe/Ni/Au with the inner diameter of 150 μm was evaporated on the top of the emitter island. The same metallization was applied as the collector contact deposited on the bottom side of the n-GaAs substrate or at the bottom of the emitter island (on the SC layer) in the case of undoped substrate, forming a vertical and a planar device structure, respectively. The epitaxial HPT structure is presented in Fig. 1.

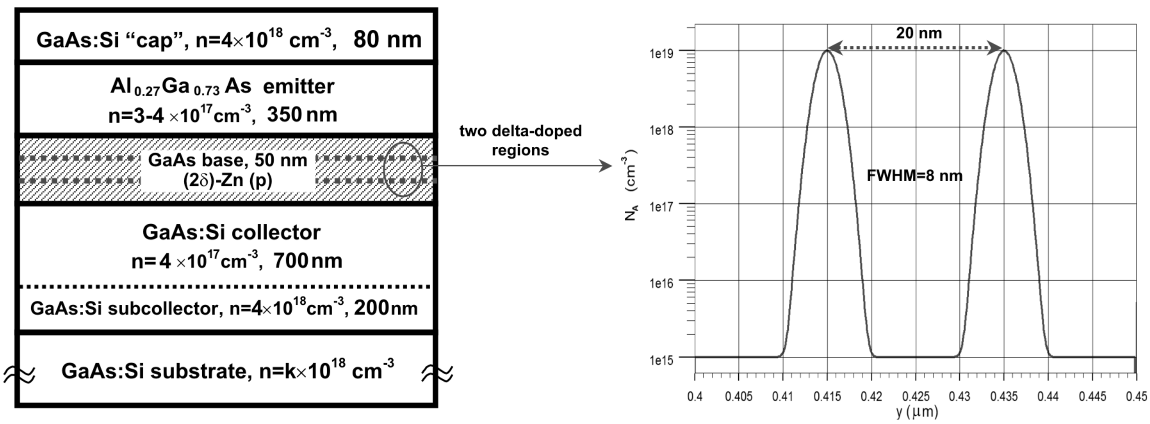

Fig.1: *Epitaxial structure of the n-p-n AlGaAs/GaAs HPT with a double delta-doped base.*

Lower values of the emitter and collector doping ($k\times10^{17}$ cm^{-3}) were applied based on the simulation results. They indicated that phototransistors with delta-doped base have higher sensitivity and the better switch times in comparison with devices with a bulk-doped base and don not require the high emitter doping. Additionally, lower value of the collector doping increases the space charge region (SCR) inside this layer, causes the absorption region also to increase. Data listed in Tab. 1 show the influence of the emitter doping N_E on output parameters (β – current gain, I_C – collector current, R_I – current responsivity, t_{on}, t_{off} - switch-on and switch-off times) of AlGaAs/GaAs HPT structures with bulk- and double-delta-doped 50 nm-thick base, determined from computer simulations using Silvaco Atlas software.

Device parameters were calculated for the pulse optical excitation of 177 μW (λ=850 nm) and collector-emitter bias U_{CE}=3 V.

Tab. 1. *Influence of the emitter doping N_E on output parameters of AlGaAs/GaAs HPTs with bulk- and double-delta-doped 50 nm-thick base working as two-terminal devices.*

N_E (cm^{-3})	β (A/A)	I_C (A)	R_I (A/W)	t_{on}(ns)	t_{off} (ns)
HPT with a bulk-doped 50 nm-thick base (two-terminal work)					
1×10^{17}	19	6×10^{-3}	32	128	45
1×10^{18}	106	31×10^{-3}	178	339	121
HPT with a double delta-doped 50 nm-thick base (two-terminal work)					
1×10^{17}	**105**	**31×10^{-3}**	**172**	**106**	**44**
1×10^{18}	**134**	**39×10^{-3}**	**224**	**325**	**109**

Where: N_E – emitter doping, β – current gain, I_C – collector current, R_I – current responsivity, t_{on}, t_{off} - switch-on and switch-off times, respectively.

3. Results

The electrical and optical properties of the obtained HPT epitaxial structure were examined using the electrochemical capacitance–voltage (EC–V) measurements and photovoltage spectroscopy (PVS) using a Bio-Rad PN 4300 system. Carrier distribution inside the phototransistor layers deposited on Si-doped substrate is shown in Fig. 2a. Electron concentration inside the emitter layer placed at the undoped base region is difficult to determine due to the lower doping value (3÷4×10^{17} cm^{-3}) what increases Debye length and reduces the resolution of the applied EC-V method.

a) **b)**

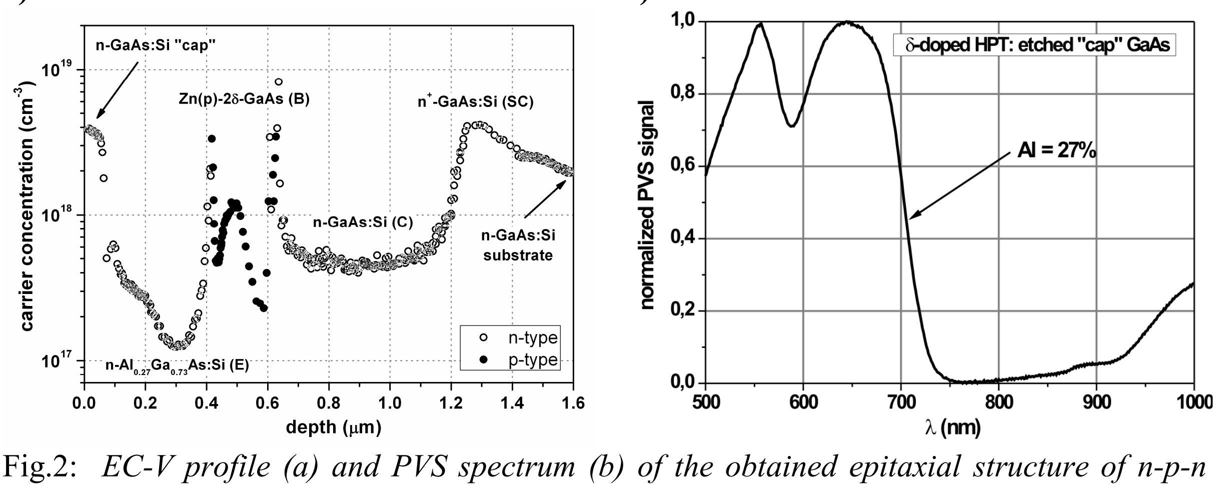

Fig.2: *EC-V profile (a) and PVS spectrum (b) of the obtained epitaxial structure of n-p-n AlGaAs/GaAs HPT with a double delta-doped base.*

In the case of a double-delta-doped 50 nm-thick base a precise determination of the thickness and hole concentration from EC-V profile is also impossible, because of the presence of p-n junctions between a very thin p-type delta layers and n-$Al_{0.27}Ga_{0.73}As$ emitter (or n- GaAs collector). So, micro-Raman and SIMS measurements are required. Photovoltage spectroscopy was applied for determination of the aluminum composition of the $Al_xGa_{1-x}As$ emitter based on the absorption edge of this epilayer. PVS spectrum of the HPT structure recorded at 300 K is presented in Fig. 2b. Aluminum content of 27 % estimated from this spectrum corresponds to the band gap value of 1.76 eV what guarantees the emitter transparency for wavelengths above 704 nm. Electrical and spectral characteristics of the device structure will be measure in the near future and compare with our earlier work [7] when we presented the similar HPT structure but with higher values of the emitter and collector doping. We hope that application of the lower emitter and collector doping distinctly improves the frequency performance of n-p-n AlGaAs/GaAs HPT structure with a double delta-doped base.

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