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A(III)B(V) detectors with graded active region

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Results of modelling and fabrication of photodetectors with composition graded active layers have been presented. Simulated and measured spectral characteristics of the proposed detectors have been shown. Advantages of such structures have been discussed with respect to conventional detectors with non-graded active areas as well as some technological problems of compositionally graded semiconductor layers.

Key words: *FGM; photodetector; compositionally graded material; epitaxy*

1. Introduction

Mechanical and electrical applications of functionally graded materials have been studied for many years. In most cases, the investigations focused on improvement of reliability and strength of composites for advanced ballistic, aircraft and automotive applications [1–3]. Progress in micro- and nanoelectronics, particularly improvement of epitaxial techniques, allowed one to grow materials with fully controlled doping and composition on a monolayer level. Introducing gradation in semiconductor structures results in improvement of optical and electrical properties of the devices [4–9].

The main goal of our work was to develop p-n photodetectors with compositionally graded active layers. Theoretical studies [10] show that gradation of composition in an emitter increases the total efficiency of the optoelectric transition by lowering the parasitic surface recombination; however reports on experimental investigation of graded photodetectors are rather scarce.

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We propose several basic compositionally graded p-n structures which could be practically used in photodetectors. They have been earlier simulated using our proprietary modelling software [11]. After theoretical optimization, two graded and one reference standard structure were fabricated by the metalorganic vapour phase epitaxy (MOVPE) technique. Wet anisotropic etching of the mesa and magnetron sputtering of metallic contact were applied to fabricate detector structures. Finally, both epitaxial structures and fabricated photodetectors were structurally, optically and electrically characterized.

2. Modelling and simulation

Because of several disadvantages of commercially available simulation programs, FMG – a proprietary software based on the finite element method and drift-diffusion model has been developed. The program calculates material properties based on their composition and doping. As a result, it allowed us to evaluate band structure of the material, potential distribution, optical generation function of carriers, band-to-band and SRH recombination rate and the value of currents flowing through the detector.

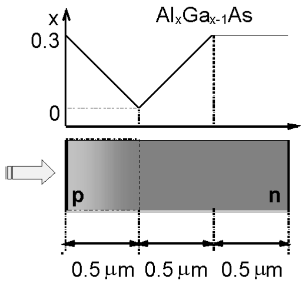

Fig. 1. Scheme of the investigated graded structure

Figures 1, 2 present a scheme, band-gap diagram and generation function diagram of the investigated "double graded" structure. Analyzing Figs. 2a, b, two main conclusions could be formulated. First, depending on the gradation profile, the graded area introduces internal electric field at the values ranging from 100 kV/m to 300 kV/m. There is not much information about dependence of Al content on the diffusion length of electrons in AlGaAs but one can assume that it changes from about 0.5 μm for pure GaAs to about 2 μm for $Al_{0.35}Ga_{0.65}As$ [12]. Thus the gradation can enhance the drift of generated minority carriers from the absorption region to the junction, especially in devices with relatively long emitters. As a result, the impact of surface recombination is decreased and the external quantum efficiency increases. Another phenomenon occurring in photodetectors with compositionally graded area is the "generation area localization". Since in compositionally graded detector structures, the band-gap width changes with the composition of the material, it is possible to obtain layers transparent for certain wavelengths (optical window effect). Moreover, in contrast to conventional photodetectors fabricated from homogeneous materials, in composition graded detectors the area where photons are absorbed changes smoothly with its energy, as is clearly shown in Fig. 2b. This phenomenon can be utilized, e.g. for fabrication of wavelength sensitive photodetectors.

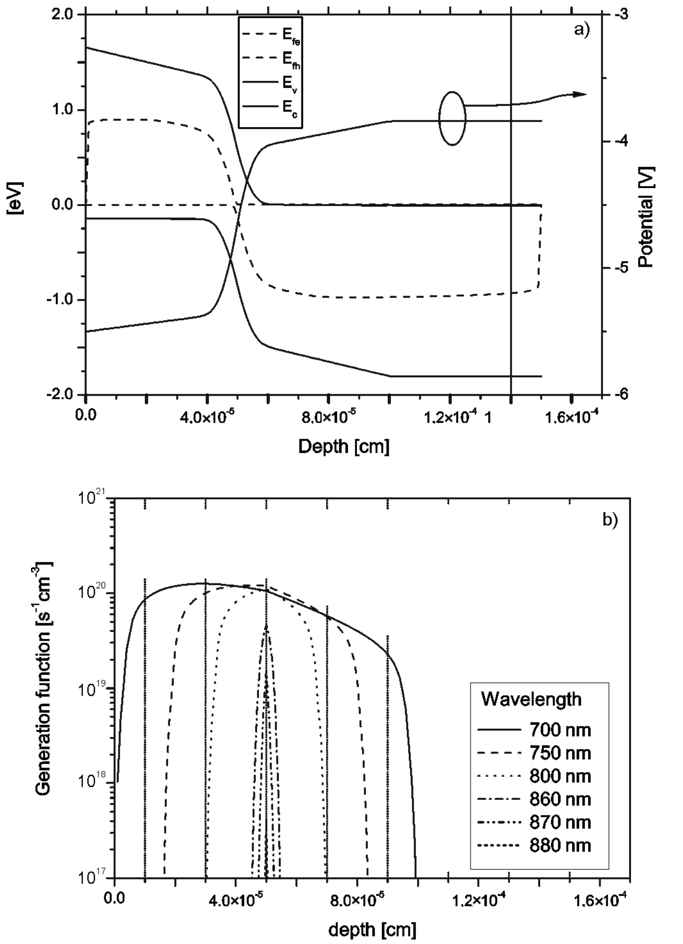

Fig. 2. Band-gap diagram (a) and generation function (b) of the investigated graded structure

Another advantage of detectors with compositionally graded active region is the possibility of adjusting spectral sensitivity of the device to the spectrum of the sun radiation. This kind of structures could replace widely reported cascade solar cells by a continuous change of absorption edge.

As a result of simulations and theoretical investigations [14], we proposed three structures of detectors shown in Fig. 3. The optimization of the structure consisted in a choice of the profile of the emitter composition and its length. The goal was to obtain spectral characteristics of a specified shape – weakly wavelength dependent or linearly wavelength dependent in a broad spectrum.

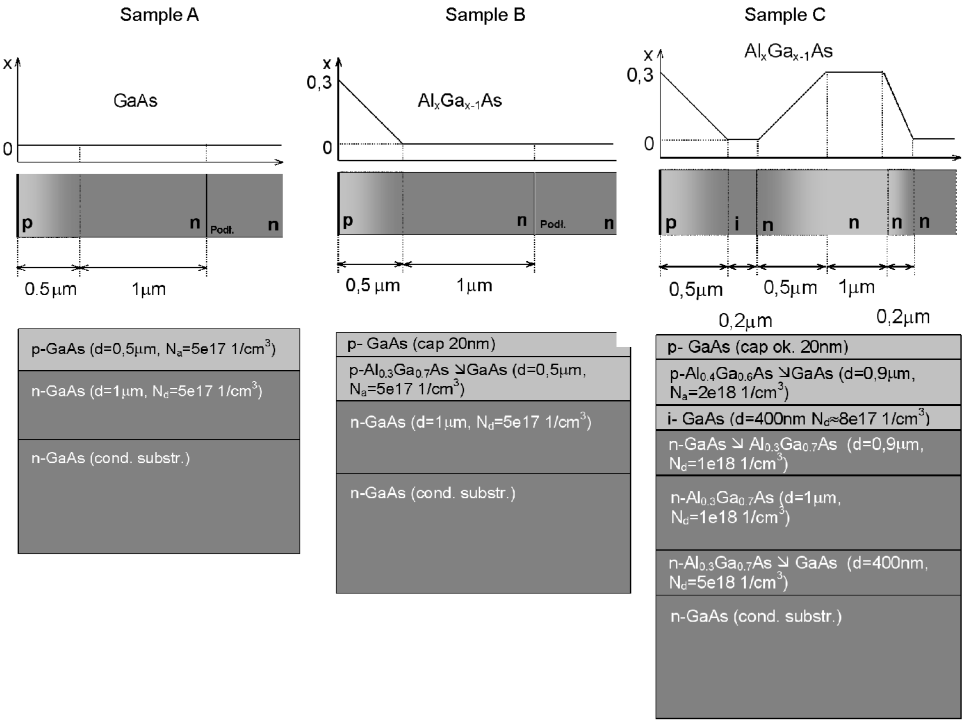

Fig. 3. Schemes of the investigated photodetectors

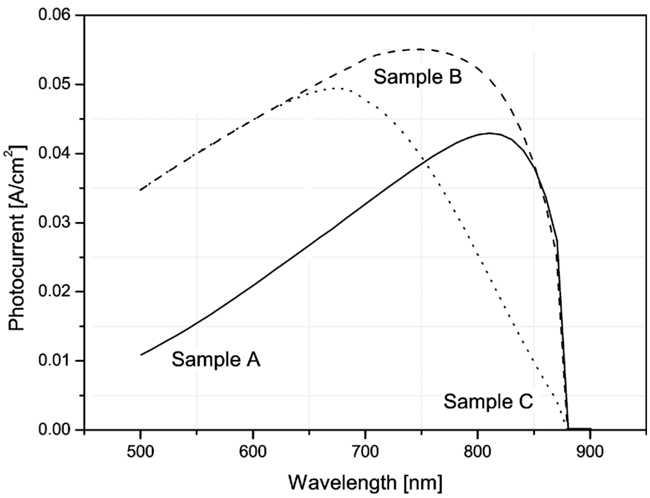

Fig. 4. Simulated spectral characteristic of the photodetectors

Figure 4 presents simulated spectral characteristics of the proposed detectors. If one compares the homogeneous detector structure (sample A) with the detectors with compositionally graded area (samples B and C), the difference of spectral characteristics can be easily seen. In the case of sample B, a higher sensitivity and broadening of spectral characteristic in the low wavelength region was obtained. The spectral characteristic of photocurrent of sample C changes linearly with the wavelength.

3. Experimental

Investigated structures (Fig. 3) were fabricated by the MOVPE method in an AIX 200 AIXTRON reactor. Te-doped 2-inch GaAs conducting substrates were used. TMGa and TMAl precursors were applied as sources of Ga and Al. After growth procedures, the samples were structurally and electrically characterized by PVS and ECV techniques [15]. The obtained results are presented in Fig. 5.

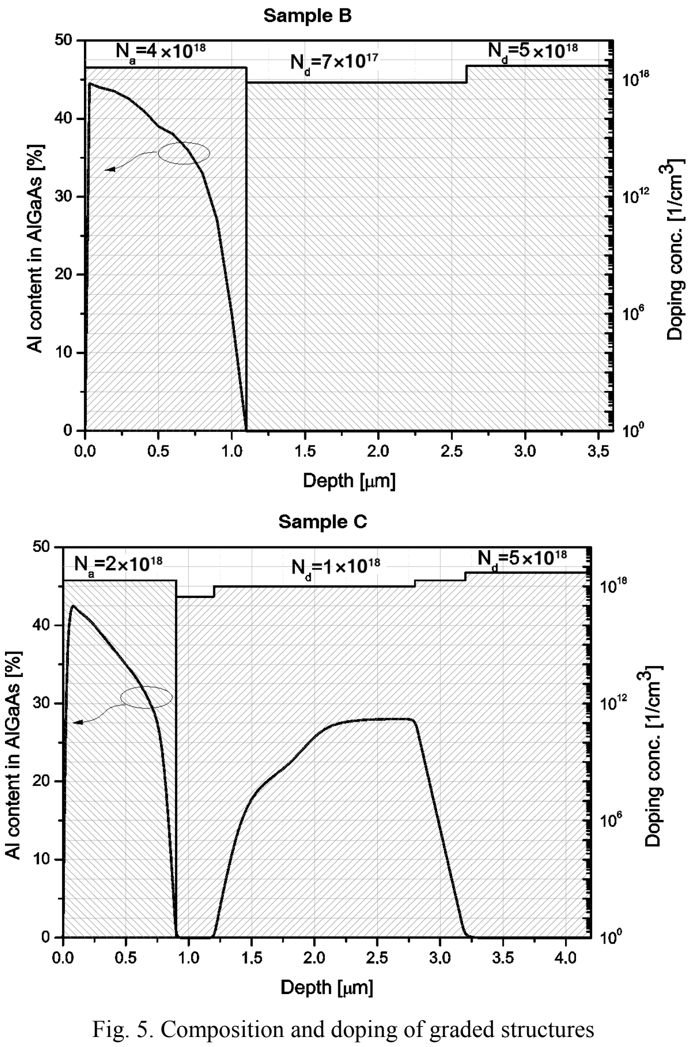

Fig. 5. Composition and doping of graded structures

As can be seen, composition and doping profiles differ from the theoretical ones (shown in Fig. 3). This is mainly due to a complex nature of the growth process of compositionally graded layers. The control of growth should include additional factors, mainly changing of growth rate and doping efficiency with altering of composition of the mixture of reagents. Mesa structures of the detectors were formed by wet anisotropic etching. Two different etching solutions were used. Composition of mixtures and process parameters are given in Table 1. Both solutions give good etching anisotropy and surface smoothness.

Table 1. Etching solutions for graded AlGaAs structures

Solution	Temperature [°C]	Etching rate [nm/min]
H_3PO_4:H_2O_2:H_2O (1:1:8)	23	819 (±5%)
H_3PO_4:H_2O_2:H_2O (1:1:40)		96 (±5%)

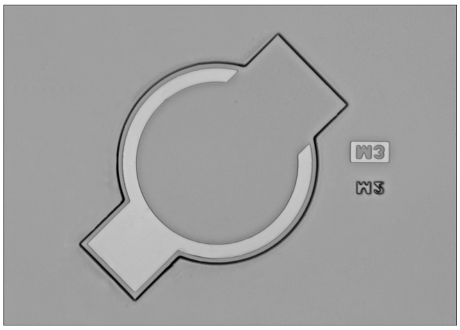

Fig. 6. Top view of the structure of the detector

Ohmic contacts were formed by using an electron beam and resistance evaporators and thermal annealing. To obtain good linear characteristics, several metallic multilayers were investigated: Ti/Pt/Au, Pt/Ti/Au, Ni/Ti/Au, Pt/Ti/Pt/Au to p-type AlGaAs and AuGe/Ni/Au to n-type GaAs from the bottom side. After sputtering, metallization was formed by the lift-off technique and annealed in a resistance furnace. The structure of the fabricated detector is shown in Fig. 6.

4. Results

Recorded spectral characteristics of investigated photodetectors are shown in Fig. 7. Higher sensitivities were obtained with samples B and C compared to a conventional GaAs p-n detector (sample A). Moreover, the maximum of sensitivity was shifted towards the low wavelength area because of the increase of Al content in the active layer. In the case of Sample B, a non-ideal "flat" characteristic was obtained due to a high Al content in the emitter (compared to the theoretically evaluated one). The sensitivity of sample C exhibits a linear dependence upon wavelength in the range from 670 to 880 nm. The characteristic edge at 850 nm is connected with the absorption edge of the intrinsic GaAs layer of the p-i-n photodiode.

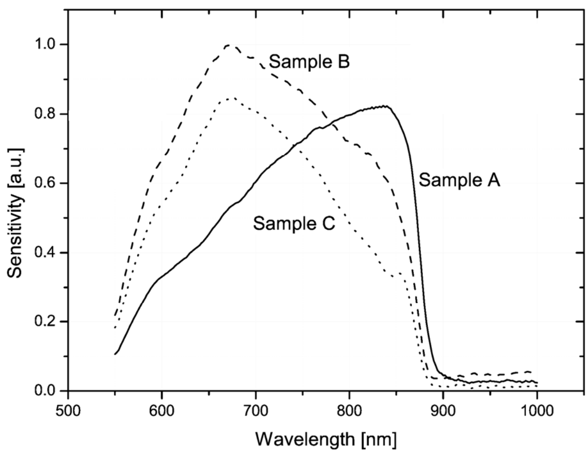

Fig. 7. Spectral characteristic of photodetectors with composition graded area

The differences between simulated and experimentally obtained spectral characteristics are caused by the imperfection of the mathematical model and by material properties data in the simulation software, as well by differences between the experimental profile of compositionally graded region and intended profile.

The deposition of compositionally graded layers by the MOVPE technique is an untrivial challenge because of complicated kinetics of the growth process. Contrary to the growth of homogeneous layers, in the case of compositionally graded materials, not only static parameters of epitaxial process like temperature, composition and pressure of gaseous atmosphere should be considered, but also composition of surface and predicted layers, inertness of the epitaxial system etc. The control of deposition of compositionally graded layers is the primary and most important problem which should be solved by using, e.g., computer aided design of the epitaxial process.

5. Conclusions

Novel AlGaAs photodetectors with compositionally graded active layers have been presented. Two basic types of photodetectors, with "flat" and wavelength dependent spectral characteristics were fabricated and characterized. The obtained results show that photodetectors with compositionally graded active layers can find advanced applications as spectrometers or colorimeters using cascade junctions in compositionally graded area to detect various wavelengths. It was shown that by using this type of structures, it was possible to modify spectral characteristics of devices in a wide spectral range. Further epitaxial process optimization must be performed to gain a better control of the growth process of the epitaxial layers with gradual change of the composition.

Acknowledgement

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