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A^{III}-B^{V}(N) photodetectors with functionally graded active area

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Functionally graded materials (FGM) find widespread for mechanical applications. Nowadays, they become more and more attractive in fabrication of electronic and optoelectronic devices. This is due to by their unique properties. FGM are potential candidates for high sensitive photonic devices which could operate in a wide spectral range (also for voltage tunable photodetectors). In this paper, the analysis of several photodetector constructions fabricated in FGM has been presented. The influence of A^{III}-B^{V}(N) grading layers composition and configuration of the detector on its optical and electrical properties has been discussed. Also, a comparison between conventional non-graded and graded devices has been made. All simulations presented in the work are performed by the specialized software designed for modeling A^{III}-B^{V}(N) graded structures. The software allow us to calculate both the parameters of FGM structure and device characteristics. During the simulation process it was noticed that the bandgap gradation in phototodetector active area improved its sensitivity up to 150% compared to classical, non-graded structures. Also, another effect such the wavelength sensitivity observed in these devices makes them very attractive for applications in which the high sensitive wavelength dependence is a key factor.

Keywords: FGM, graded materials, photodetector, simulation.

1. Introduction

Up to now graded materials and graded semiconductor layers were utilized in devices such as antireflective coatings of solar cells and GRINSH lasers [1, 2]. Gradation of the composition of semiconductor layers has influence on the physical properties (structural, optical and electrical). Some examples of new applications and theoretical discussion of the performance of devices fabricated in functionally graded semiconductor layers were described in our previous papers [3, 4].

2. Simulation

All results presented in this paper were obtained by the unique software elaborated for semiconductor graded structure modeling. The reason for creating this software was the lack of programs which would consider specific properties of graded layers and specific effects occurring in graded structures [3].

The program, called FDM, is based on a drift-diffusion model of semiconductor, supplemented by the contact effects (both Schottky and ohmic), carrier generation and recombination phenomenon as well as Fresnel reflection effect. It allows prediction of the device parameters, such as band-gap structure, potential distribution, optical generation function of carriers, band-to-band and Shockley–Read–Hall (SRH) recombination rate and the value of currents flowing through the structure. The software applies material parameters (band-gap, carrier concentration, concentration of dopants, carrier mobility, carrier lifetime, absorption coefficient, refractive index) which could be considered as constant or variable values, dependent on the composition of layers.

2.1. Photodetectors with FGM simulation results

Simplified schemes of the active area of photodetectors with graded emitter are presented in Figs. 1**a** and 2**a**. In the first case, the composition of *p*-type emitter layer was changed linearly from $Al_{0.3}Ga_{0.7}As$ to GaAs in *p*-type region. In the second case, gradation was also applied in the *n*-type region. Because of the direct recombination region the content of Al in AlGaAs layer was changed from 0 to 30%.

Spectral characteristics of both structures are shown in Figs. 1**b** and 2**b**, respectively. For comparison purposes characteristics of such detectors without the emitter gradation are presented. In the case of graded emitter, the calculated total

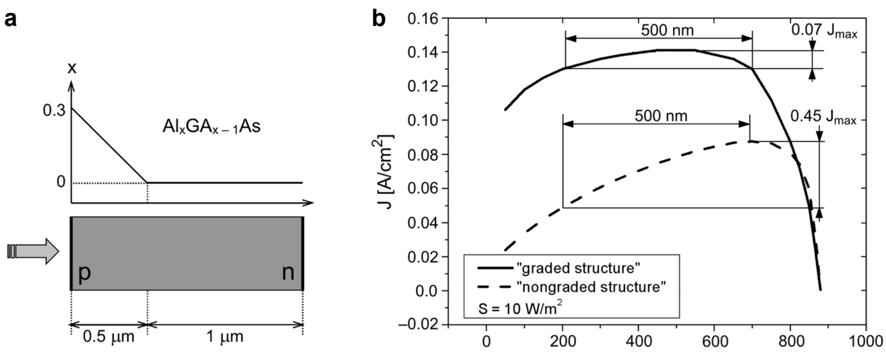

Fig. 1. Scheme of the active area of *p-n* photodetector with graded emitter (**a**) and comparison of spectral sensitivity of detectors with graded and non-graded emitter (**b**).

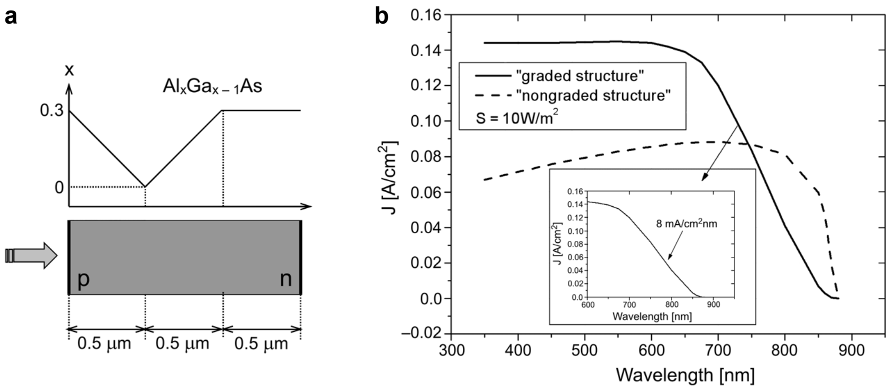

Fig. 2. Scheme of the wavelength sensitive photodetector (**a**), spectral sensitivity of structure with graded and non-graded emitter (**b**).

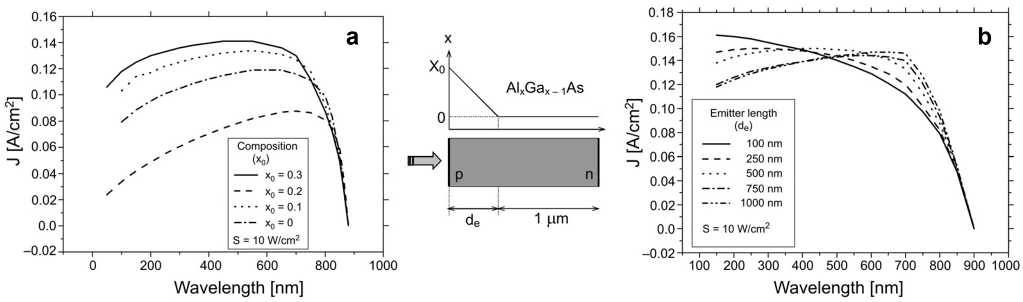

Fig. 3. The dependence of spectral characteristics of *p*-*n* photodetector with graded emitter *vs*. emitter: composition (**a**) and length (**b**).

photocurrent was about 50% higher and for mid- and short-wavelength region the slope of the characteristic is more flat. In the range from 200 nm to 700 nm the photocurrent changes of graded and non-graded structures were 10% and 45%, respectively.

Besides the improvement of sensitivity and wavelength stability observed in detectors with graded active area, it was also possible to form the shape of spectral characteristic. In the structure presented in Fig. 1, the independence of the photocurrent vs. illuminated wavelength was observed, while in the structure shown in Fig. 2, the photocurrent linear changes (8 mA cm^{-2}nm^{-1} at 10 W/cm^2 illumination) in the narrow band from 650 nm to 850 nm could be obtained. This means that it is possible to fabricate wavelength dependent/independent detectors by proper selection of the gradation profile and material composition of their emitter.

The influence of structure parameters such as composition as well as the emitter length on spectral sensitivity of *p*-*n* photodetector with graded emitter was also studied. The simulation results are shown in Fig. 3.

2.2. Phenomena in FGM detectors

For better understanding of the sensitivity increase obtained for detectors with graded emitter, it was necessary to analyse the band diagram, quasi-Fermi levels position and carrier generation function of such structures (Figs. 4 and 5). It was observed that by the gradation of the emitter the impact of surface recombination could be decreased. This is caused by the occurrence of the built-in electric field in the graded area, which effectively separates the generated minority carriers and causes their drifts toward the junction. Gradation of the emitter composition also shifted the maximum of the generation function away from the surface. Photons with energies lower than band-gap of semiconductor cannot be absorbed in the sub-surface region. As a result, the probability of reaching the junction region by carriers increases and the total photocurrent increases.

At wavelength sensitive photodetector (Fig. 5**b**) the width of the maximum of the generation function changed with the illumination wavelength, which influenced

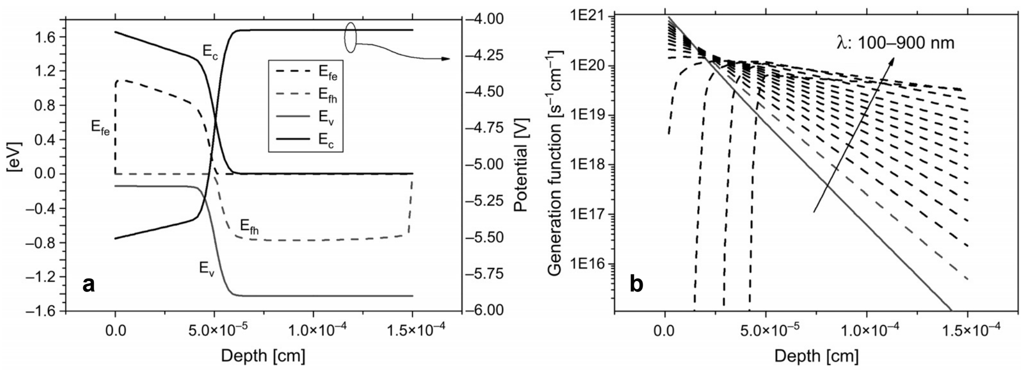

Fig. 4. Band-gap diagram (**a**) and generation function (**b**) of *p*-*n* photodetector with graded emitter.

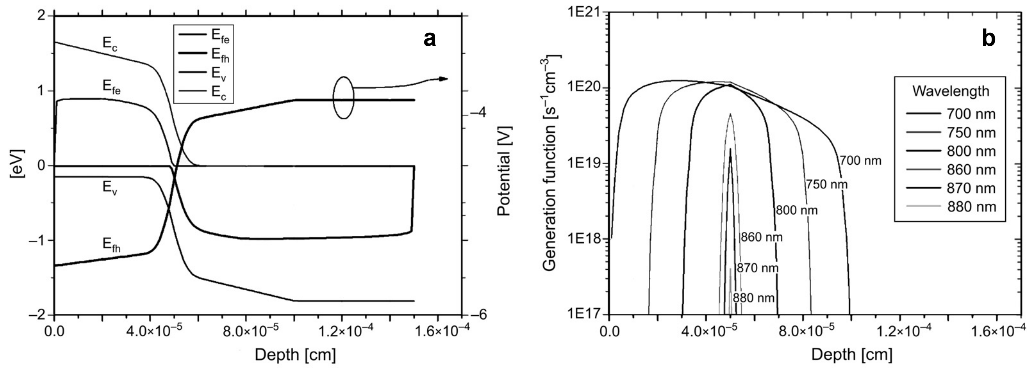

Fig. 5. Band-gap diagram (**a**) and generation function (**b**) of wavelength sensitive photodetector with graded emitter.

the quantity of generated carriers and, in consequence, influenced the photocurrent value. It was observed that the width of generation function for 800 nm is higher than for 700 nm because of the absorption edge. This effect could also be utilized in more sophisticated detector structures with several graded junctions, each of them absorbing photons with different energies.

3. Conclusions

The influence of profiling A^{III}-B^{V}(N) layers composition within the emitter area of *p-n* photodetector on optical and electrical properties of the device has been studied theoretically using the specialized software. Some new constructions of detectors with functionally graded active area have been proposed. The results obtained show advantages of such structures, *i.e.*, higher sensitivity, compared to non-graded detectors.

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References

[1] MAHDJOUB A., ZIGHED L., *New designs for graded refractive index antireflection coatings*, Thin Solid Films **478**(1–2), 2005, pp. 299–304.

[2] PIETERS B.E., ZEMAN M., VAN SWAAIJ R.A.C.M.M., METSELAAR W.J., *Optimization of a-SiGe:H solar cells with graded intrinsic layers using integrated optical and electrical modeling*, Thin Solid Films **451**–**452**, 2004, pp. 294–7.

[3] WOŚKO M., PASZKIEWICZ B., PIASECKI T., SZYSZKA A., PASZKIEWICZ R., TŁACZAŁA M., *Applications of functional gradient materials in optoelectronic devices*, Optica Applicata **35**(3), 2005, pp. 663–7.

[4] WOŚKO M., PASZKIEWICZ B., PIASECKI T., SZYSZKA A., PASZKIEWICZ R., TŁACZAŁA M., *Application and modelling of functionally graded materials for optoelectronic devices*, Proceedings of 2005 International Students and Young Scientists Workshop „Photonics and Microsystems", 2005, pp. 87–9.

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