Creating AlGaAs Photodetectors

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Abstract: AlGaAs/GaAs photodetectors operate at room temperature in the visible spectrum. Distinctive features of the photodetectors are: high absolute spectral sensitivity up to 0.112 A / W at λ_{max} = 530-570 nm; photodiodes showed the low dark current of 4.7 nA and 530 nA, accordantly, at 5 V reverse bias. The shift of the spectral characteristics which is associated with an increase in the band gap was detected.

1 INTRODUCTION

Photodetectors for the visible spectral range can be used as photodetectors in scintillation counters in experiments with space rays in neutrino physics, in experiments with particle accelerators, etc. Getting information about the particles that came to Earth from space, is an important research task. For example, the fastest accelerator allows getting the particles energy about 10^{13} eV, while the energy of the particles arrived from outer space, can reach 10^{17}-10^{19} eV. Also due to the sensitivity lack in the infrared range and high sensitivity in the visible region, such photodetectors may be used, for example to control the liquid crystal display (LCDs) backlight.

Scintillation detector consists of a scintillator which emits photons when struck by ionizing radiation and a photodetector that converts light from the scintillator into an electrical signal. In present-time detectors optical fibers are used to improve light focusing from the scintillator. Typically, the scintillators used for experiments in high energy physics, emit at a maximum wavelength λ_{max} from 375 to 430 nm. For detection of it light photomultiplier tubes (PMT) are used because their maximum spectral sensitivity is almost perfectly matches the maximum of emission spectrum of scintillator. But PMT has some disadvantages, that is why, nowadays, researchers and engineers are working on finding an alternative to replace the PMT. The most common alternative is silicon p-i-n diode (Ryzhikov and Kozin D et al., 2003) or silicon PMT (SiPM) (Patent RF, 2005; Herbert and D'Ascenzo et al, 2006; Bloser and Legere et al. 2014).

AlGaAs solid state solutions are high promising to create photodetectors for this spectral range. Si has maximum sensitivity about 900 nm, GaAs – about 800 nm, but by adding Al it can be achieved high sensitivity in the visible region (400-500 nm) due to increased bandgap. During the photodetectors creation it has been assumed that scintillation plate type SC-301 with maximum in the emission spectrum about 420 nm is used. To improve the light focusing optical fibers are used. The wavelength of transferred light to photodetector is approximately 476 nm.

In this paper photodetectors AlGaAs / GaAs for detecting light from the scintillator are presented. On the basis of heterostructures using the standard contact photolithography photodiodes were produced (tabl. 1).

Details of the construction and growth method of these structures are described in (Bloser and Legere. 2014; Murashev and Legotin et al. 2014; Bazalevsky and Didenko et al. 2014; Legotin and Murashov et al. 2014; Baryshnikov and Didenko et al. 2012; Koltsov and Didenko, et al. 2012; Legotin and Rabinovich et al. 2014). Photodiodes circular Mesa, the chip size of 4 x 4 mm and a photosensitive window diameter of 1.5 mm have been mounted in the housing type TO-39.

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Table 1: Basic structure for photodiode.

Layer's title	Concentration, (cm^{-3})	Layer's width, (nm)
Contact layer, p^+GaAs (Be)	2×10^{18}	45
"Window" p^+AlAs (Be)	2×10^{18}	50
$pAl_{0.35}Ga_{0.65}As$(Be)	2×10^{17}	500
$nAl_{0.35}Ga_{0.65}As$(Si)	2×10^{17}	500
Buffer n^+GaAs (Si)	1.5×10^{18}	200
Substrate n^+GaAs(Si)	1.5×10^{18}	400 µm

2 RESULTS AND DISCUSSION

Schematic cross-sections of finished devices are shown in figure 1.

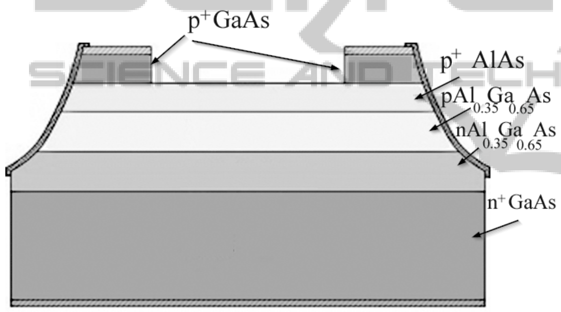

Figure 1: Cross section for photodiode.

Dark current and breakdown voltage were measured by Agilent B1500A semiconductor device analyzer. Reverse current–voltage characteristic (I-V) of photodiode is presented in Figure 2. The best samples demonstrated the dark current I_d = 3.38 nA at a reverse bias U_{rev} = 5 V. I-V control was carried out at each stage of devices production, from cutting wafers into chips till the packaging process (Fig. 3).

The measurements showed that after all production steps the dark current increased and the breakdown voltage decreased insignificantly (Fig. 3).

Calculations of spectral response were carried out for a p-i-n GaAs structure. It consists of a 0.82 microns thick top p-GaAs layer doped to $5 \cdot 10^{17}$ cm^{-3}; 45 microns thick i-GaAs region with electron density $1 \cdot 10^{14}$ cm^{-3} and heavily doped n^+-substrate from the back side of the structure. Surface recombination rate was taken as $2 \cdot 10^6$ cm/s. Figure 4 shows a spectral response of described structure. For clarity contribution of different regions is shown.

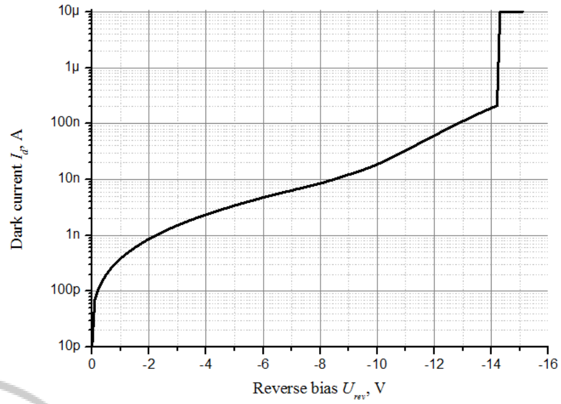

Figure 2: Reverse photodiode I-V characteristic.

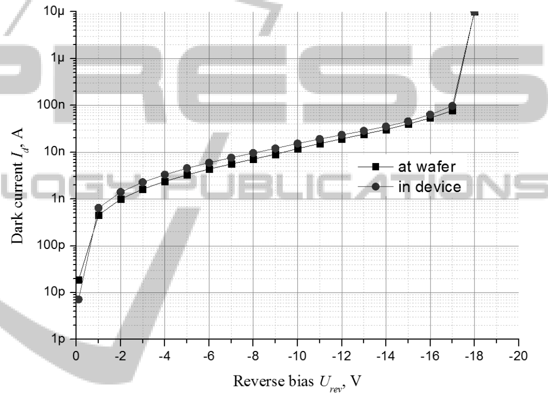

Figure 3: Photodiode I-V at wafer and after packaging.

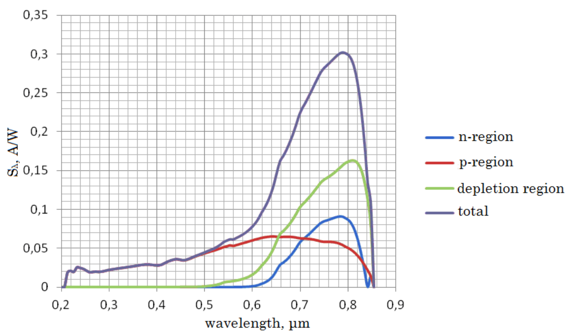

Figure 4: Calculated spectral response of p-i-n GaAs structure.

Figure 5 shows that the photosensitivity of the structure from the short-wave edge is determined by electrons in p-region, and from the long-wavelength edge by charge carriers generated in the depletion region and holes in the lightly doped i-region. Thus blue-shift of spectral response can be achieved by reducing surface recombination rate and by increasing mobility and lifetime of electrons in p-region. Also modeling of p-i-n heterostructure with p $Al_xGa_{1-x}As$ layer was performed.

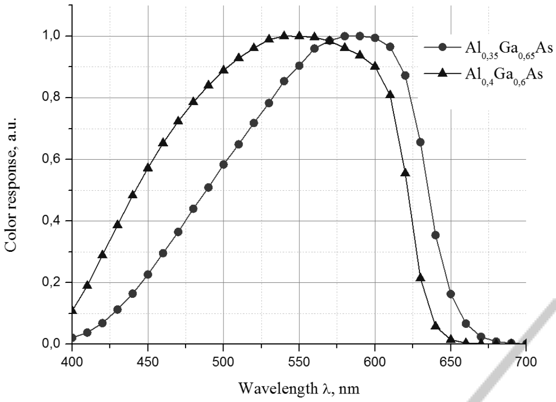

Figure 5: Photodiodes spectral characteristics.

Calculated spectral characteristics are shifted to the short-wave range and overall sensitivity increases. At the same time it could be seen that the greatest increase in sensitivity at wavelengths less than 0.4 microns takes place not for the widest bandgap material. Someone can find it strange, but the fact is that in the more wide bandgap-materials the electron mobility decreases sharply (from $3.1 \cdot 10^3$ cm^2/V·s for $Al_{0.25}Ga_{0.75}As$ to $5.4 \cdot 10^2$ cm^2/V·s for $Al_{0.419}Ga_{0.581}As$) for the same surface recombination rate and lifetime of charge carriers.

Spectral characteristics were measured using a monochromator MDP and apparatus for measuring the spectral sensitivity of photodetectors TTM3.435.088. Figure 5 shows the relative spectral characteristics of the photodiodes.

It's seen that, at changing the Al mole fraction by 0.05, maximum of spectral sensitivity was shifted by 40 nm to shorter wavelengths. At the same time the sensitivity at a wavelength of 475 nm was increased almost twice by choosing the optimum composition and thickness of the active p-layer. To achieve greater sensitivity in shorter wavelengths for photodiodes antireflection coating on "window" layer will be used.

Photodetectors created for detecting light from the scintillator based on AlGaAs/GaAs heterostructures were produced. Photodetectors measurements showed the low dark current at the level of 0.5 nA for phototransistors and 10 nA for photodiodes, for at the same time high breakdown voltage was about 600 V and 20 V, accordantly.

Experimentally determined values of composition and thickness for the $Al_xGa_{1-x}As$ solid solution allowed to increase the sensitivity almost twice from 40 to 75 % at a wavelength 475 nm. Absolute spectral sensitivity of photodiodes reached 0.13 A/W at λ = 570 nm.

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