

Selectivity control of photosensitivity of Ag-GaP and Ag-AlGa_xN structures

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Abstract. Design, growth and studies of photosensitive structures based on Ag-GaP and Ag-Al_xGa_{1-x}N contacts are reported. Methods for structure selectivity control, which allow changing the sensitivity spectrum half-width in a range of 11-210 nm were worked out. By varying the metal layer thickness, a set of Ag-GaP short-wavelength photodetectors (PD) was fabricated. The set includes PDs from broadband (spectrum half-width $\Delta\lambda=210$ nm, sensitivity $S_1 = 0,19$ A/W) to visible-blind ($\Delta\lambda=15$ nm, $S_1 = 0,034$ A/W). The use of Ag-Al_xGa_{1-x}N structures provided increased sensitivity ($S_1 = 0,071$ A/W) and $\Delta\lambda$ reduced to 11 nm due to special selection of solid solution composition.

1. Introduction

One of the key objectives of modern optoelectronics is development of photodetectors. In many cases the necessity occurs to develop a wavelength-selective narrowband photodetector. Applying broadband photodetectors in combination with optical filters is a regular solution. However such filters significantly worsen device parameters, in particular leading to reduced sensitivity, an increase of dimensions and cost. Besides, it is often a challenge to adjust the filters to the required band pass. The problem is especially important in designing short-wavelength photodetectors. Therefore, development of selective ultraviolet (UV) photodetectors with the structure providing the selectivity effect without the use of additional optical filters is a relevant problem.

Existing silicon-based photodiodes [3] show high sensitivity in the visible range of the spectrum due to a narrow band gap of the semiconductor. The use of GaP with a wider band gap allows eliminating part of spurious signals [4]. The most perspective are wide-bandgap Al_xGa_{1-x}N solid solutions [5, 6] with a band gap that is wide enough to eliminate sensitivity in the visible portion of the spectrum. In this work, the results of development and research of methods for selectivity control of the photodetectors with a possibility of varying their sensitivity within both short- and long-wavelength regions of the spectrum are presented.

2. Sample and experimental technique

The structures on the basis of gallium phosphide and solid solutions of aluminium gallium nitride have been investigated. Sulfur doped *n*-GaP epitaxial layers with a free carrier concentration of $(0.5\dots5) \cdot 10^{16}$ cm⁻³ were grown by vapour phase epitaxy. Schottky barriers were formed by vacuum thermal evaporation of silver on the semiconductor surface preliminarily cleaned in



tetrachloromethane environment. The ohmic contacts were formed by Au deposition in accordance with the standard technique [7].

$\text{Al}_x\text{Ga}_{1-x}\text{N}$ epitaxial layers were grown by hydride vapour phase epitaxy (HVPE) technique [8]. The top doped $n\text{-Al}_x\text{Ga}_{1-x}\text{N}$ layer had a carrier concentration of 10^{16} cm^{-3} . Metal layers were deposited by vacuum thermal evaporation at a residual gas pressure of 10^{-5} Torr. Ag was used as a rectifying contact material. Al with Ti underlayer were used to form Ohmic contacts. Prior to metal deposition the structures were cleaned by potassium hydroxide (KOH) during 2 min and washed with distilled water. For good metal adhesion the structures were heated to a temperature of 300°C during deposition.

Structure characteristics were measured using a set-up based on a monochromator MDR-3 with a diffraction grating and a xenon lamp as a light source. The set-up allows measuring spectral characteristics in a range of 200-2500 nm and current-voltage characteristic in a range of $10^{-15} \text{ A} - 1 \text{ A}$.

3. Experimental results and discussions

In this work, a research based on two basic selectivity control methods for the sensitivity spectrum of photodetector structures is presented. One is based on using selective properties of a Schottky contact metal layer (silver layer), while in the other method, the selectivity is controlled by varying the composition of a semiconductor epitaxial layer.

Silver is a unique material for fabrication selective ultraviolet photodetectors. The presence of a narrow spectral window around a wavelength of 322 nm allowed realizing so-called visible-blind photodetectors which are not sensitive to the visible light. It can be carried out through making a junction between silver and wide band gap semiconductor. The parameter which mostly affects the selectivity of such photodetectors is the silver layer thickness.

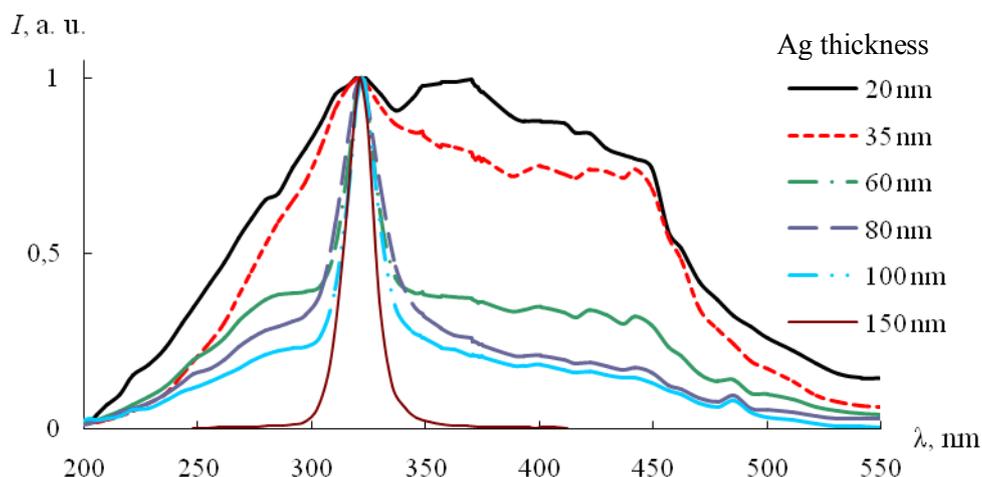


Figure 1. Spectral characteristics of Ag- GaP photosensitive structures with different selectivity degree

A set of photosensitive structures based on gallium phosphide and nitride semiconductor solid solutions with different selectivity degree was fabricated. By using thin silver layers (less than 20 nm), broadband short-wave photodetectors with the sensitivity range of 200-600 nm were designed. The sensitivity at the maximum was 0.19 A/W, the value of the spectrum half-width was greater than 210 nm. The reverse current value at a voltage of 1 V did not exceed 10^{-14} A enabling to reach good detectivity.

Varying the silver layer thickness allowed to control the selectivity degree of spectral characteristics as shown in Fig. 1. It is shown that increasing the layer thickness leads to more rapid decreasing of sensitivity in both short- and long-wave ranges of the spectrum than at the maximum of

322 nm. At 150 nm thickness of the Ag layer a visible-blind UV photodetector with the sensitivity maximum at 322 nm and a half-width of 15 nm. The sensitivity was 0.034 A/W.

To increase the photosensitivity within the UV spectrum range, structures based on direct band gap solid solutions $\text{Al}_x\text{Ga}_{1-x}\text{N}$ were investigated. The use of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ solid solutions allows not only to improve the sensitivity, but eliminate spurious signals in the long-wave region of the spectrum and reduce the spectrum half-width. Photodetector structures based on Schottky barriers $\text{Ag-Al}_{0,08}\text{Ga}_{0,92}\text{N}$ were fabricated. Such photodetectors have the long wavelength edge of photosensitivity less than 350 nm. It complies with requirements to visible-blind photodetectors. The half-width was in a range of 15-40 nm depending on the Ag layer thickness varied from 15 to 150 nm.

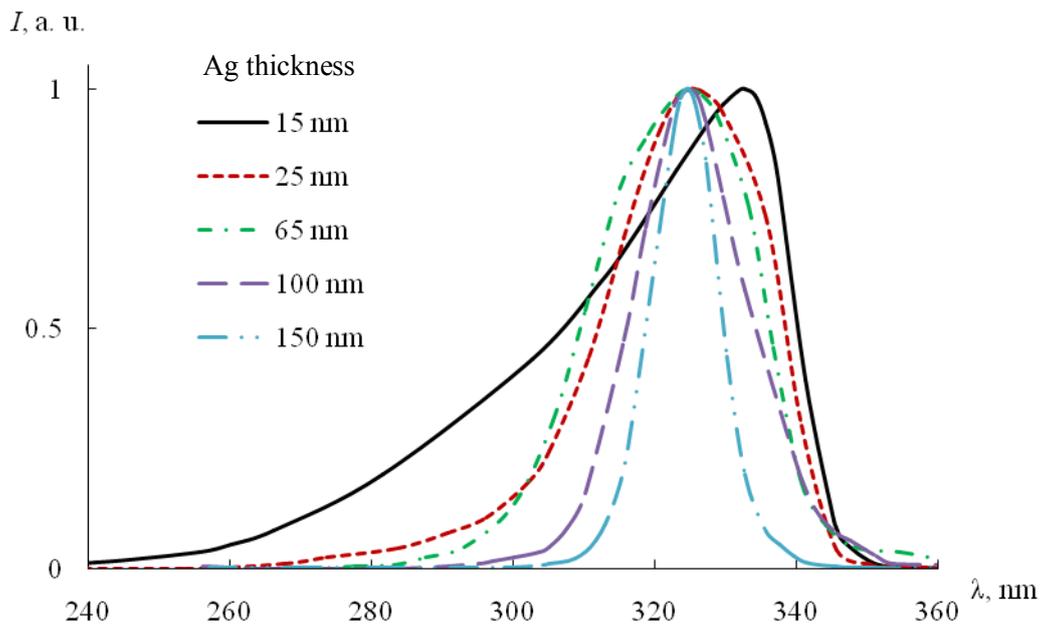


Figure 2. Spectral characteristics of $\text{Ag-Al}_{0,08}\text{Ga}_{0,92}\text{N}$ photosensitive structures with different selectivity degree

The photosensitivity spectrum is mainly determined by the absorption spectrum of a semiconductor. The photodiode sensitivity peak is within a range of maximum photoabsorption which corresponds to the photons with energy more than the band gap. The limit of photodiode sensitivity is defined by the theoretical limit of quantum efficiency η_{max} , that is, when every absorbed photon leads to formation of an electron-hole pair. The theoretical limit of quantum efficiency is shown in Fig. 3 by the dashed line.

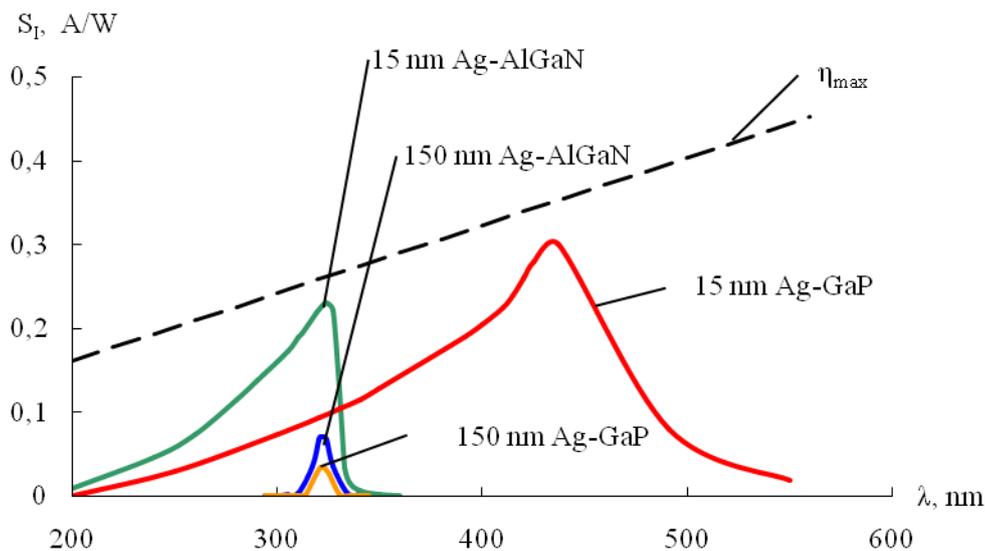


Figure 3. Theoretical spectral characteristics of photodiodes based on silver layers

In a real Schottky barrier photodiode, the cutoff wavelength on the short-wavelength side strongly depends on the surface recombination velocity. The higher the surface recombination velocity, the less the quantum efficiency of a photodetector and the sharper decline in the short-wavelength range of the spectral characteristic is observed. For a gallium phosphide photodetector in particular, the efficiency at a wavelength of 322 nm decreases by almost 3 times with respect to the efficiency maximum at a wavelength of 420 nm (Fig. 3). Since the band gap of a $\text{Al}_x\text{Ga}_{1-x}\text{N}$ solid solution exceeds the GaP band gap, the efficiency decline occurs at significantly shorter wavelengths. As a result, the quantum efficiency of a photodetector with $\text{Al}_x\text{Ga}_{1-x}\text{N}$ epitaxial layer at a wavelength of 322 nm is higher than that of GaP photodetector, that is, a selective $\text{Al}_x\text{Ga}_{1-x}\text{N}$ -based Schottky barrier photodiode will have higher sensitivity than a Ag-GaP-based photodiode.

The use of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ solid solution makes it possible not only to increase the sensitivity of silver based photodetector structures but additionally control their selectivity. Appropriate choice of solid solution composition shifts the red limit of photoeffect which narrows the sensitivity spectrum of a photodetector into longer wavelength range. For this purpose Ag- $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$ structures were created with spectral characteristics of photosensitivity shown in Fig.4. The sensitivity spectrum of the structure with Ag layer thickness of 15 nm is shown by the solid line. In this case the selectivity effect barely reveals itself, and the spectrum half-width is more than 40 nm. On the right side the sensitivity is limited by the solid solution band gap, which corresponds to a wavelength of 340 nm. When increasing the Ag layer thickness, the sensitivity in the short-wavelength range dramatically reduces due to absorption in metal, and blue limit of photoeffect shifts into a longer wavelengths range. At the same time the right side of the spectrum remains unchanged since the solid solution composition remains permanent. It allowed reaching higher degree of photosensitivity selectivity. The half-width of sensitivity obtained for Ag thickness of 150 nm was less than 11 nm.

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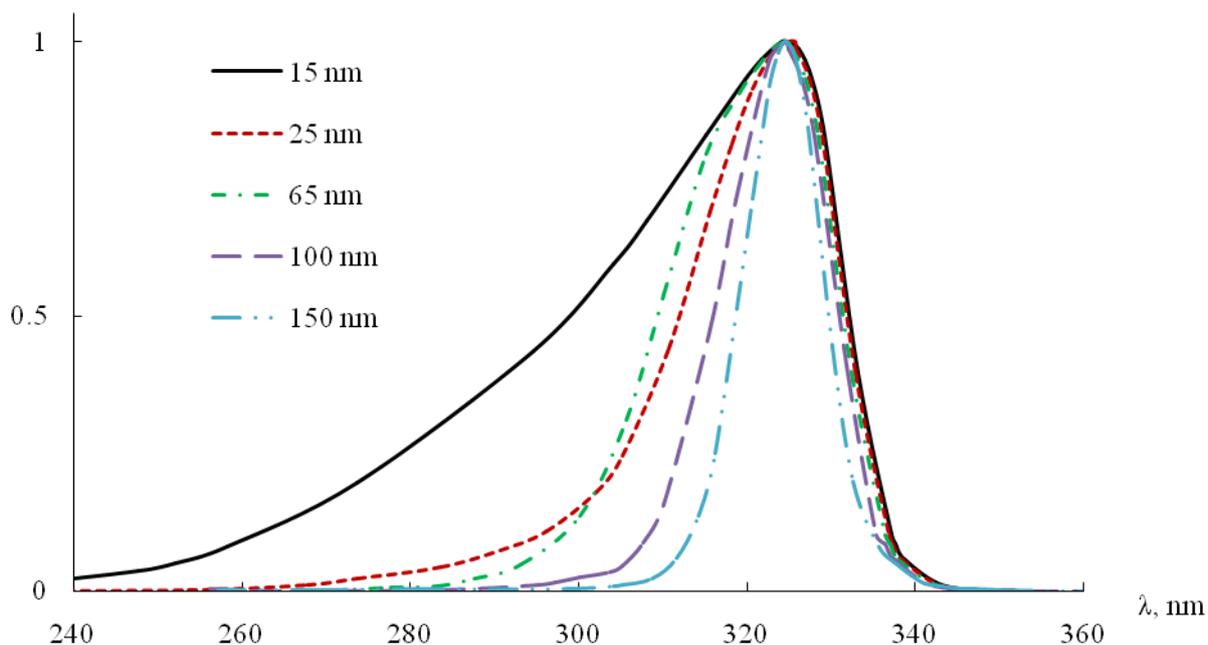


Figure 4. Spectral characteristics of Ag- $\text{Al}_{0,2}\text{Ga}_{0,8}\text{N}$ photosensitive structures with different selectivity degree

Besides, altering solid solution composition to $\text{Al}_{0,2}\text{Ga}_{0,8}\text{N}$ resulted in a sensitivity increase of a selective photodiode as the long wavelength limit of photosensitivity was shifted into a range of shorter wavelengths by increasing the Al fraction in the solid solution of the epitaxial layer. At that, the maximum absorption of the solid solution coincided with the Ag spectral window position.

4. Conclusion

In this work, photosensitive structures with different degree of spectral characteristics selectivity on the basis of gallium phosphide and aluminium gallium nitride solid solutions have been created and investigated. Two methods of structure selectivity control which allow changing the sensitivity spectrum half-width in a range of 11-210 nm were worked out: by using selective properties of the Schottky contact metal layer (silver layer) and varying the composition of the semiconductor epitaxial layer.

By using thin silver layers (less than 20 nm) broadband shortwave photodetectors based on Ag-GaP structures with the sensitivity range of 200-600 nm have been created. The sensitivity at the maximum was 0,19 A/W, the value of the spectrum half-width was more than 210 nm. It is shown that increasing the layer thickness leads to more rapid decreasing of sensitivity in both short wave and long wave range of the spectrum than at the maximum at 322 nm. With the Ag layer thickness of 150 nm a visible-blind ultraviolet photodetector with the sensitivity peak of 322 nm and 15 nm half-width. The sensitivity was 0,034 A/W.

The structures based on Ag- $\text{Al}_{0,08}\text{Ga}_{0,92}\text{N}$ Schottky barriers have been manufactured in order to improve photosensitivity in the UV range and eliminate spurious signals in a long wavelength range. It allowed to realize photodetectors which have a long wavelength edge of photosensitivity less than 350 nm. The half-width was in a range of 15-40 nm depending on the Ag layer thickness varied from 15 to 150 nm. The proper choice of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ solid solution composition provided increased

photoresponse with further reducing the half-width to 11 nm by matching the peaks of the silver transmittance spectrum and the structure sensitivity spectrum. The obtained parameters comply with requirements to visible-blind photodetectors. The sensitivity was 0,071 A/W.

The work was supported by the Ministry of Education of the Russian Federation in the framework of the project of the state task in the field of scientific activity, project number 16.1307.2014K.

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