1.06 μm wavelength photodetectors with metamorphic buffer layers grown on GaAs substrates

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Abstract. The result of investigation of InGaAs photodetectors grown on GaAs substrate with metamorphic InGaP buffer is shown in this paper. It has been shown experimentally that the use of the gradient InGaP metamorphic layer in an InGaAs photodiode structure improves the spectral characteristics and crystalline quality of the structure and leads to reduction of dark current by an order of magnitude compared to photodiodes fabricated with metamorphic InGaAs layers.

1. Introduction

The InGaAs compound has become the most suitable material for creation of active region for photodetectors at 1.06 μm wavelength during the last 20 years [1, 2]. In$_x$Ga$_{1-x}$As solid solution with indium content $x = 53\%$ is matched to a lattice constant with InP substrates and has bandgap of 0.74 eV. The device can operate at range of wavelengths from 0.9 to 1.7 μm. However, InGaAs/InP heterostructures have a significant disadvantage: InP substrates are expensive and fragile. An alternative heterosystem for the creation of photodetectors operating at the near IR range can be InGaAs structures grown on GaAs substrates [3].

The growth of InGaAs structures on GaAs substrates has specific features. When we increase the content of indium in the In$_x$Ga$_{1-x}$As solid solution the bandgap of the InGaAs decreases and the of lattices mismatch between InGaAs and GaAs increases. This leads to an increase of elastic stresses in the structure. In the first stages of growth an isomorphous growth of the layer is observed. If a critical thickness is exceeded, a part of the stresses relax with the formation of misfit dislocations [4]. An increase in the number of defects can negatively affect the characteristics of photoelectronic devices. It is proposed to use the perspective method of growth of heterostructures with the use of metamorphic layers to solve this problem.

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The structure for a photodetector at 0.94-1.06 μm wavelengths with an InGaAs active region grown on a GaAs substrate with an InGaP buffer layer, which consisted of tens of thin layers with constant composition, was presented earlier [5]. In the case of illumination through a substrate, spectral photosensitivity of such photodetectors is determined from the long-wave side by the width of the bandgap of the solid solution, and from the short-wavelength side by the bandgap of the substrate. The results of investigations of InGaAs photodetectors with metamorphic buffer layers InGaP and InGaAs are presented in this paper. A metamorphic buffer is supposed to reduce the concentration of defects in the active region and, thereby, reduce the dark current of the photodiodes. We also compare the
surface roughness of photosensitive structures with the metamorphic layers InGaP, InGaAs, and the electrophysical characteristics of photodiodes fabricated on their basis.

2. Experimental samples
Photosensitive structures were obtained by the method of MOCVD at atmospheric pressure in a horizontal quartz reactor. The structures were grown as follows. A GaAs buffer layer (100 nm) was grown on the GaAs substrate, then a InGaAs metamorphic layer (100 nm) or InGaP (1000 nm) was grown with a stepwise change in composition, then the InGaAs active region (450 nm) was grown (Table 1). The temperature of substrate was 600°C and growth rate of the metamorphic layers was 0.55 nm/sec. The III/V ratio was 8 for the InGaAs metamorphic layer, and 21 for the InGaP metamorphic layer.

Au/Pd/Ti ohmic contacts were deposited on the side of the structure by electron-beam evaporation in a vacuum, then 1 mm mesas were formed by photolithography and chemical etching. Sn ohmic contacts on the substrate side were applied by the method of spark-ignition. The surface of the samples was processed to reactive ion etching in an oxygen atmosphere and to subsequent thermal oxidation in order to minimize the surface dark current.

Table 1. The design of structures.

| Layer                  | Thickness, nm |
|------------------------|---------------|
| n+-GaAs (substrate)    |               |
| 1                      | n-GaAs        | 150          |
| 2                      | n-InGaAs or n-InGaP | 100 or 1000  |
| 3                      | n-InGaAs      | 150          |
| 4                      | i-InGaAs      | 450          |
| 5                      | p-InGaAs      | 300          |

3. Results and discussion
The morphology of surfaces of produced photosensitive structures with InGaAs and InGaP metamorphic buffer layers was investigated (figures 1 and 2). Surface roughness measurements were carried out using Taylor&Hobson TalySurf CCI 2000 interference microscope. The values of the average surface roughness for structures with InGaAs and InGaP metamorphic buffer layers were 5 nm and 40 nm, respectively. The relief of the structures’ surfaces has lines in various directions, which can indicate the formation of dislocations in the top layer. Lines in mutually perpendicular directions are observed on surface of the structure with the InGaP buffer layer.

Figure 1. The relief of the structure surface with the InGaAs metamorphic buffer layer. Figure 2. The relief of the structure surface with the InGaP metamorphic buffer layer.
Photo-emf was measured for produced structures at a wavelength of 1 μm. Photo-emf values for structures with InGaAs and InGaP buffer layers were 450 mV and 650 mV respectively.

The spectral characteristics of photocurrent were measured at room temperature. The halogen lamp was used as a source of radiation in the experiment. The modulated lamp light was focused by the collecting lens on the input slit of a monochromator. After passing the monochromator, the light shone on a photodetector sample.

Photocurrent spectra of structures with InGaAs and InGaP metamorphic buffer layers are in the range of 0.9 - 1.0 μm and the maximum photosensitivity is at wavelengths of 1.05 μm and 1.03 μm, respectively (figures 3 and 4). The spectra of sample based on the structure with the InGaAs metamorphic layer have a close to triangular shape, which can be caused by light absorption in the InGaAs metamorphic layer. Samples with the gradient InGaP metamorphic buffer layer have the form more approximate to rectangular as InGaP layer doesn’t absorb radiation in the given range of wavelengths.

![Figure 3](image1.png) ![Figure 4](image2.png)

**Figure 3.** The spectral dependence of the photocurrent of photodiodes fabricated on the basis of heterostructures with the InGaAs metamorphic buffer layer.

**Figure 4.** The spectral dependence of the photocurrent of photodiodes fabricated on the basis of heterostructures with the InGaP metamorphic buffer layer.

Current–voltage characteristic were measured using Keathley 2440 automated system. Graphs of dark currents of photodiodes with InGaP and InGaAs buffer layers are shown on figure 3. Dark current of photodiodes with the InGaP metamorphic layer is 10 times lower than reverse current of photodiodes made of heterostructures with the InGaAs metamorphic layers. Perhaps this is due to the higher crystalline quality of the active region grown on the InGaP metamorphic layer. Values of dark current of photodiodes made from structures with the InGaP metamorphic buffer layer were about 50 nA at voltage of 3 V.
4. Conclusion

It was shown experimentally that 1.06 μm wavelength photodiode structures grown by the MOCVD on a GaAs substrate with the gradient InGaP metamorphic buffer layer with have higher surface roughness value than photodiodes of similar design with the InGaAs metamorphic buffer layer. Despite this, studies of dark currents of photodiodes showed that dark current in structures with the InGaP metamorphic layer by an order of magnitude lower than in structures with the InGaAs metamorphic layer. Thus, further structural studies of the photosensitive region are necessary to explain the effect of decreasing dark current in photodiodes with a gradient InGaP buffer layer. At the same time, worse quality of the surface can be associated with dislocations formed during growth of the top layer.

We established that photocurrent of structures with the InGaP metamorphic buffer layer is characterized by rapid increase with wavelength, since InGaP transmits radiation in the range of 0.91 ÷ 1.05 μm.

It has been experimentally shown that the use of the InGaP metamorphic layer with a gradient composition is preferable to the InGaAs metamorphic layers for creation of photodiodes with the InGaAs active region for operation at 1 μm.

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