Semiconductor Physics, Quantum Electronics & Optoelectronics, 2005. V. 8, N 1. P. 79-82.

PACS: 84.60. Jt

Photoconverters with microrelief *p-n* junction on a basis of *p*-$Al_xGa_{1-x}As$ – *p*-GaAs – *n*-GaAs – *n*+-GaAs heterojunction

A.V. Karimov, D.M. Yodgorova

Physical-and-Technical Institute of the Scientific Association "Physics-Sun" of the Academy of Sciences of the Republic of Uzbekistan, 2b, Mavlanova Str., 700084 Tashkent
Phone: 998-71-1331271, fax 998-71-1354291
E-mail: karimov@physic.uzsci.net

Abstract. Given in this work are the results of studying the process of creation of diffusion and epitaxial layers in microrelief structures. It has been shown that photoconverting structures with a microrelief interface were different in their efficiency under the used level of the illumination intensity.

Keywords: photoconverter, microrelief, *p-n* junction, buffer layer, epitaxy.

Manuscript received 14.12.04; accepted for publication 18.05.05.

1. Introduction

Various methods of surface treatment became used in technology of producing the semiconductor structures with antireflection coatings. In particular, anisotropic etching that could decrease optical losses on the surface. The most effective results were obtained on silicon structures with depression in the form of "honeycombs" and "pyramids". They served as light traps that allow to markedly increase the degree of solar element efficiency as compared with the usual flat ones by 15 – 20 %.

It should be noted that microrelief interfaces could be created inside the volume of semiconductors and in the range of photocarrier separation. Photodetector with the Shottky barrier formed on a surface of quasi-lattice type or dendrite one exemplifies it. Here the *p-n* junction or rather the junction of metal-semiconductor reproduces the surface form. As a result, the structures with microrelief surface turned out to be of high performance as compared to structures with a flat surface.

Remark what would be if to create microrelief structure in *p-n* junction. So preferred parts of *p-n* junction should be increased as compared with the metal-semiconductor ones. In this aspect, the structure with *p-n* junction possesses high radiation hardness and capacity to operate under concentrated radiation, *etc.* Here it emerges one question more: what difference would arise between structures with flat and microrelief junctions.

Information about creation of structures with the microrelief interface of *p-n* junction by using liquid-phase epitaxy is absent in literature up to date. As for obtaining a microrelief surface, it is known that the technique of anisotropic etching enables to obtain the surface of quasi-lattice, dendrite and bi-lattice types [1]. At first sight, growing them on a textured surface appropriated thin layers could be obtained as homo- and heterostructures with microrelief interface.

It may be conceived that the structure with a *p-n* junction possessing a repeated surface microrelief has been artificially crimped. By smoothing out this relief, it would be obtained the same flat structure. However, preliminary results of researching these microrelief structures have shown that they enable to increase the spanning angle of an optic signal as compared with the flat structures. The heterostructure with a microrelief interface of the *p-n* junction was not sufficiently studied, and it is required to perform further researches.

In this work, given are the results of studying the photoconverters with the microrelief *p-n* junction based on *p*-$Al_xGa_{1-x}As$ – *p*-GaAs – *n*-GaAs – n^+-GaAs heterostructure. The research was carried out using the structures with buffer layers and heterolayers.

2. Experimental results

2.1. Growing the buffer layers

The heterostructure of the following composition *p*-$Al_xGa_{1-x}As$ – *p*-GaAs – *n*-GaAs could be prepared by various methods [2, 3] as well as by the liquid-phase epitaxy method. In certain cases, each layer *n*-GaAs and *p*-$Al_xGa_{1-x}As$ is grown consecutively or after growing heterolayer *p*-$Al_xGa_{1-x}As$ on the operation surface GaAs. Besides, used is a special annealing for diffusion of an acceptor impurity from solid solution into *n*-GaAs or n^+-GaAs [4]. To prepare *p*-$Al_xGa_{1-x}As$ – *p*-GaAs – *n*-GaAs – n^+-GaAs structure of a solar element, we used the equipment for epitaxial growing gallium arsenide [5] and its compounds. The used technological processes provided the epitaxial growth of AlGaAs on the GaAs substrate. It was confirmed by some methods of liquid epitaxy. As a result, we came to the conclusion that the

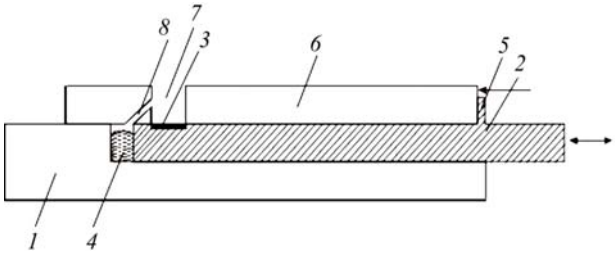

Fig. 1. Cross cut of graphite cassette for epitaxy.
1 – basis, 2 – piston, 3 – substrate, 4 – solution-melt, 5 – stop, 6 – lid, 7 – window, 8 – capillary aperture.

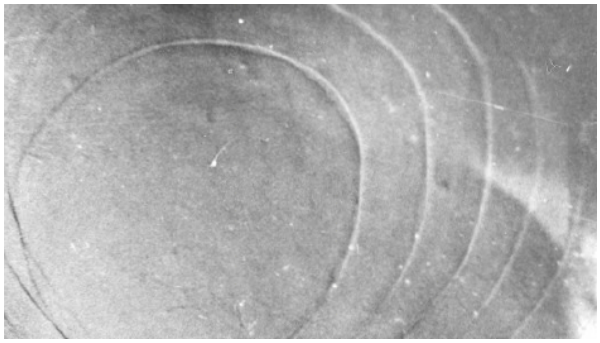

Fig. 2. The surface of buffer layer obtained with piston cassette.

process for growing the perfect layers needs to be stopped sometimes or needs other methods ensuring perfection of layers. To take it into account, we developed a cassette with a piston (see Fig. 1).

Using this cassette, a deposition of GaAs buffer layers on substrates was carried out from a limited volume of solution-melt by forced cooling (without isothermal liquid epitaxy). To support the growth of high-quality epitaxial layers, we used the method of GaAs liquid epitaxy by using an advanced technology. The distinctive sign of this technology consists in that base solution-melt from which the epitaxial layer was grown on the descrete substrate was fed by discrete portions. To realize the process, the system (Ga+GaAs+x melt) was cooled for a selected time interval $\Delta t = t_0 - t_1$. Then, the portion p_1 separated from common melt p_n was fed to the substrate. This stage was followed by the cooling the system for $\Delta t = t_1 - t_2$, and then the next portion p_2 was separated from solution-melt and fed over p_1, *etc*.

Temperature intervals ΔT and the volume of each portion were chosen in the same way to create the next temperature gradient ΔT for the process of growth to be stopped. This way let to provide a permanent front of crystallization, and so the growth of each microlayer would be realized with a variable speed, namely, with the decreased one. As a result, the concentration of defects in each following layer would be decreased, and increased perfection of structures could be obtained. Chosing ΔT within the range 3 to 5 K under the initial temperature of crystallization 815 – 830 ºC enabled to obtain GaAs epitaxial layers starting from 4 – 8 monolayers to the thickness of 2 – 3 μm, Fig. 2.

After obtaining the buffer layers with satisfactory parameters, we have a set of problems in realization of the diffusion process and growth of epitaxial layers in the same cassette and united process. With this aim, we made a special combined graphite cassette for diffusion and synchronous growth of epitaxial layers. For the first time, we carried out series of diffusion processes in the buffer layers and then, at the same time, diffusion process and growth of *p*-AlGaAs frontal layer were made.

2.2. Diffusion processes in the buffer layers

The diffusion process was carried in the developed cassette with a quasi-closed volume and baffle between the Zn resource and patterns. In the course of increasing the temperature up to 800 ºC, the baffle was open and the system was heat at this temperature for 70 – 90 minutes. All the process was carried out in epitaxy conditions with hydrogen flowing through the reaction chamber. Further cooling was carried out in the regime of epitaxy.

The preliminary estimates of load characteristics inherent to diffusion *p-n* junctions obtained using this method on the buffer layers were carried out. It turned out that increasing the Zn quantity from 90 to 190 mg we observed increase of the open-circuit voltage from 0.4 to 0.6 eV. But in this case, we revealed a decrease of the short-circuit photocurrent from 1700 down to 360 μA. The increase of the diffusion time up to 90 and more minutes resulted in the increasing open-circuit voltage. It could be explained by increasing the *p-n* junction location depth. In spite of the fact that in the latter case the duty coefficient was increased, however, we got a positive effect.

These results show that it is necessary to find a reasonable compromise between the diffusion time and quantity of diffusing element.

2.3. Processes of diffusion and growth of p-AlGaAs frontal layer

The processes of diffusion and following growth of *p*-AlGaAs frontal layer were carried out by the way of closing the baffle after reaching the required time of diffusion (70-90 minutes) at the temperature of 800 ºC. Thereafter, we increased the temperature up to 814 – 816 ºC to begin crystallization of the frontal layer and provided the growth of *p*-AlGaAs layer by cooling the system by 4-degree step with the following decrease in the temperature of epitaxy.

Each process was realized simultaneously on two *n*-GaAs buffer layers (one of them had a microrelief of the dendrite type, while the other had a flat surface), and both of them were subjected to Zn diffusion and

Parameters of photoconverter n^+-GaAs – *n*-GaAs (buffer) – *p*-GaAs (diffusion layer) – *p*-AlGaAs (epitaxial layer) structures

N of pattern	Regime of growth of buffer layer *n*-GaAs (10^{17} cm^{-3})	Diffusion Zn, acidification of *p*-GaAs, T = 800 ºC, m_{Zn} = 190 mg	Regime of growth of frontal layer *p*-AlGaAs (10^{19} cm^{-3})	Parameters of photoconverter n^+-GaAs – *n*- GaAs (buffer) – *p*-GaAs (diffusion layer) – *p*-AlGaAs (epitaxial layer) structures			
				Flat		Dendrite	
		t, min		U_{lum}, V	I_{shc}, μA	U_{lum}, V	I_{shc}, μA
23	T = 817 ºC ΔT = 8	80	T = 815 ºC ΔT = 4	0.1	0.12	0.7	6.0
				S = 0.7 cm^2		S = 0.49 cm^2	
24	T = 825 ºC ΔT = 8	70	T = 815 ºC ΔT = 4	0.38	0.8	0.6	5.0
				S = 0.9 cm^2		S = 0.81 cm^2	
25	T = 824 ºC ΔT = 8	80	T = 816 ºC ΔT = 5	0.6	5.0	0.6	8.0
26	T = 825 ºC ΔT = 5	90	T = 814 ºC ΔT = 4	0.4	5.0	0.4	7.0

following growth of *p*-AlGaAs. As a result, n^+-GaAs – *n*-GaAs (buffer) – *p*-GaAs (diffusion layer) – *p*-AlGaAs (epitaxial layer) were prepared.

Morphology of the surface of heterolayers (*p*-AlGaAs) arising on the quasi-lattice buffer *n*-GaAs epitaxial layers has a tendency to be improved. So, applying the shift method for growing from the melt with an open surface, we could observe consecutive improving of surface morphology.

If the surface of buffer layer to some extent repeats asperity of substrate, then the surface of the heterolayer, though its small thickness (1 – 2 μm), works to evening. This tendency let to conclude that exact amount of Al was responsible for positive changes in the process of layer growth on the microrelief substrates.

The researches show that the layers of the solid solution *p*-AlGaAs appeared to be more perfect as compared with the above buffer layers. Comparing the surface structure of buffer layers with that of the heterolayer, we found that in heterolayer the quasi-lattice is smoother, obviously due to sub-dilution of juts. Such behavior of the heteroboundary could be explained by the variable temperature of solid solution formation as compared with that of the arsenide gallium crystal. As a result, during the time of bringing the solution-melt Al+Ga+GaAs+Zn in contact with the crystal GaAs and reaching equilibrium between them, sub-dilution of the solid phase take place. Therefore, the speed of growth in deepenings is higher than that in juts. And finally, the surface of the solid solution layer begins to become smooth. The epitaxial layer *p*-AlGaAs is continuation of diffusion *p*-GaAs and the obtained depth of the *p-n* junction location (3 μm) is sufficient for the following growth of the layer from the liquid phase without prejudice to *p-n* junction. And also, the possibility to preserve the microrelief boundary of the *p-n* junction appears.

Summarized in Table are the parameters of obtained photoconverter structures n^+-GaAs – *n*-GaAs (buffer) – *p*-GaAs (diffusion layer) – *p*-AlGaAs (epitaxial layer). As can be seen from the table, as a ruler, the dendrite samples show preferable performances, in particular, under illumination (19200 lux) the open-circuit voltage is equal to 0.5 – 0.7 V, the density of the short-circuit current 6 – 12 mA/cm^2.

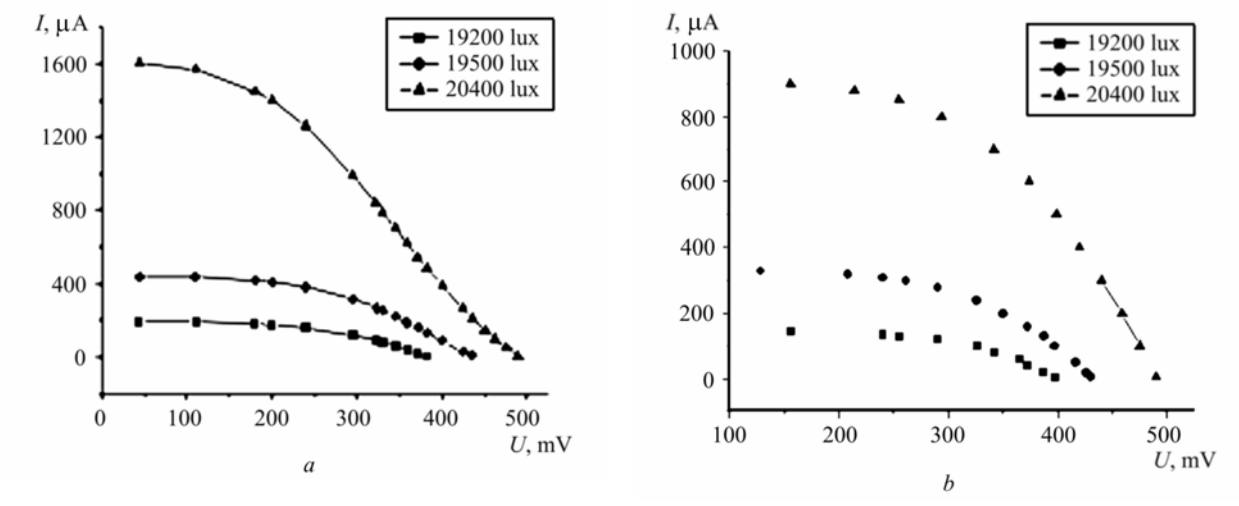

Fig. 3. Load characteristics of heterostructures n^+-GaAs – *n*-GaAs (buffer) – *p*-GaAs (diffusion layer) – *p*-AlGaAs (epitaxial layer) with the flat *p-n* junction (a) and microrelief one (b).

The initial parameters of flat and microrelief structures at the room temperature and initial illumination are practically identical. But with increasing the illumination intensity, differences become clear.

So on the structures with the flat *p*-*n* junction and the increased illumination intensity the load characteristics becomes worse, but on the microrelief structures no changes are observed (see Fig. 3b, illuminations 19200, 19500 and 20400 lux). In both cases, the short-circuit current rises with increasing the illumination intensity that may be caused an increase of the coefficient of charge collection.

3. Conclusion

The obtained results show that diffusion processes conducted for buffer layers by variable time give practically relatives data on the parameters of microrelief structures. It could be explained by the fact that the epitaxial layer *p*-AlGaAs is a continuation of diffusion *p*-GaAs, and the obtained location depth for the *p*-*n* junction (3 μm) is sufficient to further growing the layer from the liquid phase. The regimes of diffusion chosen for photoconverter structures with the buffer layers require a correction to be used in photoconverter heterostructures obtained by synchronous realization of the diffusion process and growth of the frontal layer – *p*-AlGaAs.

References

1. Z. Jianhua, A. Wang, M.A. Green, F. Ferrazza, 19.8 % efficient “honeycomb” textured multicrystalline and 24.4 % monocrystalline silicon solar cells // *Appl. Phys. Lett.* **73** (14), p. 1991-1993 (1998).
2. P. Campbell, and M.A. Green, Light trapping properties of pyramidally textured surfaces // *J. Appl. Phys*. **62** (1) p. 243-249 (1987).
3. N.L. Dmitruk, O.Yu. Borkovskaya, R.V. Konakova, *et al.*, Influence of a scale-irradiation on the characteristics of phototransformation of barrier structures metal-arsenide of gallium with microrelief by border undressed // *Technical Physics Letters* **72** (6), p. 44 (2002).
4. T.Ya. Gorbach, E.V. Pidpisniy, S.V. Svechnikov, Morphology and optical properties of anisotropy etching arsenide gallium // *Optoelectronics and Semiconductor Technique* **13**, p. 34-39 (1988).
5. A.L. Fahrenbruch, R.H. Bube, *Fundamentals of solar cells, photovoltaic solar energy conversion,* New York (1983).