ISSN 0003-701X, Applied Solar Energy, 2016, Vol. 52, No. 3, pp. 236–237. © Allerton Press, Inc., 2016.
Original Russian Text © D.V. Saparov, M.S. Saidov, A.S. Saidov, 2016, published in Geliotekhnika, 2016, No. 3, pp. 84–86.

MATERIALS SCIENCE OF SOLAR ENGINEERING

# Expansion of the Spectral Sensitivity Range of the Silicon Photocells by Growing a Solid $(Si_2)_{1-x}(GaP)_x$ $(0 \le x \le 1)$ Solution

**D. V. Saparov, M. S. Saidov, and A. S. Saidov**

*Physical–Technical Institute, Scientific Association "Physics–Sun", Academy of Sciences of Uzbekistan, 100084 Uzbekistan*
*e-mail: dada@uzsci.net*

Received June 16, 2016

**Abstract**—The article concerns the growth of a hetero-epitaxial GaP layer on a silicon substrate via a buffer layer containing a continuous solid substitutional solution $(Si_2)_{1-x}(GaP)_x$ $(0 \le x \le 1)$ from the liquid phase. Epitaxial films grown under 950–830°C have *n*-type conductivity and specific resistance of ~0.01 Ohm·cm. The thickness of epitaxial films is 10–15 μm. The spectral sensitivity of the $p$Si-$n(Si_2)_{1-x}(GaP)_x$ $(0 \le x \le 1)$ heterostructure, which allows expanding the region of the spectral sensitivity of silicon photoreceivers and photocells, is studied.

**DOI:** 10.3103/S0003701X16030154

Growing solid solutions of different semiconductors is of obvious interest for the development of the modern semiconductor material science, because a solid solution synthesized from several semiconductors may combine the advantages of each component. The main parameters of a solid solution, such as the width of the band gap, the spectral sensitivity range, and lattice parameter may be controlled by the smooth changing of the solid solution composition. For example, if a solid solution containing silicon and gallium phosphide is synthesized it will combine the sensitive regions of silicon and gallium phosphide and will have a wider sensitivity range than silicon and gallium phosphide. Expansion of an instrument's sensitivity range is important for developing more efficient instruments, for example, solar cells.

The $p$Si-$n(Si_2)_{1-x}(GaP)_x$ $(0 \le x \le 1)$ heterostructure was developed for expanding the spectral sensitivity range of the *p*–*n* transition based on silicon. A theoretical study of the possible formation of a solid solution between silicon and gallium phosphide was carried out before growing the solid solution $(Si_2)_{1-x}(GaP)_x$.

Theoretical studies concerning the possibility to form continuous solid substitutional solutions, class $(C_2^4)_{1-x}(A^3B^5)_x$, based on the generalized moments of the interchanging components [1] were carried out; and the growing technology of the continuous solid solutions $(C_2^4)_{1-x}(A^3B^5)_x$ from the liquid phase [2] was developed. In work [3], the author synthesized a metastable graded solid substitutional solution $(Si_2)_{1-x}(GaP)_x$.

Based on the results of the analysis of the data in the literature and the obtained experimental data, it may be concluded that $Si_2$ and GaP form a continuous solid substitutional solution. Tests with a change of the required parameters were carried out in order to determine the dependence of the film quality on the composition, initial temperature of crystallization, and the forced cooling rate. Silicon substrates 20 mm in diameter and 0.5 mm wide with *p*-type conductivity with specific resistance of 3–5 Ohm/cm were used as the substrates. The studies showed that the most qualitative epitaxial films of the continuous solid solution $(Si_2)_{1-x}(GaP)_x$ appeared during the cooling of the solution-melt at the rate of 0.5–1.5 deg/min. The thickness of the solution–melt, i.e., the width of the gap between two horizontally located substrates is 0.75–1 mm. This is explained by the fact that a discontinuous heat transfer from different layers of crystal takes place during forced cooling, i.e., the temperature gradient between these two layers. Epitaxial film was grown at the start of crystallization and at the end of crystallization at a temperature of –980°C and –830°C, respectively. The composition of the solution-melt containing Sn, Si, and GaP was determined by the structural diagram of the binary Sn–Si alloy, with due account of the GaP solubility in tin.

Silicon substrates 20 mm in diameter, with crystallographic orientation (111) and (100) and KDB grade with specific resistance of 1–10 Ohm cm were used as substrates. Epitaxial films $(Si_2)_{1-x}(GaP)_x$ $(0 \le x \le 1)$ on silicon substrates of crystallographic orientation (111) grew well, whereas the films on substrates with crystallographic orientation (110) grew poorly if at all. Figure 1 shows a picture explaining the peculiarities of the films' growth on silicon substrates with a different crystallographic orientation. As it is seen from the picture, each atom on the substrate surface with orienta-

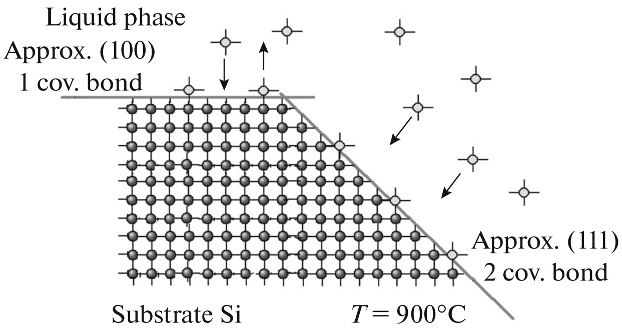


**Fig. 1.** Growth mechanism of the epitaxial films $(Si_2)_{1-x}(GaP)_x$ on silicon substrates with a different crystallographic orientation: (100) and (111).

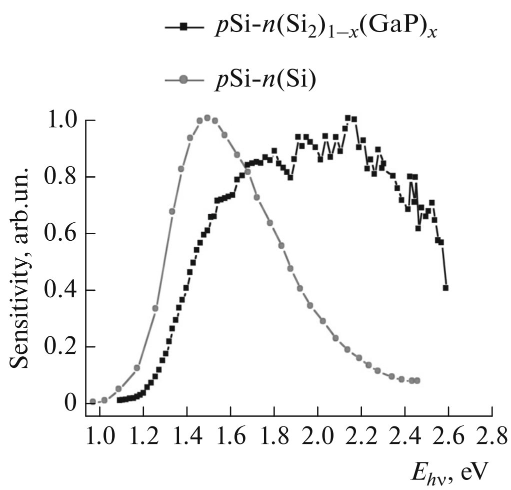


**Fig. 2.** Spectral sensitivity of $p$Si-$n$Si (*1*) and $p$Si-$n(Si_2)_{1-x}$-$(GaP)_x$ (*2*) structures.

tion (100) has one broken covalent bond. When an atom of the growing epitaxial film is absorbed on the substrate surface, it may form only one covalent bond with the substrate's atoms. As the process of liquid epitaxy is carried out under high temperatures and under conditions close to equilibrium, this covalent bond may be easily broken and the atom leaves the substrate due to the thermal vibrations of atoms. Otherwise, it is hard for the atoms of the growing layer to hold onto such a surface. When an atom of a growing layer is adsorbed on the substrate surface with orientation (111), it simultaneously forms two covalent bonds with the substrate atoms, as each atom on the surface of the silicon substrate with orientation (111) has two broken bonds. Two covalent bonds are stronger than one, which is why epitaxial layers grow well on such surfaces.

Composition of the solution–melt:

Sn–100 g. Si–1.8 g. GaP–2.5 g.

The grown epitaxial films $(Si_2)_{1-x}(GaP)_x$ had $n$-type conductivity and their thickness changed within 15–30 μm. The Cameca micro-analyzer was used for the analysis of the component distribution by the layer thickness. The analysis shows that the Ga and P content in the epitaxial layer $(Si_2)_{1-x}(GaP)_x$ increases in the direction of the growth and Ga reaches 48% and P reaches 52%, while Si decreases to zero on the film surface.

Figure 2 shows the spectral sensitivities of the $p$Si-$n$Si (1) and $p$Si-$n(Si_2)_{1-x}(GaP)_x$ (2) structures. As is seen from the picture, the $p$Si-$n(Si_2)_{1-x}(GaP)_x$ ($0 \le x \le 1$) structure has a wider spectral sensitivity range than the $p$Si-$n$Si structure.

Thus, the obtained solid substitutional solutions $(Si_2)_{1-x}(GaP)_x$ possess a wider spectral sensitivity range than silicon and may be used for expanding the spectral sensitivity range of silicon photo-receivers and photocells.

## ACKNOWLEDGMENTS

This work was supported by the grant of the fundamental research project F2-FA-0-43917 AS RUz.

## REFERENCES

1. Saidov, M.S., Koshchanov, E.A., and Saidov, A.S., The way to consider electron structure of ions and atoms for estimating the elements generalized moment, *Izv. Akad. Nauk Uzbek. SSR. Ser. Fiz.-Mat. Nauk,* 1981, no. 3, p. 47.
2. Saidov, A.S., Saparov, D., and Kholikov, K.T., The way to synthesize $(Si_2)_{1-x}(GaSb)_x$ at silicon substrates by means of liquid-phase epitaxy, *Materialy mezhdunarodnoi konferentsii "Neravnovesnye protsessy v poluprovodnikakh i v poluprovodnikovykh strukturakh* (Proc. Int. Conf. "Nonequilibrium Processes in Semiconductors and Semiconductor Structures"), Tashkent, 2007, pp. 130–131.
3. Saidov, A.S., *Liquid-phase epitaxy of* $(Si_2)_{1-x}(GaSb)_x$ *meta-stable variband solid solutions*, *Dokl. Akad. Nauk Uzbek. SSR,* 1990, pp. 78–81.

*Translated by E. Grishina*