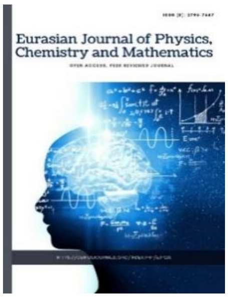

Effect of gallium and antimony impurity atoms on the photoelectric properties of silicon

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ABSTRACT

In this work, the photoelectric properties of a silicon sample doped in series with Ga and Sb impurity atoms were studied. The shift of light towards the infrared region of silicon containing GaSb binary compounds was demonstrated experimentally. The result of the experiment was explained by the fact that Ga and Sb impurity atoms form GaSb binary compounds in local regions of the silicon crystal lattice at a certain temperature (600 °C). A 2D crystal lattice of the GaSb binary compound formed in the local region of the silicon crystal lattice was presented. The obtained experimental results require in-depth research on the formation of not only Ga and Sb, but also III-V binary compounds in the silicon crystal lattice.

Keywords: Silicon, gallium, antimony, diffusion, binary compound, crystal lattice.

1. Introduction

Studying the photoelectric properties of semiconductor materials such as elemental Si, III-V compound GaSb used in the field of electronics is of both scientific and practical importance [1-3].

Due to the high mobility of charge carriers, GaSb compound semiconductor is widely used in the production of high-speed electronic devices [4-8]. These semiconductors are the main materials for creating light-emitting diodes and infrared detectors that operate in the infrared region of light due to the fact that the energies of the forbidden field are direct [9]. In addition, GaSb compound semiconductors are used in the production of photocells with high efficiency [10].

However, the production technology of GaSb compound semiconductor is complicated and not well mastered, and the supply of Ga and Sb elements as raw materials is low. Therefore, it is of high practical and scientific interest to obtain it based on a semiconductor with a large supply and a well-developed production technology, such as silicon [11,12].

The purpose of this work is to study the influence of Ga and Sb atoms on the photoelectric properties of silicon.

2. Materials and methods

For the experiment, a silicon plate grown by the Chokhral method, with a resistivity $\rho\sim0.5$ Ω:cm, ligated with boron atoms ($n_p=5\times10^{16}$ cm^{-3}) was selected. The silicon plates were cut into 10×8×1 mm^3 dimensions using a STX-420 diamond wire saw. In order to eliminate mechanical disturbances during the cutting process, the surface and sides of the samples were treated mechanically (polishing, grinding). After that, in order to remove impurities (oils and foreign atoms) on the surface of the samples, they were chemically cleaned using acids such as HF, HNO_3.

It is known that Ga impurity atoms form acceptors in silicon, and Sb impurity atoms form donors. In order to create a *p-n* transition in a silicon sample, Ga and then Sb impurity atoms were first diffused. Since the diffusion process is carried out from the gas phase, the impurity atoms diffuse into the sample from all sides of the sample. After diffusion, ~100 μm was removed from one side and sides of the sample (Figure 1). Then, the thicknesses of both groups of samples were taken to be the same *w*=400 μm.

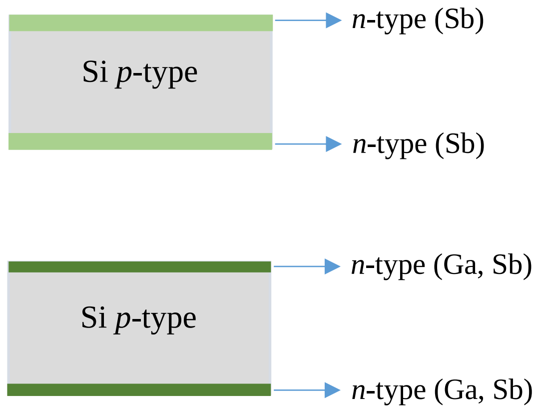
After that, the photoelectric properties of samples with a *p-n* junction were studied on an IKS-12 spectrophotometer device (Figure 3). In this case, a light beam with energy *hv* is directed to the surface of the sample, when light with a certain energy falls on the sample, a short-circuit current (I_{scc}) is formed in the sample, for this the sample must have a *p-n* junction.

Figure 2 shows the principle scheme of measure the photoelectric property of the sample. In this case, metal contacts are removed from the top and bottom of the sample, and the short-circuit current in the sample is measured through these contacts using an ammeter.

The diffusion process was carried out in two stages and the samples were divided into two groups:

Group 1 samples: in the first stage, the initial sample was heated at a temperature of 1200 °C for 0.5 hours; in the second stage, Sb impurity atoms were diffused from the gas phase at a temperature of 1200 °C for 0.5 hours;

Group 2 samples: in the first step, Ga atoms were diffused into the initial sample at a temperature of 1200 °C for 0.5 hours; in the second stage, Sb input atoms were diffused from the gas phase at a temperature of 1200 °C for 0.5 hours.



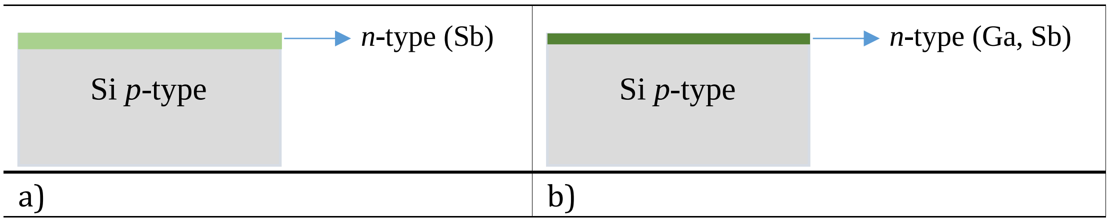


Figure 1. Appearance of samples after diffusion and mechanical treatments

3. Results and discussion

It is known that the band gap energies of Si and GaSb semiconductor materials are E_g=1.12 eV and E_g=0.726 eV respectively (at a temperature of 300 °K). It can be seen from this that the Si sample does not perceive energies smaller than 1.12 eV, that is, it passes through itself. Therefore, in order to see the effect of Ga and Sb impurities on silicon, measurements were made by shining light on the side of the samples with *p*-type conductivity where the impurity atoms were not diffused.

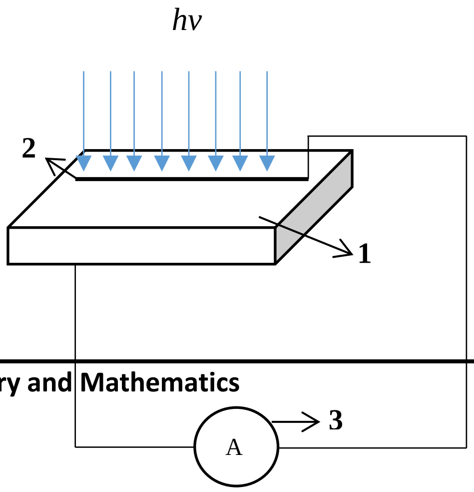
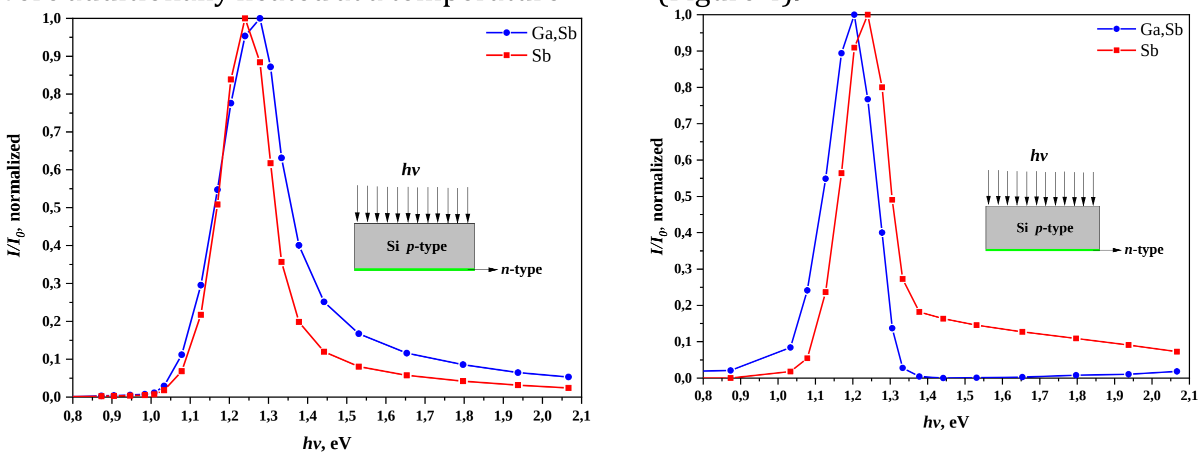


Figure 2. The principle scheme of measure the photoelectric property of the sample: 1-sample; 2-metal contact; 3 ammeter.

As can be seen from the graphs in Figure 3 – *a*, the photoelectric sensitivity of the group 1 sample, i.e., the sample with only Sb impurity atoms inserted into silicon, started at ~1 eV energy and its maximum value was observed at ~1.24 eV energy. The photoelectric sensitivity of the 2nd group sample, i.e. the sample in which first Ga and then Sb impurity atoms were diffused into silicon, started from ~1 eV energy and its maximum value was observed at ~1.28 eV energy. This situation can be explained by the increase of point defects on the silicon surface after the diffusion of the impurity atoms, and the absorption of light in the area near the surface of the sample.

After diffusion, the samples of group 1 and 2 were additionally heated at a temperature of T=600 °C, the photoelectric properties of the samples after additional heating were studied in the graph of Figure 3 – *b*. As can be seen from the graphs in Figure 3 - *b*, the photoelectric sensitivity of the group 1 sample, i.e., the sample with only Sb impurity atoms in silicon, did not change after annealing the sample (see Figure 3 - *a*). The photoelectric sensitivity of the 2nd group sample, i.e., the sample in which first Ga and then Sb impurity atoms were diffused into silicon, started from 0.87 eV and reached its maximum value at 1.2 eV energy. Such a situation can be explained by the fact that the photoelectric sensitivity of silicon shifts to the infrared region due to the interlinking of Ga and Sb atoms of the samples after additional heating (Figure 4).



a) *b*)

Figure 3. Graph of dependence of short-circuit current in the sample on light energy. *a*) after diffusion of the impurity atoms of group 1 and 2 samples, the quantum energy of light fell into the *p* area of the sample (that is, the area where the impurity atoms were not diffused); *b*) After additional heating of the samples of groups 1 and 2 at a temperature of 600 °C, quantum energy of light fell into the sample's *p* region (that is, the region where the impurity atoms were not diffused).

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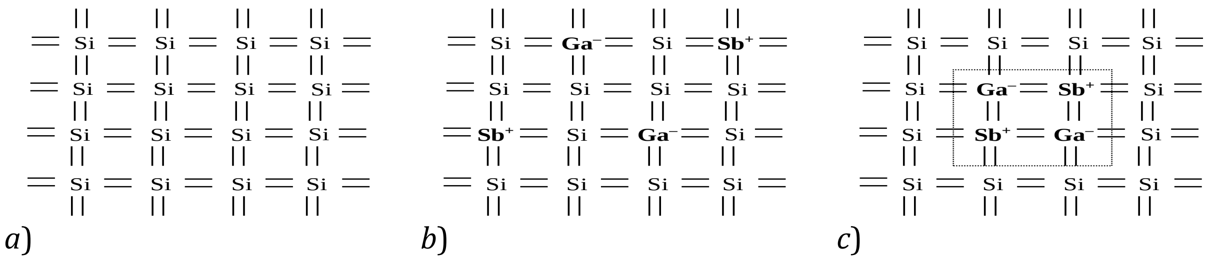

Figure 4. *a*) 2D view of a silicon crystal lattice without impurity atoms (before diffusion); *b*) 2D view of a silicon crystal lattice doped with Ga and Sb impurity atoms (after diffusion); *c*) 2D view of a silicon crystal lattice containing GaSb binary compound (after annealing).

Conclusion

The fact that the photoelectric sensitivity of the sample of the second group is shifted towards the infrared region of the light causes us to conclude that the elementary lattices of GaSb binary compounds are formed in the Si crystal lattice. In this case, due to the new structure in the form of silicon-based Si(GaSb), the possibility of producing silicon-based infrared detectors, high-speed electronic devices, and efficient solar panels will increase.

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