THERMODYNAMIC CONDITIONS FOR THE FORMATION OF GaSb BINARY COMPOUND IN Si SAMPLE

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Abstract. *In this work, silicon samples ligated with gallium and antimony impurity atoms were investigated by the 4-probe method. The diffusion process was carried out at temperatures of 1000, 1100, 1175 and 1250 °C. The results of the experiment revealed that 1100 °C is the most favorable temperature for the formation binary compound GaSb of Ga and Sb impurity atoms. These obtained results require a deeper study of the bonding conditions of Ga and Sb impurity atoms.*

Keywords: *silicon, gallium, antimony, binary compound, resistivity.*

1. INTRODUCTION

Study has scientific and practical significance how optical and photoelectric properties of elemental (Si, Ge), III-V (GaAs, GaP, GaSb, InP, InSb, InAs), II-VI (ZnS, ZnSe, CdTe, CdS, CdSe) binary compound semiconductor materials [1-5].

III-V compound semiconductors are widely used in the production of high-speed electronic devices due to the high mobility of charge carriers [6,7]. These semiconductors are the main materials in the creation of semiconductor lasers (such as GaAs) and infrared detectors (such as GaSb) due to the fact that the energy of the forbidden field is a good transition [8,9]. In addition, III-V compound semiconductors are used in the production of photocells with high efficiency [10]. However, since the production technology of III-V compound semiconductors is complex and relatively expensive, it is of great practical and scientific interest to obtain them on a semiconductor substrate with a large reserve such as silicon and a well-developed production technology [11-16].

The aim of this work is to discuss the thermodynamics of formation of binary compounds of gallium (Ga) and antimony (Sb) input atoms in monocrystalline silicon (Si). This can be concluded by measuring the electro physical parameters of the samples. It is known that there are two-probe, 4-probe, Hall effect and Van der Pauw [17,18] methods for measuring the electro physical parameters of semiconductors. In this work, the electro physical parameters of the samples were determined using the 4-probe method of measurement [19].

2. MATERIALS AND METHODS

For the experiment, a silicon plate grown by the Chochral method, with resistivity of ρ~100 Ω:cm, ligated with phosphorus impurity atoms (n_n=5×10^{13} cm^{-3}) was selected. The silicon wafers were cut in dimensions of 10×8×1 mm^3 using STX-420 diamond wire string. The surface and sides of the samples were subjected to mechanical processing (polishing, grinding). After that, in order to remove impurities (oils and foreign atoms) on the surface of the samples, they were chemically cleaned using HF, HNO_3 acids.

The samples were divided into groups as shown in Table 1 below and the diffusion process was carried out.

Table 1

Used silicon brand, KEF 100	Impurities	Diffusion temperature, *T*, °C			
		1 – batch samples	2 – batch samples	3 – batch samples	4 – batch samples
Samples of group I	Ga	1000	1100	1175	1250
Samples of group II	Sb	1000	1100	1175	1250
Samples of group III	GaSb	1000	1100	1175	1250

After the diffusion process, the electro physical parameters of the samples were studied on the RM3000+ 4-probe device belonging to the JANDEL company.

2.1. Measurement method

It is known that the 4-probe method depends on the shape and thickness of the sample, that is, if the shape of the sample is a circular plate, its specific resistance is determined by equation 1:

$$\rho = f\left(d/s\right)\frac{U_{23}}{I_{14}} \qquad (1)$$

where d is the diameter of the plate, s is the distance between the probes, $f(d/s)$ is the correction function, U_{23} is the voltage drop between probes 2 and 3, I_{14} is the current in probes 1 and 4. When measuring the relative resistance of circular plates by the 4-probe method, it is necessary to pay attention to the symmetry of the location of the probes, that is, placing the probes in the center of the plate increases the accuracy of the results.

If the samples are in the form of a rectangle with right angles, the specific resistance of the samples is determined using equation 2:

$$\rho = f\left(a/b,\, b/s\right)\frac{U_{23}}{I_{14}} \qquad (2)$$

where a is the length of the rectangular sample, b is the width of the rectangular sample, s is the distance between the probes, $f(a/b, b/s)$ is humming function, U_{23}– voltage drop between probes 2 and 3, I_{14}– current at probes 1 and 4. The values of the correction function are presented in Table 2, and the schematic view of the measurement process is presented in Figure 1.

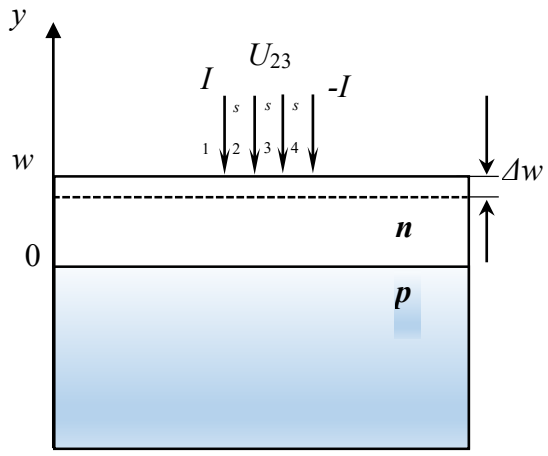

Figure 1. Principle measurement scheme of a sample with a p-n junction formed by the diffusion method

Table 2: correction function values for circular and rectangular samples

b/s *d/s*	*f(d/s)*	*f(a/s; b/s)*			
		a/b=1	*a/b*=2	*a/b*=3	*a/b*≥4
1.0				0.9988	0.9994
1.25				1.2467	1.2248
1.5			1.4788	1.4893	1.4893
1.75			1.7196	1.7238	1.7238
2.0			1.9454	1.9475	1.9475
2.5			2.3532	2.3541	2.3541
3.0	2.266	2.457	2.7000	2.7005	2.7005
4.0	2.929	3.114	3.2246	3.2248	3.2248
5.0	3.362	3.51	3.5749	3.575	3.575
7.5	3.927	4.0095	4.0361	4.0362	4.0362
10.0	4.172	4.2209	4.2357	4.2357	4.2357
15.0	4.365	4.3882	4.3947	4.3947	4.3947
20.0	4.436	4.4516	4.4553	4.4553	4.4553
40.0	4.508	4.512	4.5129	4.5129	4.5129
∞	4.532	4.532	4.5324	4.5325	4.5324

From the determined resistivity, using Figure 2, the concentration of charge carriers in the sample is found. This requires us to know exactly the conductivity of the sample. The conductivity of the sample is determined using a thermophore. All measurement processes were carried out at room temperature (T=300 °K).

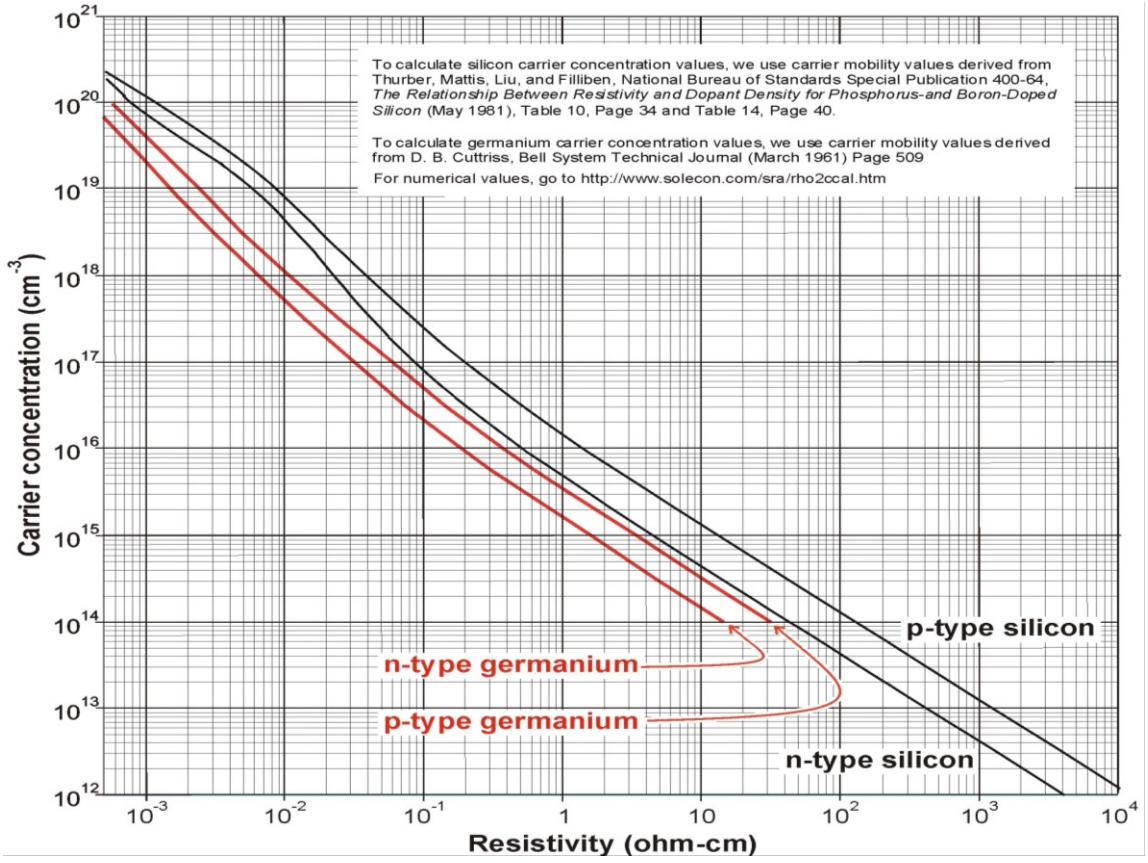

Figure 2. Dependence of current carrier concentration in Si and Ge samples on relative resistance.

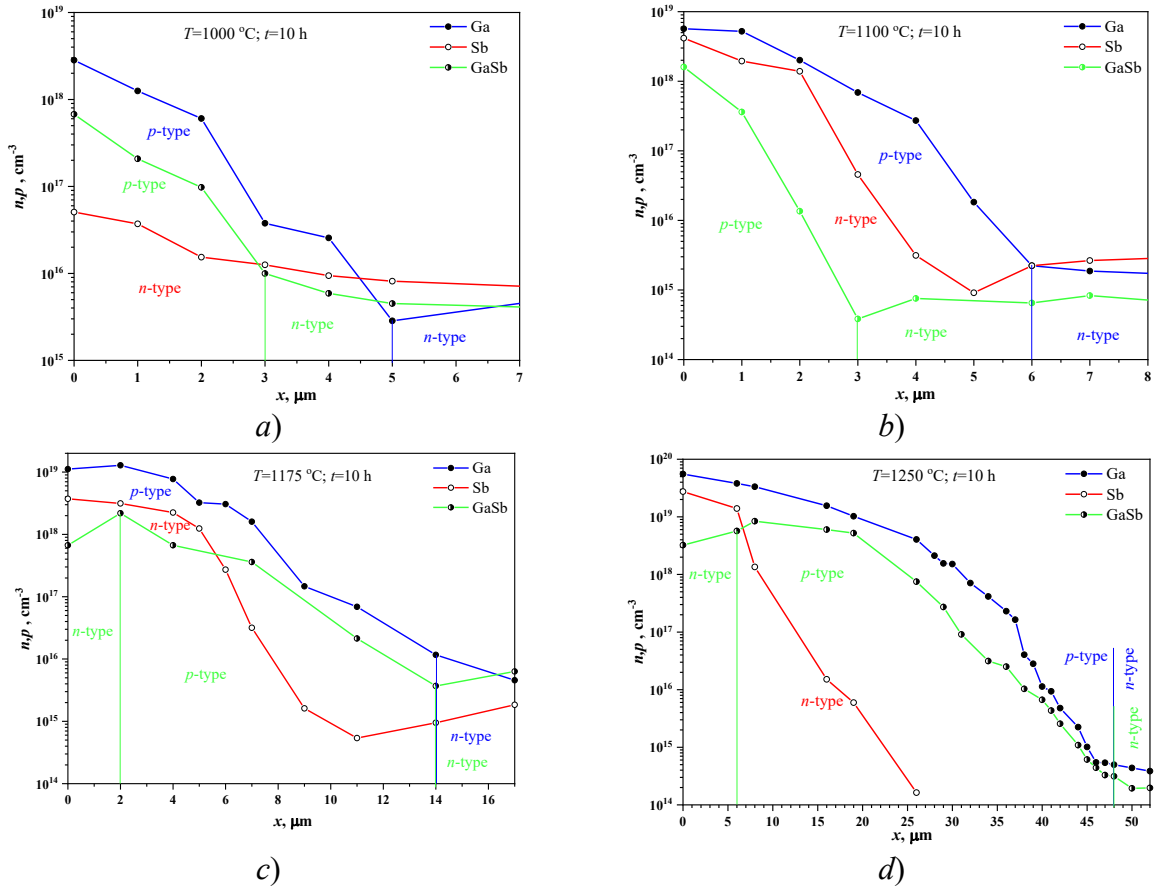

Figure 3. Distribution of the concentration of current carriers in the samples by depth.

It is known that the diffusion coefficient of the Sb impurity atom in silicon is smaller than the diffusion coefficient of the Ga input atom in silicon (see Table 3). The diffusion parameters of Ga and Sb impurity atoms in silicon are given in Table 3, and the function of the diffusion coefficient as a function of temperature is given in Equation 3.

$$D(T) = D_0 \cdot \exp\left(-\frac{Q}{kT}\right) \qquad (3)$$

where D is the diffusion coefficient (cm^2/s), D_0 is the magnitude equal to the diffusion coefficient when the temperature is infinite (cm^2/s), Q is the activation energy (eV), k is the Boltzmann constant (k=8.6173303 × 10^{-5} eV/K), T–temperature (°K).

Table 3

	D_0, cm^2/s	Q, eV	D, cm^2/s			
			T=1000 °C	T=1100 °C	T=1175 °C	T=1250 °C
Ga	3.81	3.552	3.31×10^{-14}	3.5×10^{-13}	1.66×10^{-12}	6.73×10^{-12}
Sb	40.9	4.158	1.42×10^{-15}	2.24×10^{-14}	1.38×10^{-13}	7.1×10^{-13}
$\Delta(T) = \frac{D_{Ga\to Si}(T) - D_{Sb\to Si}(T)}{D_{Ga\to Si}(T)} \cdot 100\%$			95.7%	93.6%	91.7%	89.4%

where $D(T)$ is the difference in diffusion coefficients of Ga and Sb input atoms in silicon at temperature T.

As can be seen from graphs *a* and *b* in Fig. 3, holes (Ga) in samples of group I penetrated to a depth of 5 and 6 μm, respectively. The voids in the samples of group III (Ga and Sb impurity atoms were introduced at the same time) penetrated to a depth of 3 μm. In this case, Sb impurity

atoms hindered the movement of Ga impurity atoms in the Si crystal, and as a result, the diffusion coefficient of Ga impurity atoms in silicon under the influence of Sb impurity atoms decreased. That is, as a result of the continuous crossing of Ga and Sb atoms, Sb impurity atoms slow down the movement of Ga impurity atoms.

As can be seen from the graphs *c* and *d* in Fig. 3, the holes in the samples of group I and III penetrated to the same depth of 14 and 48 μm, respectively. At temperatures of 1175 and 1250 °C, it was found that the conductivity of the silicon surface is *n*-type to a depth of 2 and 6 μm, respectively. In the graph *c* in Figure 3, the Sb input atoms in the II group sample penetrated to a depth of 11 μm, and the Sb impurity atoms in the III group sample slowed down the Ga impurity atoms to a depth of 6 μm, after which the concentration of the Sb impurity atoms decreased sharply, that is, the Sb impurity atoms to the Ga impurity atoms the effect of the impurity atoms is reduced, so the Ga impurity atoms penetrate to a depth of 14 μm. At a temperature of 1250 °C, Sb atoms in the sample of group II penetrated to a depth of 26 μm. Sb input atoms in group III samples had less effect on Ga impurity atoms due to very high temperature. Therefore, the Sb-affected Ga atoms in the group III sample penetrated to the same depth (48 μm) as the Sb-unaffected Ga atoms in the group I sample.

4. CONCLUSION

From the results of the experiment, it can be said that the temperature of fusion of Ga and Sb atoms among 4 different temperatures was found to be T=1100 °C. Because at this temperature, the electroactive concentration of Ga and Sb impurity atoms is close to each other. At the same time, at temperatures T>1100 °C, the rate of vibration and advance movements of the impurity Ga and Sb atoms increases and prevents the formation of the GaSb compound. On the contrary, at temperatures T<1100 °C, the concentration of Ga and Sb compounds can be very small due to the large difference in electroactive concentrations and diffusion coefficients of Ga and Sb impurity atoms.

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