International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 4, Issue 8, August – 2020, Pages: 290-293

Nonequilibrium Processes in the Highly Compensated Silicon

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Abstract — *It is shown that by controlling the structure of complexes - clusters of impurity atoms and their concentration in highly compensated silicon - one can change the fundamental parameters of the starting material, which allows them to be used in the development of fundamentally new classes of nanoelectronic devices. In practice, this is a new approach to the creation of quantum-dimensional structures in silicon.*

Keywords — silicon, flame retardant, diffusion, nanocluster, introduction, sulfur, diffusion.

Scientific research is also being carried out to obtain new nanocluster highly compensated materials. In experiments of world research on the development of electronic devices based on the obtainedия new materials, scientific results aimed at controlling the electrophysical parameters of semiconductor materials were obtained. It is a technology [1] for introducing various input atoms into a crystal lattice by high-temperature diffusion [2], for determining the properties of compensated silicon-based structures that show the transition of the introduced silicon to a ferromagnetic state at low temperatures, one can cite the scientific works of the authors[3].

Research on compensated silicon and clusters based on them is carried out in a number of priority areas of the world, including the development of advanced silicon diodes with input atoms of rare earth elements, the development of nanoscale structures in compensated silicon, and the electrophysical properties of superconducting semiconductors. Development oftemperature, pressure and photodetector sensors, identification and justification of quantum and nanoscale effects occurring in three-dimensional nanoclusters.

In the modern world, the main attention is paid to determining the technological conditions for the formation of unbalanced processes in highly compensated silicon, as well as physical phenomena and impacts of structures created on the basis of a new material. Much attention is paid to creating a new class of electronic devices and sensors based on their functionality. Targeted research in this area, including the following scientific objectives: determine the necessary electrophysical parameters of the primary semiconductor material and the composition of the transition group of iron and non-covalent input atoms; choose doping methods related to the nature of the input atoms, new physical phenomena in the silicon material; create a new class of electronic devices and sensors and improve their functionality.

Based on the knowledgeof technological methods of cluster formation in silicon, the regularities of interaction of introductory atoms and concentrations of structures and complexes for controlling the state of the crystal lattice were studied and analyzed.

It was found that it is possible to control the formation of bulk nanoclustersby knowing the favorable thermodynamic conditions for the interaction of introductory atoms. Based on the results, it was determined that the electrophysical parameters of supercompensated silicon depend on the electrophysical parameters of the source materials, the type of input atoms, the electrical conductivity of silicon, the location of the input atoms in the silicon crystal lattice, and the conditions of temperature processing.

The compensation level in overcompensated silicon is calculated as follows:

$$k = \frac{N_{dM}^{+}}{2N_{d\Gamma}^{-\,-}} = 0{,}9999 \qquad k = \frac{N_{aM}^{+}}{2N_{d\Gamma}^{-\,-}} = 0{,}9999 \qquad (1)$$

To clarify the properties of k было получено , three different typesof initial silicon materials were obtained. The number of incomingяших atoms and charge carriers in them: 1) r_1 = 2,1014 cm-3 (ρ = 100 Ohms / cm); 2) r_2 = 2,1015 cm-3 (ρ = 10 Ohms cm); 3) r_3 = 2,1016 cm-3 (ρ = 1 Ohms • cm). These materials include donor atoms that form deep energy levels (such as sulfur atoms). The accuracy of their number was equal. Based on this, the first group of silicon samples was used to determine the number of deep energy-generating donor atoms:

$$2N_{d\Gamma}^{++} = 0{,}9995 \cdot p_1 = 0{,}9995 \cdot 2 \cdot 10^{14} = 1{,}999 \cdot 10^{14} см^{-3}$$ it was equal.

For the second group of silicon materials:

$$2N_{d\Gamma}^{++} = 0{,}9995 \cdot p_2 = 0{,}9995 \cdot 2 \cdot 10^{15} = 1{,}999 \cdot 10^{15} см^{-3}$$ it was equal.

For the third group of silicon material:

$$2N_{d\Gamma}^{++} = 0{,}9995 \cdot p_3 = 0{,}9995 \cdot 2 \cdot 10^{16} = 1{,}999 \cdot 10^{16} см^{-3}$$ it was equal.

The compensation level for these materials is as follows:

$k_1 = \frac{1{,}999\cdot10^{14}}{2\cdot10^{14}} = 0{,}9995$ $k_2 = \frac{1{,}999\cdot10^{15}}{2\cdot10^{15}} = 0{,}9995$ $k_3 = \frac{1{,}999\cdot10^{16}}{2\cdot10^{16}} = 0{,}9995$ was formed. The results of calculations show that the value of k in all materials is close to each other, and there is a condition for extreme compensation in materials.

In other words, it was possible to get the removed silicon equal to or. Some calculations were made to determine the parameters of these materials. For materials of group I with r_1 = 2,1014 cm-3, the concentration of uncompensated cocoons in the conduction region, when the number of electrons in the conduction zone is 3 cm, when deep energy-generating donor inputs are introduced:

$\Delta p_1 = p_1 - 2N_{д\Gamma 1}^{++} = 0{,}001\cdot10^{14} = 10^{11} см^{-3}.$ it was equal.

Number of uncompensated packages for group II materials:

$\Delta p_2 = p_2 - 2N_{д\Gamma 2}^{++} = 2\cdot10^{15} - 1{,}999\cdot10^{15} = 1\cdot10^{12} см^{-3}$ it was equal.

For group III materials:

$\Delta p_3 = p_3 - 2N_{д\Gamma 3}^{++} = 2\cdot10^{16} - 1{,}999\cdot10^{16} = 1\cdot10^{13} см^{-3}$ it was equal.

Calculations show that after the introduction of the introductory atoms, the relative resistance of the materials was $\rho_1\approx105$ ohms.withm, $\rho_2\approx2.104$ Ohms • cm, $\rho_3\approx2.103$ Ohms • cm. It can be seen that a certain permeability was observed in the last two groups ρ_2 and ρ_3.

Table 1

Changes in the material parameters depending on the concentration of atoms in the original silicon during the diffusion of sulfur atoms

The source parameters of the material			Compensation condition		parameters of highly compensated silicon			
To ur	ρ, Om·cm	Number of pits , cm^{-3}, *p*	Number of deep centers , cm^{-3}, $2N_a^{++}$	Remuneration rate , *k*	To ur	ρ, Om·cm	Number of pits , cm^{-3}, *p*	$\frac{N_{dr}^{++}}{P}$
p	100	$2\cdot10^{14}$	$1{,}999\cdot10^{14}$	0,9995	i	$2\cdot10^{5}$	$<10^{11}$	$>2\cdot10^{3}$
p	10	$2\cdot10^{15}$	$1{,}999\cdot10^{15}$	0,9995	p	$2\cdot10^{4}$	10^{12}	$2\cdot10^{3}$
p	1	$2\cdot10^{16}$	$1{,}999\cdot10^{16}$	0,9995	p	$2\cdot10^{3}$	10^{13}	$2\cdot10^{3}$
p	0,1	$2\cdot10^{17}$	$1{,}999\cdot10^{17}$	0,9995	p	$2\cdot10^{2}$	10^{14}	$2\cdot10^{3}$
p	0.01	$2\cdot10^{18}$	$1{,}999\cdot10^{18}$	0,9995	p	20	10^{15}	$2\cdot10^{3}$
p	100	$2\cdot10^{14}$	$1{,}999\cdot10^{14}$	0,9995	i	$>2\cdot10^{5}$	$(2\div3)\cdot10^{10}$	10^{4}
p	10	$2\cdot10^{15}$	$1{,}9999\cdot10^{15}$	0,99995	i	$>2\cdot10^{5}$	$(2\div4)\cdot10^{10}$	$\sim10^{5}$
p	1	$2\cdot10^{16}$	$1{,}99999\cdot10^{16}$	0,999995	i	$>2\cdot10^{5}$	$(2\div4)\cdot10^{10}$	$\sim10^{6}$

p	0.1	$2\cdot10^{17}$	$1{,}99999\cdot10^{17}$	0,9999995	i	$>2\cdot10^{5}$	$(2\div6)\cdot10^{10}$	$\sim10^{7}$
p	0.01	$2\cdot10^{18}$	$1{,}99999\cdot10^{18}$	0,99999995	i	$>2\cdot10^{5}$	$(2\div7)\cdot10^{10}$	$\sim10^{8}$

In the first group, the relative resistance of the material was equal to the specific electrical conductivity. Table 1 shows the parameters of highly compensated silicon (which has been tested experimentally) as a function of different concentrations of input atoms present in the primary silicon material of highly compensated silicon.

Analysis of the results shows that one of the main factors is the parameters of the source material (the number of small energy-generating atoms) in the production of highly compensated silicon.

In the process of two-stage diffusion, the depth of penetration of atoms into silicon did not differ much from the experimental values determined in theoretical calculations. To introduce silicon into the atoms, a two-stage diffusion method was used, which allows them to control the structure and state of nanoscale structures evenly distributed over the volume.

For example, manganese atoms are located close to each other in silicon, between nodes in the crystal lattice, and existing atoms accumulate around the atom, forming a highly charged anocluster center. In the production of compensated and highly compensated material with input atoms, there is a source material with known electrophysical parameters for each type of input. The developed two-stage diffusion technology led not only to the formation of silicides of elements from non-ferrous metals on the surface of silicon, but also to the appearance of surface erosion and other defects on the surface. The created diffusion technology led to the creation of favorable conditions for the placement and interaction of introductory atoms in the silicon lattice.

Table 2

Electrophysical parameters of highly compensated silicon depending on the parameters of the source material

Introduction	The source material		Diffusion temperature T, ^{0}S	Diffusion pressure of steam, ATM.
	ρ, Om·fromm	Typ		
Mn	2–5	*p*	1140–1180	0,8-1
Zn	1–2	*n*	1120–1150	1-1,2
S	1–2	*p*	1180–1200	1-1,1
Se	0,5–1	*p*	1220–1250	1-1,1
Ni	40–60	*n*	1200–1250	-
Cr	10	*p*	1240–1250	-
Fe	10	*p*	1180–1200	-

The inclusion of different atoms is highly compensated when the silicon parameters are out of balance technological conditions of acquisition.

Table 2 shows the electrophysical parameters of highly compensated silicon depending on the parameters of the source material, as well as the diffusion temperature,time, and nature of the atoms in silicon.

Although the tensile strength of highly compensated materials is almost equal to the tensile strength of semiconductors, it has been shown that the carrier concentration in them is significantly lower than that of atomic ions. With the help of fire compensation, you can get a special material with a special resistance to the conductor. p_0, n_0 << Nd ++ Na--, since the condition is met, the protective potential of the ions of the atoms is absent, which leads to the merging of the potentials of the ions. The increase in concentrations of ions that compensate for the interaction of ion potentials is obvious.

In such materials, it is determined that the lifetimes of the electrons differ significantly from each other.

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