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INTERACTION OF VANADIUM ATOMS ALLOYED SILICON PARTICLES WITH OXYGEN

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Abstract

This article provides information on the effect of oxygen on particles in semiconductor materials doped with vanadium atoms, which are formed during the improvement of the electrophysical properties of silicon semiconductors. The research was conducted in 2021-2022 in the laboratory of the Semiconductor Physics and Microelectronics Scientific Research Institute at the National University of Uzbekistan.

Key words: Vanadium, Silicon, semiconductors, DLTS, IRS.

Indroduction

It is known that the formation of the defective structure of silicon with mixtures of transition elements, called unconventional impurities, which form a number of deep levels in the band gap of silicon and significantly affect the electrophysical parameters of silicon, plays an important role. These specially introduced impurities have different effects during the processing process with structural defects and various uncontrolled impurities, which are accompanied by almost any method for the manufacture of semiconductor devices. In this regard, we studied the interaction of vanadium atoms with carbon contained in silicon and oxygen, called technological or growth, present in the crystal lattice in high concentrations (up to $10^{17}\div10^{18}$ cm^{-3}) using IR spectroscopy.

Methods and Materials of Research

Deep levels non-stationary capacitive spectroscopy (DLTS), four-probe method of measuring the specific resistance of semiconductor material, and infrared (IR) spectroscopy methods were used for research[1;2;5].

Results

For research purposes, optically active oxygen and carbon were grown by the Chakhalsky method with concentrations of $N_o^{opt} = 5 \cdot 10^{17}$ cm^{-3}, $1.2 \cdot 10^{18}$ cm^{-3} and $N_c^{opt} = 2 \cdot 10^{16}$ cm^{-3}, respectively, as initial samples.n - and p-type silicon was used. The thickness of glossy samples, depending on the task, is 1 - 1.5 mm. The composition of oxygen N_o^{opt} and carbon N_c^{opt} was calculated by IR absorption spectra in the region of 1100 cm^{-1} (oxygen band) and 610 cm^{-1} (carbon band) measured on Specord-IR-72 infrared spectrophotometer at room temperature. The values of N_o^{opt} and N_c^{opt} were calculated according to formulas[2;4].
As a reference sample, we used oxygen-free Si polished to the same thickness as the sample under study with N_o^{opt}-10^{16} cm^{-3}, $N_c^{opt} = 5 \cdot 10^{15}$ cm^{-3}. After measuring N_o^{opt} and N_c^{opt} on the initial samples, vanadium (V) was added by diffusion from a vacuum-deposited layer of high-purity V (99.999%). Diffusion was carried out at 900 ÷ 1250^{o}C for 2 ÷ 30 hours. n-Si and p-Si with initial resistivity $\rho = 1 \div 300$ Ohm·cm were used for the alloy. At $T_{diff} = 900 \div 950^oC$, the value of ρ in n-Si and p-Si almost did not change. In n-Si crystals at T>1000^{o}C, the value of V decreased after diffusion, and in p-Si it increased. It can be concluded that V introduces donor centers from the change of its ρ value after addition of silicon with vanadium atoms [3;4].
The resistance of similar heat-treated control samples remained almost unchanged. The figure shows the IR absorption spectra of Si samples doped with V. Analysis of these results shows that the diffusion introduction of V leads to a 10÷30% decrease in the concentration of optically active internodal oxygen N_o^{opt} in n- and p-Si depending on the temperature diffusion (curve 2). This effect was not observed in samples heat treated under the same conditions as vanadium diffusion (Fig. 1 curve 1).
Also, IR spectra were recorded at a wavelength of $\lambda = 16.4$ µm, which corresponds to the absorption of optically active carbon in silicon. No reduction effect of optically active carbon was observed in control and alloyed samples[2].
Previously, it was found that various high temperature treatments lead to changes in the defect structure of monocrystalline silicon. This is accompanied by various related states of technological compounds, for example, the formation of oxygen atoms in silicon. Depending on the processing temperature, SiO_2 or SiO_4 type particles are formed. The interaction of vanadium atoms with free optically active oxygen atoms in

the interstitial state in silicon was shown above. How does this interaction manifest itself in the bound states of oxygen atoms? How does high temperature treatment affect the behavior of vanadium atoms in silicon? To investigate these issues, we produced samples that underwent high temperature treatment at 1100°C for 12 hours. In addition, vanadium atoms were diffused into these samples for 20 hours in the temperature range of 900 - 1250°C.

The mechanically damaged layers were removed from the surface of the Si samples, pre-exposed to high-temperature treatment, and then doped with V by grinding. In addition, resistivity and IR absorption spectra were measured on these samples. For comparison, we studied control samples repeatedly heat-treated under the same conditions as V diffusion (T = 900-1250°C for 20 hours), as well as samples mixed with V in the case of preliminary high-temperature treatment. The results of the research showed that the introduction of vanadium atoms into n-Si leads to an insignificant change in resistance, regardless of whether the original samples have undergone initial high-temperature treatment or not. A significant increase in resistance is observed in p-Si<V> samples subjected to initial high-temperature treatment, and the increase in p was 2-3 times less than in p-Si<V> samples that did not undergo initial high-temperature treatment.

At T = 1100°C during high-temperature processing, oxygen atoms are agitated, that is, free internodal oxygen passes to the second phase with the formation of SiO_2 particles. Part of the vanadium atoms, when introduced into the initial heat-treated silicon, probably settles into SiO_2 compounds, as a result of which they lose their electrical activity. This apparently explains the difference in the change in value of p-Si<V> samples in highly pretreated and untreated samples. Preliminary studies using capacitive spectroscopy have shown that the concentration of deep levels associated with vanadium atoms in Si depends on the initial high thermal treatment and the untreated state.

Measurements of IR absorption spectra of thermally treated silicon samples showed that high thermal treatment at 1100°C leads to agitation of oxygen atoms, resulting in a significant decrease in N^{opt} - 45-50% (Fig. 1, curve see 3). It was shown above that the introduction of V into Si leads to a decrease in the optically active oxygen concentration N_o^{opt}. The decrease in N_o^{opt} was 8-10% in the samples pre-exposed to high thermal treatment and then doped with vanadium (Fig. 1 curve 3). This is probably due to the specific characteristics of the interaction of vanadium atoms with the bound states of oxygen atoms.

Thus, it has been proven that doping Si with vanadium leads to a 20-30% decrease in the concentration of optically active oxygen N_o^{opt}, depending on the concentration of

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vanadium. This indicates the interaction of the V atoms with the oxygen atoms. It was found that the initial high heat treatment of Si samples at 1100°C for 12 hours leads to oxygen agitation with the formation of SiO_2 particles. In this case, N_0^{opt} is reduced by 40-45%. Addition of V atoms to Si, pre-heat treatment at 1100°C for 12 hours leads to a decrease of N_0^{opt} by 8-10%. This is due to the specific characteristics of the interaction of V atoms with SiO_2 particles. After the introduction of vanadium, an increase in ρ is also observed in p-Si <High thermal treatment + V> samples, but it is 2-3 times less than in p-Si <V> samples.

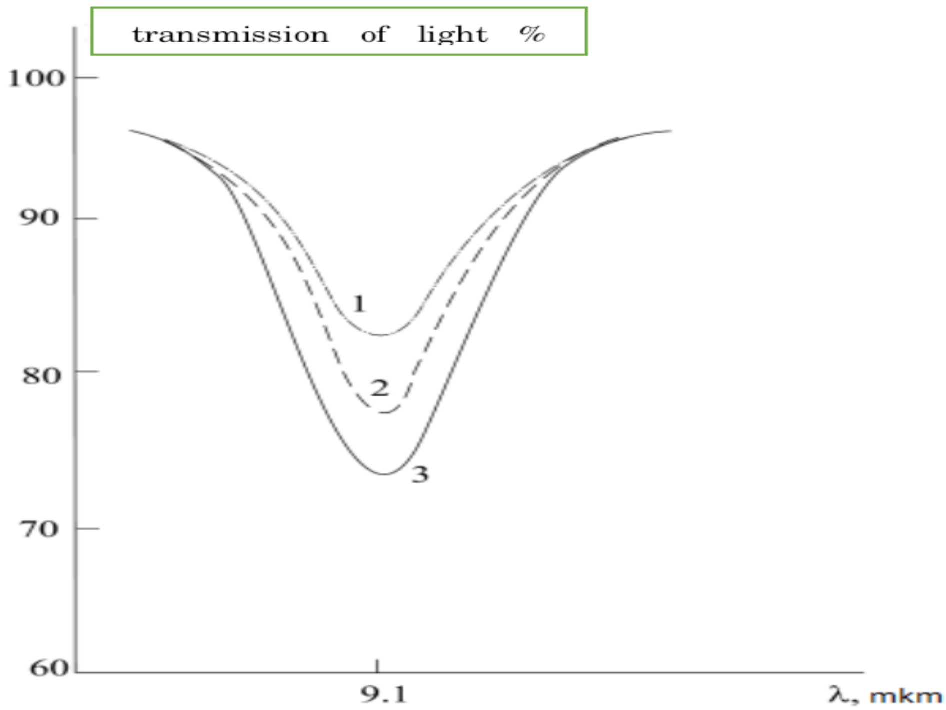

Figure 1. Typical IR absorption spectra of control samples n-Si (curve 1), n-Si <V> (curve 2), n-Si + (High thermal performance) (curve 3), n-Si <V> , at 1100°C initial (High heat treatment).

Conclusions:

The interaction of vanadium atoms with the bound states of the technological oxygen mixture in silicon was studied by infrared spectroscopy. Diffusional introduction of vanadium atoms into silicon has been found to decrease optically active (interstitial) oxygen concentration by 10-30%. High-temperature processing of silicon samples at a temperature of 1100°C leads to agitation of oxygen atoms, as a result of which N_0^{opt} decreases by 40-45%. Alloying of pre-heated samples with vanadium atoms leads to decrease of N_0^{opt} by 8-10%. This is probably due to the specific characteristics of the interaction of vanadium atoms with the bound states of oxygen atoms.

Data analysis shows that the IR absorption spectra of the Si<V> samples coincide with each other, the effect of reduced N_o^{opt} is also the same (within the experimental error). These results show that with the simultaneous introduction of both compounds (V), only vanadium atoms are involved in the interaction with oxygen.

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