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Effect of Holmium Impurity on the Processes of Radiation Defect Formation in n-Si<Pt>

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Abstract

In this paper, we study the effect of one of the rare-earth impurities, holmium, on radiation defect formation in platinum-doped silicon. The main aim of this work was to learn the influence of one of the impurities of rare earth elements - holmium on radiation defect formation in silicon doped with platinum. Using deep level transient spectroscopy (DLTS) methods, it was found that the presence of an electrically neutral impurity Ho in the bulk of n-Si leads to an even greater decrease in the rate of formation of radiation defects than in n-Si<Pt> : the concentrations of A- and E-centers in samples of n-Si<Ho,Pt> 5-6 times less than in undoped samples. It has been established that irradiation with γ-quanta of ^{60}Co at doses $\Phi \geq 6 \cdot 10^{17}$quanta/cm^2 leads to the activation of Pt atoms in silicon.

Keywords: Silicon, doping, deep level, platinum, holmium, irradiation, radiation defect.

1. Introduction

The behavior of materials under irradiation is largely determined by the nature and concentration of impurities that interact with primary radiation defects. It is of considerable interest to study the effect of irradiation on crystals in which, in addition to the main impurity, other active impurities with deep levels (DL) in the band gap, as well as various electrically neutral impurities that effectively interact with radiation defects, are introduced.

In addition, it is known that the processes of complex formation in irradiated semiconductors are determined by the concentration ratios of certain defects, their charge state, and the defect structure of the crystal as a whole (Vavilov, &Uhin, 1968; Shahovtsov, & Shindich,1977; Smirnova,1977; Bogatov, Grigoryan, &Kovalenko, 2019).

The influence of various external factors on the behavior of DL created by Pt atoms in Si has been studied by different authors for many years, but their data are scattered and rather contradictory (Milns, 1977; Komarov et al, 2013; Utamuradova, & Olimbekov, 2018).

2. Materials and Methods

The purpose of this work was to study the effect of one of the impurities of rare earth elements - holmium on radiation defect formation in silicon doped with platinum. To achieve this goal, it was necessary to solve the following tasks: to investigate the properties of n-Si and n-Si<Ho> samples doped with Pt and to identify deep levels created by Pt and Ho impurities; Irradiate these samples with ^{60}Co gamma rays and study the role of holmium in radiation defect formation. Studies of n-Si<Pt> and n-Si<Ho, Pt> samples irradiated with ^{60}Co γ-quanta were carried out by the method of deep level transient spectroscopy (DLTS). To carry out capacitive measurements on the samples under study, diode structures were fabricated according to the procedure given in (Berman, &Lebedev, 1981). The measurements and processing of the spectra are also described in detail in (Berman, & Lebedev, 1981; Mamadalimov, Lebedev, &Astrova, 1999).

The samples under study were n-Si doped with a platinum impurity by the diffusion method; in addition, we studied n-Si samples preliminarily doped with a holmium impurity during silicon growth, into which a platinum impurity was then introduced by the diffusion method. As control samples, we used n-Si with specific resistance $\rho=5\div20$ Ohm·cm and different oxygen content - the so-called “oxygen” Si with the concentration of optically active oxygen atoms $N_0^{opt} = (4\div8)\cdot10^{17}$ cm^{-3} and “oxygen-free” Si with $N_0^{opt}\leq10^{16}$ cm^{-3}. The samples were irradiated at room temperature with ^{60}Co γ-quanta with a flux intensity of ~ $3.2\cdot10^{12}$ quanta/cm^2·s.

3. Results

Previously, we have shown that the diffusion introduction of platinum atoms into n-Si leads to the formation of two DL in the upper half of the band gap of n-Si<Pt>: Ec-0.20 eV and Ec-0.25 eV (see Fig. 1).

An analysis of the measured DLTS spectra in doped and control samples showed that only one level, Ec-0.25 eV, is associated with platinum atoms in silicon, and the efficiency of the formation of this high level depends on the technological modes of introducing Pt into n-Si - temperature and diffusion time. The level Ec-0.20 eV is also observed in the control heat-treated (without Pt) samples, but its concentration is half an order of magnitude higher than in the doped samples (Fig. 1, curve 2).

It follows from a comparison of the measured DLTS spectra that, as a result of ^{60}Co γ-irradiation, both in the control n-Si samples (Fig. 1, curve 3) and in the n-Si<Pt> samples (Fig. 1, curve 4), introduced new levels with ionization energies Ec-0.17 eV and Ec-0.43 eV. The values of the parameters of this DL refer to known radiation defects - vacancy-oxygen complexes (A-centers) and vacancy-phosphorus complexes (E-centers) (Vavilov, &Uhin,1968; Shahovtsov, & Shindich, 1977).

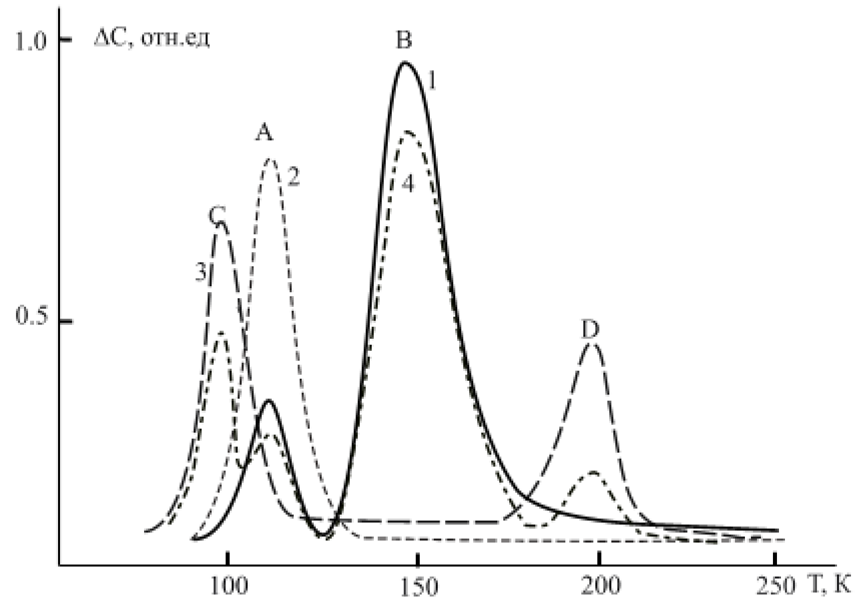

Fig.1. Typical DLTS spectra of unirradiated n-Si<Pt> samples (curve 1, peaks A and B), control n-Si (curve 2, peak A); irradiated with ^{60}Co γ rays: n-Si (curve 3, peaks C and D) and n-Si<Pt> (curve 4, peaks A, B, C, and D) (Compiled by the authors)

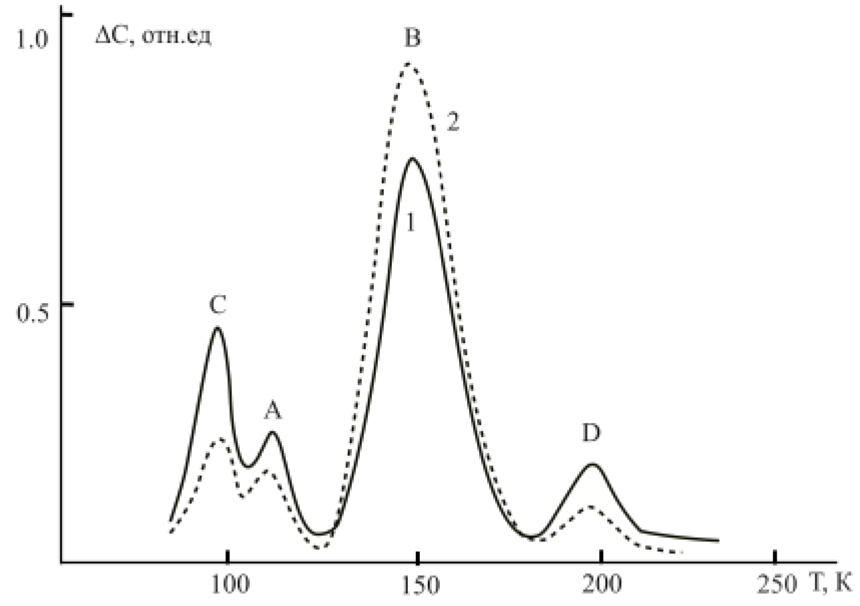

Fig.2. Typical DLTS spectra of irradiated n-Si<Pt> (curve 1) and n-Si<Ho, Pt> (curve 2) samples (Compiled by the authors).

4. Discussion

It follows from the results obtained that the presence of platinum impurity in the silicon lattice slows down radiation defect formation: the concentrations of A and E centers in n-Si<Pt>samples are 2–3 times lower than in control samples. Moreover, the higher the concentration of platinum, the lower the concentration of radiation defects.

Note that γ-irradiation at doses $\Phi \geq 6 \cdot 10^{17}$ quanta/cm2 leads to the activation of Pt atoms in silicon and an increase in the concentration of levels Ec-0.25 eV associated with platinum atoms in Si. It is assumed that the increase in the deep levels of platinum with an increase in the irradiation dose is due to the activation of Pt atoms in the neutral state.

Next, the processes of radiation defect formation in n-Si samples preliminarily doped with a holmium impurity during silicon growth were studied, into which a platinum impurity was then introduced by the diffusion method (Fig. 2).

An analysis of the results obtained from measurements of the DLTS spectra showed that the presence of an electrically neutral impurity of rare earth elements (holmium) in the volume of n-Si<Ho, Pt> (Fig. 2, curve 2) leads to an even greater decrease in the rate of formation of radiation defects than in n -Si<Pt> (Fig. 2, curve 1): concentrations of A- and E-centers in n-Si<Ho, Pt> samples are 5-6 times lower than in undoped samples.

Besides, it was found that when n-Si<Ho, Pt> samples are irradiated with Co60 γ-quanta at doses $\Phi \geq 6 \cdot 10^{17}$ quanta/cm^2, an increase in the concentration of the deep level Ec-0.25 eV associated with platinum atoms in silicon is observed. This effect is apparently explained by the additional activation of Pt atoms in silicon in the presence of electrically neutral holmium atoms during γ irradiation.

5. Conclusion

Thus, the presence of platinum atoms in the volume of silicon significantly reduces the efficiency of formation of known radiation defects of A-centers (vacancy-oxygen complexes) and E-centers (vacancy-phosphorus complexes). This effect, apparently, should be associated with the features of the interaction of specially introduced impurities with defects introduced by irradiation.

In addition, it was found that the presence of an electrically neutral impurity Ho in the bulk of n-Si leads to an even greater decrease in the rate of formation of radiation defects than in n-Si<Pt> : the concentrations of A- and E-centers in n-Si<Ho, Pt> samples 5-6 times less than in undoped samples. It has been established that irradiation with γ-quanta of ^{60}Co at doses $F \geq 6 \cdot 10^{17}$ quanta/cm^2 leads to the activation of Pt atoms in silicon.

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