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STUDY OF THE PROCESSES OF DEFECT FORMATION IN SILICON, DOPED WITH COBALT

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ABSTRACT

The processes of formation of deep centers in silicon mixed with cobalt are investigated by means of methods of capacitive spectroscopy. It was found that in n-Si, doped with cobalt formed four deep levels with fixed energy of ionization: E_c-0.20 eV, E_c-0.33 eV, E_c –0.45 eV and E_c –0.54 eV with capture cross section of charge carriers $\sigma_n=4\cdot10^{-17}$ cm^2, $\sigma_n=2\cdot10^{-15}$ cm^2, $\sigma_n=1.1\cdot10^{-15}$ cm^2 and $\sigma_n=1.5\cdot10^{-15}$ cm^2, respectively. It is shown that in the samples p-Si, doped with cobalt there is only one level E_v +0.32 eV with charge carrier capture sections $\sigma_p=2\cdot10^{-16}$ cm^2, respectively.

KEYWORDS: Silicon, cobalt, deep level, level, doping, ionization energy, media capture cross-section.

INTRODUCTION

In recent years, to modify the properties of semiconductor materials, impurities of transition elements are intensively used, the presence of which in the volume of monocrystalline silicon affects the processes of defect formation.

Therefore, the study of the behavior of various impurities with deep levels in silicon, as well as the study of the role of these impurities in the formation of electrophysical properties Si is of great interest for solving important problems in this area. The behavior of a large number of impurities with deep levels in silicon has been studied by many authors.[1-5]

It is known that the least studied admixture among the impurities of transition elements in silicon is cobalt and there is no definite opinion about the deep levels created by Co in Si and about the behavior of its atoms in the silicon lattice.[2-4] In addition, these works do not take into account the role of thermal and various uncontrolled defects in the processes of defect formation in silicon doped with cobalt.

MATERIALS AND METHODS

In order to study the processes of formation of deep centers created by cobalt atoms in silicon, we studied the properties of silicon doped by diffusion method using deep level transient spectroscopy (DLTS) and photo capacitance. Diffusion of cobalt atoms in n- Si and p-Si was carried out from the applied layer of metallic admixture in the temperature range 1000÷1250^{o}C for 0.5÷30 hours, followed by cooling at different speeds ($\rho_{initial}$ = 0.3÷40 Ohm·cm). After cobalt diffusion, the resistivity ρ of n-Si samples increased to $2\cdot10^4$ Ohms·cm, and in p-Si it did not change significantly. For carrying out capacitive measurements were created Schottky barriers by evaporation in a vacuum of gold on n-Si and antimony - on p-Si. As an Ohmic contact, Nickel was chemically deposited, sometimes antimony or aluminum were sprayed.

DLTS spectra were measured in the modes of constant capacitance[6] and constant voltage,[7] and the measurements of photo capacitance spectra were carried out according to the usual methods described in.[8]

RESULTS AND DISCUSSION

The study of the behavior of cobalt atoms introduced into silicon by diffusion showed that the specific resistance distribution profile ρ in rapidly cooled samples Si<Co>, as well as other impurities of T-ions, is not described by the erfc function, but consists of two sections (Fig.1, curve 1). Initially, there is a sharp increase in the resistivity ρ by 1.5-2 orders of magnitude to a depth of ~ 50 microns, then the value ρ is stabilized and a noticeable change ρ with a depth is not observed. It was found that the change in the resistivity depends on the cooling rate of the samples after diffusion, in slowly cooled samples such a sharp increase in the resistivity value was not found (Fig.1, curve 2). The values ρ in the control samples with depth did not change (Fig.1, curve 3).

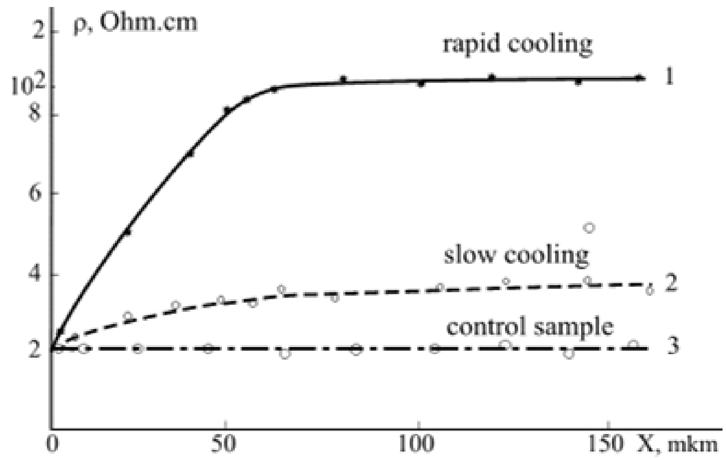

Fig. 1: Based on the resistivity distribution ρ depth in samples of Si<Co> (1, 2) and a control sample Si (3).

Measurement of DLTS spectra has shown that after the introduction of the diffusion of an impurity of cobalt in the samples n-Si (Fig.2, curves 1 and 2) deep levels with fixed ionization energies are formed: E_c -0.20 eV (peak A), E_c -0.33 eV (peak C), E_c –0.45 eV (peak C) and E_c –0.54 eV (peak D) with the capture cross section of charge carriers $\sigma_n=4\cdot10^{-17}$ cm^2, $\sigma_n=2\cdot10^{-15}$ cm^2, $\sigma_n=1.1\cdot10^{-15}$ cm^2 and $\sigma_n=1.5\cdot10^{-15}$ cm^2, respectively. It is shown that in the samples p-Si<Co> there is only one level in the lower half of the forbidden zone E_v+0.32 eV with the capture cross section of charge carriers $\sigma_p=2\cdot10^{-16}$ cm^2, respectively.

The deep level of E_c-0.21 eV is also observed in heat-treated control samples (Fig.2, curve 3), and here its concentration is much lower, than in n-Si<Co> (Fig.2, curves 1 and 2). This level is probably a heat treatment defect.

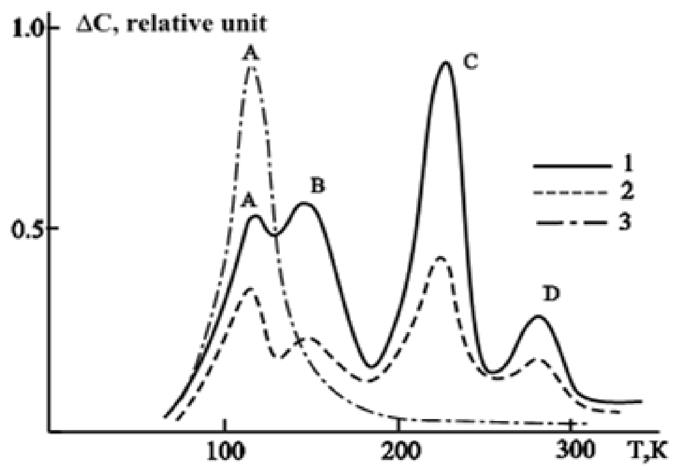

Fig. 2: DLTS spectra of n-Si<Co> samples with different cooling rate: 1-fast cooling, 2-slow cooling, 3-control sample.

Analysis of the results showed that the effectiveness of the education levels of E_c -0.33 eV, E_c -0.45 eV and E_c -0.54 eV in n-Si<Co> and level E_v +0.32 eV in p-Si<> depends on technological conditions of doping of silicon by admixture of cobalt (cooling rate after diffusion $\upsilon_{cooling}$). Comparison of curves 1 and 2 in Fig.2 shows that with a decrease in the cooling rate after the diffusion $\upsilon_{cooling}$, the concentrations of these levels fall significantly, especially those of E_c -0.33 eV and E_c -0.45 eV.

In samples n-Si diffusion doped with cobalt was also measured spectra of photo-capacitance. Spectra photo-capacitance samples of n-Si doped with cobalt discovered relaxation capacity near hν~0.21 eV, hν ~ 0.33 eV, hν ~ 0.45 eV and hν ~ 0.54 eV (Fig. 3, curve 1).

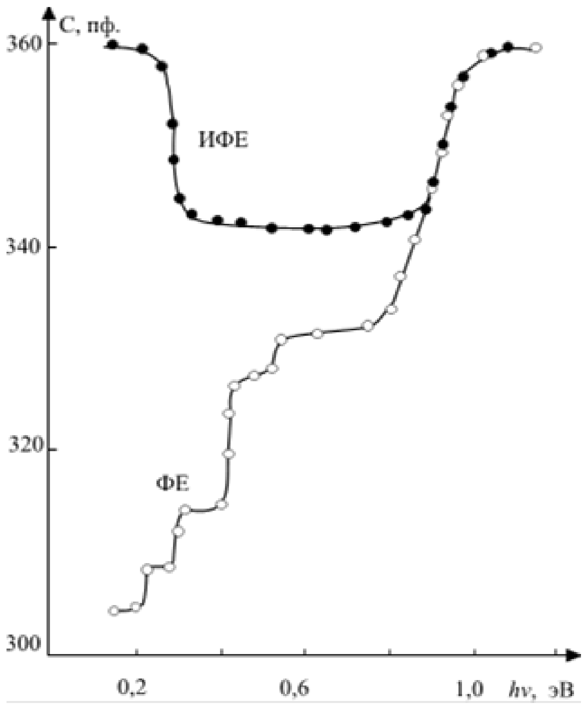

Fig. 3: Spectra of photo capacitance (curve 1) and induced photo capacitance (curve 2) of n-Si<Co>samples.

Analysis of these spectra shows that the observed relaxation is due to the recharge of four deep centers in the upper half of the forbidden zone: E_c -0.21 eV, E_c –0.33 eV, E_c –0.45 eV and E_c -0.54 eV. Spectra photo-induced capacity of these samples there is one step close to hν ~ 0.32 eV (Fig.3, curve 2) due to the level recharge in the lower half of the forbidden zone: E_v +0.32 eV. The analysis of spectra DLTS and photo-capacitance shows that the energy is thermal and the optical activation of the detected levels in samples n-Si<To> coincide within the error of measurement.

CONCLUSIONS

Thus, we can conclude that diffusion doping of n-type silicon atoms of cobalt leads to the formation of four deep levels with fixed energy of ionization: E_c -0.20 eV, E_c -0.33 eV, E_c – 0.45 eV and E_c –0.54 eV and a capture cross section of charge carriers $\sigma_n=4\cdot10^{-17}$ cm^2, $\sigma_n=2\cdot10^{-15}$ cm^2, $\sigma_n=1.1\cdot10^{-15}$ cm^2 and $\sigma_n=1.5\cdot10^{-15}$ cm^2, respectively. The introduction of cobalt in the p-Si leads to the formation of one level in the lower half of the forbidden zone E_v +0.32 eV with sections of the capture of charge carriers $\sigma_p=2\cdot10^{-16}$ cm^2, respectively.

Analysis of the obtained results shows that the last three levels are associated with cobalt atoms in silicon, and the level E_c -0.20 eV is probably a defect in heat treatment.

It is also found that the concentrations of the observed deep levels strongly depend on the cooling rate of the post-diffusion $\upsilon_{cooling}$: the higher $\upsilon_{cooling}$, the greater the concentration levels of E_c -0.33 eV, E_c -0.45 eV and E_c -0.54 eV.

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