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STUDY OF AFTER DIFFUSION REGIONS IN HIGHLY DOPED SILICON

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Abstract. *The study in this paper analyzes the occurrence of a corrugated zone in heavily doped silicon. The main two completely different situations in the implementation of the result of the corrugation of the zones, due to fluctuations in the separation of impurity atoms in the sample.*

Keywords: *corrugated, doped silicon, sensitive, impurities, phosphorus, boron, impurity center, Coulomb potential, strong compensation.*

ИССЛЕДОВАНИЕ ПОСЛЕДИФФУЗИОННЫХ ОБЛАСТЕЙ В ВЫСОКОЛЕПИРОВАННОМ КРЕМНИИ

Аннотация. *Исследование в этой статье анализирует появление гофрированной зоны в сильно легированном кремнии. Основные две совершенно разные ситуации при реализации результата гофрирования зон, обусловленные флуктуациями разделения примесных атомов в образце.*

Ключевые слова: *гофр, легированный кремний, чувствительные, примеси, фосфор, бор, примесный центр, кулоновский потенциал, сильная компенсация.*

INTRODUCTION

The creation of various photo- and temperature-sensitive structures based on compensated silicon in recent years has opened up new perspectives in the application of photo- and temperature-sensitive sensors. The sensitivity of the samples is explained by the presence of attachment levels of nonequilibrium charge carriers formed by impurity centers, as well as in the model of a random potential relief, which leads to corrugation of the conduction band and valence band in silicon [1, 2].

MATERIALS AND METHODS

The relative change in the specific integral sensitivity of the fabricated structures (K) depends on the diffusion coefficient of atoms of compensating impurities and the dose of doped silicon irradiation. It has been established that the larger the impurity diffusion coefficient, the stronger K increases. The observed effect on resistivity, which leads to an increase in the corrugation of the conduction and valence bands in compensated silicon [3-9].

RESULTS

The work analyzes the occurrence of corrugation of zones in compensated silicon. There are two fundamentally different situations in the implementation of the zone corrugation effect, which are caused by fluctuations in the distribution of impurity atoms over the sample.

1. The case of a heavily doped semiconductor. An example is the doping of silicon with a phosphorus (P) impurity to a concentration of the order of 10^{18} – 10^{19} cm^{-3} [7,8,9]. At the same

time, due to the high concentration of free electrons, all Coulomb interactions in the system are exponentially screened [1, 7]:

$e^2/\varepsilon r \to [e^2/\varepsilon r]\exp(r/r_o)$,

where r_o is the screening radius ($r_o \approx a^{1/2} n^{-1/6}$, here a is the effective Bohr radius (a = $18\cdot 10^{-8}$ cm for Si); n - is the electron concentration), r - is the distance from the electron to the impurity center; ε - dielectric constant. As a result, each phosphorus ion perturbs the electronic spectrum of the semiconductor only in the area of screening size ~ r_o. In order for this perturbation to be noticeable, it is necessary that a sufficiently large amount of phosphorus ions accumulate in the area of the shielding volume - r_o^3. The probability of this accumulation is determined by the Poisson formula [3,8]:

$$W(N_P^{av}, N_P) = \frac{\left[(4/3)\cdot\pi\cdot r_o^3 N_P^{av}\right]^{(4/3)\cdot\pi\cdot r_o^3 N_P}}{(4/3)\cdot\pi\cdot r_o^3 N_P!}\cdot\exp(-\frac{4}{3}\pi\cdot r_o^3 N_P^{av})$$

where N_Π^{av} - is the average concentration of phosphorus atoms over the sample; N_p-concentration of phosphorus atoms in a given area of the sample. Due to the small volume of the screening area -r_0^3, then it is possible only for a high average concentration of phosphorus atoms, because then the value $[(4/3)\cdot\pi r_0^3 N_\Pi^{av}]$ not very small.

Thus, in the case under discussion, the screened Coulomb potential reduces the crystal region where significant impurity fluctuations should be observed.

2. The case of a compensated semiconductor is different in that the number of free carriers - n is very small. This leads to a very large value of the screening radius r_o in the limit at $n \to 0$, $r_o \to \infty$, so that the screened Coulomb potential turns into the usual Coulomb potential:

$[e^2/\varepsilon r]\exp(r/r_o) \to e^2/\varepsilon r$

This leads to the fact that the radius of the Coulomb action of the compensating impurity centers on the electronic spectrum of an ideal semiconductor turns out to be very large (in the idealized case $r_o \to \infty$). Therefore, in the screening region r_0^3, even at a low average concentration of compensating impurities N_Π^{av}, there is a high probability for fluctuation accumulation of a significant number of compensating impurity atoms. This probability is also given by the Poisson expression

$$W(N_{im}^{av}, N_{im}) = \frac{\left[(4/3)\cdot\pi\cdot r_o^3 N_{im}^{av}\right]^{(4/3)\cdot\pi\cdot r_o^3 N_\Pi}}{(4/3)\cdot\pi\cdot r_o^3 N_{im}!}\cdot\exp(-\frac{4}{3}\pi\cdot r_o^3 N_{im}^{av})$$

where N_{im}^{av} is the average concentration of atoms of compensating impurities in the sample; N_p-concentration of atoms of compensating impurities in a given region of the sample.

DISCUSSION

Thus, for a significant perturbation of the electronic spectrum of an ideal semiconductor in the case of compensation, even against the background of a not very high average impurity concentration, the fluctuation of the impurity concentration easily occurs due to the fact that $r_o \to \infty$ the value of $[(4/3)\cdot\pi r_0^3 N_{im}^{av}]$ is such that the probability of $W(N_{im}^{av}, N_{im})$ is quite noticeable.

CONCLUSIONS

So, it is in the values of N_{im}^{av} and r_o that the fundamental differences between the cases of heavy doping and strong compensation are manifested. With heavy doping, the small value of r_o

is compensated by the large value N_{im}^{av} (for example, at r_o ~ 2,4.10^{-7} cm, N_P = n =10^{18} cm^{-3} we have $r_0^3 \cdot N_p \approx 0.13$) while with strong compensation a small value N_{im}^{av} compensated for by a large r_o (for example, at r_o ~ 3,7.10^{-5} cm, n =10^{13} cm^{-3} we have $r_0^3 N^{av} \approx 0.5$ (shielding length for the case of heavily doped $r_0^3 = (1/2) \cdot (\pi a^3/3n)^{1/2}$ and compensated material $r_0^{kom} = akT/4\pi \cdot n \cdot e^2$ [4]) is significantly different: $r^{hig.} < r^{com}$)). In both cases, this gives significant values of the probability $W(N^{av}, N)$, $r_0^3 \cdot N^{av}$ reaches the optimum (not too big and not too small).

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