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RADIATION-STIMULATED GROWTH OF THE ELECTRON MOBILITY IN SILICON SINGLE CRYSTALS

Based on the measurements of infrared Fourier spectroscopy and the Hall effect, it was established that the main radiation defects that affect on the electrical properties of n-Si single crystals irradiated by the different electron flows with the energy of 12 MeV are VO_i, C_iO_i, and VO_iP complexes. The magnitude of the Hall mobility of electrons will be determined by the phonon scattering mechanisms, electron scattering on the phosphorus impurity ions, charged radiation defects and fluctuation potential. It was established that the irradiation of n-Si by the electron flow of $\Phi=5\cdot10^{16}$ el./cm^2 leads to an abnormal increase in Hall mobility.

Key words: *radiation defects, Fourier infrared spectroscopy, Hall effect, Hall mobility, n-Si single crystals*

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РАДІАЦІЙНО-СТИМУЛЬОВАНЕ ЗРОСТАННЯ РУХЛИВОСТІ ЕЛЕКТРОНІВ В МОНОКРИСТАЛАХ КРЕМНІЮ

На основі вимірювань інфрачервоної Фур'є-спектроскопії та ефекту Холла було встановлено, що основними радіаційними дефектами, які впливають на електричні властивості опромінених різними потоками електронів з енергією 12 МеВ монокристалів n-Si, є комплекси VO_i, C_iO_i та VO_iP. Величина холівської рухливості електронів буде визначатися механізмами фононного розсіяння, розсіянням електронів на іонах домішки фосфору, заряджених радіаційних дефектах та флуктуаційному потенціалі. Встановлено, що опромінення n-Si потоком електронів $\Phi=5\cdot10^{16}$ ел./см^2 призводить до аномального зростання холівської рухливості.

Ключові слова: *радіаційні дефекти, інфрачервона Фур'є-спектроскопія, ефект Холла, холівська рухливість, монокристали n-Si*

Statement of the problem. Due to the well-developed technology of its cultivation and relatively low cost, monocrystalline silicon remains a promising material for creating various elements of micro- and nanoelectronics based on it [1,2]. As is known [3], modification of electrical parameters of silicon single crystals can be done by alloying with various impurities. But often this method becomes inapplicable due to the limited solubility of the necessary alloying impurities. Also, with significant concentrations of alloying impurities, significant inhomogeneities in their distribution over the volume of the single crystal and, accordingly, significant gradients of specific resistance may occur, which makes it impossible to use silicon technology in the serial production of various electronic devices. The solution to this problem is possible using the method of radiation technologies [4]. At the same time, the formation of radiation defects in solids in a complex combination with other influences, such as temperature, mechanical load, the presence of an external electric and magnetic field, illumination, allows to regulate the properties of solid materials in a directed manner. The use of electron or gamma radiation allows to create point defects of a given concentration and uniform distribution in the volume of a single crystal of silicon. Also, such single crystals of silicon will have higher radiation resistance, which significantly expands the scope of operation of radio-electronic equipment made on the basis of irradiated single crystals of silicon. Radiative changes in both the electrical and optical properties of silicon at almost all temperatures are determined by secondary defects (complexes of vacancies and internodal atoms with each other, with atoms of chemical impurities) or clusters of defects [5]. Since the main properties of silicon strongly depend on the presence of a defective structure, this, in turn, will affect the parameters of ready-made devices made on its basis, such as sensitivity, current gain, operating time, stability, selectivity, dark current, etc. Therefore, it is of significant scientific and practical interest to study the influence of electron irradiation on the electrical and optical properties of silicon single crystals.

An important electrical parameter of semiconductors is the mobility of current carriers. As is known [6], for example, the speed of the transistor is directly proportional to the mobility of the current carriers and inversely proportional to the channel length. Since today the length of the channel has reached its practically minimal physical limitation, the speed of the silicon transistor can be increased only by increasing the mobility of the current carriers. Taking into account that the mobility of electrons in semiconductors is usually greater than that of holes, in this respect, n-type semiconductor elements of conductivity are of more practical importance for semiconductor electronics.

Setting tasks. Obtain the temperature dependences of the Hall mobility for n-Si single crystals irradiated with different streams of fast electrons with an energy of 12 MeV and establish the irradiation and temperature conditions under which it is possible to increase the mobility of electrons.

Presentation of the main material. The researched n-type silicon samples were grown by the Chochralsky method. The concentration of the doping admixture of phosphorus was $2{,}2\cdot 10^{16}$cm^{-3}. In work [7], based on the measurements of infrared Fourier spectroscopy and the Hall effect, we found that for the same single crystals n-Si basic radiation defects that were formed during electron irradiation with energy 12 MeV and flow $F=10^{17}$ el./cm^2, was A-centers (complex VO_i), complexes C_iO_i and complexes VO_iP (A-centers modified with a phosphorus impurity). In order to check the possibility of the formation of other defects during the variation of the electron irradiation flow, we also measured absorption spectra for irradiated by different flows of fast electrons with energy 12 MeV single crystals n-Si (pic. 1). From the analysis of the obtained absorption spectra, it follows that new types of radiation defects are not formed. Electrically active defects at room temperature will be only complexes C_iO_i, which corresponds to the absorption band 865 cm^{-1} and a deep acceptor level $E_V+0{,}35$ eV, that will be deionized. The absorption band 835 cm^{-1} will correspond to the neutral state of the complexes VO_i and VO_iP. At room temperature, the energy levels of these defects will be ionized. Therefore, in this case, the amount of mobility will be determined by the mechanisms of phonon scattering, scattering of electrons on phosphorus ions, charged defects, and on the fluctuation potential, the amplitude of which increases with the increase in the degree of compensation of silicon single crystals during irradiation [8]. The increase in the intensities of these bands indicates an increase in the concentration of these complexes in the volume of silicon with an increase in the flow of electron irradiation.

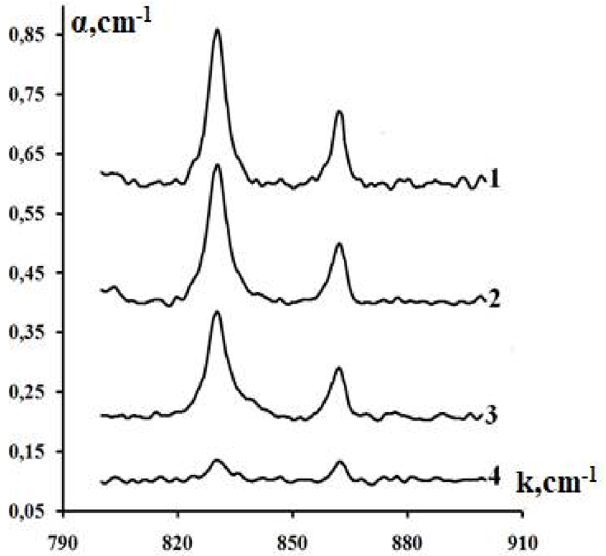

Fig. 1. **Absorption spectra at room temperature for n-Si single crystals irradiated with different electron streams F, el./cm^2: 1 – $3\cdot 10^{17}$, 2 – $2\cdot 10^{17}$, 3 – $1\cdot 10^{17}$, 4 –$5\cdot 10^{16}$.**

The results of studies of the Hall effect for these silicon single crystals are presented in Fig. 2. Characteristic for all temperature dependences of single crystals irradiated by different streams of electrons n-Si there is a decrease in the Hall mobility of electrons with increasing temperature in the range T>200 K.

This is due to the dominant role of electron scattering by optical phonons responsible for intervalley scattering at these temperatures [9]. The increase in Hall mobility with increasing temperature at T<200 K, especially at the highest radiation fluxes (Fig. 2, curve 4), is associated with a decrease in the efficiency of electron scattering on charged defects and the amplitude of the fluctuation potential. Also when exposed to radiation n-Si by the flow of electrons $F=5\cdot 10^{16}$ el./cm^2 the Hall mobility of electrons increases for the entire investigated temperature range. However, at flows $F\geq 1\cdot 10^{17}$ el./cm^2 the Hall mobility decreases. Such an abnormal increase in Hall mobility can be explained by a decrease in the concentration of phosphorus impurities, which are scattering centers for electrons. These impurities, as we established earlier on the basis of studies of infrared Fourier spectroscopy and the Hall effect, are part of the complexes formed during electron irradiation VO_iP. With a further increase in the flow of electron irradiation, the efficiency of electron scattering mechanisms on charged defects and fluctuation potential will increase, which will lead to a decrease in the Hall mobility of electrons. Based on the studies of infrared Fourier spectroscopy and the Hall effect, the complexes formed during electron irradiation are included.

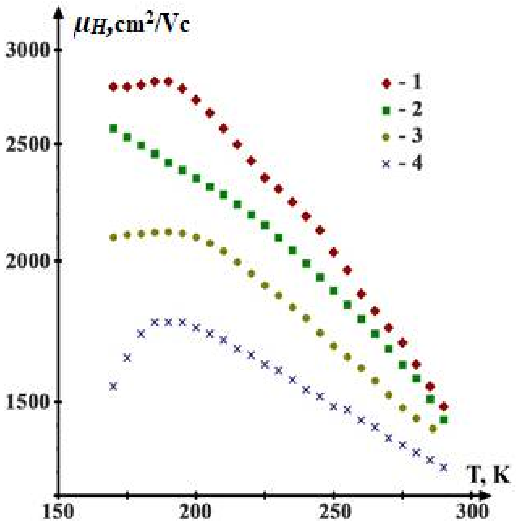

Fig. 2. **Temperature dependence of the Hall mobility of electrons for n-Si single crystals irradiated by different electron flows F, el./cm^2: 1 – 5·10^{16}, 2 – 0, 3 – 1·10^{17}, 4 – 2·10^{17}**

Conclusions. The variation of the electron irradiation flow allows changing the relative contribution of various electron scattering mechanisms on technological and radiation defects and thus the electrical parameters of silicon single crystals. The conducted studies of the optical and electrical properties of n-Si single crystals irradiated with electrons with an energy of 12 MeV made it possible to establish the mechanisms of defect formation and electron scattering for these single crystals, as well as the optimal irradiation conditions under which it is possible to achieve a radiation-stimulated increase in the mobility of electrons in silicon . The obtained results are important for radiation physics of semiconductors and scientists who work in the field of radiation technologies of semiconductors and are engaged in solving the problem of improving the parameters of silicon integrated microcircuits.

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