SCIREA Journal of Physics
http://www.scirea.org/journal/Physics
March 20, 2019
Volume 3, Issue 1, February 2019

The impact of electron irradiation on the electrical properties of n-Ge single crystals

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Abstract

The effect of electron irradiation with the energy of 10 MeV on the electrical properties of n-Ge single crystals is investigated. Based on measurements of the Hall effect, the temperature dependences of the resistivity, concentration and mobility of current carriers for the range of 180–280 K have been obtained. It was shown that for the irradiation doses $\Omega<10^{16}$ el./cm^2, germanium did not change the type of conductivity, and at doses $\Omega>2\ 10^{16}$ el./cm^2, it was converting in p-type. The obtained experimental data show that, in contrast to γ-irradiated n-Ge single crystals, the new carrier scattering mechanisms affect the temperature changes of resistivity (along with the change at the temperature of the concentration of current carriers). Due to the high thermal sensitivity, germanium single crystals, irradiated by the electrons can be promising materials for the construction on their basis of the thermistors. The effect of radiation-stimulated increase of the effective mobility of current carriers for germanium single crystals is obtained, which is explained by the formation in the volume of single crystal during electron irradiation of high-conductivity inclusions. This effect is important for the creation on the basis of germanium, which was additionally subjected to the radiation processing by the electron beam, high-speed electronic devices for micro- and nanoelectronics.

Keywords: irradiated germanium, temperature dependence of resistivity, scattering mechanisms, thermal sensitivity, high-conductivity inclusions.

1. Introduction

Semiconductor materials with a unique combination of the electrical and other physical properties are the basis of the modern sensor technique [1, 2]. At present, one of the most promising areas of the development of elemental base of measuring systems is the design of semiconductor sensors, in particular temperature sensors [3]. Requirements for such sensors may be different, depending on the their exploitation area.

One of the ways of the purposeful change of the properties of semiconductor materials for the creation on their basis various elements of functional electronics with the necessary characteristics is the projected impact of the radiation on semiconductors, which is the basis of the method of radiation technologies [4, 5]. The use of penetrating radiation allows to receive a qualitative semiconductor materials, as well as reduce costs of production of electronic devices and sensors of physical quantities on their basis. Monocrystalline Ge relates to such semiconductors, which are used as raw material for the creation of various sensors, in particular temperature. The electrophysical properties of irradiated Ge single crystals are determined mainly by the presence of various types of secondary radiation defects that arise as a result of quasi-chemical reactions between vacancies, interstitial atoms and atoms of the chemical impurities [6]. Generally, such defects create the deep energy levels in the band gap of semiconductor, which may be donors or acceptors, as well as by the recombination centers for the non-equilibrium charge carriers. Thermal ionization of the deep levels leads to a change in the concentration of current carriers, and hence the resistivity of semiconductor. Such semiconductors can be a raw material for the manufacture of thermistors. Therefore, the study of the impact of the created under radiation of defects on the electrophysical properties of Ge single crystals is an actual applied problem.

2. Materials and Methods

The impact of electron irradiation with the energy of 10 MeV on the electrical properties of n-Ge single crystals alloyed by antimony impurity, $5\cdot10^{14}$ cm^{-3} concentration. The irradiation of samples was carried out on the microtron M-30, whose parameters allow to form the beams of accelerated electrons with the energies in the range 1-25 MeV. The irradiation at the flow density of accelerated electrons of $5\cdot10^{10}\cdot cm^{-2}s^{-1}$ and room temperature in the conditions of this experiment was been carried. Temperature control was carried out in situ using copper-constantan thermocouple.

3. Results

Temperature dependencies of the resistivity, concentration of charge carriers and effective Hall mobility for unirradiated and irradiated samples of n-Ge by the various flows of electrons are obtained by Hall effect measurements. It was found that germanium does not change the conductivity type by irradiation the flows $\Omega<10^{16}$ el./cm^2. At the flows of electrons $\Omega>2\cdot10^{16}$ el./cm^2 the conductivity type has changed into p-type. Previously, in [7], we determined the energy spectrum of radiation defects that were introduced at the conditions as mentioned earlier of electronic irradiation. At the electron irradiation of germanium in the band gap are formed only two different energy levels: E_c-0,27±0,02 eV and E_V+0,27±0,02 eV belonging to the A-center was shown. The temperature dependencies of the resistivity for unirradiated and irradiated samples of n-Ge by the various flows of electrons are presented in fig. 1.

For unirradiated samples (curve 5, fig. 1), resistivity increased with increasing temperature due to the decreased mobility for the entire temperature range which being investigated, as impurities Sb are completely ionized. This effect may be explained by an increasing role of the phonon scattering [8]. The resistivity of irradiated samples at room temperature several times is greater than the resistivity of unirradiated samples It rapidly increases with a decrease of temperature and an increase of the flow of electrons to $1\cdot10^{16}$ el./cm^2. However, after n-p conversion, further increasing of the flow (from $\Omega=2\cdot10^{16}$ el./cm^2 to $\Omega=5\cdot10^{16}$ el./cm^2) has led to a decrease in the resistivity of Ge samples for the entire temperature range which being investigated (curves 3, 4, fig. 1,). The temperature dependencies of the concentration of charge carriers for unirradiated and irradiated n-Ge single crystals are presented in fig. 2. After irradiation, the concentration decreases with increasing temperature. This is characteristic for irradiated semiconductors (curves 1-4, fig. 2,). Such effect may be explained by the ionization of deep levels of A-centers.

Increase in concentration with increasing temperature leads to a decrease in the resistivity of irradiated samples (curves 1-4, fig. 1). For irradiation flow $\Omega=5\cdot10^{15}$ el./cm^2 and $\Omega=10^{16}$ el./cm^2 the concentration of electrons at temperatures T>270 K practically reaches saturation. The given effect is explained by ionization of deep-level (E_c-0,27±0,02 eV). This leads to a decrease in temperature sensitivity. When the n-p conversion occurs, the concentration of holes monotonically increases at temperatures T> 280 K (curves 3-4, fig. 1,). This allows increasing the temperature sensitivity of irradiated samples of germanium at higher temperatures relatively unirradiated. Usually, after irradiation of n-Ge by γ-quanta and electron beams with energies up to 5 MeV, the temperature dependence of the Hall mobility at temperatures more than 150 K is determined mainly by the mechanisms of phonon scattering. Under such conditions, the temperature dependence of the Hall mobility completely coincides with the corresponding dependence for unirradiated single crystals [9, 10]. However, in our case, the temperature dependences of the Hall mobility of charge carriers for irradiated germanium monocrystals are other (Fig. 3). In [11], we have analyzed the experimental and theoretical temperature dependences of the Hall mobility for the same n-Ge single crystals irradiated by the electron flows $\Omega=5\cdot10^{15}$ el /cm^2 and $\Omega=10^{16}$ el /cm^2 with the energy of 10 MeV. As follows from the analysis of these cases, the electron scattering on the regions disordering, fluctuational potential, on the scattering potential of the A-centers and the strain of crystalline lattice are an effective scattering mechanisms.

An increase in the concentration of A-centers with an increase in the flow of electrons led to the n-p conversion of conductivity type [7]. In the case of the n-type germanium matrix (at $\Phi<10^{16}$ el/cm^2), regions disordering can be considered as insulating inclusions that have the p-type conductivity and are separated from the main conductive medium by the p-n transition [12]. If the conductivity of such inclusions is greater than the conductivity of the matrix, their presence may lead to an increase in the effective mobility of the current carriers. With an increase of the flow of electron irradiation, the proportion of the volume of germanium single crystal, which occupies by the conductive inclusions, will increase. This can explain the growth of the effective Hall mobility of charge carriers with an increase in the flow of electrons (curves 1-4, fig. 3). It was interesting that the effective Hall mobility of holes at temperatures from 230 K to 270 K for irradiated by the flow of electrons $\Omega=5\cdot10^{16}$ el./cm^2, n-

Ge single crystals, in absolute value, greater than the Hall mobility of electrons for an unirradiated sample (curve 4, 5, fig. 3).

Consequently, the targeted influence of electron irradiation with the energy of 10 MeV allowed to increase the thermal sensitivity of the investigated germanium single crystals of and increase the effective mobility of charge carriers. The growth of mobility is one of the main factors that affect on the speed of work of semiconductor devices. Therefore, the obtained results are important for semiconductor electronics.

Pictures and tables

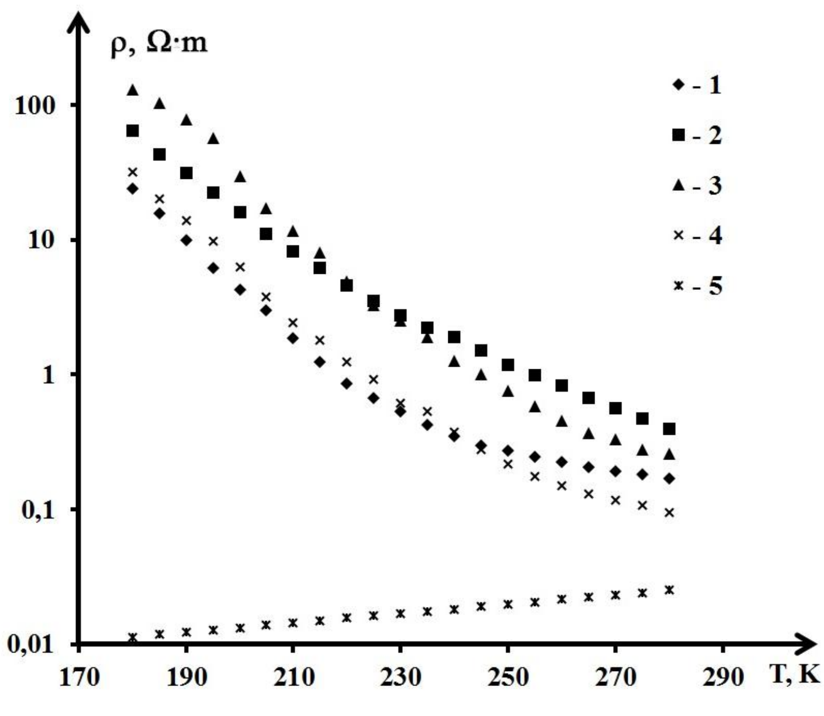

Figure 1. Temperature dependencies of the resistivity for irradiated samples of n-Ge single crystals by the flow of electrons Ω, el./cm^{-2}: 1- 5·10^{15}; 2 - 1·10^{16}; 3 - 2·10^{16}; 4- 5·10^{16}; 5- 0.

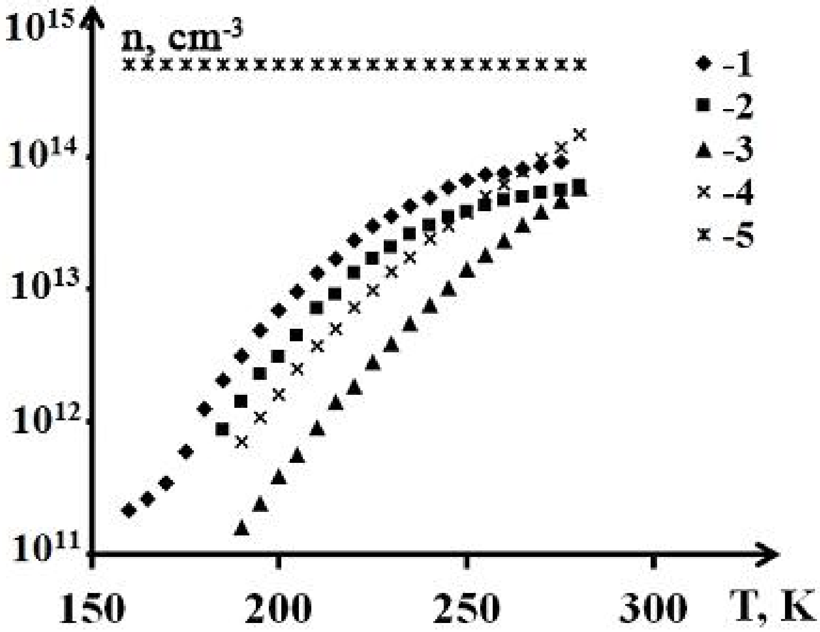

Figure 2. Temperature dependencies of the concentration of charge carriers for irradiated n-Ge single crystals by the flow of electrons Ω, el./cm-2: 1- 5·1015; 2 - 1·1016; 3 - 2·1016; 4- 5·1016; 5- 0.

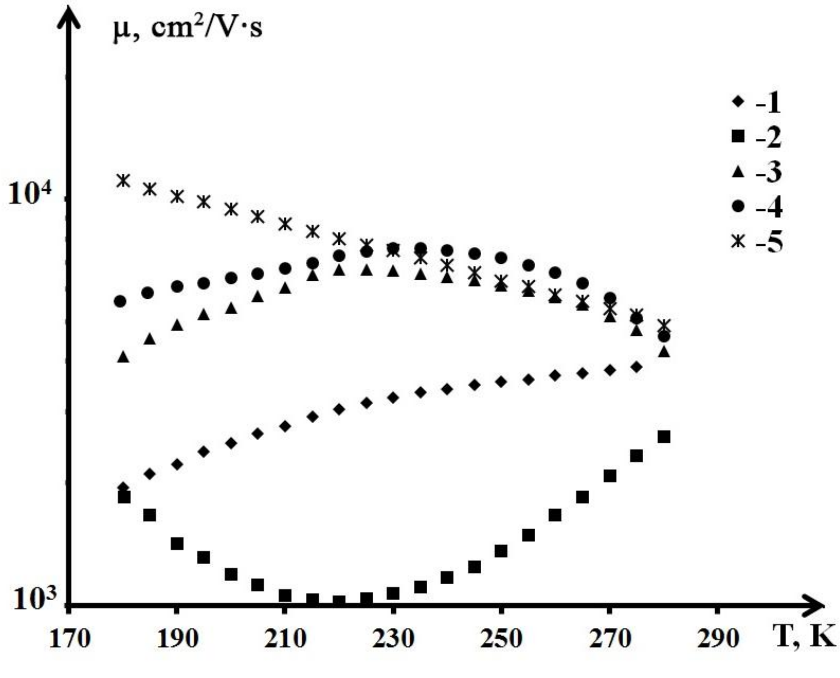

Figure 3. Temperature dependencies of effective Hall mobility for irradiated n-Ge single crystals by the flow of electrons Ω, el./cm-2: 1- 5·1015; 2 - 1·1016; 3 - 2·1016; 4- 5·1016; 5- 0.

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