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EFFECT OF RADIATION BEAMS ON THE ELECTROPHYSICAL PROPERTIES OF GaSe LAYERED SINGLE CRYSTAL

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ABSTRACT

In this research work the result of the investigation of the effect of radiation beams on the electrophysical properties of GaSe layered single crystal. Like other layered single crystals, GaSe single crystal is used in the manufacture of microelectronic devices - photoconverters, high-frequency electronic switches, and a number of optoelectronic structures. Therefore, since the mid-twentieth century, GaSe single crystals have been extensively studied as a research subject. Like other semiconductor materials, the physical properties of germanium monoselenide are affected by external factors, including radiation of various natures. In the article the reasons for the influence of different doses of electrons on the kinetic parameters of GaSe single crystal - hole concentration, mobility, and electrical conductivity has been investigated.

1. INTRODUCTION

Gallium monoselenide is a red (turquoise) layered crystal with a wide range of applications, which has been studied since the fifties of the last century. The GaSe crystal melts at a temperature of 1260 K and its density is 5.03 g/cm^3. The GaSe layered single crystal is an $A^{III}B^{VI}$ type semiconductor with a bandgap width of ~ 2 eV. Between the atoms Se-Ga-Se-Ga in the layers there is an ionic-covalent bond and a weak Van der Waals bond between the layers [1]. The layered nature of the crystal leads to strong anisotropy of the refractive index, electrical conductivity, thermal conductivity, mechanical and optical properties, a large ionic radius, and at the same time to the intercalation of impurity atoms with photoluminescence properties between the layers. The high value of birefringence makes it possible to fabricate laser emitters in the infrared and terahertz regions of the spectrum from GaSe crystals [2÷4]. Epitaxial heterojunctions have been made using the layered structure of a GaSe single crystal as a buffer layer [5].

A characteristic feature of the GaSe crystal is that its p-type electrical conductivity does not change even when alloyed with various chemical elements and its microhardness increases when alloyed with *Al, Ag, In* atoms. Only the replacement of S atoms with Se atoms is unlimited and has a strong effect on its electrical and mechanical properties. Thus, as a result of such substitutions, the resistivity of the GaSe crystal varies in the range of $10^2 \div 10^9$ Ohm·cm at room temperature [6]. The reason is the formation of structural defects in a large concentration during the synthesis of the solid solution. To change and control the electrophysical properties of the crystal, not only dopant atoms are used but also the effect of radiation rays of various nature and energy.

High-energy radiation (electron, neutron, ion beam) is used to create radiation defects that affect the electrophysical and optical properties of crystals, including layered crystals and even change the type of crystal. In recent decades, low-dose radiation has been used to affect the electronic and photoelectric properties of GaSe layered crystals [7–8].

2. EXPERIMENTAL PART

The authors [9] irradiated GaSe crystal with electrons with an energy of 4 MeV to change and control its electrophysical properties. The process was carried out at a temperature of T=300 K, at integral flux values of $1{,}3\cdot10^{17}cm^{-2}$, $1{,}5\cdot10^{17}cm^{-2}$ and $2{,}8\cdot10^{17}cm^{-2}$ in the Electron Beam Facility- 4 (EBF- 4) accelerator. During the research, sample plates with linear dimensions of 1x1 cm^2 and a thickness of 400÷800 μm were used. These samples were exposed to different radiation doses of $1.5\cdot10^{17}cm^{-2}$ and $2.8\cdot10^{17}cm^{-2}$. *In* atoms were applied to prevent heating in ohmic contacts. Electrophysical parameters were measured by the Van der Pauw method in the Ecopia HNS device, in the temperature range of 90÷350 K. The electrophysical parameters of the sample were measured using the Van der Pauw method in an Ecopia HNS device, in the temperature range of 90÷350 K.

It has been established that when a GaSe crystal is irradiated with a low-dose ($\Phi<2.8\cdot10^{17}cm^{-2}$) electron beam, the concentration of free holes decreases. In this case, the activation energy varies in the range of 300÷450 meV which is determined by the temperature dependence of the hole concentration. The temperature dependence of the hole concentration in layered GaSe single crystals exposed to radiation at different doses is shown in Figure 1. As can be seen from the graph, at low values of radiation (curves 2 and 3), a decrease in the hole concentration is observed and with a subsequent increase in the radiation dose an increase is observed. With a further increase in the radiation dose, if the concentration of radiation defects exceeds the concentration of chemical impurities, a compensation process occurs in the crystal [7]. Otherwise, a sharp increase in the hole concentration is observed (curve 4).

It can be assumed that a further increase in the radiation dose would lead to a decrease in the concentration. However, the opposite was observed in the layered GaSe single crystal. It seems that the reason for the current anomaly is the layered structure of the crystal.

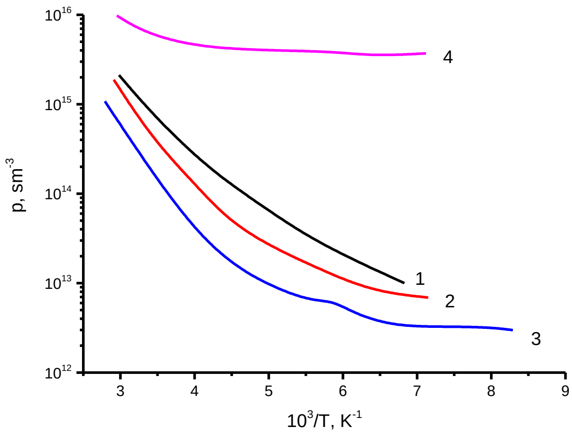

Figure 1. *Temperature dependence of the concentration of free holes in a crystal GaSe:*
$\Phi_1=0$; $\Phi_2=1{,}3\cdot10^{17}cm^{-2}$; $\Phi_3=1{,}5\cdot10^{17}cm^{-2}$; $\Phi_4=2{,}8\cdot10^{17}cm^{-2}$.

Thus, a similar phenomenon is not observed in other crystals. The results of many studies show that the same processes are observed when a current is passed along the layers of a GaSe crystal irradiated with electrons and in a direction perpendicular to the surface [8, 9].

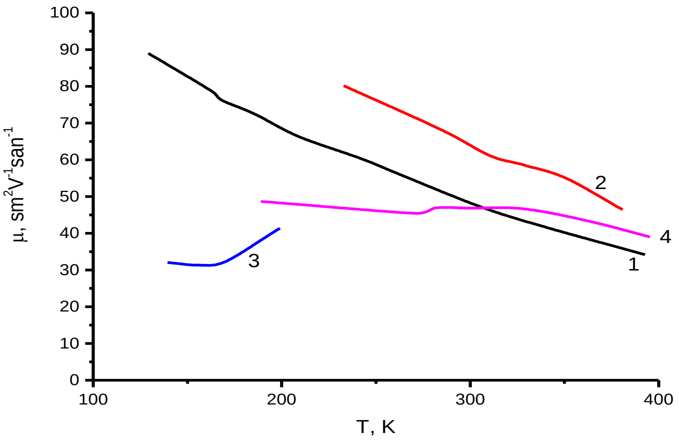

Figure 2. Temperature dependence of the mobility of free holes in a GaSe crystal in a given radiation dose: *$Ф_1$=0; $Ф_2$=1,3·10^{17}cm^{-2}; $Ф_3$=1,5·10^{17}cm^{-2}; $Ф_4$=2,8·10^{17}cm^{-2}*

The temperature dependence of the electrical conductivity of the GaSe crystal (Fig. 3) shows that at small doses of electron flux (Ф=1,3÷1,5·10^{17}cm^{-2}) the electrical conductivity partially decreases. This is due to the fact that newly formed radiation defects are compensated by the inherent defects of the crystal. An increase in the radiation dose led to a further increase in the electrical conductivity. The same increase was also recorded in GaSe crystals doped with various metal atoms.

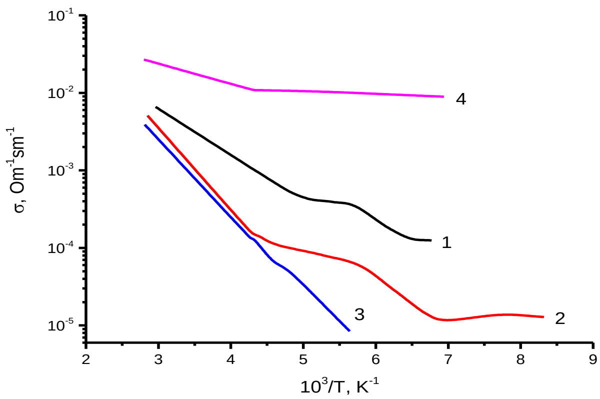

Figure 3. Temperature dependence of electrical conductivity of a GaSe crystal in a given radiation dose: *$Ф_1$=0; $Ф_2$=1,3·10^{17}cm^{2}; $Ф_3$=1,5·10^{17}cm^{-2}; $Ф_4$=2,8·10^{17}cm^{-2}.*

3. ANALYSIS OF RESULTS

The dependence of the concentration of charge carriers, their mobility, and the overall electrical conductivity of GaSe layered single crystals versus dose of electron irradiation, as well as versus temperature has been studied. The decrease in the concentration of holes at low doses of irradiation can also be explained by the formation of donor-type radiation defects in the crystal under the influence of irradiation [5]. Another reason for the decrease in the concentration is the compensation of Frenkel defects by the migration of defects formed in the crystal during synthesis and growth of the single crystal under the influence of low doses of electrons [10]. At high values of the irradiation dose (Φ=2,8·10^{17}cm^{-2}), the degradation process in the crystal leads to an increase in the concentration of holes, which leads to a violation of high order.

When irradiating a GaSe crystal at a small dose (Φ=1,3·10^{17}cm^{-2}), it leads to the formation of an ordered structure and an increase in the mobility of charge carriers (Fig. 2, curve 2). A further increase in the radiation dose leads to a decrease in the mobility due to the formation of radiation defects (curves 3,4). Like other semiconductor crystals, the electrical conductivity of the GaSe crystal also depends on the concentration of charge carriers. However, since the electrical conductivity depends more on the concentration than on the mobility, the electrical conductivity of samples irradiated at a small dose (Fig. 3, curves 2 and 3) decreases sharply compared to the unirradiated sample (as a result of compensation).

When the radiation dose is increased, as a result of the disordering of the crystal, the concentration of charge carriers increases sharply and the mobility decreases [10, 11].

Thus, summarizing the results of the study, it can be concluded that, depending on the type of crystal, growth technology and irradiation mechanism at low doses of irradiation a compensation phenomenon occurs in the crystal accompanied by high order (increase in mobility) and defect migration [12, 13]. A continuous increase in the irradiation dose leads to a decrease in the mobility of charge carriers and an increase in their concentration.

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