# EFFECT γ- RADIATION ON THE ELECTRICAL PROPERTIES OF $In_{0.999}Ag_{0.001}Se$ SINGLE CRYSTALS

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It was determined that when $In_{0.999}$ $Ag_{0.001}Se$ crystals are irradiated with 50 krad dose γ-quanta, centers with a depth of 0.17 eV are formed in the forbidden band. Before irradiation, in the prohibited band there are uncontrollable centers with the location depth Ev + 0.1 eV. Centers resulting from irradiation compensate for uncontrolled Ev +0.1eV centers. With this, the concentration of charge carriers and electrical conductivity decreases. As the radiation dose increases, new centers are not formed, the concentration of previous centers increases. The difference between the electrical conductivity of unirradiated and radiated crystals also increases with decreasing temperature.

**Keywords** : γ-quanta , irradiated crystals, perfect crystals, industrial electronics, chalcogenides, perfection of crystals due to radiation.

**PACS:** Nr.71.20Semiconductor compounds; 72.20.Fr Shipping and handling in low areas.

## INTRODUCTION

InSe belongs to the group of $A^{III}B^{VI}$ layered crystals. Despite having high defectivity, these crystals are used in the production of various devices in industrial electronics, solar cells [1,2], optical modulators [3,4], X-ray radiation detectors [5,6], radioactive measuring devices in nuclear reactors [7], pressure transmitters [ 8] are used in preparation.

Various effects are used to control the physical properties of these crystals. In the current study, different doses of γ-radiation were used as an external effect.

Semiconductors are irradiated with high-energy particles, changes in their crystal structure occur. This affects the physical properties of crystals. Since the effect of radiation on different crystals is different [7, 9, 10,11], the nature of radiation, kinetics and stability of their formation during the interaction of high-energy particles with solid bodies have been studied. In layered semiconductors, like most semiconductor materials, electrical conductivity changes significantly depending on the radiation dose during interaction with γ-quanta [12,13].

Purpose of conducting experiments; Irradiated with doses of 50 and 100 krad consists of determining the temperature dependence of the electrical conductivity of $In_{0.999}Ag_{0.001}Se$ crystals, the depth of the centers formed depending on the radiation dose, and the temperature dependence of the relative change of their electrical conductivity.

## DISCUSSION OF EXPERIMENT AND RESULTS

In InSe, the coordination number of In atoms is 4, and the coordination number of Se atoms is 3. Accordingly, a 4-coordinated In atom forms a tetrahedral bond with a 3 - coordinated Se atom, and 1 In atom hybridizes at the $sp^3$ level [14,15]. The above allows us to conclude that the nature of the chemical relationship between indium and silver monoselenides is similar, and to determine the formation of solid solutions between InSe and AgSe.

In this study, homogeneous $In_{0.999}Ag_{0.001}Se$ samples were taken to study the electrophysical properties. For this purpose, In-In 000, Se B-3 and Ag-999.9 branded elements were used. Chemical elements In, Ag, Se were chopped and filled into a quartz ampoule, air was sucked up to a pressure of $10^{-4}$ Pa. For this, the direct synthesis method was used. Single crystals of $In_{0.999}Ag_{0.001}Se$ were grown by the vertical Bridgman method. The speed of movement of the ampoule in the oven was 0.3 cm/h. The resulting crystals were studied by differential thermal analysis (DTA), X-ray phase analysis (RFA) and microhardness measurements. Silver paste was used as ohmic contacts. The contacts are placed opposite the opposite surfaces of the samples. The sample is made in the form of a parallelepiped and the size shown below is $10x4x2mm^3$ . The samples were irradiated with a $Co^{60}$ source (direct-acting radiation chemical unit) РХУНД-20000 with an γenergy of 1.25 MeV, a flux density of $1.4\cdot10^{11}$ quant/s $\cdot cm^{2}$ and a radiation power of ~ 50 rad/s in the radiation zone at room temperature· radiation doses of -quanta 0; 50; and was 100 krad. Samples for the experiment were placed in a special cryostat. The temperature of the samples was measured by a chromel-alumel thermocouple located on their surface. It was determined that $In_{0.999}Ag_{0.001}Se$ solid solutions have n-type conductivity according to the sign of thermo-eq. The electrical conductivity of $In_{0.999}$ $Ag_{0.001}Se$ samples in the temperature range of 142-294K was measured in a constant electric field. First, the temperature dependence of the electrical conductivity of the non-irradiated crystal was measured. Then, the temperature dependence of the electrical conductivity of crystals made of $In_{0.999}Ag_{0.001}Se$ crystals irradiated with 50 and 100 krad dose γquantums was measured. Based on the

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results obtained from the experiment, the temperature dependence of electrical conductivity before and after irradiation was established in Arrenus coordinates, and for both cases, the location depth of the centers located in the forbidden zone was calculated. When the sample is irradiated with a dose of 50 krad, the electrical conductivity decreases compared to the non-irradiated sample. This is because when the crystal is irradiated with a dose of 50 krad, radiation centers with a depth of 0.17 eV are formed. The electrical conductivity decreases because the uncontrolled defect centers with a depth of 0.1 eV are compensated by the radiation induced defect centers. As a result, the concentration of charge carriers decreases. As the radiation dose increases, new centers are not formed, the concentration of previous centers increases. The dependence of electrical conductivity on the radiation dose $V_{In}$ occurs with the accumulation of acceptor defects. Experimental results of this phenomenon are shown in figure 1.

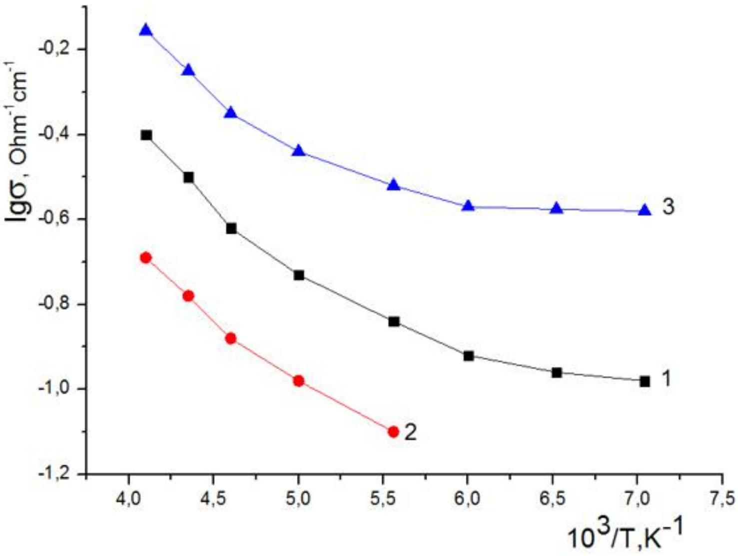


*Fig. 1.* γ- effect of irradiation on the electrical conductivity of $In_{0.999}Ag_{0.001}Se$ monocrystals: the 1st curve refers to the non-irradiated samples, the 2nd curve to the samples irradiated with a 50 krad dose **,** and the 3rd curve to the samples irradiated with a 100 krad dose.

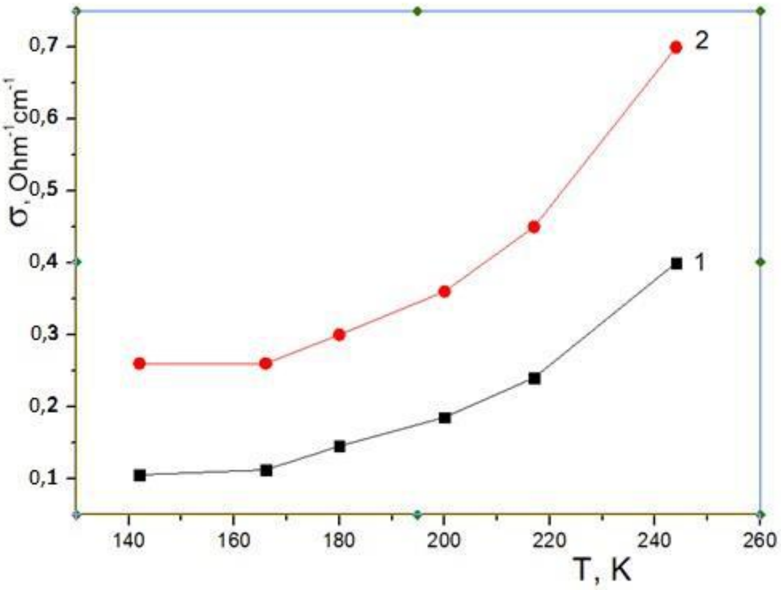


*Fig.2.* Temperature dependences of electrical conductivity of $In_{0.999}Ag_{0.001}Se$ single crystals: 1 curve refers to non-irradiated samples, 2 curve refers to samples irradiated with a dose of 100 krad.

It can be seen from the figure that the electrical conductivity varies exponentially depending on the temperature, and as the temperature decreases, the difference between the electrical conductivity of unirradiated and irradiated crystals increases. This situation becomes more pronounced when the crystal is irradiated with a dose of 100 krad.

To find the relative change in electrical conductivity, the difference between the electrical conductivity of the sample irradiated with a dose of 100 krad and the non-irradiated sample was used.

Figure 3 shows the temperature dependence of the relative change of electrical conductivity of non-irradiated and irradiated samples with a dose of 100 krad.

$In_{0.999}Ag_{0.001}Se$ samples with a dose of 100 krad, the difference between the electrical conductivity at appropriate temperatures was determined using the following formula

$$\frac{\sigma_{\gamma} - \sigma_0}{\sigma_0}$$

Here, $\sigma_0$ is the electrical conductivity of non-irradiated $\sigma_\gamma$ $In_{0.999}Ag_{0.001}$ Se samples irradiated with a dose of 100 krad .

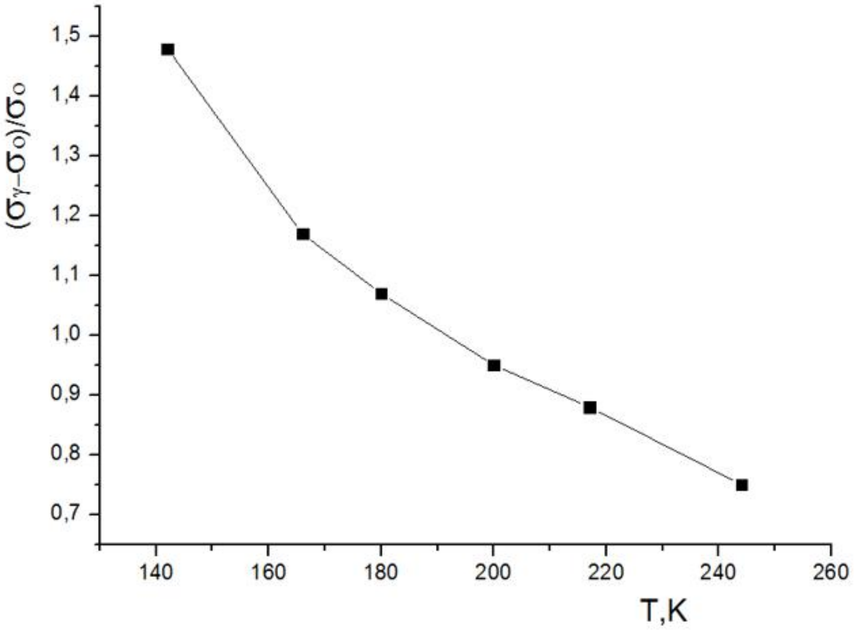


*Fig 3* . Temperature dependence of the relative change of electrical conductivities of $In_{0.999}Ag_{0.001}Se$ crystals irradiated with a dose of 100 krad and not irradiated.

## RESULTS

It was determined that when $In_{0.999}Ag_{0.001}Se$ crystals are irradiated with g-quanta with a dose of 50 krad, radiation centers with an energy of 0.17 eV appear in the forbidden band and the electrical conductivity decreases. The reason for this is that uncontrolled defects with energy $E_v$+0.1eV are compensated by defects caused by radiation. As a result of compensation, the concentration of charge carriers decreases. As the radiation dose increases, new centers are not formed, the concentration of previous centers increases. The dependence of the electrical conductivity on the radiation dose occurs with the accumulation of acceptor defects. It was determined that as a result of a dose of 100 krad, the crystals undergo a purification process, which allows the crystals we have studied to be successfully used in various fields of industrial electronics.


[1] *A. Segura, J.P. Geusdon, J.M. Besson, A. Chevy.* Fotovoltaic effect in InSe. Application to solar energy conversion. “Rev. Phys. appl.” 1979, t.14, ¹1, p.253.

[2] *A. Segura, J.P. Geusdon, J.M. Besson, A. Chevy.* Photoconductivity and fotovoltaic effect in in indium selenide. J. Appl. Phys. 1983, t.54, ¹2, p.876

[3] *А.Г. Кязымзаде, А.А. Агаев, В.М. Салманов.* Детекторы оптического излучения на основе слоистых кристаллов GaSe и InSe. ЖТФ, 2007, t.77, c.80-85.

[4] *К.Х. Нагиев, В.М. Салманов.* Оптические модуляторы на основе кристаллов GaSe и InSe. Республиканская научная конференция «Актуальные проблемы физики», посвященная 90-летию БГУ. Баку, 16 мая 2009, с.18.

[5] *Г.Д. Гусейнов, Г.И. Искендеров, Е.М. Керимова.* Взаимодействие мягкого рентгеновского излучения с монокристаллами InSe. Препринт №3, ИФАН, Баку, 1991, 20 с.

[6] *С.Н. Мустафаева, М.М. Асадов, А.А. Исмаилов* Перенос заряда по локализованным состояниям в монокристалле InSe и InSe<Sn>//Физика Низких Температур, 2010, т.36, №4, с.394-397.

[7] *С.Н. Мустафаева, М.М. Асадов, А.А. Исмаилов.* Влияние γ-облучения на параметры локализованных состояний в монокристаллах p-InSe и n-InSe<Sn>//Физика

Низких Температур 2010, т.36, №7, с.805-808.

[8] *А.А. Исмаилов, Ш.Г. Гасымов, Т.С. Мамедов, К.Р. Аллахвердиев*. Влияние давления на электропроводность и эффект холла селенида индия. ФТП, 1992, т.26, в.11, с.1994-1996.

[9] *A.A.Ismailov, N.Z.Gasanov, A.A.Ismailov, Z.M. Nasrullaeva*. Influence of γ-irradiation on the Elektrophysical Properties of $In_{1-x}Sm_xSe$ Single Crystals. American Journal of sosial and Humanitar Research. Global Rearch, Network, vol.3issue, 5-in may 2022, p.120-122.

[10] *A.Ə. İsmayılov, Q.İ. İsaqov, Ə .Ə. İsmayılov.* InSe laylı kristallarında yaranan defektlər Akademik L.M.İmanovun 100 illiyinə həsr olunmuş beynəlxalq konfrans 7 oktyabr 2022, s.141-143.

[11] *E.M. Kerimova, N.Z. Gasanov, A.A. Ismailov.* Electrical and photoelectric properties of solid solutions $In_{1-x}Er_xSe$. GESJ, Physics, 2019, №1(21), p.53-59.

[12] *В.С. Вавилов, Н.П. Кокелидзе, Л.С.Смирнов.* Действие излучений на полупроводники. М., Наука,1988, 191с.

[13] *Г.И. Исаков, А.А. Исмаилов, П.Г. Исмаилова, А.А. Исмаилов, С.С. Абдинбеков, Х.Ш.Велибеков, Т.Я.Оруджев.* Электрические свойства монокристаллов $In_{0.99}Sm_{0.01}Se$ и $In_{0.99}Er_{0.01}Se$ для солнечных элементов. Международный журнал, Альтернативная энергетика и экологии, 2022, №6, с.36-43, Саров.

[14] Конфигурационная модель вещества, под ред. Г.Б. Самсонова, И.Ф. Прядко, Л.Ф. Прядко (Киев, Наук. думка, 1975).

[15] *В.Ю. Ирхин, Ю.П. Ирхин.* Электронная структура, физические свойства и корреляционные эффекты в d–и f-металлах и их соединениях (М., Наука, 2011).

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