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INFLUENCE OF γ-RAYS ON DIELECTRIC PROPERTIES OF $TlInS_2$ CRYSTALS

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Abstract: Herein, the formation features of ions and defect levels and their management methods have been investigated based on the study of the temperature and frequency dependences of dielectric properties and impedance spectra in the temperature region, in which anomalies occur, as well as of the study of the influence of ionizing γ-rays on them, in $TlInS_2$ single crystals, which are a specific representative of triple compounds with a chain crystal structure. It was found that the shift of the sharp increase of the permittivity temperature with the increase of frequency, as well as disappearance of the sharp increase at high frequencies is the result of relaxation processes in the presence of more inert particles-ions.

Keywords: chain crystal, triple compound, defect levels, permittivity, ionizing radiation

1. Introduction

Several anomalies are observed in the dielectric and electrical properties of different representatives of triple compounds with a chain crystal structure of class $A^3B^3C_2^6$ when the temperature of the crystals is 100K and higher [1, 2]. The reason for these anomalies is due to the significant changes in the transmission mechanism of electric charge. At certain temperature values, it is characteristic that electric charge transfers from an electron mechanism to ionic conduction and a super ion state in the process of transportation in connection with the processes occurring in the monovalent Tl^+ sub lattice of a crystal lattice. The sequence, order, and temperature range of these processes depend on the purity of the crystal and the high-energy γ-radiation. Herein, the formation features of ions and defect levels and their management methods have been investigated based on the study of the temperature and frequency dependences of dielectric properties and impedance spectra in the temperature region, in which anomalies occur, as well as of the study of the influence of ionizing γ-rays on them, in $TlInS_2$ single crystals, which are a specific representative of triple compounds with a chain crystal structure. Permittivity ε and impedance spectra were performed using a bridge in size E7-25 R-L-C at a temperature range of 200-600K, at different frequencies of the applied electric field.

2. Experiments

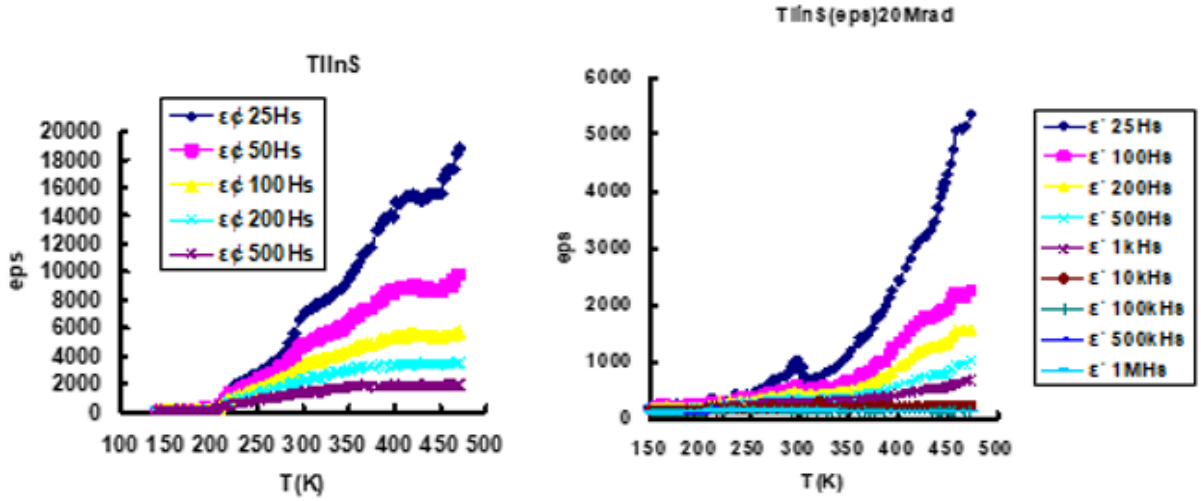
According to the available data⌊3, 4⌋, $TlInS_2$ is considered to be one of the few semiconductor compounds in which a sequence of different phase transitions is observed. At relatively high temperatures ($T > T_c$) $TlInS_2$ exists in the para electric state. The temperature dependence of the permittivity of $TlInS_2$ single crystals at different values of the external field frequency is shown in Figure 1. Measurements correspond to the temperature range of 250-600 K and the frequency range of $10\text{-}10^6$ Hz of the electric field. At relatively low frequencies, the numerical value of the permittivity varies very little at temperatures below 230K, and ε rapidly increases at high temperatures starting from T ~270K. In this temperature region, when the electric

field is parallel $\varepsilon_{\parallel}$ and perpendicular $\varepsilon_{\perp}$ to the optical axis (C) of the single crystal $TlInS_2$, the dependences of the permittivity on the temperature in the coordinates ln ε(1000/T) correspond to a straight line, the dependence ε(T) is exponential. The correspondence of the quantity ln(σ) of the 1/T dependence to a straight line with a characteristic energy ΔE demonstrates the nature of the activation of relaxation processes.

$$\varepsilon(T) \sim \varepsilon_0 \exp(-\Delta E/kT)$$

From this expression, the defined value of the activation energy is ΔE = 0.21 eV. The exponential dependence of the permittivity on the temperature in both parallel and perpendicular direction to the "c" axis is related to ionic conductivity[5].

Although the general picture of the ε(T) dependence does not change at high frequencies, the numerical value of the permittivity decreases with increasing frequency and the temperature at which its numerical value begins to increase shifts to higher temperatures. After irradiation of the $TlInS_2$ crystal with γ-quanta at a dose of 20 Mrad, the numerical value increases with increasing temperature, as the temperature dependence of the permittivity is more smooth than in the initial state (before irradiation).



a ***b***

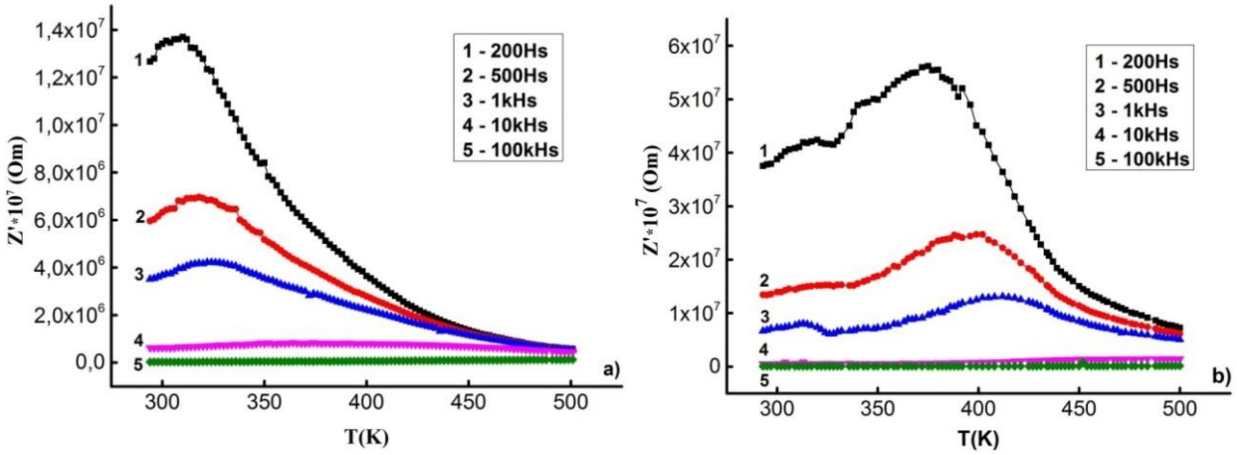
Fig. 1(a, b) Temperature dependence of the permittivity of the $TlInS_2$ crystal initial (before irradiation, a) and after irradiation with 20 Mrad γ-quanta at different frequencies of the external field

Comparison of the images shows that the numerical value of the permittivity of $TlInS_2$ decreased by ~3 times under the influence of γ-radiation. This decrease can be associated with the increase in the concentration of free carriers under the influence of γ-radiation and the increase in the mobility of the boundaries of the field with increasing temperature. The phase transitions are also observed in irradiated samples. At high frequencies, the permittivity does not almost depend on temperature.

Impedance spectroscopy is the optimal method for a comprehensive study of the dynamics of the movement of ions in materials with high ionic conductivity. The study of the system's response to a small-amplitude sinusoidal distortion signal allows us to explain in detail the process of charge transfer in matter due to ion transfer and polarization effects. According to impedance spectroscopy, the mechanism of ions diffusion is significantly expanded [4].

Figure 2, a, b, and Figure 3 a, b show the temperature dependence of the real and imaginary parts of the complex impedance $Z^*(f)$ of $TlInS_2$ crystal at different measurement frequencies,

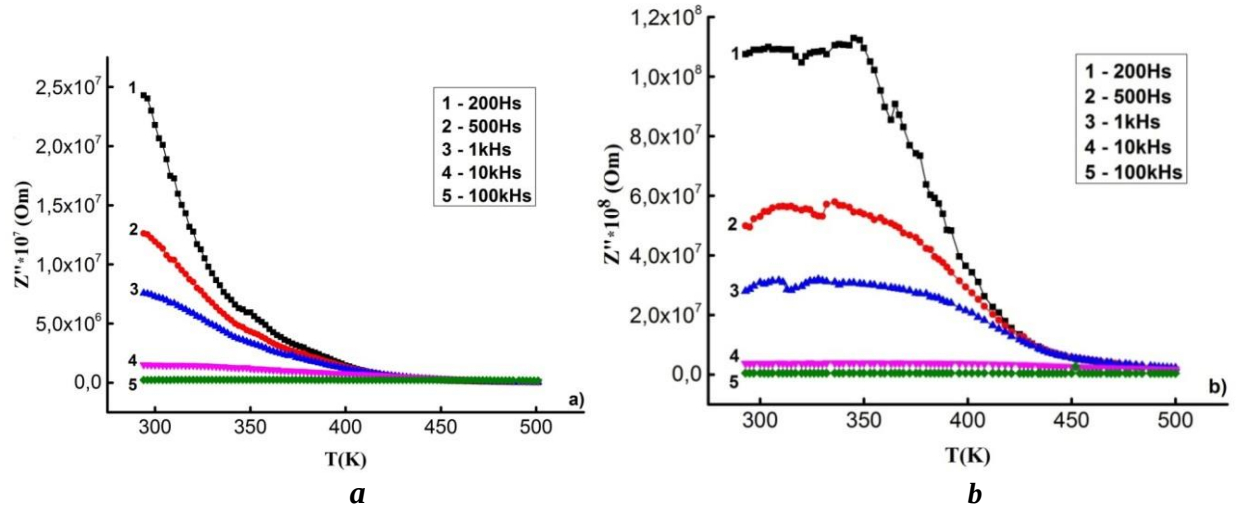
respectively. As can be seen from the figures, the real part of the complex impedance Z′(T) at low frequencies and temperatures has a high value and it decreases with increasing temperature. As the frequency increases, the impedance decreases in value and no significant change occurs in the region of temperature change. Only at high frequencies the impedance value is small and does not depend on temperature. Changes under the influence of 20 Mrad ionizing radiation can be associated with the shift of temperature to higher values by the decrease in impedance and the specificity of the relaxation process.



a ***b***

Fig. 2 (a, b). Temperature dependence of the real part of the impedance in $TlInS_2$ crystals (a-initial state, b- irradiated with 20Mrad γ-quanta)

As can be seen from Figure 3, which describes the temperature dependence of the imaginary part of the impedance at different frequency values, the temperature dependence is accompanied by peaks, and as the frequency increases, the peaks shift to higher temperatures.



a ***b***

Fig. 3. (a, b) Temperature dependence of the imaginary part of the impedance in $TlInS_2$ crystals (a - before radiation, initial state, b - after irradiation with 20Mrad γ-quanta)

As can be seen from the figure, the temperature dependence of the imaginary part of the impedance (Z″) is like a “staircase”. As the measurement frequency increases, the amplitude value of the “staircase” decreases. Although the Z″ is partially increased by the effect of 20 Mrad γ-rays,

the sharp decrease corresponds to a higher value of temperature, but the form of temperature dependence remains unchanged. Thus, no qualitative change occurs in the relaxation process under the influence of gamma rays, but only quantitative changes do.

3. Results

Placement of the experimental results in the growth regions of the permittivity with increasing temperature at low frequencies in a straight line at the coordinates ln(ε)-~1/T is associated with energy levels with activation energies $E_a^1$0,28 eV and $\Delta E_a^2 = 0.3eV$. The shift of sharp increase temperature of the permittivity to higher temperatures with the increase in frequency, as well as the disappearance of the sharp increase at high frequencies demonstrates that relaxation processes occur in the presence of more inert particles-ions. In crystals studied at low temperatures, the electron relaxation changes to partial ion relaxation. Activation of ions allows their participation in relaxation processes. Although the general states of the temperature dependence of the permittivity after the influence of gamma rays are maintained, there is a 3-fold decrease in the numerical value and a slight decrease in the activation ($\Delta E_a^1 = 0.29eV$). The features of the impedance spectrum, their dynamics of change under the influence of temperature, frequency, and ionizing gamma rays are explained by the features of ionic conductivity. Thus, as in other representatives of the class it possesses, the formation of ionic conductivity⌊5 − 7⌋ in $TlInS_2$ crystal is according to the specifics of the crystal lattice is based on the diffusion of ions in the Tl^+ sublattice by vacancies. As a result of the phase transition in the crystals, the sublattice of Tl ions melts⌊8⌋. This view is also characteristic of other materials with ionic conductivity.

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ВЛИЯНИЕ γ-ИЗЛУЧЕНИЯ НА ДИЕЛЕКТРИЧЕСКИЕ СВОЙСТВА КРИСТАЛЛОВ $TlInS_2$

О. Самедов, Н. Мехтиев, Н. Набиев

Резюме: В настоящей работе исследуются температурные и частотные зависимости диэлектрических свойств и спектров импеданса в температуре аномалиях монокристаллов $TlInSe_2$, являющихся специфическими представителями тройных соединений с цепной кристаллической структурой, а также на основе исследования влияний ионизирующих гамма излучений свойства образования ионов, уровней дефектов и способы их управления. Было обнаружено, что резкое увеличение диэлектрической проницаемости с увеличением частоты смещает температуры в сторону более высоких температур, а также исчезновение резкого увеличения на высоких частотах является результатом релаксационных процессов в присутствии более инертных частиц-ионов.

Ключевые слова: цепной кристалл, тройное соединение, уровни дефектов, диэлектрическая проницаемость, ионизирующее излучение

$TlİnS_2$ KRİSTALLARININ DİELEKTRİK XASSƏLƏRİNƏ γ-ŞÜALARIN TƏSİRİ

O. Samedov, N. Mehdiyev, N. Nəbiyev

Xülasə: Təqdim olunan işdə zəncirvari kristal quruluşa malik üçqat birləşmələrin spesifik nümayəndəsi olan $TlİnS_2$ monokristallarında dielektrik xassələrinin və impedans spektrlərinin anomaliyalar baş verdiyi temperatur oblastında temperatur və tezlik asılılıqları, eləcə də onlara ionlaşdırıcı γ-şüaların təsirinin tədqiqi əsasında ionların, defekt səviyyələrinin yaranma xüsusiyyətləri və onların idarə olunma yolları araşdırılıb. Müəyyən edilmişdir ki, tezliyin artması ilə dielektrik nüfuzluğunun kəskin artma temperaturunun daha yüksək temperaturlara doğru sürüşməsi, habelə kəskin artımın yüksək tezliklərdə aradan qalxması relaksasiya proseslərinin daha ətalətli zərrəciklərin-ionların iştirakı ilə baş verməsinin nəticəsidir.

Açar sözlər: zəncirvari kristal, üçqat birləşmə, defekt səviyyələri, dielektrik nüfuzluğu, ionlaşdırıcı şüalar