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COMPLEX IMPEDANCE SPECTRA OF $TlInS_2$(10%C) COMPOUND IRRADIATED BY γ-QUANTUM

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Abstract: Complex impedance spectra of $TlInS_2$ (10%C) crystal were studied at different absorbed doses. The analysis of complex impedance spectra using the equivalent circuit method shows that a semicircle is created in the diagram (high-frequency part of the hodograph) corresponding to the charge transport process in the $TlInS_2$ (10%C) crystal. The low-frequency part of the hodograph on the near-electrode surface corresponds to the inclined straight line characterizing the charge polarization of the volume load. An equivalent scheme has been proposed according to the hodograph. It is also shown that depending on the absorbed dose, the hodographs shift towards the high-frequency region.

Keywords: ionic conductivity, electronic conductivity, a real part of the resistance, the imaginary part of the resistance, absorbed dose, gamma quanta, impedance spectra, godograph.

1. Introduction

In recent years, $A^3B^3C_2^6$ type semiconductors and their solid solutions have been widely studied (here A-Tl; B-In, Ga; C-S, Se, Te). This type of crystal belongs to the family of layered and chain-like semiconductors [1-3]. At the same time, these doped crystals, which are analogs of disordered systems, have not been fully studied to date. The $TlInS_2$ semiconductor compound belongs to the class of $A^3B^3C^6_2$ type semiconductor compounds, and with a crystal lattice period of a=10.90Å, b=10.94Å, c=15.18 Å, β=100.21° (included in the C2/c-C_{2h}^6 space group), it crystallizes in monoclinic syngonia [4].

For the first time, it was determined that the $TlInS_2$ crystal has ionic and electronic conductivity at temperatures above room temperature, and several anomalies in the temperature dependence of dielectric permittivity ε(T) were observed. It has been shown that after exposure to gamma rays, as the absorbed dose increases, the ionic conductivity increases and the electronic conductivity decreases [5,6]. In [7], anomalies were observed in the temperature dependence of dielectric permittivity in the $TlInS_2$<5%C> compound at temperatures ε(T) T=370K, T=415K, and T=532K. It has been shown that the ionic conductivity increases and the electronic conductivity decreases as the temperature increases.

We have studied the temperature dependence (ε(T)) of the dielectric permittivity of the $TlInS_2$<10%C> crystal both along the "c" axis and perpendicular to it. It was shown that at the same temperature, the dielectric permittivity in the "c" direction of the $TlInS_2$ <10% C> crystal is 34.5 times greater than that of the $TlInS_2$ crystal. It has also been shown that the numerical value of dielectric permittivity increases at radiation doses of 0÷0.80 MGy [8].

In the present work, complex impedance spectra of $TlInS_2$(10%C) crystal were studied at absorbed doses of 0÷0.8MGy.

2. Methodology of the experiment

$TlInS_2$ <10%C> mono crystals were grown by the Bridgman-Stockbarger method. 5 × 2 × 2 mm samples were used for measurements. The electrodes are placed perpendicular to the layers of the crystals. The silver paste was used as a contact material. Complex impedance spectra were measured using an E7-20 AC bridge in the frequency range of 25-10^6 Hz using a copper-constantan thermocouple at a step of 0.1 K/min. The samples were irradiated with γ-quanta in the γ-25 radiation research facility (the radiation source in the facility is the Co^{60} isotope). Samples are placed in closed ampoules in the chamber of the γ-25 radiation research facility.

3. Experimental Results and discussion

For the first time, the impedance spectroscopy method was developed and applied to electrochemical systems. Later, it became known that this method could be applied to solids as well. Currently, this method is widely used in condensed matter physics and materials science. With the help of the impedance spectroscopy method, it is possible to obtain information about the transport of charge carriers in the sample, taking into account its microstructure. The core of the impedance spectroscopy method is to excite the system under investigation with a small-amplitude sinusoidal signal and study the response of the signal produced by it at the output. When the voltage $U(t) = U_0 \sin(\omega t)$ is applied to the input, an alternating current appears at the output according to the law $I(t) = I_0 \sin(\omega t + \theta)$), where U_0 and I_0 are the amplitude values of voltage and current, respectively, $\omega = 2\pi f$–circular frequency; θ is the phase shift; and the impedance is defined as $Z^* = U(t)/I(t)$. To understand the processes under the influence of a changing electric field, the results of complex impedance should be analyzed at the level of ($Z^* = Z' + jZ''$) impedance, ($Y^* = Y' + jY''$) admittance, ($\varepsilon^* = \varepsilon' + j\varepsilon''$) dielectric permittivity, and ($M^* = 1/\varepsilon = M' + jM''$) electrical module.

Figure 1 shows the frequency dependence of the Z'-real and Z"-imaginary parts of the resistance of the $TlInS_2$(10%C) crystal (a-0MGy, b-0.2MGy, c-0.4MGy, d-0.6MGy, e -0.8MGy). As can be seen from Figure 1, as the absorbed dose increases, the numerical values of both the Z'-real and Z"-imaginary parts of the resistance decrease and shift towards the high-frequency region.

As it is known from our previous studies, $TlInS_2$ <C> crystals doped with carbon are among compounds with ionic conductivity [8,9]. When studying compounds with ionic conductivity in an alternating electric field, it is necessary to take into account the influence of boundary effects (electrode-sample and measuring cell).

Figure 2 shows the dependence of the hodographs of the $TlInS_2$(10%C) crystal on the absorbed doses (a-0MGy;b-0.2MGy;c-0.4MGy;d-0.6MGy;e-0.8MGy). As can be seen from Figure 2, the dependence of all hodographs on absorbed doses can be divided into two parts (including non-irradiated ones). The first part characterizes the sample and is in the form of a semicircle (the high-frequency part). The second part characterizes the sample-electrode boundary and is in the form of a straight line at an angle to the abscissa axis (low-frequency region). In excess of the absorbed dose, the hodographs of the $TlInS_2$(10%C) crystal shift towards the high-frequency region.

Complex impedance spectra can be analyzed using equivalent circuits. In the simplest case, the frequency characteristics of the polarization processes of charge transport can be given with the help of parallel connected RC circuits (resistance and capacitance) [10,11]. In this case, the hodograph, that is, the dependence of Z''(Z') is in the form of a semicircle.

An equivalent scheme was proposed from the Z*(f) results obtained for the $TlInS_2$(10%C) crystal (top image in Fig. 2). An analysis of the complex impedance spectra by the equivalent circuit method shows that a semicircle appears on the diagram (high-frequency part of the hodograph) in accordance with the charge transport process in the $TlInS_2$ (10% C) crystal. This corresponds to the parallel connection of resistance and capacitance (RC) in an equivalent circuit. In the low-frequency part of the hodograph, a straight line characterizing (making an angle with the abscissa axis) the polarization of volume charges on the near-electrode surface corresponds to the Cs capacitance connected in series with the RC chain in the equivalent circuit.

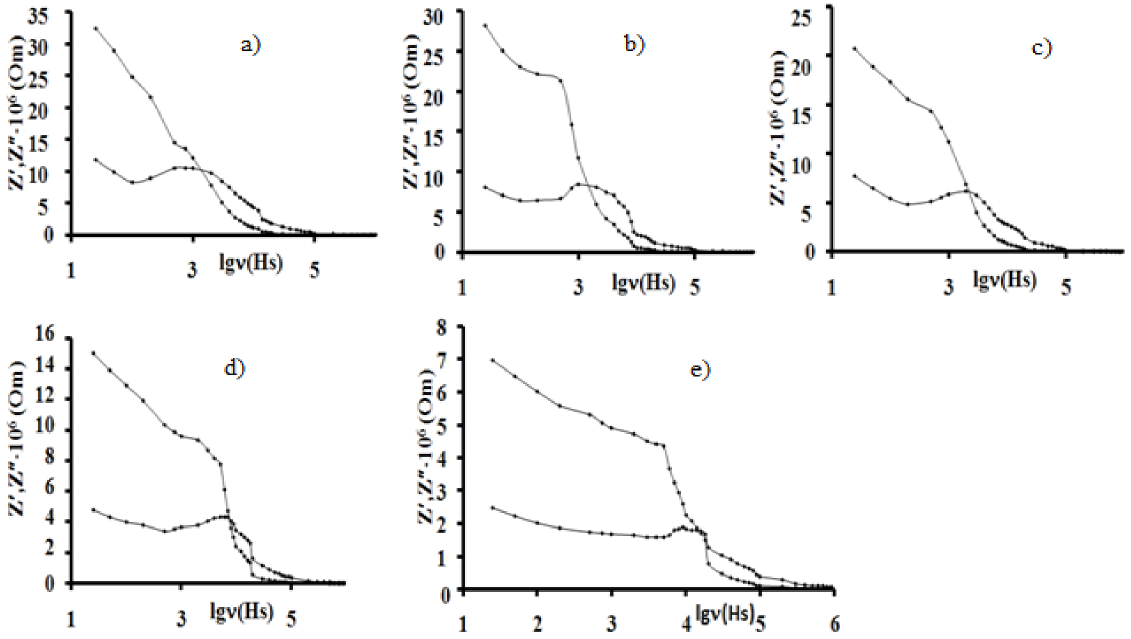

Fig. 1. Frequency dependence of Z'-real and Z''-imaginary parts of $TlInS_2$ (10%C) crystal: a-0MGy; b-0.2MGy; c-0.4MGy; d-0.6MGy; e-0.8MGy

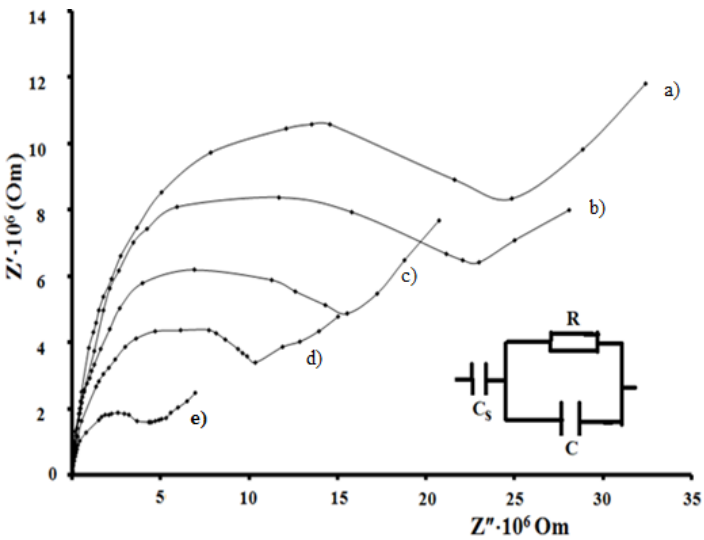

Fig. 2. Dependence of hodographs of $TlInS_2$(10%C) crystal on absorption doses: a-0MGy; b-0.2MGy; c-0.4MGy; d-0.6MGy; e-0.8MGy

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КОМПЛЕКСНЫЕ ИМПЕДАНСНЫЕ СПЕКТРЫ СОЕДИНЕНИЯ $TlInS_2$ (10%C) ОБЛУЧЕННОГО ϒ-КВАНТАМИ

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Резюме: Исследованы спектры комплексного импеданса кристалла $TlInS_2$ (10%C) при различных дозах поглощения. Анализ спектров комплексного импеданса методом эквивалентной схемы показывает, что на диаграмме (высокочастотная часть годографа) получается полуокружность, соответствующая процессу переноса заряда в кристалле $TlInS_2$ (10%C). В низкочастотной части годографов соответствует наклонной прямой линии, характеризующей объемно-зарядовая поляризации накопление объемного заряда в приэлектродных областях. Предложена эквивалентная схема по годографу. Также показано, что в зависимости от дозы поглощения годографы смещаются в область высоких частот.

Ключевые слова: ионная проводимость, электронная проводимость, действительная часть сопротивления, мнимая часть сопротивления, поглощенная доза, гамма-кванты, импедансные спектры, годограф.

γ-KVANTLARLA ŞÜALANMIŞ $TlInS_2$(10%C) BİRLƏŞMƏSİNİN KOMPLEKS İMPEDANS SPEKTRLƏRİ

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Xülasə: $TlInS_2$ (10%C) krilstalının kompleks impedans spektləri müxtəlif udulma dozalarında tədqiq olunmuşdur. Ekvivalent sxem metodundan istifadə etməklə kompleks impedans spektrlərinin analizi göstərir ki, $TlInS_2$ (10%C) ktistalında yüklərin daşınması prosesinə uyğun, diaqramda yarım çevrə alınır (qodoqrafın yüksək tezlikli hissəsi). Elektrodyanı oblastda həcmi yüklərin polyarizasiyasını xarakterizə edən meyilli düz xəttə, qodoqrafın aşağı tezlikli hissəsi uyğun gəlir. Qodoqrafa uyğun olaraq ekvivalent sxem təklif edilmişdir. Həmçinin göstərilmişdir ki, udulma dozasından asılı olaraq qodoqraflar yüksək tezliklər oblastına doğru sürüşürlər.

Açar sözlər: ion keçiriciliyi, elektron keçiriciliyi, müqavimətin həqiqi hissəsi, müqavimətin xəyali hissəsi, udulma dozası, qamma kvantları, impedans spektrləri, qodoqraf.