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Dielectric properties of $TlInSe_2$ ternary compound

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The dielectric properties of $TlInSe_2$ grown by direct fusion of their constituent elements were studied in the frequency range of 30 KHz-20 MHz, temperature range of 173-373 K. The dielectric constant and dielectric loss of $TlInSe_2$ were calculated by measuring capacitance (C) and dielectric loss factor (tan δ). Both of them were found to decrease with increasing frequency and increase with increasing temperature. This behavior can be explained with two polarization mechanisms in the investigated frequency and temperature range. The relaxation times of these polarization mechanisms were obtained from Cole-Cole fits. At lower frequencies the relaxation time is 10^{-6} while it was 10^{-8} at the higher frequencies. The maximum barrier height (W_m) was estimated from the dielectric loss measurements. The value of W_m was obtained as 0.1 eV. It was found to increase with increasing temperature.

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Keywords: $TlInSe_2$, Dielectric constant, Dielectric loss, Barrier height

1. Introduction

The semiconductor $TlInSe_2$ possesses interesting properties that lead to several applications as thermoelectric and optoelectronic devices [1]. The crystal is reported to be implantable in device production field such as a heterojunction based on semiconductors with a chain crystal structure TlSe-$TlInSe_2$ was produced [2]. The $TlInSe_2$ belongs to the family of ternary compounds $A^{III}B^{III}C^{VI}_2$ (A= Tl; B= In; C= S, Se, Te) which is a layer-chained structure [3]. A greater portion of published data deal with optical, photoelectrical, structural and switching properties of $TlInSe_2$ crystals [2, 4-9]. Furthermore, still it draws attention nowadays [10-14]. The dc electrical properties of $TlInSe_2$ compound have been extensively investigated in recent years, but relatively little work has been doing on their dielectric properties.

In the present work, we were reported on the dielectric properties of $TlInSe_2$ crystals, which have a remarkable importance in microelectronic applications, in the frequency range 30 kHz- 20 MHz and temperature range from 173K to 373K. The possible polarization mechanisms in structure were determined in the investigated frequency and temperature range. We aim to contribute to literature by adding information about the relaxation mechanisms detected in the frequency and temperature range of the $TlInSe_2$ ternary compound.

2. Experimental

The $TlInSe_2$ sample used for the measurement was grown by direct fusion of their constituent elements, explicitly described elsewhere [15]. The typical dimensions of our rectangular - shaped sample were 1.7×7.9×0.69 mm. The base and counter Au electrodes were deposited onto the sample in a 10^{-5} Torr vacuum. Copper wires fixed by indium on Au electrodes were used as the electrical contacts. The capacitance of the samples was measured using a Novo control Alpha-A high-frequency impedance analyzer (4192A) in the frequency range 30 kHz- 20 MHz and temperature from 173K to 373K.

3. Result and discussion

3.1. Frequency and temperature dependence of capacitance

The variation of capacitance (C) of the $TlInSe_2$ was studied within the temperature range 173-373 K and in the frequency range 30 kHz-20MHz. The obtained results are plotted as C versus log f at different temperatures in Fig.1. When the frequency dependence of capacitance (C) was investigated, it was observed that C decreases, by changing from 50 pF to 5 pF for different temperatures, with increasing frequency as shown in Fig. 1. In the investigated frequency range two different relaxation regions are observed. First of them, which shifts toward lower frequencies with decreasing temperature, is observed at frequencies between 30 kHz and 1 MHz. This relaxation may be attributed to dipolar polarization. The dipoles cannot orient themselves at higher frequencies and thus the capacitance decreases [16]. The second relaxation region, which also shifts toward lower frequencies with decreasing temperature, is observed at frequencies between 1 MHz and 20 MHz. This relaxation region may be attributed to a dipolar polarization having relatively smaller dipole moments. In Fig. 2, the temperature dependence of the C at some certain frequencies shows that increasing temperature causes a sharp increase of C above the temperature of 250 K. Below 250 K, the mechanism is temperature independent while the mechanism above the temperature 250 K is temperature dependent.

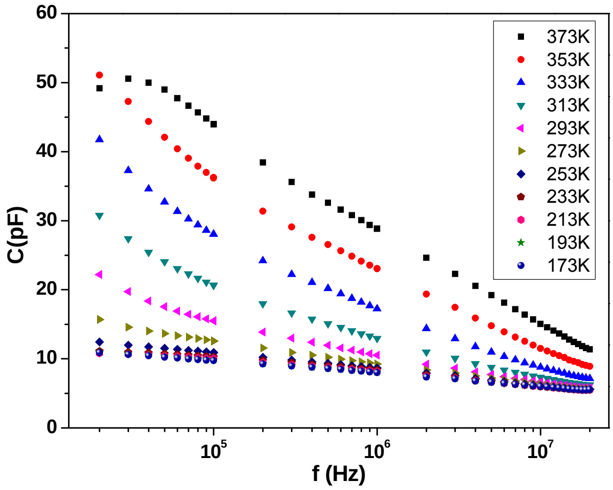

Fig. 1. Frequency dependence of capacitance at different temperatures

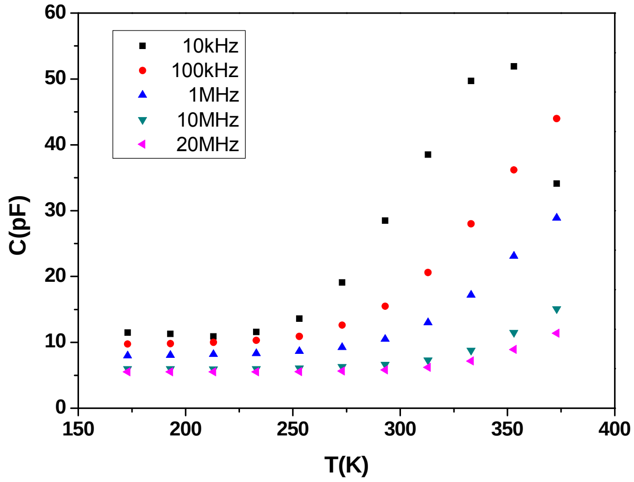

Fig. 2. Temperature dependence of capacitance at different frequencies

3.2. Frequency and temperature dependence of dielectric constant

The variation of dielectric constant ε' with frequency and temperature are shown in Fig. 3 and Fig. 4. The dielectric constant ε' was calculated by using the equation;

$$\varepsilon' = \frac{Cd}{\varepsilon_0 A} \tag{1}$$

where C is the capacitance of the sample, ε_0 the permittivity of the free space and A is the area of the surface of electrodes. The temperature dependent ε' shows similar behavior with C depending on the Equation (1). When the frequency dependence of ε' was investigated, it was observed that ε' decreases, by changing from 900 to 100 for different temperatures, with increasing frequency as shown in Fig. 3. The relaxation regions observed at frequency dependent C plots became more significant in Fig. 3 because the curves at 373 and 173 K were fitted by Cole-Cole equation as representative fits for whole temperature range [17]. Cole-Cole fits show that the relaxation time for the first relaxation region, which is observed at frequencies between 30 kHz and 1 MHz, is at the level of 10^{-6} s while the relaxation time for the second relaxation region which is observed at frequencies between 1 MHz and 20 MHz, is at the level of 10^{-8} s. At all frequencies ε' shows a temperature independent behavior below 250 K and it becomes temperature dependent above 250 K as shown in Fig. 4.

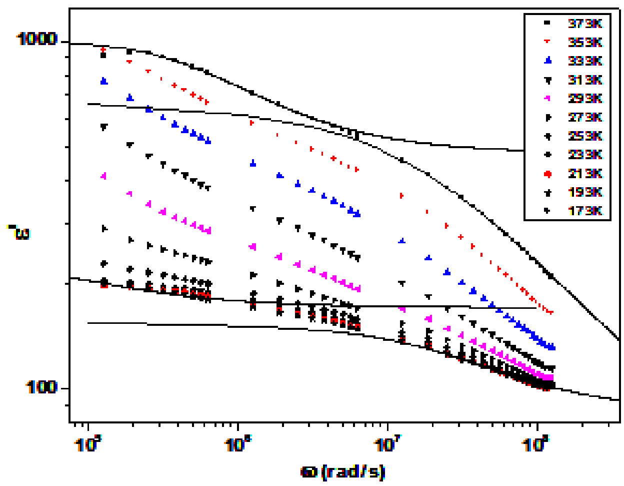

Fig. 3. Variation of the dielectric constant with frequency at different temperatures

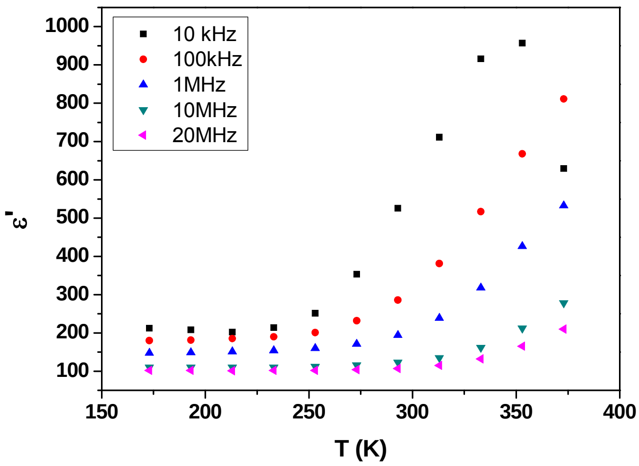

Fig. 4. Variation of the dielectric constant with temperatures at different frequencies

3.3. Frequency and temperature dependence of dielectric loss

The dielectric loss, ε" was derived by equation;

$$tg\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (2)$$

where tanδ is the electric dissipation factor. It is observed that dielectric loss linearly decreases with increasing frequency (Fig. 5) while it increases with increasing temperature as shown in Fig.6. Decreasing of the polarizability of the charges may cause the decreasing dielectric loss. The increase of dielectric loss with temperature may be attributed to the effect of thermal activation to the polarization in structure. This may be attributed to the presence of dipolar polarization.

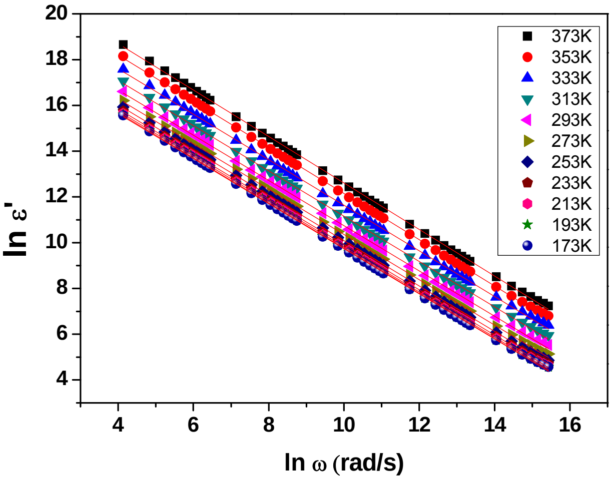

Fig. 5. Variation of the dielectric loss with frequency at different temperatures

Fig. 4 and Fig. 6 show the temperature dependence of the dielectric constant (ε') and dielectric loss (ε'') at different frequencies. As shown in figures, the values of the dielectric constant and dielectric loss is almost temperature independent in the interval 173 - 253 K, while increase with the increasing temperature in the interval 253 -373 K. The increase of the dielectric constant and dielectric loss with temperature may be attributed to orientational polarization related to thermal motion of molecules. When the temperature rises, the dipoles orientation is facilitated and the dielectric constant and dielectric loss increases [18]. The relation between dielectric loss and the angular frequency ω can be observed in equation;

$$\varepsilon''=K\omega^m \qquad (3)$$

where. K is a constant and *m* is the exponent of frequency, the obtained data was plotted as $\ln\varepsilon''$ versus lnω to calculate the value of the exponent m as shown in Fig. 5. According to the Giuntini equation *m* is given as [18]

$$m = -\frac{4kT}{W_m} \qquad (4)$$

where W_m is the maximum barrier height. The power m is obtained from the negative slope of the straight lines of the relationship of $\ln\varepsilon''$ versus lnω as illustrated in Fig. 5. The maximum barrier height W_m was calculated by using the Equation (4) and the temperature dependence of the W_m are shown in Fig. 7.

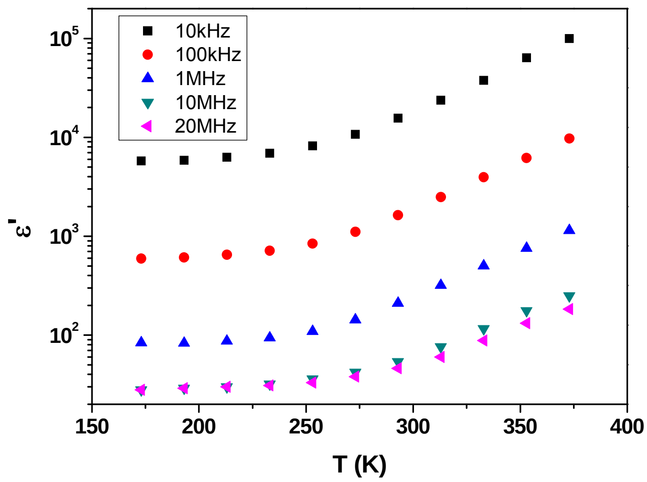

Fig. 6. Variation of the dielectric loss with temperatures at different frequencies

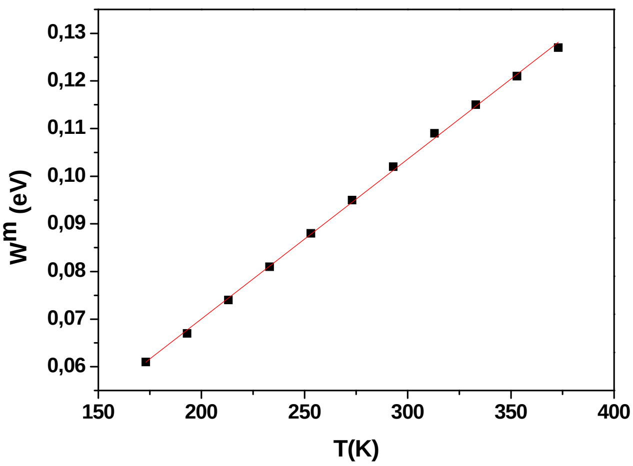

Fig. 7. Temperature dependence of the maximum barrier height

The value of W_m is obtained as 0.10 eV at room temperature for the investigated $TlInSe_2$ compound. As expected from temperature dependent ε' behavior, increasing temperature may help polarized particles to be able to pass through the barrier [16, 20, 21]. Thus, this causes an increase in ε' and ε'' with increasing temperature as obtained

4. Conclusion

Comprehensive studies of the capacitance, the dielectric constant (ε') and dielectric loss (ε'') of $TlInSe_2$ compound have been performed. The capacitance decreases gradually with increasing frequency and increases with increasing temperature. The increase in capacitance with temperature may be due to increase in termal activation of charges. It was shown that $TlInSe_2$ compound exhibits two different relaxation behavior in the investigated frequency and temperature range. These two relaxations may have different dipole moment characteristics since $TlInSe_2$ has a crystal structure [21]. The relaxation which was observed at frequencies between 30 kHz and 1 MHz may arise from dipolar polarization while the relaxation which was observed at frequencies between 1 MHz and 20 MHz may be the result of the electronic polarization. The maximum barrier height is estimated from the data of dielectric loss as 0.10 eV and it was detected that the barrier height increases with increasing temperature [13,16].

Acknowledgments

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