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Dielectric relaxation spectrum of TlSe thin films

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The dielectric properties of TlSe thin films with thickness of 2000 Å, obtained via thermal evaporation of TlSe crystals, have been measured using ohmic Al electrodes in the frequency range 0.2-100 kHz and within the temperature interval 293-353 K. The dielectric constant and the dielectric loss of are found to decrease with increasing frequency and increase with increasing temperature. This behavior is explained two possible polarization mechanisms in the films. From the dielectric constant and the dielectric loss expressions, the distribution of relaxation times was derived. There are two possible relaxation regions in the investigated frequency range.

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Keywords: Relaxation time, TlSe, thin-film, Dielectric properties

1. Introduction

Thallium selenide is an III-VI compound with a body centered-tetragonal (bct) structure. It has been shown that TlSe-type crystals are promising materials in device applications such as near and far-infrared sensors, pressure-sensitive detectors, and gamma-ray detectors [1, 2]. Switching phenomena and low-temperature metallic conductivity in TlSe have been described successfully. Energy band gap varies between 0.6 and 1.0 eV at 300 K [1, 3-6]. It was realized that electrical, optical, electrodynamical, and structural properties of bulk TlSe and compounds including TlSe were studied when literature was detected [1, 3, 6-8]. However, the dielectric properties of TlSe thin films have not been studied in the literature. We want to contribute to the literature by studying the dielectric properties of TlSe thin film depending on frequency and temperature.

2. Experimental details

The TlSe samples were grown as large single crystals by the Stockbarger-Bridgman technique using commercially available stoichiometric amounts of TlSe of very high purity (99.999%). The base and counter Al electrodes, each of approximately 2000 Å thick, were evaporated onto the sample in a 10^{-5} Torr. Thin films of TlSe were deposited on microscope slides under a vacuum of 10^{-5} Torr, by the evaporation technique using a molybdenum boat. The thicknesses of produced TlSe thin films are 2000 Å. Our samples have an Al/TlSe/Al configuration Copper wires fixed by Indium on Al electrodes were used as the electrical ohmic contacts. The average areas of capacitors were measured 6mm × 16mm by using a traveling microscope. The capacitance and dissipation factor of samples were measured using Alpha-A High-Resolution Dielectric, Conductivity and Impedance Analyzer (Novocontrol Technologies) in the frequency range 0.2-100 kHz and in the temperature range 293-353 K.

3. Results and discussion

Frequency and temperature-dependent capacitance (C), dielectric loss factor (tanδ), dielectric constant (κ') and dielectric loss (κ") are presented in Fig. 1a, b, c, and d, respectively. The dielectric constant is 21 at room temperature (293 K). Capacitance and dielectric constant results indicate two relaxation regions. One of these relaxation regions, which is observed at frequencies lower than 100 Hz, is not detected in a complete form. However, the shapes of the behavior of frequency-dependent capacitance and dielectric constant indicate that there is a relaxation toward frequencies lower than the investigated frequency range. This relaxation can not be displayed by the frequency-dependent dielectric loss factor and dielectric loss results, too. The other relaxation region is observed at frequencies higher than 100 Hz.

This relaxation region can be displayed at dielectric loss factor and dielectric loss results. The relaxation peaks which are observed at frequency-dependent dielectric loss factor results in Fig. 1b. Frequency-dependent dielectric loss peaks shift toward high frequencies with increasing temperature as shown in Fig. 1d. Dielectric constant exhibits a step-like decrease because of the multicomponent polarization. This multicomponent polarization may include space-charge polarization, dipolar polarization, ionic polarization and electronic polarization [9-13].

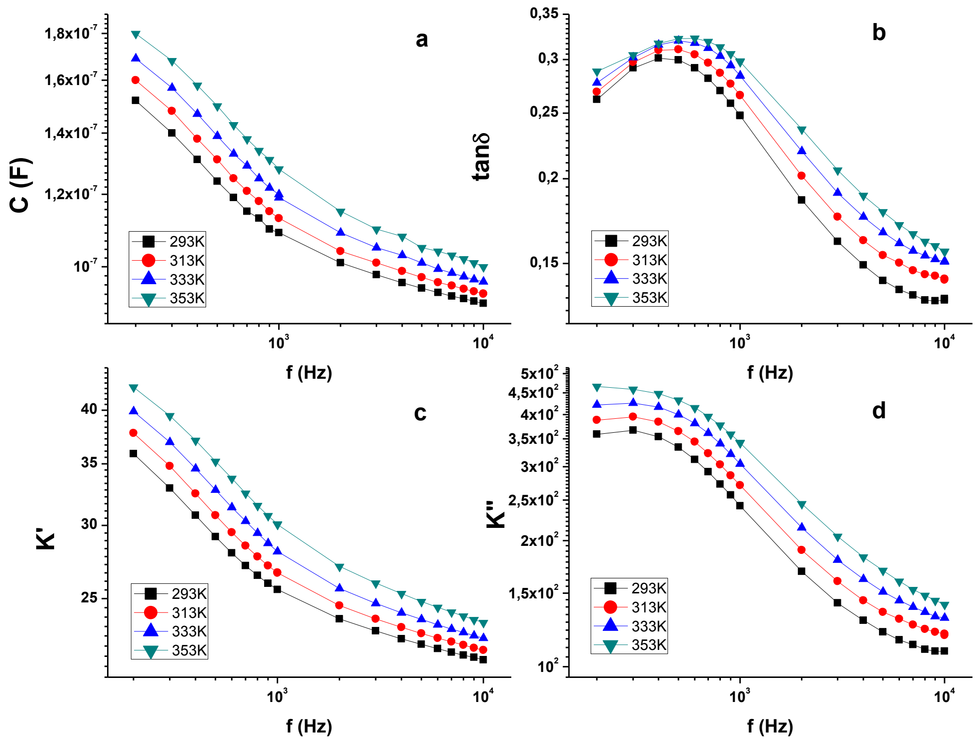

Fig. 1. Frequency and temperature dependence of a) Capacitance, b) Dielectric loss factor, c) The dielectric constant, d) Dielectric loss of TlSe thin films (color online)

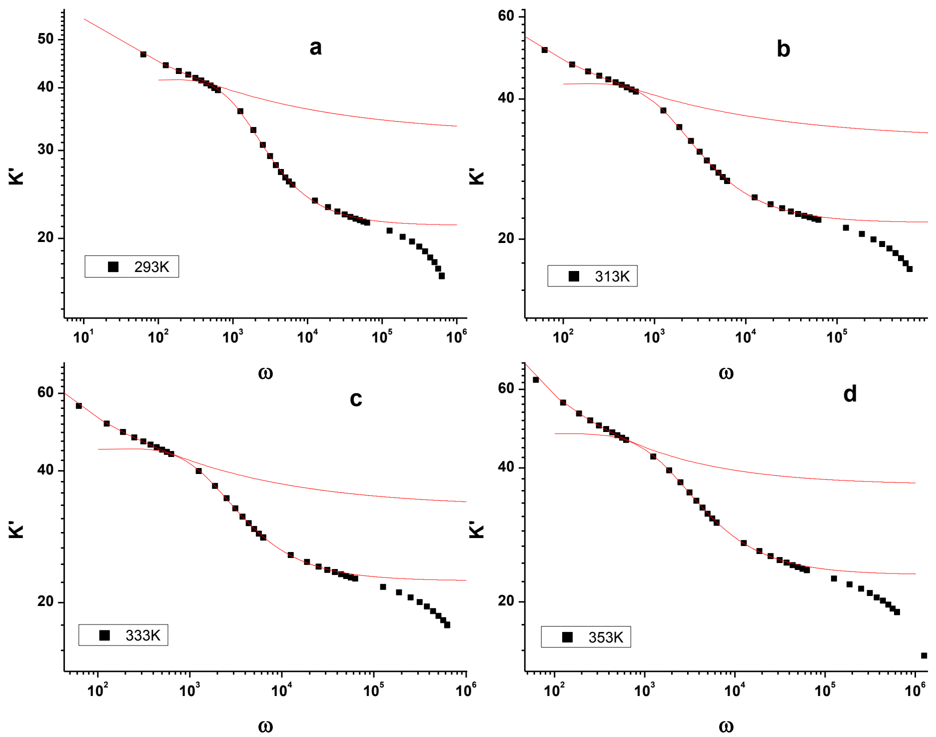

Fig. 2. Cole-Cole fitted dielectric constant of the TlSe thin films versus frequency results at a) 293 K, b) 313 K, c) 333 K, d) 353 K (color online)

The relaxation times were fitted by Cole-Cole equation,

$$\kappa^*(\omega) = \kappa_\infty + (\kappa_s - \kappa_\infty)\frac{1}{1+(i\omega\tau_{cc})^\beta}$$

where κ* is complex dielectric constant, κ_∞ is relative permittivity at high frequencies, κ_s is relative permittivity at low frequencies, ω is angular frequency, τ_{cc} is relaxation time and β is degree of curvation which has values between 0 and 1 [14, 15] Cole-Cole fitted frequency-dependent dielectric constant results at 293 K, 313 K, 333 K, 353 K are shown in Fig. 2a, b, c, d, respectively. It is shown that two relaxation regions are observed in the investigated frequency range. In Fig. 2 the relaxation which is detected at a low-frequency side can be specified well. The dielectric constant belonging to this relaxation can be determined by Cole-Cole equation as 33,7 at 293 K. The dielectric constant slightly increases with increasing temperature until 37 at 353 K. Calculated relaxation times and β values are presented in Table 1.

Table 1. Relaxation times and β coefficients calculated from relaxation behavior observed at frequencies lower than 100 Hz for the dielectric constant of TlSe thin films

Temperature (K)	Relaxation Time (ms)	β
293	0.44	0.8
313	0.442	0.78
333	0.407	0.76
353	0.396	0.72

It is thought that at the low-frequency side of the investigated frequency range, the mechanism may be space-charge [16].

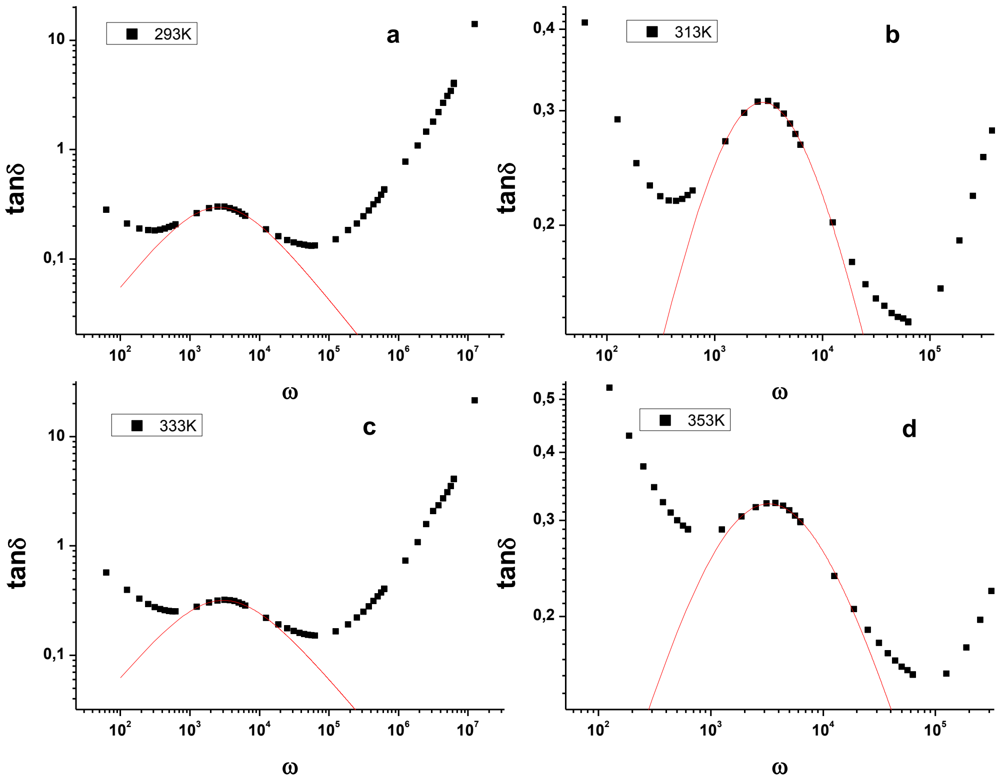

Fig. 3. Cole-Cole fitted dielectric loss factor versus frequency results at a) 293 K, b) 313 K, c) 333 K, d) 353 K (color online)

The relaxation mechanism which is detected at frequencies higher than 100 Hz was observed in frequency-dependent dielectric loss factor behavior as relaxation peaks in Fig. 3 a, b, c, d. The relaxation times calculated from the Cole-Cole equation for frequency-dependent dielectric loss factor results are given in Table 2. The calculated relaxation times are at the same level when compared to the calculated relaxation times from the frequency-dependent dielectric constant in Table 1.

Table 2. Relaxation times and β coefficients calculated from relaxation behavior observed at frequencies higher than 100 Hz for the dielectric constant of TlSe thin films

Temperature (K)	Relaxation Time (ms)	β
293	5.62	0.76
313	0.824	0.88
333	0.735	0.88
353	0.664	0.85

The mechanism at frequencies higher than 100 Hz can be detected at the frequency-dependent dielectric loss factor clearly. This mechanism can be attributed to dipolar polarization [17,18].

4. Conclusion

It was found that the dielectric constant of TlSe thin films was found to decrease with increasing frequency and to increase with increasing temperature. There are two possible relaxation regions in the investigated frequency range. Also, these relaxation regions can be shown at frequency-dependent dielectric loss factor results. These mechanisms can be classified as the mechanism observed at frequencies lower than 100 Hz and the other can be named as the mechanism observed at frequencies higher than 100 Hz. The former can be attributed to space-charge polarization and the second mechanism can be attributed to dipolar polarization.

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