Dielectric Relaxation and AC Conduction of an AgTlSe$_2$ Semiconductor in the Solid and Liquid States

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Abstract. Measurements of the dielectric properties of AgTlSe$_2$ in the solid and liquid states were carried out in a wide range of frequencies and temperatures. The material displayed dielectric dispersion, and a loss peak was observed. Cole-Cole diagrams have been used to determine the distribution parameter ($\alpha$) and the molecular relaxation time ($\tau$). The process of dielectric relaxation (loss) and ac conduction was attributed to the correlated barrier hopping model suggested by Elliott for amorphous solids, where two carriers simultaneously hop over a barrier between charged defect $D^+$ and $D^-$ states.

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Much theoretical and experimental effort has been devoted to the understand of the electronic relaxation phenomena in amorphous and liquid semiconductors. Various models [1–4] have been proposed to explain the conductivity behaviour, and it has been demonstrated that some semiconductors retain their predominantly covalent semiconducting properties in the amorphous and liquid states, whereas other semiconductors acquire metallic properties above the melting point. Measurements of the frequency and temperature dependences of the dielectric properties of amorphous and liquid semiconductors allow to obtain critical information concerning the electronic structure as well as the conduction and relaxation mechanisms.

The aim of the present work is to investigate the dielectric properties and ac conduction of AgTlSe$_2$ ternary semiconductor in the solid and liquid states. AgTlSe$_2$ possesses the chalcopyrite structure [5, 6] and its melting point is 328 °C. Ternary chalcopyrite semiconductors are of technological interest because of their peculiar nonlinear optical properties. They show promise for application in the areas of visible and infrared detection, parametric oscillators and far-infrared generation.

1. Experimental

The samples were prepared by melting the proper amounts of highly pure component elements (99.999 %). The material was sealed in a quartz tube at $10^{-3}$ Pa and heated at 1200 °C for 12 h with frequent rocking to ensure homogenization of the melt. Then the tubes were quenched in ice to obtain the sample in the amorphous state. The solid material is then heated in inert atmosphere until it melts and then transferred to the measuring cell (Fig. 1).

A cylindrical measuring cell was used which consists of two concentric graphite cylinders with $10^{-4}$ m spacing. The cell contains a temperature controlled heater, a chromel-alumel thermocouple for accurate measurements of temperature and was fitted with a guard ring electrode.

Measurements of the dielectric constants were carried out in an inert atmosphere at different frequencies and temperatures using a well shielded ac bridge connected according to the Schering-principle in conjunction with a Farnell ESG2 oscillator, and the sensitive broad-band oscilloscope type Trio CS-1560A was used as a null indicator. Measurements in the low-frequency range (from $10^{-3}$ to 100 Hz) were carried...
out using a low frequency oscillator based on the IC 8038 precision waveform generator. Electrodes were applied in various ways to see whether contacts affected the measurements, and the data were found to be reproducible to better than 2%. Moreover, the results have revealed that the type of the electrode material did not play a substantial role.

2. Theory of Measurements and Experimental Results

Figures 2 and 3 show the frequency dependence of the real part of the dielectric constant $\varepsilon'$ and the dielectric loss (tan$\delta$) at different temperatures. All curves displayed a dielectric dispersion peak and the frequency at the peak maximum shifts towards higher frequencies on increasing the temperature, moreover, the height of the loss peak (tan$\delta$)$_{\text{max}}$ increases with the temperature.

2.1. Distribution Parameter ($\alpha$) and Relaxation Time ($\tau$)

Cole and Cole [7] showed that if a dielectric system has a distribution of relaxation times then the complex plane locus, obtained by plotting $\varepsilon''$ versus $\varepsilon'$, is generally an arc of a circle intersecting the abscissa axis at the values $\varepsilon_\infty$ and $\varepsilon_\alpha$ and having its center lying below the abscissa axis, where $\varepsilon_\alpha$ and $\varepsilon_\infty$ are the static and optical dielectric constants. The diameter drawn through the center from $\varepsilon_\infty$ makes an angle $\alpha\pi/2$ with the $\varepsilon'$ axis; tan($\alpha\pi/2$) being determined from the plots and $\alpha$ is calculated. Knowing $\alpha$, one can determine the