Dielectric Properties and AC Conductivity Measurements of Amorphous Ge_15Se_{85} Glass

Balbir Singh Patial1,*, Neha2, Jai Prakash2, Rajesh Kumar3, S.K. Tripathi4,†, Nagesh Thakur2,4

1 Department of Physics, Rajiv Gandhi Govt. College Chaura Maidan (Kotsera) Shimla, 171 004, H.P., India
2 Department of Physics, H.P. University Summer Hill Shimla, 171 005 H.P., India
3 Department of Physics, Jaiyee University of Information Technology, Waknaghat 172215 H.P., India
4 Centre of Advanced Study in Physics, Panjab University Chandigarh, 160 014, India

(Rceived 15 February 2013; revised manuscript received 28 April 2013; published online 04 May 2013)

In the present study, investigations of dielectric parameters viz dielectric constant \(\varepsilon'(\omega)\), dielectric loss \(\varepsilon''(\omega)\) and AC conductivity measurements have been made for bulk chalcogenide Ge_{15}Se_{85} glass in the frequency range 10 to 500 kHz within the temperature range from 300 to 390 K. The variation of dielectric constant and dielectric loss with frequency at room temperature is reported and discussed in the investigated glassy binary alloy.

**Keywords:** Chalcogenide semiconductors, Dielectric constant, Dielectric loss, AC conductivity.

PACS numbers: 78.20.Ci, 77.22.Gm, 73.61.Jc

1. INTRODUCTION

Great consideration has been given to chalcogenide glasses in last two decades because of their potential applications in various solid state devices both in scientific and technological fields. Among the amorphous chalcogenide alloys, mostly selenium (Se) based materials are preferred due to its commercial use and technological importance. But in pure state it has disadvantages because of its short life time and low sensitivity [1]. The problem can be overcome by alloying selenium with some impurities such as Ge, Te etc which in terms gives high sensitivity, greater hardness, high crystallization temperature and small ageing effects as compared to pure Se glass [2].

Ge-Se glasses have been widely studied due to their extended amorphization composition range [3]. The fact that bulk glasses are easily obtained, makes Ge-Se system an ideal one to investigate a great variety of properties and their correlation with structure and composition. This system is extensively studied and glass formation in this system occurs predominantly in alloys enriched with Se and containing 0 to 25 at. % of Ge [4]. Furthermore, addition of Ge into the polymeric Se matrix produces a cross linking of selenium chain, mediated by the formation of Ge(Se)4 tetrahedral units [5]. At low doping \((x < 15 \text{ at. %})\), the tetrahedral units are sparsely distributed in the background matrix, with rather flexible interconnections. By \(x = 15 \text{ at. %}\), the amount of Ge becomes sufficient to join some of the tetrahedral pairs by corner sharing [6].

Chalcogenide glasses in Ge-Se system are used as switching, memory elements and optoelectronic devices and are interesting material for infrared optics too. It has been observed that the addition of the third element to Ge-Se system effectively controls its electrical, optical, thermal, dielectric and physical properties. Moreover, Ge-Se system has drawn more attention as some metallic additives have been found to change the conduction type from \(p\) to \(n\) in these glasses.

Structural studies of these glasses are very important for better understanding of transport mechanisms. The study of dielectric properties of chalcogenide glasses is predictable to reveal structural information, which in fact, can be useful for the understanding of conduction mechanism in these materials. In addition, study of temperature and frequency dependence of dielectric parameters, particularly in the range of high frequency where the dielectric dispersion occurs can be of utmost importance for the understanding of the nature as well as the origin of the various losses happening in these materials.

In the present work, we have reported and discussed the temperature and frequency dependence of dielectric properties as well as AC conductivity measurements of glassy Ge_{15}Se_{85} alloy. Studies of AC conductivity and dielectric properties of Ge-Se system are rare and have not attracted much interest. Therefore, the aim of this work is to analyze the frequency and temperature dependence of the AC conductivity \(\sigma_{AC}(\omega)\), the dielectric constant \(\varepsilon'(\omega)\) and the dielectric loss \(\varepsilon''(\omega)\) for the amorphous Ge_{15}Se_{85} chalcogenide glass.

2. EXPERIMENTAL DETAILS

Glassy alloy of Ge_{15}Se_{85} has been prepared using the melt quenching technique. 5N highly pure materials (99.999 %) are weighed according to their atomic percentages and sealed in a quartz ampoule (length ~ 5 cm, diameter ~ 12 mm) under a vacuum of \(\sim 2 \times 10^{-5} \text{ mbar}\). The sealed ampoule has been kept inside a furnace where the temperature is raised to 1000 °C at a rate of 3-4 °C/min. The ampoules are rocked frequently for 24 h at maximum temperature to make the melt homogeneous. The quenching is done in the ice cooled water very rapidly to prevent crystallization. The amorphous nature of the glassy alloy has been verified by X-ray diffraction. Fig. 1 shows the XRD pattern for Ge_{15}Se_{85}.  

---

1 bspatial@gmail.com
2 surya@pu.ac.in
3 ntb668@yahoo.com
observed that the dielectric constant decreases with the frequency. This decrease is fast at low frequency as compared to higher frequency that may be due to the electrode polarization effects [10, 11]. The decrease of $\varepsilon'$ with frequency can be attributed to the fact that at low frequency, $\varepsilon'$ for polar material is explained by the contribution of multi-component of polarization viz electronic, ionic, dipolar or orientation and space charge [12]. Thus, the total polarization ($P$) of the dielectric material can be represented as the sum of these four polarizations [13]:

$$P = P_\varepsilon + P_i + P_d + P_s$$  \hspace{1cm} (3)

Dielectric materials exhibit at least one of these polarization types. This depends on the bonding and structure of the material and frequency [14].

Fig. 3 shows the temperature dependence of the dielectric constant $\varepsilon'(\omega)$ at different frequencies. It indicates that there is an increase in the dielectric constant with temperature. The increase in the dielectric constant of the sample may be attributed to the electric field which is accompanied by the applied frequencies. Such field will cause some ordering inside the sample as well as the formation of an electric moment in the entire volume of the dielectric and in each separate polarizing molecule. The molecular dipoles in polar material cannot orient themselves at low temperature. When the temperature rises, the dipoles orientation is facilitated and the dielectric constant increases. As the frequency is increased, the variation in the field become too rapid for the molecular dipoles to follow, so that their contribution to polarization becomes less with a measurable lag because of internal frictional forces [15].

3.1.2 Temperature and Frequency Dependence of the Dielectric Loss ($\varepsilon''$)

The variation of dielectric loss $\varepsilon''(\omega)$ with frequency at room temperature is shown in Fig. 4. It is obvious from Fig. 4 that the dielectric loss also follows the same trend as followed by the dielectric constant $\varepsilon'(\omega)$. The decrease in the dielectric loss with frequency in the investigated system may be attributed to the fact that
the migration of the ions in the glass is the main source of the dielectric loss at low frequencies. Therefore, dielectric loss at low and moderate frequencies is characterized by the higher values of $\varepsilon''(\omega)$ due to the contribution of ion jump and conduction loss of ion migration in addition to the ion polarization. However, at higher frequencies, the ion vibrations may be the only source of dielectric loss. So, $\varepsilon''(\omega)$ decreases at higher values of frequency [16].

The variation in the dielectric loss $\varepsilon''(\omega)$ as a function of temperature at different frequencies is also shown in Fig. 4 which illustrates that $\varepsilon''(\omega)$ exhibits temperature dependence and is found to be more at low frequencies. The origins of dielectric loss are conduction losses, dipole losses and vibration losses [17]. As the temperature increases, the electrical conduction losses increase with further increasing of the dielectric loss $\varepsilon''(\omega)$.

The dielectric loss is also given by the following empirical relation [16]:

$$\varepsilon'' = B\omega^m$$

(4)

where $B$ is a constant and $m$ is a power of angular frequency. The plot between $\ln(\varepsilon'')$ and $\ln(\omega)$ should be a straight line and the slope of the plot enables us to obtain the value of $m$ (Fig. 6). The value of the exponent $m$ obtained from the negative slope of Fig. 6 is found to be negative ($m = 0.55691$ at $T = 298$ K) in the studied sample which is consistent with earlier values of $m$ obtained for the other chalcogenide glasses [18].

According to Guintini et al. [19] model for dielectric dispersion in chalcogenide glasses based on the Elliot’s idea [20], the dielectric loss at a particular frequency is given by:

$$m = -\frac{4kT}{W_m}$$

(6)

where $W_m$ is the maximum barrier height i.e. the energy required to move the electron from a site to infinity and is found equal to 0.18 eV for the present investigated Ge$_{15}$Se$_{85}$ glassy alloy.

The AC conductivity of the studied sample has been deduced from the data of dielectric constant $\varepsilon'(\omega)$ and loss factor $\tan\delta$ using the following relation:
σ_{ac} = \varepsilon' \varepsilon_0 \omega \tan \delta, \quad (7)

where symbols have their usual meaning.

A common feature to all the amorphous semiconductors is that AC conductivity \( \sigma_{ac}(\omega) \) changes with frequency according to the following relation [21]:

\[ \sigma_{ac}(\omega) = A_\omega \omega^s, \quad (8) \]

![Fig. 7 – Variation of AC conductivity \( \sigma_{ac}(\omega) \) with temperature at different frequencies for chalcogenide \( \text{Ge}_{10}\text{Se}_{85} \) glass](image)

where \( A_\omega \) is a constant dependent on temperature, \( \omega \) is the angular frequency and the exponent \( s \) denotes the frequency dependence of \( \sigma_{ac} \) and it is generally less than or equal to unity and is found equal to 0.45 in the studied glass. Fig. 7 shows the frequency dependence of \( \sigma_{ac}(\omega) \).

Fig. 7 shows the variation of AC conductivity as a function of reciprocal temperature at different frequencies. This figure depicts the temperature independence and the frequency dependence of \( \sigma_{ac}(\omega) \) in the investigated temperature and frequencies ranges for the studied chalcogenide alloy. It indicates that \( \sigma_{ac}(\omega) \) is not thermally activated in this range of temperature.

4. CONCLUSIONS

Dielectric properties and conductivity measurements have been made for \( \text{Ge}_{10}\text{Se}_{85} \) glassy alloy at different frequencies and temperature. Dielectric constant and dielectric loss are found to decrease with frequency at room temperatures in the studied system. The AC conductivity measurements shows that \( \sigma_{ac}(\omega) \) is independent of temperature. However, it is found to vary with different frequencies in the temperature and frequency range of the investigated binary alloy.

REFERENCES