International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Research Article

The Mechanisms of AC-conductivity for $Ge_{0.4}Te_{0.6}$ Thin Films

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Accepted 01 March 2014, Available online 01 April 2014, **Vol.4, No.2 (April 2014)**

Abstract

The $Ge_{0.4}Te_{0.6}$ alloy has been prepared. Thin films of $Ge_{0.4}Te_{0.6}$ has been prepared via a thermal evaporation method with 4000A thickness, and rate of deposition (4.2) A/sec at pressure $2x10^{-6}$ Torr. The A.C electrical conductivity of a-$Ge_{0.4}Te_{0.6}$ thin films has been studied as a function of frequency for annealing temperature within the range (423-623) K, the deduced exponent s values, was found to decrease with increasing of annealing temperature through the frequency of the range (10^{2}-10^{6}) Hz. It was found that, the correlated barrier hopping (CBH) is the dominant conduction mechanism. Values of dielectric constant ε_1 and dielectric loss ε_2 were found to decrease with frequency and increase with temperature. The activation energies have been calculated for the annealed thin films.

Keywords: *AC-conductivity, $Ge_{0.4}Te_{0.6}$, thin films, dielectric constant, polarization.*

1. Introduction

Chalcogenide glasses are sensitive to the absorption of electromagnetic radiation and show a variety of photoinduced effects. These properties show potential for numerous applications in active and passive optics (Mikhail Kibalchenko *et al*, 2010).

Recently, chalcogenide materials have attracted great attention as phase-change random access memory (PRAM) devices are regarded to be a strongly promising candidate for the next generation nonvolatile memory (Doo Seok Jeong *et al*, 2011).

Amorphous materials can be electrically insulating, semiconducting or metallic in nature. Amorphous semiconductors have attracted immense interest in the field of phase change memory (PCMs) applications due to their electrical and optical properties and are potential candidates for many commercial applications. Phase change memories based on chalcogenide glasses have been found to be suitable candidates for replacing the conventional flash non-volatile random access memories (NVRAMS).They exhibit two types of switching behaviour; threshold and memory switching, and this switching behaviour is central to their technological importance and their uses as memories (Mohammad Mahbubur Rahman *et al*, 2013).

The studying of ac-conductivity $\sigma_{a.c}$ (w) gives us information about the nature of the conduction mechanisms in a material. This conductivity $\sigma_{a.c}(\omega)$ can be represented by the empirical formula which follows a power low of the forms (A. M. Badr *et al*, 2011):

$$\sigma_{a.c}(\omega) = A\,\omega^{s} \qquad (1)$$

Where, the frequency exponent lies in the range 0<s<1. The equation (1), can write the exponent s as follows:

$$s=d(\ln\sigma(w)/d(\ln\omega)) \qquad (2)$$

Where ω: is the angular frequency.
A study of the frequency and temperature dependence of dielectric losses should provide information on relaxation processes. In the presence of relaxation effects, the dielectric constant may be given by:

$$\varepsilon^*(\omega)=\varepsilon_1(\omega)+i\varepsilon_2(\omega) \qquad (3)$$

Where $\varepsilon_1(\omega)$: the real part of the complex dielectric (dielectric constant) and $\varepsilon_2(\omega)$ is the imaginary part (dielectric loss factor). The real part or dielectric constant could give by:

$$\varepsilon_1(\omega)=tC/a\,\varepsilon_o \qquad (4)$$

Where (ε_o) is permittivity of the space ($8.854x10^{-12}Fm^{-1}$), (a) is the effective electrode area, and (C) is the capacitance of the sample and the imaginary part is given by:

$$\varepsilon_2(\omega)= \sigma(\omega)/\varepsilon_o\,\omega \qquad (5)$$

We can get $\sigma_{a.c}(\omega)$ by (M.I.Mohammed *et al*, 2002).

$$\sigma_{a.c.}(\omega) = t/A.R \qquad (6)$$
$$\tan\delta= \varepsilon_2(\omega)/\varepsilon_1(\omega) \qquad (7)$$

Where f is the measuring frequency of the applied ac electric field (Hz) and tanδ is the dissipation factor that

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describes the phase difference between the current and voltage with respect to the applied ac electric field.

The dependence of a.c. conductivity σa.c. on temperature is usually obey the well-known relation (M.I.Mohammed *et al*, 2002):

$$\sigma_{a.c.} = \sigma_o \exp(-\Delta E / KT) \qquad (8)$$

Where σ_o, is constant, ΔE is the activation energy, T is the absolute temperature and K is Boltzmann constant.

2. Experimental parts

An alloy of $Ge_{0.4}Te_{0.6}$ has been prepared in evacuated quartz tube by the melt quenching technique from elements of high purity (99.999%).

The $Ge_{0.4}Te_{0.6}$ thin films deposited via the thermal evaporation method onto glass substrate at room temperature of 4000Ȧ and rate of deposition (4.2) Ȧ /sec.

The $Ge_{0.4}Te_{0.6}$ thin films were prepared in sandwich configuration between two Al electrodes.

For A.C. measurement we used HP.R2C unit, models 4274 A and 4275 A, and multifrequency LRC meter to generate a.c current in the frequency of the (10^2-10^6) Hz. The prepared thin films were annealed at 423,523 and 623K for 1/2 hour.

3. Results and conclusions

In this work we report the frequency and temperature dependent of ac conductivity of $Ge_{0.4}Te_{0.6}$ thin films in frequency of the range (10^2-10^6) Hz.

3.1 frequency and temperature dependence of A.C conductivity

Fig. (1) Show the variation of ac conductivity σ (ω) as a function of frequency of $Ge_{0.4}Te_{0.6}$ thin films at various annealing temperature Ta=423,523 and 623K.

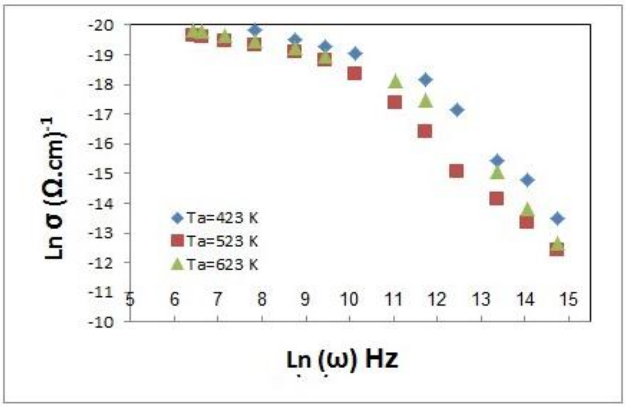

Fig.1 Frequency dependence of $\sigma_{a.c}$ conductivity for annealed $Ge_{0.4}Te_{0.6}$ thin films at various temperatures.

This figure reveals that ln $\sigma_{a.c.}(\omega)$ which represented in equation (1) increases linearly with ln(ω) at different annealing temperature in the range from 423K to 623K. The power law dependence of ac conductivity is of a universal nature and corresponds to short range hopping of charge carriers through trap sites separated by energy barriers of varied heights. Each pair of potential well corresponds to a certain time constant of transition from one site to another.

We can notice from Fig.(1) that ac-conductivity dominates at higher frequency than at the lower values, which means that the $\sigma_{a.c.}$ conductivities increases with increasing frequency.

The phenomenon has been ascribed to relaxations caused by the motion of electrons or atoms. Such motion can involve hopping or tunneling between equilibrium sites (S.R. Elliott, 1987).

The values of the frequency exponent s which presented in equation (2) were estimated from the slope of straight lines in Fig. (1).

The annealing temperature dependence of the s for investigated films is shown in table (1):

Table1 Represented the s values versus annealing temperature

	Annealing temperature (K)		
	423 K	523K	623K
s	0.899	0.896	0.873

It observed from table (1) that is a little difference between the calculated values of s, this may be due to the hopping process, also its values decreases with increasing annealing temperature.

In most chalcogenide semiconductors the values of s from 0.7 to 1.0 at room temperature, and showed a tendency to decrease with increasing temperature. Therefore, the CBH has been extensively that the obtained experimental results agree with CBH in some values of annealing temperature of charge carriers across the defect state D^+ and D^- (H. E. Atyia *et al*, 2008).

According to Ghintini model (J.C.Giuntini *et al*, 1981), each pair of D^+ and D^- assumed to form a dipole with relaxation energy this type of energy can be attributed to the existence of a potential barrier over which the carriers hop (H. E. Atyia *et al*, 2008).

Fig.(2) show the variation of capacitance with frequency at various annealing temperatures in the range (423-623) K. the capacitance initially decreases rapidly with increasing frequency.

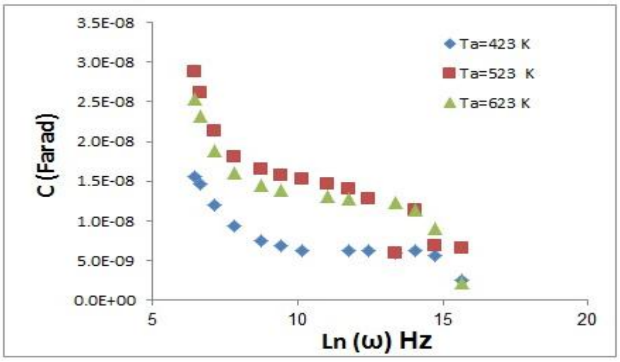

Fig.2 Dependence of the capacitance on frequency at different annealing temperatures.

3.2 Frequency and temperature dependence of the dielectric constant ε_1

Dielectric analysis measures the electric properties of a material as a function of temperature and frequency. It measures two fundamental electrical characteristic of materials: the capacitive (insulating) nature, which represents its ability to store electric charge, and the conductive nature, which represents its ability to transfer electric charge. The variation of the dielectric constant ε_1 with frequency and temperature was studied for the investigated film.

Fig.(3) represents the frequency dependence of the dielectric constant ε_1 for different annealing temperature, it is observed that ε_1 decreases with frequency and increases with temperature for the range of frequencies (100 Hz- 20000 Hz). After this range the behavior was changing to inverse behavior.

The decrease in ε_1 with increasing frequency can be attributed to the contribution of the many components of polarization, electronic, ionic, dipolar or orientation and space charge. First, valance electrons relative nucleus. This type of polarization occurs at frequencies up to 10^{16} Hz. Second, ionic polarization occurs due to the displacement of negative and positive ions with respect to each other.

The maximum frequency of ionic polarization is 10^{13} Hz. Third, dipole polarization occurs as a result of the presence of molecules with permanent electric dipole moments that can change orientation into direction of the applied electric filed. Dipole polarization occurs at frequencies up at about 10^{10} Hz. Finally, space-charge polarization occurs due to impedance mobile charge by interface. Space-charge polarization typically occurs at frequencies between 1 and 10^3 Hz. The total polarization of dielectric material can be represented by the sum of these four polarizations (M.W Barsoum, 1977).

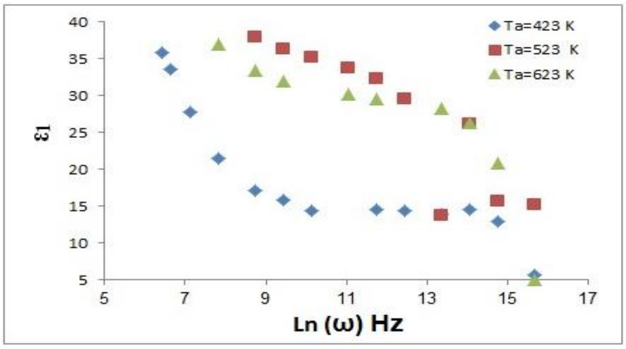

Fig.3 Frequency dependence of the dielectric constant $\varepsilon_1(\omega)$ for $Ge_{0.4}Te_{0.6}$ films at different annealing temperature.

3.3 Frequency and temperature dependence of the dielectric constant ε_2

Fig.(4) shows the frequency dependence of dielectric loss ε_2 at different annealing temperatures. it can be noticed from the figure that ε_2 decreases with increasing frequency and increases with temperature throughout the range (100 Hz- 20000 Hz) of frequency and temperature, then the behavior change to inverse behavior.

The increase of ε_2 with increasing temperature can be interpreted on the basis of the relaxation phenomena, which is divided into three parts; conduction loss, dipole loss and vibration loss. The losses that are attributed to conduction presumably involve the migration of ions over a large distance. This motion is the same as that occurring under direct current conditions. The ions jump over the highest barriers in the network. As the ions move, they impart some of the energy to the lattice as heat and the amount of heat lost per cycle is proportional to $\sigma_{a.c}(\omega)$ (J. M. Stevels, 1957) . At low temperature values, conduction losses, dipole losses and vibration losses have minimum values. However, at higher temperatures, conductions, dipole and vibration losses all contribute to the dielectric loss. This will lead to an increase in ε_2 with increasing temperature.

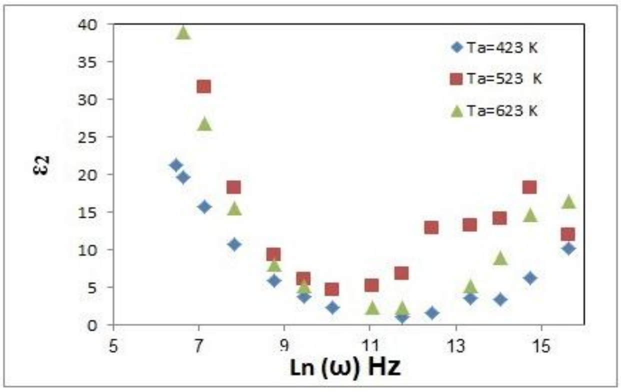

Fig.4 Frequency dependence of the dielectric constant $\varepsilon_2(\omega)$ for $Ge_{0.4}Te_{0.6}$ films at different annealing temperature.

3.4 Temperature and frequency dependence of loss tangent

Fig.(5) shows the frequency dependence of loss tangent (tan δ) at different temperatures for a typical film of thickness 230 nm. Tan d has been found to increase with frequency at different temperatures, pass through a maximum value $(\tan \delta)_{max}$ and thereafter decreases.

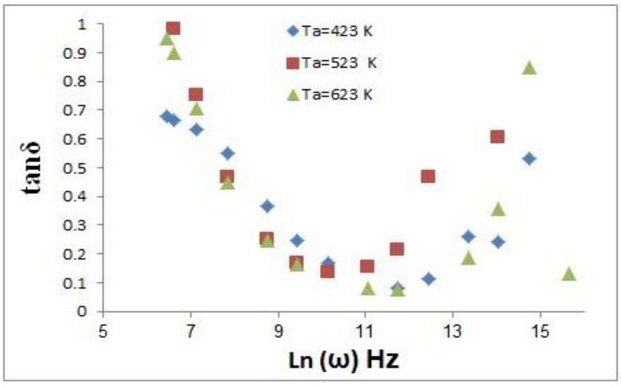

Fig.5 Plot of tanδ against frequency at different annealing temperature.

As the temperature is increased, the frequency at which (tan δ)$_{max}$ occurred shifted to higher frequencies. This type of behaviour is similar to that described by Simmons (Safa'a M. Hraibat *et al*, 2013) for films having parallel RC elements of the materials in series with a parallel combination of Schottky barriers capacitance and resistance.

Fig.(6) shows the variation of ln $\sigma_{a.c}(\omega)$ versus 1000/T (K^{-1}) for $Ge_{0.4}Te_{0.6}$ thin films at different values of frequency, the same behavior was observed in all the samples, From the figure we can deduced that $\sigma_{a.c}(\omega)$ increases non-linearly with temperature especially at a high frequency, i.e., the obtained curves are composed of two regions. One shows weak temperature dependence and other shows strong temperature dependence. The weak temperature dependent mechanism may be attributed to the bipolaron hopping between D^+ and D^- centers around the Fermi level (S.R.Elliott, 1978).

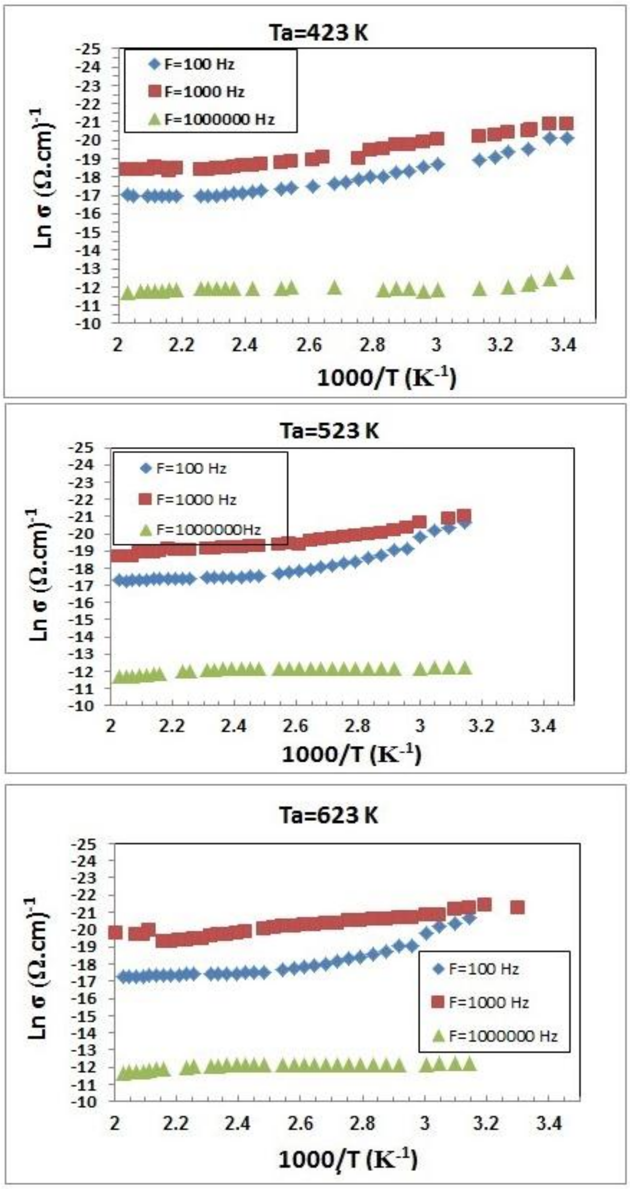

Fig.6 Variation of ln σ_{ac} (ω) versus 1000/T for $Ge_{0.4}Te_{0.6}$ thin films for different frequencies

It is clear that at low temperatures and frequencies the conductivity is frequency dependent; however, with increasing temperature the conductivity becomes frequency independent, remaining almost constant throughout the entire frequency range. The strong temperature dependence may be due to the increase of the density of neutral defects D^o (single-polaron states) at a higher temperature. The contribution to σ_{ac} (ω,T) from (CBH) of single polarons exceeds that of bipolarons at a high temperature (Sevi Murugavel and Manisha Upadhyay, 2011), i.e. the CBH of single polarons is then the predominant contribution to the AC conduction at higher temperature.

The deduced values of activation energy reported in table (2) for various values of annealing temperature.

The activation energy decreases with increasing frequency. The low value of the ac activation energy and the increase of $\sigma_{ac}(\omega)$, with the increase of frequency confirm that hopping conduction is the dominant current transport mechanisms. Thus, the increase of the applied frequency enhances the electronic jumps between the localized states; consequently, the activation energy ΔE, decreases with increasing frequency (M.S. Hossaina *et al*, 2008).

Table 2 Values of $E_{a.c}$(eV) as a function of frequency for fixed annealing temperature

		$E_{a.c}$(eV)		
Ta (K)		423K	523K	623K
F(Hz)	10^2Hz	0.194	0.211	0.211
	10^3Hz	0.164	0.156	0.121
	10^6Hz	0.044	0.0350	0.0350

Conclusions

$Ge_{0.4}Te_{0.6}$ thin films were prepared by thermal evaporation technique. Experimental results of the AC conductivity of the studied films seem to be frequency and temperature dependence.

The values of the frequency exponent s are found to be temperature dependent, decreasing with increasing temperature. This confirmed the applicability of the CBH model. Both dielectric constant ε_1 and the dielectric loss ε_2 increased with temperature and decreased with frequency within the range (100 Hz-20000 Hz).

The activation energy decreases with increasing frequency. And the increase of $\sigma_{ac}(\omega)$, with the increase of frequency confirm that hopping conduction is the dominant current transport mechanisms.

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