International Research Journal of Engineering Science, Technology and Innovation (IRJESTI) Vol. 1(5) pp. 122-129, August 2012
Available online http://www.interesjournals.org/IRJESTI

Full Length Research Paper

Effect of thickness and annealing temperature on the electrical properties of Tellurium thin films

Mahdi H. Suhail*[1], Souad G. Kaleel and Marwa R. Fahad

[1]Dept. of Physics, College of Science, Univ. of Baghdad
[2]Dept. of Physics, College of Science for women, Univ. of Baghdad

Accepted 03 August, 2012

Semiconducting properties of evaporated tellurium thin films, in the thickness range of 100 to 400 *k* are studied and correlated with observed electrical properties. The electrical properties of the Te films at room temperature with rate of deposition equal to 80 nm/sec for different thicknesses (400, 600 and800)nm and different annealing temperatures (373and 423)K were studies. The conductivity of Te films with different thicknesses and annealing temperatures has been investigated as a function of frequency and temperatures. The type of charge carriers, carrier concentration (n_H) and Hall mobility (μ_H) have been estimated from Hall measurements.

Keywords: Tellurium, Thin films, Electrical properties, Hall measurements.

INTRODUCTION

Tellurium thin films have been extensively used in various technological areas, especially in microelectronic devices such as gas sensor (Tsiulyanu et al., 2004; Shashwati et al., 2004; Tsiulyanu et al., 2001), optical information storage (Josef et al., 2004) and other applications (Lozzi et al., 1996; Lozz et al., 1995; Lozz et al., 1995). All these applications are due to remarkable physical properties of Te such as low band-gap and transparency in the infrared region.

The chalcogenide glasses exhibit many interesting properties, such as photo darkening, photo doping, photo crystallization and photoconductivity (Owens et al., 1985). The photoconductivity is very helpful in understanding the phenomenon of recombination kinetics, and the nature and distribution of localized states in the forbidden energy gap. Moreover, the photosensitivity and photogeneration of the charge carriers and their transport in the medium can also be determined.

Chalcogenide glasses are normally p-type semiconductors owing to the fact that the number of electrons excited above the conduction band mobility edge is smaller than the number of holes excited below the valence band mobility edge (Mott and Davis, 1979). These systems also contain positively and negatively charged defect states, known as valence alternation pairs (VAPs) (Kastner et al., 1976; Katner, 1978), which essentially pin the Fermi level at the middle of the band gap making them rather insensitive to doping (Adler and Yoffa, 1976).

The present paper reports the effect of thickness and annealing temperature on the electrical properties of Tellurium thin films prepared by vacuum evaporation

Experimental

Tellurium thin films were prepared by thermal evaporation technique in vacuum system supplied by Blazers Model [BL510]. The system is pumped down to a vacuum of 10^{-5} mbar, an electric current was passed through the boat gradually to prevent breaking the boat, when the boat temperature reached the required temperature the deposition process starts with constant deposition rate. After these steps the current supply was switched off and the samples were left in the high vacuum, and then the air was admitted to the chamber, and the films were taken out from the coating unit and kept in the vacuum desiccators until the measurements were made. All the samples were prepared under constant conditions (pressure, substrate temperature and rate of deposition80 nm/s); the main parameters that control the

*Corresponding Author E-mail: mhsuhail@yahoo.com

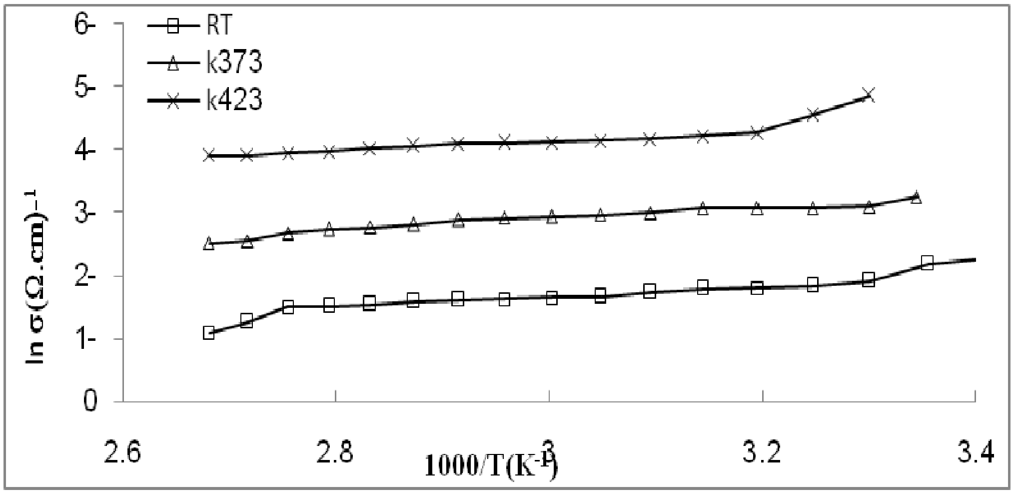


Figure 1. the plots of lnσ vs.1000/T for Te at thickness400nm and different annealing temperature

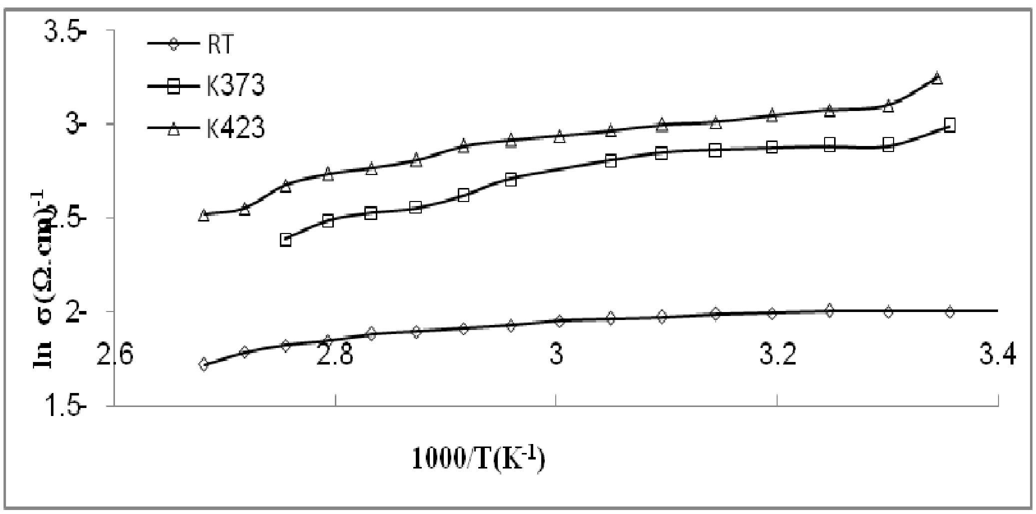


Figure 2. the plots of lnσ vs.1000/T for Te at thickness500nm and different annealing temperature

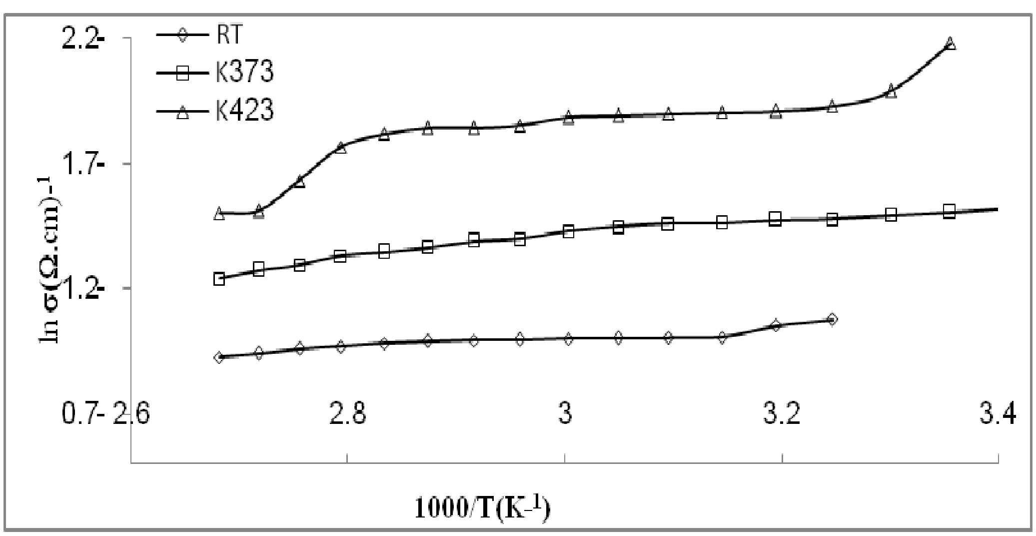


Figure 3. the plots of lnσ vs.1000/T for Te at thickness600nm and different annealing temperature

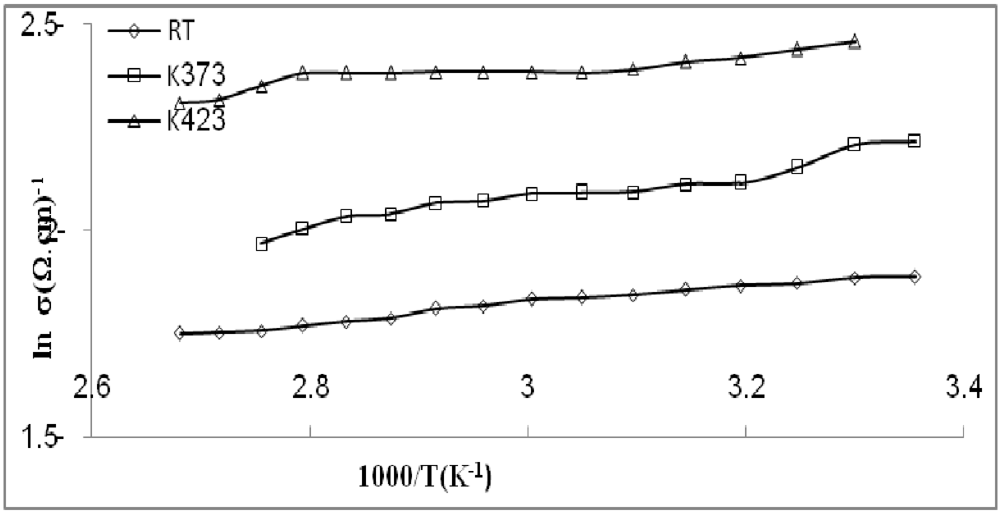


Figure 4. the plots of lnσ vs.1000/T for Te at thickness700nm and different annealing temperature.

nature of the film properties are thickness (400,500,600and700) nm and annealing temperature (373and 423) K. The electrical conductivity has been measured as a function of temperature for Te films over the range R.T-423K by using the electrical circuit. The measurements have been done using sensitive digital electrometer type keithley (616) and electrical oven. An HP-R2C unit model (4275 A) multi frequency LCR meter has been used to measure the capacitance (C) and resistance (R) with frequency range between 120Hz-10 kHz, with an accuracy of 0.1%. Ac instrument is shielded by the copper sheet to avoid the distortion signal, and to prohibit the connectors among the experimental portion from becoming a source of noise by using coaxial cables and BNC connectors were used. The resistivity (ρ) of the films is calculated from $\rho = \frac{R.A}{L}$, Where R is the sample resistance, A is the cross section area of the films and L is the distance between the electrodes.

The activation energies could be calculated from the plot of lnσ versus 1000/T according to equation $\sigma=\sigma_o \exp(-E_a/K_BT)$. The Hall Effect is used to measure certain properties of semiconductors: namely, the carrier concentration, the type ($R_H = \frac{1}{p \cdot q}$ and $R_H = \frac{-1}{n \cdot q}$ for n and p –type respectively) and the mobility ($\mu_H = | R_H | \sigma$).

RESULTS AND DISCUSSION

The electrical properties (include the d.c conductivity from which the transport mechanism of the charge carriers can be estimated and the Hall Effect which gives information about the type, density and mobility of carriers) of Te films which are deposited on glass substrate at room temperature for different thicknesses and heat treatment at different annealing temperatures will be presented.

D.C conductivity of Te Films

In order to study the conductivity mechanisms, it is convenient to plot logarithm of the conductivity (ln σ) as a function of 1000/T for Te films over the range 293–373K for different thicknesses (400,500,600 and 700) at different annealing temperature(373 and 423) as shown in Figures 1,2,3 and 4 respectively .

It is clear from these figures that there are two transport mechanisms, giving rise to two activation energies E_{a1} and E_{a2}. At higher temperature (range (343-373) K) the conduction mechanism is due to carrier excited into the extended states beyond the mobility edge and at lower temperature (range (293-343) K) the conduction mechanism is due to carrier excited into localized states at the edge of the band (Mott and Davis EA, 1979).

Figures (1-4) shows the relation between the conductivity and film thickness at different annealing temperatures. It is clear that $\sigma_{R.T}$ decreases with increasing annealing temperatures; this is probably caused by rearrangement that may occur during annealing, which produce an irreversible process in conductivity, so annealing may be reduced the density of states, structural defects and eliminated tails in the band gap improved the structure of films, elimination of voids and reduction of dangling bond concentration.

There is an increasing in the value of conductivity at room temperature when film thickness increases from 400nm to 700nm. This is probably attributed to expected

Table 1. D.C conductivity parameters for Te films at different thicknesses and annealing temperatures

Thickness (nm)	T_a (K)	(293 –343)K E_{a1} (eV)	(343 –373)K E_{a2} (eV)	$\sigma_{R.T} \times 10^{-6}$ $(\Omega.cm)^{-1}$
400	R.T	0.0619	0.0683	0.101
	373	0.064	0.080	0.038
	423	0.068	0.083	0.0077
500	R.T	0.0113	0.056	0.134
	373	0.051	0.092	0.050
	423	0.060	0.100	0.038
600	R.T	0.019	0.026	0.34
	373	0.0215	0.043	0.217
	423	0.0218	0.053	0.093
700	R.T	0.0145	0.0177	0.151
	373	0.021	0.040	0.108
	423	0.031	0.051	0.085

structural discontinuities in thin films. These results may be agreement with Beyer (Beyer W, Stuke J (1971).

It is clear that the activation energies decrease with increasing of thickness but increase with increasing of annealing temperatures due to the tailing both of the conduction and the valence band is diminished thus moving the conduction into regions with higher density of states and mobility, also may be the variation of crystallinty of film with increasing of annealing temperature in term partial crystallization. Table 1 illustrates the values of conductivity and activation energies E_{a1} and E_{a2}.

A.C. Conductivity

The study of the frequency and temperature dependence of electrical conductivity offers a lot of information about the electrical properties of the films (Amorphous and liquid semiconductors, Taylor and Francis; ASTM-Card 15-0770).

Frequency Dependence on A.C Conductivity

Figure (5a, b, c, d) shows the total measured conductivity $\sigma_{tot}(w)$ as a function of frequency in the frequency range 100 Hz - 400 kHz at various annealing temperatures in the range 300-423 K. The conductivity behavior can be divided according to the measured frequency. In the low frequencies region, the conductivity is constant and is taken to be the dc conductivity σ_{dc}.. Theoretically, this behavior may be modeled by transport taking place through infinite random free-energy barriers (Chu, 2011).

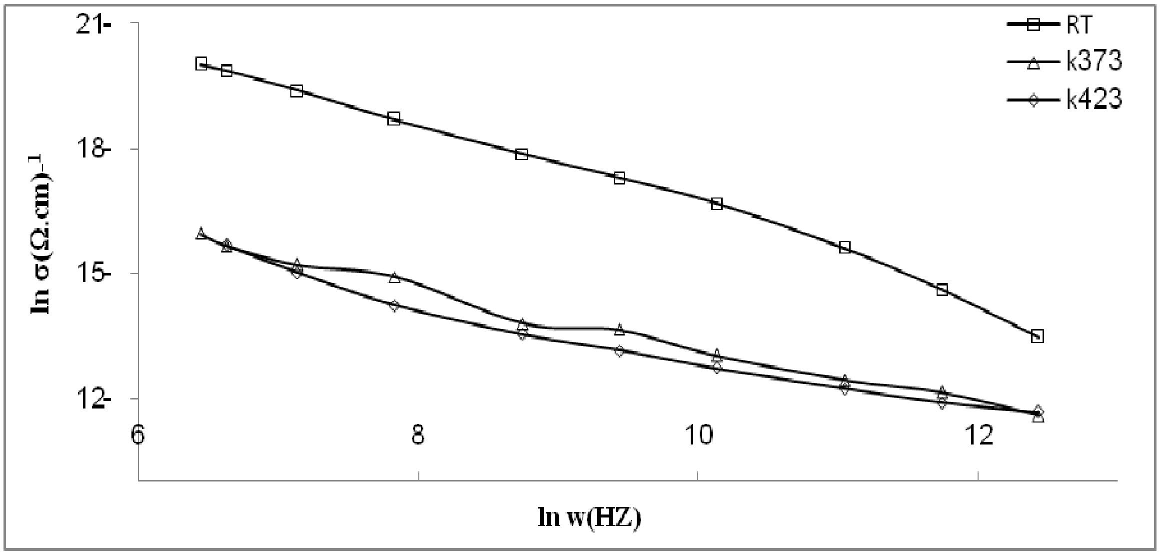
Figure (5a, b, c, d): $\text{Ln}\sigma_{a.c}$ as a function of $\text{Ln}(\omega)$ for Te films at different thickness and annealing temperatures(a): 400nm, (b): 500nm, (c): 600nm and(d): 700nm respectively.

When the frequency is increased, the conductivity is found to obey a power relation, $\sigma_{ac} \approx w^s$, where s is a function of temperature. Such behavior may be modeled as transport is dominated by conduction hopping through infinite clusters. The crossover frequency from σ_{dc} to σ_{ac} is the frequency of peak of dielectric loss, and increases with temperature. At higher frequencies, the conductivity tends to stability. At higher temperature, the curve of $\ln\sigma_{tot}$ vs. $\ln w$ becomes nearly linear, behavior which may be dc conduction.

The values of exponent (s) are estimated from the slope of the curves plotted between $\text{Ln}\sigma_{a.c}(\omega)$ versus Ln (ω) declared in Table (2). The values of (s) found to be less than unity for all prepared films and showing that (s) is temperature-dependent for each temperature.

The values of S are less than unity for all prepared films and they decrease with increasing annealing temperature. The behavior of $\sigma_{a.c}(\omega)$ with frequency can be explained in terms of polarization effect and hopping i.e. polarization effect in low frequency region where polarization is slightly changed and $\sigma_{d.c}$ is dominated, and at higher frequency region the hopping takes place.

Thus the experimental results agree with the correlated barrier hopping model (CBH), for a critical test of the CBH models comes from the temperature dependence of the ac conductivity and the frequency exponent (S) fits C.B.H. model given by Elliott (Jeppe and Dyre, 1988). For the mechanism of ac conduction, the model of correlated barrier hopping (CBH) of bipolarons (i.e., two-electron hopping charged defects D^+ and D^-) has been proposed. According to the Guintini model, each pair of D^+ and D^- is assumed to form a dipole with relaxation energy E_r (activation energy of dielectric relaxation). This type of energy can be attributed to the existence of a potential barrier over which the carrier can hop. This observation leads to a decrease in the density of states due to the conversion of some bipolaron states (D^+ and D^-) states into a single polaron state (D^o)


RT
k373
k423
21
18
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8
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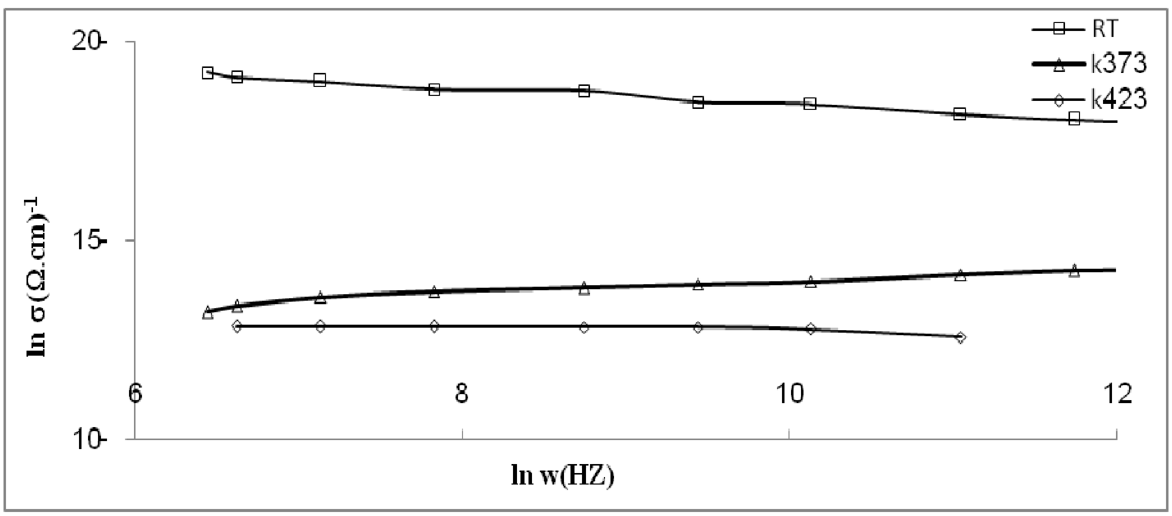
ln σ(Ω.cm)-1
ln w(HZ)

(a)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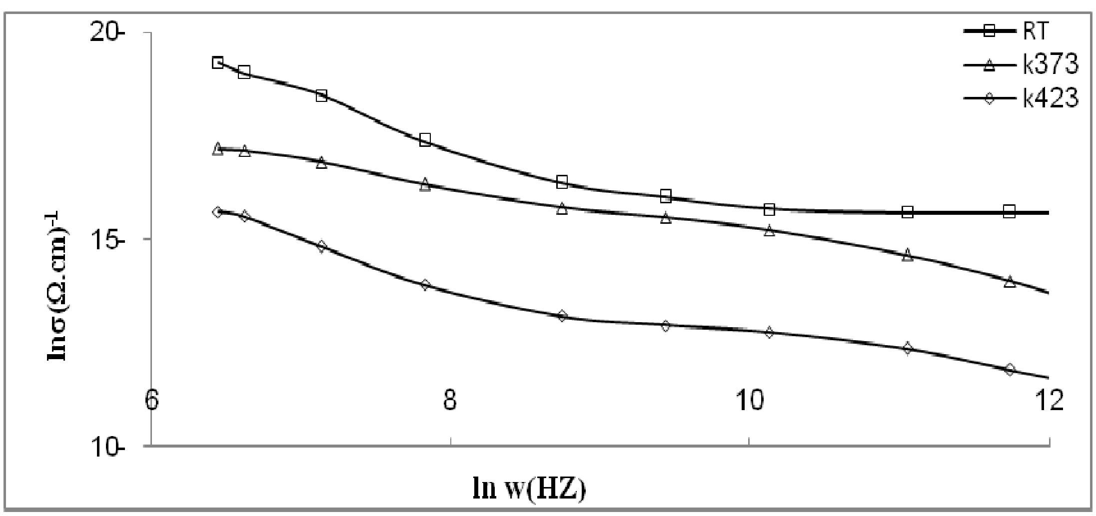
(b)


RT
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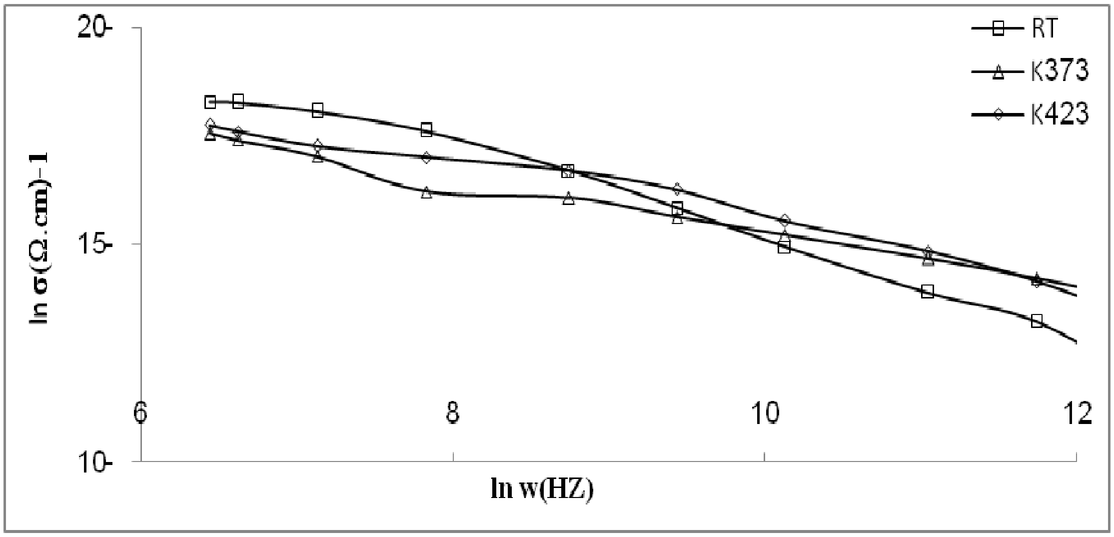
ln w(HZ)

(c)



(d)

Figure (5a, b, c, d). Ln$\sigma_{a.c}$ as a function of Ln(ω) for Te films at different thickness and annealing temperatures(a): 400nm, (b): 500nm, (c): 600nm and(d): 700nm respectively.

Table 2. the values of S for Te films at different thicknesses and annealing temperature

Thickness (nm)	**400**	**500**	**600**	**700**
T_a(k)	S	S	S	S
R.T.	0.910	0.62	0.84	0.959
373	0.814	0.60	0.712	0.741
423	0.748	0.48	0.676	0.418

according to the relation (D^+) + (D^-) ! 2(D^o). The theory has explained many low temperature features, particularly the temperature dependant values of the parameters A and s. However, it does not explain the high temperature behavior so well, particularly in the low frequency range. Shim-akawa (Elliot, 1987) suggested that D^o states are produced by thermal excitation of D^+ and/or D^- states and that single polaron hopping (i.e. one-electron hopping between D^o and D^+ or D^-) contributes at high temperature.

Temperature Dependence on A.C Conductivity

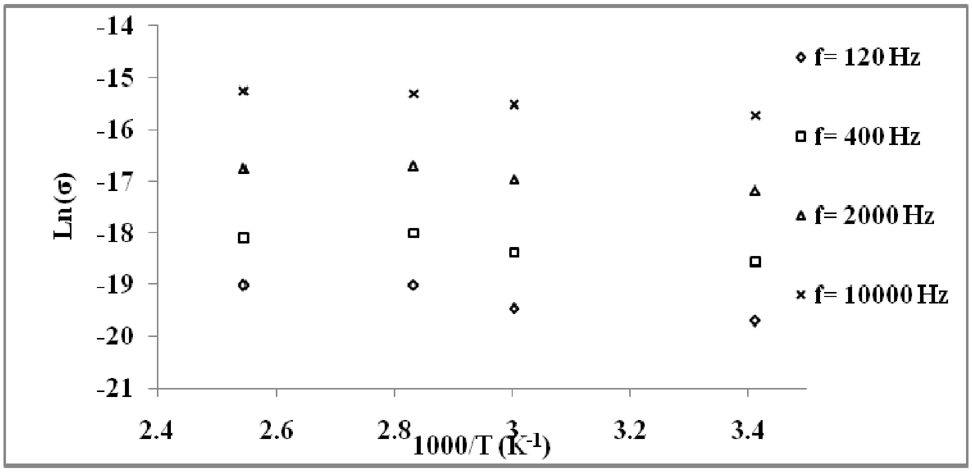
The variation of Lnσa.c (ω) with reciprocal temperature (10^3/T) for Te films for four fixed frequencies (120, 400, 2000 and 10000) Hz at different thicknesses and annealing temperatures are shown in Figures (6a, b, and c).

The other effect of thicknesses on the A.C-conductivity was shown in Table 3.

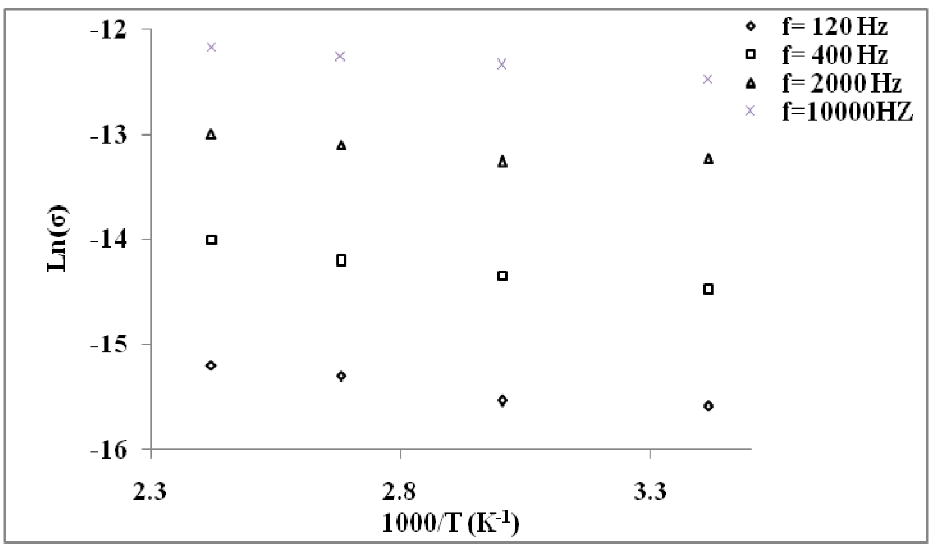
A linear behavior of **$\sigma_{a.c}$ (ω)** of one stage has been observed indicating a thermal activated conduction mechanism. The A.C activation energy; **E_{w1}** decrease with increasing film thickness and this may be attributed to the increasing of the absorption and decreasing the energy gap. It can be seen also that **E_{w1}** decrease with the increasing of Ta due to the annealing process near Fermi level. It is obvious that there is a decrease in **E_{w1}** with frequency increasing and such result complies with the theory of CBH model.

Hall Effect

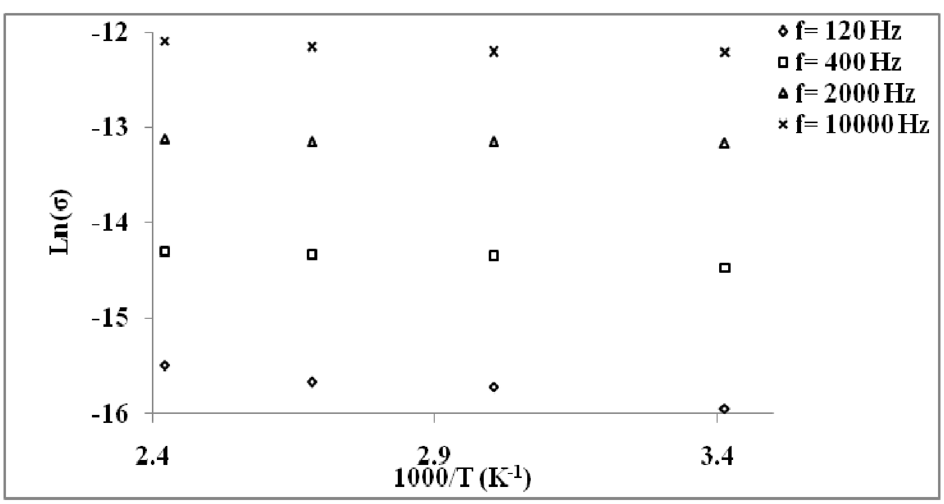
The variation of Hall voltage with the current for Te films deposited at R.T for different thicknesses and annealing temperatures have a positive Hall coefficient (p-type charge carries). The carrier's concentration and mobility increase with increasing of annealing temperatures while the mobility increase with increasing of thickness but carrier's concentration decrease with increasing of thickness. These results agree with Dutton and Muller (Dutton and Muller, 1971), Rusu (Rusu, 2001), and with Capers and White (Capers and White, 1973).



(a)



(b)



(c)

Figure 6. Ln $\sigma_{a.c}$ as a function of 1000/T for Te films at thickness 400nm for (a): as deposited (b): T_a=373K (c): T_a=423K

Table 3. A.C activation energies for Te films at different thicknesses and annealing temperatures at (120,400,2000and10000) Hz

Thickness (nm)	T_a (K)	E_{W1} 120HZ	400HZ	2 kHz	10 kHZ
400	R.T	0.071	0.069	0.061	0.054
	373	0.060	0.048	0.036	0.025
	423	0.055	0.026	0.024	0.0085
500	R.T	0.066	0.064	0.054	0.040
	373	0.053	0.045	0.042	0.028
	423	0.046	0.044	0.037	0.002
600	R.T	0.053	0.044	0.037	0.03
	373	0.024	0.026	0.019	0.02
	423	0.019	0.015	0.014	0.010
700	R.T	0.043	0.040	0.032	0.0178
	373	0.037	0.035	0.030	0.010
	423	0.022	0.019	0.015	0.0028

CONCLUSIONS

The film was deposited on glass substrate by thermal evaporation method. The analyzed results show that the films electrical properties are influenced by many factors such as film thickness and annealing temperature. The Hall mobility and the concentration of the holes in thin evaporated Te films were investigated as a function of different thicknesses and annealing temperatures. The values of S are less than unity for all prepared films and they decrease with increasing annealing temperature. Thus the experimental results agree with the correlated barrier hopping model (CBH), for a critical test of the CBH models comes from the temperature dependence of the ac conductivity and the frequency exponent (S). It is obvious that there is a decrease in Ew1 with frequency increasing and such result complies with the theory of CBH model.

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