Structural and electrical properties of tellurium thin films prepared by vacuum thermal deposition

Mahdi H.Suhail[1], Souad G.Kaleel[2] , Marwa R. Fahad[2]

1) Department of Physics, College of Science, University of Baghdad

2) Department of Physics, College of Science for Women, University of Baghdad

E Mail: mhsuhail@yahoo.com

Abstract

Thin films of highly pure (99.999%) Tellurium was prepared by high vacuum technique ($5*10^{-5}$torr), on glass substrates .Thin films have thickness 0.6μm was evaporated by thermal evaporation technique. The film deposited was annealed for one hour in vacuum of ($5*10^{-4}$torr) at 373 and 423 K. Structural and electrical properties of the films are studies. The x-ray diffraction of the film represents a poly-crystalline nature in room temperature and annealed film but all films having different grain sizes. The d.c. electrical properties have been studied at low and at relatively high temperatures and show that the conductivity decreases with increasing temperature at all range of temperature. Two types of conduction mechanisms were found to dominate in the measured temperature range.

Key words
Tellurium,
Thin films,
Electrical properties.

Article info
Received: Dec. 2011
Accepted: May. 2012
Published: May. 2012

الخواص التركيبية والكهربائية لاغشية التليريوم المحضرة بطريقة التبخير الحراري

مهدي حسن سهيل[1] ، سعاد غفوري خليل[2] ، مروة رحيم فهد[2]

[1]قسم الفيزياء، كلية العلوم ، جامعة بغداد

[2]قسم الفيزياء، كلية العلوم للبنات ، جامعة بغداد

الخلاصة

أعدت أغشية رقيقة من التليريوم عالي النقاوة (99.999٪) بواسطة تقنية عالية الفراغ ($5x10^{-6}$) تور، على ارضيات من الزجاج. حضرت الأغشية الرقيقة بسمك 0.6 مايكرون بواسطة تقنية التبخير الحراري. لدنت الاغشية المحضرة لمدة ساعة في فراغ ($5x10^{-6}$) تورعند 373 و 423 كلفن.درست الخصائص التركيبية والكهربائية للاغشية المحضرة. حيود الأشعة السينية للاغشية اظهرت ان الاغشية متعدده التبلور في درجة حرارة الغرفة والملدنة ولكن جميع الأغشية ذات أحجام حبيبة مختلفة. تم دراسة الخصائص الكهربائية المستمرة عند درجات حرارة منخفضة درجة حرارة مرتفعة نسبيا، وتبين أن التوصلية تتناقص مع زيادة درجة الحرارة ولجميع مديات درجة الحرارة. نوعان من آليات التوصيل موجودة فى الاغشية في نطاق درجة الحرارة المقاسة.

Introduction

The semiconducting films exhibit electrical properties which are generally less well understood than those of either the bulk single crystal material or metallic films. One material of particular interest in this field is Tellurium, an elemental semiconductor, easily evaporated without fear of dissociation, the bulk properties of which are well documented [1]. Several investigators [2-4] have studied the structural and electrical properties of Tellurium thin

films, but in the main these investigations have been restricted to a study of the dependence of the electrical properties on specimen preparation. Rusu [5] in his study on the structure of evaporated Te thin films, has established that during the growth process, the film crystallites change their orientation with increase of the film thickness. In relatively thin films (100–300 nm) Te crystallites have a preferred orientation with their *c*-axis (tellurium has a hexagonal structure) parallel to the substrate. As the film thickness increases, the crystallites grow with their *c*-axis oblique to the substrate. This specific stratified structure of evaporated Te films may have an important role in determining their physical properties.

Chalcogenide glasses are promising materials because of their potential application in various solid state devices and in optical applications [6-8]. Tellurium with atomic number of 52 is one of the rarest elements in the earth crust with an bundancy of only 10pb.It was first discovered by a Hungarian Mineralogist Franz-Joseph Muller Von Reichenstein in 1782[9]. Tellurium is a narrow-band gap semiconductor with band gap energy of 0.35ev.It has considered being an excellent candidate for use in future high-efficiency photoconductors, thermoelectric and piezoelectric devices [10].

The present work reports the study of the structural and electrical properties measurements in thin films of Tellurium prepared by vacuum evaporation. The measurements are carried out over annealing temperature range from room temperature to 423 K.

Experimental

Thin films of Tellurium have been typically deposited by thermal evaporation technique supplied by Blazers Model [BL 510] using molybdenum boat on glass substrate. 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. During vacuum deposition, the temperature of the substrates was maintained at 300K. After these steps the current supply was switched off and the samples were left in the high vacuum, 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 deposition); the main parameters that control the nature of the film properties are thickness (0.6) μm and annealing temperature (373, and 423) K. Vacuum evaporated Al electrodes at bottom were used for the electrical contact. The film thicknesses measured with an interference microscope. The films structure was investigated by standard X-ray diffraction (XRD) technique, using CuK_{α} radiation.

Results and Discussion

1.The Structural Properties of Tellurium Films

X-ray diffraction pattern of Tellurium at thickness 0.6μm for the as deposited film and annealed to 373 and 423 K are shown in Fig.1.

For the as prepared Te films, the XRD pattern displays strong reflections at (100) and (110) direction as well as the low intensity peaks at (011), (200) and (021), these are hexagonal planes. The intensity of planes has increased with annealing. At T_a=423 K another small peak has grown in (012) plane. From this figure we can see that the intensity of (100) plane increase and become sharp as the annealing temperature increase. Our results agree with Ott and Gunter [11] and Rusu[12].

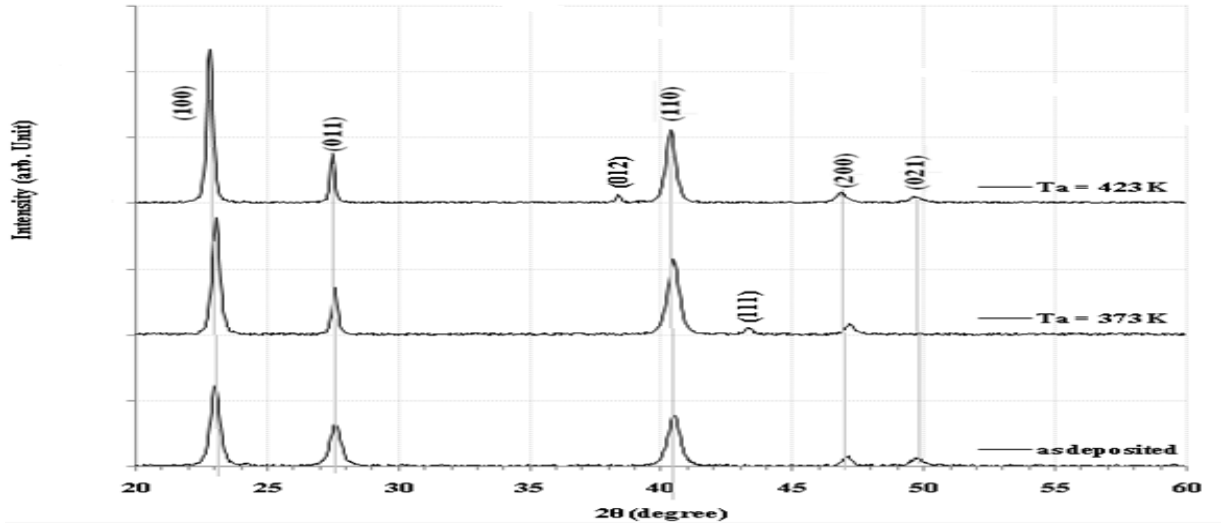

Fig.1 The XRD for a Tellurium thin films for as deposited and annealed films

2.The Electrical Properties of Tellurium Films

2-1.D.C conductivity

A D.C voltage of 10 volt is applied across the film and the resulting current is measured by digital Electrometer (Keithley, model 614). The D.C. conductivity can, therefore, be written as

$$\sigma_{dc} = \sigma_0 \exp(-E_a/kT) \quad (1)$$

where E_a is the activation energy for conduction which are calculated using the slope of Fig.2 and Eq.1.

The electrical conductivity σ was calculated from the relation:

$$\rho = 1/\sigma = RA/L \ (\Omega.cm) \quad (2)$$

where A is the cross-sectional area, L is the length between the potential probes.

It is well known that the electronic transport properties of the polycrystalline thin films strongly depend on their structure [8]. The study of the temperature dependence of electrical conductivity offers a lot of information about the electrical properties of the films [13].The d.c conductivity for Te films has been studies as a function of 1000/T at RT and annealing temperatures (373k and 423k) for 1h, under vacuum, and thickness of 0.6μm are showing in Fig.2

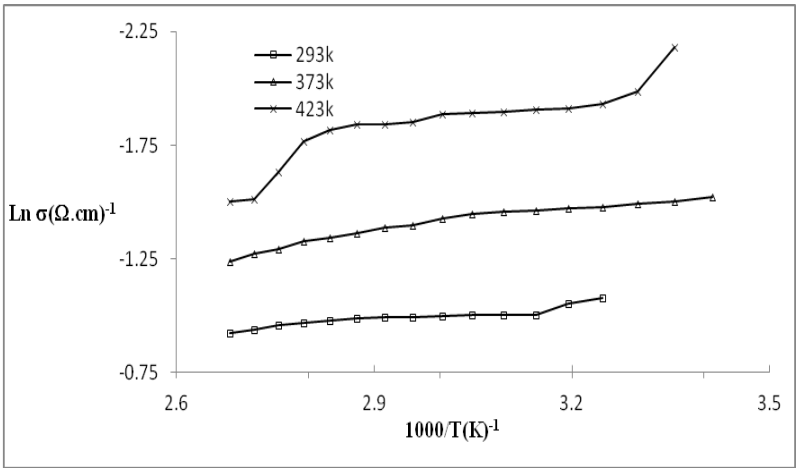

Fig.2 The plot of lnσ vs .1000/T for Te thin films at different annealing temperature

The conductivity decreases with increase of annealing temperatures because of the 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 and improved the structure of films.

It is clear from the Fig.2 that there are two transport mechanisms, giving rise to two activation energies E_{a1} and E_{a2}. The conduction mechanism of the activation energy (E_{a2}) at the higher temperatures is due to carries excitation into the extended states beyond the mobility edge, and at the lower of temperatures. The values of E_{a1} and E_{a2} increase with increasing of annealing temperatures due to the elimination of some defects from the films and the improvement in crystalline during annealing.

Table (1) D.C. conductivity parameters for Te films at different annealing temperature.

Thickness (μm)	T_a (K)	$\sigma_{d.cR.T}X10^{-5}$ $(\Omega.cm)^{-1}$	E_{a1} (eV)	Temp. Range (K)	E_{a2} (eV)	Temp. Range (K)
0.6	R.T	0.340	0.019	313-333	0.026	348-368
	373	0.217	0.0215	293-343	0.043	338-363
	423	0.093	0.0218	318-338	0.053	343-358

2-2.A.C conductivity

Figure 3 shows the total measured conductivity as a function of frequency $\sigma_{tot}(\omega)$ 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 [14]. When the frequency is increased, the conductivity is found to obey a power relation, $\sigma_{ac} \approx \omega^s$, where *s* is a function of temperature. Such behavior may be modeled as transport is dominated by conduction hopping through infinite clusters [15]. 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. $\ln\omega$ becomes nearly linear, behavior which may be dc conduction.

That (s) is temperature-dependent for each temperature. The values of exponent (s) are estimated from the slope of the curves plotted between $\ln\sigma_{a.c}(\omega)$ versus $\ln(\omega)$ declared in Fig. 3 and listed in Table (2) found to be less than unity for all prepared films and showing that (s) is temperature dependent for each temperature.

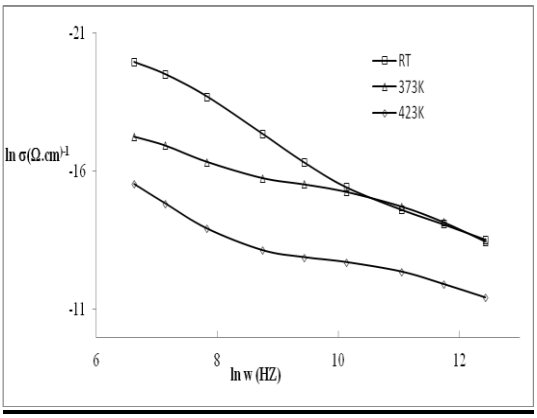

Fig.3 Lnσ vs.Ln ω for Te films at different annealing temperatures

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 [16].

Table (2) The values of s for Te films at different annealing temperatures

Thickness 0.6 (μm)	
T_a(k)	**S**
R.T	0.95
373	0.851
423	0.813

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^+, D^-) states into a single polaron state (D^o) according to the relation $(D^+) + (D^-) \rightarrow 2(D^o)$. 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. Shimakawa [17] 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.

Conclusions

Thin films of Tellurium have been deposited by thermal evaporation technique on glass substrate. The x-ray diffraction of the film represents poly-crystalline nature for as deposited and annealed films, but all films having different grain sizes. The electrical properties (D.C measurements) shows that the values of E_{a1} and E_{a2} increase with increasing of annealing temperatures due to the elimination of some defects from the films and the improvement in crystallinity during annealing and the (A.C measurement) show that the variation of the a.c. conductivity $\sigma_{a.c.}(\omega)$ with frequency for Tellurium films at different annealing temperature and the results agree with the correlated barrier hopping model (CBH).

References

[1] C.Cooper, The Physics of Se and Te, Pergamon, New York, 1969.
[2]G.Kruger, Thin Solid Films, 12 (1972) 335.
[3]M.J.Cupers and M.White, Thin Solid Films, 15 (1973) 5-14.
[4]T. Balasabramaniam, Sa. K. Narayandass and D. Mangalara J, Bull. Mat. Sci., 20 (1997) 79.
[5] M. Rusu, Appl. Phys., A66(1998) 357.
[6] A.Elshafie, A. Abdel-All, Physica B 269 (1999) 69.
[7] K. Abe, H.Takebe, K. Maronaga. J. Wenzel, G.H.Sigel, J.Non-cryst Solids, 212 (1997) 143.
[8] K.Wei, D.P.Machewirth, J.Wenzel, G.H.Sigel, J.Non-Cryst Solids 182 (1995) 257.
[9] Yang Huang, Shuanglin Yue, Zhongli Wang, Qiang Wang, Chengying Shi, Z. Xu, X. D. Bai, Chengcun Tang, and Changzhi Gu, J. Phys. Chem., B110, 2 (2006) 796–800.
[10] F.Habashi, Handbook of Extractive Metallurgy, 1997, vol.3.
[11]P. Ott, J.R Günter, Thin Solid Films, 366 (2000) 100.
[12]M. Rusu: J. of Optoelectronics and Advanced Materials,3, 4(2001)867 – 872.
[13] ASTM-card 15-0770.
[14] T.A.CHU, Paper presented at the NARST (2011) Annual International Conference in Orlando.
[15] C.Jeppe Dyre, J. Appl. Phys., 64 (1988) 2456.
[16] S.R. Elliot, Phil. Mag., B40 (1979) 507.
[17] K. Skimakawa, Phil. Mag., B46 (1982) 123.