EFFECT OF COMPOSITION AND THICKNESS ON THE ELECTRICAL BEHAVIOR OF Ge-As-Se-Te CHALCOGENIDE GLASSES

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ABSTRACT

Thin films of thickness in the range of 50-300 nm of Ge_{20}_ As_{30} Se_{50-x} Te_x, chalcogenide glasses,for x= 0 and 20; are prepared by thermal evaporation. D.C. conductivity and switching effect are reported for the investigated films. All films follow the same pattern, where the activation energy decreases by increasing film thickness . This is mainly due to the variation in the role of surface defects with respect to the bulk. It has been found that the addition of Te increases the threshold voltage V_s , while reduces the threshold current I_s . Te obtained data has been discussed in terms of the current theories.

Keywords: Chalcogenide glasses, Conductivity, Switching, Thermal evaporation, Activation energy.

1. INTRODUCTION

Switching devices prepared from chalcogenide semiconducting films have attracted much interest as described by Ovshinsky in 1968 [1]. Later on, switching has been intensively investigated [2,3].

Quaternary amorphous systems find increasing interest due to their practical applications. Recently, they are used as modulators in optical communications. However, both electrical and optical behavior still need more understanding.

Two approaches have been devoted to explain switching phenomena. The first assumes that it is of pure thermal origin, whereas the second assumes that it is of electronic origin. Homma et al [4] showed evidences against thermal approach and thereby supported the electronic model for chalcogenide glasses.

As for the conduction of chalcogenide glasses, there are different mechanisms which can be observed in different temperature regions. The conductivity s in the chalcogenide can be written as [5]

$$\sigma = \sigma_o \exp(-\Delta E/KT) + \sigma_1 \exp(-E_1/KT) + \sigma_2 \exp(-E_2/KT) \qquad (1)$$

The three terms arise from three different conduction mechanisms. The first term describes the high temperature region where the dominant mechanism is the band conduction through the extended states. The constant s_o for the chalcogenide glasses varies from 10^{-2} to $5x10^{-3}$ $\Omega^{-1}cm^{-1}$ and is found to depend on composition [5], where ΔE is the activation energy, K being Boltzman constant, and T is the absolute temperature.

Hopping conduction via localized states is responsible for the conduction in the second region. Here the conductivity arises from tunneling through unoccupied levels of the nearest neighbouring centers. The value of σ_1 is approximately 10^2 - 10^4 times less that σ_o partly because of the smaller density of localized states and their low mobilities.

Hopping conduction near the Fermi level is the third contribution to conductivity in an amorphous semiconductor which is analogous to impurity conduction in heavily doped semiconductors. It is expected to play a part only at low temperature and is not observed in the present experiment. In this case the conductivity is given by the third term on the R.H.S.

The present work displays results on the D.C. conductivity and switching phenomena of thin films for different thickness of amorphous $Ge_{20}As_{30}Se_{50-x}Te_x$, for x= 0 and 20. To the best knowledge of the authors, no prior information is available about the electrical conductivity of such kinds of glasses, so far.

2. EXPERIMENTAL WORK

Two glasses of the system $Ge_{20}As_{30}Se_{50-x}Te_x$ where x=0 and 20 were prepared from elements of purity 99.999%. These glasses are reactive at high temperature with oxygen. Therefore, synthesis was accomplished in evacuated clean silica tubes. The weighed materials were introduced into the cleaned silica tubes, then evacuated to about 10^{-6} torr and sealed at 800°C for about 8 hours. Then, they were subsequently quenched in liquid nitrogen. The specimens employed for D.C. conductivity measurements were prepared by thermal evaporation of chalcogenide source material onto a substrate of glass. The later had previously been equipped with coplanar gold electrodes, separated by a gap with 0.2 mm. The ingots were proved to be amorphous by means of X-ray diffraction and confirmed by differential thermal analysis (DTA).

The specimens used for switching measurements were prepared by evaporation of chalcogenide material onto substrate of pyrographite. Edward 306 coating unit was used for thin film preparation. The thickness of the prepared films was measured with thickness monitor type FM3. X-ray diffraction proved the amorphous nature of the prepared films. Keithly electrometer type 616 digital electrometer was used for the resistance measurements. A special cell was constructed for the switching measurements. The cell was made of teflon block in order to give high insulation.

3. RESULTS AND DISCUSSION

3.1 *The Effect of Variation of Te Content and Thickness of Films on Electrical Conductivity*

The dependence of ln (σ) on 1/T for the investigated films with different thickness is shown in Figures (1) and (2). All samples follow a common pattern, where two regions of conductivity are observed. The first is for high temperature range which is described by the first term of equation 1. In this region, band like conduction through extended states is the dominant mechanism. Values of σ_o and σ_{RT} and DE for different films were estimated and listed in Table (1). The obtained data reveal that both σ_o, σ_{RT} and ΔE depend on the Te content and the thickness. Increasing Te content leads to a decrease of the activation energy. Similar trend is also observed by increasing film thickness. The room temperature conductivity σ_{RT} exhibits another behaviour. σ_{RT} increases by one order of magnitude by increasing either Te content or film thickness. Obtained values of σ_o suggest that the conduction is mainly due to the transport of charge carrier through the extended states. In other words, we are dealing with a band-like conduction mechanism. On the other hand, Mott and Davis [6] have argued that there is no definite correlation between the intercept σ_o and the activation energy DE . However, the present investigations reveal opposite trend, since the present data obey the compensation law, as shown in Figure (3). Mott and Davis suggested that the intercept σ_o decreases with increasing the density of localized states. This, in turn; affects the values of both σ_o and ΔE. The observed decrease in σ_o with the increase of Te suggest that the addition of Te leads to an increase of both the density of localized states and hence the decrease of carrier mobility. The observed continuous change in electrical properties with composition can be accounted for by assuming that Te atoms act as impurity centers. In this respect, the cohesive energy (C.E.) has been calculated for the two compositions [7]. It is found that the addition of Te reduces the average C.E. This agrees well with the observed increase of conductivity by addition of Te.

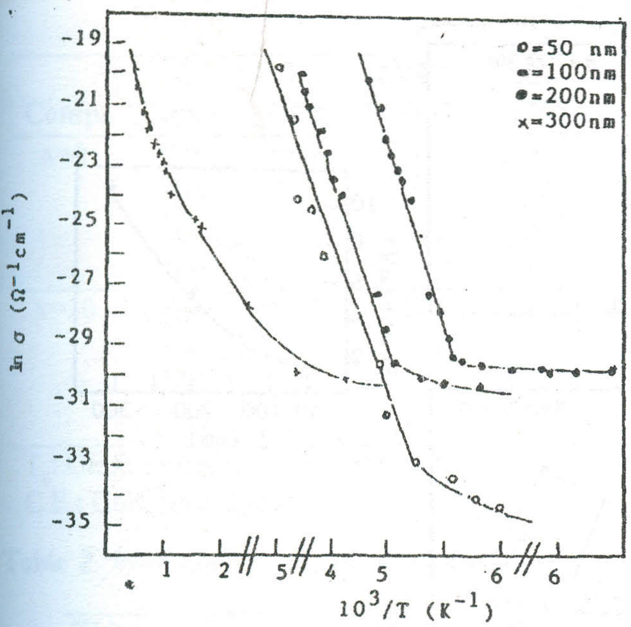

Figure 1. Conductivity-temperature characteristics for Te free films ($Ge_{20}As_{30}Se_{50}$) for various thickness.

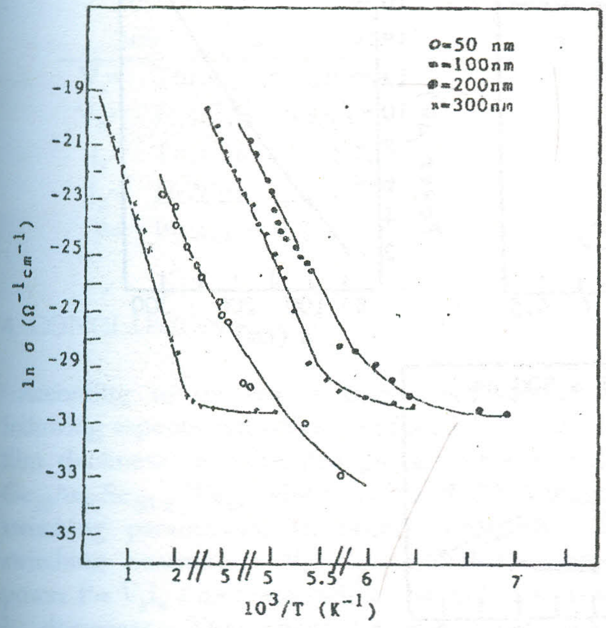

Figure 2. Conductivity-temperature characteristics for 20% Te content films ($Ge_{20}As_{30}Se_{30}\ Te_{20}$) for various thickness.

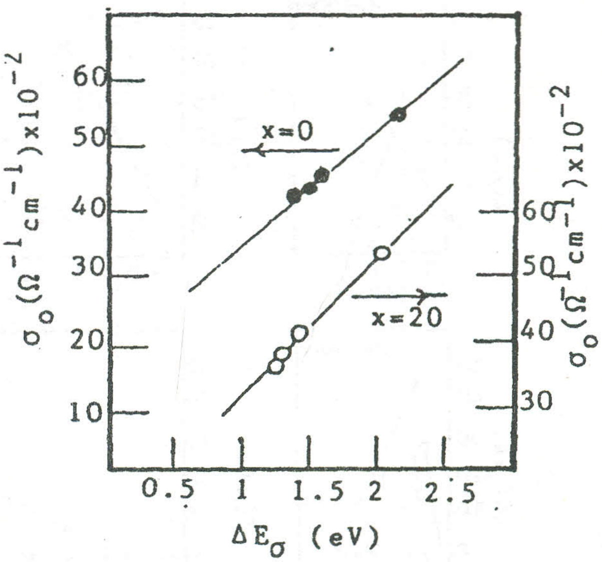

Figure 3. Fig. 3 Relation between s_o and DE for $Ge_{20}As_{30}Se_{50-x}\ Te_x$.

3.2 *Effect of Te Content and Thickness on Switching Characteristics*

Switching static characteristics of the investigated films are shown in Figures (4) and (5). It is worth noting that both Te and thickness affect static switching characteristics of the films. It is found that Te free composition (x=0) at a thickness (d) of 300 nm shows the highest threshold and holding voltage, V_s = 5.5 volt and V_h = 4.5 volt, respectively. On the other hand, the ON state current was not so high. Moreover, it is interesting to note that the Te free composition at a thickness of 50 nm shows the best switching characteristics, i.e. the smallest holding voltage, V_h=0.4 volt; the highest ON state current, I_h = 45 μA; and the smallest threshold voltage, V_s = 1.5 volt. By adding 20% of Te at the same thickness, d=300 nm; it is observed that the threshold voltage has increased to 6 volt, while the holding voltage has not given any change and the ON state current was still not so high. Films of smaller thickness of 50 nm for the same Te content, 20 %; show better switching characteristics, i.. the smallest holding voltage value of 1.3 volt, the highest ON state current of 30 μA, and the smallest threshold voltage of 2 volt.

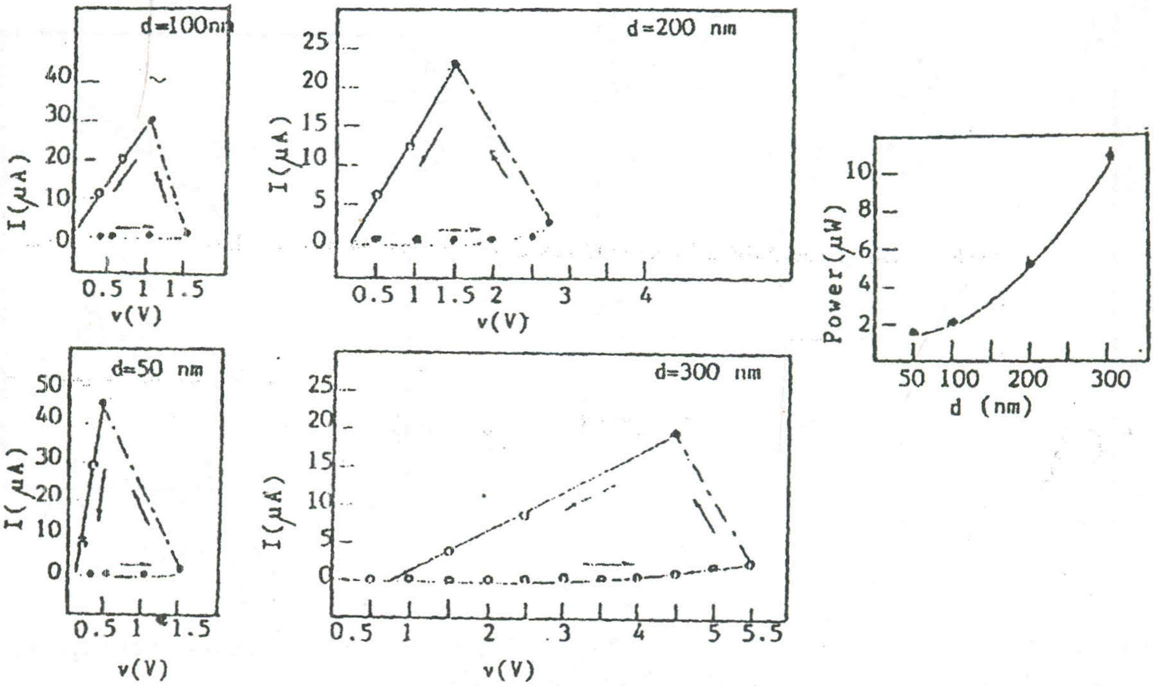

Figure 4. D.C. switching characteristics for Te free films ($Ge_{20}As_{30}Se_{50}$) for various thickness.

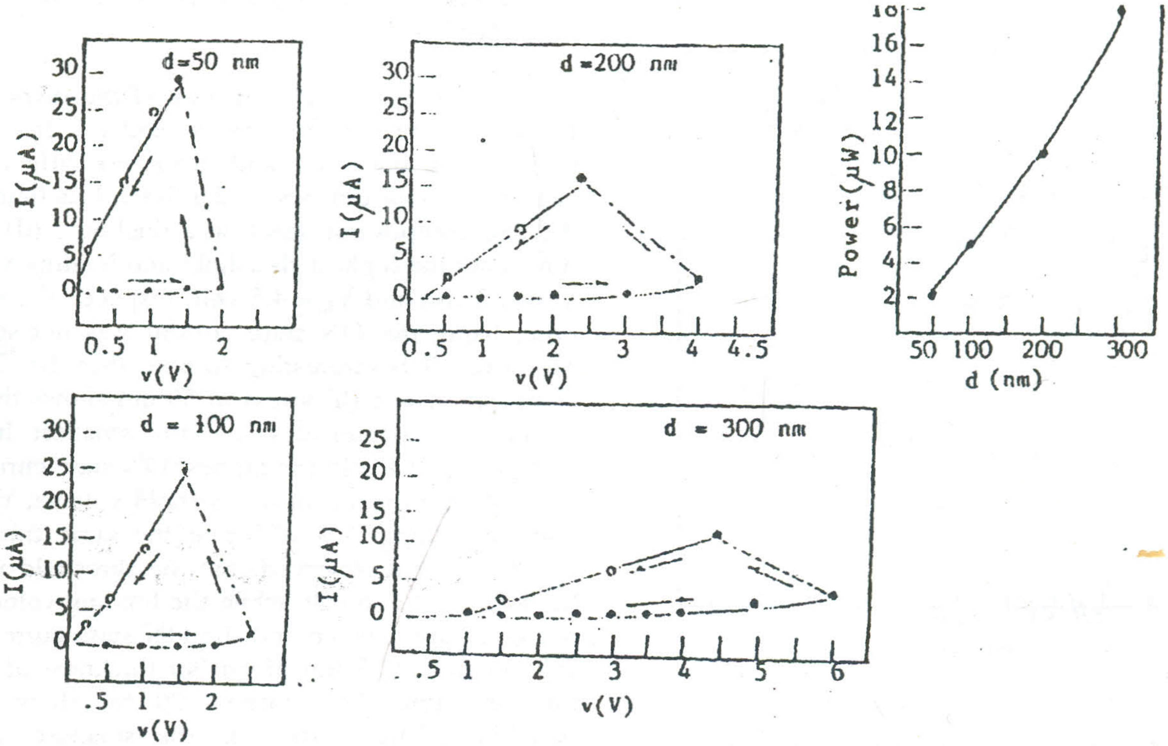

Figure 5. D.C. switching characteristics for 20% Te content films ($Ge_{20}As_{30}Se_{30}Te_{20}$) for various thickness.

Table 1. Composition and thickness dependence of the electrical characteristic quantities for thin film glasses in the system $Ge_{20}As_{30}Se_{50-x}Te_x$.

Comp.	d (nm)	T_g (°C)	C. E. eV	ΔE_σ eV	$\sigma_{R.T.}$ $\Omega^{-1}cm^{-1}$	$\sigma_o x10^{-2}$ $\Omega^{-1}cm^{-1}$	E_1	σ_1
x=0	50	240	2.56	2.18	$1.69x10^{-11}$	55.0	0.098	$1.70x10^{-11}$
	100			1.62	$2.29x10^{-11}$	45.0	0.250	$4.34x10^{-12}$
	200			1.56	$2.79x10^{-11}$	44.9	0.100	$1.08x10^{-12}$
	300			1.49	$5.40x10^{-11}$	44.2	0.073	$6.70x10^{-13}$
x=20	50	253	2.369	2.03	$6.76x10^{-12}$	54.0	0.220	$7.60x10^{-11}$
	100			1.37	$1.39x10^{-11}$	42.2	0.200	$9.40x10^{-11}$
	200			1.36	$2.73x10^{-11}$	37.9	0.190	$3.65x10^{-12}$
	300			1.26	$3.13x10^{-11}$	37.0	0.100	$7.09x10^{-13}$

T_g: Glass transition temperature
C.E.: Cohesive energy

Table 2. Switching characteristics of the two compositions $Ge_{20}As_{30}Se_{50}$ and $Ge_{20}As_{30}Se_{30}Te_{20}$.

Thickness (nm)	$Ge_{20}As_{30}Se_{50}$					$Ge_{20}As_{30}Se_{30}Te_{20}$				
	V_s (volt)	V_h (volt)	I_s (μA)	I_h (μA)	P (μ Watt)	V_s (volt)	V_h (volt)	I_s (μA)	I_h (μA)	P (μ Watt)
50	1.5	0.4	1.0	45	1.50	2.0	1.3	1.0	30	2.0
100	1.5	1.0	1.3	30	1.95	2.5	1.5	2.0	25	5.0
200	2.7	1.5	1.9	23	5.13	4.0	2.3	2.5	17	10
300	5.5	4.5	2.0	19	11.0	6.0	4.5	5.0	12	18

V_s= Threshold voltage
V_h= Holding voltage
I_s= Threshold current
I_h= Holding current
P= Power = V_sI_s

4. CONCLUSIONS

According to the above mentioned results, the following aspects can be concluded. The increase of film thickness of the two glasses of the system $Ge_{20}As_{30}Se_{50-x}$ Te_x, where x=0 and 20; affects all switching parameters. In other words, the main switching parameters V_s, V_h, and P (switch-on power P= V_sI_s) increase, while the holding current I_h decreases. This means that the quality of switching is reduced by increasing film thickness. Inspection of data given in Table (2) shows that the addition of Te gives rise to the same behaviour.

The obtained results can be accounted for by considering the cohesive energy and bond defects, and some other related parameters. The addition of Te reduces the cohesive energy, which in turn affects the switching properties. When an electric pulse is introduced to the sample, it will try to move some atoms to another metastable position. This gives rise to a memory device behaviour. But if the atoms are strongly bound, the pulse will not move the atoms but it will only affect electrons giving rise to switching effects. The above argument means that high cohesive energy reduces the quality of switching properties. This can explain the effect of Te content on switching quality of a given composition. Thickness effects can be understood in a similar manner. By increasing the film thickness, the probability of void formation increases and the density of defect bonds reduce the average binding energy. This will lead to a reduction in the average bonding, which is equivalent to the reduction of cohesive energy.

At last, it can be concluded that either the addition of Te or increasing the film thickness increases the impurity centers and voids.

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