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The threshold switching in semiconducting glass $Ge_{21}Se_{17}Te_{62}$

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Abstract : The preliminary measurements show the material $Ge_{21}Se_{17}Te_{62}$ is CCNR with memory type. The I–V characteristics have been carried out for virgin bulk samples as a function of the temperature and the thickness of the sample in the range 27–60°C and 0.41–0.86 mm respectively. Empirical equations for the dependence of the threshold resistance, the current and the electric field across the sample terminals on the thickness have been proposed. The conduction at threshold may be due to the transport of carriers excited into localized states at the edges of the valence or the conduction band. The specific heat and the thermal conductivity at threshold are temperature independent through out the measured temperature range. The dependence of dc conductivity on temperature shows the amorphous-crystalline transformation at 435 K.

Keywords : Semiconducting glasses, threshold switching, electrical properties

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1. Introduction

The chalcogenide glasses in Ge–Se–Te system have been obtained earlier [1] by quenching the melt from high temperature into ice water [2]. The glass forming region of the system has been studied [3–5]. The DTA measurements for the tellurium-rich glass of the system [6] and the optical properties of Ge–Se–Te glass fibers [7,8] have been carried out.

The electrical controlled switching and the memory effects for the chalcogenide glasses have been obtained earlier [6]. The threshold switching of the I–V characteristic of the chalcogenide glasses has been affected by many factors (*e.g.* the ambient temperature, the thickness of the sample, the static pressure on the sample, the kind of the material and the area of the electrode *etc.*) [9].

The study of threshold switching phenomena of $Ge_{21}Se_{17}Te_{62}$ under the effect of the temperature and the thickness gives more information on its physical nature, which is of much scientific and technological interest. Our main interest is to study the nature of the conduction mechamism and the dependence of the electrical parameters at threshold, on the ambient temperature (below T_g) and the thickness of the sample.

2. Experimental details

Appropriate constituents of spectroscopic pure Ge, Se and Te have been sealed in silica tube under a vacuum of 10^{-3} torr. The tube was heated at 1000°C for 6 hours and shaken from time to time, then quenched in ice water. The amorphous state has been assured by X-ray diffraction technique. Using differential thermal analysis (DTA) the glass transition and crystallization temperatures are about 152 and 255°C respectively. The current and the voltage across the sample have been measured at different constant temperatures for virgin samples with thicknesses 0.41, 0.55, 0.72 and 0.86 mm with an accuracy of ± 0.005 mm. The temperature range is 27°C–60°C with an accuracy of ± 1.0°C. The current and the voltage have been measured using digital electrometer (Keithley Y-616) and vacuum tube voltameter (Simpson-USA) respectively.

The specific heat at threshold (S_{th}) has been calculated using the equation

$$V_{th}\, I_{th} \cdot t = 4.186.\ a\, x\, d\, S_{th}\ (T_{th} - Ta), \tag{1}$$

where V_{th} and I_{th} are the voltage and the current at threshold, t is the time necessary for the voltage turnover (threshold) and $\simeq 10^{-5}$ sec [9], a is the cross sectional area of the electrode $\equiv$ the cross sectional area of the filament current passing at threshold, the density of the material $d = 5.51$ gm/cc [10], x is the thickness of the sample, T_a is the ambient temperature which is equal to the temperature of the sample and T_{th} is the temperature of the material when the threshold current passes through it [10].

Also the thermal conductivity at threshold κ_{th} has been determined according to the ralation

$$\kappa_{th} = \varepsilon\, S_{th}, \tag{2}$$

where $\varepsilon = 8.4 \times 10^{-3}$ cm/gm sec.

This equation can be applied in the temperature range where the phonon propagation may be absent.

3. Results and discussion

The general I–V characteristic curve of the studied chalcogenide glass in shown in Figure 1 in which two distinct states exist, a high resistance and a low resistance state. The curve shows that the material is CCNR with memory according to the classes of the switching effects [9]. The I–V traces were reversible unless we exceed the negative resistance state (NR) and reach the holding voltage. The material transits to the ON state (memory) above the holding voltage.

The I–V curves for a sample with thickness x = 0.41mm at different constant ambient temperatures are shown in Figure 2. Simillar behavior of I–V curves have been

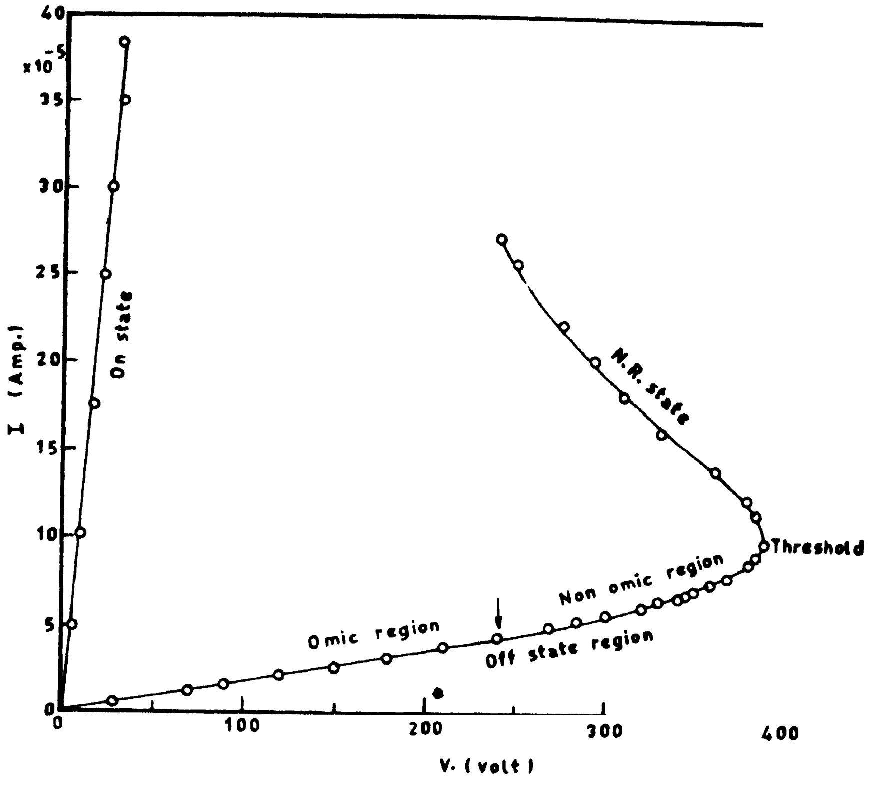

Figure 1. The general behaviour of I V characteristics for $Ge_{21}Se_{17}Te_{62}$

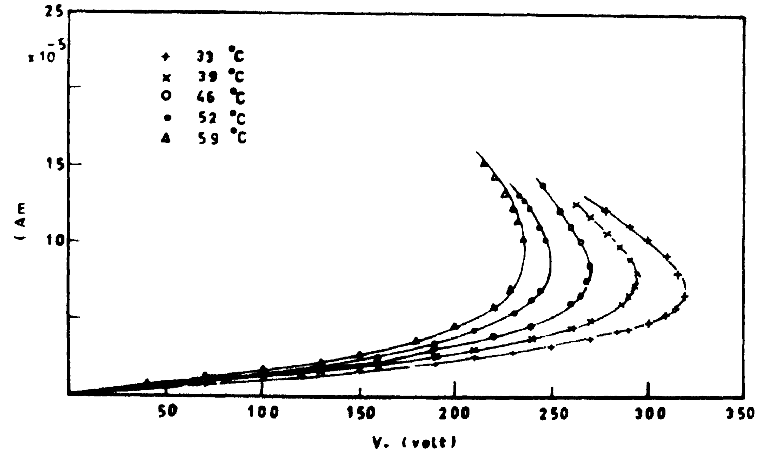

Figure 2. The I V characteristics curves at different constant temperature T_a for the thickness $x = 0.41$ mm.

obtained for the other thicknesses. At threshold, V_{th} decreases while I_{th} increases by increasing T_a. These are realized for all measured samples. The decreasing of V_{th} or the increasing of I_{th} with the temperature is exponential for each thickness. The

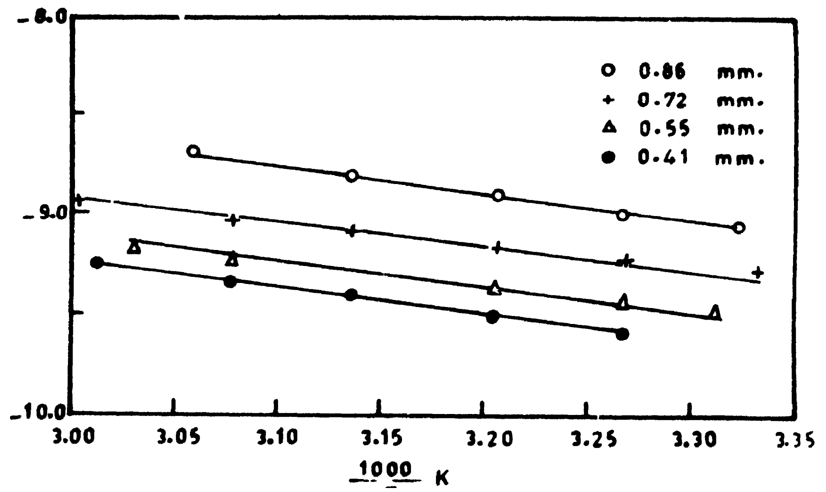

Figure 3(a). Ln I_{th} *versus* $1/T_a$ for different constant thickness x

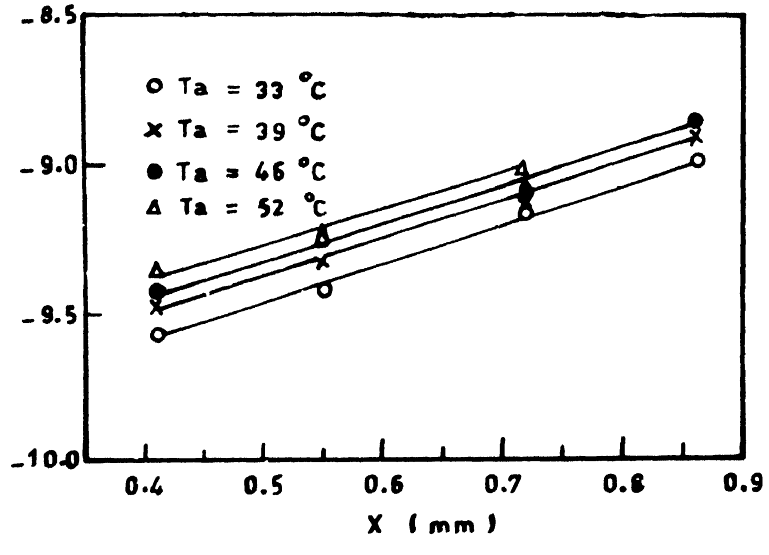

Figure 3(b). Ln I_{th} *versus* x at different constant temperature T_a

between In I_{th} and $1/T_a$ give parallel straight lines as shown in Figure 3a, the constant slope of these relations comfirms the experimental data where the slope is a thickness independent.

It was found that the threshold current increases exponentially by increasing the thickness at constant ambient temperature. The relations between In I_{th} and x at different constant temperature are shown in Figure (3b). The obtained straight lines have a constant slope (n). These mean that the variation of In I_{th} with the thickness is independent of ambient temperature. A proposed equation of the threshold current dependence on the sample thickness in the measured range can be written as

$$I_{th} = B\, e^{nx}, \tag{3}$$

where B and n are constants, these constants are temperature dependent and independent respectively.

The dependence of the threshold resistance R_{th} on the temperature indicates a semiconducting behaviour and it obeys an Arrhenius equation, $R_{th} = R_o \exp\,(W/KT_a)$, where R_o is constant and W the activation energy.

The relation of ln R_{th} *versus* $1/T_a$ for different thicknesses give straight lines with constant slope as shown in Figure (4a). In other words, the threshold conductivity increases by increasing the temperature (T_a). The value of activation energy at threshold is $\equiv 0.19$ ev which is small compared to the value obtained from dc conductivity measurments (0.49 ev). By considering the effect of temperature on the mode of conduction in amorphous semiconductor, particularly the chalcogenide glasses [11], the conduction mechanism at threshold may be due to the transport of carriers excited into localized states at the edges of the valence or conduction band.

The dependence of R_{th} on thickness is also exponential, where the relations between ln R_{th} and x at different constant temperature are linear as shown in Figure (4b). The slope of the linear dependence of ln R_{th} on x is temperature independent. A proposed empirical equation of the threshold resistance on the thickness can be written as

$$R_{th} = C \exp[(m - n)\, X], \tag{4}$$

where C is a constant which is temperature dependent and m and n are constants in case of V_{th} and I_{th} respectively which have positive values. Figure (4b) shows a decrease of R_{th} with

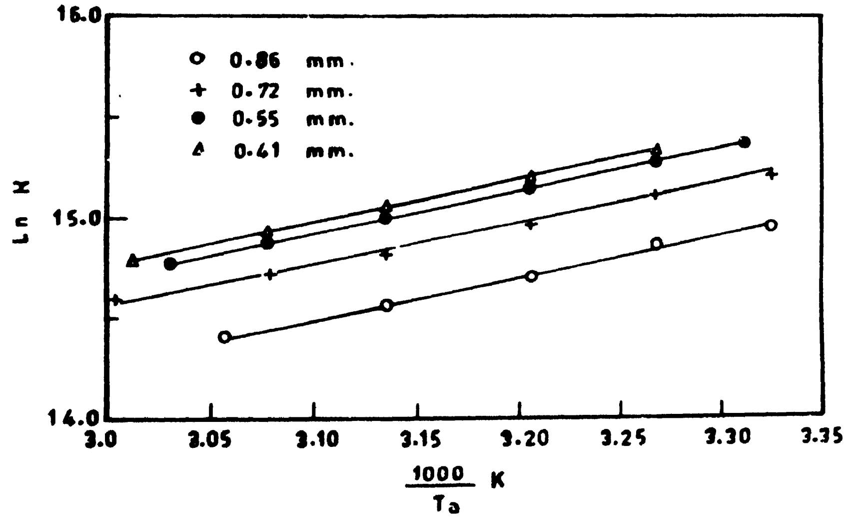

Figure 4(a). Ln R_{th} *versus* $1/T_a$ for different constant thickness.

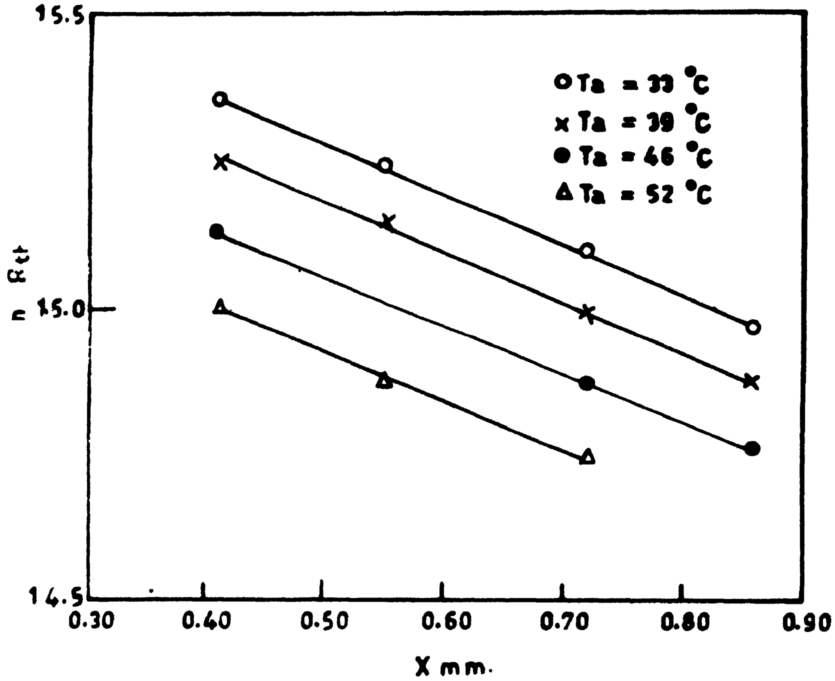

Figure 4(b). Ln R_{th} *versus* x at different constant temperature

increasing sample thickness, hence the threshold conductivity will increase with increasing thickness.

The experimental data indicate an exponential dependence of the threshold electric field across the sample on the ambient temperature and the thickness of the sample. The temperature dependence shows a decrease of F_{th} with increasing the temperature at constant thickness as shown in Figure (5a) where the values of F_{th} are large for the smaller thickness. The slopes of the linear relations in Figure (5a) are constant. Also the thickness-dependence shows a decrease of F_{th} with increasing thickness at an ambient temperature. Figure (5b) shows the linear relations between ln F_{th} and x where the values of F_{th} are larger for the lower temperature. These relations have a constant slope (m).

The decrease of R_{th} with increasing thickness at constant temperature means an increase of the threshold conductivity σ_{th} with thickness. As a result, the current path increases and the electric field across the sample will decrease as shown from the experimental results. At threshold, the thermal initiation as a result of an increase of the ambient temperature and the Joule heating due to the electric current passing through its path introduce a small thermal energy. This energy is not sufficient to make a sensible change in the amorphousity of the material identified by X-ray diffraction. Accordingly, it can be said that at threshold, the non-equilibrium carriers generated by the field increases by increasing the thickness.

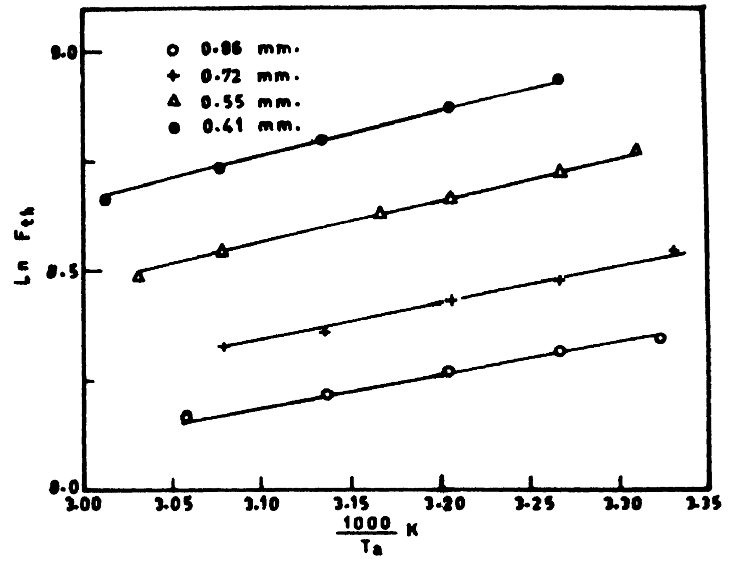

Figure 5(a). Ln F_{th} *versus* $1/T_a$ for different constant thickness.

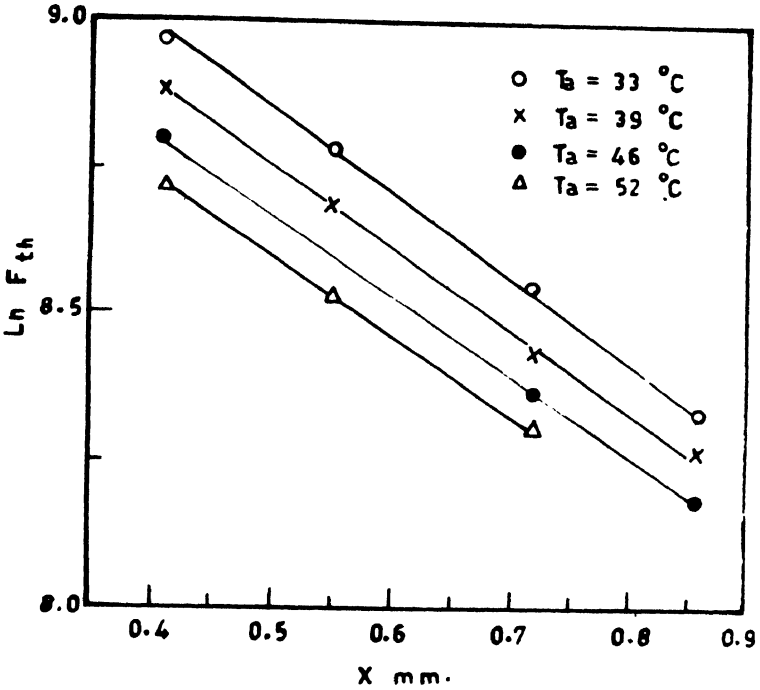

Figure 5(b). Ln F_{th} *versus* x at different constant temperature.

The threshold power P_{th} shows an exponetial dependence on the sample thickness and is independent of the ambient temperature as shown in Figure 6. The obtained specific heat at threshold S_{th} for each sample at different constant ambient temperature shows

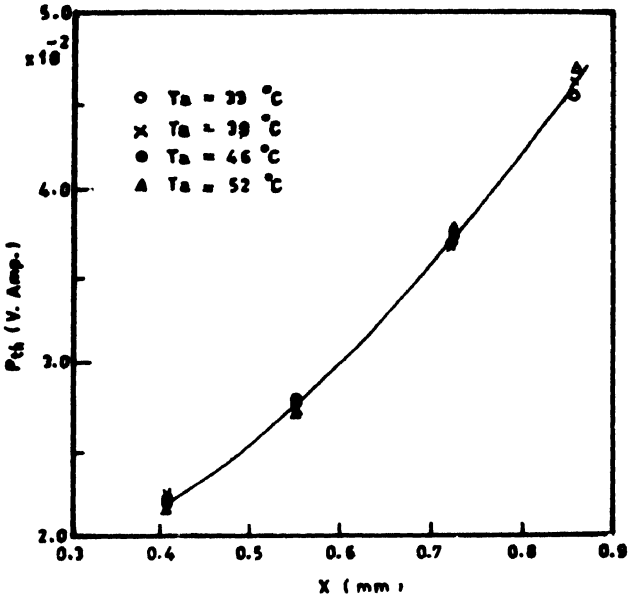

Figure 6. The threshold power P_{th} dependence of thickness at different constant temperature.

Table 1. The calculated specific heat at threshold (S_{th}).

T(°C)	X(mm)	S × 10^5 (Cal/gm°C)	T(°C)	X(mm)	S × 10^5 (Cal/gm°C)
33	0.41	6.4	46	0.41	6.0
	0.55	6.2		0.72	6.0
	0.72	6.4		0.86	6.2
	0.86	6.2			
39	0.41	6.4	52	0.41	6.2
	0.55	6.0		0.55	6.0
	0.72	6.0		0.72	6.0
	0.86	6.2			

temperature independence (see Table 1) where its value is nearly constant through the measured temperature range. Consequently, the calculated thermal conductivity at threshold K_{th} according to equation (2) will be temperature independent.

The dependence of dc conductivity on the temperature, indicates a semiconducting behaviour as shown in Figure 7. This dependence obeys an Arrhenius equation of the form $\sigma = \sigma_0\, e^{-W/KT}$ where W is the activation energy. Figure 7 shows the amorphous-crystalline transformation at transition temperature (T_{kink}) = 435°K which is higher than T_g.

The obtained activation energies of amorphous and crystalline states are 0.49 and 1.21 eV respectively. The conduction in the former state may be a transport of carriers

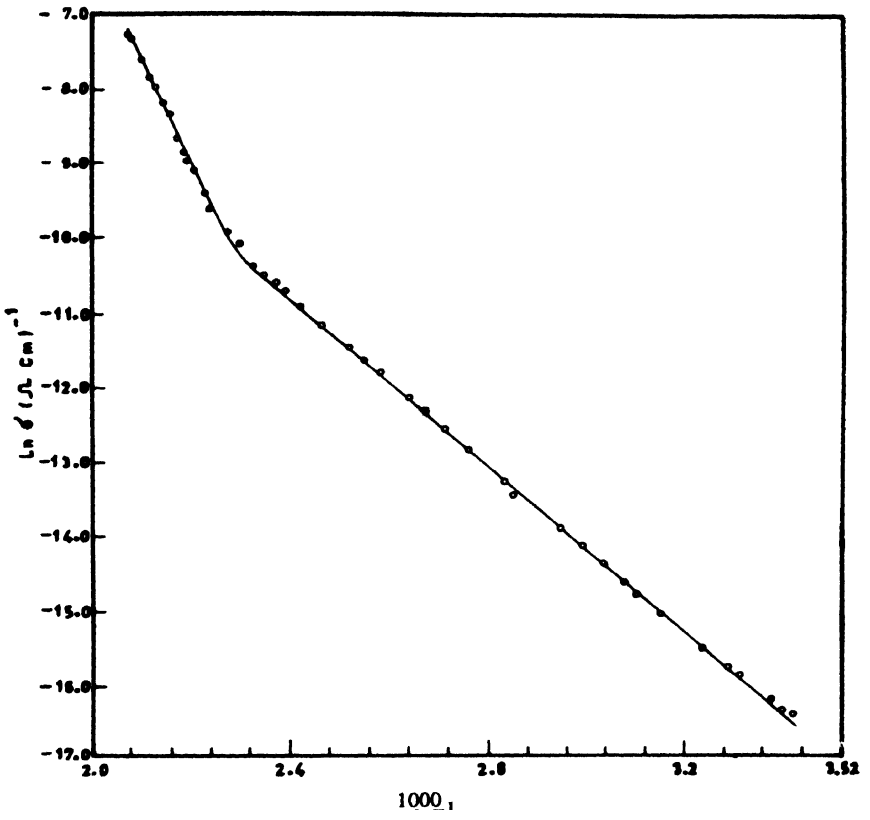

Figure 7. The dc conductivity dependence of temperature.

excited beyond the mobility edges into non-localized (extended) states at E_c or E_v where $W = (E_c - E_F)$ or $(E_F - E_v)$ where E_c and E_v are the energy of conduction and the valence band mobility edges respectively and E_F is the Fermi energy. In the later state, the transport of carriers may be in the conduction band, where $W = (E_c - E_F) + (E_F - E_v)$. It can be said that the Fermi energy lies near to the mid-gap in the amorphous state.

4. Conclusion

The results of I–V characteristics indicate the semiconducting glass $Ge_{21}Se_{17}Te_{62}$ is a current controlled negative resistance (CCNR) device with memory. The threshold current, voltage, resistance, electric field across the sample are exponential dependent on the ambient temperature (in the range of 27–60°C) and the thickness (in the range of 0.41–0.86 mm), while the threshold power is temperature-independent. The proposed empirical equations for the thickness-dependence have been deduced experimentally.

The conduction mechanism at threshold may be attributed to the transport of carriers excited into localized states at the edges of the valence or the conduction band. The conduction in amorphous state may be a transport of carriers excited beyond the mobility edges into non-localized states.

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