ELECTRICAL SWITCHING BEHAVIOR OF ANTIMONY DOPED BULK Si-Te CHALCOGENIDE GLASSES

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Electrical switching studies undertaken on antimony doped $Si_{18}Te_{82-x}Sb_x$ ($1 \leq x \leq 10$) glasses, indicate that these samples exhibit a memory type electrical switching behavior with a strong composition dependence of threshold/switching voltages (V_T); the threshold voltages of $Si_{18}Te_{82-x}Sb_x$ glasses are found to increase with the addition of Sb, with a maximum at x = 4, the Stiffness Threshold of the system. A similar maximum has been observed in the composition dependence of V_T of base glassy system Si_xTe_{100-x}, which indicates the possibility of chemical effects playing a role at compositions above x = 4. Further, the threshold voltages of $Si_{18}Te_{82-x}Sb_x$ glasses have been found to increase almost linearly with the sample thickness as observed in other memory type glasses.

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Keywords: Electrical switching; Stiffness threshold; Threshold voltage

1. Introduction

Chalcogenide glasses are usually high resistance semiconducting materials which can be switched to a low resistance state by applying a suitable electric field. The voltage at which switching occurs is known as threshold or switching voltage (V_T). There are two types of switching, namely threshold switching which is reversible and memory switching which is an irreversible process. The phenomenon of electrical switching in chalcogenide glasses, first found by Ovshinsky in 1968, finds applications in power control, information storage devices, etc. [1].

Several Te and Se based chalcogenide glasses have been found to exhibit the electrical switching [2-7]. Further, the addition of metallic impurities to the chalcogenide glasses are found to bring remarkable changes in the electrical switching behavior of these glasses, such as variations in V_T values, a cross-over in switching type, etc.

Both threshold and memory switching processes are primarily electronic in nature and occur when the charged defect states present in the chalcogenide glasses are filled by the field injected charge carriers [8-12]. However, additional thermal effects come into play in memory switching, which lead to the creation of a conducting crystalline channel in the electrode regions [12-14].

Chalcogenide glasses with Sb additives are found to exhibit interesting switching characteristics and are already in use in information storage devices such as DVD-RAM, CD-RW, etc.[15-16]. In this work, the electrical switching behavior of $Si_{18}Te_{82-x}Sb_x$ glasses over a wide compositional range ($1 \leq x \leq 10$) has been undertaken in order to understand the effect of Sb on switching voltages.

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2. Experimental

Bulk $Si_{18}Te_{82-x}Sb_x$ glasses ($1 \leq x \leq 10$) were prepared by conventional melt-quenching method. Constituent elements of 99.995% purity were appropriately weighed and sealed in flattened, evacuated quartz ampoules at a pressure of 10^{-5} mbar. The ampoules were kept inside a horizontal furnace and the temperature was gradually raised up to ~1200 °C at the rate of 100 °C per hour. The ampoules were maintained at this temperature, with a continuous rotation at 10 rpm for 48 hours, to ensure homogeneity of the melt; they are subsequently quenched in a bath of ice-water and NaOH mixture. The bulk glass was recovered by breaking the ampoules carefully. The amorphous nature of the bulk samples was confirmed from the X-ray diffraction studies using a Phillips powder X-Ray diffractometer with Cuk_α radiation.

Electrical switching studies of $Si_{18}Te_{82-x}Sb_x$ glasses prepared ($1 \leq x \leq 10$), were undertaken using a Keithly Source-Meter® (2410^c; 1100V & 21mA) controlled by a PC using LabVIEW 6.1 (National Instruments). Samples, polished to 0. 25mm thicknesses were mounted in a sample holder made of brass in between a flat-plate bottom electrode and a spring loaded point-contact top electrode. A constant current (0-2mA) was passed through the sample and the voltage developed across the sample was measured. The current-voltage (I-V) studies were repeated for at least three to five times for each sample and the error in measured V_T was found to be within ±3%.

3. Results and discussion

3.1. I-V characteristics and electrical switching behavior

Figs. 1 and 2 show the I-V characteristics of $Si_{18}Te_{82-x}Sb_x$ glasses, indicating that these samples exhibit memory type electrical switching, even at currents of the order of 2mA. The switching/threshold voltages of $Si_{18}Te_{82-x}Sb_x$ glasses are found to lie in the range 160-250 volt, depending on the composition, for a sample thickness of 0.25mm. It is also interesting to note here that an unstable threshold tendency has been observed in all the $Si_{18}Te_{82-x}Sb_x$ glasses at lower currents (< 2 mA), for a few cycles, before the samples latched onto the memory state.

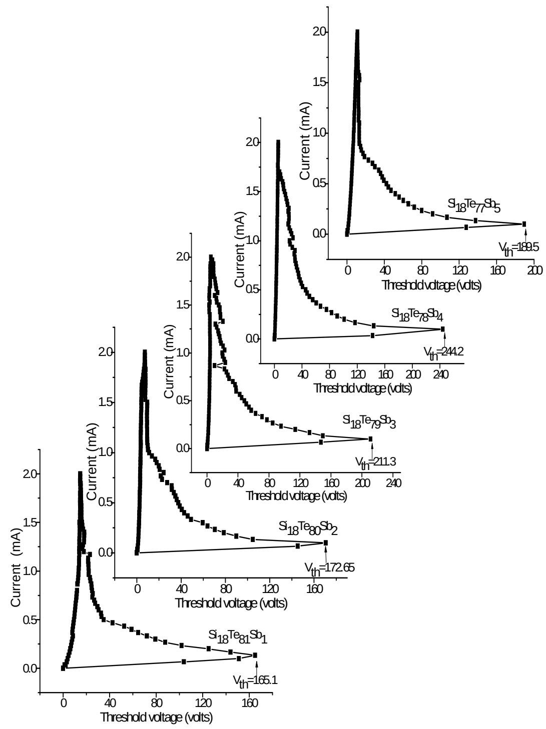

Fig. 1. I-V characteristics of the representative $Si_{18}Te_{82-x}Sb_x$ glasses in the composition ranges x=1 to x=5.

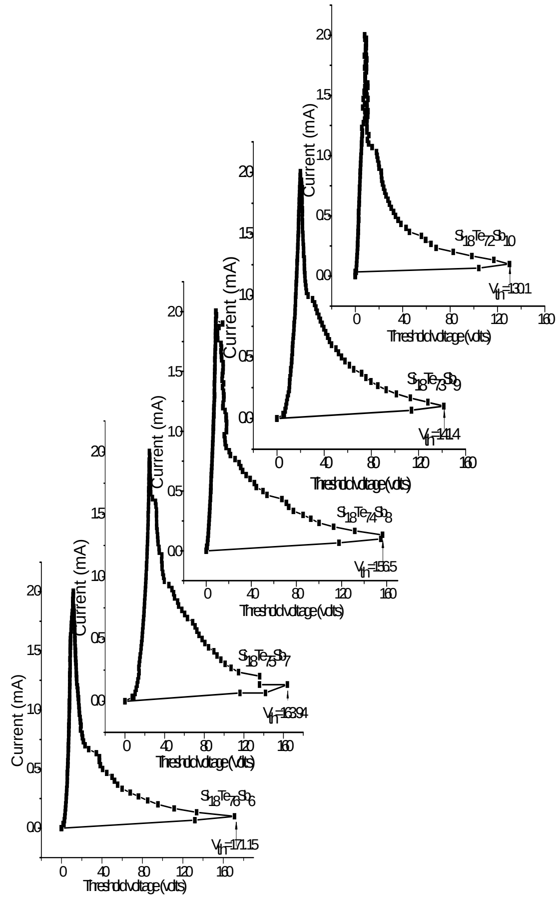

Fig. 2. I-V characteristics of the representative $Si_{18}Te_{82-x}Sb_x$ glasses in the composition ranges x=6 to x=10.

As mentioned earlier, memory type switching seen in chalcogenide glasses is the result of a phase transformation occurring (from amorphous to crystalline) in the sample, in the electrode region. This transformation is ascribed mainly due to Joule heating, involving the formation of a conducting crystalline channel in the sample after it switches to the ON state. Generally, Te rich chalcogenide glasses such as Ge-Te. Al-Te, Ge-As-Te, Al-Te-Si and Ge-Te-Sb [2-7] etc., are found to exhibit memory switching over wide composition ranges; this is mainly because of their greater conductance which results in a larger power dissipation and their easy crystallizability (lower T_c values). The present $Si_{18}Te_{82-x}Sb_x$ series of glasses also contain a large amount Te and the observed memory switching is therefore consistent with other telluride glasses.

3.2. Composition and thickness dependence of the switching voltage

Fig. 3 shows the variation of threshold/switching voltages (V_T) of $Si_{18}Te_{82-x}Sb_x$ glasses with composition / <r>. It can be seen that, there is an increase in the threshold voltage V_T with Sb addition, with a sharp maximum seen at the composition x = 4 (<r> = 2.4). A decrease is seen in V_T with composition, above x = 4.

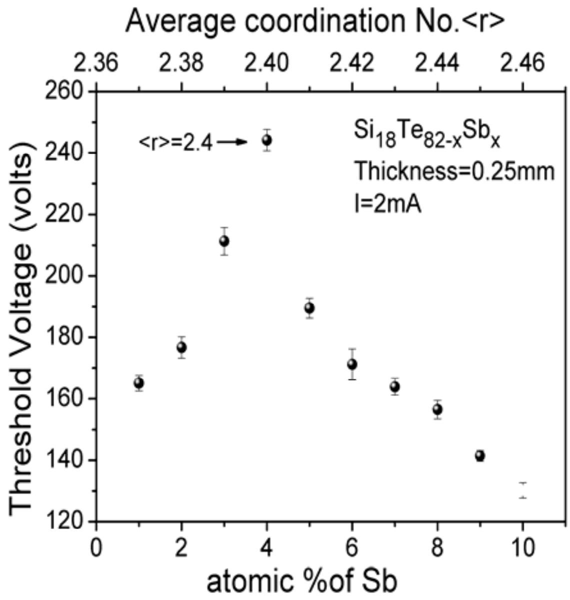

Fig. 3. The variation of threshold/switching voltages (V_T) of $Si_{18}Te_{82-x}Sb_x$ ($1 \leq x \leq 10$) glasses as a function of composition (X)/average coordination number <r>.

It is known that the composition dependence of threshold voltage of chalcogenide glasses is determined by several factors such as resistivity of the additives, network connectivity and chemical ordering. The switching voltages are usually found to decrease with the addition of more metallic dopants (metallicity factor) [7]. On the other hand, an increase in the switching voltages is generally observed with the incorporation of higher coordinated additives, due to an increase in network connectivity and rigidity (rigidity factor) [17]. The increase of chemical ordering results in lowering of the switching voltage as chemically ordered state is closest to the crystalline state [18].

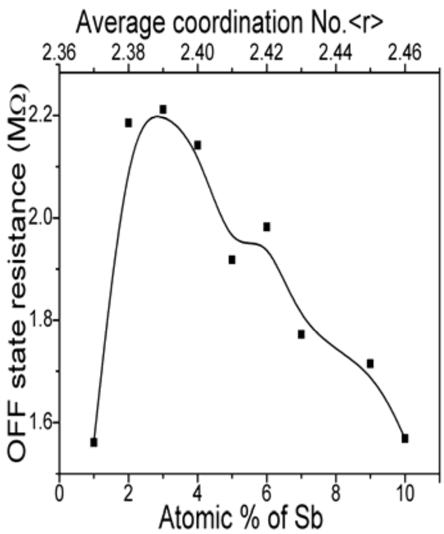

Fig. 4. The variation of OFF state resistance (R) of the $Si_{18}Te_{82-x}Sb_x$ ($1 \leq x \leq 10$) glasses with composition.

In the present $Si_{18}Te_{82-x}Sb_x$ glassy system, the addition of more metallic Sb ($\rho_{Sb} = 40 \times 10^{-8}$ Ωm and $\rho_{Te} = 1 \times 10^{-4}$ Ωm) is expected to lead to a decrease in the switching voltages, as the switching voltages are directly related to electrical conductivity of the material [19]. However, based on the network connectivity, the addition of three fold coordinated Sb (at the expense of the two fold coordinated Te) is expected to increase the switching voltages. The initial increase in the switching voltages of $Si_{18}Te_{82-x}Sb_x$ glasses with x indicates the dominance of the network connectivity over the metallicity factor in the composition region $1 \leq x \leq 4$.

In several chalcogenide systems such as As-Te [20], Ge-Te [2], Al-Te [21], Ga-Te [17], Ge-Te-Si [22], As-Te-In [23], etc., a sharp slope change (lower to higher) is seen in the composition dependence of switching voltages at the stiffness threshold. However, in the base glassy system Si_xTe_{100-x}, an increase in V_T and a subsequent maximum is observed at the mean-field rigidity percolation threshold, which has been understood on the basis of occurrence of a chemical threshold in the close vicinity of the rigidity percolation threshold [2]. The present results indicate the composition dependence of V_T of $Si_{18}Te_{82-x}Sb_x$ glasses is similar to that of Si_xTe_{100-x} samples, indicating the possibility of chemical effects in this system above x = 4.

The composition dependence of the resistance of the $Si_{18}Te_{82-x}Sb_x$ glasses in the OFF state is shown in Fig. 4. In general, a direct relationship is observed in the composition dependence of switching voltages and OFF state resistance (R) of chalcogenide glasses [24]. Thus, we see that the composition dependence of switching voltages and resistances in the OFF state of $Si_{18}Te_{82-x}Sb_x$ glasses are consistent.

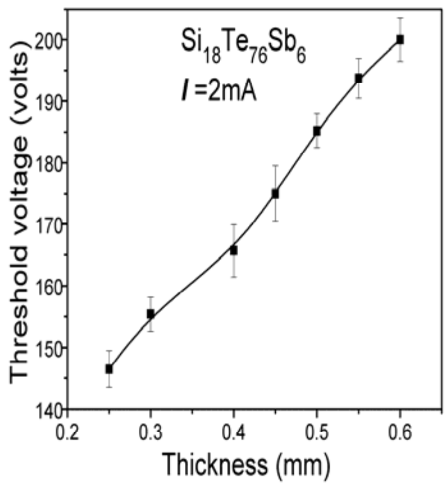

Fig. 5. The variation of switching/threshold voltages (V_T) as a function of thickness for a representative sample $Si_{18}Sb_6Te_{76}$.

Fig. 5 shows the variation of V_T with thickness of a representative sample $Si_{18}Te_{76}Sb_6$ in the thickness range of 0.25-0.6 mm at a current of I=2 mA. In general, a linear or square root dependence of V_T is observed in memory samples, whereas square dependence is seen in threshold samples [25-26]. It can be seen that V_T increase almost linearly with the sample thickness as observed in other memory type glasses confirming the thermal origin of switching in these samples.

4. Conclusions

Electrical switching studies indicate that $Si_{18}Te_{82-x}Sb_x$ glasses exhibit a memory type electrical switching, with a strong composition dependence of switching voltages. It is found that the threshold /switching voltages of $Si_{18}Te_{82-x}Sb_x$ glasses increase with the addition of Sb, exhibiting a maximum at the Stiffness Threshold of the system. A similar maximum has been observed in the switching voltages of the Si_xTe_{100-x} base glassy system, which indicates the possibility of chemical effects playing a role in the composition dependence of V_T of $Si_{18}Te_{82-x}Sb_x$ glasses above x = 4. Further, the threshold voltages of $Si_{18}Te_{82-x}Sb_x$ glasses have been found to increase almost linearly with the sample thickness as observed in other memory type glasses.

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