LIST OF PUBLICATIONS

1. Reversible Threshold Switching in the Zn-doped Selenium and Tellurium System.

2. Electrical Transport in the Bulk Amorphous [Se$_{0.7}$Te$_{0.3}$]$^{100-x}$ System

3. Reversible Threshold Switching in the Pb-doped Selenium and Tellurium System
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Reversible threshold switching in the Zn-doped selenium and tellurium system

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Abstract. Threshold switching in bulk amorphous samples of (Se₆₇Te₃₃)₁₀₀₋ₓZnx has been studied experimentally. It is observed that above a certain voltage across the sample the current through the material rises to a very high value without any increase in the potential across the sample. This threshold value of the voltage depends upon the zinc concentration in the material and the temperature of the sample. The switching behaviour is completely reversible in nature.

1. Introduction

Threshold switching in amorphous materials has attracted the attention of a number of workers in recent years [1-7]. Widely studied systems are [Sb-Se-Te] [8], [As, Ge, Se] [9], [Te, GeSe, S] [10]. The selenium-tellurium system has been recognized as a unique pressure-induced system over a wide composition range [11-13]. Amorphous selenium is known to have a chain-and-ring structure. The added tellurium atoms may enter the chain termination positions and intra-ring positions by random substitution. Because of the different electronegativities of Se and Te, different types of bonding positions and microstructure groups are expected to develop during the annealing process. These microstructures make the Se-Te system a pressure-sensitive system. The addition of zinc as an impurity atom in a controlled manner is expected to change the very chemical nature of the microstructural units which may result in a change in electronic properties of the material. The present paper is concerned with the current-voltage (I-V) characteristics of Zn-doped Se-Te samples. The basic Se-Te system studied is Se₆₇Te₃₃. Zinc has been added in a controlled manner in the Se-Te system in accordance with the compositional formula (Se₆₇Te₃₃)ₓ₋ₐZnₓ. In selenium-tellurium systems without any zinc content, the nature of the I-V characteristics curve is linear. For the samples with zinc content, it is observed that the I-V characteristic curve shows the threshold switching type of behaviour. The threshold voltage depends upon the temperature and the zinc content of the material. The threshold switching behaviour is reversible in nature.

2. Experimental aspects

Bulk samples of (Se₆₇Te₃₃)ₓ₋ₐZnₓ were prepared by quenching of a melt in ice cold water. Appropriate materials (99.9995% supplied by Loba Industrial Co Bombay 400005, India) were weighed as per the composition (Se₆₇Te₃₃)ₓ₋ₐZnₓ, sealed in evacuated (10⁻⁵ Torr) quartz tubes and heated in a rocking furnace for about 30 hours at about 1100 K. Five samples with compositions (Se₆₇Te₃₃), (Se₆₇Te₃₃)ₓ₋ₐZnₓ, (Se₆₇Te₃₃)ₓ₋ₐZnₓ, (Se₆₇Te₃₃)ₓ₋ₐZnₓ, (Se₆₇Te₃₃)ₓ₋ₐZnₓ were prepared. Irregular bulk pieces were lapped to attain proper dimensions of the slab geometry. These samples were tested for the structure with the help of Siemens powder x-ray diffractometer fitted with a diffracted beam monochromator and a scintillation counter as detector. It was observed that all the materials were amorphous in nature. Using standard techniques (Potential Probe) [14], data for I-V characteristic curves were taken with the help of an EA 560 (Electronics Corporation of India) piezometer and specially designed sample holder consisting of two sets of electrodes capable of holding the sample between them. The proper pressure contacts among the metal electrodes and sample surfaces were ensured. The temperature of the sample was maintained by circulating water at constant temperature through the water jacket of the sample holder with the help of a MW UP thermostat. In order to prevent Joule heating of the sample and to ensure that the sample attained the temperature of its environment, readings were taken after an interval of 10 minutes from the new settings. Actual temperature of the sample w
3. Results and discussion

Results of DC measurements are presented in the form of curves for different concentrations and temperatures. Figure 1 gives the $I-V$ characteristic curves for the basic Se–Te system without any zinc content at different temperatures. Figure 2 is concerned with the $I-V$ characteristic curves of samples $(\text{Se}_{0.7}\text{Te}_{0.3})^{33.3}\%\text{Zn}_{0.5}$, $(\text{Se}_{0.7}\text{Te}_{0.3})^{33.3}\%\text{Zn}_{1.1}$, $(\text{Se}_{0.7}\text{Te}_{0.3})^{33.3}\%\text{Zn}_{1.3}$, $(\text{Se}_{0.7}\text{Te}_{0.3})^{33.3}\%\text{Zn}_{1.0}$ at 295 K. For the basic selenium–tellurium system sample (figure 1) it is observed that the $I-V$ characteristic curve is linear in the temperature range studied. The conductivity increases with increasing temperature. The linear nature of the $I-V$ characteristic curve at fixed temperature may be explained on the basis that the average velocity of charge carriers increases linearly with increasing field strength. The increase in conductivity with increasing temperature may be explained with the help of the fact that, with increasing temperature, more and more charge carriers become free and contribute to the conduction process.

The $I-V$ characteristic curves for the zinc-doped samples are found to be non-linear (see figure 2). These characteristic curves can be divided into three regions. Regions 1 and 3 are the straight-line sections and region 2 is the region of negative differential resistance. Region 1 is the low-field region having high resistance while region 3 is a high-field region of low resistance. In between these two regions is a small region of negative differential resistance (region 2). The sudden change of resistance from high (region 1) to low (region 3) may be regarded as a switching phenomenon from an OFF state (high resistance) to an ON state (low resistance). The voltage at which the negative differential resistance region starts may be called the threshold voltage $V_t$. All these characteristic curves are found to be reversible. The threshold voltage decreases with increasing temperature (figure 3). The threshold voltage is also found to depend upon the concentration of zinc (figure 4), decreasing non-linearly with increasing zinc content.

The non-linear nature of the $I-V$ characteristic curve may be explained on the basis of a defect model [15–16]. According to this model, the lowest energy defect states are positively charged three-fold coordinated $C_3^+$ and negatively charged one-fold coordinated $C_1^-$ chalcogen atoms in chalcogenide glass.
Figure 3. Variation in threshold voltage with temperature for the four different compositions. A–D as in figure 2.

Figure 4. The dependence of threshold voltage on zinc concentration.

These charge centres are present in equal concentration and their density is very high. The $C_1^+$ defect state acts as a donor. The $C_1^-$ defect state acts as an acceptor. A $C_1^-$ defect state may trap electrons and $C_1^+$ may trap holes and give rise to a neutral higher excited $C_0^0$ state. On the application of electric field at two ends of the sample of amorphous semiconducting material, electrons are injected from the cathode and holes from the anode into the material, since there is no internal build-up of electric field in the structure. These charge carriers do not move deep into the structure and hence are held up at the electrodes only. At the cathode, electrons are trapped by $C_1^-$ defect centres and these $C_1^-$ centres are transformed to neutral $C_0^0$ centres. At the anode, holes are captured by $C_1^+$ centres and the $C_1^+$ centres are transformed to $C_0^0$ neutral centres. Electrons, being more mobile than holes, are captured at a faster rate at the cathode than the holes captured at the anode. This results in the higher concentration of $C_1^+$ centres as compared with $C_1^-$ centres. This creates a high field at the anode and holes drift towards the cathode where they are captured by $C_1^+$ defect centres, changing them to $C_1^+$ centres at the cathode. This in turn increases the field at the cathode and electrons drift towards the anode. Near the anode they are captured by $C_0^0$ centres, which are transformed to $C_1^-$ centres. This in turn again increases the field at the anode. In this way motion of charge carriers from one terminal of the sample to the other terminal of the sample starts and the sample has high resistance value in region 1. At the high injection rate of charge carriers at high voltage, injected charge carriers (electrons at the cathode and holes at the anode) drift through the bulk of the material without much recombination and are available for conduction. The traps in the sample get fully filled at the threshold voltage. At voltages higher than threshold voltage, injected charge carriers drift through the material without recombination. Moreover emission from the traps gives rise to a steep increase in current and hence gives low resistance. The decrease of threshold voltage with increase in temperature may be explained in terms of the fact that, with increasing temperature, more and more defect centres get ionized because of increased thermal energy, thus lowering the voltage at which the recombination of the charge carriers is minimum. High resistance and low resistance regions are found to be separated by a small region of negative differential resistance. The presence of a region of negative differential resistance may be because of the heating-up of the entire current path. Similar results have been reported [17–18]. The absence of switching behaviour when Zn is absent (figure 1) shows that Zn atoms occupy special bonding positions in the structure so as to drastically alter the chemical nature of microstructural groups.

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References

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