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DC AND AC CONDUCTIVITY MEASUREMENTS ON $Ge_2Sb_2Te_5$ FILMS

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Thin films of $Ge_2Sb_2Te_5$ were prepared using thermal evaporation technique. The amorphous structure and stoichiometery of the films were identified by X-ray diffraction and Energy Dispersive X-ray analysis, EDX. The conductivity measurements were carried out using DC I-V curves and AC Impedance spectroscopy techniques. The measured activation energy (E_v) is found to be about 0.36–0.39 eV, respectively, which is approximately half the energy gap (E_g= 0.72–0.78 eV). The amorphous-crystalline transition temperature (T_c) of the films was also estimated to be 135°C. The results can be reserved as an evidence for the chalcogenide nature defects in $Ge_2Sb_2Te_5$ films.

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1. Introduction

Phase change materials based on chalcogenide alloys are found to be suitable for optical and electrical memories due to its fast crystallization. The operation principle of these devices is based on the ability of the active materials to reversibly transform between amorphous and crystalline phases. Among these alloys, $Ge_2Sb_2Te_5$ exhibits the best performance when used in DVD-RAM in terms of speed and stability [1, 2]. This alloy ($Ge_2Sb_2Te_5$) demonstrates high thermal stability at room temperature, high crystalline rate at high temperatures (can be crystallized by a less than 50 ns laser pulse), and extremely good reversibility between amorphous and crystalline phases (more than 10^5 cycles) [3]. In the last years, these materials have been extensively studied to understand the crystallization phenomena [4-11]. The rapid and reversible amorphous-to-crystalline phase transformation is accompanied by increase in the optical reflectivity and the electrical conductivity. However, uncertainties about the optical band gap and electrical properties of this material have persisted. Hereafter, the optical properties of $Ge_2Sb_2Te_5$ phase change material had been investigated and showed that the optical absorption in all phases (amorphous and crystalline) follows the Touc relation, which corresponds to the optical transitions in most amorphous semiconductors, [12]. The common feature of these glasses is the presence of localized states in the mobility gap. This is due to the absence of long range order as well as various inherent defects. In chalcogenide glasses, it is assumed that the localized states in the mobility gap are the charged defects D^+ and D^- with negative effective correlation energy. This type of defects usually pins the Fermi energy level in the middle of the forbidden energy gap and result in the absence of electron spin resonance signal [13, 14]. The investigation of electrical conductivity in chalcogenide glasses is a valuable tool for determining the position of the Fermi energy level in the energy gap of semiconductor materials.

In this work, a program of DC and AC conductivity measurements was carried out to investigate the electrical properties of $Ge_2Sb_2Te_5$ thin films. In particular, using I-V curves and AC

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impedance spectrum, the amorphous-crystalline transition temperature (T_c) and the activation energy (E_v) of $Ge_2Sb_2Te_5$ film were determined and hence the energy gap is estimated.

2. Experimental

Glassy alloy of $Ge_2Sb_2Te_5$ is prepared by melt quenching technique. Materials (99.995% pure) are weighed according to their atomic percentage and sealed in quartz ampoules in a vacuum $\sim 10^{-3}$ Pa. The sealed ampoule is kept inside a rotating cylindrical furnace and heated at 1050°C for 24 h to make the melt homogeneous. Thereafter, the quenching is done in ice-water bath. Thin films of $Ge_2Sb_2Te_5$ were prepared by thermal evaporation technique. The amorphous nature of these thin films is confirmed by X-ray diffraction (XRD).

The compositions of the evaporated samples are measured by Energy Dispersive X-ray analysis EDX. Pre-deposited thick gold electrodes on glass substrates are used for the electrical contacts as shown in Fig. 1. Using this sample configuration the effect of electrodes on the electrical properties of the thin film is eliminated [15].

A planar geometry of the film with active area of 1×1 mm^2 is used for electrical measurements. The thickness of the film is ~ 0.7 μm. Two and four gold electrodes were used for the AC impedance spectroscopy and I-V measurements, respectively.

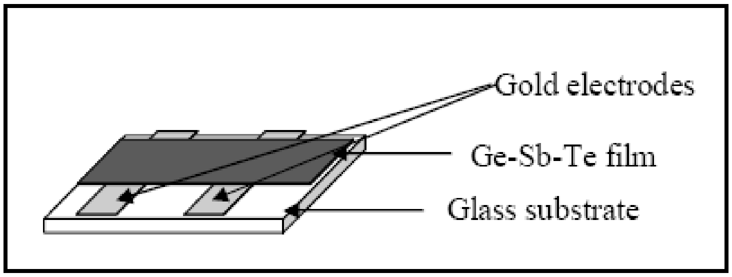

Fig.1. Schematic diagrams of the electrical contacts. The gold electrodes are evaporated on a glass substrate and then the film is deposited.

The impedance spectroscopy measurements were performed using 1260 Solartron impedance analyzer in the range of 1 Hz–10 MHz, with amplitude of 0.5 volts and zero bias. Silver paste has been used to make contact between the coaxial cable and the gold electrodes. The measurements were performed at different temperatures from 30-130°C using Monotherm (VARIMAG Electronics) electrical heating plate. The temperature was measured by a K-type thermocouple integrated with the heating plate. The samples were heated in Argon gas environment.

Four probes technique has been used to measure I-V characteristics (Keithley 238) of the sample using the configuration of figure 1 with the addition of two other gold electrodes. The samples were heated from room temperature up to 150 °C.

3. Results

Fig. 2 shows the current versus voltage (I-V) curves for $Ge_2Sb_2Te_5$ film at different temperatures (70-150°C). The I-V curves are straight lines in the measured temperature and voltage ranges. This indicates that the material has an ohmic resistance, which can be calculated from the slope of the I-V curve at each temperature. The resistance of the $Ge_2Sb_2Te_5$ film is plotted as function of temperature in figure 3. A sharp drop in the resistance is evident at T≈ 135°C ($10^3/T$= 2.45 K^{-1}). This temperature is the amorphous-crystalline phase transition temperature (T_C) of the material, [11]. Below this temperature the *ln R* versus *1/T* curve is a straight line in the measured temperature range below 135^{o}C. The resistance R can, therefore, be expressed by the well known Arrhenius relation [16],

$$\sigma \propto e^{-E_V / kT} \quad or \quad R \propto e^{E_V / kT} \qquad (1)$$

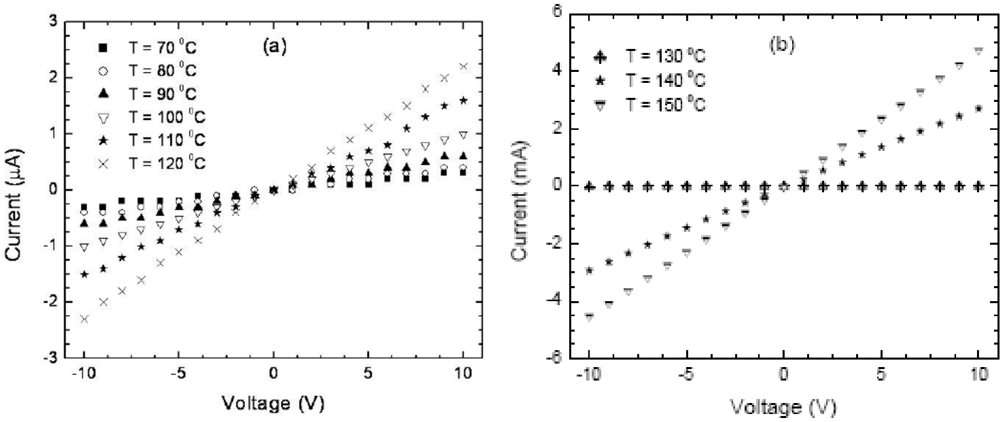

Fig. 2.The I-V curves for $Ge_2Sb_2Te_5$ films at different temperatures a) in the amorphous phase and b) around and after the transition to the crystalline phase.

where σ is the conductivity, E_v is the activation energy for dark conductivity and k_B is the Boltzmann constant. From figure 3, the value of E_v is estimated as 0.36 eV.

The impedance spectra at different temperatures (T= 80-120^{o}C) for $Ge_2Sb_2Te_5$ film are shown in Fig. 4. The impedance spectra is the plot of imaginary part of the impedance Z" versus its real part Z′, the so called Nyquist plot. It can be observed that at the same temperature, the distribution of frequencies from low to high fit with one semicircle. A parallel resistor and capacitor (RC) equivalent circuit accurately fit the frequency data [17]. Hence the electrical properties of $Ge_2Sb_2Te_5$ film can be associated to a simple RC equivalent circuit. R is determined from the radius of the semicircle and C is determined by using the frequency at the peak maximum of each semicircle (relaxation frequency, f_0), where $2\pi \ f_0 RC = 1$ should be satisfied. As expected, the radius of the semicircle (sample resistance R) keeps decreasing with increasing the temperature. Moreover, the semicircle peaks shift toward higher frequency as the temperature increases. These two behaviors are due to the thermal activation that occurs in semiconductor materials.

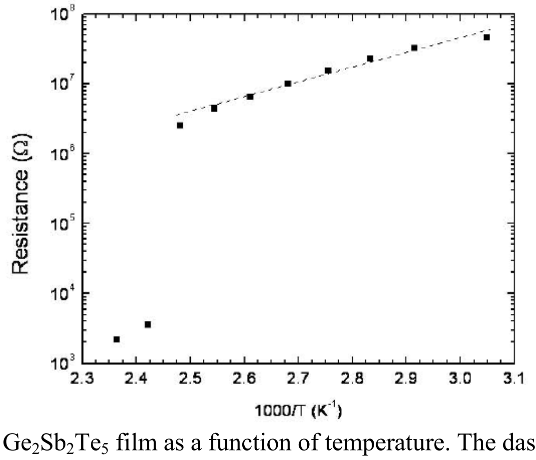

Fig.3. Resistance of $Ge_2Sb_2Te_5$ film as a function of temperature. The dashed line is the linear fit of the resistance in the amorphous state.

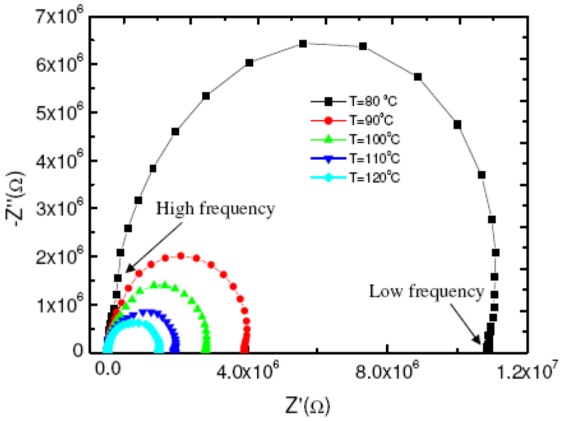

Fig. 4. Impedance spectra for $Ge_2Sb_2Te_5$ film at different temperatures.

The relaxation frequency obtained is plotted against temperature, as shown in Fig. 5. It is obvious from the figure that the frequency is thermally activated according to the Arrhenius relation.

$$f_o \propto e^{-E_v / k_B T} \tag{2}$$

From Fig. 5 the relaxation frequency increases exponentially in the measured temperature range. The activation energy, E_v, calculated from the slope of the straight line fit is found to be 0.39 eV. This value is relatively close to the one obtained by I-V measurements.

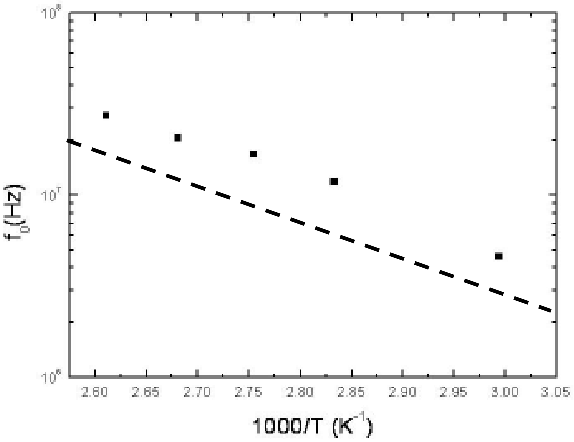

Fig.5. Frequency at the peak of the semicircle as a function of 10^3/T (K^{-1}).

4. Discussion

The temperature behavior of the DC and AC measurements indicate that the conduction in these glasses, $Ge_2Sb_2Te_5$, is through an activated process having single activation energy in the investigated temperature range, where both resistance and relaxation frequency have the same temperature dependence. The calculated activation energy values from figures 3 and 5 are close to each other, 0.36 and 0.39 eV, respectively. To the first approximation, the value of the activation energy determines the position of the Fermi energy level with respect to the conducting mobility edge. If $Ge_2Sb_2Te_5$ film has chalcogenide characters, this means that the Fermi energy level is pinned in the middle of the energy gap, E_g [16]. Therefore the energy gap can be estimated to be $E_g= 2E_v$. Therefore the corresponding energy gap obtained from I-V measurements and AC impedance spectroscopy are 0.72 and 0.78 *eV*, respectively. This value for the energy gap is in good agreement with the optical gap E_o= 0.7 eV measured by Bong-Sub Lee et al. [12]. This can be reserved as an evidence for the chalcogenide nature defects in amorphous $Ge_2Sb_2Te_5$ films, which characterized by the negative effective correlation energy charge centers D^+ and D^-.

5. Conclusion

The electrical properties of $Ge_2Sb_2Te_5$ thin films using impedance spectroscopy and I-V measurements are presented. The data shows similar resistance and relaxation frequency temperature dependence with activation energies 0.36 and 0.39 eV, respectively. Therefore the corresponding-energy gap is estimated to be 0.72 eV and 0.78 eV. This value for the energy gaps is compared well with that reported in literature by optical measurements. This agreement between electrical and optical measurements confirms that $Ge_2Sb_2Te_5$ belongs to the chalcogenide family. The amorphous-crystalline transition temperature (T_c) is found to be 135 °C.

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