Journal of Asian Ceramic Societies 4 (2016) 178–184

Contents lists available at ScienceDirect

Journal of Asian Ceramic Societies

journal homepage: www.elsevier.com/locate/jascer

Dielectric relaxation and AC conductivity studies of $Se_{90}Cd_{10-x}In_x$ glassy alloys

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ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form 5 January 2016
Accepted 19 February 2016
Available online 6 March 2016

Keywords:
Chalcogenide glass
DSC
SEM
Dielectric properties

ABSTRACT

Chalcogenide glassy alloys of $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) are synthesized by melt quench technique. The prepared glassy alloys have been characterized by techniques such as differential scanning calorimetry (DSC), scanning electron microscopy (SEM) and energy dispersive X-ray (EDAX). Dielectric properties of $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) chalcogenide glassy system have been studied using impedance spectroscopic technique in the frequency range 42 Hz to 5 MHz at room temperature. It is found that the dielectric constants ε', dielectric loss factor ε'' and loss angle Tan δ depend on frequency. ε', ε'' and loss angle Tan δ are found to be decreasing with the In content in $Se_{90}Cd_{10-x}In_x$ glassy system. AC conductivity of the prepared sample has also been studied. It is found that AC conductivity increases with frequency where as it has decreasing trend with increasing In content in Se–Cd matrix. The semicircles observed in the Cole–Cole plots indicate a single relaxation process.

1. Introduction

Chalcogenide glasses have attracted much attention due to their potential applications in optoelectronic devices, solar cell, memory switching, infrared photo detectors and bio-sensors [1–5]. A variety of applications including phase change memory, photo receivers, and change of electrical resistance have been reported using these glasses [6–8]. Such dielectric materials have been widely employed in various industrial devices such as dynamic access memory microwave filter, voltage controlled oscillator and telecommunication technologies [9]. Among VI–II–III group ternary compound selenium–cadmium–indium (Se–Cd–In) has found applications in optoelectronics and solar cells due to its higher value of absorption coefficient. Dielectric relaxation studies are important to understand the nature and the origin of dielectric loss which, in turn, may be useful in the determination of structure and defects in solids. As these materials are covalently bonded solids, the dispersion is not expected at low frequencies. However, recent measurements have indicated [10–13] that dielectric dispersion loss does exist in these glasses even at very low frequency. The origin and nature of dielectric losses in these materials has, therefore, become a matter of curiosity.

Frequency-dependent electrical conductivity of chalcogenide semiconductors is helpful to understand the conduction mechanism in their alloys. Therefore, it is interesting to study the electrical behavior of these materials in AC fields which gives the important information about the transport process in localized state in the forbidden gap [14].

AC conductivity and dielectric measurements have been reported for a wide variety of amorphous chalcogenide semiconductors in order to understand the mechanisms of conduction processes in these materials and type of polarization [15–25]. Chalcogenide glasses are known to be structurally disordered system and addition of impurities in the disordered system changes their structure, which leads to the change in conduction mechanism, which has been found to vary with different impurities [26–31]. The alloys produce characteristic effect which depends on the electronic structure of the alloying elements. Among various chalcogenide elements only Se is available in amorphous form, but it suffers from the disadvantage of short life time and low sensitivity [32]. However, the addition of impurities leads to relatively stable glasses with improved physical qualities [33,34]. Many researchers have studied conduction mechanism and structural and optical properties of Se-based chalcogenide semiconductors [35–37]; however, the studies on AC conductivities are too limited and require more understanding.

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Peer review under responsibility of The Ceramic Society of Japan and the Korean Ceramic Society.

http://dx.doi.org/10.1016/j.jascer.2016.02.003

In the present work indium (In) has been chosen as an additive element in Se–Cd alloys because it is recognized as one of the most efficient elements used to improve the opto-electronic properties of compounds [38]. The third element behaves as chemical modifier and creates compositional as well as configurational disorder in the material with respect to binary alloys, which will be useful in understanding the structural, electrical and optical properties of Se–Cd–In chalcogenide glasses [39–41]. The literature survey on dielectric studies shows that relatively very few research works have been reported on dielectric relaxation studies of Se–Cd–In systems.

In the present work SEM and EDAX have been measured to analyze the surface morphology and elemental compositions of $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) glassy alloys. Dielectric measurements of $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) chalcogenide glasses have been carried out in the frequency range 42 Hz to 5 MHz at room temperature. The dependence of dielectric constant ε', dielectric loss factor ε'' and loss angle Tan δ with In concentration as well as frequency is discussed. Frequency- and composition-dependent AC conductivity have been studied. The complex impedance plots have been studied for $Se_{90}Cd_{10-x}In_x$ glassy alloys.

2. Experimental details

Chalcogenide glassy alloys of $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) were prepared from high purity (99.999%) Se, Cd and In elements by the melt quench technique. The exact amounts of alloying elements were weighed according to their atomic weight percentage using an electronic balance (LIBROR, AEG-120) with the least count of 10^{-4} g and placed into ultra-cleaned quartz ampoules (length ≈ 5 cm and internal diameter ≈ 8 mm). The ampoules were evacuated and sealed under a vacuum of 10^{-5} Torr to avoid reaction of alloying elements with oxygen at a higher temperature. The sealed ampoules were heated in a furnace at rate of 4–5 K min^{-1}, the temperature raised up to 800 °C and kept at that temperature for 12 h. During the heating process, the ampoules were constantly rocked by rotating ceramic rod to ensure the homogeneity of alloying materials. The ampoules with molten materials were rapidly quenched into ice-cooled water. The ingots of glassy materials were taken out from ampoules by breaking them. To determine the glass transition and crystallization temperatures differential scanning calorimetric (DSC) measurements were carried out on powdered samples of $Se_{90}Cd_{10-x}In_x$ under pure N_2 atmosphere using Mettler Toledo Star instrument (Model No. DSC-200PC). Surface morphology was studied using the JEOL, Japan JSM-6510 Model SEM. The magnification used was 10,000×. The compositional analysis of the prepared alloy was studied by EDAX attachment to the above-mentioned SEM model. Dielectric and electrical conductivity measurements have been done with Hioki LCR Hi-Tester (3522) in the frequency range from 42 Hz to 5 MHz. For this, glassy samples were pressed into cylindrical pellet forms having diameter 10 mm and thickness about 1.2 mm under uniform load of 5 tons using hydraulic press. A pellet was sandwiched between two circular silver discs in order to ensure good electrical contact between sample and electrodes of the LCR meter. This whole assembly of sample and discs is placed between the electrodes of the LCR meter. The signal voltage level was kept at 0.02 V.

3. Results and discussion

3.1. Differential scanning calorimetric analysis

A typical DSC thermogram of $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) at a particular heating rate of 10 K min^{-1} is shown in Fig. 1. Similar thermograms were obtained for other heating rates at 5, 15, and 20 K min^{-1} also (results not shown here). It is evident from Fig. 1 that each thermogram shows two distinct peaks corresponding to glass transition (T_g) and peak crystallization temperature (T_c). Glass transition and peak crystallization temperatures for $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) have been determined and listed in Table 1.

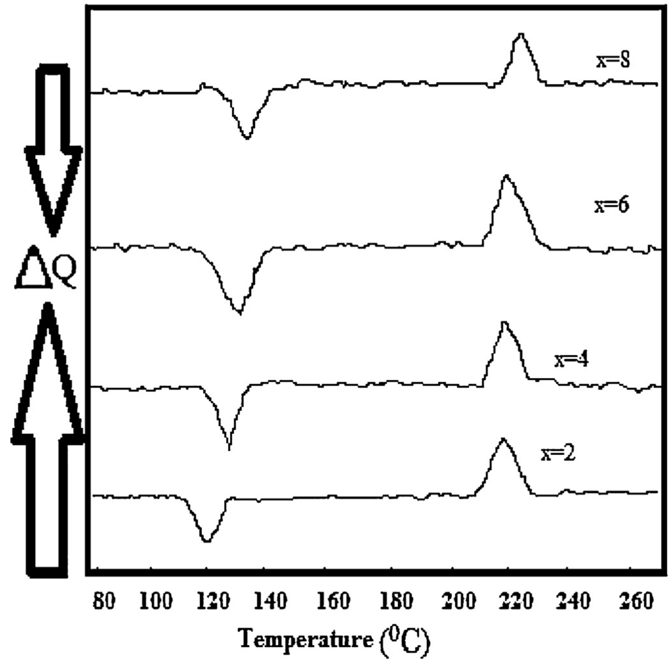

Fig. 1. DSC thermograms for glassy $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) alloys at heating rate of 10 K min^{-1}.

Table 1
Glass transition (T_g) and crystallization temperatures (T_c) for glassy $Se_{90}Cd_{10-x}In_x$ ($x = 2, 4, 6, 8$) alloys.

Sample $Se_{90}Cd_{10-x}In_x$	T_g (°C)	T_c (°C)
$x = 2$	120	218
$x = 4$	126	219
$x = 6$	128	220
$x = 8$	130	224

3.2. Surface morphological analysis

SEM is a promising technique for the topographic analysis, which gives important information regarding growth mechanism, shape and size of the sample. Fig. 2 shows the scanning electron micrographs of the studied samples, and it can be observed that morphology of the prepared bulk samples (pellet) changes with Indium content. From SEM micrographs it is evident that images of the samples are uniform and without any pin holes or cracks and there is formation of conchoidal contours, which shows the presence of some micro-crystallites embedded in the glass matrix of the synthesized material.

The elemental compositions of $Se_{90}Cd_{10-x}In_x$ glassy alloys were checked by energy dispersive X-ray analysis (EDAX). Fig. 3 shows the energy dispersive X-ray spectroscopy (EDAX) of $Se_{90}Cd_8In_2$ glassy alloy. EDAX for other compositions are also studied (results not shown here). Table 2 gives the compositional analysis of $Se_{90}Cd_{10-x}In_x$ glassy alloys. EDAX analysis indicates the absence of impurity elements in the studied composition.