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High-field conduction and dielectric study in a-$Se_{78-x}Te_{22}Bi_x$ alloys

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Abstract

The present paper reports the measurements on space charge limited conduction (SCLC) in vacuum evaporated amorphous thin films and dielectric relaxation study in bulk of $Se_{78-x}Te_{22}Bi_x$ where $0 \leqslant x \leqslant 4$. At high fields ($\sim 10^4$ V/cm), the current could be fitted to the theory of SCLC, in case of a uniform distribution of localized states in the mobility gap of these materials. The results indicate an increase in the density of localized states on addition of bismuth (Bi) in the $Se_{78-x}Te_{22}Bi_x$ system. The value of density of the states $N(E_F)$ increases two orders of magnitude at $x \geqslant 2$. The nature of the capacitances is also changes at $x \geqslant 2$, i.e. from positive to negative capacitance. This transition at $x \geqslant 2$ may be explained in terms of a change in conduction from p- to n-type, when the Bi concentration is increased.

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Keywords: Space charge limited conduction; Thin films; Density of states

1. Introduction

Amorphous semiconductor films have been investigated from the points of view of basic physics as well as of device technology for various applications [1–4]. The use of these films for reversible optical recording by change its phase from amorphous to crystalline has been reported [3,4]. The choice of selenium-based alloys is due to its device application like rectifiers, photocells, and switching and memory. But pure selenium has low sensitivity and short lifetime. In order to overcome this difficulty, several workers have used certain additives (Bi, Te, Ge, etc.) for alloying Se to some extent.

The optical and electrical properties of amorphous solids are determined by the structural bonding between the neighboring atoms. The structural bonding in the case of chalcogenides, for instance selenium and tellurium, is divalent in

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nature which gives rise to a one-dimensional structural stability of the amorphous materials. The structural bonding in this amorphous matrix is not highly stable [3,5], and chalcogenides in the amorphous state have a strong tendency to crystallize. The transition from the amorphous state to the crystalline state can be induced by several factors [5] such as heat treatment, incident light, electric field, etc.

One of the most direct methods for the determination of $N(E_F)$ involves the measurement of the space charge limited current (SCLC), which can easily be observed at high fields in amorphous materials because of their low conductivity. This technique has already been applied [6–8] to hydrogenated amorphous silicon and it is generally observed that $N(E_F)$ obtained by this method is lower by a factor of 3–5 than by other techniques as surface states do not come into the picture in this experiment. The work presented in this paper has been done with the purpose of studying the effect of a third element on $N(E_F)$ in binary Se–Te alloy.

We have chosen Bi because of its special role in the type of conduction [9]. The chalcogenide materials usually show p-type conduction. Tohge et al [10] and Negels et al. [11] reported that the type of conduction changes from p to n-type when $Bi \geqslant 7$ at%. This change is related to the chemistry of the system and ascribed to a change in the Fermi level [12]. Several workers have added different elements to Se–Bi system, and most of these materials exhibit a p- to n-type transition [13–15].

Dielectric relaxation studies are also important to understand the nature of dielectric losses in these materials. The dielectric constant and dissipation factor are reported here in the frequency range (.04–100 kHz).

Beale et al. [16,17] have observed a negative capacitance (NC) in a metal–insulator–metal structure prepared from Mn-doped ZnS, with relatively high electric fields under the condition of impact ionization. NC has also been observed by various workers [18–20] in amorphous chalcogenide films, semi-insulating polycrystalline silicon, GaAs Schottky diode and electrolyte cells, etc. NC indicates that the current variation in the device lags behind the voltage agitation. This somehow resembles an inductor. One possibility is that the alignment of the electron spin or of the orbital magnetic momentum at the interface makes the device act like an inductor under AC influence. In the present study, we have observed that the density of states $N(E_F)$ increases two orders of magnitude at $x \geqslant 2$. The nature of the capacitances also change at $x \geqslant 2$, i.e. from positive to NC. This transition at $x \geqslant 2$ may be explained in terms of a change in conduction from p- to n-type, when the Bi concentration is increased.

2. Experimental details

Glassy alloys of a-$Se_{78-x}Te_{22}Bi_x$ ($x = 0$, 0.5, 2, and 4) were prepared by a melt-quenching technique. Materials of 99.999% purity were sealed in quartz ampoules (length ~12 cm, internal diameter .8 cm) with a vacuum $\sim 10^{-6}$ Torr. The sealed ampoules were kept inside a furnace where the temperature was raised slowly (3–4 °C min^{-1}) to 900 °C. The ampoules were rocked frequently for 10 h at the maximum temperature to make the melt homogeneous. Quenching was done in ice water. X-ray diffraction traces of all four samples were taken at room temperature and found to show almost similar trends. Therefore, only two of them (for $Se_{78}Te_{22}$ and $Se_{76}Te_{22}Bi_2$ samples) are shown in Fig. 1. The absence of sharp structural peaks in these X-ray diffraction traces confirmed the amorphous nature of the samples.

Thin films of the glassy alloys were prepared by vacuum evaporation technique using a standard coating unit. Well-degassed corning glass plates, having predeposited indium electrodes, were used as a substrate for depositing amorphous films in the planar geometry (length ~1.2 cm) with different electrode gaps. These films were prepared by evaporation technique keeping the substrate at room temperature at a base pressure 10^{-6} Torr, using molybdenum boats. The thickness of the amorphous films was ~5000 Å .The films were kept in the deposition chamber in the dark for 24 h before mounting them in the sample holder. This