Journal of Alloys and Compounds 506 (2010) 661–665

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

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

Comparative study of electrical properties of Cd and Te-enriched CdTe thin films at cryogenic temperature

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ARTICLE INFO

Article history:
Received 12 February 2010
Received in revised form 5 July 2010
Accepted 7 July 2010
Available online 15 July 2010

Keywords:
Thin films
Coatings
Resistivity
Cadmium telluride

ABSTRACT

Cd and Te-enriched cadmium telluride (CdTe) polycrystalline thin films were grown on corning glass substrates by Close Spaced Sublimation (CSS) technique. The structural investigations performed by means of X-ray diffraction (XRD) technique, scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDX) showed that the deposited films exhibit a polycrystalline structure with ⟨1 1 1⟩ as preferred orientation. The optical transmittance for Te-enriched CdTe sample was above 0.8 in the range of 1500–2500 nm, which was significantly below 0.8 for Cd-enriched CdTe sample. The electrical properties of these samples were analyzed as a function of the Cd and Te concentration at cryogenic temperature. The electrical resistivity dropped several orders of magnitude. These properties are significantly changed at cryogenic temperature. The comparative study revealed that using this deposition technique, *n*-type, and *p*-type Cd and Te-enriched CdTe polycrystalline films can be produced.

1. Introduction

Search for efficient photo-receiving materials is a long standing demand of scientific community. CdTe is II–VI semiconductor material quite appropriate for applications to solar energy conversion devices [1–3]. Though this semiconductor has been focused as solar cell material but could not get much attention commercially due to its cost factors. An important reduction in the cost of solar cells can be achieved by preparing doped polycrystalline thin films of appropriate quality. CdTe thin films have been prepared by several growth techniques [4–19]. However, the best CdTe thin films based solar cells have been fabricated using CSS method which is one of the various techniques with large area manufacturing potential due to its high throughput and efficient material utilization [20]. Thin films prepared by the CSS method have distinct novel features such as large grain sizes, well-defined preferential orientation and relatively high absorption coefficients needed in the fabrication of solar cells material [20].

In this paper we present some of the electrical properties of Cd and Te-enriched CdTe thin films prepared by the CSS method. The experiments were carried out by taking Hall measurements at cryogenic temperature. Furthermore, comparative analysis of measured physical properties is presented. To our knowledge the comparative study of Hall measurements on Cd and Te-enriched CdTe thin films at liquid nitrogen temperature are not reported earlier.

2. Experimental

The deposition of CdTe thin films by the CSS technique is based on the following reversible dissociation of CdTe at high temperature:

$$2CdTe_{(s)} \Leftrightarrow 2Cd_{(g)} + Te_{2(g)} \quad (1)$$

The schematic diagram of Close Space Sublimation (CSS) experimental set up is shown in Fig. 1, where a small distance of about 5 mm separates the CdTe source from a corning glass substrate. The source temperature was kept higher than that of the substrate, because the source CdTe dissociates into its constituent elements, i.e. Cd and Te and then recombines on the substrate surface, which was kept at a lower temperature. The source and substrate could be maintained at the desired temperature as they were heated and controlled separately. Two K-type thermocouples were used to monitor the temperatures of the source and the substrate during the evaporation process. The temperatures of the source and substrate were maintained at 500 and 400 °C, respectively.

The source material (CdTe 99.999% purity) was placed in a graphite sublimation cast as shown in Fig. 1. The substrate was first cleaned with IPA bath in an ultrasonic cleaner for about 60 min and further cleaned by lint free tissues with the help of tweezers and finger cots to avoid fingerprints on the glass substrate. The substrate was then supported by the cast which was made of heat insulating mica sheet and kept in a close proximity to the source material. Initially the vacuum chamber was allowed to evacuate by a rotary vane pump. The chamber was kept for evacuation for about an hour each time to reach approximately 10^{-3} mbar.

The optimized time for deposition was 5 min for each thin film. The thin film was then kept at substrate temperature until the temperature of source became lower than the substrate temperature after that the substrate heater was switched off to allow cooling to ~40 °C before opening the vacuum chamber. By using the automatic temperature controller for heating the source and substrate, the quality of the thin film was optimized.

In the next step, these as-deposited CdTe thin films were used as substrate for varying excess Cd mass (99.99% purity) deposition by the same technique to get Cd-enriched samples. The source (Cd) and substrate (CdTe) temperatures were kept at 350 and 250 °C, respectively.

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doi:10.1016/j.jallcom.2010.07.038

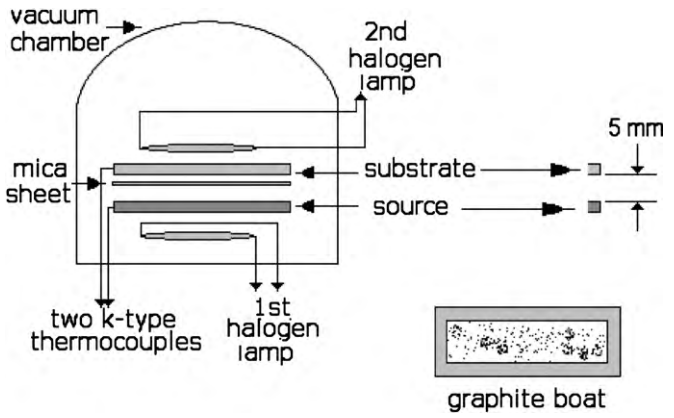

Fig. 1. Schematic diagram of Close Space Sublimation (CSS) experimental set up.

Similarly the CdTe thin films were covered with varying excess Te mass, which was evaporated onto them by CSS technique under the same vacuum conditions to get Te-enriched samples. This time the temperature of the source (Te) and substrate were kept at 200 and 100 °C, respectively. The time of Te evaporation was 5 min for each thin film. After that all the Cd and Te-enriched thin films were annealed at 300 °C for about 30 min under the same vacuum. The annealed samples were characterized and their electrical properties were studied at cryogenic temperature.

The structure of the samples was studied by XRD technique. The compositional analysis of the samples was determined by EDX attached with the SEM. Transmission spectra of Cd and Te-enriched samples were taken by the UV–vis–NIR spectrophotometer. Resistivity, mobility and carrier concentration of samples were measured by Hall Effect measurements system HMS 3000 Ecopia at liquid nitrogen temperature.

3. Results and discussions

3.1. X-ray diffraction studies

The structural analysis of the samples were carried out by using X-ray diffraction technique with Cu-K_α radiation (λ = 1.5418 Å). The XRD patterns of the as-deposited and Cd and Te-enriched CdTe samples are similar in the main reflection and can be indexed based on a cubic CdTe lattice. The strong (1 1 1) reflection in the patterns indicates a preferential orientation of [1 1 1] in thin films as already reported for thermally evaporated CdTe thin films [18,19]. The position of (1 1 1) crystalline line shifts slightly to a higher angular position by increasing Cd concentration. There is an inverse relationship between lattice constant and Cd concentration; lattice constant decreased on increasing Cd concentration. The incorporation of extra Cd reduces the lattice constant which is due to reduction in the bond length produced by the interstitial Cd atoms in CdTe lattice. While the increase in the lattice constant of the Te-enriched samples can be explained as follows. The diffusing Te atoms may replace the Cd atoms by a kick off mechanism besides its diffusion at interstitial position in the lattice, during the annealing process. This may result in an increase of the lattice constant [19].

Table 1
Composition of Cd and Te in Cd-enriched CdTe samples.

Sample no.	Cd (at.%)	Te (at.%)	Lattice constant (Å)
1 (as-deposited)	45	55	6.48
2	46	54	6.46
3	48	52	6.45
4	51	49	6.43
5	52	48	6.42

Table 2
Composition of Cd and Te in Te-enriched CdTe samples.

Sample No.	Cd (at.%)	Te (at.%)	Lattice constant (Å)
1 (as-deposited)	47	53	6.48
2	46	54	6.49
3	43	57	6.56
4	41	59	6.57
5	40	60	6.54

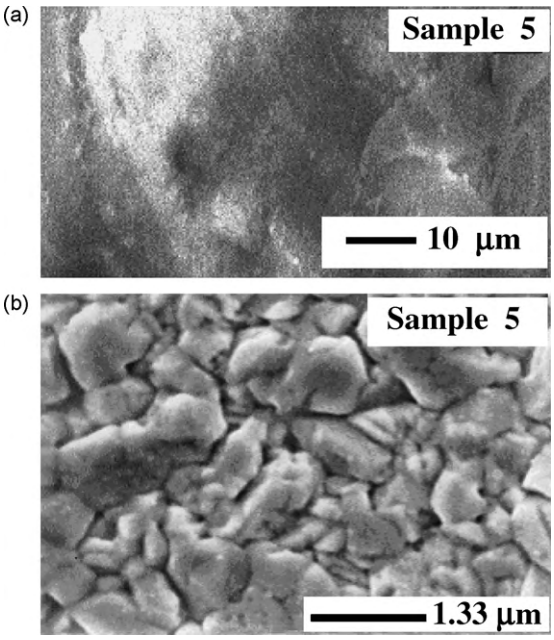

Fig. 2. (a) SEM image of the Cd-enriched sample 5. (b) SEM image of the Te-enriched sample 5.

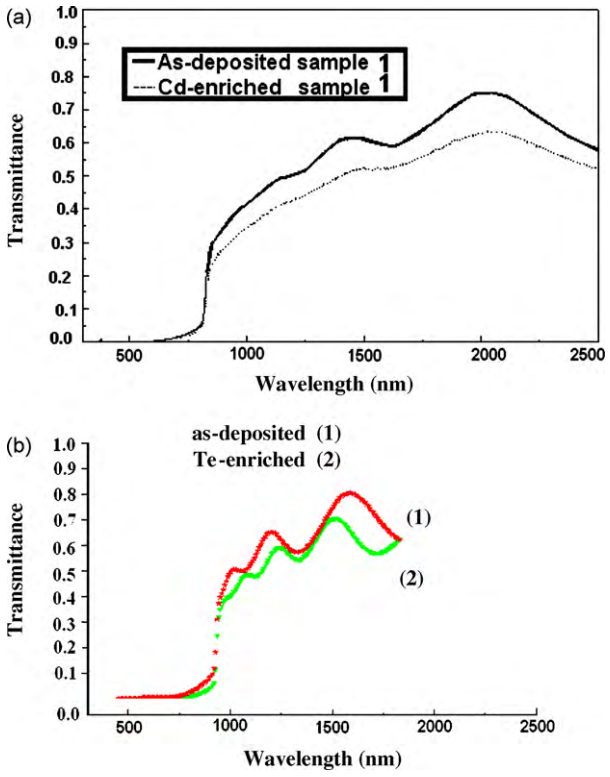

Fig. 3. (a) Transmittance spectra of as-deposited and Cd-enriched sample 1. (b) Transmittance spectra of as-deposited and Te-enriched sample 1.