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Effect of laser annealing on thermally evaporated CdTe thin films for photovoltaic absorber application

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ABSTRACT

CdTe thin films were deposited on soda lime glass substrates (SLG) by thermal evaporation technique under high vacuum condition. As-deposited CdTe thin films were subjected to post deposition laser annealing treatment at three laser output energies of 50, 60, and 70 J/pulse. Laser annealing was employed using the laser beam with combined wavelengths of 1064 nm and 532 nm, where the laser energy was varied and the oscillator frequency was kept fixed at 10 Hz. XRD was employed to find the structural properties of the as-deposited and laser annealed CdTe thin films. Topography and surface morphology of the CdTe thin films were investigated using AFM and FESEM, respectively. Chemical composition and stoichiometry of the films were analysed by EDX integrated with FESEM. Electrical properties of the CdTe films were measured using Hall Effect measurement system and the optical properties of the as-deposited and laser annealed CdTe films were studied by UV–Vis. XRD analysis showed that as-deposited and laser annealed CdTe thin films had a mixed phase of cubic and hexagonal structures with the preferential crystal orientation of C (1 1 1) at approximately 2θ = 23.80°. CdTe thin films laser annealed at 60 J/pulse had better crystalline property having minimum internal strain with lower surface roughness and larger grain size resulting in optimized coalescence. EDX, Hall Effect, and UV–Vis results for the film laser annealed at 60 J/pulse depicted good compositional stoichiometry, better electrical properties and optimum optical properties showing the prospects as a potential absorber for CdTe thin film solar cells.

1. Introduction

The semiconductor devices such as photodiodes, detectors, photoconductors and photovoltaic solar cells that are currently in use are made from thin film semiconductors (Hernandez-Contreras et al., 2004; Romeo et al., 2000; Seto et al., 2001; Becerril et al., 2001; Azhari et al., 1997). The II-VI compound semiconductor cadmium telluride (CdTe) is a very attractive and popular photovoltaic material because of its high potential properties (Amin et al., 2001). Some of its properties such as high absorption coefficient (5.1×10^5/cm) and ideal energy band gap (Eg) of 1.45–1.5 eV at room temperature makes CdTe a very attractive material for solar cells (Islam et al., 2013; Williams and Patterson, 1982; Lalitha et al., 2004; Uda et al., 1990). In thin film hetero-junction solar cells CdTe is a very promising absorber layer because of its long term performance stability (Batzner et al., 2001). CdTe can be deposited by varies deposition techniques which include close spaced sublimation (CSS), vapour transport deposition (VTD), physical vapour deposition (PVD), metal organic chemical vapour deposition (MOCVD), electro-deposition and screen printing (McCandless and Sites, 2004; Khan et al., 2014). Deposition technique which has plasma based method like magnetron sputtering has significant benefits due to using of excited state species to improve the doping control during growth and the use of low energy particle bombardment to achieve lower growth temperatures (Alvin, 2004). Thermal evaporation technique which is a physical vapour deposition method (PVD) done in vacuum condition has many advantages such as in the growing layer the amount of impurities included will be minimized, as well as the formation of oxides will be significantly reduced and finally propagation from source

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Table 1
Sample identification with description.

Sample number	Description
P2	As-deposited at 28 A current
P2A1	As-deposited at 28 A current and laser annealed at 50 J/pulse
P2A2	As-deposited at 28 A current and laser annealed at 60 J/pulse
P2A3	As-deposited at 28 A current and laser annealed at 70 J/pulse

to substrate will occur in straight line (Lalitha et al., 2007) (see Table 1).

In this paper, the effect of laser annealing on the thermally evaporated CdTe thin films was investigated by varying the laser output energy. The laser annealing on CdTe thin films was carried out under low vacuum at 10^{-3} Torr by illuminating with pulsed Nd:YAG laser beam with combined wavelengths of 1064 nm and 532 nm at various energies 'E' between 50 J/pulse to 70 J/pulse. Laser annealing has many advantages which include excellent annealing selectivity for a short process duration and heating time and zone could be controlled with delicate precision (Tang et al., 2009; Kim, 2013; Schade et al., 2013; Kim, 2013).

2. Methodology

The commercially available soda lime glasses (SLG) were used as a substrate to deposit CdTe thin films by thermal evaporation technique. Initially, the soda lime glasses were cleaned in an ultrasonic bath degreased by methanol-acetone-methanol and deionized water for 10 min, respectively. Then the degreased glasses were dried using compressed N_2. The thermal evaporation system, Ulvac Kiko VPC-060 was used to deposit the CdTe thin films of approximately 2 µm thickness on to the ultrasonically cleaned glasses using 99.99% pure CdTe powder at a deposition current of 28 A. The tungsten boat with 99.9% purity was used as filament heater and the boat to substrate distance was kept fixed at 5 cm. By the combination of rotary and diffusion pump, the chamber was evacuated to a pressure of 10^{-5} Torr. The tungsten boat was then resistively heated by supplying adequate power to achieve sufficient thermal energy which was achieved by gradually increasing the current from 0 A to the set parameter of 28 A. The temperature of the boat increased with the increase in current ultimately heating the CdTe source and once the temperature went above the melting point of CdTe, it started to evaporate, and the evaporation time was fixed at 26 min to maintain uniform thickness of all the CdTe thin films. The deposition was carried out at room temperature without any substrate heating. After the deposition completion, the current was gradually reduced, and the deposited films were left inside the chamber for half an hour to allow the tungsten boat to cool naturally.

The laser annealing of CdTe thin films was done by placing the thin films on a stage controller with an x-y translation which offered a low level vacuum of 10^{-3} Torr using a roughing pump. Laser annealing was carried by illuminating with pulsed Nd:YAG laser system and the laser beam with a combined wavelength of 1064 nm and 532 nm were used at different laser energies 'E' of 50, 60 and 70 J/pulse respectively. The combined wavelength of 1064 nm and 532 nm was chosen based on the previous study which showed that the combined wavelength is better than a single wavelength of 532 nm (Khan et al., 2015). The pulse repetition rate was maintained at 10 Hz and the scanning velocity for the laser beam irradiance was kept fixed at 0.5 mm/s. The working distance of the focusing lens was at 60 mm and the spot size of 1 mm was focused by the Nd:YAG laser system.

The structural properties of CdTe thin films were examined by X-ray diffraction (XRD). The atomic force microscope (AFM) was used to measure the film roughness. The surface morphology and the chemical composition were analysed using a field emission scanning electron microscope (FESEM) and energy dispersive X-ray spectrometry (EDS), respectively. The electrical and the optical properties were measured by the Hall Effect measurement system and ultra violet visible spectroscopy (UV–Vis), respectively.

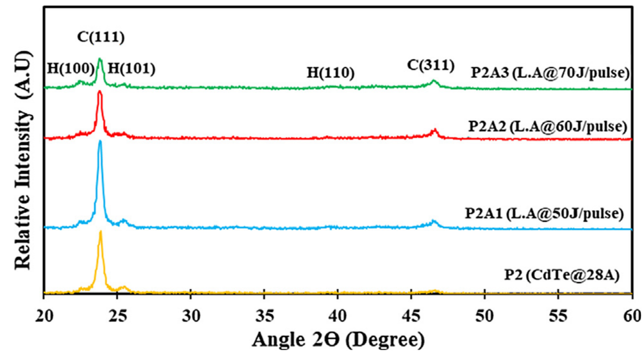

Fig. 1. XRD pattern of as-grown and laser annealed CdTe thin films.

3. Results and discussion

3.1. Structural analysis

To investigate the structural properties of CdTe thin films, XRD analysis was carried out using 'BRUKER aXS-D8 Advance Cu-Kα' diffractometer. The information obtained from XRD was used for the determination of phases, crystallinity, dislocation densities, micro-strain, etc. Fig. 1 shows the XRD pattern for the CdTe thin films that were as-grown at 28 A current and then laser annealed at three different energies 'E' of 50, 60 and 70 J/pulse respectively. The XRD pattern for all the CdTe thin films exhibits polycrystalline nature with a mixed phase of zinc-blende (cubic, C) and wurtzite (hexagonal, H) crystal structures (Kim, 2013; Arizpe-Chavez et al., 1997). The diffraction pattern for all the films shows the predominant C (1 1 1) plane at $2\theta = 23.80°$ as the preferential orientation and a minor C (3 1 1) peak observed at approximately $2\theta = 46.60°$. The presence of hexagonal phase in all the CdTe thin films was evident with a few smaller peaks of H (1 0 0), H (1 0 1), and H (1 1 0) at $2\theta = 22.50°$, 25.50° and 39.50°, respectively. The diffraction peaks reflected are in good agreement with the JCPDS data file (00-015-0770) and (01-073-2871), respectively (Khan et al., 2015). The XRD pattern for all the CdTe thin films indicated that the grain growth occurred with a preferential orientation of C (1 1 1) regardless of the different laser energies.

The interspacing between the planes in the atomic lattice, *d* has been calculated using the Brag's Law (Islam et al., 2013)

$$d_{hkl} = (\lambda/2)\,\mathrm{cosec}\theta \quad (1)$$

where λ is the X-ray wavelength (0.154 nm) and θ is the angle between the incident ray and the scattering planes.

Scherrer formula was used to obtain more structural information, the crystallite sizes *D* for the CdTe thin films (Rahman et al., 2014; Warren, 1990; Sarmah et al., 2008)

$$D_{hkl} = 0.9\lambda/(\beta\cos\theta) \quad (2)$$

where θ is the Bragg diffraction angle, λ is the X-ray wavelength (0.15406 nm) and β is the full width at half maximum [FWHM] of the film diffraction peak at 2θ. The micro-strain (ε) developed in the thin films are related to lattice 'misfit', which in turn depends on the growing condition of the films. The lattice strains are developed by varying displacement of the atoms with respect to their reference lattice positions. The micro-strain (ε) is calculated from the relation (Sarmah et al., 2008)

$$\varepsilon = \beta/(4\tan\theta) \quad (3)$$

where β and θ have their usual significance. The larger value of 'ε' indicates the highly polycrystalline film whereas single crystalline