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Characteristics of Cadmium Tin Selenide Nanostructured Thin Films Prepared by DC Sputtering

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Abstract

In this work, nanostructured cadmium-tin selenide (CdSnSe) thin films were deposited on glass substrates by dc plasma sputtering technique. The sputtered target was prepared by the thermal casting of Cd, Sn and Se samples at 350°C. The structural characterizations showed that the prepared targets were polycrystalline while the deposited CdSnSe films exhibited amorphous structure due to the growth of nanostructures on the substrates, which was also confirmed by the scanning electron microscopy. These films showed high absorption in the ultraviolet and visible regions while low absorption was observed in the near-infrared region (>800nm). They have two allowed types of energy band gaps; indirect at 1.233eV and direct at 1.655eV. The dispersion relationship showed that these films have approximately constant refractive index in the visible region, which is attributed to the optical homogeneity of the prepared films.

Keywords: CdSnSe; Thin films; Plasma sputtering; Thermal casting

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1. Introduction

Cadmium tin selenide (CdSnSe) is a ternary semiconductor material with unique physical, chemical, and optoelectronic properties that make it a promising candidate for various technological applications [1]. CdSnSe typically crystallizes in a tetragonal structure with lattice parameters influenced by the stoichiometric ratio of its constituent elements. It exhibits a wide bandgap, tunable in the range of 1.1–1.5 eV, making it suitable for optoelectronic applications. Its nanostructures, such as thin films and nanoparticles, demonstrate high absorbance in the visible to near-infrared range, along with excellent photoconductivity [2-4]. CdSnSe is stable under ambient conditions but sensitive to high temperatures and reactive environments, where it can degrade into its elemental constituents [5]. It is moderately resistant to oxidation but requires careful handling during synthesis and storage to prevent contamination. CdSnSe can be synthesized using various methods, including chemical vapor deposition (CVD), solvothermal techniques, and electrodeposition [6-8]. Thin films are typically grown via thermal evaporation or sputtering, while nanoparticles are synthesized through chemical methods using precursors like cadmium, tin, and selenium salts [9]. CdSnSe is primarily utilized in solar cells, where its tunable bandgap enhances light absorption [10,11]. It is also used in photodetectors, thermoelectric devices, and light-emitting diodes (LEDs) [12]. Furthermore, its nanostructures are investigated for use in photocatalysis and bioimaging applications [13,14].

In this study, an effort was made to fabricate sputtering targets from the CdSnSe compound for the deposition of nanostructured thin films. Additionally, certain structural and spectral characteristics of these films are discussed.

2. Experiment

Highly pure bulk samples of cadmium (99.999%), tin (99.999%) and selenium (99.999%) were placed in a graphite pot of 8cm diameter and then melted inside digitally-controlled furnace at 350°C with slow increasing rate (5 °C/hr). The molten was cooled down to room temperature at the same rate in order to avoid the formation of bubbles and hence cracks in the final sample. The produced sample was characterized by x-ray diffraction (XRD) and field-emission scanning electron microscopy (FE-SEM).

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The partial amounts of Cd and Sn in the produced sample were varied by different weight percentages in the molten, while the partial amount of Se was kept constant.

This sample was cut with dimensions of 5x5cm and grinded and polished to a mirror-like degree to be used as a sputtering target. This target was maintained on the cathode inside discharge plasma chamber. This chamber was initially evacuated down to 10^{-5} mbar using rotary and diffusion pumps before highly-pure argon gas was pumped to the chamber at a pressure of 0.05mbar to generate the discharge plasma. The electrical power required for the breakdown of argon gas was provided by a dc power supply (0-5kV). The quartz substrate on which the thin film is deposited was carefully cleaned then placed on the anode inside the deposition chamber. The cathode was cooled down to 5°C to prevent the secondary electron emission while the anode (and hence the substrate) was kept at room temperature.

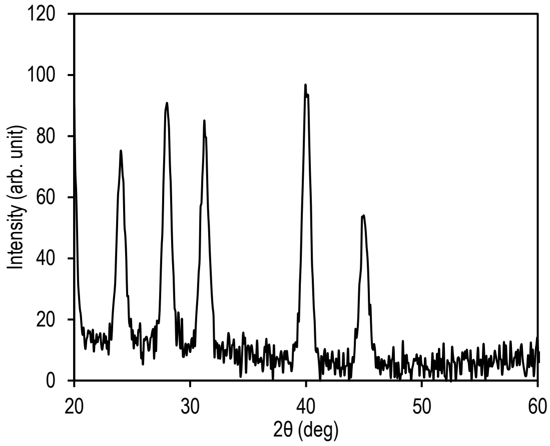
The inter-electrode distance could be varied from 1 to 8cm. The deposition parameters, such as inter-electrode distance, gas pressure, discharge current and deposition time, were optimized to choose the best samples for structural and optical characterization measurements. More details on the experimental part of this work can be found elsewhere [15-18].

3. Results and Discussion

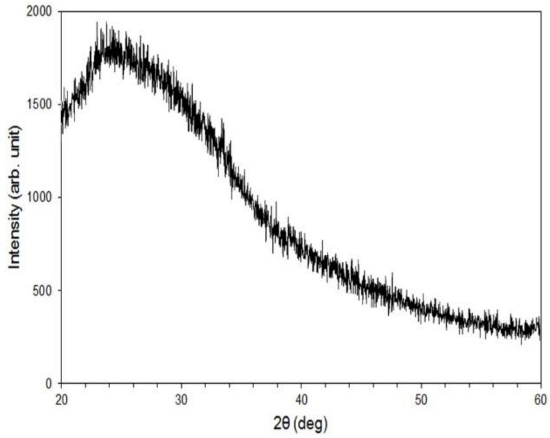
Figure (1a) shows the x-ray diffraction (XRD) pattern of the polycrystalline CdSnSe sample prepared by thermal casting at 350°C. The crystal planes of (210), (101), (201), (111), (020), (510), (221) and (610) are corresponding to diffraction angles (2θ) of 23.9°, 24.95°, 27.2°, 30.9°, 38.0°, 42.1°, 47.6° and 49.55°, respectively. These values may be all attributed to the formation of CdSnSe, however, some peaks may interfered with others belonging to CdSe or SnSe but for different crystal orientations. The formation of nanocrystalline structure is initially confirmed by the amorphous pattern in Fig. (1b).

Figure (2a) shows the scanning electron microscopy (SEM) image of the CdSnSe sample to be used as sputtering target. Agglomerated grains are inevitable result of thermal casting at high temperatures. In Fig. (2b), the formation of <100nm CdSnSe nanoparticles is confirmed in the thin film sample deposited on glass substrate by dc plasma sputtering technique. This extreme decrease in particle size is a main feature of dc plasma sputtering. Despite the existence of some difference in particle size (Fig. 2b), the homogeneous distribution can be accepted for some applications that only require the prepared structures to be in the nanoscale.

The spectral transmittance of the CdSnSe thin film is shown in Fig. (3). The low transmission behavior of this film in the UV and visible regions is converted into high transmission at 700nm. This behavior put CdSnSe thin films on high rank of energy conversion semiconductors with reasonably high transparency in the NIR region and high absorption in the spectral range of 200-600 nm, which is actually the effective range of solar radiation conversion.

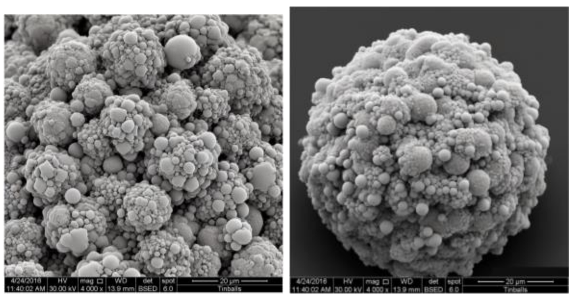


(a)



(b)

Fig. (1) The XRD pattern of (a) CdSnSe sample prepared by thermal casting at 350°C and (b) CdSnSe thin film deposited by dc plasma sputtering technique



(a) (b)

Fig. (2) The SEM images of (a) CdSnSe sample prepared by thermal casting at 350°C and (b) CdSnSe thin film deposited by dc plasma sputtering

Two types of energy band gap (E_g), direct and indirect, were determined for the CdSnSe thin film deposited in this work, as shown in Fig. (4). The

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direct allowed energy band gap was determined at 1.655 eV. These properties enable such films to absorb well in the UV and visible regions. Such compounds can be effectively used to construct low-cost and large-area solar conversion devices with very good chemical, mechanical and structural characteristics [19].

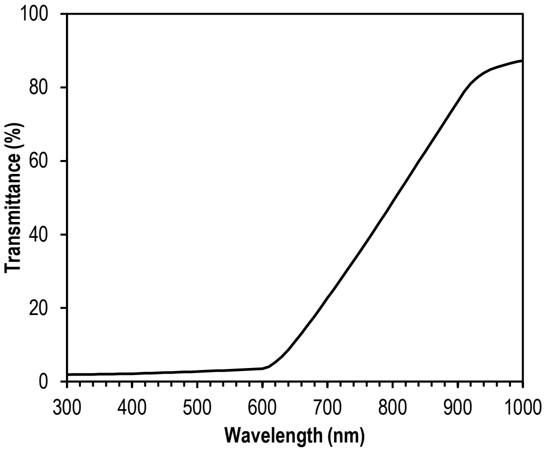

Fig. (3) Spectral transmittance of the CdSnSe thin film deposited in this work

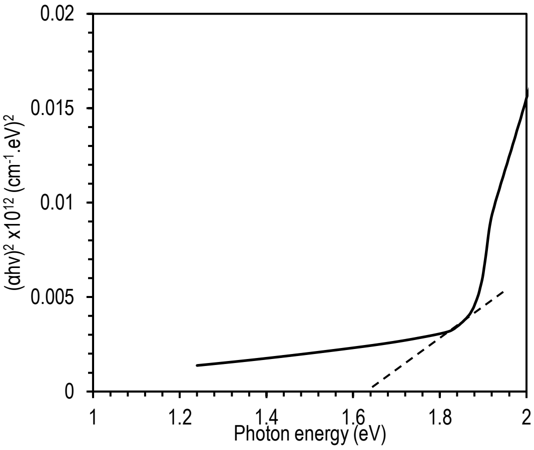

Fig. (4) Determination of energy band gaps of the CdSnSe thin film deposited in this work

The structural homogeneity of the deposited CdSnSe thin films is shown in Fig. (5) by the relationship of refractive index with the wavelength. The value of refractive index is approximately constant (~1.74) within the range 450-750nm. This feature assigns the reliability of DC plasma sputtering technique to prepare optically homogeneous nanostructures and chemically stable compounds [20].

4. Conclusion

In summary, nanostructured CdSnSe thin films were successfully deposited using DC plasma sputtering from a CdSnSe target prepared via thermal casting at 350°C. The optical analysis of these semiconducting films revealed low transmission (<10%) in the UV and visible regions, the presence of both direct and indirect energy band gaps, and excellent optical homogeneity, characterized by a nearly constant refractive index in the visible spectrum. The deposition of these uniform nanostructured CdSnSe thin films highlights their potential for use in the fabrication of cost-effective and reliable photovoltaic devices, such as thin-film solar cells.

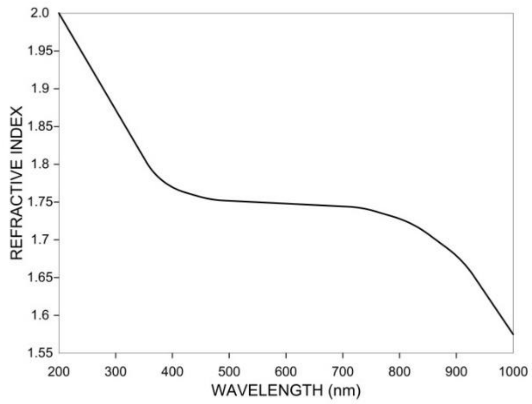

Fig. (5) Dispersion relationship of the CdSnSe thin film deposited in this work

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