Raman and Ellipsometric Investigation of 570 nm CdTe thin film layer deposited by RF-Sputtering system

Andra Naresh Kumar Reddy^{1,3,*}, Mahdieh Hashemi², Payal Verma⁴, Svetlana N. Khonina^{1,5}

1. Department of Technical Cybernetics, Samara National Research University, 443086, Samara, Moskovskoye Shosse, 34, Russia
2. Department of Physics, College of Science, Fasa University, Fasa 74617-81189, Iran
3. School of Engineering, Anurag Group of Institutions, Venkatapur, Ghatekesar, Medchal District, Hyderabad, 500088, Telangana, India
4. Department of Electronics and Communication Engineering (ECE), Dayananda Sagar University, Bangalore-560068, India
5. Image Processing Systems Institute – Branch of the Federal Scientific Research Centre “Crystallography and Photonics” of the Russian Academy of Sciences, 443001, Samara, Russia.

(*) E-mail: naarereddy@gmail.com

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ABSTRACT:

In this work, we characterized the 570 nm CdTe layer deposited on a glass substrate by RF-Magnetron sputtering technique at the substrate temperature of 200°C. Four experimental techniques were used in this study to characterize the thin film layer; Raman spectroscopy, Spectroscopic Ellipsometry, X-ray dispersive spectroscopy (EDX) and high-resolution scanning electron microscopy (SEM). An elemental composition, the surface morphology and the phase of the thin film material were discussed. The optical properties such as refractive index, extinction coefficient, and absorption coefficient were investigated for CdTe thin film. The deposited thin film shows the maximum absorption in the visible spectrum which makes it an ideal candidate for photovoltaic applications.

Keywords: CdTe, RF-Sputtering, Raman Spectroscopy, Ellipsometry, optical absorption, UV-VIS spectroscopy, photovoltaics.

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1. Introduction

Cadmium Telluride (CdTe) is an important semiconductor material which has a variety of uses in potential applications such as the construction of photovoltaic devices [1-2]. Usually, CdTe thin films are polycrystalline materials [3-4], can be synthesized by different deposition techniques [5-6]. Among them, RF-Magnetron sputtering method [7-8] is famous like thermal evaporation deposition technique [9] because of their excellent deposition rate as well as less consumption of target material. This material became competent to famous Si which has high efficiency in low-cost solar cell applications. One can find a growing interest in CdTe thin films due to its properties like stability [10], optimized direct band gap for photovoltaic applications [11] and high optical absorption [12].

In this study, CdTe thin film was deposited by RF-Magnetron sputtering technique. The surface properties such as roughness and uniformity of the deposited thin film much depend on the substrate temperature. The Raman shift in the spectrum has characterized the phase of the material. Importantly, the optical properties of the material thin film have been investigated using Spectroscopic Ellipsometry.

2. Experiments

A Cadmium Telluride (CdTe) thin film was deposited on a glass substrate by RF-Magnetron Sputtering system (Caroline D12A). For this purpose, we used a target of 2-inch diameter for deposition of the CdTe thin film and the gap between the substrate and target was 300 mm. For this deposition, we used an RF power of 40-150 Watts, a vacuum pressure of 2×10^{-5} Torr and the substrate is maintained at 200°C temperature. Note that, the blending of the CdTe thin film to the substrate has been improved by heating the substrate. The layer thickness of the investigated sample was measured with the help of a stylus profiler (KLA Tencor P-16+). To measure the film thickness precisely, we scratched the sample at the edge in order to produce a reference point with the substrate. The film of 570 nm is obtained. The elemental analysis of the thin film deposited on a glass substrate was done by Energy dispersive X-ray spectroscopy (Oxford-EDX). It concluded that the deposited thin film contains 48.05% of cadmium and 51.95% tellurium, as shown in Fig. 1. Raman spectroscopy was employed to study the phonon frequency measurements higher than 100 cm^{-1} . However, by using Ellipsometer the refractive index (n), extinction coefficient (k) and absorption coefficient (α) were measured for the sample.

Fig. 1. EDX spectrum for elemental analysis of CdTe layer

Fig. 2. (a) SEM image of the surface morphology of CdTe film on a glass substrate at 200°C; (b) scratch making on the surface of the material thin film; (c) Magnified version of the scratch area

The surface morphology of 570 nm CdTe thin film was viewed through SEM (Zeiss-sigma 500), as seen in Fig. 2(a). Note that, the films grown on an optical glass substrate at 200°C temperature show the surface smoothness and uniformity of thickness [2]. However, the films deposited on the glass substrate at a temperature of less than 200°C reflect non-uniformity and rough surface [2,5&9]. The films deposited beyond 200°C may suggest more improved surface morphology [2,5&9]. In order to demonstrate the surface quality of CdTe thin film, deliberately we produced a scratch on the surface and examined under high resolution scanning electron microscope (SEM), as seen in Fig. 2(b) & (c). As evidence that the thin film has a good surface quality relative to the scratch on the CdTe thin film layer. Using SEM image analysis tool, we measured the thickness of a layer as ~570 nm (Fig. 2(c)). The lower stain and dislocations were found for the film deposited at a substrate temperature of 200°C, signifying better surface quality.

High crystallite size and lowest dislocations and strain were noticed for CdTe thin films deposited at higher substrate temperature [2]. The smoothness of the material surface, as well as uniformity of film thickness, were good for thin films deposited at substrate temperatures between 200°C -250°C relatively to different substrate temperatures [2].

3. Results and Discussion

3.a. Raman Spectroscopy Analysis

In order to investigate the phase of the deposited CdTe thin film on a glass substrate, we performed Raman spectroscopy on the sample and obtained Raman shift peaks at 128 cm^{-1} , 130 cm^{-1} , 147 cm^{-1} , and 165 cm^{-1} . Among them, the two peaks are strong (128 cm^{-1} and 130 cm^{-1}), and the Raman shift peaks at 147 cm^{-1} and 165 cm^{-1} are weak, as illustrated in Fig. 3. In other words, the peaks appear between the wavelength ranges 535-540 nm, which designate the phase of CdTe thin film [2, 9 & 13]. According to the spectral region estimation, the accuracy of the Raman measurements studied in the plot is about $\pm 0.1 \text{ cm}^{-1}$. A CW laser of 532 nm wavelength was used to excite the CdTe thin film sample in this study. It is observed that the strong peaks at wavenumbers close to 128 cm^{-1} and 130 cm^{-1} due to longitudinal acoustic phonons [9][13].

Weak peaks at $\sim 147 \text{ cm}^{-1}$ can be attributed to transverse optical phonon mode, whereas weak peaks at $\sim 165 \text{ cm}^{-1}$ due to longitudinal optical phonons for the thin film sample [9,13]. The sharp peaks of Raman spectra are centered at 128 cm^{-1} , 130 cm^{-1} for LA phonon mode and the weak peaks for TO and LO-phonon wave numbers ($\sim 147 \text{ cm}^{-1}$, $\sim 165 \text{ cm}^{-1}$). Note that, the measured frequencies might be shifted for CdTe films fabricated at a substrate temperature beyond 200°C (e.g., 250°C, 300°C).

Fig. 3. The Raman spectrum of CdTe thin film deposited on a glass substrate at 200°C

3.b. Optical properties of CdTe layer by use of an Ellipsometer

The optical properties of CdTe thin film on the glass substrate were recorded through a spectroscopic Ellipsometer (M2000DI). The gradient in the refractive index of the thin film is related to the wavelengths of incident radiation. It is observed as the wavelength of incident light increases, the refractive index of the thin film sample decreases gradually, as shown in Fig. 4. Besides, according to Fig. 5, 'n' gradually increases with the incident photon energy $E(\approx h\nu)$. Therefore, the highest refractive index (3.28) for the sample is observed at 410 nm whereas the lowest refractive index (2.89) is found for the incident radiation of 700 nm. 'k' is the extinction coefficient, which represents a loss of energy in the wave. In other words, the k value provides information about the absorption of photons in the medium of CdTe thin film. In this study, both n and k are varying with wavelength. It is observed that the 'k' value decreases steadily with the visible wavelength which ranges from 400-700 nm, as shown in Fig. 6.

Fig. 4. Refractive index (n) measurement on CdTe thin film layer obtained on an optical glass substrate at 200°C

The absorption coefficient (α) of CdTe thin film was calculated from the extinction coefficient (k) measurements using the following relation (1). Fig. 6 shows that the absorption coefficient steadily decreases with the wavelength (λ).

$$\alpha = \frac{4\pi k}{\lambda} \quad (1)$$

Fig. 5. The distribution of the refractive index (n) of CdTe thin film deposited on a glass substrate functions of Energy of Photon ($\approx h\nu$)

Fig. 6. Variation in extinction Coefficient (k), optical absorption Coefficient (α) of CdTe thin film on a glass substrate.

The absorption coefficient can be given as a function of the energy of the incident photon (e.v.) to verify the energy gap (E_g) for CdTe thin film using following equations (2) and (3).

$$E \text{ (ev)} = h\nu \cong \frac{1240}{\lambda \text{ (nm)}} \quad (2)$$

$$\alpha h\nu = A(h\nu - E_g)^n \quad (3)$$

Fig.7. The plot of $(\alpha h\nu)^2$ Vs. $h\nu$ for 570nm CdTe thin film layer deposited on a glass substrate at 200°C

Fig.8. Transmittance spectrum of CdTe thin film layer on a glass substrate

In the above relations (2) and (3), A is the constant, ' h ' is the Plank's constant and ν is the frequency of incident wave radiation. ' n ' is equalized to 0.5 for the direct band transition of the deposited CdTe material film on a glass substrate. Fig.7 shows a linear response plot $(\alpha h\nu)^2$ Vs. $h\nu$, which indicates the variation $(\alpha h\nu)^2$ concerning the incident photon energy. The direct band gap estimated to be 1.76 eV. The transmittance of CdTe thin film was measured in the wavelength range of 400 – 700 nm, as seen in Fig.8. The transmittance was around 10% to 48% in the visible wavelength range, whereas the absorbance was being high (52% to 90%). Possibly, beyond 700 nm (IR region), the absorption of the thin film may decrease more and finally reaches zero value. It is emphasized that the electromagnetic radiation in the frequency range 450-750 THz, this band corresponds to the visible light spectrum has proper absorption in a medium of 570 nm thick CdTe layer deposited on a glass substrate at 200°C.

3.c. UV-Visible absorption spectroscopy analysis

Fig. 9 UV/VIS absorption spectra of the CdTe thin film layer as a function wavelength (nm)

Fig. 9 shows the absorption spectra for CdTe thin film layer as a function of wavelength. It has shown that the absorbance increases in the lowest UV-wavelength range, but moderately decreases in the lower UV-wavelength range (300 nm - 350 nm). For visible wavelengths (400 nm - 750 nm), initially optical absorbance of the material thin film is adequate, and later it decreases gently with an increase in wavelength. In IR regime, the optical absorbance of the thin film approaches close to the zero-value.

4. Conclusions

This study concluded that the substrate temperature could influence the surface morphology of the CdTe thin film layer. In the deposited thin film on a glass substrate, a smooth surface and uniformity of thickness were observed by using high-resolution SEM imaging, i.e., the lower strain and dislocations were noticed for the thin film deposited at a substrate temperature of 200°C, realized a improved surface quality. The polycrystalline phase of CdTe thin film was determined by using Raman Spectroscopy. This semiconducting thin film showed good absorption in the visible spectrum. Due to a suitable surface and optical properties, the deposited thin film can be applied for photovoltaic applications.

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