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DISTINGUISHING TRAITS OF THIN FILMS OF ANTIMONY-DOPED CADMIUM SELENIDE (CDSE/SB) ON GLASS SUBSTRATE VERSUS FLUORINE TIN OXIDE (FTO) THROUGH SPRAY PYROLYSIS: AN INVESTIGATIVE ANALYSIS

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ABSTRACT

Thin films of antimony-doped cadmium selenide (CdSe/Sb) were fabricated using the spray pyrolysis technique on both glass and fluorine tin oxide (FTO) substrates at a deposition temperature of 200ºC. Sodium selenosulphite (Na_2SeSo_3) served as a stable source of Se^{2-} ions, and to ensure complete desolation and achieve ion-by-ion deposition, Ethylenediamine tetraacetic acid (EDTA) was employed as a stabilizer and complexing agent. Antimony and cadmium were sourced from their respective chlorides. The optical and solid-state properties were determined through absorption and transmittance measurements in the wavelength range of 300 to 1500 nm. A comparison of the spectral properties between films deposited on glass and FTO substrates revealed distinct characteristics. Films on glass exhibited a continuous spectral nature, while those on FTO displayed a quantized energy level characteristic with a lower band gap ranging between 2.65 to 2.80 eV. In contrast, films on glass substrates demonstrated a higher band gap in the range of 3.7 eV to 4.0 eV. The observed lower band gap and quantized energy levels in films on FTO substrates suggest their suitability for photovoltaic applications by enhancing the absorption of a broader range of solar radiation. In contrast, films on glass with a higher band gap are more suitable for applications requiring selective light absorption or filtering, such as solar thermal collectors or windows, enabling control over specific wavelengths while maintaining transparency. The ability to adjust the band gap through film deposition conditions allows tailored material optimization for diverse solar technologies, impacting efficiency, and manufacturing costs based on specific requirements and considerations.

KEYWORDS: Cadmium Selenide, Autimony, Fluorine Tin oxide, thin films, Continuous spectra, quantized energy level.

INTRODUCTION

Solar energy technologies continue to advance and the exploration of innovative materials plays a pivotal role in enhancing the efficiency of solar devices. One promising avenue in this pursuit is the investigation of thin films composed of Antimony-Doped Cadmium Selenide (CdSe/Sb) on different substrates, particularly glass and Fluorine Tin Oxide (FTO), utilizing the spray pyrolysis technique. These thin films exhibit distinctive characteristics that can significantly impact their performance in solar energy applications [1]. Spray pyrolysis, a process involving the atomization of a precursor solution, evaporation in a heated reactor, and subsequent decomposition into particles and films [2, 3], has proven to be a versatile method for producing thin films. The aerosol formation experiences gravitational, electrical, and thermophoretic forces [4, 5], this leads to continuous vaporization, solvent evaporation, component diffusion, solute precipitation, and ultimately the formation of a dense particle or thin film due to high-temperature sintering.

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Antimony-doped cadmium selenide (CdSe/Sb) is a valuable material in various applications, particularly in optoelectronic devices [6]. Previous studies have demonstrated its impact on improving the bandgap of Ag/CdSe, thereby enhancing electrical conductivity, and increasing photovoltaic efficiency when deposited on Fluorine Tin Oxide (FTO) compared to glass substrates [6]. Additionally, CdSe/Sb deposited on FTO has shown promise in the development of semitransparent solar cells for colorful photovoltaic windows [7]. In this research, we focus on elucidating the distinctive optical and solid-state properties of CdSe/Sb thin films deposited on both glass and FTO substrates using the spray pyrolysis technique. Our investigation aims to contribute valuable insights into the material's behavior and its potential implications for optimizing solar energy applications.

EXPERIMENTAL DETAILS

Antimony-doped cadmium selenide thin films were deposited on glass substrates (76mm x 26mm x 1mm) and fluorine tin oxide (FTO) substrates (13mm x 24mm x 3mm) using the spray pyrolysis technique. The selection of substrate sizes was determined by the availability of sizes easily accessible within the laboratory during the course of this research. Two separate baths, labeled Cd_4 and Cd_5, were prepared. Cd_4 contained 5ml of 0.81g $CdCl_2$, while Cd_5 contained 5ml of 1.00g $CdCl_2$. Both baths included 5ml of 2.1g Na_2SeS0_3, 5ml of 0.76g Sb_2Cl_3, and 10ml of EDTA ($C_{10}H_{16}N_2O_8$) as a complexing agent, with the volume made up to 50ml using distilled water. Stirring with a glass rod ensured particle distribution uniformity in the solutions. The solutions were sprayed onto the glass and FTO substrates in a deposition chamber at 200°C and left for 5 minutes before washing and drying. To improve the structural, electrical, and optical properties of the deposited films and activate dopants, films containing $CdCl_2$ with weights of 0.81g and 1.00g (Cd_4 and Cd_5) were annealed on both glass and FTO substrates. These annealed films were then compared with their unannealed counterparts. Band gaps of the films were determined using absorbance and transmittance measurements obtained from a Unico-UV-2102 PC spectrophotometer at normal incident light in the wavelength range of 300-1500nm.

RESULTS AND DISCUSSION

In Fig. 1a and 1b, optical conductivity versus wavelength (λ) graphs for Cd4 (0.81g $CdCl_2$) and Cd5 (1.00g $CdCl_2$) samples are presented, representing depositions on glass and FTO substrates, respectively. The as-deposited Cd5 sample exhibited a nearly uniform optical conductivity of 50M Siemens per meter (S/m) in the wavelength range of 350–1500nm, while its annealed counterpart showed a consistently lower optical conductivity of 38M(S/m) in the same range. For Cd4, both as-deposited and annealed samples displayed a conductivity of 50M (S/m) at a wavelength of 350nm, gradually reducing uniformly to approximately 35M ohms at 1500nm. Comparing these findings with Fig.1b, it was observed that as-deposited Cd5 samples initiated conductivity at a wavelength of 620nm, reaching 75M (S/m), which sharply decreased to 25M (S/m) around λ ≈950nm. The Cd5 sample annealed at 573K exhibited conductivity starting at λ of 475nm, reaching 48M (S/m), and peaking at 75M (S/m) at λ of 590nm. Similar trends were noted for Cd4 samples, with both annealed and as-deposited samples commencing conductivity at the ranges of 320nm. Notably, those on glass demonstrated conductivity across the entire spectrum from UV to IR, qualifying them for solar cell applications [7, 8, and 9]. Conversely, those on FTO exhibited quantized energy level characteristics compared to glass substrates, indicating different behavior aligned with the work function of the specific sample.

Figures 2a and 2b present the real dielectric constant (ε_r) versus wavelength for Cd4 and Cd5 films deposited on glass and FTO substrates. In Fig. 2a, it is evident that the dielectric constant of the samples generally remains low (less than zero), ranging from -200 to -1000 and decreasing as the wavelength increases, reaching approximately -2500 around λ≈1500nm. The as-deposited Cd5 sample, however, exhibits a dielectric constant of approximately 4500 at λ of 1500nm. Comparing these figures with Fig. 2b, it is observed that the refractive indices are negative, starting in the range of -1000 to -4000 between 300nm and 530nm wavelength. Instead of decreasing with increasing wavelength, the refractive indices exhibit an upward trend. The as-deposited and 573K annealed samples of Cd4 show some contrasting characteristics, ultimately reaching a dielectric constant range of -100 to -300 at a wavelength of 1500nm. Despite having negligible dielectric constants, all samples demonstrate the ability to conduct at minimal incidence ray values. Notably, FTO introduces quantization characteristics into the dielectric properties.

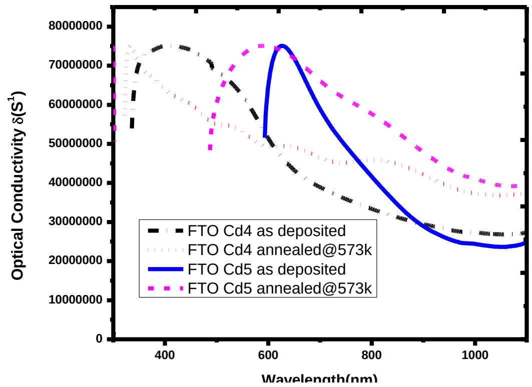

Figure 1a: Optical conductivity Vs wavelength for Cd4 and Cd5 filmson FTO

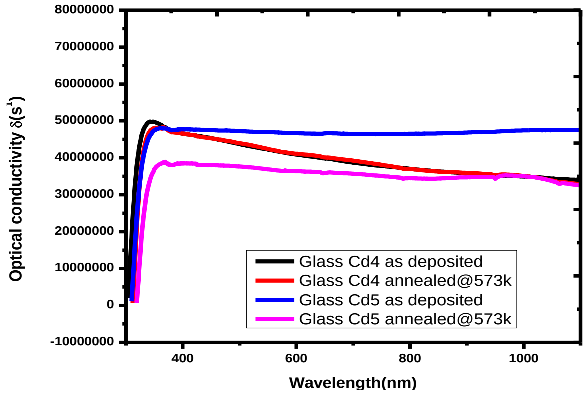

Figure 1b: Optical conductivity Vs wavelength for Cd4 and Cd5 films on glass

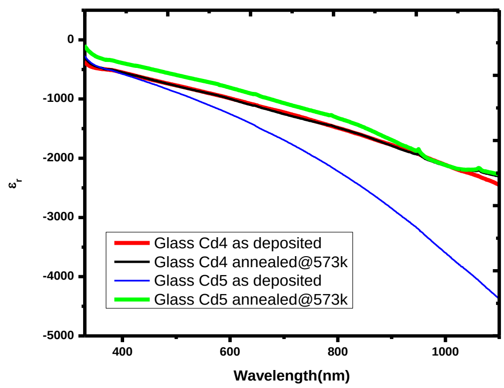

Figure 2a: Real dielectric constant (Ɛr) Vs wavelength for Cd_4 & Cd_5 on glass

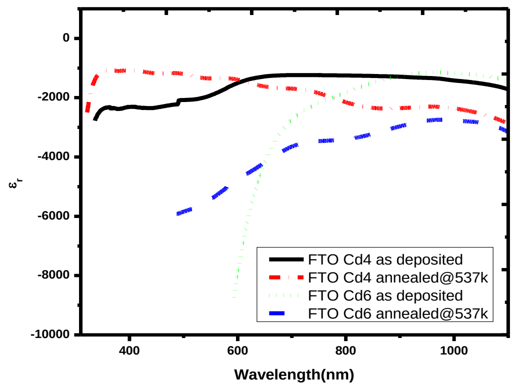

Figure 2b: Real dielectric constant (Ɛr) Vs wavelength for Cd_4 & Cd_5on FTO

Figure 3a depicts the inverse of Figure 2a, representing the imaginary refractive indices of Cd4 and Cd5 samples deposited on glass substrates. In contrast, Figure 3b diverges from this trend compared to Figure 3a. While the samples in Figures 2a and 2b displayed dielectric sensitivity at different wavelengths, the imaginary dielectric constant in Figure 3b shows sensitivity from visible light to the far-infrared region of the spectrum, similar to those deposited on glass. However, the range for Figures 3a and 3b is between 175 and 320.

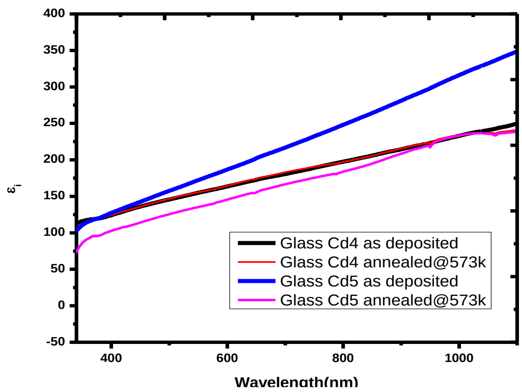

Figure 3a: Imaginary dielectric constant ($Ɛ_I$) vs wavelength for Cd_4& Cd_5on glass

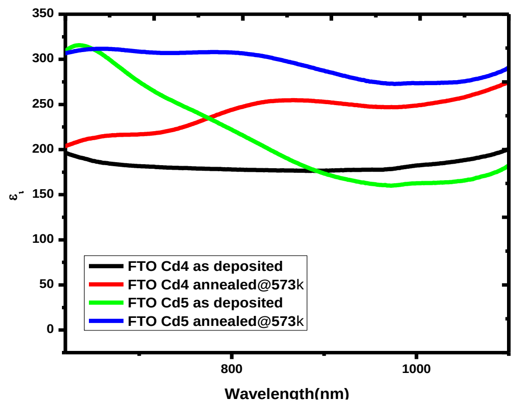

Figure 3b: Imaginary dielectric constant ($Ɛ_I$) vs wavelength for Cd_4& Cd_5on FTO

Figures 4a and 4b illustrate the refractive index versus wavelength for Cd4 and Cd5 samples deposited on glass and FTO substrates. In Figure 4a, the refractive indices of the samples are observed from the visible light region starting at 300nm, swiftly increasing from 1.21 to over 2.6. The as-deposited sample of Cd5 maintains a stable value throughout the entire spectrum. The Cd5 sample annealed at 573K exhibits the lowest refractive index of 2.55 at a wavelength of 350nm, maintaining this value through the visible to far-infrared regions. In Figure 4b, focusing on FTO: Cd4 and Cd5, the refractive indices are indicated at different wavelengths. FTO: Cd4 annealed at 572K is observed at a wavelength of 310nm, as the as-deposited sample of FTO: Cd4 emerges around λ≈320nm. The annealed sample of FTO: Cd5 is prominent at λ≈475nm, while the as-deposited sample of FTO: Cd5 surfaces at λ≈590nm. Both samples increase steadily from an average value of 1.08 to approximately 2.7, maintaining this value towards the infrared region with a slight depression, excluding the 573K annealed sample of FTO: Cd5. This outcome reveals another quantization characteristic of FTO, causing them to refract rays at selected wavelengths associated with specific particles [10, 11].

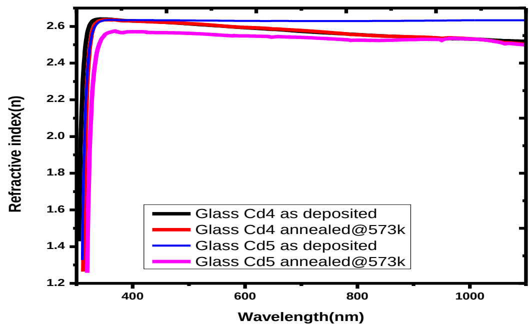

Figure 4a: refractive index Vs wavelength for Cd_4& Cd_5 on Glass:

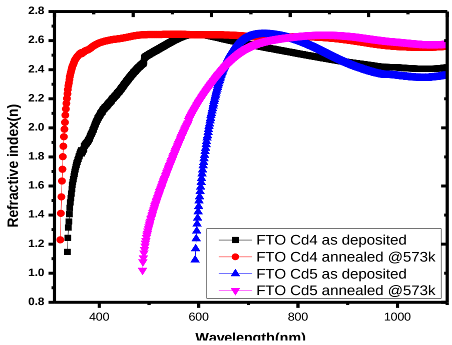

Figure 4b: refractive index Vs wavelength for Cd4& Cd_5 on FTO

Figures 5a and 5b depict the band gap values of antimony-doped cadmium selenide samples deposited on glass and FTO substrates. In Figure 5a, the Cd5 sample annealed at 573K exhibits the smallest band gap of 3.7eV, followed by the 573K annealed Cd4 sample with a band gap value of 3.75eV. Unannealed Cd5 samples have a band gap of 3.87eV, while the largest band gap of 4.0eV is observed in the as-deposited Cd4 sample. Conversely, Figure 5b demonstrates that FTO: Cd_5 annealed at 573K has the smallest band gap of 2.65eV, followed by the annealed FTO: Cd_4 sample with a band gap value of 2.8eV. The as-deposited samples of FTO: Cd4 have the largest band gap value of 3.8eV, preceded by FTO: Cd5 with a band gap of 3.6eV. The results indicate that those deposited on FTO exhibit a smaller band gap compared to those on glass. This suggests that particles deposited on FTO possess a more semi conductive nature and would release electrons more readily to the conduction band than those on glass when utilized in the fabrication of solar cells [12, 13].

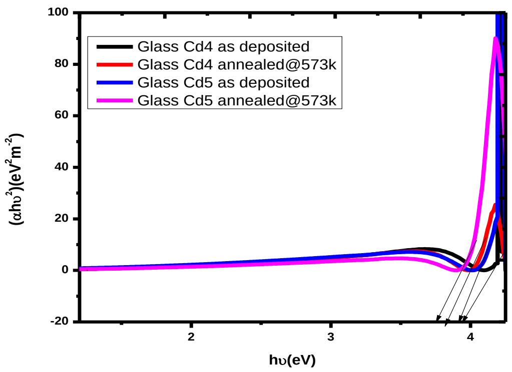

Figure 5a: A graph of ($\alpha h\upsilon^2$) Vs hυ for Cd_4& Cd_6 on glass

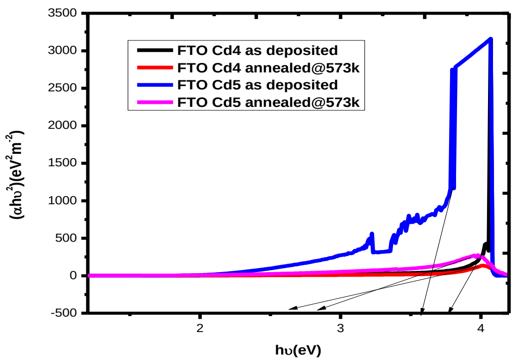

Figure 5b: A graph of ($\alpha h\upsilon^2$) Vs hυ for Cd_4& Cd_6on FTO

CONCLUSION

In conclusion, the comprehensive examination of antimony-doped cadmium selenide (CdSe/Sb) thin films on glass and fluorine tin oxide (FTO) substrates reveals noteworthy disparities in optical, dielectric, and conductive attributes. Notably, the as-deposited Cd5 sample on glass demonstrates uniform optical conductivity over a wide wavelength range, while the annealed counterpart exhibits lower yet consistent conductivity. The FTO-deposited samples exhibit quantized energy level characteristics, signifying a distinctive behavior in comparison to glass substrates. The dielectric constants exhibit distinctive trends with negative values in both glass and FTO substrates. FTO substrates, in particular, introduce quantization characteristics, influencing dielectric sensitivity from visible light to the far-infrared region.

Refractive indices display notable variations, particularly in FTO substrates, indicating diverse behaviors aligned with the specific sample's work function. FTO-deposited samples exhibit smaller band gaps compared to those on glass, implying a more semiconductive nature. This suggests that particles deposited on FTO may release electrons more readily to the conduction band, presenting potential advantages for solar cell fabrication.

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REFERENCES

Chen, Z., Pan, D., Li, Z., Jiao, Z., Wu, M., Shek, C. H., and Lai, J. K., 2014. Recent advances in tin dioxide materials: some developments in thin films, nanowires, and nanorods. Chemical reviews, 114(15), 7442-7486.

Ardekani, S. R., Aghdam, A. S. R., Nazari, M., Bayat, A., Yazdani, E., and Saievar-Iranizad, E., 2019. A comprehensive review on ultrasonic spray pyrolysis technique: Mechanism, main parameters and applications in condensed matter. Journal of Analytical and Applied Pyrolysis, 141, 104631.

Jung, D. S., Park, S. B., and Kang, Y. C., 2010. Design of particles by spray pyrolysis and recent progress in its application. Korean Journal of Chemical Engineering, 27, 1621-1645.

Han, S., Li, Y., Wen, G., and Huang, T., 2022. Study on thermophoretic deposition of micron-sized aerosol particles by direct numerical simulation and experiments. Ecotoxicology and environmental safety, 233, 113316.

Prodi, F., Santachiara, G., Belosi, F., Vedernikov, A., and Balapanov, D., 2014. Phoretic forces on aerosol particles surrounding an evaporating droplet in microgravity conditions. Atmospheric research, 142, 40-44.

Sahu, P. K., and Das, R., 2022. Microstructural and Optoelectronic Properties Investigation of Sb Doped CdSe Thin Films. Journal of Electronic Materials, 1-12.

Asim, N., Mohammad, M., and Badiei, M., 2018. Novel nanomaterials for solar cell devices. In Nanomaterials for green energy (pp. 227-277).

Elsevier. Grisorio, R., De Marco, L., Allegretta, G., Giannuzzi, R., Suranna, G. P., Manca, M., ... and Gigli, G., 2013. Anchoring stability and photovoltaic properties of new D (-π-A) 2 dyes for dye-sensitized solar cell applications. Dyes and Pigments, 98(2), 221-231.

Aydin, E., El-Demellawi, J. K., Yarali, E., Aljamaan, F., Sansoni, S., Rehman, A. U., ... and De Wolf, S., 2022. Scaled Deposition of Ti3C2 T x MXene on Complex Surfaces: Application Assessment as Rear Electrodes for Silicon Heterojunction Solar Cells. ACS nano, 16(2), 2419-2428.

Zhang, S., 2017. Study of fluorine-doped tin oxide (FTO) thin films for photovoltaics applications (Doctoral dissertation, Technische Universität (Darmstadt, Allemagne)).

Kumar, D. S., Kumar, B. J., and Mahesh, H. M., 2018. Quantum nanostructures (QDs): an overview. Synthesis of inorganic nanomaterials, 59-88.

Dharmadasa, I. M., Bingham, P. A., Echendu, O. K., Salim, H. I., Druffel, T., Dharmadasa, R., ... and Abbas, A., 2014. Fabrication of CdS/CdTe-based thin film solar cells using an electrochemical technique. Coatings, 4(3), 380-415.

Husain, A. A., Hasan, W. Z. W., Shafie, S., Hamidon, M. N., and Pandey, S. S., 2018. A review of transparent solar photovoltaic technologies. Renewable and sustainable energy reviews, 94, 779-791.