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OPTICAL PROPERTIES OF CADMIUM MANGANESE TELLURIDE ($Cd_{1-x}Mn_xTe$) THIN FILMS

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ABSTRACT

Cadmium manganese telluride ($Cd_{1-x}Mn_xTe$) is a tunable II–VI semiconductor with significant potential for optoelectronic and photovoltaic applications. In this study, $Cd_{1-x}Mn_xTe$ thin films were fabricated and their optical properties systematically investigated over the ultraviolet–visible spectral range. Spectrophotometric measurements of absorbance, transmittance, and reflectance were employed to evaluate key optical parameters, including the absorption coefficient (α), extinction coefficient (k), refractive index (n), and optical conductivity (σ_{opt}). The optical band gap was determined using the Tauc relation, revealing direct allowed electronic transitions. The films exhibit strong absorption in the ultraviolet region, moderate reflectance, and a progressive increase in transmittance toward the visible region. Furthermore, manganese incorporation was observed to significantly influence band gap tuning. These results indicate that $Cd_{1-x}Mn_xTe$ thin films possess promising optical characteristics for applications in UV photodetectors, photovoltaic devices, optical windows, and radiation detection systems.

1 INTRODUCTION

II–VI semiconductor materials have continued to attract considerable research interest due to their tunable optical and electronic properties, which are essential for a wide range of optoelectronic, photonic, and sensing applications [7,15,16]. Among these materials, cadmium telluride (CdTe) is particularly notable for its direct band gap and high optical absorption coefficient, making it highly suitable for photovoltaic and radiation detection technologies [9,11,12]. The performance and efficiency of CdTe-based devices have been widely investigated, with significant progress reported in solar cell applications and optical absorption optimization [10,18,19].

Extensive studies have been conducted on CdTe thin films to understand their structural and optical behavior under different fabrication and processing conditions [3,5,6].

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Techniques such as chemical bath deposition, electrodeposition, and thermal treatment have been shown to significantly influence film quality, optical constants, and band gap characteristics [8,14,20]. In particular, annealing processes and deposition parameters play a critical role in improving crystallinity and enhancing optical performance [1,2,21].

To further enhance and tailor its properties, CdTe is often alloyed with transition metals such as manganese. The incorporation of Mn into the CdTe lattice leads to the formation of cadmium manganese telluride ($Cd_{1-x}Mn_xTe$), a ternary semiconductor that enables band-gap engineering through controlled cation substitution [1,7,23]. This compositional flexibility allows for precise tuning of optical and electronic properties, thereby expanding its applicability in advanced functional devices. In addition, doping and defect engineering mechanisms have been shown to strongly influence recombination processes and carrier dynamics in CdTe-based systems [24].
The optical characteristics of $Cd_{1-x}Mn_xTe$ play a pivotal role in determining its performance in applications such as high-efficiency solar cells, ultraviolet photodetectors, radiation detectors, magneto-optical devices, and spintronic systems [9,12,19]. Consequently, a detailed understanding of key optical parameters—including absorption coefficient, refractive index, extinction coefficient, optical conductivity, and band gap—is essential for optimizing device efficiency and performance [4,17,22]. Theoretical and experimental frameworks, such as the Tauc model, have been widely employed to evaluate optical transitions and band gap energies in semiconductor thin films [17].

Furthermore, recent advancements in thin-film engineering have demonstrated that compositional variation, deposition control, and post-deposition treatments significantly affect optical response and photon–material interaction in CdTe-based materials [13,20,21]. These developments highlight the importance of systematic optical characterization in understanding and optimizing material performance for practical device integration.

In this study, $Cd_{1-x}Mn_xTe$ thin films were fabricated and systematically investigated using ultraviolet–visible spectrophotometry. The optical properties of the films were analyzed to elucidate photon–material interactions and assess their suitability for optoelectronic applications. The findings provide valuable insights into the role of manganese incorporation in tuning the optical response of CdTe-based thin films [3,6].

2. EXPERIMENTAL DETAILS

2.1 Materials and Deposition Procedure

$Cd_{1-x}Mn_xTe$ thin films were deposited on thoroughly cleaned glass substrates using the electrodeposition technique.

The deposition bath consisted of aqueous solutions containing cadmium ions (Cd^{2+}), manganese ions (Mn^{2+}), and telluride ions (Te^{2-}) as precursor species. The deposition process was carried out in an alkaline medium with pH maintained in the range $9 \leq pH \leq 11$.

The deposition parameters were as follows:

- Temperature: $T = 300\ K$
- Deposition time: $20 \leq t_d \leq 40$ minutes
- Substrate: glass
- Growth mechanism: controlled nucleation and ion-by-ion deposition.

The manganese composition parameter x was controlled through precursor concentration ratios as follows:

Sample A: $x \approx 0.010$, Sample B: $x \approx 0.020$, Sample C: $x \approx 0.030$

The film thickness t obtained for the samples is:

- CdTe: $t = 114.97\,nm$
- $Mn_{0.01}CdTe$: $t = 109.65\,nm$
- $Mn_{0.02}CdTe$: $t = 107.34\,nm$
- $Mn_{0.03}CdTe$: $t = 105.46\,nm$

2.2 Chemical Formation Mechanism

The formation of $Cd_{1-x}Mn_xTe$ thin films occurs through the controlled release and subsequent reaction of Cd^{2+}, Mn^{2+}, and Te^{2-} ions in an alkaline medium. The process involves the co-deposition of these ionic species onto the substrate surface, leading to the formation of a ternary semiconductor alloy via partial substitution of Cd by Mn within the CdTe lattice.

The overall film formation process can be represented in a simplified form as:

$(1-x)\,Cd^{2+} + xMn^{2+} + Te^{2-} \rightarrow Cd_{1-x}Mn_xTe$ (solid film)

The deposition mechanism is governed by nucleation and growth processes, which are strongly influenced by bath composition, pH, temperature, and ion release kinetics. These parameters play a critical role in determining the film uniformity, crystallinity, and optical quality.

2.3 Optical Measurements

Ultraviolet–visible (UV–Vis) spectrophotometric measurements were carried out over the wavelength range of 200–1100 nm. The measured absorbance (A), transmittance (T), and reflectance (R) spectra were used to evaluate the optical constants of the films.

The absorption coefficient (α) was determined using

$$\alpha = 2.303A/t$$

where *t* is the film thickness.

The extinction coefficient (k) was calculated as:

$k = (\alpha\lambda) / 4\pi$

The refractive index

(n) was estimated from reflectance data using appropriate approximations valid within the measured spectral range.

The optical conductivity (σ_{opt}) was obtained from:

$\sigma_{opt} = (\alpha n c) / 4\pi$

where *c* is the speed of light.

The optical band gap (E_g) was determined using the Tauc relation:

$(\alpha h\nu)^2 = B(h\nu - E_g)$

which confirms direct allowed electronic transitions in the material.

Structural characterization of the deposited films was carried out using X-ray diffraction (XRD) to assess phase formation and crystallinity.

RESULTS AND DISCUSSION

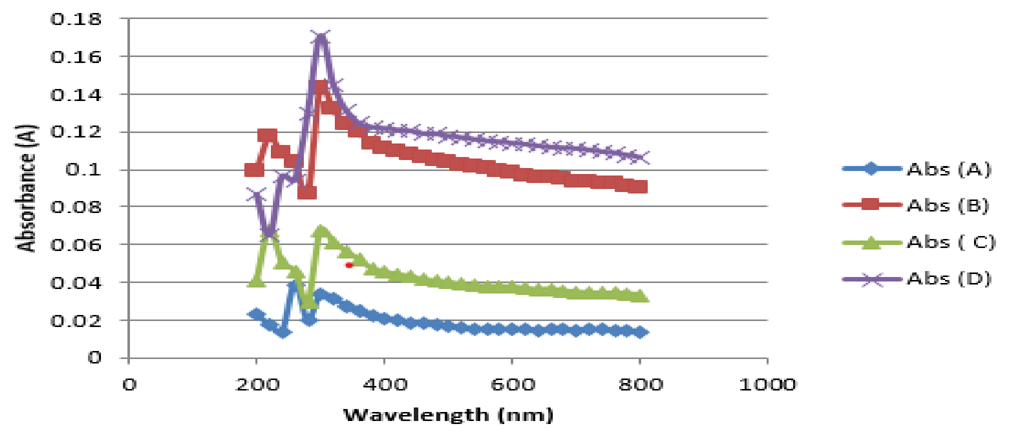

Figure 1: Plot of Absorbance against Wavelength for Deposited Thin Films of CdMnTe at various Concentrations (A-undoped, B-Mn0.01CdTe,

Figure 1 - Absorbance vs Wavelength

The films exhibit strong absorbance in the UV region, which gradually decreases toward the visible range. This behavior confirms intense photon–material interaction at lower wavelengths and indicates suitability of $Cd_{1-x}Mn_xTe$ films for UV–visible optoelectronic applications.

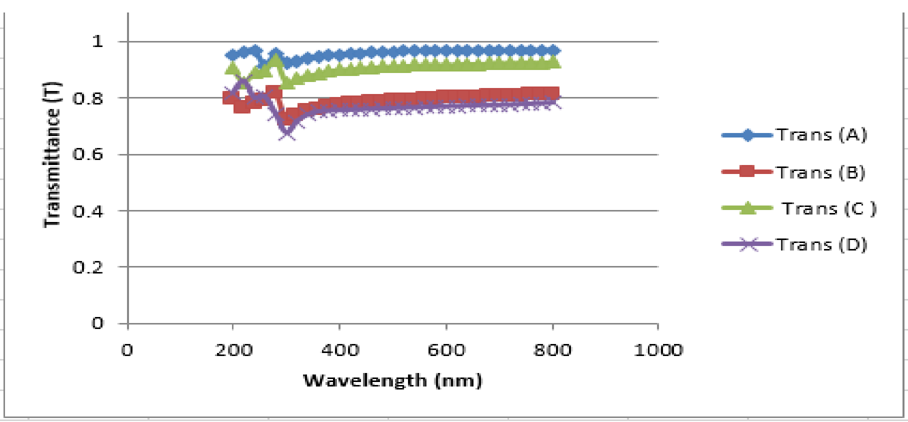

Figure 2: Plot of Transmittance against Wavelength for the Deposited Thin Films of CdMnTe at various Concentration (A-Undoped, B-Mn0.01CdTe, C-Mn0.02CdTe, D-Mn0.03 CdTe)

Figure 2 – Transmittance vs Wavelength

Transmittance is low in the UV region and progressively increases into the visible region. This inverse trend relative to absorbance confirms efficient photon absorption in the UV range and indicates reduced optical losses at longer wavelengths.

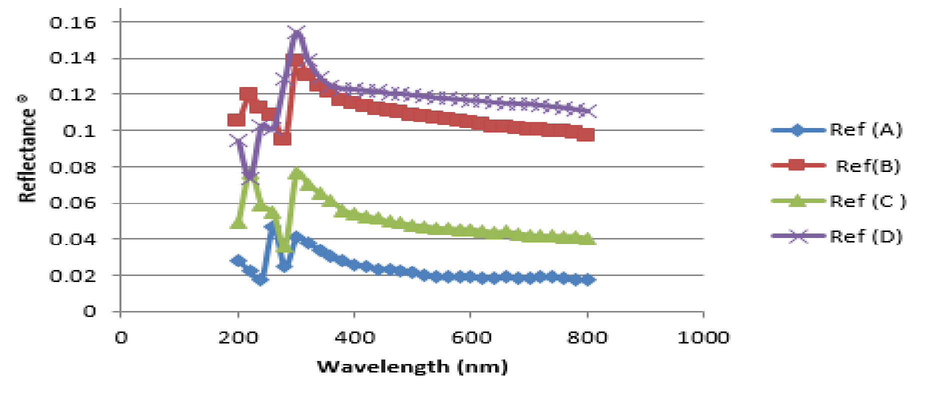

Figure 3: Plot of Reflectance against Wavelength for the Deposited Thin Films of CdMnTe at Various Concentrations (A-undoped, B-Mn0.01CdTe, C-Mn0.02CdTe D-Mn0.03CdTe)

Figure 3 – Reflectance vs Wavelength:

Reflectance remains moderate across the spectrum with slight fluctuations. The relatively low reflectance values suggest minimal surface light loss and enhanced internal absorption, which is beneficial for optical and photovoltaic applications.

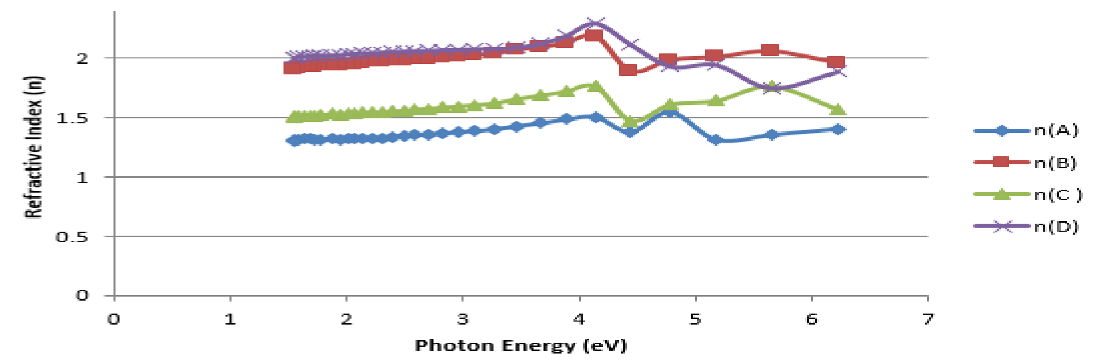

Figure 4: Variation of Photon Energy with Refractive Index for the Thin Films of CdMnTe Deposited at Various Concentrations (A-Undoped, B-Mn0.01CdTe, C-Mn0.02CdTe and D-Mn0.03CdTe)

Figure 4 – Refractive Index vs Photon Energy.

The refractive index decreases with increasing photon energy, indicating normal dispersion behavior. This trend is consistent with semiconductors exhibiting strong optical polarization and confirms good optical uniformity of the deposited $Cd_{1-x}Mn_xTe$ films.

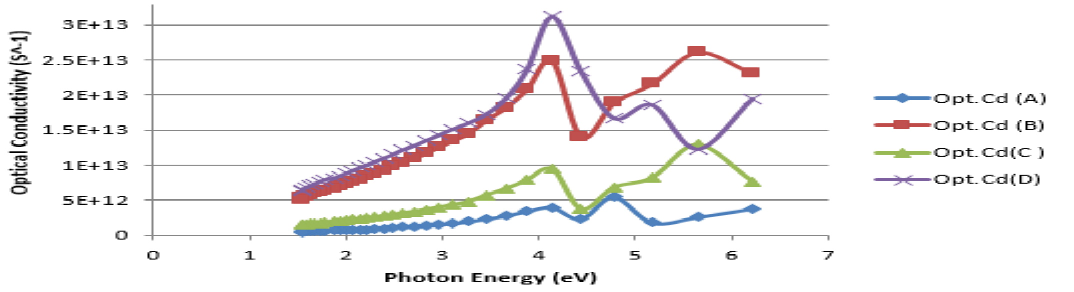

Figure 5: Variation of Optical Conductivity with Photon Energy of the Thin Films of CdMnTe Deposited at Various Concentrations (A-undoped, B-Mn0.01CdTe, C-Mn0.02CdTe and D-Mn0.03CdTe)

Figure 5 – Extinction Coefficient vs Photon Energy.

The extinction coefficient shows a decreasing trend with photon energy, reflecting reduced light attenuation at higher energies. This behavior indicates a decline in absorption probability and is linked to electronic transition characteristics within the material.

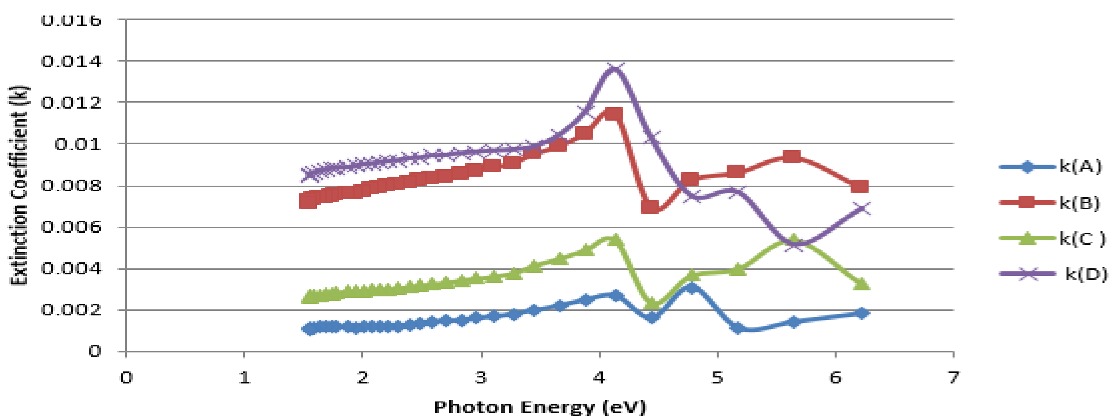

Figure 6: Plot of Extinction Coefficient against Photon Energy of the thin Films of CdMnTe Deposited at Various Concentrations (A-Undoped, B-Mn0.01CdTe, C-Mn0.02CdTe and

Figure 6 – Optical Conductivity vs Photon Energy.

The Optical conductivity increases significantly in the UV region, implying strong photon-induced charge carrier excitation. This demonstrates enhanced optical response and confirms that the films possess good optoelectronic activity.

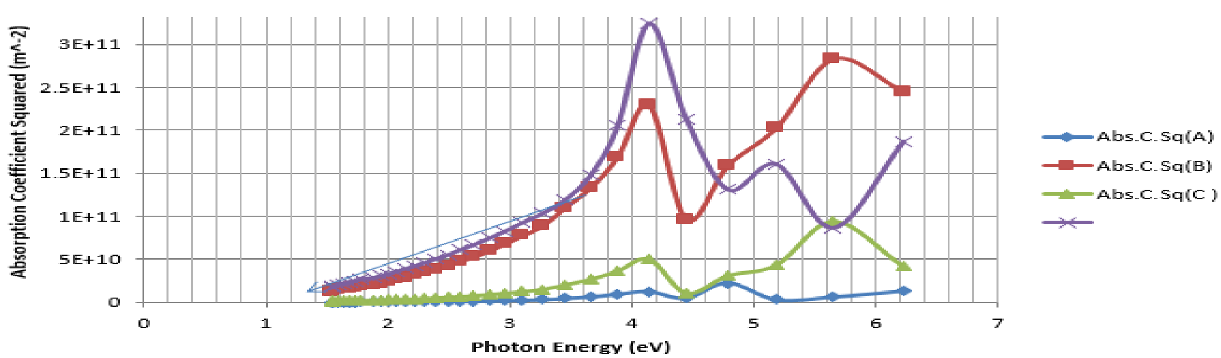

Figure 7: Plot of Absorption Coefficient Squared as a function of Photon energy of the

Figure 7 – Tauc Plot ($(\alpha h\nu)^2$ vs Photon Energy) shows linear regions, confirming direct allowed electronic transitions. Extrapolation of the linear portion to the energy axis yields the optical band gap values, validating tunable band structure behavior due to Mn incorporation.

The obtained optical band gap values E_g for Samples A, B, and C lie within the range $2.00 - 2.33$ eV, which is higher than the band gap of bulk CdTe ($\sim 1.5\ eV$).

These values are consistent with reported results for $Cd_{1-x}Mn_xTe$ thin films, where the band gap increases with manganese composition and typically falls within the range:

$$1.8\ eV \leq E_g \leq 2.4\ eV$$

This agreement with literature confirms that the observed band gap variation is physically meaningful and is attributed to Mn incorporation and thin-film effects.

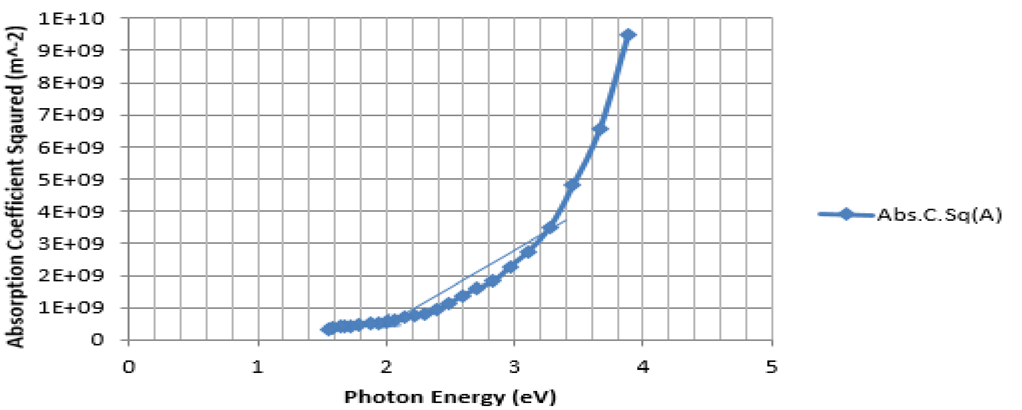

Figure 8: Plot of Absorption Coefficient Squared against Photon Energy for Sample A that is undoped

Figure 8 – Tauc Plot for Sample A exhibits a clear linear absorption edge whose extrapolation gives the band gap energy. The trend confirms direct band-gap characteristics and indicates strong electronic transition probability in Sample A.

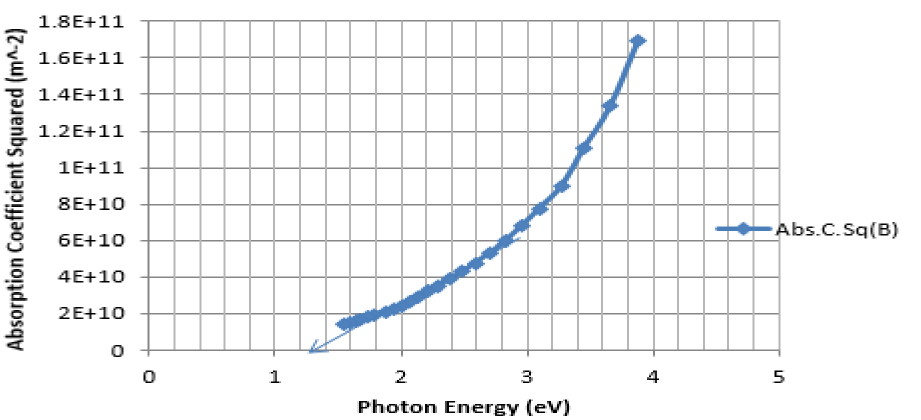

Figure 9: Plot of Absorption Coefficient Squared against Photon Energy For

Figure 9 – Tauc Plot for Sample B also shows a distinct linear Tauc plot region, with an optical band gap slightly modulated relative to Sample A. This demonstrates the influence of composition on band structure tailoring

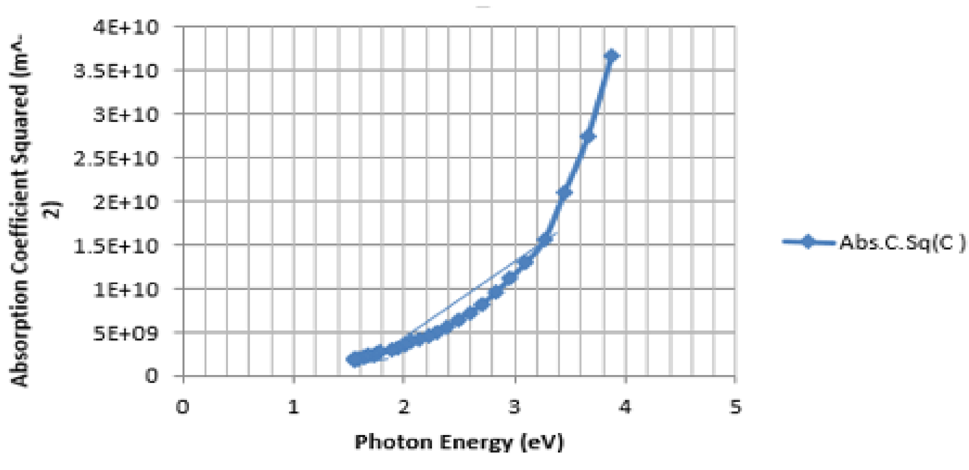

Figure 10: Plot of $(\alpha h\nu)^2$ versus photon energy (eV) for Sample C (x = 0.03).

Figure 10 further confirms direct allowed transitions, with the band-gap energy derived from linear extrapolation. The behavior supports successful optical band-gap engineering across the samples, making $Cd_{1-x}Mn_xTe$ films suitable for tunable optoelectronic device applications.

3.1 Band Gap Discussion

The optical band gap values obtained (2.002 − 33 eV) are higher than that of bulk CdTe (~1.5 eV). This increase can be attributed to several factors:

- Alloying effect**:**
  The incorporation of Mn into the CdTe lattice leads to band gap widening due to the difference in electronic structure between Cd and Mn.
- Quantum confinement effect:
  The thin film nature of the deposited layers leads to confinement of charge carriers, resulting in an increase in band gap energy.
- Burstein–moss effect:
  An increase in carrier concentration can shift the absorption edge toward higher energies.

These effects collectively explain the observed band gap values.

3.2 Structural Consideration

Structural characterization using X-ray diffraction (XRD) was performed to examine the crystalline nature of the deposited $Cd_{1-x}Mn_xTe$ thin films.

However, detailed XRD results and analysis are not included in this manuscript as they form part of a separate ongoing study. Nevertheless, the optical properties presented in this work are consistent with expected behavior of polycrystalline $Cd_{1-x}Mn_xTe$ thin films.

CONCLUSION

$Cd_{1-x}Mn_xTe$ thin films were successfully deposited using the electrodeposition technique and their optical properties systematically investigated using UV–Vis spectrophotometry.

The films exhibited strong absorption in the ultraviolet region and a gradual increase in transmittance toward the visible region, indicating effective photon–material interaction. The optical band gap values were found to be $E_g \approx 2.33\ eV$ (Sample A), $2.00\ eV$ (Sample B), and $2.05\ eV$ (Sample C), confirming direct allowed electronic transitions.

The variation in band gap with manganese concentration demonstrates the tunability of the electronic structure of $Cd_{1-x}Mn_xTe$ thin films. The observed increase in band gap relative to bulk CdTe is attributed to Mn incorporation and associated modifications in the band structure.
Structural characterization using X-ray diffraction (XRD) was carried out as part of the study to examine phase formation and crystallinity; however, detailed XRD results are beyond the scope of the present work.

Overall, the results indicate that $Cd_{1-x}Mn_xTe$ thin films possess tunable optical properties and are suitable for applications in optoelectronic devices such as photodetectors and related semiconductor systems.

CONFLICT OF INTEREST: The author declares no conflict of interest.

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