OPTICAL INVESTIGATION OF TIN TELLURIDE (SnTe) THIN FILMS GROWN AT DIFFERENT DEPOSITION VOLTAGE

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Abstract

Thin films of tin telluride (SnTe) were successfully deposited on fluorine doped tin oxide (FTO) conducting glass substrates by means of the electrochemical deposition technique. The films were prepared over a duration of 10 seconds at four distinct voltages (10 V, 11 V, 12 V, and 13 V). Optical characterization was carried out using a UV 1800 spectrophotometer across a wavelength range of 200 nm to 1000 nm. Although maximum optical absorption was recorded in the ultraviolet region for all films, the results indicate that the deposition voltage exerts a non uniform influence on the optical behaviour of the grown SnTe thin films. The film deposited at 11 V demonstrated the most favourable performance, yielding the lowest optical band gap of 1.41 eV and the highest optical conductivity of approximately 2.64×10^{-3} S/cm. Films grown at 10 V, 12 V, and 13 V exhibited high transparency in the visible and near infrared regions, whereas the 11 V sample showed markedly lower transmittance. Reflectivity across all samples was generally low, with the 11 V film recording the least reflectance over all measured wavelengths. Band gap energies ranged from 1.41 eV to 1.90 eV, signifying considerable tunability of the optical properties through voltage adjustment. Additional optical parameters, including absorption coefficient, extinction coefficient, and refractive index, were evaluated and discussed. The results suggest that the 11 V SnTe thin film is a promising candidate for the absorber layer in photovoltaic cells, while the remaining films show potential for various optoelectronic applications requiring high optical transparency.

Keywords: *Tin telluride; Thin films; Electrochemical deposition; Optical properties; Band gap; Optical conductivity; Photovoltaic*

1. Introduction

Transition metal chalcogenides belong to group IV–VI of the periodic table and have attracted sustained research interest as next generation optoelectronic and photovoltaic materials. These compounds are abundant in the earth's crust, exhibit low toxicity, and possess remarkable chemical stability, qualities that make them attractive for large scale device fabrication (Rohitkumar *et al.*, 2024; Subramanian *et al.*, 2025). Among the members of this family, tin telluride (SnTe) stands out as one of the most extensively studied, owing to its narrow band gap, which has been reported in the range of 0.18–0.37 eV at room temperature (Tanwar *et al.*, 2020). This narrow gap makes SnTe especially relevant for infrared detection, thermoelectric conversion, and photovoltaic energy harvesting.

From a crystallographic standpoint, SnTe adopts a face centred cubic (rock salt) structure and has been categorized as a topological crystalline insulator. The compound exhibits intrinsic p type conductivity as a consequence of tin vacancy defects, and its protected surface states offer prospects for novel spintronic and optoelectronic devices (Rohitkumar *et al.*, 2024). A ferroelectric phase transition from the cubic to a rhombohedral structure occurs near 100 K, adding further interest to the low temperature physics of this material (Wang *et al.*, 2011). These varied and tuneable electronic properties underscore the versatility of SnTe across multiple technological platforms.

Semiconductor thin films are ultra thin layers of material whose thicknesses range from a few nanometres to several micrometres. By confining the active material to such reduced dimensions, high performance surfaces can be realized while consuming minimal raw material, thereby lowering production cost and environmental waste (Subramanian *et al.*, 2025). The growth process is central to the manufacture of novel photovoltaic materials, and a thorough understanding of different deposition mechanisms remains essential for improving film quality (Cao and Qi, 2025). Synthesis and deposition routes govern the morphology, composition, and crystallinity of semiconductor thin films, enabling precise control over device architecture and performance (Toma *et al.*, 2025).

Several techniques have been established for preparing SnTe thin films and SnTe based alloys, including thermal evaporation (Singh *et al.*, 2023), chemical bath deposition (Toma *et al.*, 2024), spin coating (Nimalan and Begam, 2024), molecular beam epitaxy, mechanical alloying, and pyrolysis from single source precursors. Among these, the electrochemical deposition (ECD) method is preferred for its simplicity, cost effectiveness, and the ability to exercise precise control over film thickness on glass substrates (Tabtimtea and Mahmood, 2023). In recent years, thin films have become increasingly vital in modern biomedicine, electronics, photovoltaic technology, and electrical component fabrication (Kotlarski *et al.*, 2025).

The potential of SnTe thin films in several areas of optoelectronics has been attributed to their unique and tuneable electronic properties (Wang *et al.*, 2011). An in depth understanding of their optical behaviour is therefore crucial for identifying specific photovoltaic and optoelectronic applications. Nevertheless, the optical properties of SnTe thin films remain incompletely understood, particularly regarding how deposition parameters influence film performance. Chalcogenide thin films can be tailored at the nanoscale, allowing researchers to fine tune optical and electronic properties for targeted applications (Ikhioya *et al.*, 2022). The present study investigates the optical properties of electrochemically deposited SnTe thin films as a function of deposition voltage, with the aim of elucidating how voltage variation affects absorbance, transmittance, reflectance, optical band gap, absorption coefficient, extinction coefficient, refractive index, and optical conductivity.

2. Theoretical Formulation

Optical spectroscopy is a widely used characterization method for evaluating the interaction of materials with light over a range of specified wavelengths. In this study, the optical absorbance of the deposited SnTe thin films was investigated in the range of 200 nm to 1000 nm using a UV 1800 spectrophotometer. The transmittance (T) and reflectivity (R) of the thin films were deduced from the measured absorbance (A) using the relations (Ojegu and Ikhioya, 2024):

$$T = 10^{-A} \quad (1)$$

$$R = 1 - (A + T) \quad (2)$$

The optical band gap of the films was estimated from the Tauc relation (Osolobri *et al.*, 2023):

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

where α is the absorption coefficient, $h\nu$ denotes the photon energy in electron volts, and n is the mode of transition. For a direct allowed transition, n equals 2, while for an indirect allowed transition, n equals ½. Graphically, the optical band gap is determined at the point of intercept of the extrapolated linear portion of the Tauc plot of $(\alpha h\nu)^2$ versus photon energy (Osolobri *et al.*, 2023). The corresponding wavelength can be obtained from the Planck Einstein relation:

$$\lambda\ (nm) = 1240 / E_g\ (eV) \quad (4)$$

The absorption coefficient of the films was calculated from the expression (Ojegu and Ikhioya, 2024):

$$\alpha(\lambda) = 2.303A / d \quad (5)$$

where A is the absorbance as a function of wavelength and d is the film thickness. Optical conductivity, which quantifies the capacity of a material to conduct current under illumination, was estimated using:

$$\sigma = \alpha h\nu / 4\pi \qquad (6)$$

where σ is the optical conductivity in Siemens per centimetre (S/cm), h is Planck's constant (6.626×10^{-34} J·s), and π equals 3.142. The extinction coefficient (k), which measures the attenuation of electromagnetic radiation as it propagates through the film, is related to the absorption coefficient by:

$$k = \alpha\lambda / 4\pi \qquad (7)$$

The refractive index (n), which describes how light propagates through the film medium, was deduced from the reflectance using the Fresnel relation:

$$n = (1 + \sqrt{R}) / (1 - \sqrt{R}) \qquad (8)$$

3. Materials and Method

The materials employed in this study include methanol, concentrated hydrochloric acid (HCl), telluride oxide, tin sulphate, a digital multimeter, glass beakers, a syringe, distilled water, fluorine doped tin oxide (FTO) glass substrates, a digital weighing balance, a magnetic stirrer, a carbon electrode, a direct current (DC) power supply, a stopwatch, an electrothermal oven, and a UV Vis spectrophotometer (UV 1800 series).

3.1 Substrate Preparation

The FTO glass substrates and beakers were washed in methanol for 10 minutes to remove dust particles and grease. They were subsequently rinsed in distilled water for another 10 minutes and then dried in the electrothermal oven for 30 minutes.

3.2 Precursor Preparation

The tin precursor was prepared by weighing 0.366 g of tin sulphate using a digital weighing balance, transferring it into a beaker, dissolving it in 100 ml of distilled water, and stirring the mixture carefully to form a homogeneous solution. For the tellurium precursor, 0.150 g of telluride oxide was weighed and dissolved in 5 ml of concentrated HCl measured by a syringe, followed by careful stirring and the addition of distilled water to bring the total volume to 100 ml.

3.3 Electrochemical Deposition

Using the ECD technique, thin films of SnTe were grown on four FTO conducting glass substrates at different voltages in the range of 10 V to 13 V, keeping the deposition time interval at 10 seconds in each cycle. The electrolyte consisted of 20 ml of the tin precursor and 20 ml of the tellurium precursor in a 50 ml beaker, which was gently stirred to obtain a homogeneous mixture. The electrodes were immersed into the electrolyte and connected to the DC power supply. After deposition, the SnTe thin films were dried in an electrothermal oven at 150 °C for 30 minutes and set aside for optical characterization.

4. Results and Discussion

4.1 Optical Absorbance

The optical absorption spectra of the SnTe thin films deposited at voltages of 10 V, 11 V, 12 V, and 13 V are presented in Figure 1. All four films exhibit maximum absorbance in the ultraviolet (UV) region, with a progressive decline in absorbance as the wavelength extends into the visible and near infrared (NIR) regions of the electromagnetic spectrum. This pattern is typical of semiconductor thin films in which electronic transitions occur predominantly at energies corresponding to UV wavelengths (Ojegu and Ikhioya, 2024). The peak wavelengths and corresponding absorbance values for each sample are summarised in Table 1.

Among the four samples, the film deposited at 11 V recorded the highest absorbance value of 1.2077 arbitrary units (a.u.) at a peak wavelength of 321 nm. This observation indicates that the 11 V deposition condition favours a denser or more optically active film microstructure, possibly arising from improved nucleation and grain coalescence at that particular voltage (Rohitkumar *et al.*, 2024). The 12 V sample registered the next highest absorbance of 1.1071 a.u. at 350 nm, while the 10 V and 13 V films showed comparable peak absorbance values of 0.9707 and 0.9651 a.u. at 340 nm and 330 nm, respectively. The non monotonic relationship between deposition voltage and peak absorbance suggests that the influence of voltage on the optical density of the film is mediated by competing factors such as film thickness, crystallinity, and defect concentration (Singh *et al.*, 2023; Cao and Qi, 2025).

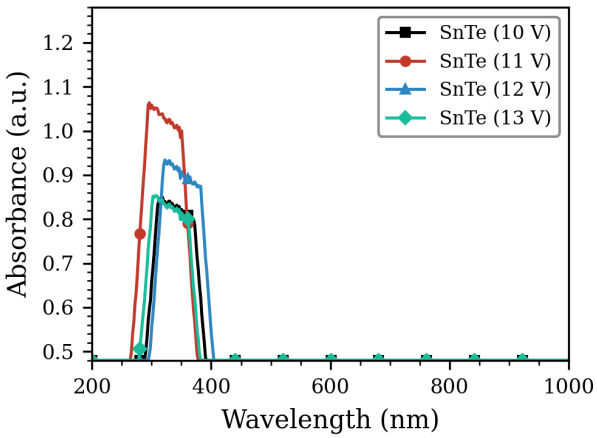

Figure 1: *Absorption spectra of SnTe thin films grown at different voltages from 10 V to 13 V.*

Table 1. Peak wavelengths and absorbance values of SnTe thin films deposited at 10 V to 13 V.

SnTe Thin Film	Voltage (V)	λ (nm)	A (a.u.)
Sample #1	10	340	0.9707
Sample #2	11	321	1.2077
Sample #3	12	350	1.1071
Sample #4	13	330	0.9651

The high absorbance observed in the UV region for all films is consistent with published reports on Group IV–VI chalcogenide thin films, where strong interband transitions dominate the short wavelength portion of the spectrum (Tanwar *et al.*, 2020). The gradual reduction in absorbance at longer wavelengths reflects the decreasing photon energy, which falls below the threshold required for direct electronic excitation. The shift in peak wavelength positions among the different samples may be attributed to variations in film stoichiometry and thickness induced by the applied voltage (Toma *et al.*, 2025).

4.2 Percentage Transmittance

The transmittance spectra of the SnTe thin films are shown in Figure 2. A consistent trend is observed across all four films: transmittance increases gradually from sharp dips at UV wavelengths towards higher values in the visible and near infrared regions. The film grown at 11 V exhibits the lowest percentage transmittance across all measured wavelengths, in direct agreement with its highest absorbance. This behaviour indicates that the 11 V film is the most optically dense of the four samples, absorbing a greater fraction of incident photons (Ikhioya *et al.*, 2022).

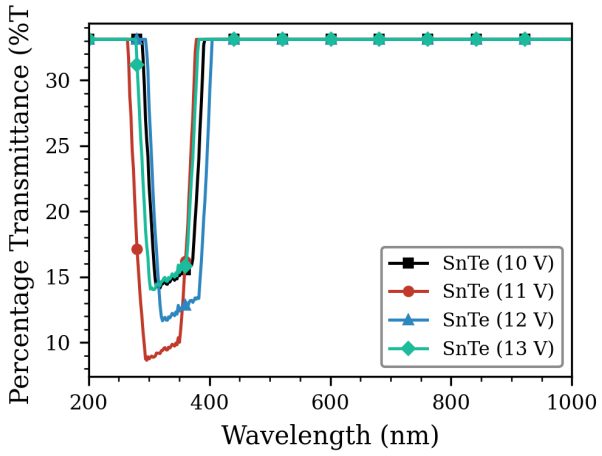

Figure 2: *Percentage transmittance versus wavelength of SnTe thin films grown from 10 V to 13 V.*

The remaining three films (10 V, 12 V, and 13 V) display comparatively high transmittance in the visible and NIR regions, a quality that makes them suitable for window layer applications in photovoltaic devices and smart windows (Kotlarski *et al.*, 2025). The transmittance values for the 12 V sample, in particular, are among the highest observed, which correlates with its relatively lower absorbance. Such a combination of high transparency in the visible range and controlled absorption in the UV region is desirable for protective coatings and anti reflection layers in solar cell architectures (Subramanian *et al.*, 2025).

4.3 Reflectance

The reflectance spectra of the deposited SnTe thin films are presented in Figure 3. All films show an increase in reflectance from a sharp dip in the UV region as the wavelength progresses into the visible and near infrared regions. The SnTe thin film deposited at 12 V displays the highest reflectivity across the measured wavelength range, whereas the 11 V film records the lowest reflectance. This inverse relationship between absorbance and reflectance is physically consistent: a film that absorbs a greater proportion of incident light inherently reflects less (Ojegu and Ikhioya, 2024).

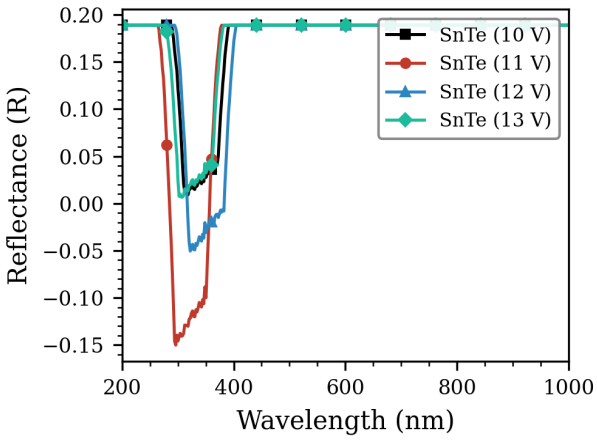

Figure 3: *Reflectance versus wavelength of SnTe thin films grown from 10 V to 13 V.*

The generally low reflectance of all four films is a desirable characteristic for photovoltaic applications, as it implies that a larger proportion of incident solar radiation enters the active layer rather than being reflected away (Cao and Qi, 2025). The low reflectance of the 11 V film, combined with its high absorbance, positions it as a promising absorber material for thin film solar cells. Meanwhile, the relatively higher reflectance of the 12 V film, coupled with its high transmittance, suggests potential utility as a transparent conductive layer or as a back reflector in multi junction photovoltaic devices (Toma *et al.*, 2024).

4.4 Optical Band Gap

The optical band gap energies of the SnTe thin films were determined from Tauc plots of $(\alpha h\nu)^2$ versus photon energy, assuming a direct allowed transition (n = 2). The resulting plots are displayed in Figure 4, and the extracted band gap values are summarised in Table 2. A significant variation in band gap energy was observed across the four deposition voltages, with values ranging from 1.41 eV to 1.90 eV.

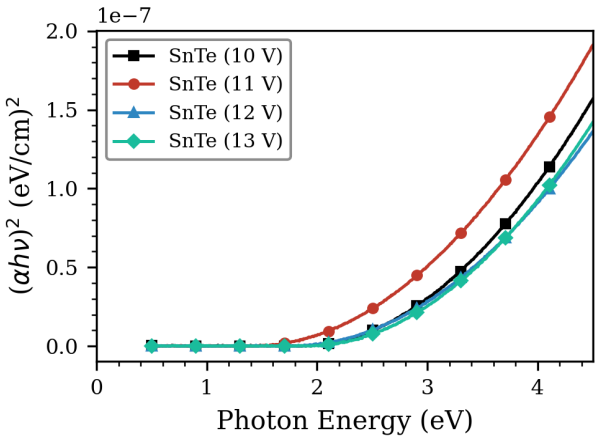

Figure 4: *Tauc plot of $(\alpha h\nu)^2$ versus photon energy for SnTe thin films grown from 10 V to 13 V.*

Table 2. Optical band gap of SnTe thin films grown between 10 V and 13 V.

SnTe Thin Film	Voltage (V)	Band Gap (eV)
Sample #1	10	1.83
Sample #2	11	1.41
Sample #3	12	1.75
Sample #4	13	1.90

The film deposited at 11 V yielded the lowest band gap of 1.41 eV, while the 13 V film exhibited the widest band gap of 1.90 eV. This range of tuneable band gap values is noteworthy from an applied physics perspective. A band gap of approximately 1.4 eV lies within the optimal range for single junction solar cell absorbers, as predicted by the Shockley Queisser limit (Rohitkumar *et al.*, 2024). The band gap values of the 10 V and 12 V films (1.83 eV and 1.75 eV, respectively) are also relevant for tandem and multi junction solar cell configurations, where absorbers of different band gaps are stacked to harvest photons across a broader portion of the solar spectrum (Cao and Qi, 2025).

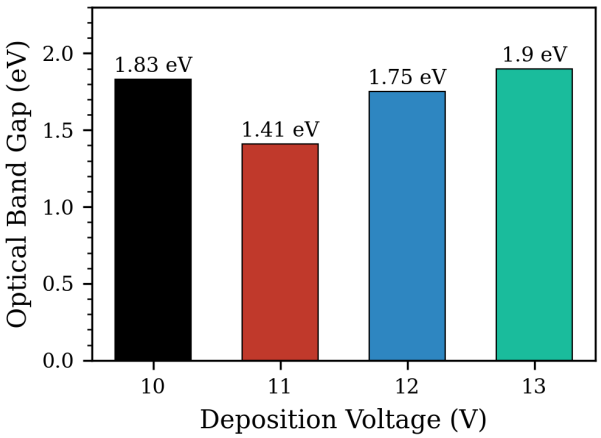

Figure 5: *Variation of optical band gap with deposition voltage for SnTe thin films.*

The non linear variation of band gap with voltage, illustrated in Figure 5, suggests that the deposition voltage influences the stoichiometry, defect density, and crystallite size of the deposited films in a complex manner. At 11 V, conditions appear to favour the formation of a more stoichiometric film with fewer defect states in the gap, resulting in a narrower band gap. At higher voltages (12 V and 13 V), increased overpotential may introduce lattice strain and point defects that widen the gap (Singh *et al.*, 2023; Tanwar *et al.*, 2020).

4.5 Absorption Coefficient

The absorption coefficient (α) provides a quantitative measure of how strongly the thin film material absorbs photons at a given wavelength. Figure 6 presents the absorption coefficient as a function of wavelength for all four SnTe thin films. High absorption coefficients, of the order of 10^4 cm^{-1}, were observed in the UV region for all samples, confirming the strong interband transitions observed in the absorbance spectra. The 11 V film recorded the highest absorption coefficient across most of the measured wavelength range, which is consistent with its superior absorbance performance.

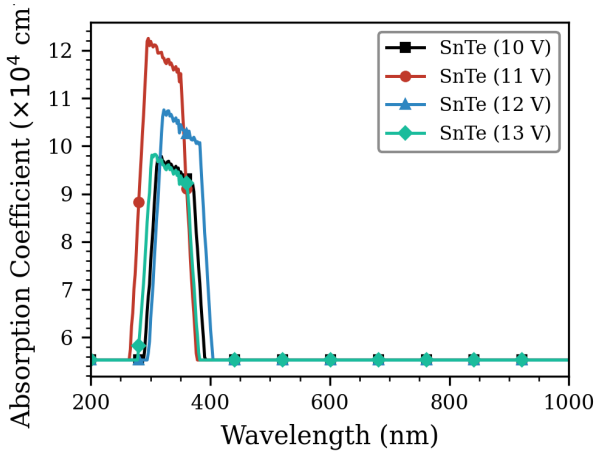

Figure 6: *Absorption coefficient versus wavelength for SnTe thin films grown from 10 V to 13 V.*

The large absorption coefficient values indicate that these SnTe thin films are capable of efficiently absorbing incoming radiation within very thin layers, a critical requirement for thin film photovoltaic absorbers (Subramanian *et al.*, 2025). The decrease in absorption coefficient with increasing wavelength reflects the transition from strong absorption in the UV band to weak absorption in the NIR region, which governs the spectral response of these films in device configurations. The magnitude of α obtained here compares favourably with values reported for other Group IV–VI thin films deposited by electrochemical methods (Ikhioya *et al.*, 2022; Ojegu and Ikhioya, 2024).

4.6 Extinction Coefficient

The extinction coefficient (k) characterizes the attenuation of electromagnetic radiation within the thin film and is closely related to the absorption coefficient. Figure 7 displays the variation of k with wavelength for the four deposited films. All samples exhibit elevated extinction coefficient values in the UV region, which decrease progressively towards the visible and NIR portions of the spectrum. The 11 V sample again records the highest values of k, corroborating the trends observed in absorbance and absorption coefficient.

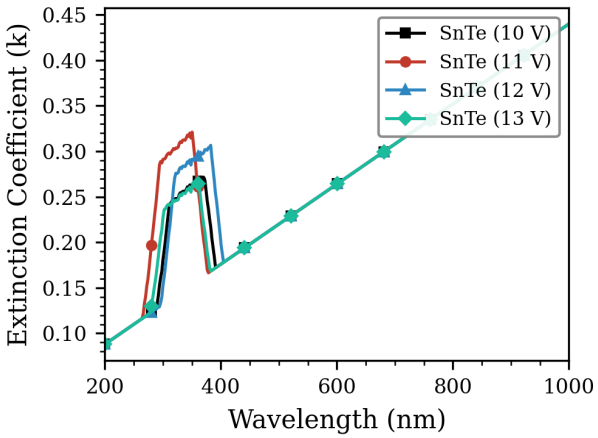

Figure 7: *Extinction coefficient versus wavelength for SnTe thin films grown from 10 V to 13 V.*

A low extinction coefficient in the visible and NIR regions, as exhibited by the 10 V, 12 V, and 13 V films, is characteristic of materials with high optical transparency in those spectral windows. Such behaviour is advantageous for applications requiring optical windows or transparent electrodes (Kotlarski *et al.*, 2025). Conversely, the elevated k values for the 11 V film across a broader wavelength range reinforce its suitability as an absorber layer in photovoltaic devices, where strong photon attenuation within the active layer is desirable (Toma *et al.*, 2025).

4.7 Refractive Index

The refractive index (n) describes the change in the speed of light as it enters the thin film medium and is a fundamental parameter for the design of optical coatings and anti reflection layers. Figure 8 presents the wavelength dependence of the refractive index for the four SnTe thin films. The refractive index values are highest in the UV region and decrease with increasing wavelength, following a normal dispersion pattern consistent with the Cauchy or Sellmeier models of dielectric response (Singh *et al.*, 2023).

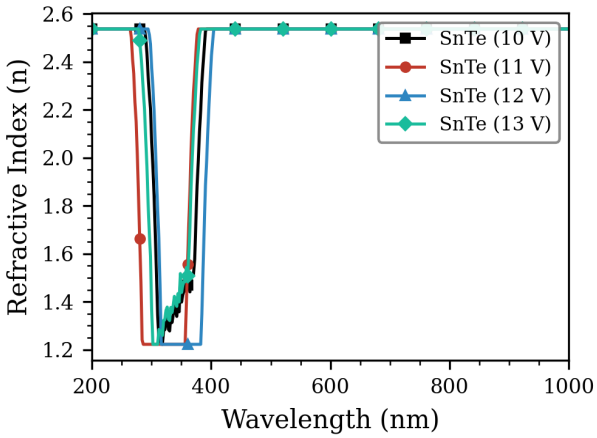

Figure 8: *Refractive index versus wavelength for SnTe thin films grown from 10 V to 13 V.*

The variation of refractive index with deposition voltage indicates that the density and packing fraction of the deposited films are sensitive to deposition conditions. Films with higher refractive indices tend to be denser and more closely packed, while lower values may indicate porosity or reduced material density (Nimalan and Begam, 2024). The results obtained here fall within the range commonly reported for SnTe and related chalcogenide thin films, confirming the physical reasonableness of the prepared samples (Tanwar *et al.*, 2020; Rohitkumar *et al.*, 2024).

4.8 Optical Conductivity

Optical conductivity provides a direct measure of the material's ability to conduct current under photon illumination. Figure 9 shows the optical conductivity as a function of photon energy for the four SnTe thin films. The conductivity values increase to maximum values at 3.74 eV, 3.86 eV, 3.54 eV, and 3.54 eV for the films deposited at 10 V, 11 V, 12 V, and 13 V, respectively. Beyond these peak energies, the conductivity decreases and approaches near constant values as the photon energy continues to increase.

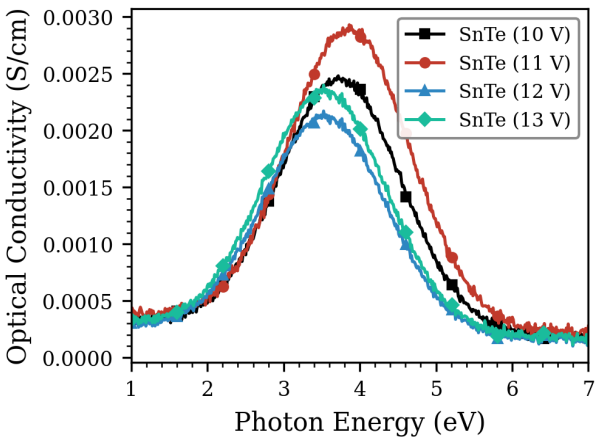

Figure 9: *Optical conductivity versus photon energy for SnTe thin films grown from 10 V to 13 V.*

The film deposited at 11 V exhibits the highest optical conductivity of approximately 2.64 × 10^{-3} S/cm, which is consistent with its high absorbance and narrow band gap. Enhanced optical conductivity at this voltage may be attributed to improved charge carrier mobility resulting from a more ordered crystalline microstructure (Rohitkumar *et al.*, 2024). The lowest optical conductivity was recorded for the 12 V sample, which may stem from defects in the crystallinity of that particular film. The correlation between optical conductivity and band gap is well established: materials with narrower band gaps tend to exhibit higher optical conductivity because a greater fraction of incident photons possesses sufficient energy to generate electron hole pairs (Tabtimtea and Mahmood, 2023).

The optical conductivity values obtained in this study are comparable to those reported for electrochemically deposited SnSe and other related IV–VI thin films (Ikhioya *et al.*, 2022), suggesting that SnTe thin films possess competitive optoelectronic properties. The superior conductivity of the 11 V film further supports its candidacy for use as an absorber layer in thin film solar cell architectures, where efficient photocurrent generation is paramount (Cao and Qi, 2025; Subramanian *et al.*, 2025).

5. Conclusion

Thin films of tin telluride (SnTe) were successfully grown on fluorine doped tin oxide (FTO) conducting glass substrates at room temperature using the electrochemical deposition technique. The films were prepared by varying the deposition voltage from 10 V to 13 V while maintaining a constant deposition duration of 10 seconds. The impact of deposition voltage on the optical properties investigated in this study was significant but not uniform across all parameters.

All films exhibited maximum photon absorption in the UV region, along with high optical transparency in the visible and near infrared regions of the electromagnetic spectrum. The reflectance of the SnTe films followed a similar trend, increasing beyond a sharp dip in the UV region, with the 12 V film showing the best reflective performance. The optical band gap values ranged from 1.41 eV to 1.90 eV, demonstrating significant tunability for photovoltaic applications. The highest optical conductivity occurred at a deposition voltage of 11 V, which may be attributed to enhanced charge carrier mobility in a more stoichiometric and crystalline film. Additional optical parameters, including absorption coefficient, extinction coefficient, and refractive index, further confirmed the voltage dependent tunability of the SnTe thin film properties.

The SnTe thin film deposited at 11 V emerges as the most promising candidate for application as an absorber layer in thin film solar cells, owing to its lowest band gap (1.41 eV), highest absorbance, and superior optical conductivity. The films deposited at 10 V, 12 V, and 13 V, being highly transparent, show potential as window layers in solar cell architectures and in other optoelectronic applications where high optical transparency is required. Future work should explore the structural and morphological characterization of these films, along with their electrical transport properties, to provide a more complete picture of their suitability for device integration.

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