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Effects of Deposition Time on the Synthesis and Characterization of Lead Telluride (PBTE) Thin Films Deposited Using Electrochemical Techniques

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Abstract

Lead telluride (PBTE) is a narrow-bandgap IV–VI semiconductor widely used in infrared detectors and thermoelectric devices. Electrodeposition provides a cost-effective and scalable technique for producing PbTe thin films with tunable composition and structure, where parameters such as bath composition, deposition potential, temperature, and annealing influence phase purity and performance. Experimental findings show that PbTe films deposited for 10 seconds exhibited maximum light absorption (1.1253 a.u) at 308 nm in the UV region, while absorption decreased with increasing deposition time. Films deposited for 30 and 40 seconds displayed higher transmittance across visible and near-infrared wavelengths, indicating reduced light absorption. The film thickness increased slightly from 106.78 nm to 107.91 nm as deposition time rose from 10 to 40 seconds. The optical band gap also increased from 1.45 eV to 1.98 eV, suggesting tunability well above the bulk value (0.3 eV). Optical conductivity peaked at 0.00239 S/cm for films deposited for 10 seconds and decreased with longer deposition times, consistent with reduced charge transport in thicker films. The results indicate that shorter deposition times yield films with higher light absorption and conductivity, while longer times enhance transmittance and bandgap. The study concludes that electrodeposition is an economical and effective technique for producing high-quality PbTe thin films, with deposition time serving as a key factor in optimizing their optical and electronic properties for photovoltaic and optoelectronic applications

Keywords: Deposition Time, Lead Telluride, Narrow Bad-Gap, Semiconductor, Electrochemical Technique.

Introduction

The importance of energy in today ever-growing world of technology cannot be overemphasized. All technology of today and of the future is driven by energy, especially electrical energy. Various mean needs to be harness in order to achieve maximum requirement of electrical energy demand. Lead chalcogenides like PbS, PbTe, and PbSe are narrow band-gap semiconductors largely used in thermoelectric (TE) and infrared (IR) applications. There is a thermoelectric advantage associated with chalcogenides which allows the conversion of temperature fluctuations into electrical voltage (Agbrara et al., 2025). According to Tingjun et al. (2021) electrodeposition seems to be a capable synthesis methods used in the fabrication of devices due to its capability to control crystallinity, composition, morphology, and the crystal structure of materials through the control of electrodeposition parameters.

PbTe is among the narrow-gap semiconductors with bandgap of approximately 0.32 to 0.36 eV depending on stoichiometry and temperature. It has been studied widely for mid-infrared detectors, IR optics, and thermoelectric applications (Böhm, et.al., 2015), where its high Seebeck coefficient and favorable carrier effective mass are useful at elevated temperature. Thin films enable device integration (microdevices, on-chip thermal energy harvesters) and allow property tuning by microstructure and doping. Compared with vacuum techniques (MBE, PVD, ALD), electrochemical routes bring advantages in affordability, conformal coating on complex shapes, and low-temperature processing. Lead salts which is also known as lead chalcogenides (PbX where X is S, Te, and Se) have widely been studied in IR detections. And it happens to be a semiconductor with direct narrow band-gaps of 0.41eV, 0.32eV, and 0.29eV, respectively, at temperature 300K (Jürgen et al., 2024).

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Different deposition techniques have been used for depositing PbTe thin films by various authors (Zogg et al., 1991; Gorer et al., 1995; Leskelä et al., 1993s; Nykänen, 1990; Kanniainen et al., 1999). Electrodeposition remain one of the most cost effective method for the deposition of PbTe with various advantages (Fekadu et al., 2015; Saloniemi, 1998).

Lead chalcogenides are highly potent in the applications of IR detectors, laser diodes and thermo photovoltaic energy converters. (Mahalingam et al., 2010; Kellermann et al., 2004; Zimin et al., 2002; Ugai et al., 1998; Samoylov et al., 2002).

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It is pertinent to note that various findings have shown that increase deposition time, using electrochemicaldeposition technique on lead telluride (PbTe) thin films generally results in a linear increase in film thickness (Mahalingam et al., 2010) though this can be over extended periods. The thicker the films of PbTe the more improvement in its crystallinity, larger its grain sizes, and more defined structural properties. Excessive deposition time sometimes lead to changes in morphology and the potential for film detachment. Characterization shows that film properties like optical bandgap, crystal structure, and surface morphology are directly influenced by the deposition time.

Materials and Methods

Materials

The following materials were used in the course of the study. All reagents used are analytical grade and require no further purification. They include Methanol, Conc. hydrochloric acid (HCl), Telluride oxide, Iron sulphate, Distilled water, Conducting glass substrates (FTO), Carbon Electrode, Electro thermal oven, UV-Vis Spectrophotometer (UV – 1800 series), Multimeter, Beakers, Syringe, Digital weighing balance, Stirrer, DC power supply, Ammeter, Stop watch.

Method

Cleaning of FTO substrates and glass wares

Wash the FTO glass substrates in methanol for 10 minutes to remove dust particles and grease. Then rinse in distilled water for another 10 minutes and allowed to dry in an electro thermal oven for a few minutes.

Preparation of Pb and Te precursors

The following steps were carefully adopted in preparing the precursor solution of Pb and Te. Measure 0.303g of lead using a digital weighing balance and transfer into a beaker then dissolve with 100 ml of distilled water and stir carefully to form a solution. Measure 0.150g of telluride oxide and dissolve with 5ml of conc. HCl measured using a syringe then stir carefully. Add distilled water to make up the solution to 100ml.

Deposition of PbTe Thin Films

The lead telluride (PbTe) thin films were deposited using the electrochemical deposition technique illustrated in figure 2. The ECD set-up consists of a graphite rod (anode) while the FTO conducting glass substrate acts as the cathode. Thereafter, measure 20ml of lead precursor and 20ml of telluride precursor into a 50 ml beaker and stir carefully to obtain PbTe precursor. Pass the electrodes through the mold into the PbTe precursor and set the process running using DC power supply at a fixed voltage of 10 volts for 10 seconds. Repeat the procedure using different deposition time 10 sec, 20 secs, 30secs and 40secs with the deposition voltage held constant at a magnitude of 10 volts. The deposited PbTe thin films were dried in an electro thermal oven for 30 minutes at 150^{o}C.

Characterization of the Deposited PbTe thin films

UV spectroscopy

Upon drying, the PbTe thin films deposited were characterized using UV-Vis spectrophotometer (UV 1800 series) for the range of wavelengths from 200 nm to 1000 nm.

Film Thickness

The surface roughness and thickness of the deposited PbTe thin film were obtained using stylus profiler. The values obtained are presented in table 2.

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Results

Optical absorbances

The amount of light absorbed by the PbTe films deposited at different deposition time were measured using UV-Vis spectrophotometer (UV 1800 series) for the wavelength range of 200 nm to 1000 nm at interval of one nanometer. The optical absorbance results obtained are presented in the figure below.

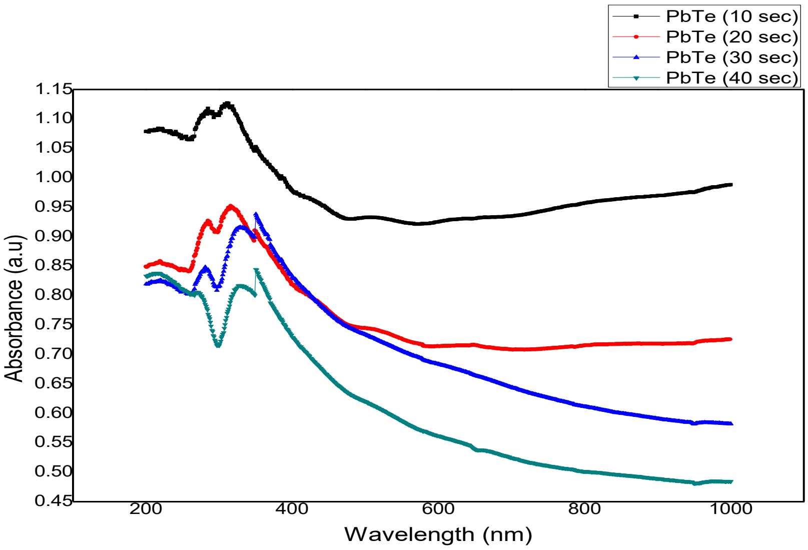

Figure 1: Absorption spectra of PbTe films deposited at different deposition time from 10 sec to 40 sec.

Table 1: Asssbsorbance Peak Wavelengths of the deposited PbTe films.

PbTe Films	Deposition Time	Ultraviolet (UV) Region		Visible region	
		𝝀 (nm)	**A (a.u)**	**𝝀 (nm)**	**A (a.u)**
Sample #1	10 sec	306	1.1223	405	0.9757
		308	1.1253	496	0.9320
				520	0.9319
Sample #2	20 sec	285	0.9272		
		316	0.9522		
Sample #3	30 sec	277	0.8409		
		329	0.9149		
		351	0.9354		
Sample #4	40 sec	272	0.8057		
		328	0.8176		
		350	0.8447		

Transmittance (T)

The transmittance describes the amount of light transmitted by the PbTe films over the incident radiation projected on the material. The transmittance is often expressed in percentage (%T).

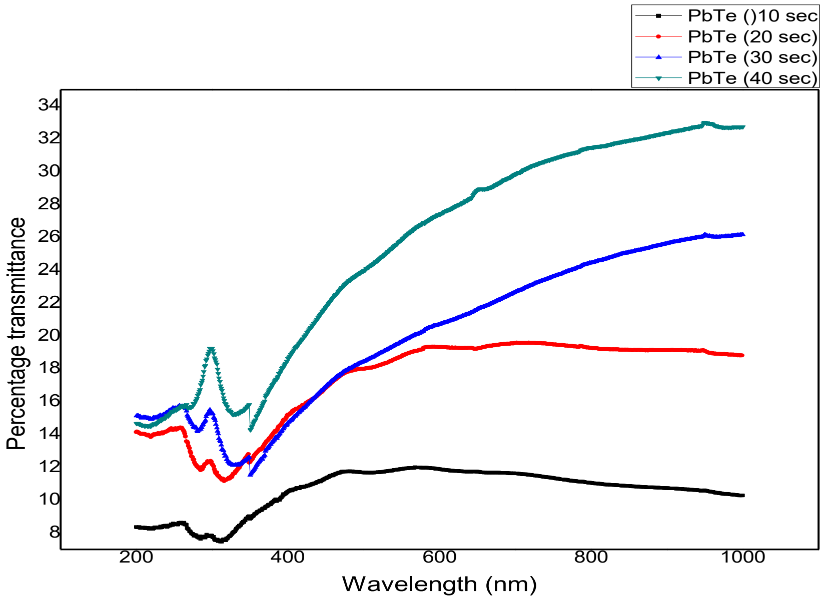

Figure 3: Graph of percentage transmittance (%T) versus wavelength of PbTe films deposited at different deposition time from 10 sec to 40 sec.

Reflectance (R)

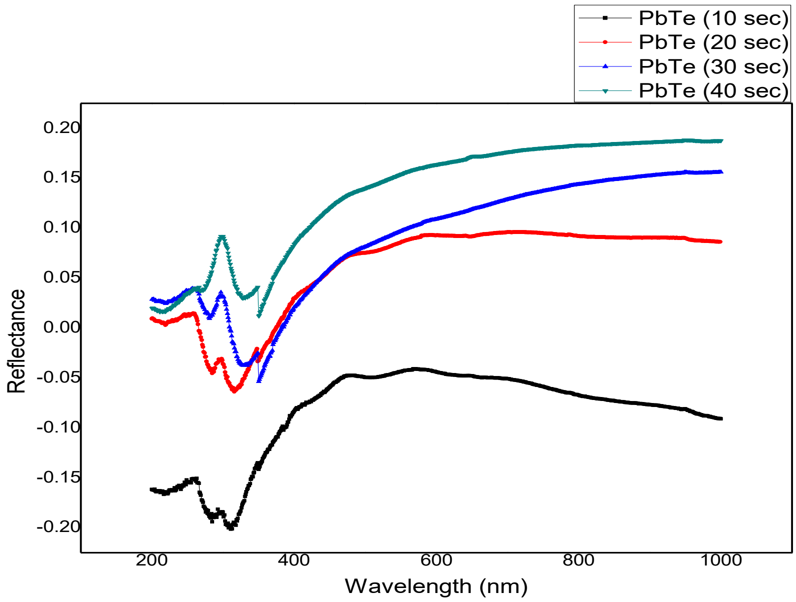

Figure 3: Graph of reflectance versus wavelength of PbTe films deposited at different deposition time from 10 sec to 40 sec.

Film Thickness

The thickness of the PbTe films deposited at different deposition time are presented in table 2.

Table 2: Thickness of PbTe Films.

PbTe Film	Deposition Time	Thickness in nanometer
Sample #1	10 sec	106.76 nm
Sample #2	20 sec	106.86 nm
Sample #3	30 sec	107.45 nm
Sample #4	40 sec	107.91 nm

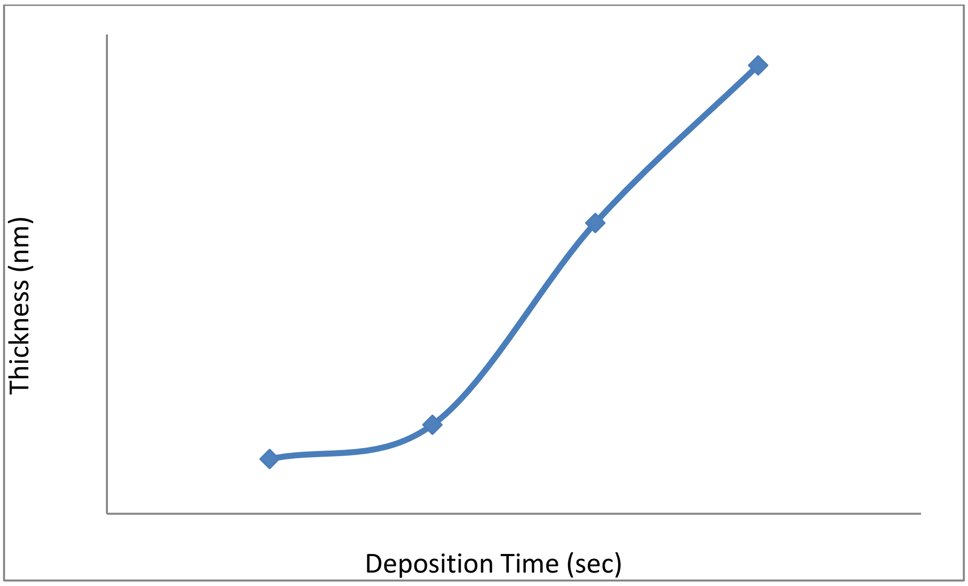

Figure 4: Graph of Thickness of PbTe Films with deposition time

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Energy Band – gap

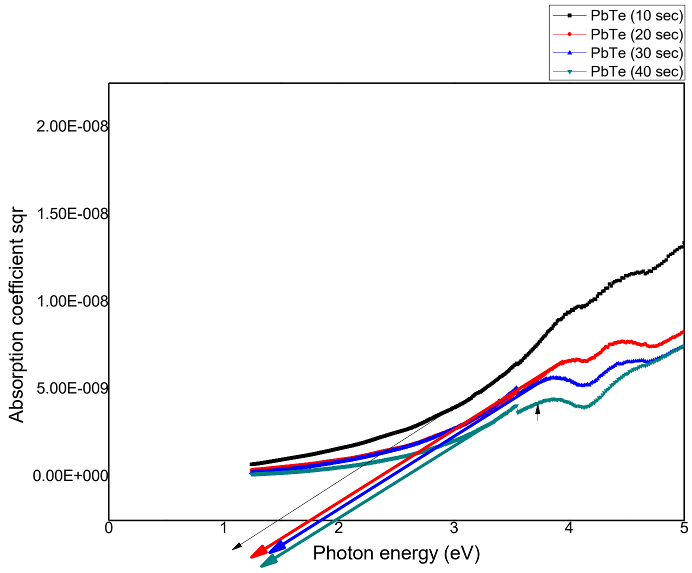

Figure 5: Tauc plot of absorption coefficient square versus photon energy of the PbTe films deposited at different time of 10 sec to 40 sec

Table 3: Band – gap values of the PbTe Films

PbTe Films	**Band – gap (in electron volt)**
Sample #1	**1.45 eV**
Sample #2	**1.74 eV**
Sample #3	**1.82 eV**
Sample #4	**1.98 eV**

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Optical Conductivity (σ)

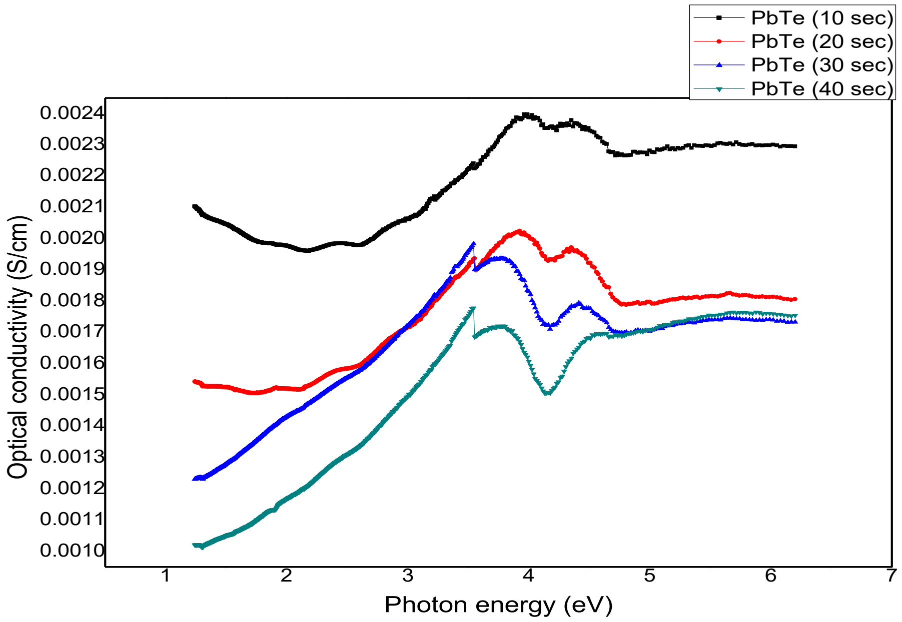

Figure 6: Optical conductivity of PbTe films deposited at different deposition time from 10 sec to 40 sec

Discussion

The lead telluride (PbTe) films deposited all have maximum light absorption in ultra violet (UV) region. The highest absorbance value of 1.1253 a.u at a wavelength of 308 nm was recorded for the PbTe film deposited at 10 sec deposition time, which slightly reduces and increases again as wavelength approaches the visible and near infrared region. The film deposited at 20 sec also follows a similar trend but increase to a near constant value. The PbTe deposited at the longest deposition time of 40 sec has the lowest absorbance particularly in the visible and near infrared region of the electromagnetic spectrum as shown in Figure 1, and summarized in Table 1.

The percentage transmittance of the PbTe films deposited at 30sec and 40 sec increases from wavelength of 35 n and 351 nm respectively, across all measured wavelengths in the visible and near infrared region of the EM spectrum. The film deposited at 10 sec has the lowest transmittance, which increases from the wavelength of 311 nm in the visible region, and then tends to reduced values as the wavelength approaches near infrared region.

The reflectance of the PbTe films deposited follow a similar trend as the percentage transmittance of the films but with an enhanced performance across all measured wavelengths in the UV, visible and near infrared regions of the electromagnetic spectrum. The thickness of the deposited PbTe films increases from 106.78 nm to 107.91 nm as deposition time increases from 10 sec to 40 sec.

The band – gap of the PbTe films deposited were deduced from the extrapolation of the linear portion of Tauc plot to be 1.45 eV, 1.74 eV, 1.82 eV and 1.98 eV for the films deposited using deposition time of 10 sec, 20 sec, 30 sec, and 40 sec respectively.

The optical conductivity of all the PbTe samples increases with photon energy to a peak energy of and then drop slightly in all the films. The optical conductivity at the peak varies in the range of 10.00239 S/cm, 0.00201 S/cm, 0.00198 S/cm and 0.00177 S/cm for PbTe films deposited at deposition time of 10 sec, 20 sec, 30 sec and 40 sec respectively.

Conclusion

All of the PbTe films deposited have good light absorption in the UV region. The best light absorption a.u at wavelength of nm was exhibited by the PbTe film deposited in a duration of 10 sec. while the PbTe film deposited at longest deposition time has the poorest result. The optical spectra of all the PbTe filmsshow that the shorter the deposition time, the more light was absorbed by PbTe films. The percentage transmittance of the PbTe films deposited improve with deposition time, with the films deposited at 30 sec and 40 sec showing better results. The lest performance in the visible and near infrared region was recorded by the PbTe film deposited at 10 sec, The reflectance of the PbTe films deposited follow a similar trend as the percentage transmittance of the films but with an enhanced performance across all measured wavelengths. The PbTe films become thicker as deposition time increases from 10 sec to 40 sec

The band – gaps of the PbTe films vary from 1.45 eV to 1.98 eV showing a significant fine tuning of the band – gap of PbTe as these values are larger than the bulk material of band-gap of approximately 0.3 eV. The optical conductivity of all the PbTe samples increases with photon energy to a peak energy of and then drop slightly in all the films, with the highest conductivity of 0.00239 S/cm exhibited by the PbTe film deposited at the lowest deposition time of 10 secs, which is in agreement with lower band – gap of the film resulting to enhance charge transport. The conductivity of the films reduces significantly as deposition time increases from 10 sec to 40 secs. This can be attributed the thickness of the films. The lowest optical conductivity of 0.00177 S/cm was exhibited by the PbTe films deposited at longest deposition time of 40 sec. From the findings of this research, the time variation significantly up tuned the optical properties of the PbTe films deposited by varying the deposition time. The values of the band gap fall in the range suitable for photovoltaic application in single junction solar cells, optoelectronic devices such as photo detector, as well as infrared detector. Having successfully carried out the research on electrochemically deposited lead telluride films at different deposition time, it is therefore recommended that electrochemical deposition technique is very economical and suitable method for preparing high grade PbTe films suitable for optoelectronic application and the variation of deposition time is a remarkable way to up tune the optical properties of PbTe films in order to achieve and expand their application in the field of photovoltaic (that is in solar energy conversion). This is made possible by obtaining a new set of energy band gaps whose wavelengths lie in the visible and near infrared regions.

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