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Influence of Deposition Potential on Lead Sulphide (PbS) Thin Film Using Electrodeposition Technique

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Authors' contributions

This work was carried out in collaboration between all authors. Author IIL designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ES and IIL managed the analyses of the study. Author IBO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This current paper studied the effect of variations in deposition voltage on lead sulphide (PbS) thin film, using electrodeposition technique, with zinc plate as the substrate. The result showed an inverse relationship between voltage and the thickness of the film. An inverse relationship between film's thickness and its resistivity was also obvious. For given values of voltage, the dependence of absorbance, transmittance, and reflectance of the film on the wavelength of the incident radiation was observed. The absorbance and reflectance were found to exhibit an inverse relationship with the wavelength. However, the transmitter was observed to increase as the wavelength is increased. The highest transmittance of 0.716% in the infrared region at the wavelength of 300 nm was recorded for all samples deposited at 1V. In the ultraviolet region, a transmittance of 0.946% at an incident wavelength of 1500 nm for all samples deposited at 5V was recorded. From the result analysis, it was observed that the reflection index, optical conductivity, extinction coefficient, real dielectric constant, and imaginary dielectric constant increased as the photon energy. The observe energy band gap of 1.7eV-2.4eV shows that PbS is a good material for solar cells fabrication.

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1. INTRODUCTION

Semiconductor thin films of IV-VI have been studied due to their potential application in solar cells and sensors. Lead sulphide (PbS) is a very important direct narrow gap binary semiconducting material with relatively large excitation Bohr radius of 18 nm [1]. This is the very important property for the applications of infrared detection [2]. This PbS is also used in variety of applications such as ion-selective sensors, solar absorption, solar control coatings and diode lasers [3-10]. Due to its physical properties, PbS is considered a prime candidate for a photovoltaic (PV) material and has generated great interest in its use. The PbS material is characterized by a direct band gap (1.5eV) with a high absorption coefficient. Another great advantage of PbS is that it can be deposited by a number of techniques including evaporation, sublimation, sputtering and chemical methods. The growth of PbS films by electrodeposition is a simple and low-cost process of producing high-quality material for PV device fabrication. Thin film PbS has attracted a great deal of interest for low-cost, high-efficiency photovoltaic energy conversion applications [11]. Among the various techniques that are available for PbS thin film deposition, electrodeposition, a non-vacuum technique, has the advantage of low cost, efficient utilization of raw material, and scalability for high-volume production. At the same time, additional research is still needed to improve upon the process reproducibility and performance levels achieved to date. Among the significant issues are interface carrier recombination and top-layer photon absorption which presently limit the short circuit current, junction recombination which limits the open-circuit voltage, and series-resistance losses which suppress the fill-factor [8]. In this research paper, we are interested in the deposited of PbS thin films semiconductor by looking at the influence of deposition potential on the electrical and optical properties of the material deposited.

2. MATERIALS AND METHODS

The experimental analysis of PbS thin films was carried out using lead Nitrate $Pb(NO_3)_2$, Sodium Sulphate Anhydrous (Na_2SO_4), Potassium tetraoxosulphate VI (K_2SO_4) and H_2SO_4. Deposition potential (voltages) was varied and the growth of PbS films and others bath parameter were determined with respect to the different bath parameters which includes time of deposition and substrate for the deposition. The concentration of the solution was kept constant throughout the experiment. The concentration of the compounds was maintained as prepared. The following are the concentration of the concentration of the substance prepared: 0.1M -$Pb(NO_3)_2$, 0.1M - (Na_2SO_4), 0.092M - K_2SO_4 and 0.1M - H_2SO_4. A volume of 20 cm^3 each of $Pb(NO_3)_2$ and (Na_2SO_4) was measured into 150 ml beaker using burette. A volume of 10 cm^3 of K_2SO_4 was measured into the same 150 ml beaker containing $Pb(NO_3)_2$ and (Na_2SO_4) respectively to serve as the inert electrolyte which helps to dissociate the Pb from the $Pb(NO_3)_2$ and S from the (Na_2SO_4) to form the required PbS film on the substrate. Finally, 5 cm^3 of H_2SO_4 was added to acidified the solution. The entire mixture was stirred with the glass rod to achieve uniformity. In each of the reaction baths prepared, a metal substrate (Zinc plate) and carbon electrode were connected to a DC power supply source and the voltage was maintained at 7V. The absorbance was measured using M501 UV-visible spectrophotometer in the wavelength range of 300-1500 nm and other solid state properties were calculated. The electrical (I/V) was obtained using four point probe (Model T345) and the resistivity and conductivity were calculated for various thickness.

3. RESULTS AND DISCUSSION

3.1 Electrical Analysis of PbS Thin Films

The electrical (I/V) characterization analysis was carried out using a four-point probe instrument (Model-T345), where the sheet resistivity and conductivity of the films were studied. The arrangement was made in such a way that the voltage across the transverse distance of the films and the values of the current were measured using silver paste to ensure good ohmic contact with the film. The calculated results for the sheet resistivity and electrical conductivity with their corresponding time and thickness are shown Table 1. The results showed that PbS thin films resistivity increases as the voltage increases and conductivity of the material increases as the thickness of the material decreases. The high resistivity and low

Table 1. Variation of parameters PbS thin films

Samples	Volume of $Pb(NO_3)_2$ (cm^3)	Volume of Na_2SO_4 (cm^3)	Volume of K_2SO_4 (cm^3)	Volume of H_2SO_4 (cm^3)	Voltage(V)	Time(s)
LS1	20.00	20.00	10.00	5.00	1.00	60.00
LS2	20.00	20.00	10.00	5.00	2.00	60.00
LS3	20.00	20.00	10.00	5.00	3.00	60.00
LS4	20.00	20.00	10.00	5.00	4.00	60.00
LS5	20.00	10.00	10.00	5.00	5.00	60.00

Table 2. Electrical properties of PbS thin films

Samples	Voltage (v)	Thickness, t (nm)	Resistivity, ℓ (Ωm)	Conductivity,σ $(\Omega m)^{-1}$
LS1	1.00	386	5.345x10[illegible]	1.870x10[illegible]
LS2	2.00	355	4.456x10[illegible]	2.244x10[illegible]
LS3	3.00	321	3.324x10[illegible]	3.008x10[illegible]
LS4	4.00	211	2.451x10[illegible]	4.079x10[illegible]
LS5	5.00	190	1.398x10[illegible]	7.153x10[illegible]

conductivity of the deposited films make the material suitable for mass production of PV solar panel and other electronics devices. It is a semiconductor that has large potential applications in thin films technology like photoluminescence and electroluminescent devices [9-14].

3.2 Optical Analysis of PbS Thin Films

Fig. 1 shows the plot of absorbance as a function of the wavelength of PbS thin films deposited at a different potential at constant time (60s). From the graph, it was observed that as the wavelength of the films radiation increases the absorbance of the films decreases. From Fig. 1, it was noticed that samples deposited at 5V recorded the value of 0.249 which is the highest value of absorbance at a wavelength incidence of 360 nm while Sample deposited at 1V was found to recorded lowest absorption value of 0.149 at incidence wavelength of 300 nm and sample deposited at 4V tend to maintain a steady increase which recorded the absorption value of 0.235 at incidence wavelength of 320 nm. However, absorbance of the films was found to be low in the both regions. The variation of the potential of the films deposited was done to find out at what particular potential to get a material suitable for solar cells fabrication and it was noticed that all the films deposited are good material for solar cells fabrication [9-14].

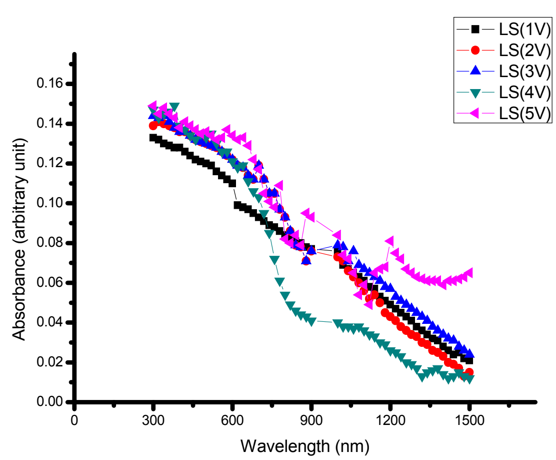

Fig. 1. Plot of absorbance as a function wavelength

Fig. 2 shows the plot transmittance (%) as a function of the wavelength of PbS thin films deposited at a different potential at constant time (60s). From the graph, it was observed that the wavelength of incident radiation increases as the transmittance increases. From the graph, it was noticed that all the samples deposited at different time interval followed the same trend. It was also observed that sample deposited at 1V recorded the highest transmittance of 0.716% in the infrared region at incidence wavelength of 300 nm and transmittance of about 0.946% in the ultraviolet region at incidence wavelength of 1500 nm. The sample deposited at 5V recorded the lowest transmittance. However, all the samples deposited recorded transmittance above 50% [9-14].

Fig. 3 shows the plot reflectance as a function of the wavelength of PbS thin films deposited at a different potential at constant time (60s). From Fig. 3, it was observed that the wavelength of incident radiation increases as the reflectance decreases. It was observed that sample deposited at 5V recorded the highest reflectance value of 0.182 at incidence wavelength of 300 nm in the infrared region and reflectance value of 0.041 in the ultraviolet region at incidence wavelength of 1480 nm. The sample deposited at 1V recorded the lowest reflectance value of 0.139 at incidence wavelength of 300 nm in the near infrared and reflectance value of 0.030 at incidence wavelength of 1460 nm at the ultraviolet region [9-14].

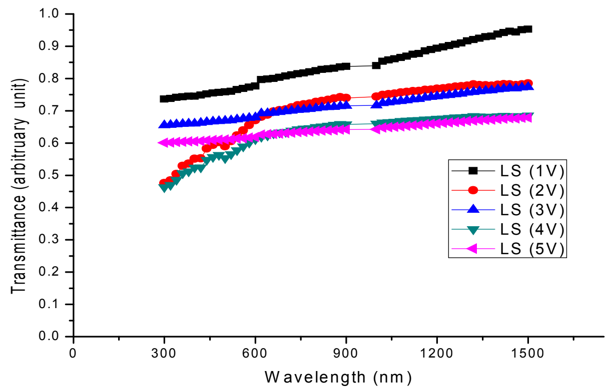

Fig. 2. Plot of transmittance as a function wavelength

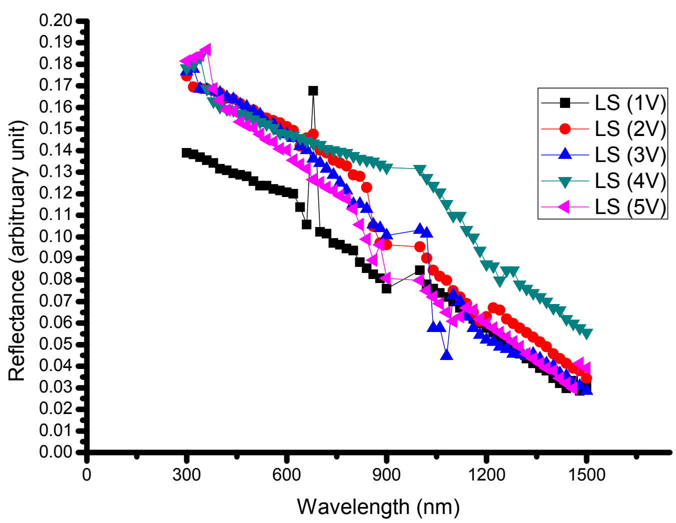

Fig. 3. plot of reflectance as a function wavelength

Fig. 4 shows refractive index as a function of photon energy of PbS thin films deposited at a different potential at constant time (60s). From Fig. 4, it was observed that the refractive index increases as the photon energy increases. It was observed that sample deposited at 1V recorded the lowest refractive index of 0.14 with wavelength of 300 nm, while sample deposited at 4V recorded the highest refractive index of 2.484 with photon energy value of 4.137. However, the refractive index increases moderately in both regions [9-14].

Figs. 5-6 shows the plot optical conductivity and extinction coefficient as a function of photon energy of PbS thin films deposited at a different potential at constant time (60s). From the graph, it was observed that the optical conductivity and extinction coefficient increase as the photon energy increases [9-14].

Figs. 7-8 shows the plot real and imaginary dielectric constant as a function of photon energy of PbS thin films deposited at a different potential at constant time (60s). From the graph, it was observed that the real and imaginary dielectric constant was increased the photon energy increases [9-14].

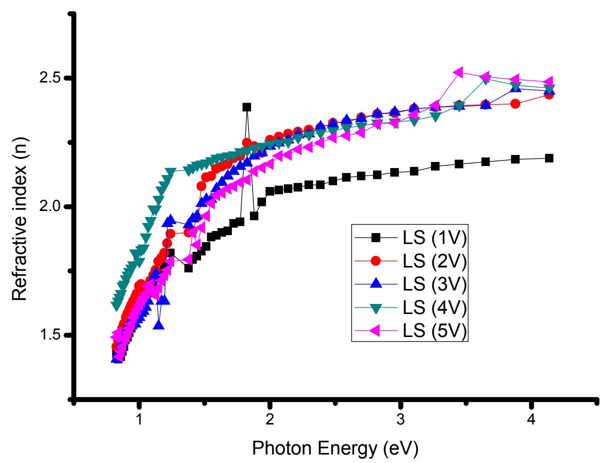

Fig. 4. Plot of refractive index as a function photon energy

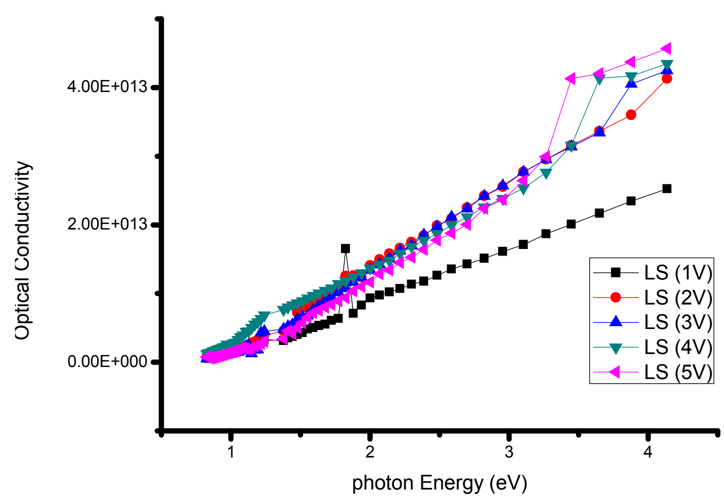

Fig. 5. Plot of optical conductivity as a function photon energy

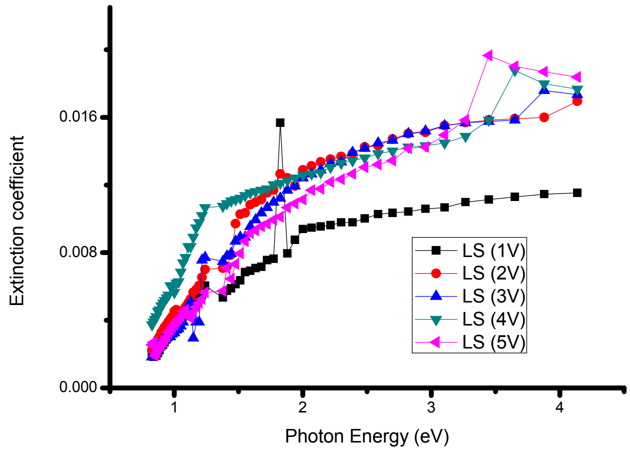

Fig. 6. Plot of extinction coefficient as a function photon energy

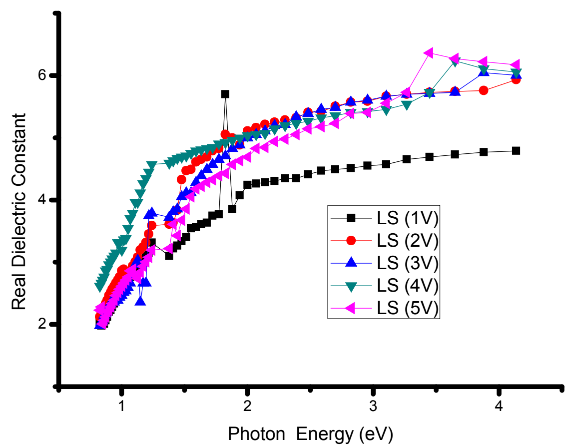

Fig. 7 Plot of real dielectric constant as a function photon energy

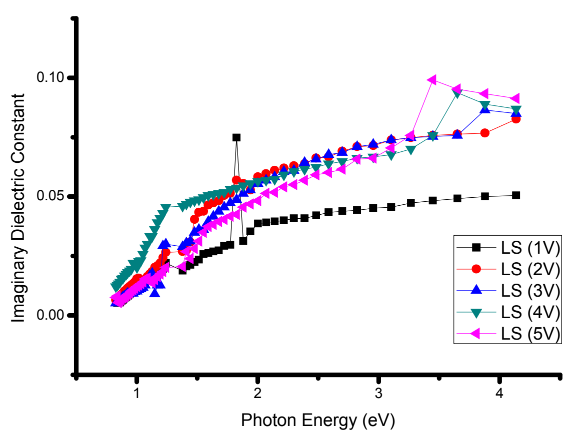

Fig. 8. Plot of an imaginary dielectric constant as a function photon energy

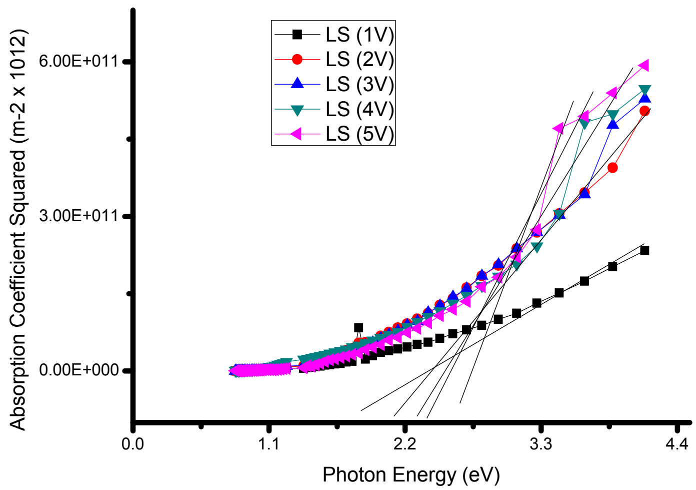

Fig. 9. Plot of absorption coefficient square as a function of photon energy

The band gap energy and transition types were derived from the mathematical processing of the data obtained from the optical absorbance versus photon energy with the following relationships for near edge absorption.

$$\alpha = n\left(h\nu - E_g)\right)/2 \qquad (1)$$

Where ν is the frequency, h is the Planck's constant, while n carries the value of either 1 or 4. The band gap E_g could be obtained from a straight line plot of α^2 as a function of hυ; an extrapolation of the value of α^2 to zero will give band gap. If a straight line graph is obtained from n=1, it indicates a direct transition between the states of the semiconductor, whereas the transition is indirect if a straight line graph is obtained from n = 4. The band gap energy of 1.7eV-2.4eV was obtained with a direct transition shows in Fig. 9 [9-14].

4. CONCLUSIONS

Electrodeposition techniques have been used to grown PbS thin films in this paper. It was observed that the thickness of the material as deposited depend on deposition potential. The resistivity and conductivity of the films increases as the thickness of the films increases. It was observed that as the absorbance decreases the wavelength of the films radiation increases. It was noticed that samples deposited at 5V recorded the value of 0.249 at a wavelength incidence of 360 nm while Sample deposited at 1V was found to a recorded lowest absorption value of 0.149 at incidence wavelength of 300 nm. Sample deposited at 4V tend to maintain a steady increase which recorded the absorption value of 0.235 at incidence wavelength of 320 nm. It was observed that the transmittance increases with the wavelength of incident radiation, it was noticed that all the samples deposited at different time interval followed the same tread. It was also observed that sample deposited at 1V recorded the highest transmittance of 0.716% in the infrared region at incidence wavelength of 300 nm and transmittance of about 0.946% in the ultraviolet region at incidence wavelength of 1500 nm, while sample deposited at 5V recorded the lowest transmittance. From the result analysis it was observed that when the wavelength of incident radiation increases, the reflectance decreases. It was observed that sample deposited at 5V recorded reflectance value of 0.182 at incidence wavelength of 300 nm in the infrared region and reflectance value of 0.041 in the ultraviolet region at incidence wavelength of 1480 nm. Sample deposited at 1V recorded the reflectance value of 0.139 at incidence wavelength of 300 nm in the near infrared and reflectance value of 0.030 at incidence wavelength of 1460 nm in the ultraviolet region. From the result analysis it was observed that the refractive index, optical conductivity, extinction coefficient, real dielectric constant and imaginary dielectric constant were increased as the photon energy of the material was increased and the energy band gap of 1.7eV-2.4eV was obtained which shows that PbS is a suitable material for solar cells fabrication and others optoelectronic devices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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