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Effect of Annealing and Thin films' Thickness on the Optical & Electrical properties of thermally evaporated Silver Indium Telluride (AgInTe)

Q. A. Adeniji[1], R. K. Odunaike[2], O. A. Banjoko[2], O. Adegboyega[3] & M. G. Rasaki[4]

[1]Department of Physics, Federal University of Kashere, Gombe State, Nigeria.
[2]Department of Physics, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.
[3]Department of Physics, Emmanuel Alayande College of Education, Oyo State, Nigeria.
[4]Department of Mathematics, Lagos State University of Education, Lagos, Nigeria.
*Corresponding author's mail: qadeniji@yahoo.com

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Abstract: This study investigated the effect of annealing and thin films' thickness on the optical and electrical properties of synthesized Silver Indium Telluride (AgInTe). High purity Silver (99.999%), Indium (99.999%) and Tellurium (99.999%) chips were deposited on SLG substrates using a Kurt Lesker evaporator to obtain two varying thickness of 350 Å and 250 Å for groups one and two respectively. The electrical and optical characterizations of the films were analysed using Keithly Four Point Probe and UV Spectrophotometer respectively. The electrical resistivities and conductivities of group one ranges from 1.93 x 10^{-4} Ωm to 1.37Ωm while for group two ranges from 1.58 x 10^{4} Ωm to 1.08 Ωm. The energy band gap for group one varies from 1.14 eV to 1.19 eV and that of group two varies from 1.17 eV to 1.20 eV. The optical band gaps were found to be closer but the films with higher thickness have a higher energy band gaps at different annealing temperature when compared with their counterpart of smaller thickness. This revealed that varying thickness of the deposition has effect on the electrical and optical characteristics of the deposited AgInTe thin films.

Keywords: AgInTe, Thermal Evaporation, Energy bandgap, Optical and electrical characterization.

Introduction

The constantly increasing world population and the growth in the economy are the main reasons for an increasing demand for energy consumption (Ayashamariam, *et al*. 2014) Extinction of resources brought about a problem of what will happen when the said fossil fuel runs out for use and therefore makes it necessary to think of how to replace them with other alternative sources as soon as possible (Chander and Dhaka 2015, Chang and James 2000). Combustion of fossil fuels releases carbon dioxide into the atmosphere which is a greenhouse gas is believed to be responsible majorly for climate change specifically global warming (Enriquez and Xavier, 2003). The environmental degradation these fossil fuels caused needed to be critically appraised (Richard 2004, IEA 2014). There are energy sources which will never run out nor have harmful effects on the environment (Petrus, 2014). Alternative sources of energy are also referred to as renewable energy source (Pearce, 2002). The sun is one of the most important renewable energy source provides the earth every year with approximately 4 x 10^{24} J of energy with a total energy consumption of about around 5 x10^{20} J per year (Kim et al. 1999, Waite et al. 2010). It is therefore necessary to create materials that could absorb energy from sun thereby trapping sunlight as a renewable energy from sun, such materials are called photovoltaics (PVs) materials. Due to high cost of silicon solar cells, it opens way for thin film technologies that requires less material, more cost efficient (Alsema and Niewlaar, 2000). This therefore motivated this study to synthesise AgInTe thin films via thermal evaporation technique and investigate the effect of annealing and the thin films' thickness on the electrical and optical properties.

Materials and Methods

The Soda Lime Glass (SLG) substrates were sterilized with a sonicator. SLG substrates were placed inside the ethanol filled glass beaker with a substrate picker and ensuring that each SLG substrates were placed in the ethanol-filled beaker for about 15 minutes. 250 ml of beaker containing the ethanol and the glass substrates was removed from the sonicator while the glass substrates were still inside the ethanol-filled beaker. Deionized water was added into another 250 ml beaker and placed inside the water-filled sonicator. The glass substrates were left inside the ethanol filled beaker which were later transferred with the aid of a substrate picker into the deionized water-filled beaker such that the glass substrates were submerged. After this process of sterilization, the glass substrates were removed from the beaker and placed in a substrates' rack to air-dried and prevented from being contaminated. High purity Silver (99.999%), Indium (99.99%) and Tellurium (99.999%) pellets were obtained from Sigma Aldrich Company, Germany. A thermal evaporator was used to deposit the precursors (Silver, Indium and Tellurium) on the SLG substrates. The molybdenum boat in the thermal evaporator was removed while putting on a disposable glove. A vacuum cleaner was used to remove any debris or particle of the previously deposited materials by the thermal evaporator after which ethanol was used to clean the inside of the thermal evaporator. Three molybdenum boats were placed where the previous boats were removed after which four glass slides were placed on the substrate holder and screwed tight to avoid the sliding from the substrate holder while being placed in the thermal evaporator. The glass filled substrates' holder was replaced at the top of the thermal evaporator wall, above the location of the different boats and screwed tightly. The different materials to be deposited were then placed in the boat with Indium placed in boat one, Silver in boat two and Tellurium in boat three. The evaporator's cover was replaced such that there is no access for air to get into the thermal evaporator. The thermal evaporator was allowed to attain a vacuum pressure of 2.5 x 10^{-5} Torr. Having reached this vacuum pressure, the materials in the boats were evaporated sequentially with Silver being the first to evaporate followed by Indium then finally Tellurium while their respective film's thickness was noted. At the completion of the deposition, the vacuum pressure was reduced with the aid of Nitrogen gas (N_2). The thermal evaporator was opened and the substrate's holder was removed from the thermal evaporator while the Soda Lime Glass (SLG) slides were removed and placed inside the substrate's rack with a picker and covered to avoid being contaminated before the characterization. The previous process was repeated for another set of precursors (Silver, Indium and Telluride) for the second group. In the second experiment and the programming of the evaporator, the settings of the boat 2 (Silver) that was the only changed parameter while other parameters remained same as earlier

done. The evaporator was left to attain a vacuum pressure of 2.7×10^{-5} Torr

Table 1: Thermal evaporator set-up for first deposition

	BOAT 1/INDIUM	BOAT 2/SILVER	BOAT 3/TELLURIUM
Ramp 1	6 %	25 %	10 %
Ramp1 Time	15 s	30 s	10 s
Soak 1 Time	2 s	10 s	6 s
Ramp 2	9 %	30 %	20 %
Ramp 2 Time	10 s	30 s	5 s
Soak 2 Time	0	4 s	5 s

Table 2: Thermal evaporator set-up for second deposition

	BOAT 1/INDIUM	BOAT 2/SILVER	BOAT 3/TELLURIUM
Ramp 1	6 %	20 %	10 %
Ramp1 Time	15 s	30 s	10 s
Soak 1 Time	2 s	5 s	6 s
Ramp 2	9 %	25 %	20 %
Ramp 2 Time	10 s	20 s	5 s
Soak 2 Time	0	4 s	5 s

At the end of the second deposition process, $N_2(g)$ was equally used to reduce the vacuum pressure. Thereafter the substrate holder was removed from the evaporator and placed in another substrate's rack. This is to distinguish the later from the former and covered the rack to avoid contamination of the samples by alien particles.

Substrates' Annealing

One sample from each deposition was selected with the aid of a picker and placed in a separate petri-dish labelled and covered. And later placed in an electric furnace and set to anneal at a temperature of 100 °C. On completion of the annealing process, they were removed and placed alongside their group in the substrate's rack after labelling. Same process was repeated for another sample from the second group but set at 120 °C for annealing and labelled accordingly.

Deposition Thickness

The first set of SLG substrates in the evaporator with the initial thickness of 350 Å were deposited sequentially with Silver having 200 Å, Indium with 100 Å and Tellurium with 50 Å these were labelled as group one. The second SLG substrates in the evaporator with thickness 250 Å having Silver thickness of 100 Å, Indium of 100 Å and Tellurium of 50 Å thickness respectively were therefore labelled group two of experiment.

Results and Discussion

Resistivity and Conductivity of Group one:

The resistivity value can be calculated from the relation

$$\rho = 4.53 \frac{V}{I} x\, t$$

Where: $\rho = resistivity,$

$V = voltage, I = current\ and$

$t = thickness\ of\ the\ film.$

Thin Film annealed at 100 °C

The value for the resistivity of the thin film annealed at 100 °C is calculated as:

V = 0.0998142V

$$I = 1.15871 \times 10^{-8}\ \text{A}$$

$$t = 3.5 \times 10^{-6}\ cm$$

$$\rho = 4.53 V/I \times t$$

$= (0.0998142/1.15871 \times 10^{-8}) \times 4.53 \times 3.5 \times 10^{-8}$

$\rho = 1.37\ \Omega m$

Conductivity $\sigma = 1/\rho = 1/1.37$

$= 7.30 \times 10^{-1}$ S/m

Thin Film annealed at 120 °C

From Table 3 the value of the maximum voltage and its corresponding current is deduced as:

V = 0.0998959V

$I = 5.17948 \times 10^{-5}$ A

And the resistivity and conductivity were calculated using:

$\rho = 4.53 V/I \times t$

$= (0.0998959/5.17948 \times 10^{-5}) \times 4.53 \times 3.5 \times 10^{-8}$

$\rho = 3.06 \times 10^{-4} \Omega m$

Conductivity $\sigma = 1/\rho = 1/3.06 \times 10^{-4}$

$= 3.27 \times 10^{3}$ S/m

As-Deposited Thin Film

From Table 3 the value of the maximum voltage and its corresponding current is deduced as:

V = 0.0999577V

$I = 8.21715 \times 10^{-5}$ A

And the resistivity and conductivity were calculated using:

$\rho = 4.53 V/I \times t$

$= (0.0999577/8.21715 \times 10^{-5}) \times 4.53 \times 3.5 \times 10^{-8}$

$\rho = 1.93 \times 10^{-4}\ \Omega m$

Conductivity $\sigma = 1/\rho = 1/1.93 \times 10^{-4} = 5.19 \times 10^{3}$ S/m

Resistivity and Conductivity of Group Two:

Thin Film annealed at 100 °C

From Table 3 the value of the maximum voltage and its corresponding current is deduced as:

V = 0.100559V

$I = 1.05221 \times 10^{-7}$ A

And the resistivity and conductivity were calculated as:

$\rho = 4.53\ V/I \times t$

$= (0.100559/1.0521 \times 10^{-7}) \times 4.53 \times 2.5 \times 10^{-8}$

$\rho = 1.08\ \Omega m$

Conductivity $\sigma = 1/\rho = 1/1.08$

$= 9.24 \times 10^{-1}$ S/m

Thin Film annealed at 120 °C

From Table 3 the value of the maximum voltage and its corresponding current is deduced as

V = 0.100086V

$I = 6.45165 \times 10^{-5}$ A

And the resistivity and conductivity were calculated as:

$\rho = 4.53\ V/I \times t$

$= (0.100086/6.45165 \times 10^{-5}) \times 4.53 \times 2.5 \times 10^{-8}$

$\rho = 1.76 \times 10^{-3}\ \Omega m$

Conductivity $\sigma = 1/\rho = 1/1.76 \times 10^{-3}$

$= 5.69 \times 10^{3}$ S/m

As-Deposited Thin Film

Also, From Table 3 the value of the maximum voltage and its corresponding current is deduced as

V = 0.0998286V

$I = 7.17015 \times 10^{-5}$ A
And the resistivity and conductivity were calculated:
$\rho = 4.53$ V/I x t
$= (0.0998286/7.17015 \times 10^{-5}) \times 4.53 \times 2.5 \times 10^{-8}$
$\rho = 1.58 \times 10^{-4}$ Ωm
Conductivity $\sigma = 1 / R = 1/ 1.58 \times 10^{-4}$
$= 6.34 \times 10^{4}$ S/m

Table 3: Electrical results of the thin films

	GROUP ONE (350 Å)		GROUP TWO (250 Å)	
Anneal. (°C)	**Resistivity ρ (Ωm)**	**Conductivity σ (S/m)**	**Resistivity ρ (Ωm)**	**Conductivity σ (S/m)**
100	1.37	7.30×10^{-1}	1.08	9.24×10^{-1}
120	3.06×10^{-4}	3.27×10^{3}	1.76×10^{-3}	5.69×10^{3}
As-deposited	1.93×10^{-4}	5.19×10^{3}	1.58×10^{-4}	6.34×10^{4}

Table 3 shows the electrical results of the films for the two groups (thickness 250 Å and 350 Å). The calculated resistivity value varies from 1.93×10^{-4} Ωm to 1.37 Ωm for the group whereas that of group two varies from 1.58×10^{-4} Ωm to 1.08 Ωm. The conductivity varies from 7.30×10^{-1} S/m to 5.19×10^{3} S/m for the group one while that of group two varies from 9.24×10^{-1} S/m to 6.34×10^{4} S/m. With these low values of resistivity and high conductivity, it implies that the thin films could allow easy passage of electricity. The increase in thickness from 250 Å to 350 Å could be attributed to the increase in the value of conductivity. These results disagreed with the report of Mardare and Luca (2006) where a 150 nm-thick ITO film grown at room temperature in an oxygen pressure of 10 mTorr, has a resistivity of 4×10^{-4} Ωcm and 170 nm-thick ITO film deposited at 300 °C in 10 mTorr of oxygen, has a resistivity of 2×10^{-4} Ω cm. However, these results agreed with the work of Aravinth et al. (2014) who measured electrical resistivity of $AgGaTe_2$ crystal to be 6.55 Ωcm and 1.53×10^{-1} Ωcm conductivity. It could be therefore inferred that, the group one films have better conductions when compared to their group two counterparts considering their lower values of resistivity and high conductivity. Figures 1 and 2 show the graph of wavelength against transmittance, the transmission spectra of AgInTe film of thicknesses 350 Å and 250 Å thicknesses respectively annealed at 100 °C, 120 °C and as-deposited with wavelength ranges from 200 nm to 1000 nm. In Figures 1 and 2, it was observed that the film annealed at 120 °C has highest transmittance before reaching a wavelength of 700 nm, while as-deposited has the least transmittance. This means that the effect of heat on the thin film was significant. After 700 nm wavelength, annealed at 100 °C has highest when compared to other films in the group and this anomaly could be as a result of environmental error. It was observed that transmission increases with an increase in wavelength. Comparing Figures 1 and 2, it could be concluded that the higher the thickness of the film, the higher the transmittance. Figures 3-5 and Figures 6-8 show the energy bandgap for group one and two-annealed at temperatures of 100 °C, 120 °C and as-deposited respectively. The estimated optical energy bandgaps for group one was 1.19 eV, 1.15 eV and 1.14 eV for annealed at 100 °C, annealed at 120 °C and as-deposited respectively whereas for the group two, the estimated optical energy bandgaps were 1.20, 1.17 and 1.18 eV for film annealed at 100 °C, 120 °C and as-deposited film respectively. These results were similar to the results of the work of Amarjit and Bedi (2001) who synthesized $AgInTe_2$ films by a hot wall epitaxy technique onto KCl substrates kept at different temperatures in a vacuum with a band gap energy that ranges from 1.12 eV and 1.26 eV

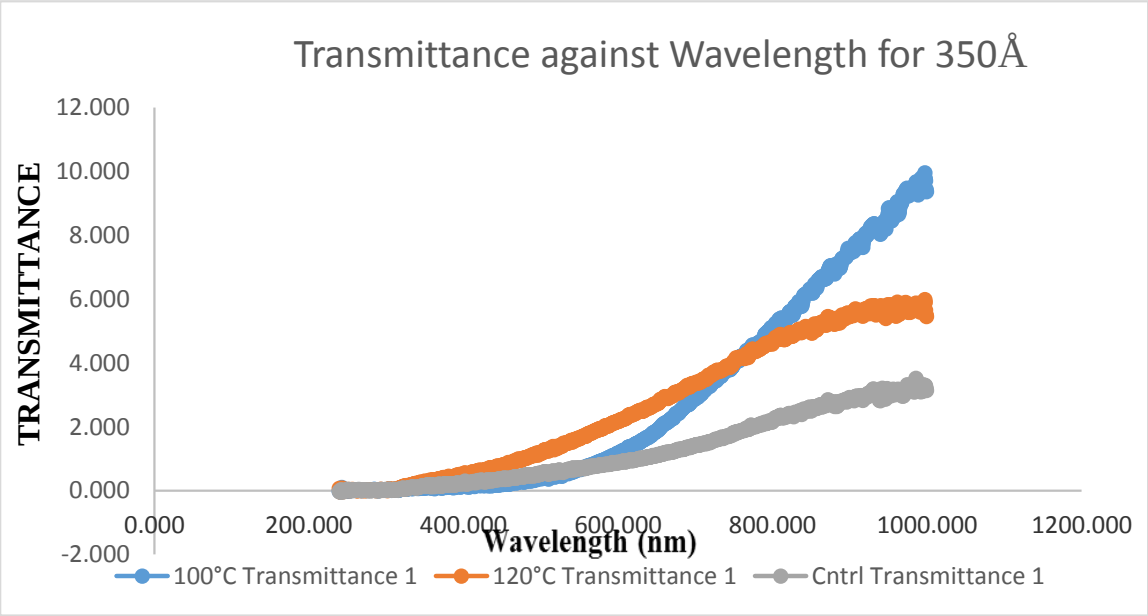

Figure 1: Wavelength vs transmittance graph for group one

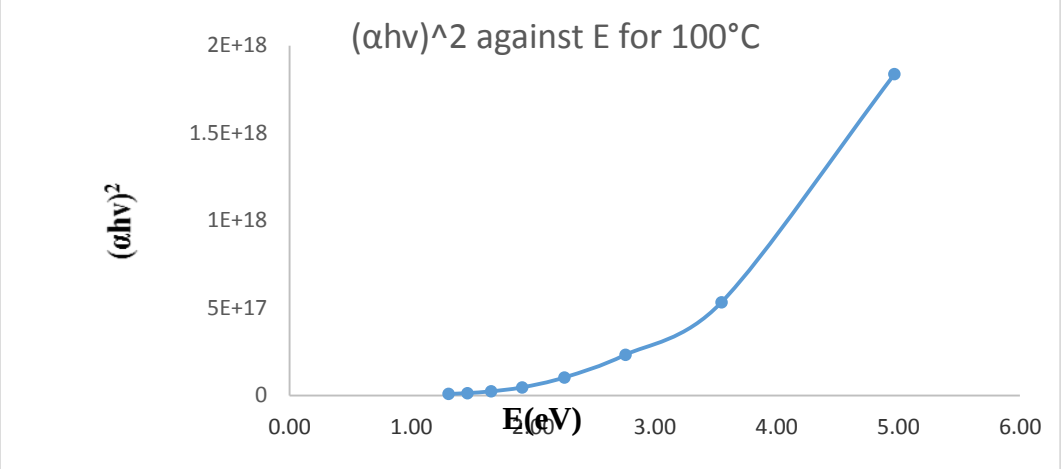

Figure 2: Wavelength vs transmittance graph for group two

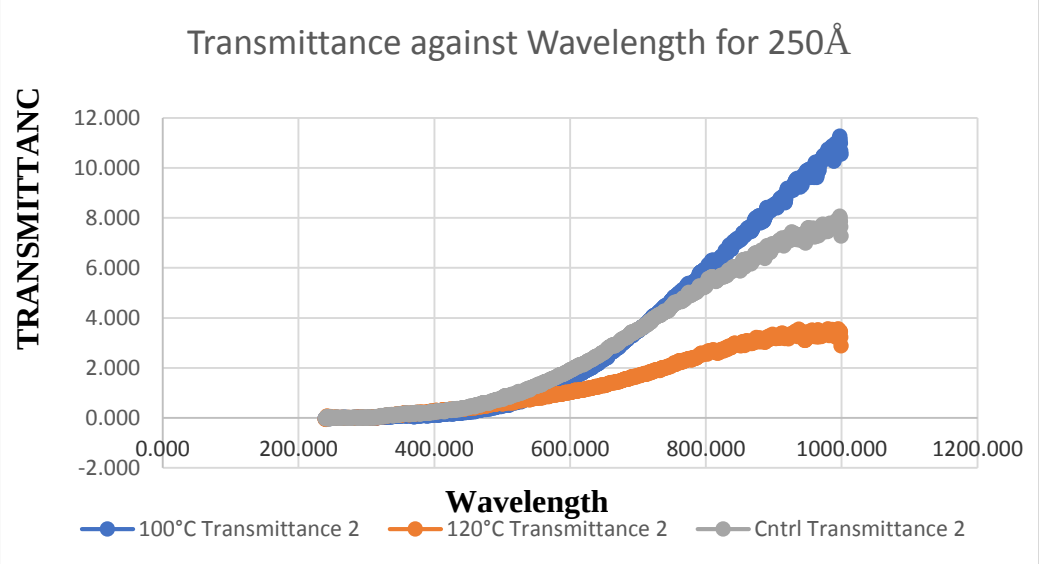

Figure 3: $(\alpha hv)^2$ against eV for thin film annealed at 100 °C (group one)

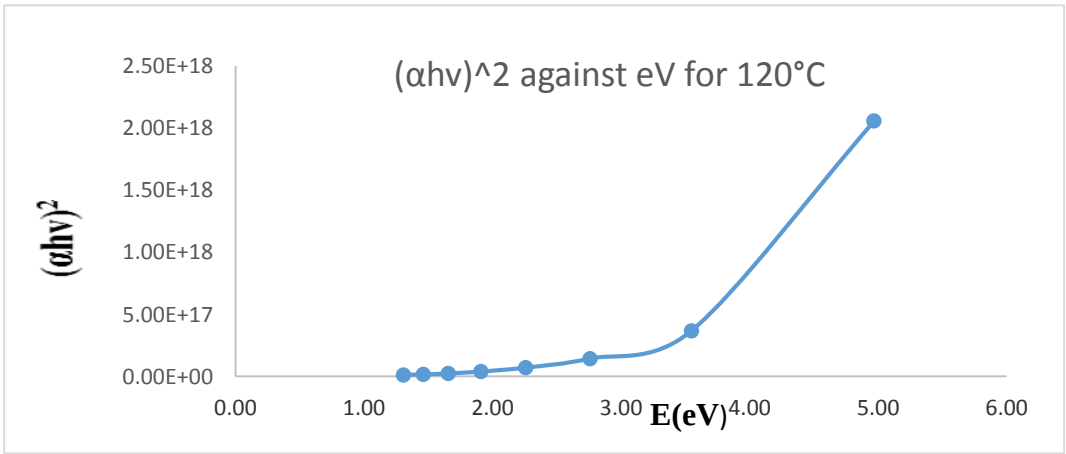

Figure 4: $(\alpha hv)^2$ against eV for thin film annealed at 120 °C (group one)

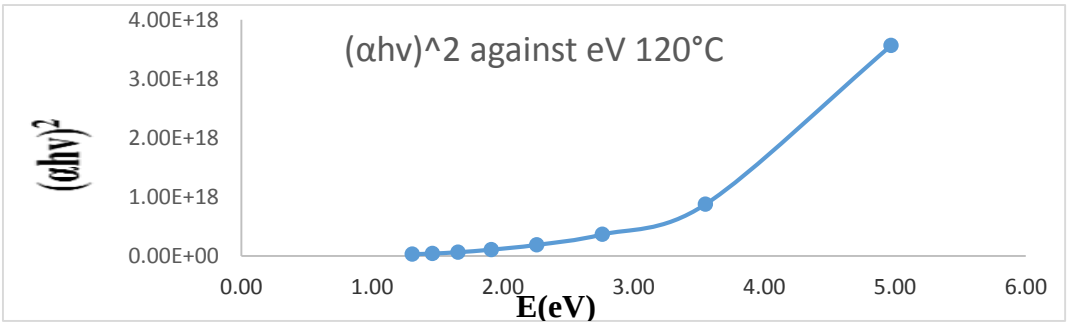

Figure 5: $(\alpha hv)^2$ against eV for as-deposited thin film (group one)

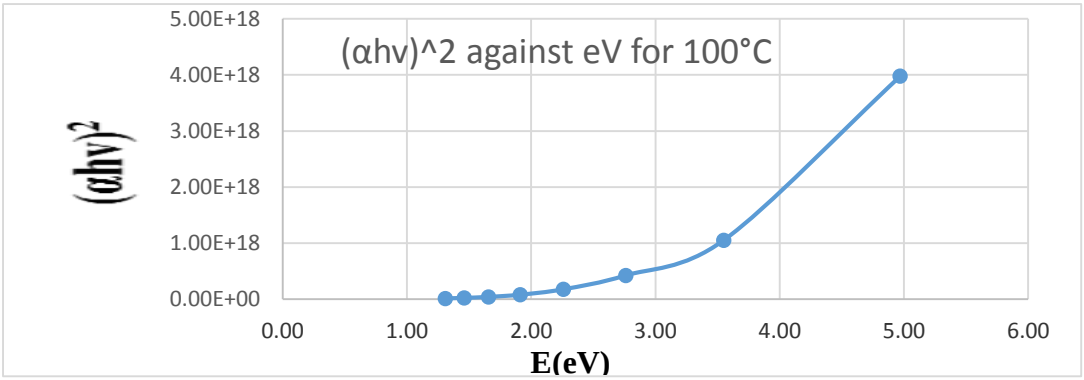

Figure 6: $(\alpha hv)^2$ against eV for thin film annealed at 100 °C (group two)

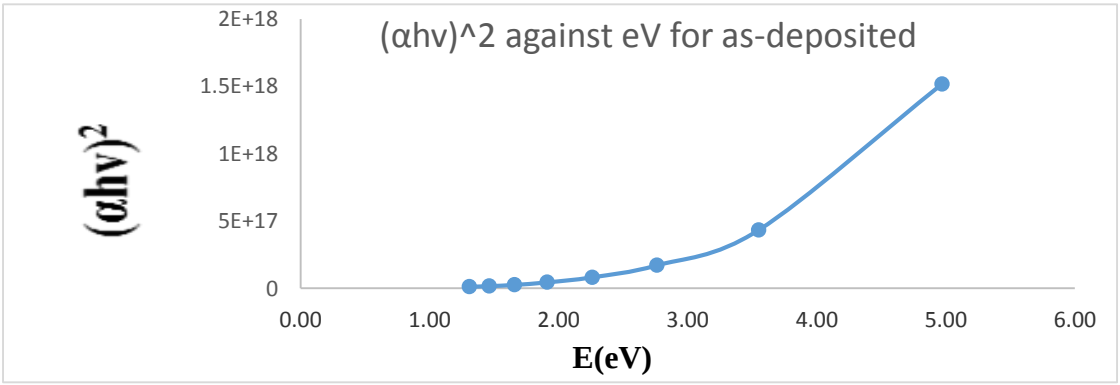

Figure 7: $(\alpha hv)^2$ against eV for thin film annealed at 120 °C (group two)

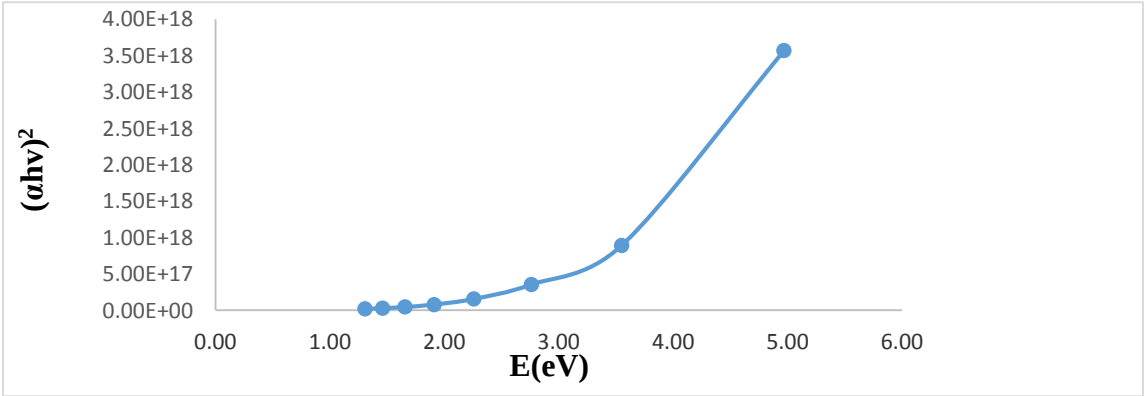

Figure 8: $(\alpha hv)^2$ against eV for as-deposited thin film (group two)

Conclusion

Silver Indium Telluride (AgInTe) thin films have been successfully grown on the Soda Lime Glass (SLG) substrates through thermal evaporator with varied thickness of the films and annealed at different temperature of 100 °C and 120 °C. The inf1uence of different thickness and annealing on their electrical and optica1 properties were studied. Their respective resistivity and corresponding conductivity were obtained. The resistivity of the materials was low while their conductivity was high which implies the ability to allow current pass through it easily but with film of higher thickness being a better conductor with a higher conductivity but lower resistivity. Finally, the optical band gap was determined and it was noticed that even with the varying thickness of the film formed the optical band gap were found to be close but films with higher thickness having higher band gap energies at different annealing temperature when compared to their counterpart with smaller thickness. These then imply that the varying thickness of the deposition has though minimal but clear effect on the electrical and optical characteristics of the deposited thin film. Also, it is advisable to use the thin films as absorbance layers in solar cells.

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Not Applicable

Conflict of Interest

Authors declare no conflict of interest.

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