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Optical Properties of a Thin Layer of Antimony Selenide Using Chemical Bath Deposition Method

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Optical properties of antimony selenide thin film synthesized for solar cell application via chemical bath deposition method (CBD) is presented in this research. Antimony trichloride and hydrogen selenide are the starting materials. The influence of varying concentration of Ethylenediaminetetra-acetic acid (EDTA), and Ammonia (NH3) at constant time in the deposition process remains the major landmark of this research. The optical properties of the resulting thin film was investigated. The thin films were characterized using M501single beam scanning UV-Vis spectrophotometer to analyze their optical absorption properties. It was seen that, transmittance appears to be higher at a lower concentration of EDTA and NH3. Transmittance attained a maximum value of 94% and 91% for variation of EDTA and NH3 respectively. Optical absorbance of Sb2Se3 thin film was found to be generally low even as concentration of EDTA and NH3 increased. The highest value of absorbance was found to be 17.5% which is low. Concerning optical reflectance, increase in the

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concentration of EDTA and NH3 did not produce increase in reflectance. The optical band gap of the thin film was determined using Taucs plot. The optical band gap for the variation of EDTA and NH3 was in the range of 3.5eV to 3.8eV and 3.7eV to 4.0eV respectively. These findings contribute to the understanding of the optical characteristics of Sb2Se3 thin film and proffers insight for optimizing their performance in photovoltaics. Characterization should be extended in the medium and far infra-red region so as to know the behavior of antimony selenide thin film in that region.

Keywords: Absorber material; antimony selenide; absorption; photovoltaic cells.

1. INTRODUCTION

The development of thin film technology is a major factor responsible for the decrease in cost of photovoltaic solar cells [1]. In thin film based photovoltaic cells, active layer materials which are several micrometers thick are used compared to silicon -based solar cells. These materials have a higher absorption coefficient than crystalline ones. As a result, only a very thin absorber layer is needed for sunlight absorption [2]. Antimony selenide is a compound composed of antimony (Sb) and selenide (Se). It is a semi - conductor material having applications in photo voltaics solar cell, thermo-electric devices and optoelectronics. Antimony selenide (Sb_2Se_3) is a primary absorber material. Antimony selenide is a binary metal chalcogenide that has an absorption coefficient in the order of 10^5 cm^{-1} at short wavelength [3]. The component elements Se and Sb are inexpensive and widely available on earth. This is the reason they were chosen in this research above other materials having the same kind of application. Also they are a very promising absorber material for thin film solar cells [4]. Antimony selenide is used as an optical coating in thermos photovoltaic systems, as well as in the creation of available solar cells and hall effect devices. A variety of methods, including electro deposition, SILAR, [5], pulsed laser ablation, thermal and photochemical chemical vapor deposition can be used for the preparation semi-conductor materials.

Chemical bath deposition (CBD) method was chosen for this research due to its low temperature, cheap cost, and non-polluting nature. This thin film preparation method is receiving a lot of interest. It is the most convenient method for large area deposition [6]. The basic principle involved in the chemical bath deposition method is the controlled precipitation of the desired compound from a solution of its constituents. In this study, antimony selenide thin film was prepared from a solution of antimony trichloride ($SbCl_3$) and sodium hydrogen selenium oxide ($NaHSeO_3$) as a source of Sb^{3+} and Se^{2-} ions respectively using chemical bath method. Ethylenediaminetetra-acetic acid (EDTA) was used as complexing agent. The influence of increase in ammonia (NH_3) and EDTA as a major deposition parameter in preparing the thin film was studied. Optical characterization was carried out to determine properties which includes bandgap, transmittance, reflectance, absorbance. By studying the optical properties of antimony selenide thin film, the research contributes to the understanding of their suitability for specific application. Identifying the optical properties of CBD deposited antimony selenide thin film helps in evaluating their tapped and untapped potential.

2. EXPERIMENTAL METHODS

All solvents and reagents used for the thin films growth includes; EDTA, Ammonia solution (NH_3), Antimony trichloride ($SbCl_3$), Sodium hydrogen selenium oxide ($NaHSeO_3$) and distilled water. Apparatus used include digital meter balance, glass substrate, and hydrochloric acid. 0.1M of each of the reagents were prepared at room temperature. NH_3 is already in a solution form. Other masses of the reagents were obtained using a meter balance. The method used in this research work is the chemical bath deposition technique. In order to avoid spontaneous precipitation of the reaction bath, a suitable complexing agent is added to the reaction bath to control the release of the metallic ion in the solution. Although thin films can be deposited in different kinds, shape and size of substrate [7], a microscope slide was used as the substrate in this work. The procedure on how to clean the substrate is very important in deposition of thin film [8]. The four glass substrates on which the desired compound is to be deposited were first washed with distilled water and detergent to remove ant sticky dirt. There after the glass substrate is soaked in hydrochloric acid (HCl). After this, it is then immersed in the beaker containing the solution. The glass substrates were suspended into the chemical bath using

Table 1. Variation of EDTA concentration at constant time (12hrs)

Solution	Chemical bath 1 (ml) Slide 1	Chemical bath 2 (ml) Slide 2	Chemical bath 3 (ml) Slide 3	Chemical bath 4 (ml) Slide 4
$SbCl_3$	5	5	5	5
NH_3	5	5	5	5
EDTA	2	4	6	8
$NaHSeO_3$	5	5	5	5
Distilled water	33	31	29	27

Table 2. Variation of NH_3 concentration at constant time (12hrs)

Solution	Chemical bath 1 (ml) Slide 1	Chemical bath 2 (ml) Slide 2	Chemical bath 3 (ml) Slide 3	Chemical bath 4 (ml) Slide 4
($SbCl_3$)	5	5	5	5
EDTA	5	5	5	5
NH_3	2	4	6	8
($NaHSeO_3$)	5	5	5	5
Distilled water	33	31	29	27

rack holder to hold the substrate firmly with the tip not touching the bottom of the chemical bath. Dip time of 12 hours was maintained for each chemical bath. The deposited antimony selenide thin film was uniform and adhesive. Optical characterization which entails determining the optical properties of materials by subjecting the sample to some kind of radiation. Optical spectrums are the principal means to obtain experimentally the band gaps and energies for inter band transitions. Optical properties were measured using a M 501 UV –VIS spectrophotometer at normal incidence of light in the wavelength ranging from 300 - 1100nm for variation of EDTA and NH_3.

Total volume of all the solution in the chemical bath = 50ml as seen in the Tables 1 and 2.

3. RESULTS AND DISCUSSION

3.1 Absorbance against Wavelength for Variation of EDTA Concentration

From the plot of Fig. 1, it can be observed that in the visible region Slide number 4 with 8ml concentration of EDTA has the highest absorbance of 17.5% than others. Therefore, at higher concentration of EDTA, the absorbance of the thin films slightly increased. An absorbance of 17.5% is low. This observation of the thin films having a very low absorbance could be as a result of inadequate reaction conditions which could bring about insufficient deposition of antimony selenide on the substrate.

3.2 Transmittance against Wavelength for Variation of EDTA Concentration at Constant Time

From the graph in Fig. 2, it can be observed that thin films generally have a higher transmittance. Slide number 2 with 4ml concentration of EDTA has the highest transmittance of 94%. Transmittance appears to be higher at a lower concentration of EDTA. This high transmittance could arise as EDTA could react with impurities that otherwise contribute to absorption in the thin film, resulting in lower absorbance and higher transmittance. Hence it can be used as a good transmitting material.

3.3 Reflectance against Wavelength for Variation of EDTA Concentration at Constant Time

Considering the graph in Fig. 3, it can be seen that thin films have a low reflectance. Slide 3(6ml) has the highest reflectance of 22.6 % more than the others. Increase in the concentration of EDTA did not necessarily produce the highest increase in reflectance.

3.4 Refractive Index against Wavelength for Variation of EDTA Concentration at Constant Time

From the Fig. 4, it is seen that thin film showed high refractive index ranging between 1.6 to 2.7. This is slightly different from the refractive index of 3.2 which has already been reported [9]. As the concentration of EDTA increases, one would expect slide 4 (8ml) to show the highest value. However, this isn't the case. Therefore, increase in concentration of EDTA, slightly affected the refractive index when comparing the 6ml concentration with the 2ml and 4ml. This is because EDTA can modify surface chemistry which may in turn alter refractive index.

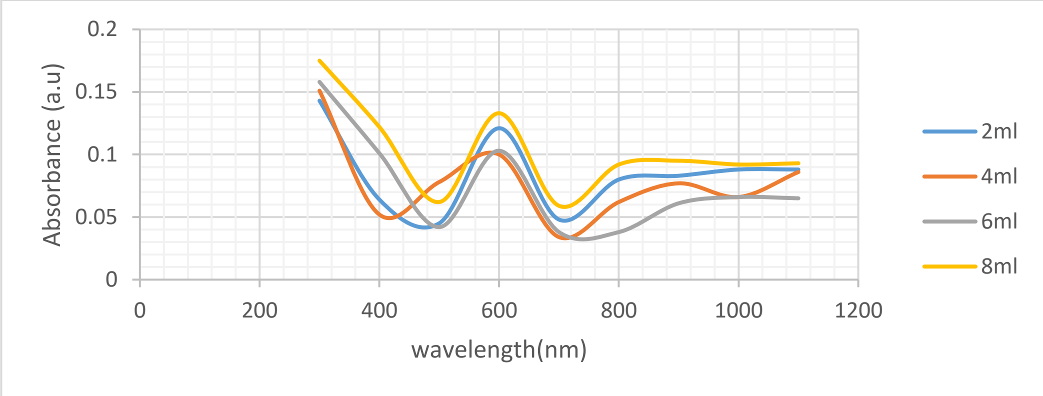

Fig. 1. Plots of absorbance against wavelength for variation of EDTA concentration

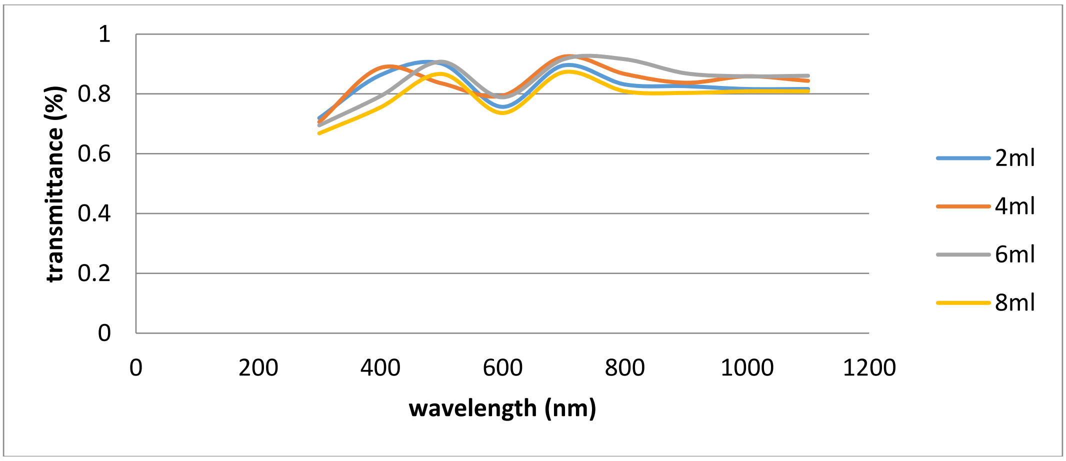

Fig. 2. Plots of transmittance against wavelength for variation of EDTA concentration at constant time

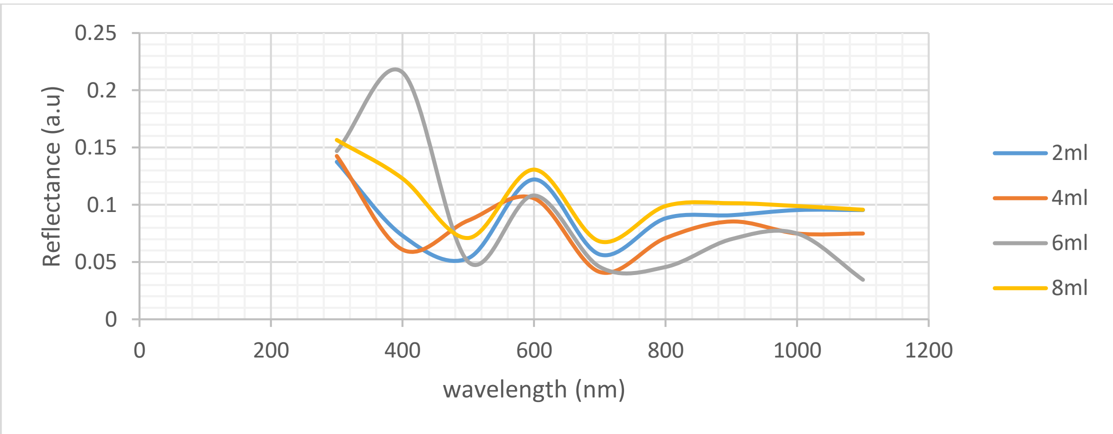

Fig. 3. Plots of reflectance against wavelength for variation of EDTA concentration at constant time

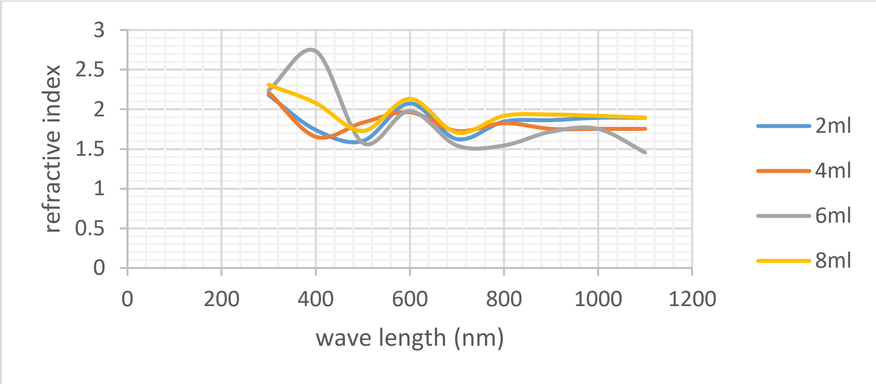

Fig. 4. Plots of refractive index against wavelength for EDTA variation

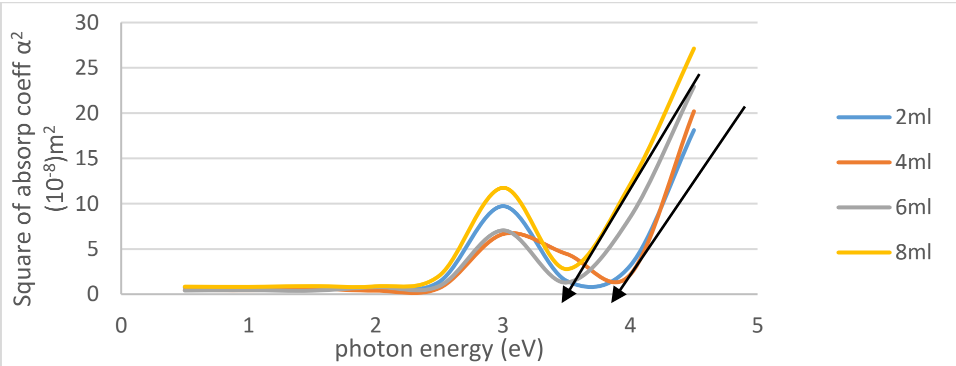

Fig. 5. Plots of square of absorption coefficient against photon energy for variation of EDTA concentration at constant time

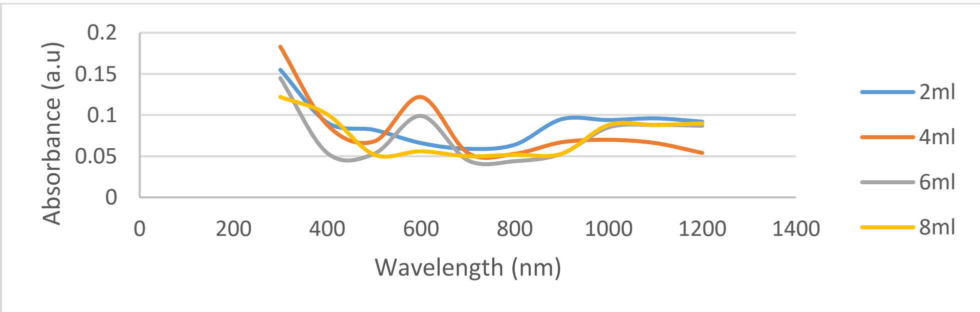

Fig. 6. Plots of absorbance against wavelength for variation of NH_3 concentration at constant time

3.5 Square of Absorption Coefficient against Photon Energy for Variation of EDTA Concentration at Constant Time

The graph in Fig. 5 reveals that the band gap energy for antimony thin films was found to be within the range of 3.5eV – 3.8eV. Band gap energy is an important parameter that determines the electrical and optical properties of a material. The optical band gap with direct transition can be calculated from the following relation $\alpha h\nu = A(h\nu\text{-}Eg)^n$ [10, 11, 12]. The value of the energy gap Eg was determined by plotting $(\alpha h\nu)^2$ versus hv and then extrapolating the straight line portion to the energy axis at α = 0. High absorption coefficient shows it can be applied in photovoltaics cell materials. A band gap energy of 1-1.2eV was reported for antimony selenide [13]. This disparity in result for optical band gap could be as a result of measurements conducted at different temperature. The slide with 8ml concentration of EDTA showed the lowest energy gap. Increase in EDTA does not bring an increase in energy gap.

3.6 Absorbance against Wavelength for Variation of NH_3 Concentration at Constant Time

From the graph in Fig. 6, it was observed that the thin films have very low absorbance. Slide number 2 with 4ml concentration of ammonia has the highest absorbance of 18.2% more than others. It is clear that increase in the concentration of NH_3 does not necessarily produce the highest absorbance. Low absorbance can occur as ammonia may modify the crystal structure to reduce light scattering, allowing more light to pass through the thin film without being absorbed.

3.7 Transmittance against Wavelength for Variation of NH_3 Concentration at Constant Time

From the graph of Fig. 7, it is generally observed that thin films have a high transmittance. But slide number 3 (6ml) has the highest transmittance of 91%. To this end, increase in the concentration of NH_3 does not translate to increase in transmittance. Hence antimony selenide can be used as a good transmittance material that could be serve in various optical applications, such as lenses, windows, and prisms. This high transmittance could be due to the fact that ammonia treatment can clean the surface of thin film, thereby removing contaminants, which leads to a high transmittance. This value of transmittance is higher than 80% which has already been reported [9].

3.8 Reflectance against Wavelength for Variation of NH_3 Concentration at Constant Time

From the chart above (Fig. 8), it was observed that the thin films generally have low reflectance in the visible region. Slide number 2 with 4ml concentration of ammonia has the highest reflectance of 16.1% more than the others. Therefore, increase in the concentration of NH_3 does not result to an increase in reflectance as slide 4 having 8 ml turned out to have the lowest reflectance.

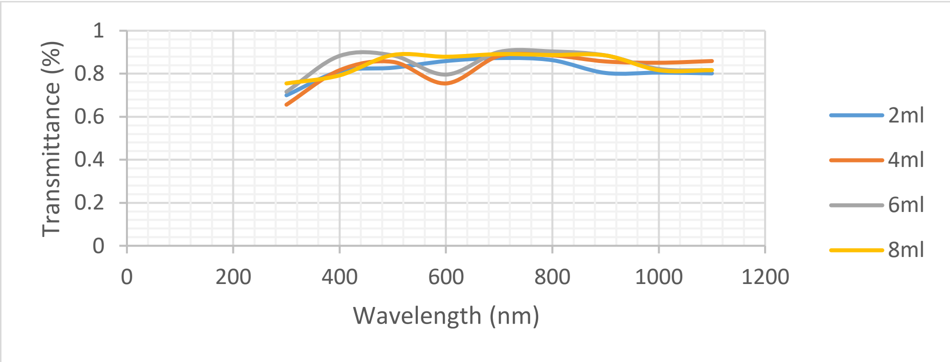

Fig. 7. Plots of transmittance against wavelength for variation of NH_3 concentration at constant time

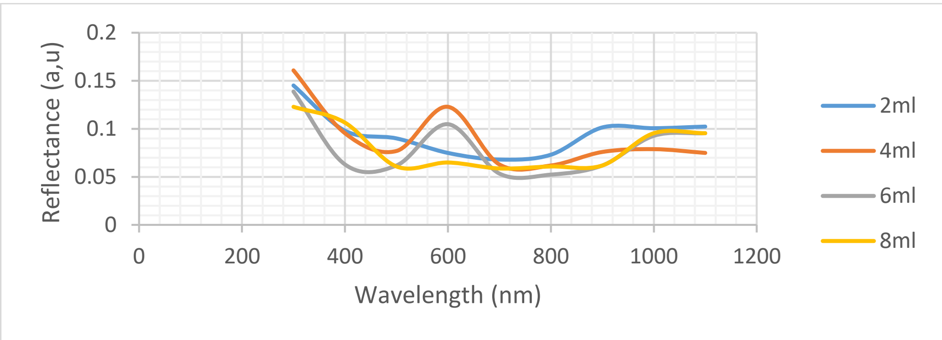

Fig. 8. Plots of reflectance against wavelength for variation of NH_3 concentration at constant time

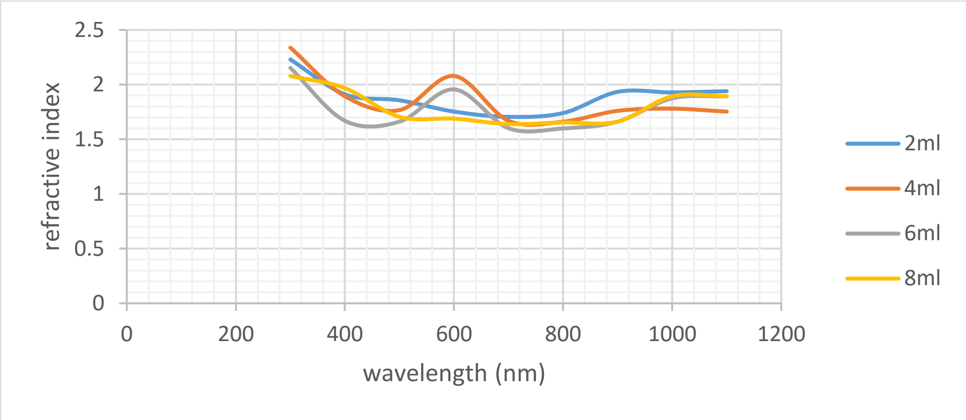

Fig. 9. Plots of refractive index against wavelength for NH_3 variation

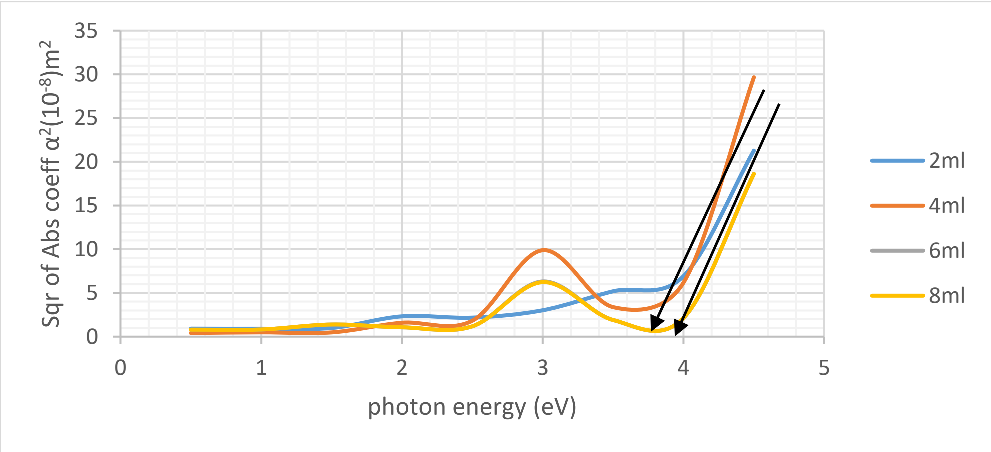

Fig. 10. Plots of square of absorption coefficient against photon energy for variation of NH_3 concentration at constant time. From the above graph, the values of band gap energy for antimony thin films was found to be in the range 3.7eV – 4.0eV

3.9. Refractive Index against Wavelength for Variation of NH_3 Concentration at Constant Time

From the Fig. 9, showing a graph of refractive index against wavelength, it clearly shows that increase in concentration of ammonia had no effect on the refractive index of antimony selenide as the 4ml concentration showed a higher value than the 8ml concentration. The refractive index of antimony selenide ranges from 1.6 to 2.35.

3.10 Square of Absorption Coefficient against Photon Energy for Variation of NH_3 Concentration at Constant Time

Fig. 10 Plots of square of absorption coefficient against photon energy for variation of NH_3 concentration at constant time. From the above graph, the values of band gap energy for antimony thin films was found to be in the range 3.7eV – 4.0eV.

4. CONCLUSION

The thin film of antimony selenide was successfully grown and deposited using chemical bath technique. The films had good adherence to the substrates. The optical characterization of the deposited thin films was done with M501 single beam scanning spectrophotometer. The results show that;

- Optical absorbance of antimony selenide thin film was found to be generally low. Increase in the concentration of complexing agent EDTA and NH_3 produced a slight increase in absorbance.

The highest value was found to be 17.5% which is too low.

- Optical transmittance of antimony selenide thin film was found to generally high with the highest value of 94%. Also transmittance appears to be higher at a lower concentration of EDTA and NH_3.
- Optical reflectance of antimony selenide thin film was also low. Furthermore, increase in the concentration of EDTA and NH_3 did not result to an increase in reflectance.
- Optical band gap energy was measured at room temperature. The value of the band gap energy obtained for antimony selenide thin film was at the range of 3.5 – 3.8eV.
- The refractive index of antimony selenide was found to be between 1.6 to 2.7. Increase in concentration of EDTA and NH_3 only produced a minimal increase in refractive index of antimony selenide.

Characterization should be extended in the medium and far infra- red so as to know the behavior of antimony selenide in that range. Furthermore, characterization should include photoluminescence spectroscopy to investigate the emission properties of the thin film. Also, fourier transform infrared spectroscopy should be carried out to investigate the chemical bonding and functional groups present in the thin film.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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