World Applied Sciences Journal 34 (6): 801-804, 2016
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2016.34.6.15642

Progress in Optical Properties of Sb_2S_3 Thin Films for Applications in Photonic Devices

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Abstract: Thin films of antimony sulphide doped with copper, were successfully deposited on glass substrate using the chemical bath technique. Optical characterisation was done using UV-VIS-NIR spectrophotometer in the wavelength range of 300-1100 nm. The optical study reveals a direct energy bandgap of 1.6 eV. Our results show that the properties displayed by the films in the visible and near infrared region indicates that it is a good candidate for photonic applications.

Key words: Antimony sulphide · Copper · Transmittance · Extinction coefficient · Energy band gap

INTRODUCTION

Chalcogenides of the group V – VI are very useful semiconductors which have capability of forming binary compounds. The thin films of these semiconductor materials have potential application in many areas of applied science and engineering: optoelectronics devices, decorative coatings, thermoelectric coolers etc. [1]. Photonics is the science of light generation, detection and application. Photonic crystals are materials that can control or manipulate light in unexpected manners because of their peculiar physical structures. Photonic crystals can induce unusual phenomena and affect photon behavior in ways that traditional optical materials and devices may not.. They are popular materials of study for applications in lasers, solar energy, LEDs, metamaterials and more.

Most photonic applications are in the range of visible and near infrared portion of the spectrum. Photonics is applied in telecommunications, holography, information processing solar sail etc due enhanced light-matter interaction occasioned by light concentration.

Chemical bath technique for the preparation of semiconducting chalcogenides thin films offer the advantages of economy, convenience and capability of large area deposition and easy reproducibility.

Many authors [1-4 etc] have reported on the properties of antimony sulphide deposited by various techniques. However in this work, we report on the progress on the optical properties of chemical deposited antimony sulphide thin films for applications in photonic devices.

MATERIALS AND METHOD

The source of antimony I n this experiment was $SbCl_3$. To get the $SbCl_3$ solution, 11.5g of $SbCl_3$ was dissolved in 50 ml of acetone. This was also placed in 33 ml of double distilled water. The resulting solution was stirred using a magnetic stirrer for 10 minutes in order to ensure even dissolution of the solutes. The pH of the resulting solution was maintained at 3.5. The glass substrates used in the experiment measuring (16 x 30) mm was ultrasonically cleaned after washing with H_2SO_4 and rinsed with distilled water. The substrate were then introduced vertically into the solution in a 100ml beaker using synthetic foam as the holder. Deposition was allowed to take place for a period of 5 hours at 298K after which the slides were removed and washed with running distilled water and then dried in the open. The deposited films were then annealed at 373K for 1 hour in order to improve on their crystallinity.

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The absorbance and transmittance measurement was done using UV- spectrophotometer at wavelength range 300 -1100) nm.

RESULTS AND DISCUSSION

The optical absorption studies have guide to a variety of interesting thin film parameters. Usually the optical properties of the thin film are different from those of the bulk. The optical transmittance of the antimony sulphide thin films as determined using the UV –spectrophotometer is as shown in Figure 1 gives the plot for the variation of the percentage transmittance against wavelength for the as-deposited antimony sulphide thin film and the copper doped antimony thin film. The curve shows that the transmittance in each case increases with decreasing photon energy. However, the as- deposited film has the highest percentage of 85% while the Cu-doped antimony sulphide recorded highest transmittance value of 65%.. The plot equally indicates that the as deposited film displayed better transmittance than the copper doped antimony sulphide film. High values of transmittance in the visible and the near infra-red portion is an indication that the deposited film can be used in any desired photonic application. The values of transmittance for the as-deposited film is in agreement with the reports given by Sami *et al* [1]. The difference in values of transmittance obtained for the as-deposited and the copper doped film could attributed to decrease in the grain size occasioned by the addition of Cu impurity [5].

According to Tauce, the optical bandgap and the energy of the incident photon is given by [6]

$$(\alpha h\nu) = A\left(h\nu - E_g\right)^n \tag{1}$$

where α is the optical absorption coefficient, h is the Planck's, A is a constant and E_g is the bandgap and n is a number which has values depending on the nature of transition involved. Critical analysis of the data obtained from the transmittance measurements indicate that the transitions was direct, thus a graph of $(\alpha h\square)^2$ against h□ was plotted in order to obtain the optical band gap. The optical band gap was thus obtained by extrapolating the linear portion near the onset of absorption edge to the energy axis as shown in Fig. 2. And is found to be 1.6eV. This value is in close agreement that obtained by Nicolae [4]. The plot of extinction coefficient against wavelength is displayed is Fig.3. Generally, the extinction coefficient can be obtained using the relation, [5].

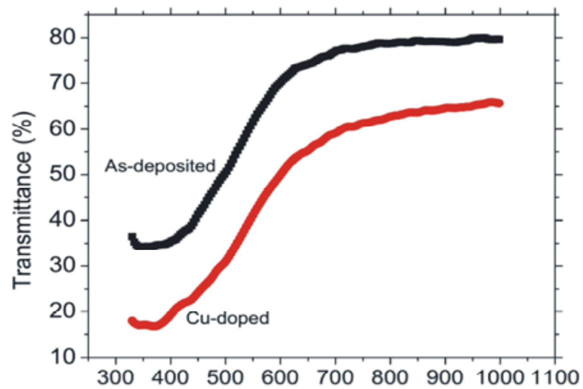

Fig. 1: Plots transmittance (%) vs wavelength

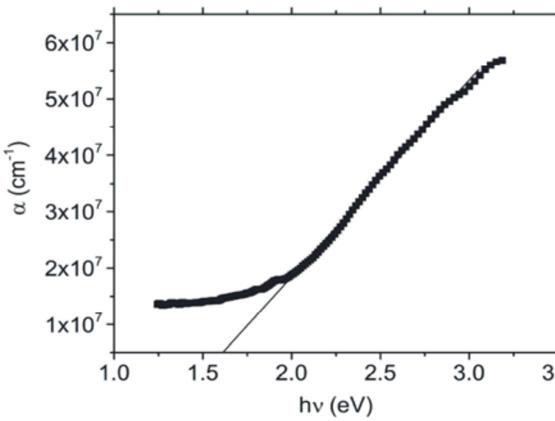

Fig. 2: Plot for determination of optical bandgap.

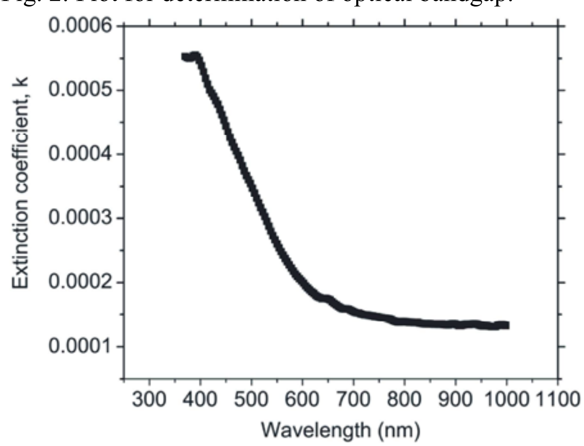

Fig. 3: Plot of Extinction coefficient against wavelength

$$k = \frac{\alpha\lambda}{4\pi} \tag{2}$$

where λ is the wavelength and α is the absorbance. The extinction coefficient decreased at longer wavelength (shorter photon energy) up to the critical wavelength and then increased. Similar behaviour has been reported by other authors [1, 10].

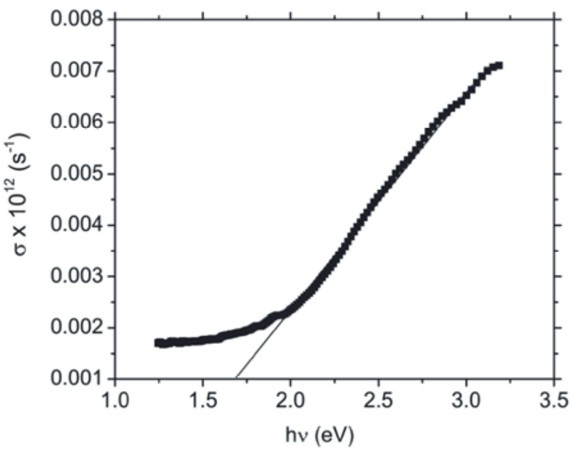

Fig. 4: Plots of optical conductivity against photon energy

The plot indicates that high value of extinction coefficient were observed in the visible, ultra visible and the near infrared portion of the spectrum indicating that the imaginary part of the complex index of refraction is high within these wavelength region. The plot equally indicates that at higher wavelengths and lower energies the extinction coefficient is very small and was almost constant even as the wavelength increases. Fig. 4 gives the plot of the variation of the optical conductivity against photon energy. The optical conductivity was deduced using the relation [5] $\frac{\alpha nc}{4\pi} = \delta_{optical}$, where α is the optical absorption coefficient, n is the refractive index, c is the speed of light in vacuum and 4π is a constant [7]. The optical conductivity gives an insight to the optical behaviour by virtue of its direct relationship with the optical absorption coefficient and the refractive index [6]. From the plot, it is observed that the optical conductivity increased with increasing photon energy. However as from photon energy of 1.67 eV, it is found that the trend was almost linear. Since the optical conductivity is dependent on the index of refraction, it can also be deuced from the plot of Figure 4 that the index of refraction increases with increase in photon energy. In photonics, the behavior of light is a function of the index of refraction of the material involved [12]. The plots (Fig. 4) reveals clearly that the energy bandgap is within the range earlier shown on Fig.2. This is in close agreement to results obtained by other researchers [4, 11].

CONCULSION

At temperature of 298K, chemical bath technique is employed in the deposition of Sb_2S_3 thin film. The deposited film was annealed at 373K in order to increase its crystallinity. Analysis of the deposited film from the results of UV-spectrophotometer show that the film is transparent in the visible and near infrared region. The optical band gap obtained is in close agreement to those obtained by other researchers.

ACKNOWLEDGEMENTS

The authors are grateful to technical staff of the Division of Materials Science and Renewable Energy, Ebonyi State University Abakaliki and Dr Alayade Gbenga of Energy Research and Development, Obafemi Awolowo University, Ile Ife for their contributions in the course of this research.

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