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EFFECT OF DOPING CONCENTRATION ON THE OPTICAL PROPERTIES OF INDIUM-DOPED GALLIUM ARSENIDE THIN FILMS

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ABSTRACT

Effects of indium doping (concentration 0.2, 0.3 and 0.4%) on the optical properties of GaAs thin films were studied. Thin films of 600 nm were grown onto chemically and ultrasonically cleaned glass substrate by thermal evaporation method in high vacuum (~10^{-4} Pa) at 50°C fixed substrate temperature. The samples were annealed for 15 minutes at a fixed temperature of 200°C. The thicknesses of films were being measured *in situ* by a quartz crystal thickness monitor during deposition. The transmittance and reflectance data were found using UV-VIS-NIR spectro-photometer in the photon wavelength range of 310 ~ 2500 nm. These data were utilized to compute the absorption coefficient, refractive index, extinction co-efficient and band gap energy of the studied films. Here transmittance was found 78 for 0.2% indium doping concentration. The band gap energy decreased with the increase of doping concentration.

Key words: Doping concentration, Optical properties, GaAs thin films

INTRODUCTION

Today, III - V compound semiconductors are showcasing advanced performances in electronics and optoelectronics areas such as diode laser, light emitting diodes, photo detectors, electro-optic modulators and many more. GaAs which is a III - V compound semiconductor of zinc-blende structure has been focused for its potentially intrinsic advantages. The direct band gap of GaAs makes it an important candidate in the fields of manufacturing light emitting diodes and semiconductor lasers.

There are huge aspects in the study of ternary alloy semiconductor like $In_xGa_{1-x}As$ as it has a specific band structure. The purpose of using group III arsenide alloys is to obtain a material which consumes minimum power with maximum brightness (Srivani *et al.* 2014).

Doped or undoped GaAs can be prepared by many methods. Molecular beam epitaxy method was used for optical absorption and photoconductivity measurement of 50 nm

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ultra-thin films of single crystal GaAs (Halliday *et al*. 1995). Electrical conductivity and temperature dependence on GaAs thin films deposited by RF sputtering were measured (Tsuji *et al*. 1992). Thermal evaporation method was used for studying the effect of rate of deposition on the optical parameters of GaAs thin films (Majeed 2011). Biswas et al. (2016) studied structural and optical characterization of Mg-doped ZnO thin films deposited by spray pyrolysis method. Das *et al.* (2013) prepared n-type GaAs thin films by vacuum evaporation methods and studied their optical properties. Optical and transport properties of p-type GaAs were also investigated (Sharmin *et al.* 2012). Hydrogen-doped GaAs thin films were made by RF magnetron sputtering technique and their structural, optical and electrical properties were studied (Yan-Ping *et al.* 2008). Optical properties of undoped and indium-doped tin oxide thin films were studied (Chowdhury *et al.* 2011). Research in physical properties of III - V arsenide ternary semiconductor alloys were done (Srivani *et al.* 2014).

The present work reports the effect of various indium doping concentration on the optical properties of vacuum evaporated thin films of GaAs via transmittance and reflectance measurements. Optical parameters such as absorption coefficient, refractive index, extinction co-efficient were determined. Optical process or absorption method was implied to determine the band gap energy.

MATERIALS AND METHODS

Thin films of indium-doped GaAs were prepared using a vacuum evaporation unit type Edwards 306A, UK in vacuum ($\sim 10^{-4}$ Pa) onto chemically and ultrasonically cleaned glass substrates by thermal evaporation method. The substrate temperature was fixed at 50°C. The films were then thermally annealed in situ at the temperature of 200°C for 15 minutes. The thickness of the films were 600 nm. The evaporation rate for GaAs was 0.2 nm/sec which was measured in situ by the FTM5 quartz crystal thickness monitor (Edwards, UK). The concentration of indium doping was 0.2, 0.3 and 0.4%.

The variations of transmittance and absolute specular reflectance of the films with wavelength of light incident on them were measured using a dual beam UV-VIS-NIR recording spectrophotometer (Shimadzu, UV-3100, Japan) in the photon wavelength range of 300 to 2500 nm. Light signals coming from the samples were detected by an integrating sphere. The thickness of the composite films was checked using an infrared interference method with the spectrophotometer, which depends on the reflectance characteristics of the films. In this method the thickness of a film is given by

$$d = \frac{\Delta m}{2\sqrt{n_1^2 - \sin^2\theta}} \frac{1}{\left(1/\lambda_1\right) - \left(1/\lambda_2\right)}$$

(1)

where, n_1 is the refractive index of the film, θ is the incident angle of light to the sample, λ_1 and λ_2 are the peak or valley wavelengths in the reflectance spectrum and Δm is the number of peaks or valleys between λ_1 and λ_2, where $\lambda_2 > \lambda_1$.

For transmittance $(T\%)$ at normal incidence and reflectance $(R\%)$ at near-normal incidence of light on the films, expressions for the multiple reflected systems have been given by Heavens (1995). Tomlin (1968) simplified these expressions for absorbing films on non-absorbing substrates and expressed as

$$\frac{1+R}{T} = \frac{1}{4n_2(n_1^2+k_1^2)}\begin{bmatrix}(1+n_1^2+k_1^2)\left\{\left(n_1^2+n_2^2+k_1^2\right)\cosh 2\alpha_1 + 2n_1n_2\sinh 2\alpha_1\right\} \\ +(1-n_1^2-k_1^2)\left\{\left(n_1^2-n_2^2+k_1^2\right)\cosh 2\gamma_1 + 2n_2k_1\sin 2\gamma_1\right\}\end{bmatrix} \quad (2)$$

$$\frac{1-R}{T} = \frac{1}{2n_2(n_1^2+k_1^2)}\begin{bmatrix}n_1\left\{\left(n_1^2+n_2^2+k_1^2\right)\sinh 2\alpha_1 + 2n_1n_2\cosh 2\alpha_1\right\} \\ +k_1\left\{\left(n_1^2-n_2^2+k_1^2\right)\sinh 2\gamma_1 + 2n_2k_1\cos 2\gamma_1\right\}\end{bmatrix} \quad (3)$$

where n_1 and n_2 are refractive indices of the film and substrate respectively, k_1 is the extinction co-efficient of the film, $n_2 = 1.45$, $\alpha_1 = \frac{2\pi k_1 d}{\lambda}$ and $\gamma_1 = \frac{2\pi n_1 d}{\lambda}$, where λ is the wavelength of light and d is the thickness of the film. Equations (1) and (2) are solved for k_1 and n_1 utilizing a computerized iteration process. The absorption co-efficient, α is then calculated using $\alpha = 4\pi k/\lambda$.

The optical band gap E_g can be estimated from the following relation which is known as the Tuac plot (Tuac 1974):

$$\alpha h\nu = A\left(h\nu - E_g\right)^n \quad (4)$$

where, A is a constant, ν is the transition frequency and the exponent n characterizes the nature of band transition. n = $^1/_2$ and $^3/_2$ corresponds to indirect allowed and indirect forbidden transitions, respectively.

RESULTS AND DISCUSSION

Fig. 1 shows the optical transmittance spectra of indium doped GaAs thin films in the visible range. Transmittance shows better result approximately 78 for 0.2% indium concentration. Here increase of doping concentration reduces transmittance and shifts the peak of transmittance spectrum toward the higher wavelength. Decrease in transmittance may occur due to increase of particle size because of the progression of indium in the GaAs thin films (Salina *et al.* 2012). The shifting of peaks is also due to structural improvement i.e., increase of crystalline grain size (Balkanski and Wallis 2000).

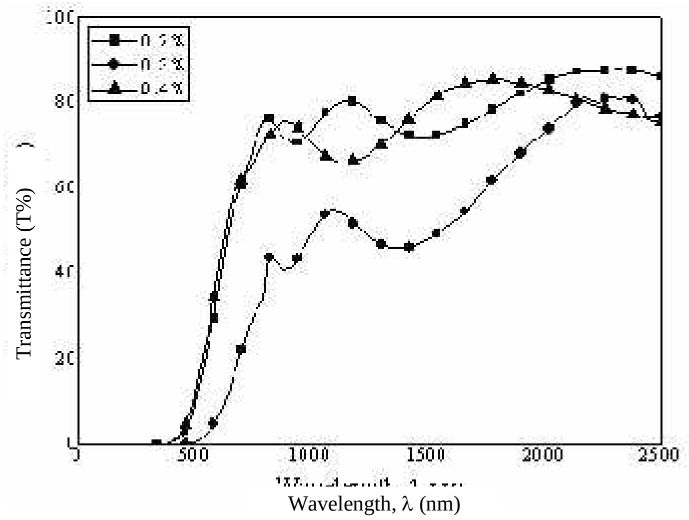

Fig. 1. The transmittance spectra at different indium concentration for 600 nm GaAs thin film.

The reflectance spectra have been presented in Fig. 2. Interference pattern with distinct rise and fall is observed in the reflectance spectra of the films.

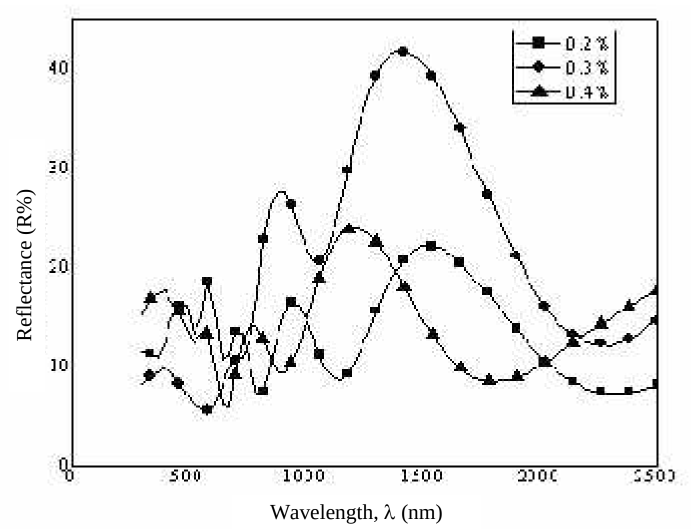

Fig. 2. The reflectance spectrum at different indium concentration for 600 nm GaAs thin film.

The behavior of absorbance spectra is shown in Fig. 3. It is observed that in the shorter wavelength the absorption co-efficient exhibits higher values ($>10^4$). These higher values means there is a large probability of the allowed direct transition which agrees with other workers (Mott and Davis 1979). The absorption co-efficient decreases with increasing wavelength because of inverse relation between transmission and absorption (Majeed 2011) and remains consistent at higher wavelengths. The semiconductor alloys with higher value of absorption co-efficient can be used for photovoltaic devices (Srivani *et al.* 2014).

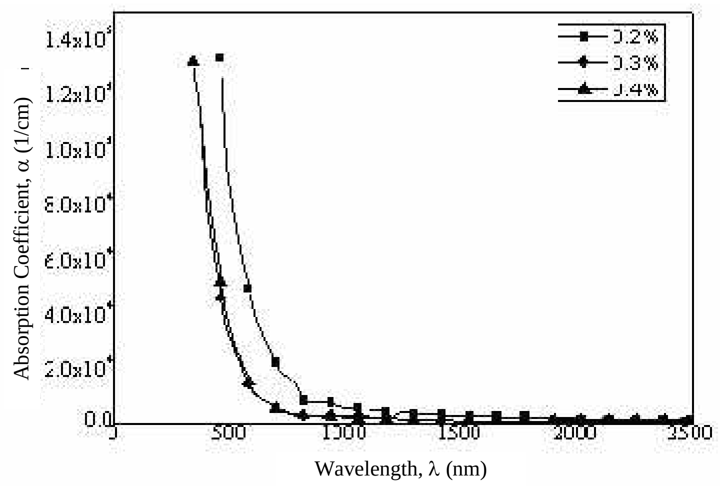

Fig. 3. The absorption coefficient at different indium concentration for 600 nm GaAs thin film.

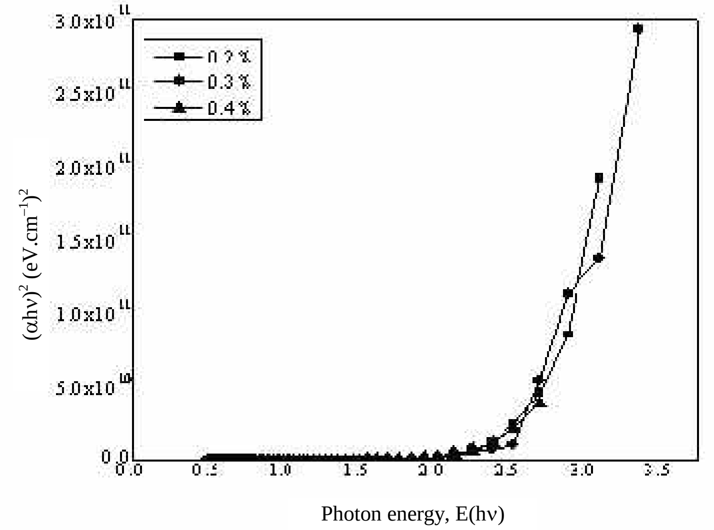

Fig. 4. Variation of $(\alpha h\nu)^2$ with photon energy of indium concentration for 600 nm GaAs thin film.

Fig. 4 shows the variation of $(\alpha h\nu)^2$ versus photon energy for different indium concentration of GaAs thin films. The band gap can be obtained from extrapolation of the straight line portion of $(\alpha h\nu)^2$ vs $h\nu$ plot to $h\nu = 0$. The band gap energies found to be 2.88 , 2.83 and 2.39 eV for 0.2, 0.3 and 0.4% indium concentration, respectively. The band gap decreases with increase of doping concentration. The decrease of energy band gap leads to strong disorder when a small amount of Ga atoms are replaced by In. This happens due to the large disparity in the electronegativity and the atomic size between in and Ga in $In_xGa_{1-x}As$. The indium atom brings several perturbations in the host crystal (Srivani *et al.* 2014).

From Fig. 5, the behavior of refractive index with wavelength can be observed. Firstly, they increase gradually. After attaining a maximum peak they decreases abruptly and at higher wavelengths they start to increase again. The sharp decrease depends on the surface and volume imperfections. Low refractive index occurs due to successive internal reflections or due to the trapped photon energy within the grain boundary (Ong *et al.* 2000).

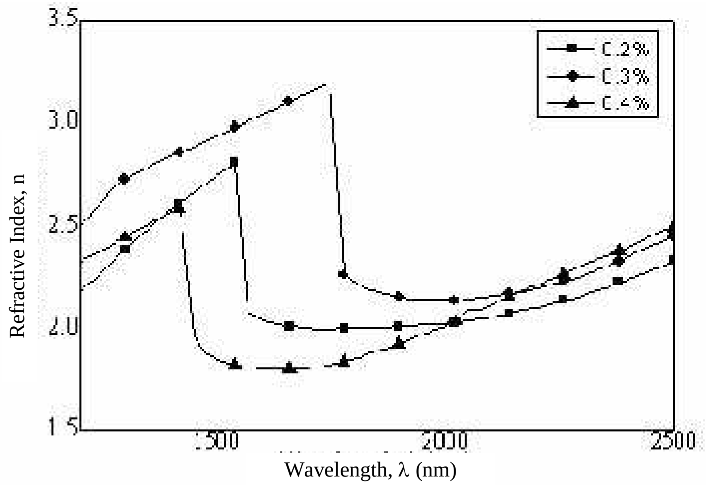

Fig. 5. The reflective index at different indium concentration for 600 nm GaAs thin film.

Fig. 6 shows the variation of extinction co-efficient of the films with wavelength for indium concentration 0.2, 0.3 and 0.4% at a fixed thickness of 600nm GaAs thin films. It was observed that extinction co-efficient decreased with the increase of wavelength.

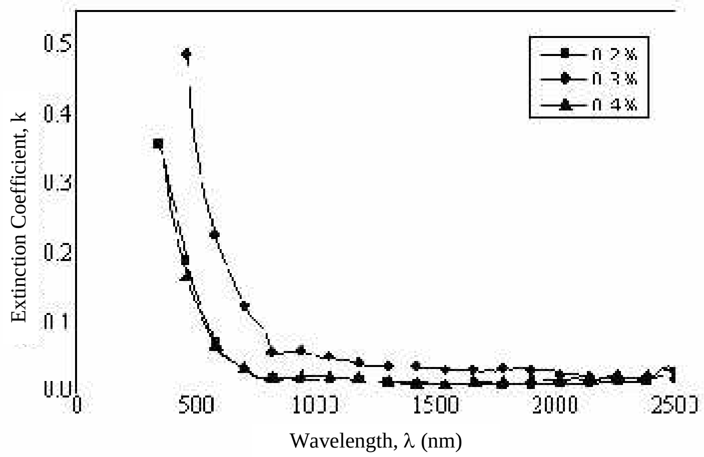

Fig. 6. The extinction co-efficient at different indium concentration for 600 nm GaAs thin film.

The changes occurred due to the variation of absorbance. The fall in the extinction co-efficient may be due to the absorption of light at the grain boundaries (Das *et al.* 2013). The low value of extinction co-efficient is a qualitative indication of excellent surface smoothness of the thin films (Bhaskar *et al.* 2001). The higher values of extinction co-efficient are the representation of greater attenuation of light in a thin film and also the higher probability of raising the electron transfer across the mobility gap of photon energy.

CONCLUSIONS

From the present work it can be summarized that, with the increase of doping concentration of indium the transmittance decreases. Absorbance of 0.2% indium concentration has higher value than the other two percentages concentration. The optical band gap decreases with increasing doping concentration. The refractive index increases with increase of doping concentration. Finally, extinction co-efficient of 0.3% concentration shows higher values rather than 0.2 and 0.4% indium doping concentration.

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