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Optical properties of $Zn_xCd_{1-x}S$ thin films prepared by the sputtering technique

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Abstract. The optical properties of $Zn_xCd_{1-x}S$ thin films were studied using the sputtering technique. The thickness of the film deposited at (50°C) was around one micrometre. The optoelectronic transitions between valence and conduction bands were recognised by analysis of the absorption coefficient values within the fundamental absorption region. This test shows direct allowed transitions of (2.44 eV). The change in refractive index versus energy of the incident photon were calculated from the transmission spectrum. The study also shows the possibility of using such films as anti-reflection coatings when deposited on the surface of silicon solar cells.

1. Introduction

An interest is being shown in the use of binary II–VI semiconductor compounds (for example CdS, ZnSe, ZnS, . . . etc) as thin films. Thin films are currently of interest in the technology of solar collectors, photo-conductive sensors and many other optical devices [1–5]. Experience shows that a partial substitution of Zn for Cd in CdS films produces a mixture of $Zn_xCd_{1-x}S$ films of the desired composition [6, 7] that have a high transparency, a high conductivity and high IR reflectivity. These characteristics make these films useful as heat mirror coatings in the production of flat plate collectors. They allow the visible spectrum to pass through and reflect the IR radiation back to the absorber thereby reducing the energy loss and loss in the heat efficiency. Moreover, thin films find many technological applications in solar cell fabrication as they have the advantage of their direct gap and low resistivity [7, 8].

El-Akkad *et al* [9] prepared polycrystalline films of $Zn_{0.05}Cd_{0.95}S$ using RF-sputtering technique. They studied the electrical and the optical characteristics of these films as a function of substrate temperature. They found that the high deposition temperature reduces the optical transmission. The work reported in the present paper is an extension of the above work. By using the transmission properties of the prepared film of a $Zn_{0.05}Cd_{0.95}S$ film deposited at 50 °C we study the refractive index, extinction coefficient and the type of electronic transition.

2. Preparation of the film

The $Zn_xCd_{1-x}S$ films were prepared by using the sputtering technique described by El-Akkad [9]. This method has also been described by Deforges [10]. The prepared films are deposited on a glass substrate in argon at a pressure of about 9.3 Pa, power density 7 W cm^{-2}, deposition rate 18 nm min^{-1} and target voltage 1.5 kV. All the preparation

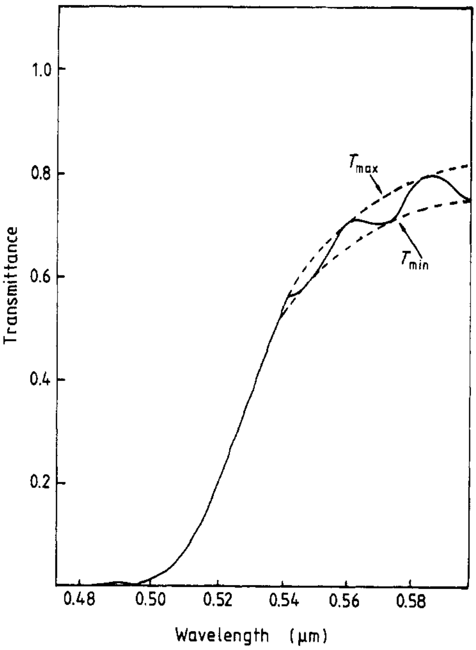

Figure 1. Transmission spectrum for sputtered film at 50 °C.

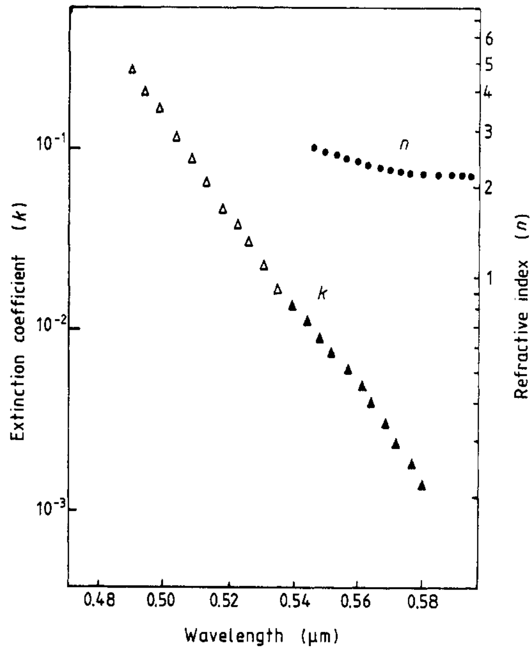

Figure 2. The refractive index, n, and the extinction coefficient, k, versus photon wavelength for a sputtered film at 50 °C. Sample a: ▲ values deduced from the fundamental absorption region; △ values deduced from the interference pattern.

parameters are kept constant during the preparation. Optical analysis has been done on films of about 1 μm thickness.

3. Results and discussion

Figure 1 shows the spectral dependence of the optical transmission of $Zn_{0.05}Cd_{0.95}S$ thin films prepared by the sputtering technique and deposited at a substrate temperature of 50 °C. At high wavelength range (~500–600 nm) the transmission spectrum shows some fluctuation. This fluctuation can be overcome by raising the substrate temperature as was shown by El-Akkad [9]. Manifacier and Fillard [11] noticed the same fluctuation in the transmission spectrum of tin- dioxide films at high wavelength (the range 400–1500 nm), they attributed this fluctuation to the interference phenomena, and called this the interference pattern. By using the technique employed by Manifacier we can calculate the refractive index, n, and then the extinction coefficient, k, of these films. This technique depends on the analysis of the optical data in the interference pattern. T_{max} and T_{min} as indicated in figure 1 can be considered as continuous functions of the wavelength. In this region the absorption coefficient $\alpha \neq 0$ and $e^{-\alpha d} < 1$. The refractive index can then be calculated from T_{min} by using the equation reported by Manifacier and Fillard [11]

$$n = \{[2n_s(1 - T_{min})^{1/2} + n_s(2 - T_{min})]/T_{min}\}^{1/2} \qquad (1)$$

where n_s is the substrate refractive index. In the region of the band to band transition, the transmission can be given as

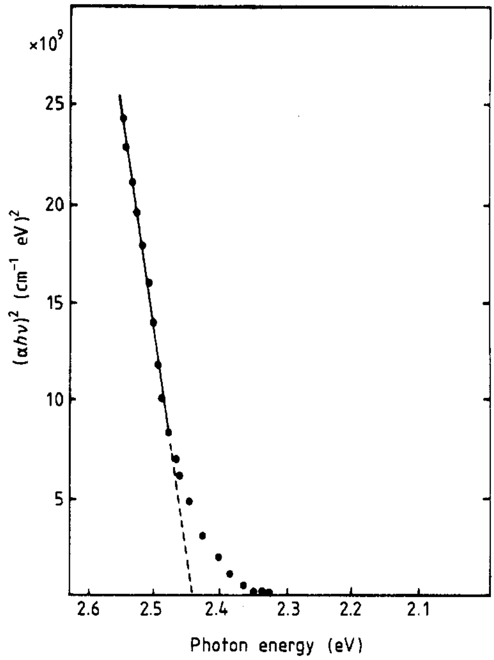

Figure 3. (Absorption coefficient)² versus photon energy.

$$T \simeq A \exp(-\alpha d) \tag{2}$$

where

$$A = 24(n^2+k^2)/(2n+n^2+k^2)[(1.5+n)^2+k^2]$$

for $k^2 \ll n^2$ and $A \approx 1$ the principal variation of T that occurs is in the exponential term. (2) can then be written as

$$T \approx \exp(-\alpha d). \tag{3}$$

Using (3), the absorption coefficient can be deduced to be

$$\alpha = (2.303/d)\log(1/T) \tag{4}$$

then, the extinction coefficient can be calculated using the relation

$$k = \alpha\lambda/4\pi. \tag{5}$$

The absorption coefficient in the interference region is given by the relation [13]

$$\alpha = (2.303/d)\log(1/Y) = 4\pi k/\lambda \tag{6}$$

where

$$Y = E_{\rm m} - [E_{\rm m}^2 - (n^2-1)^3(n^2-5.06)]^{1/2}/(n-1)^3(n-2.25)$$

$$E_{\rm m} = 12n^2/T_{\rm max} + (n^2-1)(n^2-2.25).$$

The variation of the refractive index, n, and extinction coefficient, k, with the wavelength of the incident photon is shown in figure 2, in which the k values exhibit a smooth continuity. In the low value region of k the average refractive index is 2.3 which is larger than the air refractive index and smaller than that for silicon. It can therefore reduce the air–silicon refractive index mismatch when deposited on silicon surface. This can lead to a considerable increase in the ability to capture solar radiation and therefore increases the efficiency of the silicon solar cell. Optical absorption data were analysed for evidence of direct transition as suggested by the theory of Bardeen *et al* [14]. The variation of absorption coefficient with photon energy for direct allowed band-to-band transitions is of the form

$$\begin{aligned} \alpha &= A(h\nu - E)^{1/2}/h\nu^{-1} \qquad & h\nu > E \\ \alpha &= 0 & h\nu < E \end{aligned} \tag{7}$$

where $h\nu$ is the photon energy, E is the direct band gap and A is nearly constant and independent of photon energy. The plot of $(\alpha h\nu)^2$ against $h(\nu)$ is shown in figure 3 and yields a straight line which fits well with the above equation. Extrapolation of the straight line to $\alpha h\nu^2 = 0$ gives an energy gap of 2.44 eV which is equal to 3.6×10^{-4} cm^{-1} when extrapolated for the direct transition. The value of the energy gap is quite similar to that previously obtained for polycrystalline films [9]. However, near the band edge there is an interesting application of such films as they may be used as optical filter for the short wavelength. Consequently the values of the optical parameters obtained reveal the suitability of the thin film for various solar applications.

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