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Refractive Index of Cadmium Sulfide Films Determined from Transmittance Measurements

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Abstract

In the present work the refractive indices of thermally evaporated films of cadmium sulfide (CdS) on fused silica substrates were obtained from measurement of transmittance (T, alone) at normal incidence. Earlier, the same were determined by using measurements of reflectance (R) and transmittance (T) again at normal incidence. On comparison of the two results, we noted that the present results are in fact more, closer than those obtained earlier to the corresponding values reported for the bulk cadmium sulfide.

Keywords: CdS, optical properties**,** thin films, transmittance

1. Introduction

Cadmium sulfide (CdS) is a compound semiconductor comprising group II–VI elements [1]. These compounds are transparent over a wide spectral region, and also have high refractive indices [2]. Therefore, they are widely used in the design of multilayer optical coatings. In the design of multilayer optical coatings, it is very important to know the accurate values of the refractive indices of each one of these coatings used in multilayer optics. Among these compounds, CdS has a wide band gap, that is, 2.42 eV at 300K and large electrical conductivity. Based on these attributes, CdS is utilized in a wide variety of device fabrication applications [3, 4, 5] such as solar cells, photoconductors, green lasers, photovoltaic, gas sensing and light emitting diode etc. [6]. Due to the third order non-linear optical behavior of CdS, its films are widely employed in non-linear optical devices [7, 8, 9].

The present work deals with the determination of the refractive indices of CdS thin films prepared by thermal evaporation. Simple measurements of normal incidence transmittance in the wavelength range from 0.8 µm to 2.5 µm were made using a commercial spectrophotometer. The refractive indices were extracted from these measurements using a method proposed earlier [10].

2. Experimental Details

A coating unit pumped by a turbo molecular pump was used for the deposition of thin films of CdS on unheated fused silica substrates. The CdS of 99.99% purity was evaporated from molybdenum boats. Before the commencement of evaporation, the base pressure in the system was about 10^{-6} mbar. The distance of source to substrate was about 40 cm. A quartz-crystal thickness controller was used to maintain the rate of deposition of films at 0.7 nm/s. In the present work, the films had thickness in the range from 0.15-0.5µm. The film thickness used in generating results was 0.469 µm. In the vacuum chamber, ambient temperature was maintained for all deposited films on substrates. After deposition, the films were removed from the coating chamber and exposed to the ambient atmosphere prior to the measurement of optical properties. A JascoV570 spectrophotometer was used to measure the transmittance of the films.

The structure of the films was determined by recording X-ray diffraction (XRD) patterns at room temperature using a PANalytial X'pert PRO diffractometer with CuKα radiation source.

3. Results and Discussion

X-ray diffraction patterns (Figure.1) show that all films are predominantly hexagonal. There is some possibility of cubic structure present in the films for reasons discussed below. It is found in the JCPDS Card no. 80-0006, for hexagonal CdS that the reflection from the plane (101) is the most intense. While, from the pattern for CdS films shown in Figure.1, it is clear that reflection from (002) is the most intense.

This difference could be explained by the presence of some cubic phase in the films because the most intense reflection in the cubic structure (JCPDS Card no. 89-0440) is due to the plane (111). The d-value for this plane is almost equal to that for hexagonal (002) plane. So, the hexagonal (002) reflection observed in Figure.1, may have some contribution from cubic plane (111). On the other hand, reflection from cubic plane (200) is absent, but this line ought to be weak. Therefore, the existence of a small proportion of the cubic phase cannot be ruled out. As far as higher order reflections from the cubic phase are concerned, it is found that there are corresponding reflections due to the hexagonal phase with almost the same values of d. Hence, it is difficult to separate these two structures. It may be concluded that CdS films are predominantly hexagonal with a possibility of cubic structure present in them in a small proportion. Thermally evaporated thin films of CdS are known to have a hexagonal structure [11, 12]. Peaks other than those corresponding to CdS films and Al substrates were not detected.

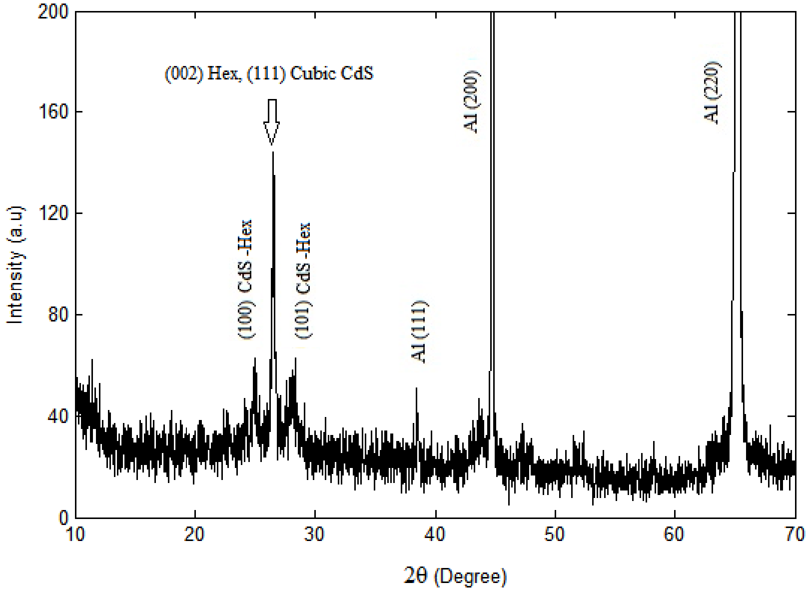

Figure 1. XRD pattern for a film of CdS on aluminum substrate. Hex is for hexagonal structure

Measured transmittance (T) from a CdS film on a fused silica substrate is shown in Figure.2.

It may be noted that during the measurement of T, air was the medium along the path of the reference beam in the spectrophotometer. The data of Figure.2 was used to extract refractive indices using the method of [10]. The results are shown in Figure.3. The method assumes a single uniform film with perfectly parallel faces on a transparent substrate. The thickness of the film is adjusted graphically until a continuous dispersion curve is obtained [10]. The method yields thickness values with an error less than 1%. Proper closure of the dispersion curve (Figure. 3) suggests that CdS films do meet the characteristics close to those stated above.

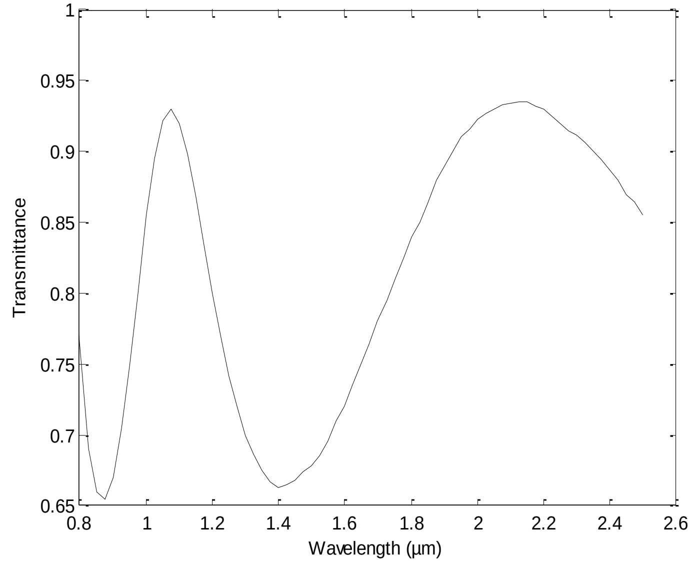

Figure 2. Measured transmittance from CdS film of thickness 0.469 µm

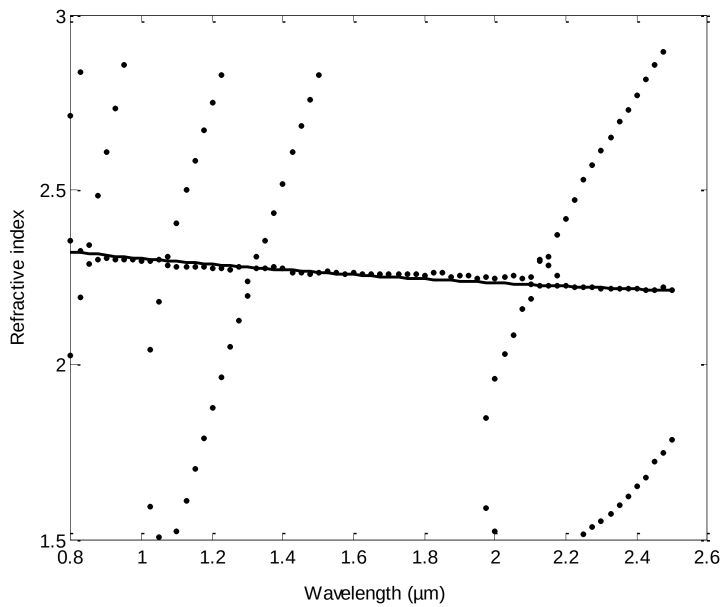

Figure 3. Refractive index versus wavelength curve for a CdS film, derived from the data of Figure 2 by using the method of [10]. The continuous curve shown here represents the correct solutions while other solutions are unwanted

In Figure. 3, average dispersion curve is represented by a continuous bold line. The dots surrounding the continuous curve are the unwanted solutions arising due to multiple reflections in the film. Similar results are obtained for other films which varied in thickness from 0.15-0.5 µm. Variations in refractive indices from film to film were found to be less than 1%.

Figure. 4 shows the dispersion curves for (a) CdS films (present work), (b) obtained from R and T measurements made on CdS films from [11], and (c) bulk CdS from [13].The values of the refractive indices of the films (Figures 4a and 4b) are lower than those of the bulk (Figure 4c). Generally, the density of a film is lower than that of the corresponding bulk material [14].

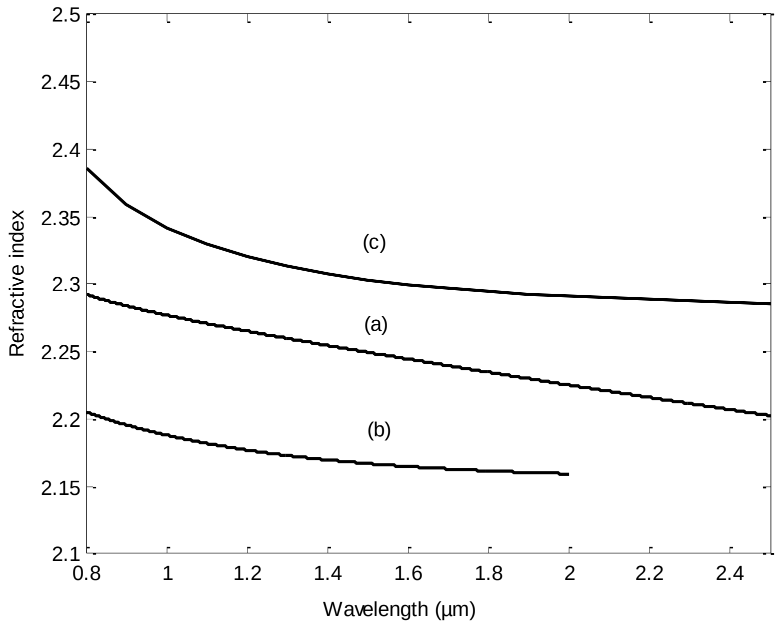

Figure 4. The dispersion curves for (a) CdS films (present work), (b) obtained from R and T measurements made on CdS films from [11], and (c) bulk CdS from [13]

According to Lorentz-Lorenz Law, the lower density of a material is expected to yield lower refractive index of the same material, thus explaining the above observations. Moreover, the values of the refractive indices in the present work (Figure. 4a) are greater (upto 4%) than those of Figure. 4(b) from [11]. In [11], the refractive indices were determined from the measurement of R and T. It was found [11] that a proper continuity of the dispersion curve could not be obtained when a film was assumed to be a uniform single film. The reason for this behavior of the dispersion curves became clear when the surfaces of these films were examined under electron microscopy [11]. The surfaces were found to be rough. Hence, losses in reflectance are expected due to the surface roughness of the films. In the highly absorption region where multiple reflections were absent, reflectance values were compared with the corresponding results for bulk crystalline CdS [11]. The reflectance of CdS films were about 10% to 20% less than the corresponding values for bulk CdS. To account the surface roughness, a two-layer film model was used [11] to extract optical constants. Lower values of refractive indices in [11] as compared to the present results may be due to losses in the measured values of R in [11].

It has been found that for polycrystalline films such as CdS [11], the measurements (R and T) were not those appropriate to perfectly plane parallel uniform thin films such as those assumed for derivation of the formulae used. However, such a problem did not exist when the only transmittance measurements were employed. The CdS films in the present work are polycrystalline and may have rough surfaces as was the case in [11]. The synthesis of a single uniform CdS film showed more appropriate results under various characterization techniques discussed in this research work. In the present case, transmittance measurements may not be seriously affected as compared to reflectance measurements.

The present results in Figure. 4(a) are much closer to those for the bulk (Figure. 4c) as compared to the results of [11]shown in Figure. 4(b). The densities of II-VI films are known [14, 15] to be closer (within about 5%) to the corresponding values for the relative bulk material; therefore, it is expected that their refractive indices to be close to the corresponding bulk values. Hence, the present results may be more appropriate.

4. Conclusion

The refractive indices of CdS thin films were extracted from measurement of transmittance at normal incidence. The results were compared with those obtained from reflectance (R) and transmittance (T) measurements of CdS films. The present results as compared to those determined from R and T, are closer to the bulk values of the refractive indices. The use of readily available facilities for the measurement of transmittance is a plus point of the present work.

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