OPTICAL ABSORPTION AND REFRACTIVE INDEX OF EVAPORATED CADMIUM ARSENIDE THIN FILMS IN INFRARED REGION

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ABSTRACT

Measurements of transmission in the infrared showed interference maxima and minima from which the refractive index n_1 and the absorption coefficient α were determined. Values of refractive index of 5.3 and 5.6 were determined for films deposited under different conditions, and are reasonably consistent with each other in view of the differences in thickness and deposition temperature. The value of the absorption coefficient, α calculated was in the range of 10^4 (cm^{-1}) for film thickness 1.5 mm and substrate temperature, T_s at 300 K and it increases to in the range of 10^5 (cm^{-1}) for film thickness 0.46μm and substrate temperature 453 K. Some other samples showed the dependence of α on hv for a Cd_3As_2 film of thickness 0.24μm deposited onto a KCl substrate at a temperature of 300 K. These results are similar to those reported by Zdanowicz and Kwiecien (1977), having a value of α somewhat less than 10^5 cm^{-1} for hv = 1 eV and falling to round 10^3 cm^{-1} below 0.1 eV.

1.0 INTRODUCTION

The absorption coefficient α (m^{-1}) was calculated from the transmission data by using the transmittance T, of a weakly-absorbing thin film of thickness *d* and may be expressed by the relation,

$$T=A \exp(-\alpha d)/1 - 2R_1R_2 \exp(-\alpha d) + R^2{}_1R_2{}^2 \exp(-2\alpha d) \quad (1)$$

where n_1 is the film refractive index and n_2 substrate of NaCl or KCl refractive index

$$A=16n^2{}_1n_2/(1 + n_1)^2 (n_1 + n_2)^2 \quad (2)$$

and α is the absorption coefficient of the film, R_1 and film - substrate interface, R_2 are given by

$$R1 = (n^1 - 1)/ (n_1 + 1) \quad (3)$$

$$R2 = (n_1 - n_2)/ (n_1 + n_2) \quad (4)$$

In the spectral region where extinction coefficient of the film $k_1 << n_1$, the transmittance at a maximum is given by

$$T=A \exp(-\alpha d)/1 + R^2{}_1R_2{}^2 \exp(-\alpha d) \quad (5)$$

2.0 EXPERIMENTAL PROCEDURE

The basic infrared measurements were performed in the wavelength range 1.6 to 10 μm corresponding to energies of 0.05 eV to 2.0 eV. A Perkin Elmer System 2000 FTIR spectrometer was used to perform the measurements. Measurements of transmission *T* as a function of wave number 1/λ were made for various films of different thickness. The films were deposited by vacuum evaporation system at a pressure about 10^{-5} Nm^{-2} onto substrates of either NaCl or KCl at a rate of 0.5 nm s^{-1}; the substrate temperatures were either 300 K or 453 K. A selection of the results obtained is described below.

3.0 RESULTS

Fig. 1 shows the dependence of *T* on 1/λ for a film of thickness *d* = 1.5 μm deposited onto a NaCl substrate at T_s = 300 K. Fig. 2 shows a similar set of measurements for a film with *d* = 0.46 μm deposited with T_s = 453 K (180°C), also onto a NaCl substrate. Both of these figures show maxima and minima in the transmission, owing to interference effects. The absorption coefficient α was determined using the above expression (eq.1).

In performing these calculations, the film refractive index n_1 was first calculated from the spacing of the interference maxima using the method descibed by Zdanowicz (1967) and Moss (1959). This allows R_1 and R_2 to be calculated using Eqn. (3 and 4). n_2 values used in these calculations were 1.50 for NaCl and 1.49 for KCl. Finally *A* was calculated from Eqn. (2) and the calculated R_1, R_2 and *A* values inserted into Eqn (5) with the appropriate value of *T* at a maximum in the characteristic. Table 1 lists the value of *T* and $1/\lambda$ for each of the maxima shown in Figs. 1 and 2. Eqn (1) reduces to a simple quadratic equation in $\exp(-\alpha d)$ which yields two solutions in each case. Using the relevant value of *d* for each film, two values of α were obtained, and the appropriate positive values are given for each maximum in Table 1.

From Fig. 1 the value of the refractive index n_1 of the Cd_3As_2 film deposited at 300 K was found to be 5.3, whereas from Fig.2 a value of 5.6 was obtained for the film deposited at 453 K. These values are reasonably consistent with each other in view of the difference in thickness and deposition temperature. They are also slightly higher than values of up to 5.3 measured by Zdanowicz (1967), but this is probably not significant in view of the limited number of samples investigated. Zdanowicz (1967) obtained a value of n_1 of about 4.6 at $\lambda = 12$ ìm for a Cd_3As_2 film deposited at 160°C and the maximum value of 5.3 occurred at $\lambda = 1.9\ \mu m$.

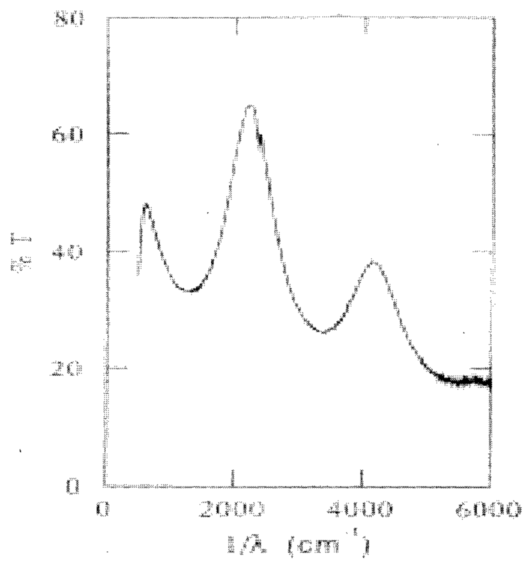

Figure 1: Dependence of transmittance on wave number for a Cd_3As_2 film of thickness 1.5 μm deposited onto a NaCl substrate at a temperature of 300 K.

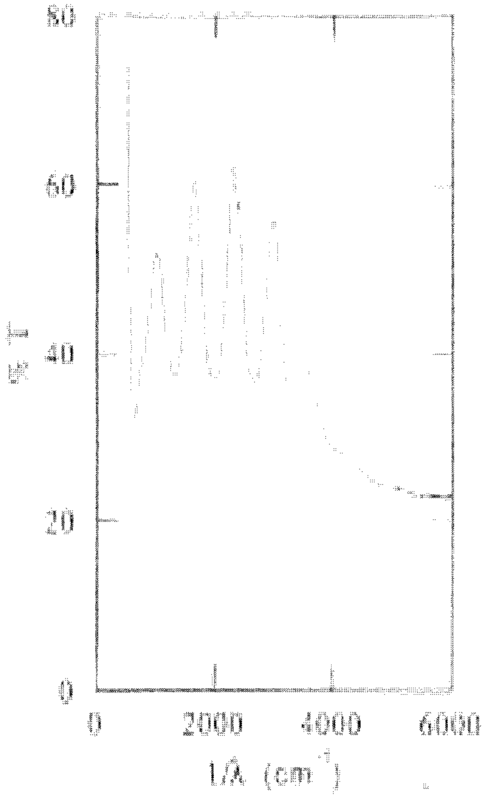

Figure 2: Dependence of transmittance on wave number for a Cd_3As_2 film of thickness 0.46 μm deposited onto a NaCl substrate at a temperature of 453 K.

d (μm)	T_s (K)	n_1(Cd_3As_2)	T (%)	1/λ (cm⁻¹)	hν (eV)	α (cm⁻¹)
1.5	300	5.3	51.5	988	0.123	2123
1.5	300	5.3	60.1	1626	0.202	1554
1.5	300	5.3	62.1	2300	0.286	1435
1.5	300	5.3	55.3	2973	0.369	1854
1.5	300	5.3	37.5	3576	0.444	3394
0.46	453	5.6	47.1	612	0.076	6808
0.46	453	5.6	64.9	2216	0.275	4060
0.46	453	5.6	38.2	4100	0.509	10481
0.46	453	5.6	18.1	5865	0.729	21391

Table 1: Values of the transmittance maxima T and the corresponding wave numbers $1/\lambda$ for each of the peaks of Figs. 1 and 2, d represents the film thickness, T_s the substrate temperature during deposition and hv the incident photon energy corresponding to $1/\lambda$. Calculated values of the film refractive index n_1 and the absorption coefficient α are also given.

Turner *et al* (1961) from reflection measurements on Cd_3As_2 single crystals obtained a value of 3.6 for the refractive index at $\lambda = 12\ \mu m$. The different values of refractive index obtained may be due to the surface conditions of the films and the different preparation conditions, such as the substrate temperature and the film thickness. Zdanowicz and Kwiecien (1977) also reported a value of refractive index of about 6 at λ= 14.5 μm which was obtained from a sample of thickness 2.6 ìm. This value is also in agreement with results reported by Cisowski and Bodnar (1975). In the present work a definitive correlation could also not be drawn between the value of the refractive index and the deposition temperature. These values of n_1 obtained from Figs. 1 and 2 are also given in Table 1

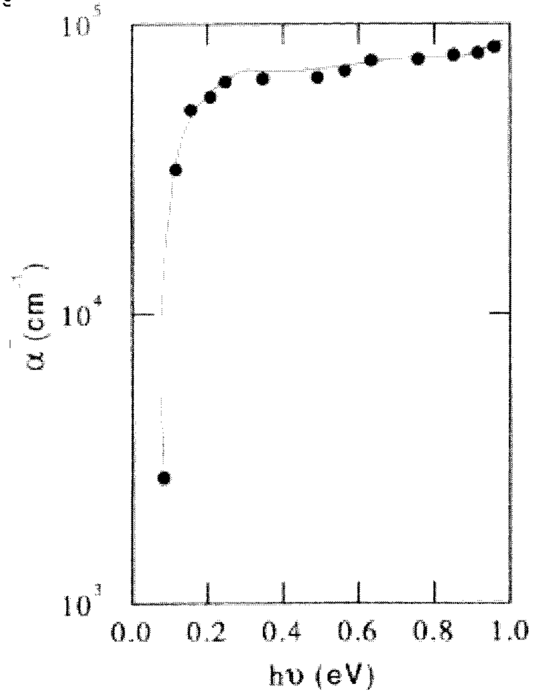

Figure 3: Dependence of absorption coefficient a on photon energy hv for a Cd_3As_2 film of thickness 0.24 µm deposited onto a KCl substrate at a temperature of 300K

The value of the absorption coefficient,α calculated by using eqn. 1 was in the range of 10^4 (cm^{-1}) for film thickness 1.5 mm and substrate temperature, T_s at 300 K and it increases to in the range of 10^5 (cm^{-1}) for film thickness 0.46 mm and substrate temperature 453 K. This value is an agreement with the value reported by Zdanowicz and Kwiecien, (1976) where they used a film thickness in the range of 0.3 – 0.5 µm.

Fig. 3 shows the dependence of α on $h\nu$ for a Cd_3As_2 film of thickness 0.24 μm deposited onto a KCl substrate at a temperature of 300 K. These results are similar to those reported by Zdanowicz and Kwiecien (1977), having a value of α somewhat less than 10^5 cm^{-1} for $h\nu$ = 1 eV and falling to a round 10^3 cm^{-1} below 0.1 eV.(Din, 1998)

4.0 CONCLUSION

The transmission in the infrared region showed interference of maxima and minima from which the refractive index n_1 and the absorption coefficient α were determined. Values of refractive index of 5.3 and 5.6 and the value of absorption coefficient á in the range of 10^3 -10^5 cm^{-1} were determined for films deposited under different conditions, and are reasonably consistent with each other in view of the differences in thickness and deposition temperature. A more comprehensive study of the infrared absorption properties in films of both crystalline and amorphous Cd_3As_2 is clearly required. Due to insufficient data, it was not possible to distinguish between direct and indirect transitions, although the higher energy transition in the present work appears to be a direct, rather than an indirect transition.

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