ISSN 1330–0008
CODEN FIZAE4

OPTICAL PROPERTIES OF CADMIUM TELLURIDE THIN FILM IN THE INFRARED REGION

ABDEL HAMID EID, SIHAM MAHMOUD and MAGDA M. SAYED

Physics Department, National Research Centre, Cairo, A. R. E.

Received 4 December 1990
UDC 538.958

Original scientific paper

The values of refractive index, extinction coefficient, dielectric constant, optical conductivity and some physical data of cadmium telluride film were estimated in the infrared region using transmission technique. The transmission is close to 70%. The index of refraction was determined to be ≈ 2.65 and the extinction coefficient is very small. The value of 0.2 for the reflectivity coefficient R was obtained by plotting transmission against thickness for various wavelengths and extrapolating to zero thickness. It is seen that our values are in a satisfactory agreement with those given in the literature. The results show the presence of maximuma in ε_1, ε_2, α and σ_1 at about 0.06, 0.08 and 0.197 eV. These peaks may be attributed to transitions from the valence band to an acceptor level.

1. *Introduction*

Studying the optical properties of a semiconducting material is one of the most familiar methods to gain an adequate knowledge about its band structure. Absorption by bound and free electrons are both significant in semiconductors. The former gives rise to the intense absorption at the short wavelength side of the main absorption edge, while at long wavelengths, free carrier absorption becomes significant. In an ideal semiconductor at zero temperature the valence band would be completely full, so that an electron could not be excited to a higher energy state within the band. The only possible absorption is that of quanta sufficiently energetic for the electrons to be excited across the forbidden gap into the empty conduction band. In practice the resulting absorption spectrum is a continuum of intense absorption at short wavelengths, bounded by a more or less steep absorption edge beyond which the material is relatively transparent. The intensity of the absorption, due to direct transitions in the simple case, is determined primarily by the numbers of occupied states in the valence band and unoccupied states in the conduction which are energetically within $h\nu$ of each other, and on the transition probability[1)].

The optical properties of CdTe in the near and far infrared have been investigated by many workers[2)]. Mitsuishi[3)] measured the reflectance as a function of wavelength from 400 μm to 200 μm at 90 K. He got a peak at 71.4 μm. Fisher and Fan[4)] reported a reflectance peak at 86 μm, and two absorption bands at 35 μm and 40 μm for measurements made at room temperature. They suggested the former (35 μm) as the second harmonic of the fundamental optical absorption frequency. Some authors[2)] determined the dielectric constant of CdTe in the far infrared from 1000 μm to 132 μm by means of interference fringes. The reported value of ε_0 is 9.7 ± 0.3. The high frequency dielectric constant of CdTe was determined by Marple[5)] as $\varepsilon_\infty = 7.21$. The index of refraction in the infrared was determined to be 2.61[6)].

Near-IR transmission spectra of vacuum evaporated CdTe thin films grown at different temperatures and rates were studied, as well as the effect of thermal annealing on the spectra. The condition for the preparation of films with a high transmission and a well-defined absorption edge were determined. The absorption coefficient and optical band gap of the films were obtained from the transmission spectra. The optical band gap is associated with direct interband transitions[7)].

2. *Experimental technique*

The investigated cadmium telluride layers were obtained by vacuum sublimation onto KBr discs of highly controlled weight and thickness for IR region. The KBr discs were prepared by pressing about 200 mg KBr in a special disc under vacuum at about 150 kP/cm^2 pressure by means of a hydraulic press. The produced disc was 1.2 cm in diameter and about 0.15 mm thick. The film thickness varied from 300 to 900 nm and the sublimation rate was fixed at 7 nm/s in vacuum of 10^{-4} Pa. The film thickness was measured by the Tolansky interference method[8)]. The transmission spectra were obtained with the help of a 4220 Beckmann double beam spectrophotometer with an accuracy of 1% used in the infrared region. The optical transmission measurements were made over the spectral range from 2.5 to 40 μm for infrared region.

3. *Results and discussion*

The variation in the transmittance T of CdTe films of different thicknesses on KBr discs with the wavelength in microns is shown in Fig. 1. The transmittance shows a pronounced dip at about 6.3, 15 and 22.2 μm, moreover, the transmittance decreases and increases gradually as the film thickness and wavelength, respec-

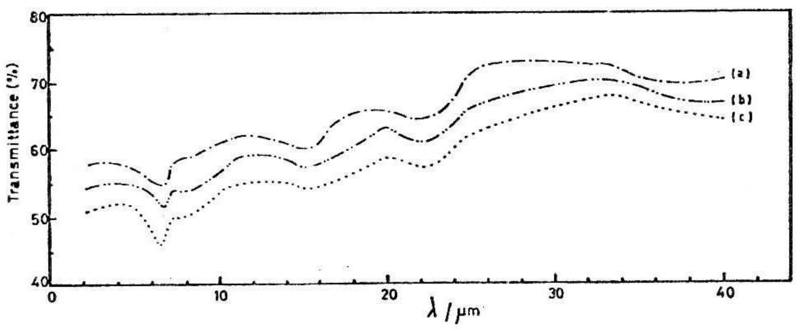

Fig. 1. Percent transmission vs. wavelength for CdTe *films of different thickness (a)* $d = 460.7$ nm, *(b)* $d = 663.4$ nm, *(c)* $d = 819$ nm.

tively, increases. The transmittance is close to ≈ 70%. Lorimor et al.[9] observed that the transmittance from 1 to 22.2 μm is essentially constant at ≈ 65% for three different thicknesses of CdTe films. But below 25 μm only two previously reported transmission minima were observed.

In calculating the absorption coefficients, corrections were made for reflections. The reflectivity coefficient R, used in the calculations of K and α, was obtained by plotting transmission against thickness for various wavelengths (2.6, 5, 10, 14 μm) and extrapolating to zero thickness according to the formula[10]

$$T = (1 - R)^2 \mathrm{e}^{-\alpha d}. \tag{1}$$

The data are shown in Fig. 2. The value of 0.2 for R calculated from the present

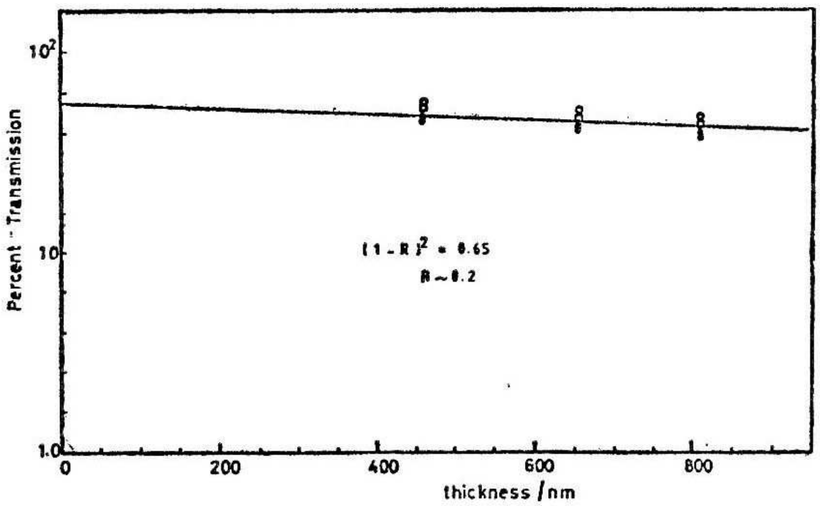

Fig. 2. Percent transmission vs. thickness.

work (2.5-40 μm) agrees well with the value of 0.2 obtained by Davis et al.[6] and Lorimor et al.[9]. As well, it is confirmed by the value of 0.21 obtained by Marple et al.[11] using the reflection technique and the value of 0.207 published by Danielewicz et al.[12].

In Fig. 3 the values of n, k and α for various thicknesses are plotted against photon energy. It is clear that the extinction K and absorption coefficient α decreases gradually with increase of photon energy and thickness, but the refractive index n increases with the increase of photon energy. The absorption peak at about 0.197 eV may be attributed to transitions from the valence band to an acceptor level. The optical absorption of p-type CdTe samples at photon energies less than E_g has been measured by Vul et al.[13] and by Capek et al.[14]. The authors obtained the absorption peak at about 0.2 eV, which is not strongly temperature dependent. It is attributed to transitions from the valence band to an acceptor level, while the temperature dependent absorption at lower energies is attributed to interband free-carrier transitions from the light-hole valence to the heavy-hole valence band. Also it is found that the values of the extinction coefficient K are small and ranges between 0.07 to 0.9 and the value of the refractive index is about 2.65. It is seen that our values are in a satisfactory agreement with those given in the literature[9,12,15]. The index of refraction in the infrared was determined interferometrically to be 2.61[6].

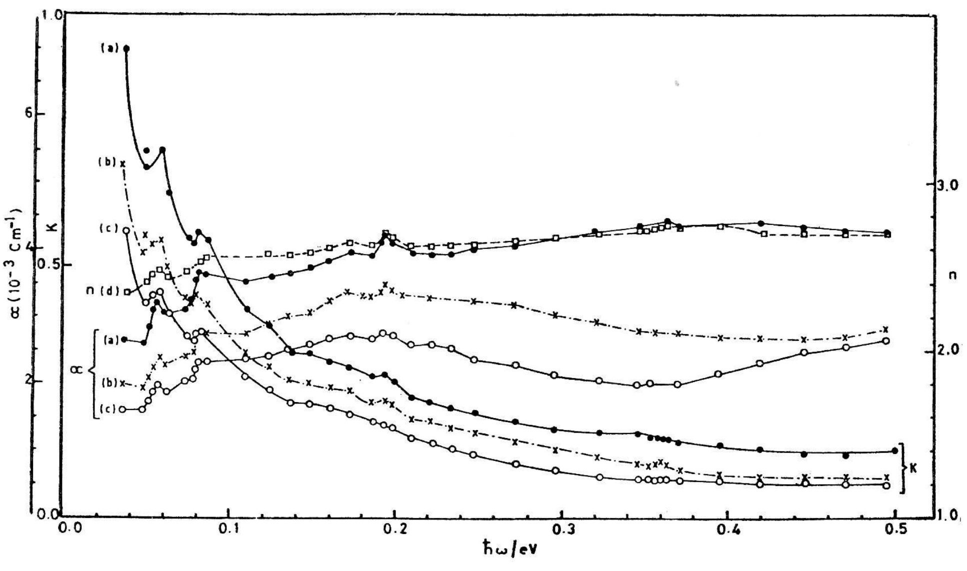

Fig. 3. Dependence of the extinction coefficient (K)*, refractive index* (n) *and the absorption coefficient* (α) *on the photon energy (a)* $d = 460.7$ nm *(b)* $d = 663.4$ nm *(c)* $d = 819$ nm *(d)* $d = 460.7$ nm.

De Nobel and Hofman[16] reported a low-frequency dielectric constant of 11.0 ± 0.3 from electrical measurements on CdTe which corresponds to a refractive index of about 3.32. A comparison of this value with the optical refractive index (2.65) determined in the present work suggests that bonding in CdTe is somewhat ionic. This conclusion, as well as the value of the optical refractive index, is at variance with the observations of Garlick et al.[17] but is supported by earlier estimates of de Nobel[18] and by recent detailed measurements of Fisher and Fan[8].

In ionic crystals there is a strong absorption band at long wavelengths which arises from the oscillation of the atoms or ions. Although the interatomic forces in ionic crystals are comparable with electronic forces in atoms, the fact that the ionic masses are some 10^4 times greater than electronic masses means that the absorption bands lie at very long wavelengths.

The detailed variation of real ε_1, and imaginary ε_2 parts of the dielectric and optical conductivity σ_1 with photon energy, for the 460.7 nm sample are shown in Fig. 4. The values of ε_2 decrease gradually as the photon energy increases, moreover, the values of ε_1 and σ_1 rise gradually as the photon energy increases. Figure 4 shows the presence of maximum in ε_1, ε_2 and σ_1 at about 0.06, 0.08 and 0.197 eV.

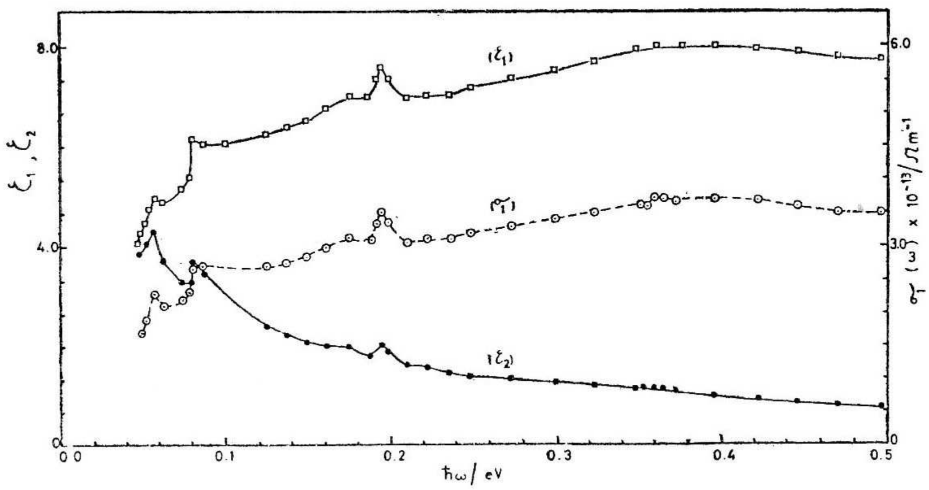

Fig. 4. Dependence of the dielectric constants and optical conductivity on photon energy $d = 460.7$ nm.

The impurity states in semiconductors always exist and there is no way to avoid their role on the optical and electrical properties of any semiconductor. The transition of an electron either from the matrix to the impurity "acceptor", or from the impurity "donor" to the matrix is directly related to the ionization of the impurity atom. The hydrogen type model yields an expression of the form[19]

$$E = \frac{13.52}{\varepsilon^2} Z^2 \left(\frac{m^*}{m} \right) \text{ eV}, \tag{2}$$

where 13.52 eV is the energy of ionization of a free hydrogen atom. To differentiate between impurities, their ionization energies have to replace that of the hydrogen free atom. It is clear from Eq. (2), that the ionization energy of the embeded impurity atom is $1/\varepsilon^2$ times less than the value of the free atom.

Since CdTe is partially ionic (ionicity of 0.717)[20], the polarization of the ions under the applied electric field component of the electromagnetic wave will reduce the value of the static dielectric constant. Accordingly, an effective value ε_e should replace the static ε and the optical one ε_0 and is given by

$$\frac{1}{\varepsilon_e} = \frac{1}{\varepsilon} + \frac{5}{16}\left(\frac{1}{\varepsilon_0} - \frac{1}{\varepsilon}\right). \tag{3}$$

The ionization energy of the embeded impurity atom is then given by

$$E = \frac{E(\text{impurity free atom})}{\varepsilon_e}\, Z^2 \left(\frac{m^*}{m}\right) \text{ eV}, \tag{4}$$

introducing the known values of E (*impurity*), ε_e, m^*/m and the value of Z. E may turn out to be some hundredths or thousandth fractions of an electronvolt. These fractions still have to be reduced due to the reduction of the impurity ionization energy by increasing the concentration of the already ionized impurities.

Accordingly, the impurities which form their own shallow levels either just below the bottom of the conduction band or just above the top of the valence band, with a slow rise in temperature, will be the main source of free charge carriers. This implies that the optical and electrical properties of the CdTe films are controlled mainly by the concentration of the already existing impurities during thermal sublimation of the film under vacuum.

Acknowledgements

The authors like to acknowledge Prof. Dr. M. Z. Zidan for his kind cooperation and interest.

References

1) T. S. Moss, *Optical Properties of Semiconductors*, Butterworths, London (1961);
2) O. M. Stafsudd, F. A. Haak and K. Radisavlzevic, J. Opt. Soc. Amer. **57** (1967) 1475;
3) A. Mitsuishi, Phys. Soc. Japan **16** (1961) 533;
4) P. Fisher and H. Y. Fan, Bull. Am. Phys. Soc. **4** (1959) 409;
5) D. T. F. Marple, J. Appl. Phys. **35** (1964) 539;
6) P. W. Davis and T. S. Shilliday, Phys. Rev. **118** (1960) 1020;
7) J. Aranda, J. L. Morenza, J. Esteve and J. M. Codina, Thin Solid Films **120** (1984) 23;

8) S. Tolansky, *Introduction to Interferometry*, 2nd ed., Longmans Green and Co., London (1973) p. 157;
9) O. G. Lorimor and W. G. Spitzer, J. Appl. Phys. **36** (1965) 1841;
10) N. V. Agrinskaya, E. N. Arkad'eva and O. A. Matveev, Sov. Phys. Semiconductors (USA) **4** (1970) 370;
11) D. T. F. Marple and B. Segall, Bull. Am. Phys. Soc. **9** (1964) 1841;
12) E. J. Danielwicz and P. D. Coleman, Appl. Opt. **13** (1974) 1164;
13) B. M. Vul, V. M. Salman and V. A. Chapnin, Sov. Phys. Semiconductor **4** (1970) 52;
14) V. Capek, K. Zimmerman, C. Konak, M. Popova and P. Polivka, Phys. State. Sol. (b) **56** (1973) 729;
15) J. E. Kiefer, T. A. Nussmeier and F. Goodwin, IEEE, J. Quantum Electronics **8** (1972) 173;
16) D. de Nobel and D. Hofman, Physica **22** (1956) 252;
17) C. F. J. Garlick, J. M. Hough and R. A. Fatchally, Proc. Phys. Soc. **72** (1958) 925;
18) D. de Nobel, Phillips Research Reps. **14** (1959) 320;
19) P. S. Kireev, Semiconductor Physics (1975);
20) A. J. Strauss, Revue De Physique Appliquée **12** (1977) 167.

OPTIČKA SVOJSTVA TANKIH SLOJEVA CdTe U INFRACRVENOM PODRUČJU

ABDEL HAMID EID, SIHAM MAHMOUD and MAGDA M. SAYED

Physics Department, National Research Centre, Cairo, A. R. E.

UDC 538.958

Originalni znanstveni rad

Koristeći transmisionu tehniku određeni su indeks loma, koeficijent gušenja, dielektrična konstanta i optička vodljivost slojeva CdTe u infracrvenom području. Koeficijent prolaza je blizu 0,70, a indeks loma je približno 2,65, dok je koeficijent gušenja vrlo malen. Dobiveni rezultati su u dobrom slaganju s objavljenima u literaturi. Maksimumi na otprilike 0,06, 0,08 i 0,197 eV mogu se pripisati prijelazima iz valentne vrpce na akceptorske nivoe.