YU ISSN 0015—3206
FZKAAA 23 (1) 37 (1991)

OPTICAL PROPERTIES OF CADMIUM TELLURIDE THIN FILM IN THE VISIBLE AND UV REGION

SIHAM MAHMOUD, ABDEL HAMID EID and MAGDA SAYED

Department of Electron Microscopy and Thin Films, National Research Centre, Dokki, Cairo, A. R. E.

Received 1 September 1989
Revised manuscript received 10 September, 1990
UDC 538.975
Original scientific paper

The direct transmission spectrum of cadmium telluride thin films deposited on quartz slides has been measured at room temperature (300 K). Some specimens were deposited on substrates heated up to 473 K under vacuum during film deposition. Optical transmission measurements were made over the range from 200—900 nm for CdTe deposite having thickness of 300 to 800 nm. The values of the absorption coefficient α as a function of frequency were obtained at various thickness and substrate temperature. It is of interest to note that for different thicknesses (344—795 nm) of CdTe, the calculated absorption coefficient in the region from 1.4 to 1.6 eV on heated substrate were very close to each other. Plotting $\sqrt{\alpha}$ and α^2 vs. frequency, gives the minimum energy for direct transitions (at room substrate temperature) to be 1.503 eV, and for indirect transitions 1.43 eV.

1. Introduction

The basic information for determining the optical constants of a semiconductor comes from measurements of reflection and transmission. Although the same method is used throughout the spectrum, there are three different processes to be considered. Short-wavelength photons interact with the valence electrons and excite them up to the conduction band. As the photon energy decreases past that corresponding to the energy gap, the transmission shows a sudden increase, and from the position and shape of this absorption-edge one obtains information on the nature of the transition from the valence to the conduction band. At longer wavelengths the optical properties are affected by interaction between the photons and the free carriers, and the resulting transition takes place either within the valence or the conduction band. At wavelengths longer than about 10 μ there can be interaction between the photons and the lattice. The optical properties in this wavelength region are influenced by both, lattice vibrations and free carriers[1].

The optical constants of CdTe thin films were determined in the wavelength range 400—1000 nm. Some parameters which affect these optical properties of CdTe thin films, such as film thickness, rate of evaporation and substrate temperature were investigated$^{2)}$. The absorption spectra of n-type and p-type CdTe crystals were determined in the 1.6—0.8 μm range at 77 and 300 K. It was found that at room temperature the minimum energy for direct transitions is 1.5 eV and for indirect transitions 1.44 eV$^{3)}$. Various absorption bands were attributed to simple lattice defects and their complexes$^{4)}$. Then, the influence of the crystalline structure of thin CdTe on the absorption in the region of intrinsic band edge at liquid nitrogen temperature was investigated. In the more perfect thin films the excitation absorption at wavelength of 0.781 μm was observed and the magnitude of this absorption depends on the perfection of their crystalline structure$^{5)}$.

The dependence of the absorption coefficient α on the photon energy $\hbar\omega$ was determined for evaporated CdTe films. The absorption coefficient was plotted as log α vs. m log ($\hbar\omega$). These dependences with $m = 1/2$ and $m = 2$ indicate, respectively, that direct and indirect optical transitions occur in CdTe thin films. The absorption data for these films were analysed by applying the procedure of Khawaja and Tomlin$^{6)}$ to find the energies of direct ($E_d = 1.68$ eV) and indirect ($E_i = 1.47$ eV) transitions, which have not been obtained before$^{7)}$.

2. *Experimental technique*

The samples were obtained by vacuum sublimation of high quality CdTe powder onto quartz slides for UV and visible region. A mini-oven was build into the jar to allow for heating the substrates from room temperature up to 473 K. The sublimation rate was fixed at 7 nm/s in vacuum of 10^{-4} Pa. The film thickness was varied from 300 to 800 nm. A multibeam interferometer method$^{8)}$ was used for measurement of the thickness. The instrument used in this work for the measurement of the visible absorption spectra was fully automatic double beam spectrophotometer type Beckmann 5260. The direct transmission spectrum of CdTe thin films deposited on quartz slides has been measured at room temperature (300 K), and were made over the spectral range from 200 to 900 nm.

3. *Results and discussion*

The transmittance in Fig. 1 shows a maximum near 860 nm moreover, the transmittance decreases strongly with photon energy. From the wavelength corresponding to the commencement of transmission as determined from the abscissa of the point of intersection of the tangents to the transmission curve Fig. 1, the room temperature value of the forbidden gap width was calculated for each specimen using the relation:

$$E_g = \frac{1239.6}{\lambda} \tag{1}$$

where E_g is expressed in eV and λ in nm. Burdiyan[9] determined in this way the forbidden gap width for AlSb-GaSb solid solution. The forbidden gap width which we obtained for CdTe was 1.44 eV and 1.503 eV on heated and non-heated substrates, respectively, which is slightly lower than the value obtained by Dubrovskii and S. S. Ou et al.[10,11] who gave the optical energy gap of CdTe as 1.45, 1.46 eV but is in good agreement with the value 1.44 eV reported by Davis et al.[3] and Yamadas[12].

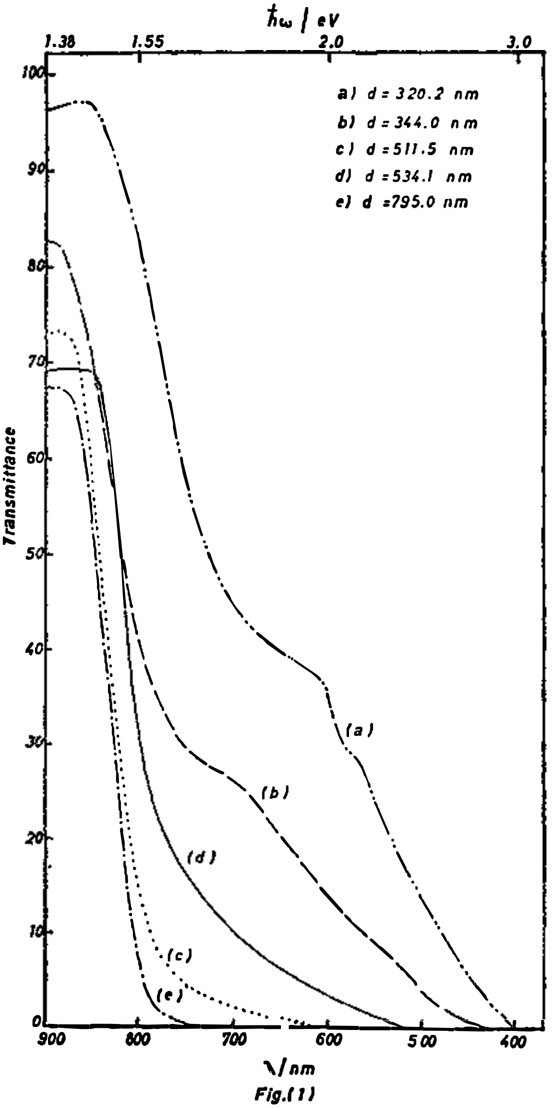

Fig. 1. Spectral dependence of the transmission of CdTe films in the visible range.
a) $d = 320.2$ nm b) $d = 344$ nm
c) $d = 511.5$ nm d) $d = 534.1$ nm
e) $d = 795$ nm.

Figs. 2, 3 show the variation of the calculated values of the real and imaginary part of the refractive index with the photon energy for a layer of different thicknesses and substrate temperature of 300 and 473 K. For comparison it has been plot-

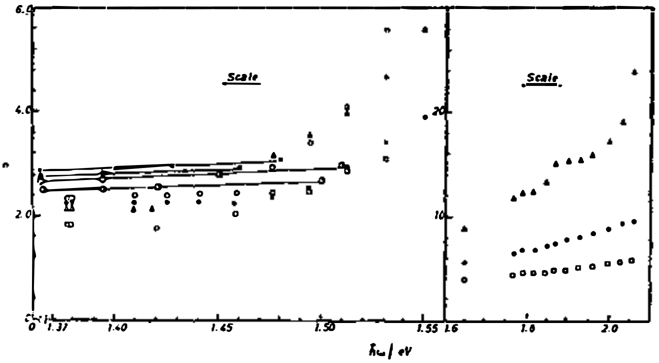

Fig.(2)

Fig. 2. Dependence of refractive index (n) on the photon-energy compared with Ref. 13.
○ $d = 795$ nm · $d = 534$ nm
△ $d = 511.5$ nm □ $d = 344$ nm.

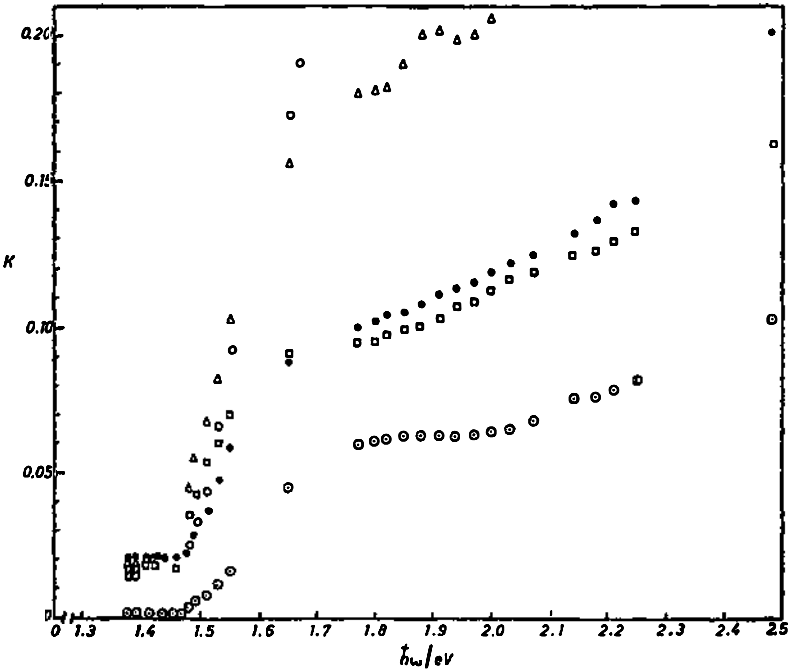

Fig.(3)

Fig. 3. Dependence of the extinction coefficient K on photon energy.
○ $d = 795$ nm · $d = 534.1$ nm
△ $d = 511.5$ nm □ $d = 344$ nm
⊙ $d = 320.2$ nm.

ted together with the results of Karmazin et al.[13] taken at 533, 503, 473 and 323 K. The present results of the optical constants are in good agreement with the previously published data on CdTe[13] in the region from 1.3—1.65 eV. Karmazin et al.[13] showed that these quantities depend considerably on the degree of perfection of the sample. The refractive index of disordered samples is less than for single crystal, approaching the latter value when the substrate temperature is $T_s =$ $= 503$ and 533 K. There is a broadening of the edge, a general decrease of absorption, and as hift of the edge to shorter wavelengths as T_s decreases. The reasons for these changes are discussed elsewhere[14]. The grain size in the film is of great importance here, when it decreases; various effects occur which are due mainly to the development of intergranular layers.

The absorption edge of a semiconductor is usually a region of very rapidly rising absorption. It is a direct consequence of the dispersion relation[15] between the real and imaginary parts of the complex index of refraction that this rapid rise in absorption will lead to structure in the index of refraction near the photon energy of the absorption edge. Frank[16] examine this structure using both numerical absorption data and a number of simple models for the absorption near the edge and find that there is rapid dispersion of the index of refraction near the edge, and in some cases a peak in the index. However, the total variation of the index near the absorption edge is small in the semiconductors.

From the calculated values of the imaginary part of the refractive index K one can evaluate the absorption coefficient a by the equation

$$K = \frac{a\lambda}{4\pi} = \frac{ca}{2\omega} = hca/2E = 0.98 \cdot 10^{-5}\, a\,(\mathrm{cm}^{-1})/E\,(\mathrm{eV}). \qquad (2)$$

The results of the measurement are shown in Fig. 4 in the form of a plot of the absorption coefficient a as a function of the energy of the incident photons $\hbar\omega$. The width of the forbidden energy gap of CdTe as determined from the spectral dependence of the absorption coefficient of Fig. 4 is approximately equal to 1.44 and 1.503 eV on heated and nonheated substrates, respectively. These values agree very well with the available data[3,10,13]. It is of interest to note that for different thicknesses (344—795 nm) of CdTe, the calculated absorption coefficient in the region from 1.4 to 1.6 eV on heated substrate were very close to each other.

When the square root of the absorption coefficient is plotted against the photon energy only one straight line is observed in CdTe samples; it corresponds to the excitation of an electron by photon with the emission of a phonon according to the following equation[10]:

$$a = A\left[\frac{1}{1 - e^{-\Theta/T}}\left(\frac{h\nu - E_g - K_\Theta}{h\nu}\right)^2 + \frac{1}{e^{\Theta/T}}\left(\frac{h\nu - E_g + K_\Theta}{h\nu}\right)^2\right]. \qquad (3)$$

Accordingly, for the smaller values of absorption coefficient, $\sqrt{a}$ is plotted against the photon energy in Fig. 5 for various thicknesses and substrate temperature. The straight line portions are extrapolated to zero absorption and the values obtained are taken as the absorption edge for indirect transitions at the temperature

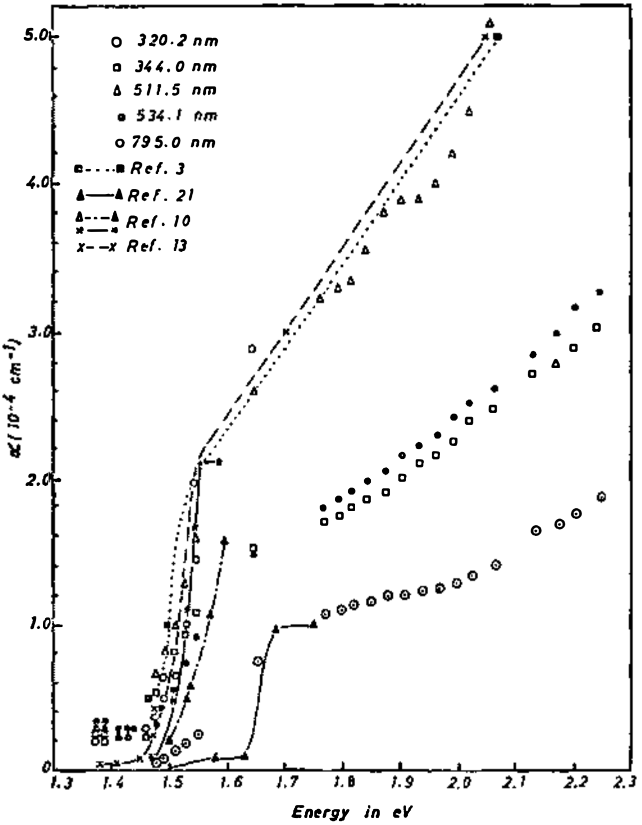

Fig. 4. The variation of the absorption coefficient as a function of energy in eV for CdTe samples.

⊙ $d = 320.2$ nm □ $d = 344$ nm
Δ $d = 511.5$ nm · $d = 534.1$ nm
0 $d = 795$ nm

▲——▲ Ref. 21 □----□ Ref. 3
▲-·-·-·-▲ Ref. 10 ×·······× Ref. 13
✳———✳ Ref. 10

and thickness given. The indirect transition energy gap is ≅1.43 eV at 300 K for both heated and non-heated substrates. It was found that at room temperature the minimum energy for indirect transitions is 1.44 eV[12]. At very low values of $\sqrt{\alpha}$ the curve (Fig. 5) has a complicated shape, which bears no resemblance to a straight line. This behaviour indicated that the distortion of the linear dependence between $\sqrt{\alpha}$ and $\hbar\omega$ is caused by the presence of an impurity absorption band in this region[17].

Plotting α^2 for various thicknesses as a function of photon energy, a straight line is obtained in the region 1.5—2.0 eV. By extrapolating to zero absorption coefficient, the direct gap results is = 1.503 eV as shown in Fig. 6. This value is

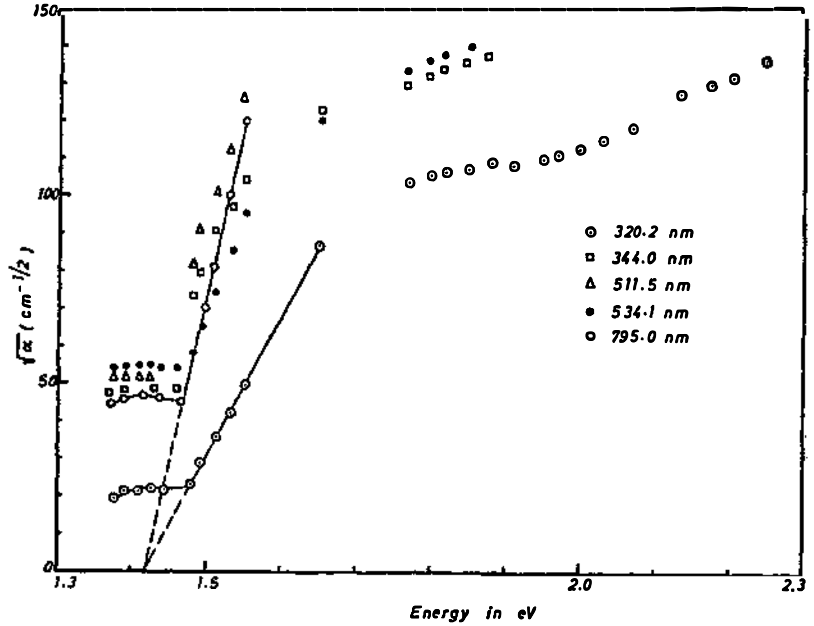

Fig. 5. Plot of square root of absorption coefficient ($\sqrt{\alpha}$) versus the energy in eV for CdTe samples.
0 $d = 320.2$ nm □ $d = 344$ nm
△ $d = 511.5$ nm ● $d = 534.1$ nm
○ $d = 795$ nm

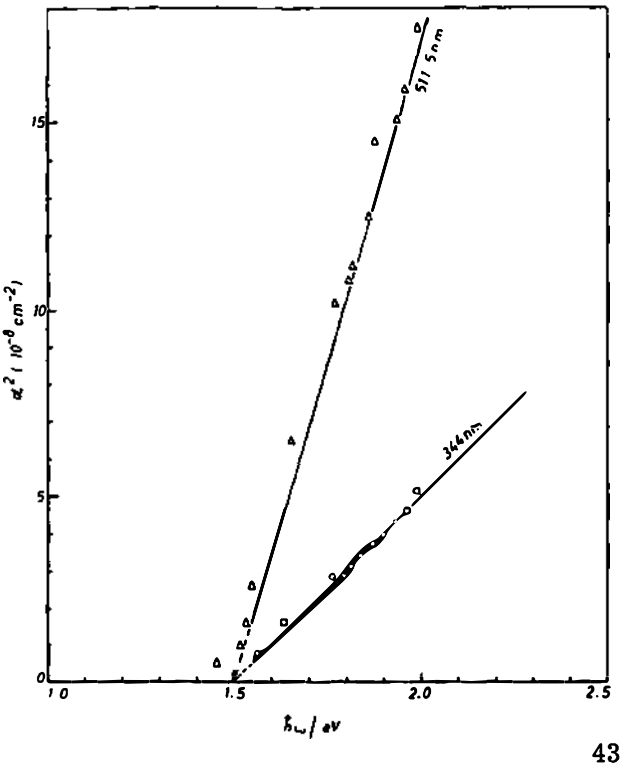

Fig. 6. Dependence of α^2 on $\hbar\omega$.

rather in good agreement with the value of 1.5 eV obtained by other workers[3,13,18]. However it is slightly lower than the value of 1.52 eV obtained by Marple[19] for the direct energy gap of CdTe.

Fig. 7 shows the electronic energy band structure of CdTe. It is clear from this figure, that the energy gap is direct and involves a transition from Γ_{15} to Γ_1. According to Loferski's theoretical calculations[20], and energy gap of 1.52 eV is very close to the value that can potentially yield the maximum possible efficiency for the conversion of solar radiation to electric power by means of semiconductor solar cells.

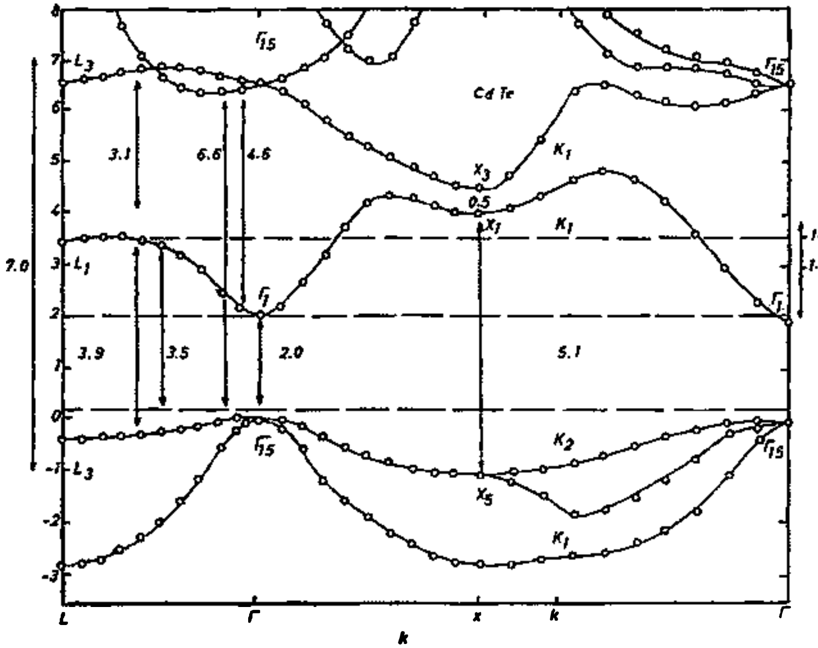

Fig. 7. Energy band structure of CdTe at 0 K. The energy gap is directed and involves a transition from Γ_{15} to Γ_1.

Acknowledgement

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

References

1) C. Hilsum and A. C. Rose, *Semiconducting III—V Compounds*, Volume I, Innes Pergamon Press, New York, (1961);

2) A. A. El-Shazly and H. T. El-Shair, Thin Solid Films **78** (1981) 287;

3) P. W. Davis and T. S. Shilliday, Phys. Rev. **118** (1960) 1020;

4) N. V. Agrinskaya, E. N. Arkad'eva and O. A. Mateev, Sov. Phys. Semiconductors (USA) **4** (1970) 370;

5) V. B. Tolutis and A. P. Deksnis, Acad. Sci. Lithuanian USSR Litov. Fiz. **1** (1970) 113;

6) Khawaja and Tomlin, Sov. Phys. Semiconductors (1975);

7) A. A. El-Shazly, H. T. El-Shair and M. K. El-Mously, Thin Solid Films **78** (1981) 295;

8) S. Tolansky, *Introduction to Interferometry,* Longmans Green and Co., London 2nd Edition (1973) 157;

9) I. I. Burdiyan, Sov. Phys. Solid State **1** (1960) 1246;

10) G. B. Dubrovskii, Sov. Phys. Solid State **3** (1961) 943;

11) S. S. Ou, O. M. Stafsudd and B. M. Basol, J. Appl. Phys. **55** (1984) 3769;

12) Yamadas, J. Phys. Sos. Japan **17** (1962) 645;

13) V. V. Karmazin and V. K. Miloslavskii, Sov. Phys. Semiconductors **5** (1971) 928;

14) V. K. Miloslavskii, E. N. Naboikina, V. P. Lebedev and V. I. Khramtsova, UKV, Fiz. Zh. **14** (1969) 819;

15) F. Sten, *Solid State Physics* edited by F. Seitz and D. Turnbull (Academic Press Inc., New York) **15** (1963) 327;

16) Frank Stern, Phys. Rev. **133** (1964);

17) D. de Nobel, Philips Research Reps. **14** (1959) 320;

18) H. M. Brown and D. E. Brodie, Canadian J. Phys. **50** (1970) 2502;

19) D. T. F. Marple, Phys. Rev. **150** (1966) 728;

20) J. J. Loferski, J. Appl. Phys. **27** (1956) 777;

21) A. J. Strauss, Revue De Physique Appliquee **12** (1977) 167.

OPTIČKA SVOJSTVA TANKIH FILMOVA KADMIJ TELURIDA U V I UV REGIJI SPEKTRA

SIHAM MAHMOUD, ABDEL HAMID EID i M. SAYED

Department of Electron Microscopy and Thin Films, National Research Centre, Dokki, Cairo. A. R. E.

UDK 538.975

Originalni znanstveni rad

Mjeren je direktni transmisioni spektar tankih filmova CdTe, deponiranih na tanku podlogu. Neki uzorci deponirani su na substrate na sobnoj temperaturi, a ostali na 473 K. Transmisiona mjerenja načinjena su u intervalu 200—900 nm za CdTe slojeve debljine od 300—800 nm. Vrijednosti absorpcionog koeficijenta α kao funkcije frekvencije dobivene su za različite debljine slojeva i različite temperature podloge. Treba napomenuti, da računate vrijednosti apsorpcionog koeficijenta za debljine CdTe slojeva od 344—795 nm, u regiji od 1,4 eV—1,6 eV, za grijane substrate, padaju vrlo blizu jedna drugoj. Dijagram $\sqrt{\alpha}$ i α^2 vs frekvencija, daje za minimum energije direktnih prijelaza 1,503 eV a za minimum indirektnih 1,43 eV.