Optical Constants of Zinc Telluride Thin Films in the Visible and Near-Infrared Regions

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Received on: 25/4/2007
Accepted on: 4/10/2007

Abstract

In this study, thin films of ZnTe were deposited on glass substrates using vacuum evaporation technique. The optical measurements on the deposited films were performed to determine the transmission spectrum and the absorption spectra as a function of incident wavelength. As well, optical parameters, such as extinction coefficient, value and type of energy gap, type of the dominant absorption processes, real and complex refractive index as functions of incident photon energy, were determined. This study may present better understanding for the optical properties of ZnTe thin films and their devices in order to enhance their characteristics and improve their efficiencies.
Keywords: ZnTe devices, Thin films, Optical constants, Optical dispersion energy

الخلاصة

في هذا البحث، جرى ترسيب أغشية رقيقة من تيلورايد الخارصين (ZnTe) على قواعد زجاجية باستخدام تقنية التبخير الحراري في الفراغ. أجريت القياسات البصرية على الأغشية المرسبة لتحديد طيف النفاذية والامتصاصية كدالة للطول الموجي الساقط ومن ثم تحديد المعاملات البصرية مثل معامل الامتصاص ومعامل التخميد وقيمة ونوع فجوة الطاقة وعمليات الامتصاص وقيمة معامل الانكسار المركب. هذه الدراسة يمكن أن تقدم فهماً أفضل للخواص البصرية لأغشية تيلورايد الخارصين الرقيقة ونبائطها من أجل تحسين خصائصها وزيادة حدود الكفاءة لها.

Introduction

Polycrystalline thin films of II-VI compound semiconductors have reasonable importance in electronic and optoelectronic devices fabrication due to their high absorption coefficients and low fabrication costs. The photonic devices made of zinc telluride thin films are recently the subject of interest as they have excellent optical properties permitting to achieve high quantum efficiencies when they are used as photodetectors or solar cells, or antireflection coatings for the infrared detectors. As well, the relatively wide direct energy gap of such semiconductors encouraged the researchers to fabricate semiconductor lasers and light-emitting diodes in the blue and green regions of wavelengths. Fabrication of such bipolar devices requires good optical characteristics on both (or all) sides of the structure. Zinc telluride (ZnTe) is good candidate for such purposes [1-9].

Zinc telluride has a zinc-blende lattice and expansion of $8.3x10^{-6}$/K. Most heterostructures including ZnTe are characterized by very low lattice mismatch. For example, it is 0.7% for

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InAs/ZnTe structure, 0.09% for GaSb/ZnTe and 0.26% for GaAs/ZnTe [1].

Experimental Work

Thin films of high purity (99.999) ZnTe with 350nm thickness were deposited on glass slides using Balzers BAE 370 vacuum evaporation system at 10^{-6}torr pressure. Transmission measurements were performed for a range 400-900nm using UV-VIS-PV-8800 spectrophotometer. The characterizations included determination of the absorption coefficient as a function of incident photon energy, determination the value and type of energy gap and as well as the dominant absorption processes, determination of the extinction coefficient, real and complex refractive index as functions of incident photon energy. The presented data of transmission is an average of two consecutive readouts.

. Results and Discussion

Fig. (1) explains the transmission spectrum of the samples as a function of the incident wavelength. It is shown that the transmission of these films increases rapidly within the range 400-600nm reaching the maximum value. After this maximum, the transmission approximately remains constant at near-infrared wavelengths. This makes ZnTe good candidate to be used as an antireflection coating within this spectral region[14].

Figure (2) shows the relation of absorption coefficient (a) of ZnTe thin films versus the photon energy (h□) of the incident light. As shown, the value of absorption coefficient increases slowly at the long wavelength region (long wavelengths) whereas it increases fast at short wavelength region (short wavelengths). This behaviour supports the assumption of using these thin films as antireflection coatings in the first region while they are used for fabrication of photodetctors, solar cells, semiconductor lasers and light-emitting diodes in the second region[15].

In order to determine the value and type of energy gap as well as the dominant absorption processes in such material, the relation of (□h□)^2 with the incident photon energy (h□) is explained in Fig. (3). The obtained value of energy gap is about 2.26eV and it is very close to the value obtained by previous works (2.24eV) [2-6]. The relation was linear, which indicates that the ZnTe of this work has direct energy gap and the direct allowed absorption processes are the dominant and the absorption coefficient of such processes is given by:

$$\alpha_d = A\{h\nu - E_g\}^{1/2} \qquad (1)$$

The value of constant A is about 6.77×10^4 $cm^{-1}.(eV)^{-1/2}$ at the cutoff wavelength (530nm).

The relation of extinction coefficient (k_{ex}) with the incident photon energy was determined as shown in Fig. (4). The behaviour of the k_{ex} coefficient is similar to that of the absorption coefficient as they are proportional to each other. Hence, the extinction coefficient increases in some rapid scale with the increasing energy of the incident photon over the energy gap point.

Te refractive index of the prepared thin films can be determined depending on the obtained transmittance as a function to the incident wavelength as [10-11]:

$$n = \sqrt{Y + (Y^2 + n_S^2)^{1/2}} \qquad (2a)$$

$$Y = 2n_S\left(\frac{T(\lambda) - T_{\min}}{T(\lambda)\times T_{\min}}\right) + \frac{n_S^2 + 1}{2} \qquad (2b)$$

where n_S is the refractive index of the substrate (glass), T(□) the wavelength-dependent transmittance of the thin film and T_{min} is the minimum obtained transmittance at the minimum wavelength of work (400nm). Figure (5) explains the variation of refractive index with the incident photon energy. It is shown that the value of refractive index remains approximately constant at the near-infrared (NIR) wavelengths and this behaviour represents an optical stability within this spectral region[16]. Whereas the rapid increasing of refractive index within the visible region is important when ZnTe is employed to fabricate the optical waveguides and the elementary structures of the photonic devices since this material can be used to form the layers required for the optical confinement of charge carriers in such devices[16].

In order to introduce the optical dispersion property of the deposited thin films, we can use the following relation [12-13]:

$$n^2(h\nu) = 1 + \frac{E_d E_0}{E_0^2 - (h\nu)^2} \quad (3)$$

where E_d is the optical dispersion energy inside the bulk, E_0 is the oscillation energy between valence and conduction bands of the semiconductor. It is supposed that the oscillation energy is twice the energy gap ($E_0 \sim 2E_g$). the value of the optical dispersion energy (E_d) is given empirically y [12-13]:

$$E_d = \beta N_C Z_a N_e \quad (eV) \quad (4)$$

where β is a constant depends on the state of material (ionic or covalence), N_C the coordination of the cation with respect to the anion inside the compound material, Z_a is the chemical parity of the positive part of the compound (Zn) and N_e is the electronic concentration in the valence band.

Regarding to the obtained results and the relation shown in Fig. (6), the value of the optical dispersion energy (E_d) can be determined as a function of the incident wavelength as:

$$E_d = (n^2 - 1)\{E_0 - \frac{(h\nu)^2}{E_0}\} \quad (5)$$

As can be seen from Fig. (7), the optical dispersion energy of the material varies more within the visible region of the spectrum while it tends to vary slightly within the longer wavelengths region. This explain that the interaction between high frequency electromagnetic radiation and the matter, and hence the optical dispersion inside the ZnTe bulk, is more probable than that of the lower frequencies (i.e., NIR wavelengths). This may interpret the higher transmission of the latter.

The complex refractive index is one of the most important optical constants of the materials used in the fabrication of the quantum photonic devices and especially semiconductor lasers. So, the relation of the complex refractive index of ZnTe with the incident photon energy was determined as shown in Fig. (8). The observed uniformity in the behavior of the complex refractive index is an indication to the high uniformity of the optical properties of this material as a function of the incident photon energy.

Conclusion

it can be concluded that the ZnTe material deposited as thin films on glass slides using the vacuum evaporation technique has energy gap of (2.26eV) and the direct fundamental absorption processes are the dominant within the spectral range (400-900)nm. Results explained that both the real and complex refractive indices vary fast with photon wavelength within the range (400-600)nm until they reach an approximately constant value at NIR wavelengths. The constant value of the allowed absorption processes was determined to be (6.77×10^4 $cm^{-1}(eV)^{-1/2}$). Also, the optical dispersion energy was determined as a function of the incident photon energy. The behavior of the optical constants of ZnTe with photon energy reflects the high optical quality of such material leading to increase the interest to use such material in design and fabrication of the quantum photonic devices and optical waveguides in the spectral range (400-600)nm as well as use it as an antireflection coating in the NIR spectral region.

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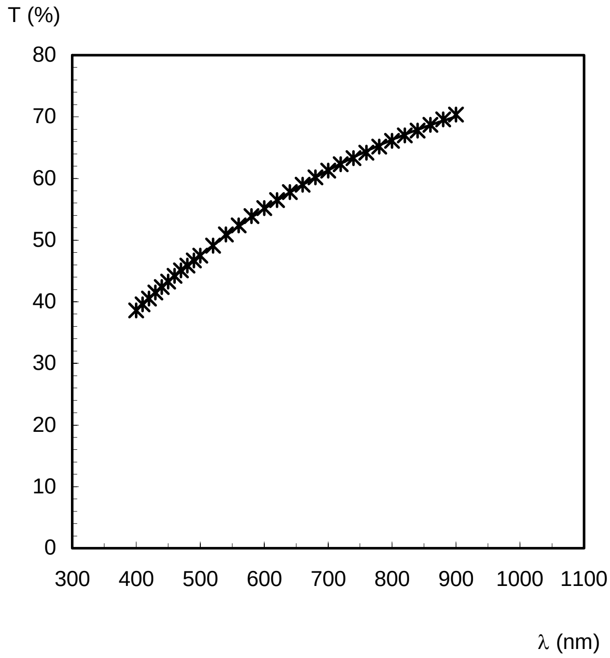

Fig. (1) The transmission spectrum of the thin films prepared in this work

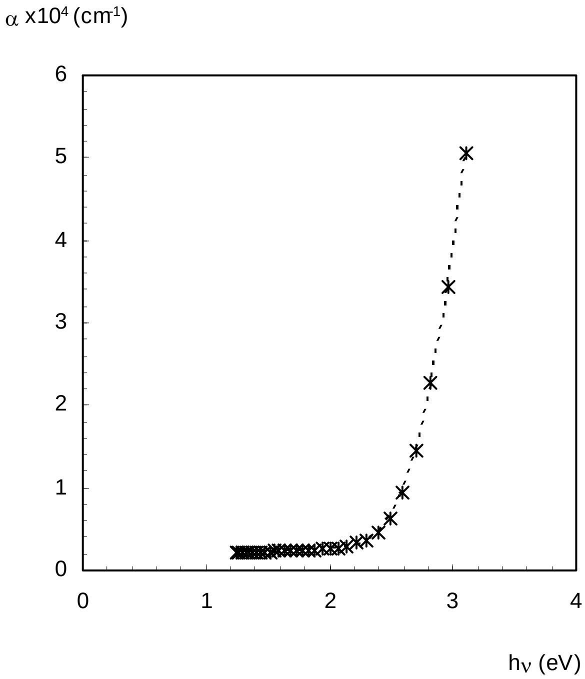

Fig. (2) Variation of the ZnTe absorption coefficient with the incident photon energy

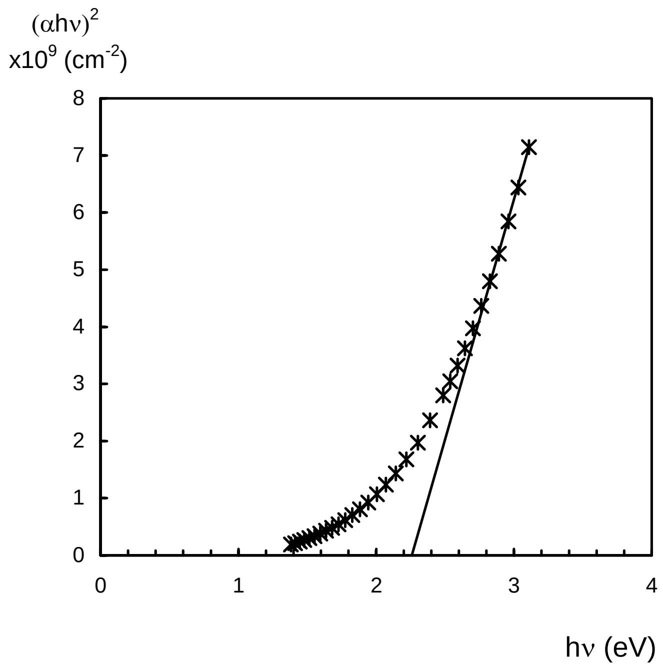

Fig. (3) variation of the parameter $(\alpha h\nu)^2$ with the incident photon energy

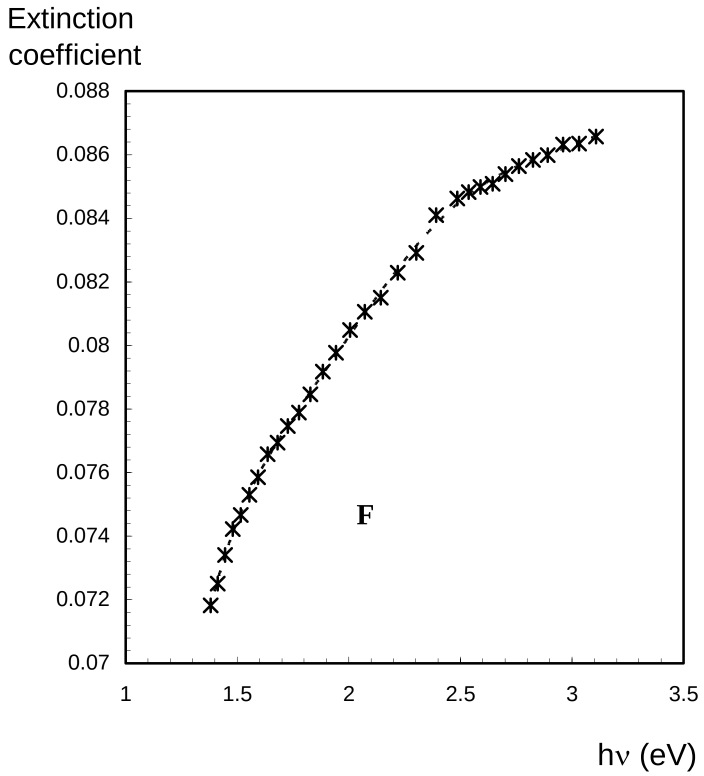

Fig. (4) Variation of the extinction coefficient (kex) with the incident photon energy

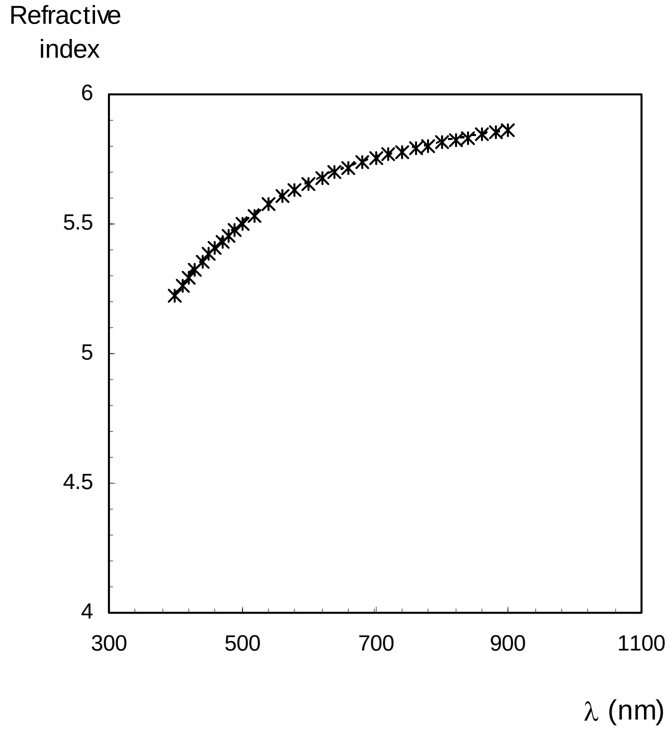

Fig. (5) Variation of real refractive index with the incident photon wavelength

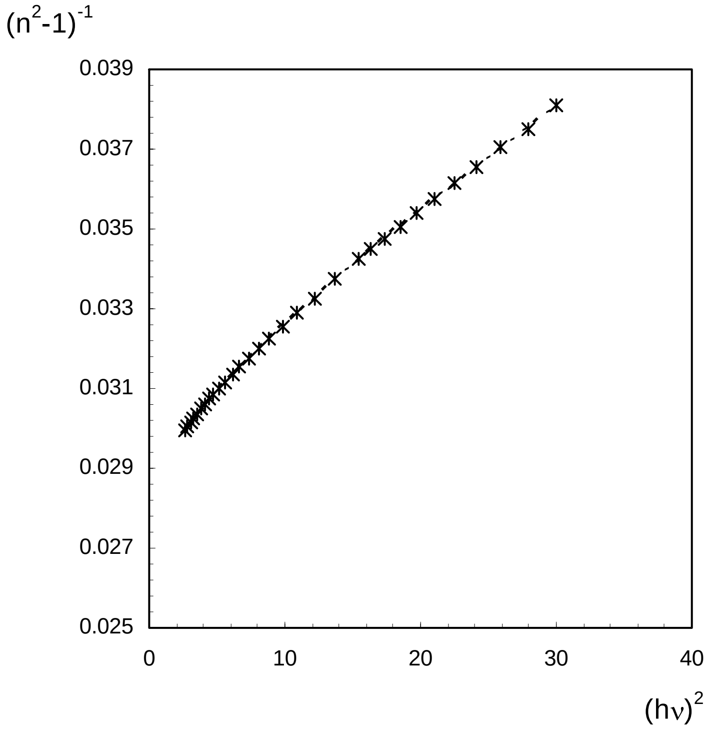

Fig. (6) Variation of the (n2-1)-1 parameter with the incident photon energy

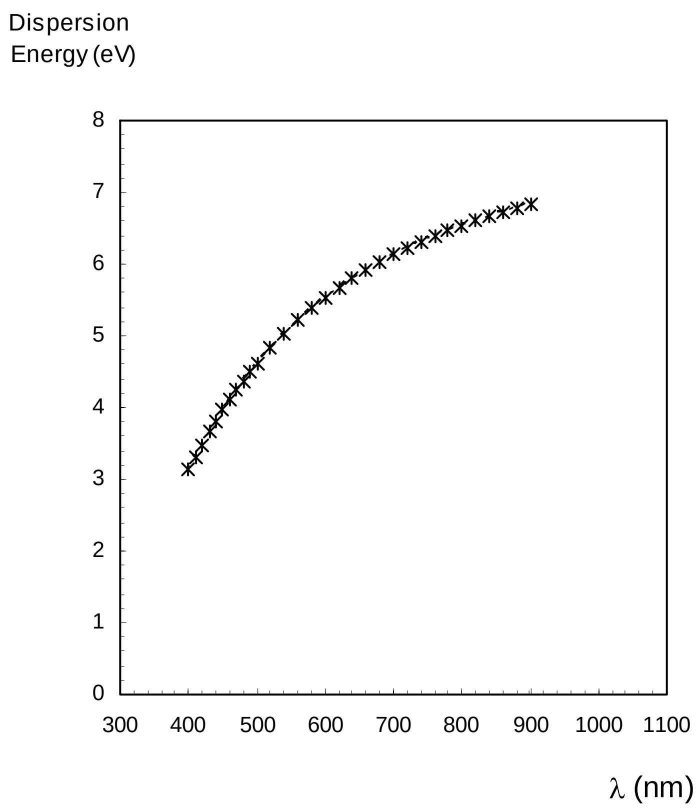

Fig. (7) Variation of the optical dispersion energy with the incident photon wavelength

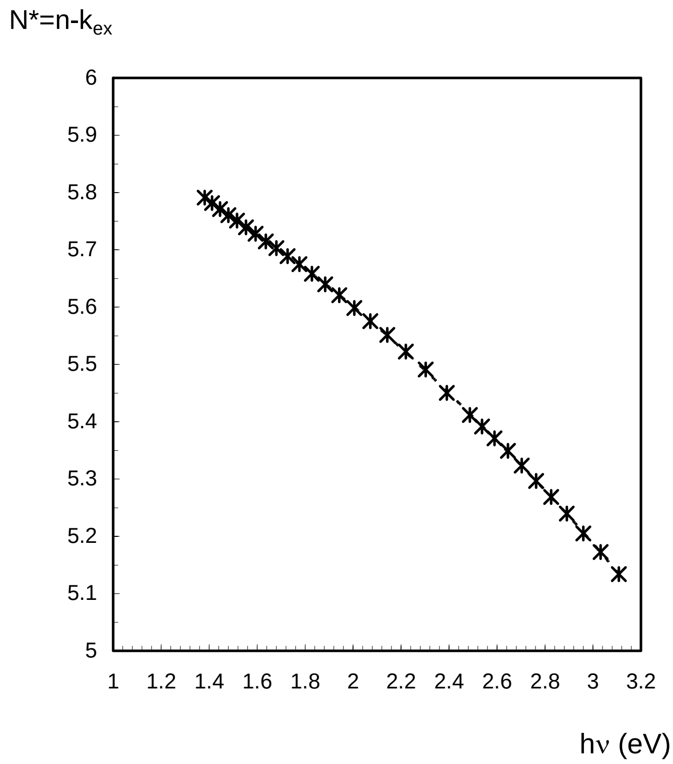

Fig. (8) Variation of the complex refractive index with the incident photon energy