Nanostructures based on CdTe thin films

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The work presents the first results obtained from investigations of the structure CdTe/glass-ceramics grown by the vacuum deposition of cadmium telluride thin films on dielectric substrates at different temperatures (T_s). Structural examinations show a polycrystalline structure of (111) orientation and an inhomogeneous surface relief of the as-grown films. The morphological peculiarities of crystal growth in the films and their phase composition are discussed. The optical properties of the samples were studied by optical transmission spectra, measured within the wavelength range 460 - 1500 nm. The manner in which atmospheric oxygen affects the major electrical characteristics is examined.

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1. Introduction

CdTe is one of the most popular materials for modern optoelectronics. There are hundreds of publications concerning the problems of the compound technologies and applications. Nevertheless, some properties of CdTe thin films prepared by vacuum technology, in particular the optical characteristics, are of special interest.

Here, one must note that none of the optoelectronic active elements operates out of its environment, i.e. we have to consider the unavoidable effect of atmospheric oxygen on all investigated characteristics. Inorganic solids with wide band gaps are usually used in industry as optical materials. Many metallic oxides have wide band gaps, because of the significant contribution of the ionic character of the chemical bonds between metallic cations and oxide ions [1-2]. However, their application for the design of different active elements for optoelectronics requires more detail information concerning the formation and properties of the corresponding compound.

This work presents the structural, optical and electrical properties of CdTe thin films, accounting for the influence of the environment.

2. Experimental

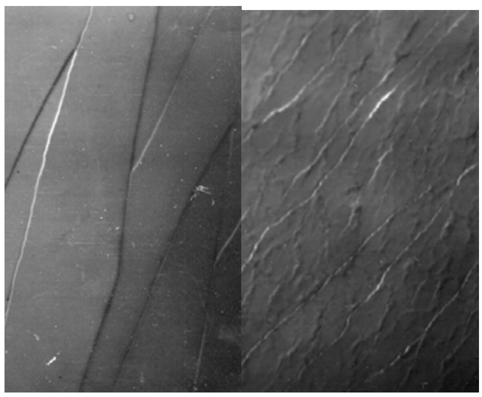
Cadmium telluride thin films grown on glass-ceramic substrates by resistive evaporation from a quasi-closed volume were examined at room temperature. Two sets of samples were chosen. The first consisted of films grown at T_s = 700 K (set No.1); films obtained at T_s = 473 K were denoted as set No.2. The thicknesses and areas of the samples were estimated to be 1 - 2 μm and 8 - 10 mm^2, respectively.

Transmission electron microscopy (TEM), electron diffraction methods and scanning electron microscopy (SEM) were applied for the structural examination of the CdTe thin films. The method of extraction replicas for TEM sample preparation was used.

Optical transmission spectra were recorded as a function of the wavelength of the incident light, in the range λ = 460-1500 nm.

3. Results and discussion

Fig. 1 shows micrographs of the CdTe films surface morphology, as observed by SEM. The relief of both films is likely to be a quasi-3D pattern at a depth of about 50-162 nm from the film surface; the surface of the film (set No. 2) has a hillock-like character.



(a)——— 1 μm (b)

Fig. 1. SEM micrographs of the CdTe thin film structures prepared on glass-ceramics substrates at: (a) set No.1, T_s=700 K;(b) set No.2,T_s=473 K.

Fig. 2 presents a TEM micrograph and a microdiffraction image of the CdTe particles. The orientation of the coupling surface of the particles is (111). The microdiffraction studies enabled us to identify the phases present at the film – substrate interface. Cd and CdO phases, as well as a $Cd(OH)_2$ component were observed (Fig. 3).

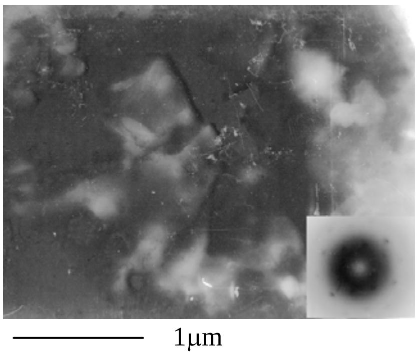
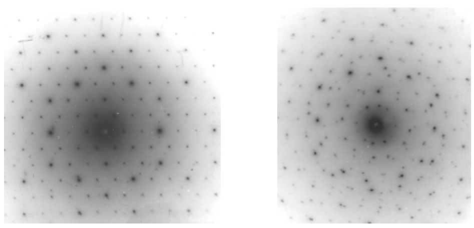


Fig. 2. Typical TEM image of the free surface of a CdTe film (set No.1, T_s=700 K) and a microdiffraction pattern from the extracted CdTe particles with (111) orientation.

The following interesting features of the samples were noted: (i) the film structure revealed a (111) orientation. (ii) the surface structure of the films from set No.1 demonstrated a hillock-like structure, similar to that of nanoclusters (see Fig. 4), (iii) the films grown on the glass-ceramic substrate at T_s=473 K (set No.2.) had more perfect crystal structures.



(a) (b)

Fig. 3. Typical microdiffraction patterns of different monocrystalline particles extracted from a back CdTe film surface with: (a) (111) orientation; (b) (100) orientation.

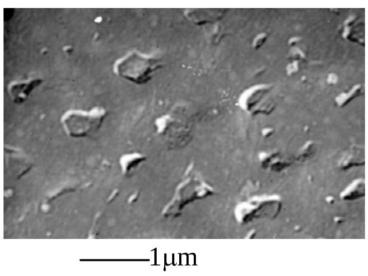


Fig. 4. TEM image of the surface structure of a CdTe film (set No.1, T_s=700 K).

Transmittance measurements and electrical studies were performed at room temperature on the best samples from both sets. The results are plotted in Figs. 5- 8.

As shown, the spectra are of a Gaussian type. The maxima of the curves are at 900 nm and 1000 nm, i.e. 1.24 eV and 1.38 eV, respectively. It is obvious that neither of these corresponds to the band gap of CdTe (1.44eV).

The effect of native oxide on the electrical properties of the investigated structures is also important. To clarify it, current-voltage measurements were performed using the bridge method [3-4].

The current-voltage characteristics were shown to exhibit non-linear dependencies, typical of structures in which space-charge limited (SCL) current dominates [5].

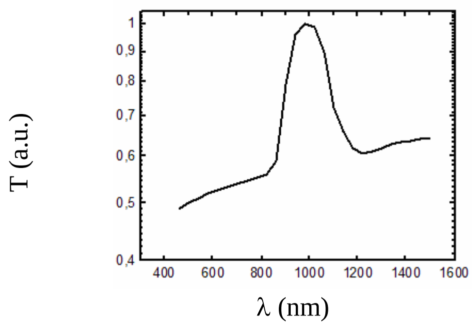


Fig. 5. Transmission spectrum of a CdTe film (set No.1, T_s=700 K) at T = 300 K.

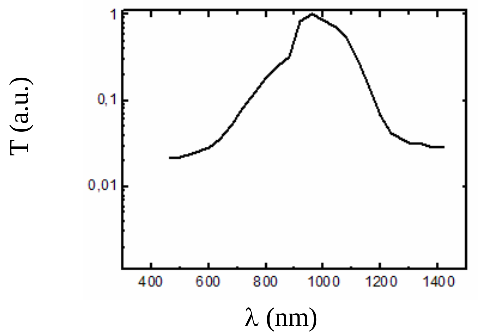


Fig. 6. Transmission spectrum of a CdTe film (set No.2, T_s=473 K) at T = 300 K.

A typical logarithmic current-voltage plot of the space-charge limited current is shown in Fig. 7.

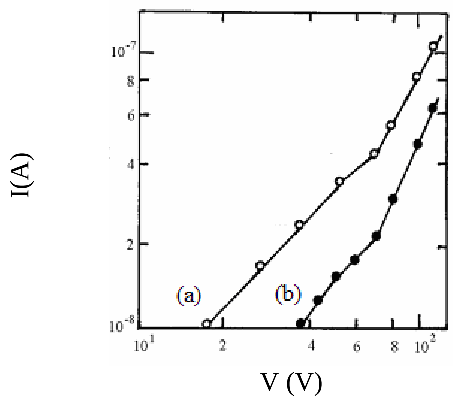


Fig 7. Logarithmic I-V plot of the experimental current-voltage characteristics observed for a CdTe sample No.1. (a) forward branch; (b) reverse branch. T = 290 K.

In forward bias, the experimental current-voltage dependencies show a space-charge limited current in the velocity saturation regime.

According to [3] and references therein, the experimental dependence can be described by expression:

$$I = 2k\varepsilon_0 \varepsilon v_{sat} A \frac{V}{L^2}, \qquad (1)$$

where ε_0 is the permittivity in vacuum, ε is the semiconductor permittivity, v_{sat} is the saturation velocity, L is the film thickness and A is the sample area. However, at higher voltages a corresponding section of the experimental I-V characteristic is expressed by

$$I = 9k\varepsilon_0 \varepsilon A \mu \frac{V^2}{8L^3}, \qquad (2)$$

where μ is the mobility of the majority charge carriers [2]. The reverse current-voltage characteristic can be described as follows [3]:

$$I = 4k\varepsilon_0 \varepsilon \frac{A}{9L^2}\left(\frac{2e}{m*}\right)^{1/2} V^{3/2} \qquad (3)$$

where *e* is the electronic charge and *m** is the effective mass of the carriers. The upper section of the reverse current-voltage dependence indicates a dominant process of charge carrier tunneling through the potential barrier formed by the heterostructure CdTe/CdO valence band discontinuity [3].

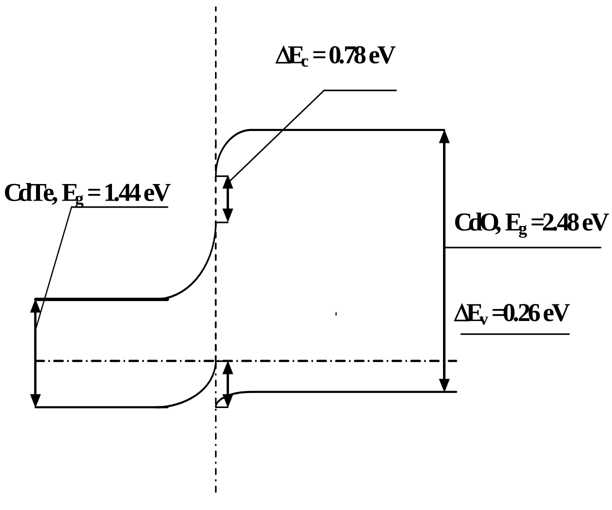


Fig. 8. One-dimensional energy-band diagram of the heterostructure CdTe/CdO formed on a cadmium telluride thin film. The valence band discontinuity ΔE_v and conduction band discontinuity ΔE_c form potential barriers for carriers tunneling in both the reverse and forward directions.

Fig. 8 shows the energy-band diagram of the CdTe/CdO heterostructure. As TEM/SEM examinations have shown, the film surface has inhomogeneous micro- and nano-defect clusters which, under the applied bias, become electrically charged and form a surface charge region. As is known [3,5], the presence of such a region in a semiconductor is reflected by the corresponding energy spectrum, in particular, the energy bands exhibit bending. This phenomenon is especially typical of different heterostructures (irrespectively of the method of preparation). The complex relief of the energy bands changes drastically the charge carrier trajectories and forms the so-called “percolation level” representing the lowest value of the energy for which the carrier trajectory is not interrupted.

In other words, there is a semiconductor potential E_i which the charge carriers must overcome in order to reach the conduction band or the valence band [2, 3].

The obtained parameters appear useful for estimating the coefficient *k* in the general expression $I = kV^m$ $(m>1)$, describing the experimental current-voltage characteristics (see Fig. 7 and equations (1)-(3)). More detailed analysis has shown that the coefficient *k* appears as a coefficient of the tunneling transparency characterizing the potential barriers at the formed heterointerfaces. Assuming the total potential barrier to be a triangle one, we have estimated its value according to the theory developed in [6]:

$$k = k_0 \exp\left\{-\left[\frac{4d(2m*)^{1/2}}{3\hbar} + \frac{E_i(r) - E_i(f)}{k_B T}\right]\right\}, \qquad (4)$$

where k_0 is ~ 1, *d* is the barrier width, *m** is the charge carrier effective mass (in our case $0.11m_0$), k_B is the Boltzmann constant and $T = 290$ K is the temperature of the experiment.

Comparison of the theoretical data and the values obtained experimentally ($9.2\text{x}10^{-10}$ and $7.8\text{x}10^{-10}$, respectively) confirmed our conclusion that electrons are the majority charge carriers in the investigated samples.

4. Conclusions

Atmospheric oxygen absorbed on the inhomogeneous relief of CdTe films noticeably affects the transmission spectra observed experimentally. Optical studies carried out at room temperature demonstrated that the spectral distribution of the transparency coefficient is significantly dependent on the substrate temperature: the samples grown at T_s = 700 K revealed a Gaussian spectrum in the wavelength region 460-1380 nm, whereas the samples grown at T_s = 473 K showed a wide spectrum at 460-1500 nm. Transmission maxima were observed in the interval of about 1.26-1.29 eV. Room-temperature current-voltage characteristics showed a space-charge-limited current in the range of applied voltage 0-100 V.

Acknowledgments

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References

[1] H. Kawazoe, H. Yanagi, K. Ueda, H. Hosono, MRS Bulletin **N5,** 28 (2000).
[2] T. J. Coutts, D. L.Yung, X. Li, MRS Bulletin **N8,** 58 (2000).
[3] V. Bilozertseva, V. Bazakutsa, G. Khlyap, M. Andrukhiv, Proc. 5th Intern. Conf. Molecular Interaction in Matter, Lublin, ed. K. Sangwal, Lublin Polytechnic University, Poland 1999, p. 53.
[4] G. Khlyap, V. Bilozertseva, N. Diakonenko, S. Ovcharenko, Thin Solid Films **453-454**, 145 (2004).
[5] Y. Gu, L.J. Lauhon, Appl. Phys. Lett. **89**, 14102 (2006).
[6] A. Gubanov, Semiconductors (Russia) **17**, 1679 (1983).

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