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ON THE PHOTOMAGNETIC EFFECT IN CdTe THIN FILMS EVAPORATED ONTO UNHEATED SUBSTRATES

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Cadmium telluride (CdTe) thin films (*d*=500–700 nm) were deposited onto unheated glass substrates by thermal evaporation under vacuum. The dependence of the photomagnetic voltage on the magnetic induction for the as deposited and heat-treated films was investigated. The spectral dependence of the photomagnetic voltage was also investigated. The results are discussed in relation with structural characteristics of the studied films.

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1. Introduction

Cadmium telluride (CdTe) thin films have attracted the interest of many researchers due to its important applications in technology of thin films devices such as photovoltaic cells, photodetectors, field effect transistors, etc [1–3]. In the search of the method for preparation of these films which to assure a lower cost for respective devices, the interest in the physical properties of CdTe films deposited at lower temperature has increased in last years [4–6].

In a series of our previous papers [7–11] we have been studied the influence of various factors such as deposition parameters (substrate temperature, source temperature, deposition rate) and heat treatment on the structural, electrical and optical characteristics of CdTe films prepared by thermal evaporation under vacuum. The obtained results revealed that the CdTe films deposited onto unheated substrates at greater source temperature have a nanocrystalline structure and are characterized by a higher electrical conductivity ($\approx 10^{-4}\Omega^{-1}m^{-1}$) and a higher absorption coefficient ($\approx 10^5$ cm^{-1}), compared with CdTe thin films deposited onto heated substrates.

In present paper, we extended our investigations on the photomagnetic effect in CdTe films. The dependence of the photomagnetic voltage both on the magnetic induction and wavelength of the exciting light for as-deposited and heat treated films were investigated. Such studies are still necessary because the experimental results concerning the photomagnetic effect in such CdTe films there are still insufficient.

2. Experimental

CdTe thin films were deposited by thermal evaporation under vacuum onto glass substrates at room temperature. A special Pyrex cylindrical chamber of height of 10 cm and having at top extremity a radius of 2 cm limits the deposition space and confines the vapour steam in the vicinity of the film substrate. The source-substrate distance was about 7 cm and the temperature of the evaporation source, T_{ev}, was 1270 K. The experimental arrangement used for film deposition is described in detail elsewhere [10,11].

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After the preparation, some samples were heat-treated before photomagnetic measurement by annealing in air for 30 min at 550 K.

The geometry used for the study of the photomagnetic effect is schematically presented in Fig. 1. The diffusion currents are oriented in the x direction, the magnetic induction, ***B***, is along z axis and the Lorentz forces are oriented in the y direction. Samples with planar geometry have been used.

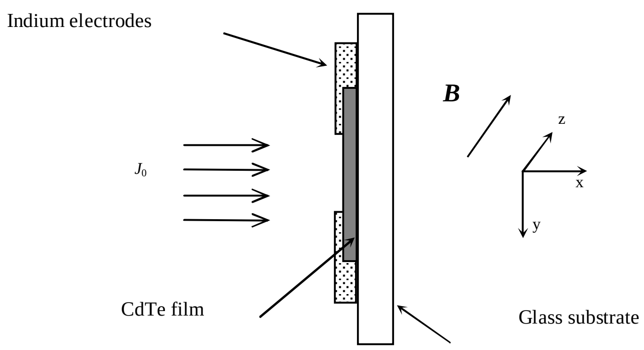

Fig. 1. Experimental arrangement used for the study of the photomagnetic effect.

The films were illuminated with white light of a constant intensity (J_o=1000 lx). The static magnetic field was produced by an electromagnet and was measured by a teslameter with Hall probe. The photomagnetic voltage was measured using a Keithley 6517A electrometer. For the electrical measurements, vacuum deposited thin indium films were used as contact electrodes. The distance between electrodes was 2 mm and the width of the film was 1 cm. The experimental procedure used for the study of the photomagnetic effect is described in detail elsewhere [10].

The film thickness, d, measured by an interferometric method, ranged between 500 nm and 700 nm.

The crystalline structure of the films was investigated by standard X-ray diffraction (XRD) technique using Co K_α radiation.

3. Results and discussion

At low injection (illumination) level ($\Delta n \ll n_0$ and $\Delta p \ll p_0$, where n_0 and p_0 are the equilibrium carrier concentrations), and $L_B \ll d$ (L_B is ambipolar diffusion length), the open-circuit photomagnetic voltage, V_{PM}, is given by [3, 12–14]:

$$V_{PM} = \frac{a}{d}\frac{e\left(\mu_{e,H} + \mu_{h,H}\right)\ \eta J_0 L_B}{\sigma_0} B \quad , \qquad (1)$$

where a is the distance between the electrodes, e – the electron charge, B – the magnetic induction, $\mu_{e,H}$ and $\mu_{h,H}$ are the Hall mobilities for electrons and holes respectively, σ_0 is the dark electrical conductivity of the sample, η is the quantum efficiency and J_0 is the intensity of incident radiation at surface of the sample.

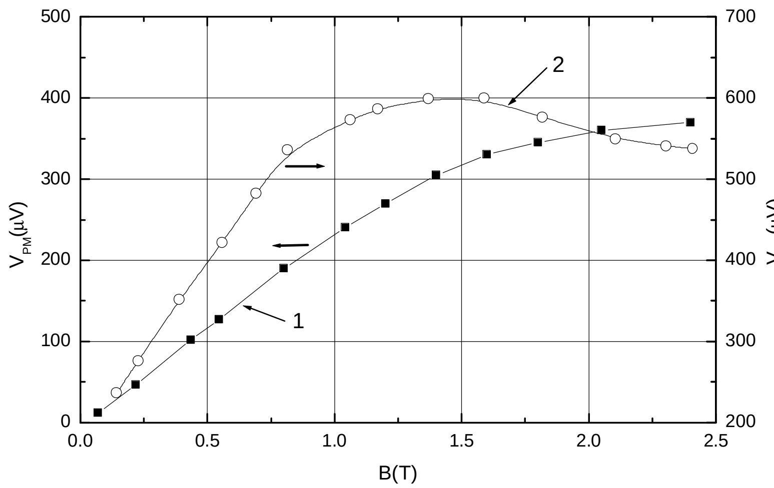

Fig. 2. Typical dependence of the open-circuit photomagnetic voltage on the magnetic induction for as-deposited films (curve 1) and for heat-treated films (curve 2).

In Fig. 2, the typical experimental dependences of the open-circuit photomagnetic voltage on the magnetic induction for the studied samples are shown. Curve (1) corresponds to as-deposited films and curve (2) is for the heat treated samples. It can be observe that for lower values of *B*, the experimental data are in good agreement with expression (1) (the V_{PM} = f(*B*) is linear) both for as-deposited and heat treated films. At higher values of *B*, the photomagnetic voltage tends to saturate for as-deposited films (curve 1) and decreases in the case of heat-treated films (curve 2).

Generally, the decrease of V_{PM} for greater value of *B* is determined by the carrier recombination on the trapping centers [12].

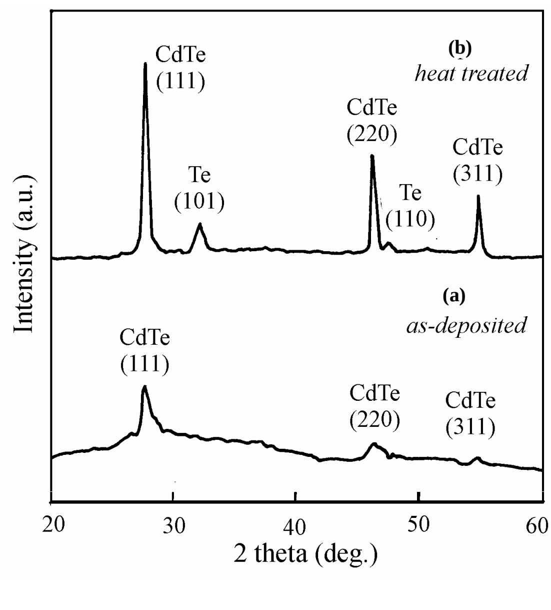

Fig. 3. Typical XRD patterns for as-deposited (a) and heat treated (b) films

Therefore, the decreasing of V_{PM} for greater values of magnetic induction observed for heat-treated samples may be due to this recombination process. Also, as it results from Fig. 2, the values of V_{PM} for such films are higher compared with those for unheated films. This may be correlated with structural characteristics of respective films and their electrical behavior. As it may be seen from Fig. 3, the XRD pattern for as-deposited sample exhibit the weak broad peaks which indicate the existence of fine grained CdTe crystallites in respective films. After post-deposition heat-treatment, the films present a polycrystalline structure (pattern (b)). An important structural characteristic of the studied films is the presence of an excess of tellurium atoms which aggregate in crystalline form as consequence of annealing process (pattern (b)).

These structural characteristics influence the electrical and optical properties of respective films.

In our previous papers [7, 8], we have been established that the CdTe films evaporated onto unheated substrates with greater source temperature (as the actual studied samples) have a higher electrical conductivity (about $10^{-4}\ \Omega^{-1}m^{-1}$) due to this excess of Te atoms. These act similarly to the acceptor impurities in p-type semiconductor, determining an increasing of the charge carriers density, hence an increasing of the electrical conductivity, σ_0. In the case of heat-treated films, due to the recrystallisation process, the amount of the free Te atoms not bonded in CdTe lattice decreases, so, the acceptor states induced by these atoms decrease too. Consequently, the electrical conductivity, σ_0, of respective films is lower compared with untreated samples. As results from equation (1), a decreasing of σ_0, determines an increasing of V_{PM}. This explains the higher value of V_{PM} in the case of heat-treated CdTe thin films.

For studied films the dependence of the open-circuit photomagnetic voltage on the wavelength of incident radiation was also investigated. In Fig 4 the typical spectral curves obtained both for as-deposited and heat-treated samples are presented.

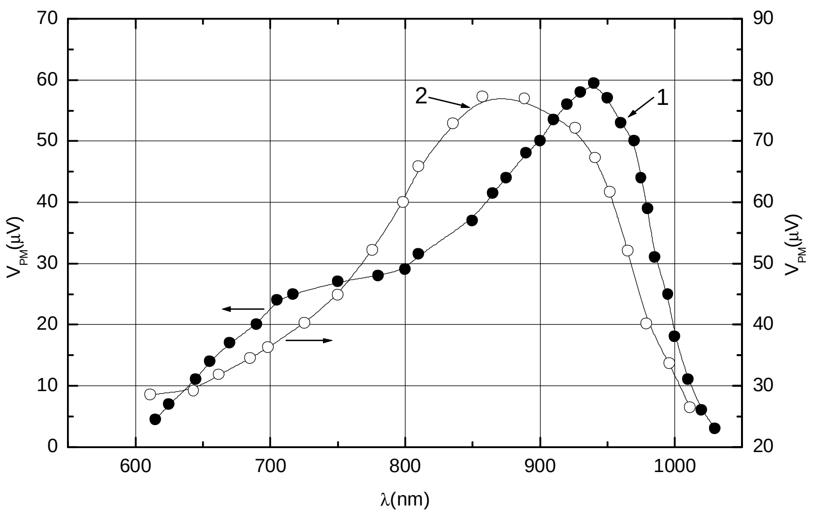

Fig. 4. Typical Dependence of the open-circuit photomagnetic voltage on the wavelength for as-deposited films (curve 1) and for heat-treated films (curve 2).

As it may be seen, the maximum of curves correspond to 941 nm (1.32 eV) for as-deposited films (curve 1) and to 872 nm (1.45 eV) for the heat-treated samples (curve 2). These values are in good agreement with those obtained for optical activation energy of CdTe films using the absorption spectra and spectral dependences of the photoconductivity [9, 10]. The value of 1.45 eV obtained for the heat-treated CdTe films is in good agreement with energy gap E_g established by other researchers for CdTe thin films [15, 16] and indicates the direct nature of fundamental band-to-band transitions. The lower value for optical activation energy (1.32 eV) obtained for the as-deposited samples may be related to the greater amount of the free tellurium atoms which appear in excess in respective films. These Te atoms introduce within the forbidden band of CdTe acceptor levels placed at about 1.3 eV below the conduction band [15, 17]. The absorption of the photons with such energies will determine the electron transitions from these levels to the conduction band and consequently an increasing of the nonechilibrum carrier concentration in the respective spectral range. Otherwise, the same value of 1.3 eV we have been obtained for the thermal activation energy for respective samples calculated from the temperature dependence of their electrical conductivity [8].

4. Conclusion

The photomagnetic effect in CdTe thin films deposited onto unheated substrates was studied. The influence of post-deposition heat-treatment on the open-circuit photomagnetic voltage, V_{PM}, and its spectral dependence was investigated.

It was established that the dependence of photomagnetic voltage on the magnetic induction for CdTe films are influenced by the structural characteristics of the films, especially by the presence of Te excess which influences electrical conductivity of the films. The as-deposited films are characterized by lower values of V_{PM} due to their greater electrical conductivity. The recrystallization of the films as consequence of the heat treatment determines an increasing of the photomagnetic voltage and a shift of the maximum of the spectral curve $V_{PM}=f(\lambda)$ to the lower wavelength. The values of 1.32 eV and 1.45 eV corresponding to maximum of spectral curves for as deposited and heat-treated films respectively are in good agreement with energy gap values established from electrical and optical measurement for respective films.

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