Short Communication

Thermal Annealing Effect on Optical Properties of the Cadmiun Telluride Films

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The thermal treatment effect on optical properties of cadmium telluride thin films was studied. By comparison of the optical transmission spectra and reflection of original and annealed films the formation of modified surfaces was detected. The possibility to get the intense photoluminescence, forming by the band-to-band recombination and transitions as a result of energy dimensional quantization of charge carriers was identified.

Keywords: Thin films, Cadmium telluride, Optical transmission, λ-modulated spectra, Luminescence.

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1. INTRODUCTION

Cadmium telluride remains one of the most perspective semiconductors for creation of solar cells [1]. In comparison with other currently applied materials, CdTe has a set of advantages. In particular, they have much higher radiation and temperature resistance as compared to Si. The technology of Cd Te crystal growing is also much simpler and does not require significant financing. The thin-film technology may be used for production of photoconverters based on cadmium telluride , thus, considerably reducing consumption of materials and cost of equipment respectively. The applied technological principles of rectifying structures with improvement of material properties and parameters made it possible to produce diodes with efficiency of minimum 13% at 300 K in conditions of solar illumination AM-2 [2]. At the same time, parameters of the synthesized thin films do not always comply with essential requirements; therefore, additional technological operations shall be performed for their correction. As a result, the study of the thermal annealing effect on optical properties of CdTe films, in particular, is relevant.

2. SAMPLES AND INVESTIGATION TECHNIQUES

CdTe films were produced on mica washers using a hot-wall epitaxy method [3]. The preliminarily synthesized CdTe compound sample was used. Its evaporation temperature reached $T_e = (400 \div 500)$ C, the chamber wall was heated up to 50 C higher. The washers, where film deposited, were at $T_w = 200$ C. The cadmium telluride film thickness was specified by deposition time t = (60-300) sec. and regulated using the optical method (by interference pattern of optical transmission spectra). The control of analyzed CdTe film properties was performed on the universal optical bench allowing to measure optical transmission T_ω, reflection R_ω and luminescence N_ω. These investigations were performed according to the known classical procedure [4] and using a highly sensitive λ-modulation method [5]. The selection of optical methods is justified by the possibility of non-destructive check of characteristics and parameters. The obtained spectral dependencies were corrected by means of the apparatus function of the spectral bench with consideration of special properties and characteristics of MDR-23 monochromator, FEP-79 photodetector, LGN-21 N_2laser and ELC/C xenon lamp.

3. RESULTS AND DISCUSSIONS

The selected method of CdTe film production is one of the most perspective processes among vapor-phase vacuum deposition technologies in quasi-closed volume. The analysis of its special features showed that selection of the evaporator, wall and washer temperatures ensure the constant temperature gradient. That is why the films are grown in the conditions approximated to equilibrium ones to a maximum extent. Under such circumstances the surface morphology is determined by crystallization conditions, when the size and distribution of grains are uniform, Fig. 1.

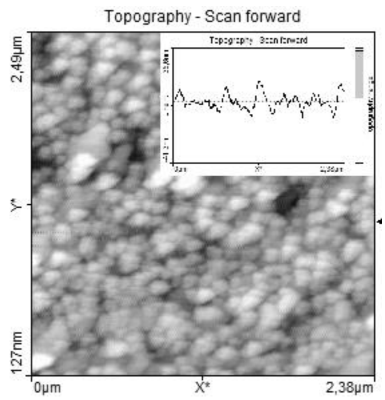

Fig. 1 – AFM-hologram of CdTe thin film surface. $T = 300$ K

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As it is known [2], for obtaining of surface-barrier photocells with efficiency of 13-15 %, it is important to organize the process of film annealing in the air within temperature range of 700-1000 K. Under such conditions the modified surface with corresponding geometric parameters. Thermal annealing of analyzed CdTe films was performed. As a result, their properties considerably changed.

During analysis of optical transmission spectra using λ-modulation method, changes of the maximum positions, Fig. 2. They characterize optical processes on the long-wavelength absorption edge.

On original films (curve 1) the maximum is observed at $\hbar\omega_m = 1.5$ eV, matching with the energy-gap width of CdTe – $E_g = 1.5$ eV (see, for example, [1]). At this, position of maximums T'_ω of films after annealing is characterized by displacement up to ~ 1.3 eV (curve 2). During this analysis of optical reflection of CdTe annealed films, change of the energy-gap width was not detected. On representative differential curves the special characteristic is observed at $\hbar\omega \sim 1.5$ eV, curve 3, Fig. 2. It corresponds to cadmium telluride value $E_g = 1.5$ eV. It allows explaining the observable shift by formation of the modified surface. As a result of dissipation on its roughnesses, dissipation of optical radiation during transmission analysis T'_ω.

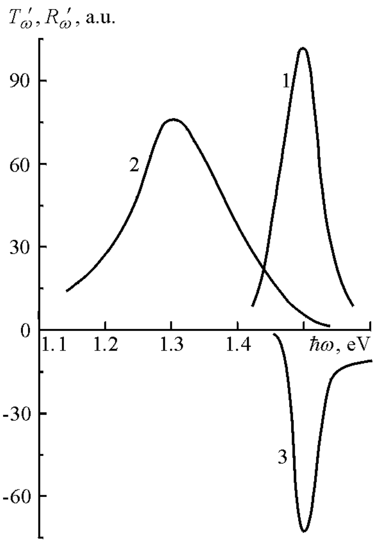

Fig. 2 – λ-modulated optical transmission T'_ω (1, 2) and reflection R'_ω (3) original (1) and annealed (2, 3) CdTe films. $T = 300$ K

The important result of thermal annealing of CdTe films is represented by sufficiently intense photoluminescence not observed on original samples. Its spectrum is defined by two bands, conditionally designated as A and B, Fig. 3. The luminescence character is consistent with radiation of wide-band II-VI compounds with modified surface [6, 7]. Analysis of microrelief of CdTe, CdSe, CdS, ZnSe substances using atomic-force microscopy revealed the presence of quantum-dimensional structure consisting of two different, by lateral sizes, groups of grains. In our case the maximum of band A falls on photon energy region $\hbar\omega \sim 1.5$ eV. In such conditions the radiation character can be explained by the band-to-band recombination. They are inherent to crystals and, respectively, are detected on large grains. In this case they determine optical radiation dissipation, T'_ω observed during transmission analysis, Fig. 2. The appearance of intense luminescence after thermal treatment indicates the significance of radiationless processes with involvement of surface defects. For this reason such result is important for obtaining detectors of different kind, as surface current losses and noise levels will reduce in them and photosensitivity will increase considerably (by ~ 2 orders) [2, 7].

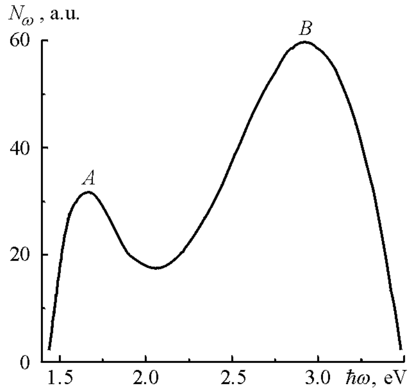

Fig. 3 – Photoluminescence spectra of films of cadmium telluride, annealed in the air. $T = 300$ K.

High-energy band B is explained by peculiar radiation of the modified surface formed as a result of thermal treatment. A large half-width of band and stretched maximum are caused by dispersion of sizes and shape of small grains. The similar situation was observed in case of annealing under certain conditions of low-resistance washers of n-CdTe in the air [2, 7]. The performed thermal annealing of cadmium telluride thin films caused formation of grains with various pyramid shapes. Change of their sizes from the small ones on the top to the considerable ones in the base causes energy quantization of charge carriers on formed nanostructure [8]. It is confirmed by presence in the radiation spectrum of photons with the energy corresponding to grain sizes. The size reduction of nanostructures causes increase of photon energy. As a result, the formed structured surfaces not only improve photosensitivity of possible obtained photodetectors, but also expand spectral range of their photosensitivity. This is a subject for further study.

4. CONCLUSIONS

Cadmium telluride thin films can be obtained in quasi-closed volume using a "hot-wall epitaxy" method. Thermal annealing of films causes modification of the surface structure, affecting optical properties of films. Their transmission spectra, due to formation of micrograins are characterized by dissipation increase of optical radiation, thus, causing the maximum displacement into the long-wave region. The formation of intense photoluminescence is important for practical use of thermally annealed films. The radiation spectrum covers a wide spectral region, determined by the modified structure of surface and forms by the band-to-band recombination and transitions as a result of energy dimensional quantization of charge carriers.

Вплив термічного відпалу на оптичні властивості плівок телуриду кадмію

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Досліджено вплив температурної обробки на оптичні властивості тонких плівок телуриду кадмію. За співставленням спектрів оптичного пропускання та відбивання вихідних і відпалених плівок виявлено утворення модифікованої поверхні. Встановлено можливість отримання інтенсивної фотолюмінесценції, яка формується міжзонною рекомбінацією та переходами внаслідок розмірного квантування енергії носіїв заряду.

Ключові слова: Тонкі плівки, Телурид кадмію, Оптичне пропускання, λ-модульовані спектри, люмінесценція.

Влияние термического отжига на оптические свойства пленок теллурида кадмия

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Исследовано влияние температурной обработки на оптические свойства тонких пленок теллурида кадмия. Из сопоставления спектров оптического пропускания та отражения исходных та отожженных пленок выявили образование модифицированной поверхности. Установлена возможность получения интенсивной фотолюминесценции, которая формируется межзонной рекомбинацией и переходами вследствие размерного квантования энергии носителей заряда.

Ключевые слова: Тонкие пленки, Теллурид кадмия, Оптическое пропускание, λ-модулированные спектры, Люминесценция.

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