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PHOTOSENSITIVE EPITAXIAL HETEROJUNCTIONS CdTe/ $Cd_{1-x}Mn_xTe$

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Abstract: It has been studied the possibilities of creating photosensitive p-n heterojunctions based on the epitaxial films n-CdTe and p- $Cd_{1-x}Mn_xTe$ (x=0.4). Heterojunctions have been obtained by molecular beam condensation method in a single technological cycle without vacuum deterioration, applying additional compensating source of Te vapor in growth process. It has been established optimal conditions of obtaining structurally perfect epitaxial films and creating heterojunctions based on them, photosensitive at the range of wavelength λ=0,6-0,8 μm, which can be used as solar cells. It is shown that the influence of γ-irradiation at doses D_γ=30 krad increases of photoconductivity of $Cd_{1-x}Mn_xTe$ epitaxial films.

Keywords: Epitaxial film, chalcogenide, heterojunction, photosensitivity, VAC.

1. Introduction

One of the actual problems of modern science and technology is the formation of energy converters on the base of solar cells. For many years, in industry it was used solar cells formed on the basis of crystalline silicon (Si) and compounds of group A^2B^5 [1]. The promising ones among semiconductor compounds are also considered A^2B^6 groups [2]. Theoretical and experimental studies conducted in recent years and published in [3-10] show that, the compounds of A^2B^6 groups (CdTe) and solid solutions based on them ($Cd_{1-x}Mn_xTe$) are promising materials for creation of solar cells based on them.

It has been obtained and studied the structurally perfect films of the shown semiconductors grown on different substrates. Within formation of the shown solid solutions, cubic structure of crystal lattice of CdTe is saved, however lattice constant decreases from 6.48 A˚ for CdTe till 6.44 A˚ for $Cd_{0.6}Mn_{0.4}Te$. Solid solution with the given content enables varying band gap width [11, 12]. Mn atoms usually occupy crystall lattice point and form "ideal" semiconducting solution, that call forth the study of $Cd_{1-x}Mn_xTe$ for creating barrier structure [13, 14]. The band gap width of the shown compositions slowly increases from 1.5 eV for CdTe till 2.05 eV for $Cd_{0.6}Mn_{0.4}Te$. The values of band gap allows using the applicable solid solutions for preparing a structure based on them for solar energy.

The paper presents the results of study of possibility of creating p-n heterojunctions on the base of CdTe epitaxial films and solid solutions $Cd_{1-x}Mn_xTe$ (x=0.4), as well as influence of γ-quantum on photoelectric properties of the $Cd_{1-x}Mn_xTe$ thin films.

2. Experimental

CdTe and $Cd_{1-x}Mn_xTe$ (x=0.4) epitaxial films and heterojunctions based on them were obtained by molecular beam condensation at vacuum 10^{-4} Pa on freshly cleaved surfaces of monocrystals of muscovite mica and glass. Selection of mica monocrystals as substrate is dictated by their optical transparency in spectral range 280-2700 nm and chemical inertness. Glass substrates are low cost and promising for use.

As a source it has been used pre-synthesized CdTe compounds and solid solutions $Cd_{1-x}Mn_xTe$ (x=0.4) based on them, evaporable from graphite Knudsen cell. The evaporator temperature is set so that the evaporation process occurs quickly with minimum partial decomposition of vaporized material. It was also used additional source of Te vapors for compensation of volatile component (Te) as a result of partial decomposition of materials in the process of evaporation. Due to this, the obtained vapors have practically the same composition with the source material.

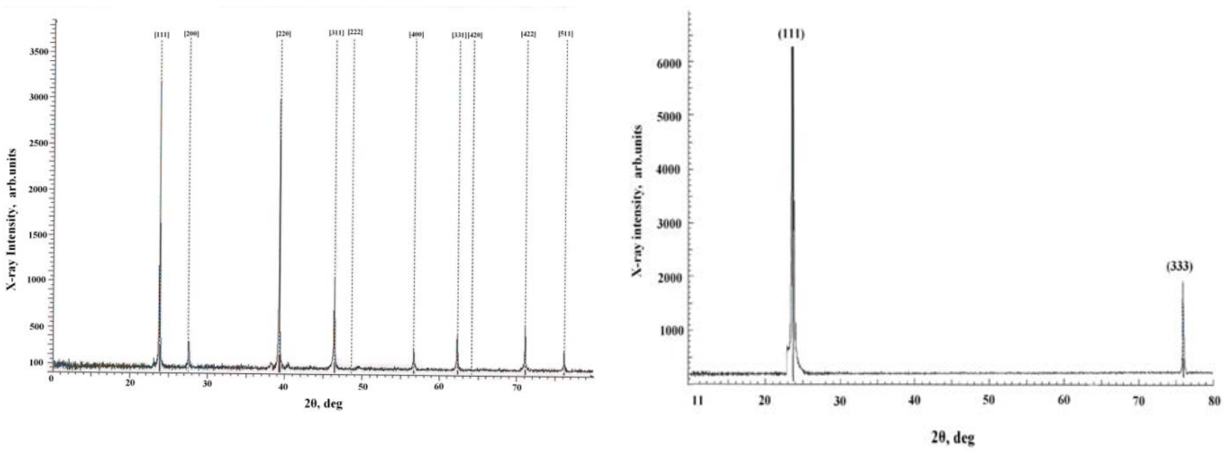
The distance between evaporator and substrate – 10 cm is selected so that the evaporator heated up to maximum temperature (1150 K) did not significantly affect the temperature of substrate, thickness of deposited layer was identical over the entira surface.

The temperature of evaporator substrate and additional source was controlled via Platinum thermocouple and regulated by device VRT-3 and RIF to within ±0.5 ˚C.

Chemical composition of synthesized materials used as a source of the obtained films was determined by X-ray phase analysis. Structural perfection of the films was adjusted by electron diffraction and X-ray diffraction analysis. Surface morphology was studied by electron microscopy analysis.

3. Results and discussion

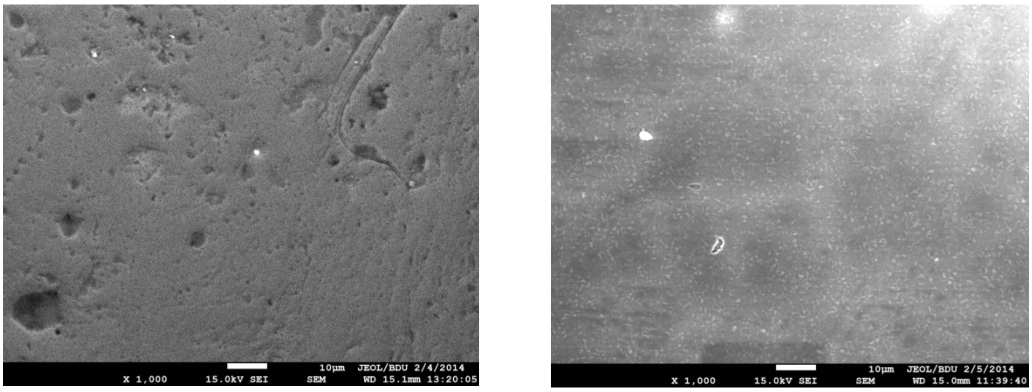
Heterojunctions (HJ) n-CdTe/p- $Cd_{1-x}Mn_xTe$ (x=0.4) were produced by depositing thin layers of p- $Cd_{1-x}Mn_xTe$ of the shown composition with thickness d=1.5-2.5 micron on n-CdTe with thickness d=0.5-1.2 microns. Firstly, n-CdTe layer was applied, then p- $Cd_{1-x}Mn_xTe$ without changing the vacuum in a single technological cycle. It was determined optimal conditions for obtaining (υ=14-16 A/sec, $T_{\text{п}}$=640-650C for n-CdTe and υ=18-20 A˚/sec, $T_{\text{п}}$=470-520C for p- $Cd_{1-x}Mn_xTe$) structurally perfect epitaxial films grown in the (111) plane of face-centered cubic lattice (Fig. 1). The study of crystal structure and determination of parameters of lattice was carried out in the X-ray diffractometer XRD Advance D8, Bruker, Germany.



a) b)

Fig.1. Diffractogram of CdTe films, obtained on glass substrates a) polycrystalline film (T_f=470C), b) epitaxial – monocrystalline film (T_f=670C).

Black cluster is observed in electron microscope images of these films, obtained on JEOL JSM-7600F Field Emission Scanning Electron Microscope (SEM), in accordance with previously conducted analogous investigation [8-10] (Fig.2 a). According to these literature data, these clusters are oxides, formed as a result of oxygen capture of extra atoms of the metal (Cd) in the growth process. Capture of oxygen occurs on the film surface of superfluous cadmium atoms, which diffuse from the volume through the interstices. Surpluses of cadmium atoms are formed as a result of partial decomposition of the investigated material in the deposition process due to volatilization chalcogen (in this case, Te). For removing the observed clusters, films were doped with additional compensating source of Te vapor in the growth process. The use of this source led to the improvement of the films structure, along with the disappearance of these clusters. Thus, the obtained films had a clean, smooth surface without inclusion of the second phase (Fig.2 b).

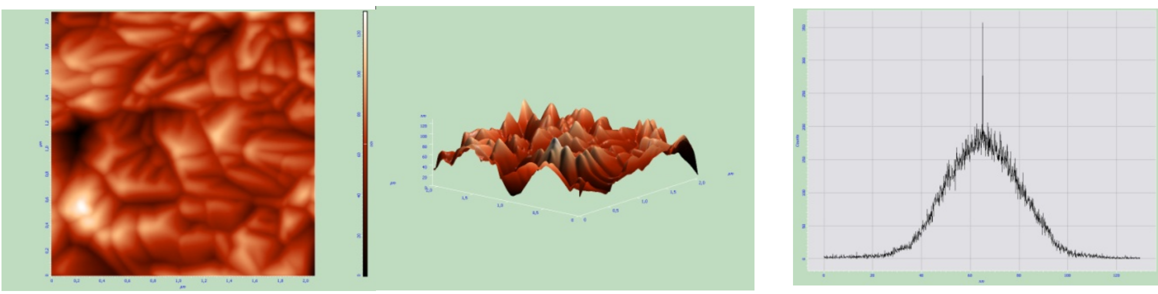


a) b)

Fig. 2. Electron Microscope images of the surface of CdTe a) before compensation and b) after compensation

The thickness and size of the particles of these films were investigated on atomic force microscope Intecra Prima AFM.

By applying AFM, it was obtained three-dimensional images of surface and curves of the distribution of elements in size – histogram, characterizing structure of surface of the investigated epitaxial CdTe films, obtained on glass substrates with and without compensation of Te in the growth process (Fig. 3). Calculations show that the size of the particles in CdTe film before the compensation of Te is 0.14–0.7µm, and the gaps between the particles comprise 0.6µm (Fig. 3). After compensation of Te (Fig. 3b) particle sizes comprise 0.5–1.0µm, and the gaps between the particles are 0.5µm. Thus, after the compensation the structure improves, the particle size increases, roughness reduces. From 3D- images and histograms, it was determined the distribution of particle height, the maximum value of which was ~ 100 nm and 90 nm for the films with and without compensation, respectively, which coincide with the results of X-ray diffractometer analysis as well as the number of particles, which were 178 and 210, respectively.



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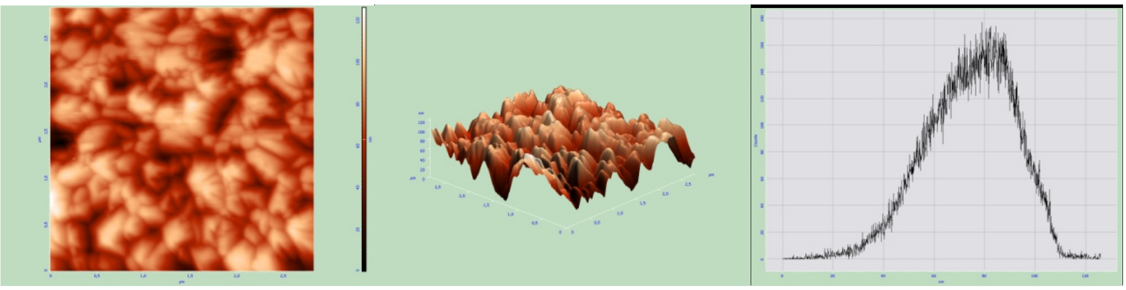


b)

Fig.3. 2D, 3D images and histograms of CdTe thin films a) before compensation b) after compensation

It was determined the lifetime of minority charge carriers from kinetics of change in photocurrent, which was τ = 4.1 msec (Fig. 4).

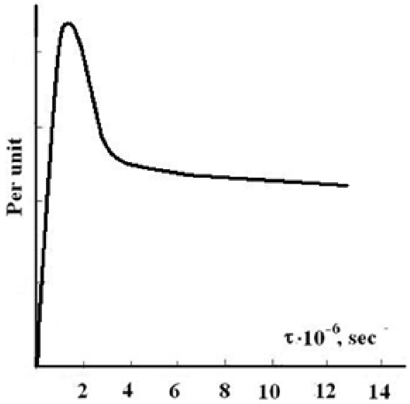


Fig.4. Kinetics of changes of photosignal under the influence of light in $Cd_{1-X}Mn_XTe$ thin films on a mica substrate

The influence of γ-irradiation on photoconductivity of epitaxial $Cd_{1-x}Mn_xTe$ films was investigated. The samples were first exposed to irradiation for 7 minutes at D_γ =10 krad dose, and then were irradiated for 16 minutes at D_γ=20 krad dose, for the third time within 15 minutes at D_γ =20 krad dose. After first irradiation the conductivity of the samples decreased, but photosensitivity increased. After second irradiation (D_γ=30 krad) the photosensitivity decreased and the samples were not sensitive at D_γ =50 krad dose (Fig.5). Thus, $Cd_{1-x}Mn_xTe$ films increases at D_γ=30 krad irradiation dose.

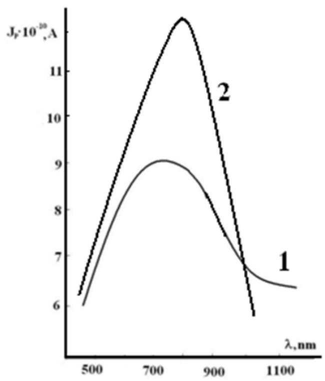


Fig.5. The photoconductivity of $Cd_{1-X}Mn_XTe$ thin films on mica substrate 1- before irradiation, 2- after irradiation

Usually generation of p-n junctions is impeded by the formation of various types of surface defects, which sharply reduce the parameters made on their basis of devices. Considering this, p-n junctions were obtained in a single technological cycle, without vacuum deterioration.

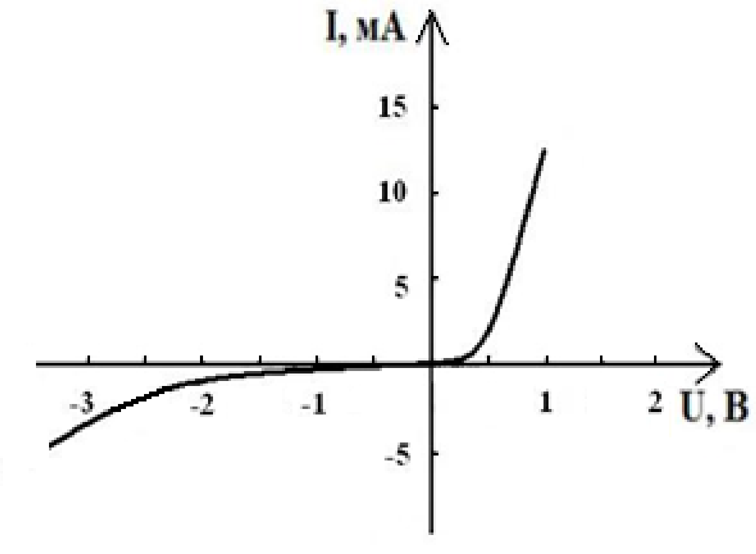
In heterojunctions obtained on mica substrates as ohmic contacts, the element In was used for n-CdTe films and Ni for p Cd1-xMnxTe (x = 0.4) layers, by applied vacuum-evaporation. In heterojunctions obtained on glass plates by sequentially depositing CdTe and $Cd_{1-x}Mn_xTe$ (x=0.4) as ohmic contacts, it was used SnO_2 layers on CdTe and Ni, vacuum-evaporated on $Cd_{1-x}Mn_xTe$ (x=0.4).

It was studied the electrical and photoelectric properties of the obtained heterojunction. It is known that, the study of the electrical properties of HJ is of great interest, because knowledge of current dependence through the junction on the applied external voltage allows to evaluate their fitness for the production of various devices, in particular the ability of formation of high-effective solar cells.

Dark VAC was investigated at room temperature for the study of current transport mechanism in HJ n-CdTe- p- $Cd_{1-x}Mn_xTe$. The obtained VAC is shown in Fig.6 a. From figure it is seen that, VAC is sharply asymmetric, direct currents within displacement 1V exceed reverse currents 10^3-10^4 times. The height of potential barrier is U_d = 0.52 V. As it is seen from Fig.6 b, the initial section of VAC of heterojunctions based on n-CdTe- p- $Cd_{1-x}Mn_xTe$ grows at small direct bias according to the following law

$$J = J_s\,[\exp(eU/A\kappa T)-1] \qquad (1)$$

where J_s - saturation current, U - bias voltage, A- coefficient of perfection, k - Boltzmann constant, T - temperature.



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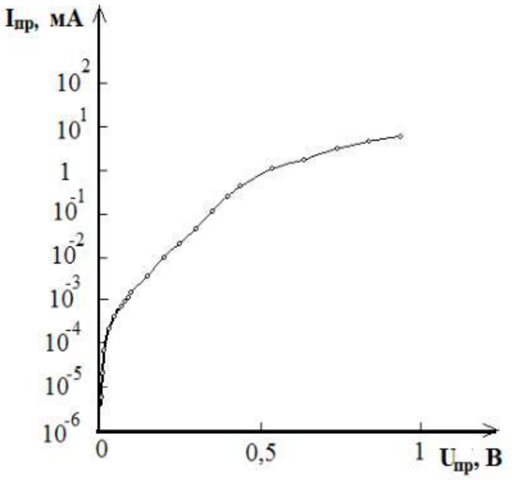

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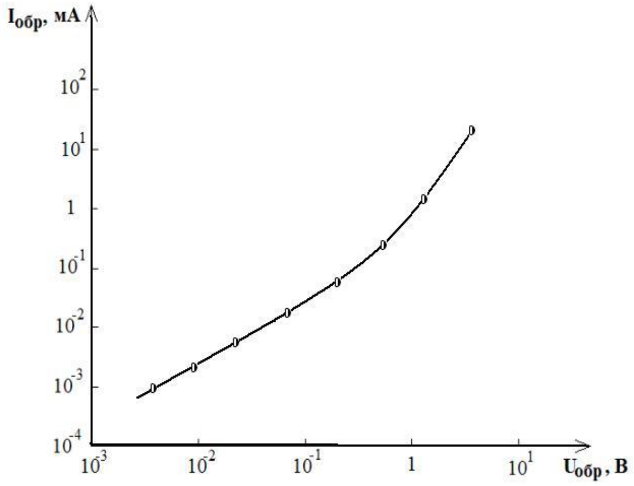


c)

Fig. 6. VAC of HJ CdTe /$Cd_{1-x}Mn_xTe$ (x=0.4) at T = 300 K a) the dependence of I(U), b) the dependence of $I_{dr}(U_{dr})$, c) the dependence of $I_{rev} = f(U_{rev})$.

The saturation current and coefficient of perfection were determined by extrapolation of the straight sections up to crossing with axis currents, which are 2.5 10^{-7} A and 2.1 at 300 C. It can serve as basis for the assumption in favor of recombination mechanism of change transport. For reverse branches of VAC (Fig.6 c) it is characteristic power law of the current on voltage $J \sim U^m$, where the power law indicator got the value at small voltages m = 2 ÷ 3, which corresponds to the generation-recombination processes in space-charge layer of the structure, but at higher voltages modulation of conductivity of the base part of the structure. Such behaviour of VAC of neutral region is characteristic for the current bounded by space charge.

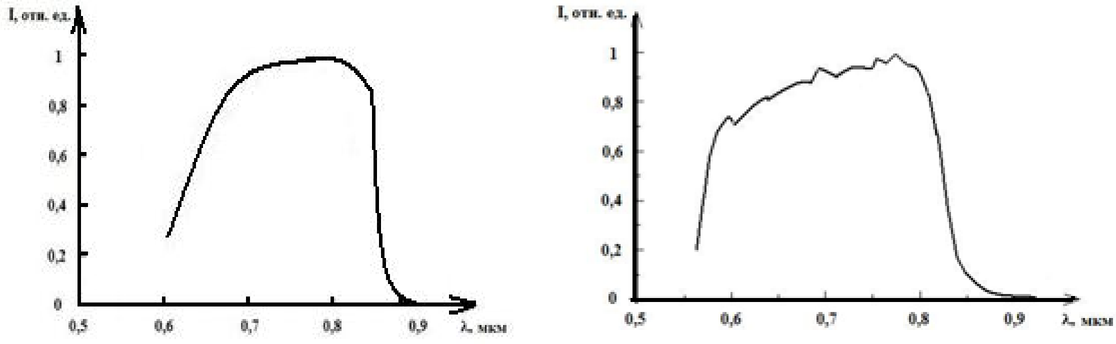
Light VAC of HJ SnO_2 - n-CdTe / p- $Cd_{1-x}Mn_xTe$-Ni were obtained under different lighting conditions. Lighting is not dependent on the voltage of photocurrent, which is typical for transitions with little generation-recombination processes in the area of space charge.

In this case, VAC is determined by expression

$$J = J_s\,[\exp(eU/A\kappa T)-1] - J_p \qquad (2)$$

At reverse displacement with increasing light intensity of short-circuit current J_{sc} and the photocurrent J_p PF increases linearly and but U_{oc} tends to saturation.

Study of the spectral distribution of the photosensitivity showed that HJ CdTe / $Cd_{1-x}Mn_xTe$ is sensitive in λ = 0.6-0.8micron wavelength (Fig.7a). As it is seen that, the edge of the photosensitivity in the short - wavelength spectral region is determined by light absorption in $Cd_{1-x}Mn_xTe$ (x = 0.4), and sharp decline in the long-wavelength edge of the spectrum is caused by the absorption in CdTe. In the process of obtaining HJ, at evaporation of solid solutions with a lower Mn content the characteristic shifts to long-wavelength range (Fig.7b), that indicates a decrease in band gap width in the grown layer.



a) b)

Fig.7. The spectral sensitivity of HJ CdTe / $Cd_{1-x}Mn_xTe$ a) x=0.4 b) x=0.5

Thus, it was prepared epitaxial photosensitive HJ CdTe / Cd1-xMnxTe, which can be used as photodetector and radiation energy converters.

4. Conclusion

Using CdTe and $Cd_{1-x}Mn_xTe$ corresponding chemical compositions as a source of the synthesized compounds and adjusting the temperature of compensating source in the growth process, it was obtained epitaxial CdTe / $Cd_{1-x}Mn_xTe$ (x=0.4) films by molecular beam condensation method. In a single technological cycle, without vacuum deterioration, it was formed HJ on their base, photosensitive at the range of wavelength λ=0,6-0,8μm, which can be used as solar cells and photodetectors. Radiation resistance of $Cd_{1-x}Mn_xTe$ (x=0.4) films was established. Irradiation at D_γ = 30 krad dose leads to increase of photosensitivity of these thin films.

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ФОТОЧУВСТВИТЕЛЬНЫЕ ЭПИТАКСИАЛЬНЫЕ ГЕТЕРОПЕРЕХОДЫ CdTe/ $Cd_{1-x}Mn_xTe$

И.Р. Нуриев, М.А. Мехрабова, А.М. Назаров, Р.М. Садыгов, Э.И. Мирзоев

Резюме: Исследованы возможности создания фоточувствительных p-n гетеропереходов на основе эпитаксиальных пленок n-CdTe и p-$Cd_{1-x}Mn_xTe$ (x=0.4). Гетеропереходы получены методом конденсации молекулярных пучков, в едином технологическом цикле без нарушения вакуума, с применением дополнительного компенсирующего источника паров Te в процессе роста. Установлены оптимальные условия получения структурно совершенных эпитаксиальных пленок и создания гетеропереходов на их основе, фоточувствительных в интервале длин волн λ=0,6-0,8 мкм, которые могут быть использованы в качестве солнечных эдементов. Показано,что влияние γ-облучения при дозах D_γ=30 крад приводит к увеличению фотопроводимости эпитаксиальных пленок $Cd_{1-x}Mn_xTe$.

Ключевые слова: Эпитаксиальная пленка, халькогениды, гетеропереход, фоточувствительность, ВАХ.

FOTOHƏSSAS EPİTAKSİAL CdTe / $Cd_{1-x}Mn_xTe$ HETEROKEÇİDLƏRİ

İ.R. Nuriyev, M.A. Mehrabova, A.M. Nəzərov, R.M. Sadıqov, E.İ. Mirzəyev

Xülasə: n-CdTe və p-Cd1-xMnxTe (x = 0,4) epitaksial təbəqələri əsasında fotohəssas p-n heterokeçidlərinin yaradılması imkanları tədqiq edilmişdir. Heterokeçidlər molekulyar dəstədən kondensasiya metodu ilə, vakuumu pozmadan, vahid texnoloji tsikldə, böyümə prosesində əlavə kompensəedici Te mənbəyindən istifadə etməklə alınmışdır. Mükəmməl quruluşa malik epitaksial təbəqələrin alınması və onlar əsasında günəş elementləri kimi istifadə oluna bilən, spektrin λ=0,6-0,8mkm dalğa uzunluğu oblastında fotohəssaslığa malik heterokeçidlərin yaradılmasının optimal şərtləri müəyyən edilmişdir. Göstərilmişdir ki, D_γ=30krad dozada γ-şüalanmanın təsiri $Cd_{1-x}Mn_xTe$.epitaksial təbəqələrinin fotokeçiriciliyinin artmasına səbəb olur..

Açar sözlər: Epitaksial təbəqə, halkogenidlər, heterokeçid, fotohəssaslıq, VAX.