MUHAMMAD AL-XORAZMIY
NOMIDAGI TATU FARG'ONA FILIALI

FERGANA BRANCH OF TUIT
NAMED AFTER MUHAMMAD AL-KHORAZMI

"AL-FARG'ONIY AVLODLARI"

ELEKTRON ILMIY JURNALI | ELECTRONIC SCIENTIFIC JOURNAL

TA'LIMDAGI ILMIY, OMMABOP VA ILMIY TADQIQOT ISHLARI

4-SON 1(8)
2024-YIL

TATU, FARG'ONA
O'ZBEKISTON

ISSN 2181-4252

O‘ZBEKISTON RESPUBLIKASI RAQAMLI TEXNOLOGIYALAR VAZIRLIGI

MUHAMMAD AL-XORAZMIY NOMIDAGI TOSHKENT AXBOROT TEXNOLOGIYALARI UNIVERSITETI FARG‘ONA FILIALI

Muassis: Muhammad al-Xorazmiy nomidagi Toshkent axborot texnologiyalari universiteti Farg‘ona filiali.
Chop etish tili: O‘zbek, ingliz, rus.
Jurnal texnika fanlariga ixtisoslashgan bo‘lib, barcha shu sohadagi matematika, fizika, axborot texnologiyalari yo‘nalishida maqolalar chop etib boradi.

Учредитель: Ферганский филиал Ташкентского университета информационных технологий имени Мухаммада ал-Хоразми.
Язык издания: узбекский, английский, русский.
Журнал специализируется на технических науках и публикует статьи в области математики, физики и информационных технологий.

Founder: Fergana branch of the Tashkent University of Information Technologies named after Muhammad al-Khorazmi.
Language of publication: Uzbek, English, Russian.
The magazine specializes in technical sciences and publishes articles in the field of mathematics, physics, and information technology.

2024 yil, Tom 1, №4
Vol.1, Iss.4, 2024 y

ELEKTRON ILMIY JURNALI **ELECTRONIC SCIENTIFIC JOURNAL**

«Al-Farg‘oniy avlodlari» («The descendants of al-Fargani», «Potomki al-Fergani») O‘zbekiston Respublikasi Prezidenti administratsiyasi huzuridagi Axborot va ommaviy kommunikatsiyalar agentligida 2022-yil 21 dekabrda 054493-son bilan ro‘yxatdan o‘tgan.

Jurnal OAK Rayosatining 2023-yil 30 sentabrdagi 343-sonli qarori bilan Texnika fanlari yo‘nalishida milliy nashrlar ro‘yxatiga kiritilgan.

Tahririyat manzili:
151100, Farg‘ona sh.,
Aeroport ko‘chasi 17-uy,
202A-xona
Tel: (+99899) 998-01-42
e-mail: info@al-fargoniy.uz

FARG’ONA - 2024 YIL

Jurnal quyidagi bazalarda indekslanadi:

MUNDARIJA | ОГЛАВЛЕНИЕ | TABLE OF CONTENTS

MUNDARIJA | ОГЛАВЛЕНИЕ | TABLE OF CONTENTS

MUNDARIJA | ОГЛАВЛЕНИЕ | TABLE OF CONTENTS

CHARACTERIZATION OF PHOTOLUMINESCENCE SPECTRUM OF CHALCOGENIDE CADMIUM-BASED SEMICONDUCTOR POLYCRYSTALLINE FILMS

Polvonov Baxtiyor Zaylobidinovich,
Fergana branch of TUIT named after Muhammad al-Khorazmi, professor
bakhtiyorp@mail.ru

Khudoyberdieva Muxayyoxon Zoirjon qizi,
Researcher of FerSU

Abdubannabov Mo‘ydinjon Iqboljon o‘g‘li,
Fergana branch of TUIT named after Muhammad al-Khorazmi, assistant

Ergasheva Gulruxsor Qobiljon qizi,
Fergana branch of TUIT named after Muhammad al-Khorazmi, student

Tohirjonova Zahro Shovkatjon qizi,
Fergana branch of TUIT named after Muhammad al-Khorazmi, student

Mamasodiqov Shohjahon,
Fergana branch of TUIT named after Muhammad al-Khorazmi, student

Abstract. In the spectrum of low temperature photoluminescence of the fine-grained ( ) thin films is discovered a band of the own ( ) radiation, specified by the subsurface potential barriers on border of crystalline grains and marginal double-acting band, appearing as phonons repetitions of the band. The alloyage of the film by impurity leads to stewing double-acting band, but its further thermal processing to activation of the own band, short-wave offset of the red border ( ) and modulation of the full width on half maximum ( ) which is correlated with by the height of the micro potential barriers and temperature of recombined hot photocurrents.

Keywords: polycrystalline thin films, telluride cadmium, impurity, alloyage, thermal processing, anomalous photovoltages properties, spectrum of photoluminescence, the potential barrier, the border of grains, intensity

Introduction. One of the most sensitive, reliable and informative, optical methods of the study semiconductors and film structures is an analysis of their spectrums of low-temperature photoluminescence ($LTPL$). Currently, the spectrums $LTPL$ of $CdTe$ crystals are explored in detail and the methods of the prediction and controlling change of electro physical properties of the semiconducting structures on their base. So, by means of studying dynamic change of spectrum photoluminescence, the authors of the works [1, 2] have offered the method of deep peelings samples and have got polycrystalline $CdTe$ of stehiometric composition, in the spectrum of photoluminescence which is completely absent the impurity radiation and only exciton part remains. The electronic spectrums of solid solution $CdTe:In$ [3], $CdTe:Fe$ [4] are explored by the analysis of the form

of the marginal radiation under laser excitation. The role of intercrystalline borders in shaping properties of mega grained cadmium tellurian is explored in the works of Ushakova V.V. and Klevkova Yu.V. [5, 6] by the methods of microphotoluminescent probing and is shown that additive-defective composition of subbordering and internal areas monocrystalline grains with sizes $1-2\,mm$ enough noticeably differs. However hitherto the shaping of the spectrum photoluminescence (PL) of fine grained $(d_{cr} \le 1\,\mu m)$ semiconductor samples, beside which intercrysalline borders render the significant influence upon their properties, practically were not considered depending on structural and dotted defects. Certainly, there is an interest of studying correlation between spectrums $LTPL$ and photovoltaic properties of thin polycrystalline with the purpose of improving technology by the reception of the film structures with necessary workers parameters for semiconducting optoelectronics.

The purpose of the work is a study of interconnection the form of the spectrum $LTPL$ with anomalous photovoltaic (APV) by the properties of slanting spraying films $CdTe$, $CdTe:In$ depending on structured imperfection. Earlier with the participation of one of the authors was reported [5-7] that the alloyage by impurity In and the following thermal processing (TP) greatly perfects the photovoltaic parameters of $CdTe$ films: photocurrent of the short circuit increases on two orders, but maximum value of photo-EMF V_{APV} - on order. Here, the spectrums of own and marginal PL of these films at $T = 4.2\ K$ for finding of the mechanism of the discovered effect are analyzed. Turned out to be that in $LTPL$ spectrums of fine grained polycrystalline films $CdTe$, $CdTe:In$ with APV properties, unlike monocrystals and large-block polycrystalline, do not reveal the channels of the radiation excitons and donorly-acceptor steam (DAS), which reason is a process of generation of photo-EMF in bordering areas of crystalline grains, bring about stimulation of own $(e-h)$ luminescence and inflammation its longitudinally-optical (LO) phonon repetitions in undoped samples. It Is found that the essential short-wave offset $\Delta E_r \approx 20\ meV$ of the red border $e-h$ - spectral band depending on point and structured defects of crystalline grains, full width on half maximum which correlated with maximum value generated by the film of anomalous big photovoltage (ABP) $V_{APV} = 10^2 - 10^3\ V/sm$. The given method of the analysis spectrums $LTPL$ with photoelectrical properties of fine-grained polycrystallines $CdTe$ offered in this paper and can be used with success for studying properties and other semiconducting film structures.

Technology. The Results of the experiment.

Being studied undoped films by the area $5x20\ mm^2$ got from powder $CdTe$ of the mark "for semiconductors" by the method of the thermal evaporation in vacuum at pressure of the remaining steam $(1-4)\cdot 10^{-2}\ Pa$ on a glass substrate with the temperature $T_s = 500-550\ K$. The most stable, reproducible photoelectrical parameters and high photovoltaic properties were reached at the thickness of the film $d = 0.5-0.8\ \mu m$, the speed of sediment $(1.2-1.5)\ nm/s$ and under the angle of the evaporation $40-60^0$. Electronic-microscopically and roentgenstructural study has shown that growing layers possess the polycrystalline structure with cubic modification mainly and axis of the texture along crystallographic direction [111], perpendicular plane of the substrate. The sizes of separate crystallites have formed $0.5-0.7\ \mu m$. Fresh prepared films under room temperature under the action of normally falling natural light of the lamp heating with intensity $L \approx 10^4\ lx$ generated photovoltage $V_{APV} \approx 600\ V$ and current of the short circuit $I_{sc} \approx 10^{-10}\ A$. Photovoltaic parameters of the film practically did not feel the degradation for a year.

The alloyage process of the thin slanting spraying layers $CdTe$ was realized directly during their growing by the method of thermal evaporation in vacuum $(3-5)\cdot 10^{-2}\ Pa$ by the way of preevaporation $CdTe$ and In from separate crucibles. The initial mass of evaporation impurity formed $3-7\ mass\ \%$ from the mass of the main semiconductor connection. The evaporation In detained on $2-3$ min and stopped on $3-5$ min earlier, than evaporation of the main material. Fresh prepared polycrystalline samples $CdTe:In$ with thickness $d \approx 0.8-1.5\,\mu m$, with the speed of condensation $v_к \approx 1.5-2.0\ nm/s$, and with the angle $30-50^0$ of evaporation turned out to be more low-resistance and comparatively were weakly expressed APV by the properties $(V_{APV}=50-100\ V)$ However after thermal processing (TP) at the temperature $450-550\ K$ during $20-25$ min in the vacuum or $10-15$ min on a clean air or $3-5$ min on air in presence of steam codopant $CdCl_2$ resistance of the sample on $2-3$ times increased. In the same time they generated at the room temperature maximum photovoltage before value $(2-4)\cdot 10^3\ V$ (i.e. nearly on the order more, than specially undoped $CdTe$ samples), but photocurrent of the short circuit increased more than on two orders and reached before value $I_{sc} \approx 10^{-8}\ A$. Electrophysical and APV properties of annealed films are greatly stabilized. In the event of TP in vacuum or on air in pairs $CdCl_2$ were needed films with thickness $1.2-1.5\ \mu m$, but more thin films $(d<1{,}0\,\mu m)$ came out of the order at such TP that is connected with processes of reevaporation and recrystallization.

The methods of photohall measurements at room temperature, as well as the analysis of lux-ampere characteristics and thermostimulated current of annealed films $CdTe:In$ have shown [6], that optimum on value V_{APV} of the concentrations In^{+i} and vacancy cadmium V_{Cd}^{-j} form the order $10^{17}-10^{18}\ sm^{-3}$. Herewith Hall concentrations and mobilities of electrons vary within $10^{12}-10^{13}\ sm^{-3}$ and $50-250\ sm^2/V\cdot s$, i.e. the film $CdTe:In$ presented itself powerfully inhomogeneous structure from powerfully compensated semiconductor with n - type conductivity.

For measurement of $LTPL$ spectrums film samples directly sunk in pumped fluid helium at the temperature $4.2\ K$. The spectrums were registered on installation, collected on the base of the spectrometer $DFS-24$, working in mode of the count photons under minimum width of the slot $0.04\ meV$. Own excitation of the semiconductor was realized on wavelength $\lambda = 476.6\ nm$ by the light of unceasing gazodisruptive Ar^+ - laser, focused on the surface of the layer $CdTe$ in spot with the size $0.4x4\ mm^2$ at power of the light flow $\sim 7\ mW$. The experiment was conducted in geometry of the normal illumination and nearly normal radiation).

The $LTPL$ spectrum of undoped $CdTe$ film with APV properties in vicinities of the fundamental band of the absorption was submitted on Fig.1, *a*. For comparison here is shown by dotted line PL spectrum of the clean monocrystalline sample from the work [6], which spreads only in area of the frequencies $\hbar\omega < E_g$ and consists of exciton $(E_{ex} \approx 1.59\,eV)$, DAS $(E_{DAS} \approx 1.54\,eV)$ - lines of the radiation and their LO - phonon repetitions. As can be seen from the figure, the $LTPL$ spectrums of polycrystalline films and monocrystalline from $CdTe$ differ qualitatively.

The main contribution to $LTPL$ film gives emitting recombination $e-h$ of free carriers (A - line with full width on half maximum $14.2\pm 0.1 meV$) and marginal luminescence with comparatively broad doublet structure (B - and C - lines of the radiation

with full width on half maximum $18.5 \pm 0.1 meV$ and $32.2 \pm 0.1 meV$), but exciton, DAS - channels of the radiation and their phonon repetitions on the background $A,\ B,\ C$ – of spectral lines are not marked or absent. In the field of frequencies $\hbar\omega > 1.65\,eV$ exists hot photoluminescence, conditioned by radiate recombination relaxated on energy of hot electron-hole steam (the frequency of laser excitation $\hbar\omega = 2.60\,eV$). The sharp long wave border $\hbar\omega = 1.627\,eV$ of the own band of the radiation speaks that separate grains possess a perfect crystalline structure. The end lines of density conditions, conditioned by strong breaches of the crystalline lattice, in $LTPL$ spectrums are not found. We shall notice that the red border A - lines displaced aside short waves on energy $0.021\ eV$ in contrast with bottom edge of the band conductivity of $CdTe$ monocrystalline (the vertical dash mark of dotted line on Fig.1, a) at $T = 4.2\ K$ ($E_g = 1.606\ eV$). It is difficult to explain, for instance, the presence of the internal mechanical pressure of the sprain in thin film $CdTe$ because of the difference thermal coefficient expansion or interatomic distances of the film and substrate that bring to the width of the forbidden band E_g to increase.

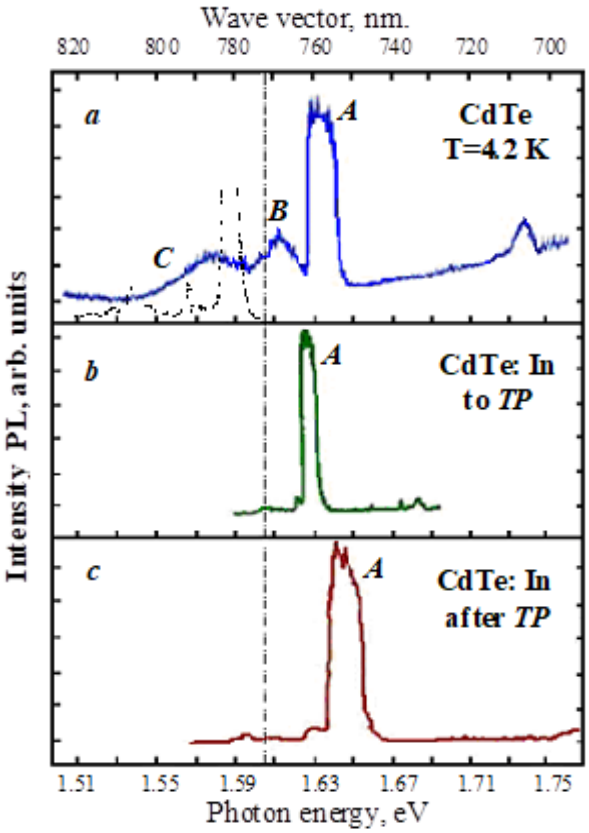

Fig. 1. The experimental $LTPL$ spectrums of undoped (a), which is alloyed by impurity In $CdTe$ films before (b) and after (c) of the thermal processing. Dashing line is a PL spectrum of undoped monocrystalline $CdTe$ [6], but the dotted line is shown upper border its forbidden band at $4.2\ K$.

From the figure 1, a we see that maximums , and - lines of the radiation differ on energy of longitude optical phonon in [4]. This allows to confirm that symmetrical - line is - by repetition, but - line - - by repetition of own - bands of the radiation, which also, as fundamental band, were absent in the spectrum of monocrystalline and large-block polycrystalline at the given intensities of laser excitation .

Sloping maximum C - lines of the radiation lags behind from A - lines on energy a little more than $2\hbar\omega_{LO}$ and has a long wave line end that means the given spectral line is undoubtedly formed as a result $e-h-$ recombination with the following radiation $2LO + nLA$ phonons ($n = 1, 2, 3\ldots$), i.e. in forming C - lines participate as well as longitudinally acoustic (LA) phonons.

On Fig. 1, b the $LTPL$ spectrum of $CdTe:In$ film without TP is shown. It is seen that the process of the film alloyage by impurity indium, volume concentration which no less $10^{17}-10^{18}\ sm^{-3}$, powerfully deforms its $LTPL$ spectrum. First, is greatly narrowed full width on half maximum A - lines (drops to $6\ meV$), and correlated by falling nearly on order of maximum value V_{APV} at fresh prepared $CdTe:In$ films in contrast with undoped $CdTe$ film; second, band of marginal luminescence (B – and C - lines), as well as the channel of hot PL disappears; third, sharp red border of the own radiation slips in long wave side on energy $\approx 3-5\ meV$ and lags behind from upper border of the forbidden band of monocrystalline on energy $16-18\ meV$, probably, also it is difficult to explain with reduction E_g as a result of weakening of the internal mechanical pressure in alloying sample. Thus, it is possible to conclude that donor admixture of substitution In_{Cd} or penetration In_i in fine-grained $CdTe$ create the powerful channel of no radiating recombinations, hereunder, they reduce strongly the role LO - and $LA-$ phonons. Herewith the red border of A -lines radiations slip in a long wave area, its full width on half maximum decreases, as well as increases conductivity of the $CdTe:In$ film, where is defined its deterioration APV properties.

As can be seen from the Fig. 1, c, after optimal TP film $CdTe:In$ $LTPL$ spectrum qualitatively does not suffer strong change. However, immediately we notice that TP brings to spreading A - lines nearly in three times (full width on half maximum reaches value $\sim 17\ meV$ in accordance with growing of the value V_{APV} on order, i.e. to $3\cdot 10^3\ V$) and to slipping of the red border A -lines on $\sim 11\ meV$ in short-wave side in contrast with not annealed $CdTe:In$ film, at first thought it is difficult explicable problem. Follow to note, that the process TP in the result of self-compensation of donor and acceptor steam as in volume, and as well on grain surfaces stimulates alongside with APV properties of alloying films, as well as its own band $LTPL$.

Thereby, we see the clear correlation between APV properties and the form discovered here bands of own luminescence of slanting spraying $CdTe$: at film alloyage and also after its TP form A - line is strongly transformed in accordance with the change APV properties of the film. In $LTPL$ spectrums of polycrystalline films $CdTe$, $CdTe:In$ unlike of spectrums monocrystalline or large-block polycrystalline $CdTe$ do not reveal exciton and DAS (marginal) channels of the radiation and their LO - phonon repetitions, reason which, probably, is fine grained structure of the film and the process of generation photo- EMF in bordering areas of crystalline grains, bringing to stimulation of the own luminescence.

Discussion of the results.

Fundamental band of the radiation with full width on half maximum $\sim 10-20\ meV$ (A -line on the Fig.1) and its LO - phonon repetitions in $LTPL$ spectrums of polycrystalline $CdTe$ films earlier were not discovered in the works of the other authors. Below we’ll try to analyze the mechanism of the forming this spectral line and interpret the main its parameters depending on technological factors.

Let us consider the event of laser excitation of fine-grained polycrystalline semiconductor from the area of the own absorption with intensity L_0. Known that in the process of the forming the radiation of polycrystalline samples follows conditionally to distinguish separate contributions of three typical areas

$$L=\beta L_0=L_{AIB}+L_{AVC}+L_{QNA}, \qquad (1)$$

where $L_{AIB} = R_s \cdot \hbar\omega$,

$$L_{AVC} = \int_0^{\ell_{D1}} R_{AVC}^{(1)} \cdot \hbar\omega \, d\ell + \int_0^{\ell_{D2}} R_{AVC}^{(2)} \cdot \hbar\omega \, d\ell \quad ,$$

$$L_{QNA} = \int_{\ell_{D1}}^{d-\ell_{D2}} R_{QNA} \cdot \hbar\omega \, d\ell$$

- contributions to the intensity of the radiation accordingly from the area of intergrained borders (AIB), areas of volume charges (AVC) and quasi-neutrality areas (QNA); R_s, R_{AVC}^i, R_{QNA} - temps of radiating recombinations in these areas; d - a linear size of crystalline grain, $\ell_{Di} = \left(\frac{2\varepsilon\varepsilon_0\varphi_i}{e^2(N_D - N_A)} \right)^{1/2}$ - a length of Debay screening, β - a quantum output. Naturally, in big grained samples $(d >> \ell_{Di})$ dominating role plays QNA and considered problem is reduced to the known volume photoluminescence. However, in explored fine grained $(d \approx \ell_{Di})$ polycrystalline films with APV properties are basically due to the role AIB, AVC, and QNA plays the inessential role in $LTPL$ forming. Really, as can be seen from Fig.1, a, for undoped $CdTe$ monocrystallines at the given intensity of laser excitation radiation $\left(\approx 7 \frac{\text{mW}}{\text{sm}^2} \right)$ does not find the own radiation (the dotted line [6]). This is explained that $e-h$ - radiating time of life τ_r of non-equilibrium photo carriers vastly exceeds their time of output τ_0 by the formation of excitons or phonons emission. In general, full time of life of non-equilibrium electron is defined by radiative τ_r and non radiative τ_0 time of life by the expression

$$\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_0} \quad ,$$

$$\frac{1}{\tau_0} = \frac{1}{\tau_{LO}} + \frac{1}{\tau_{LA}} + \frac{1}{\tau_{ex}} + \frac{1}{\tau_{DA}} + \frac{1}{\tau_M} + \frac{1}{\tau_p} + \cdots \quad , \qquad (2)$$

where τ_{LO}, τ_{LA}, τ_{ex}, τ_{DA} - time of the output electron from given energetic condition with formation LO, LA - phonons, excitons and DAS, but τ_M, τ_p - Maxwell time of relaxation and time of relaxation on impulse.

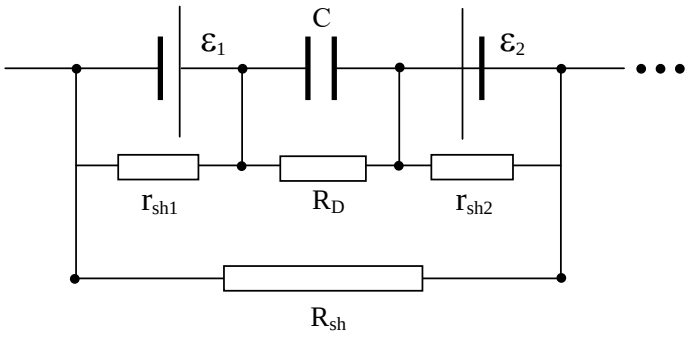

Fig. 3. The equivalent electrical circuit of one structured cell SDS under the action of light, generating photo – EMF. ε_1, ε_2 - surface photo- EMF, generated by AVC on the left and on the right from the interface; r_{sh1}, r_{sh2} - shunting their resistance in favor of the surface conductivity, R_{sh} - shunting resistance of the channel conductivity; C - and R_D - electro- capacitance and active resistance of the interface.

Comparatively broad spectral band A (full width on half maximum $\Delta_A \approx 14\,eV$ corresponds to $\tau_r \approx 3 \cdot 10^{-11}\,s$) in $LTPL$ spectrum of the $CdTe$ film with APV properties in areas of the fundamental absorption $(\hbar\omega > E_g)$ corresponds to the inverse situation $\tau_r \le \tau_0 \approx \tau_{ex}$, and witnesses the absence in $LTPL$ spectrum exciton and DAS - channels of the radiation. We shall analyze the reason of the realization of such condition of $LTPL$ forming. For this, let’s consider the structural model of the slanting spraying of fine grained ($d \sim \ell_{Di}$) polycrystalline film. According to this model we shall present that crystalline grains, their borders of the section and pores between them in the direction of passage of the electric current as linear periodic chain consecutively included semiconductor-dielectric-semiconductor (SDS) of the contact structures with asymmetric subsurface potential barriers.

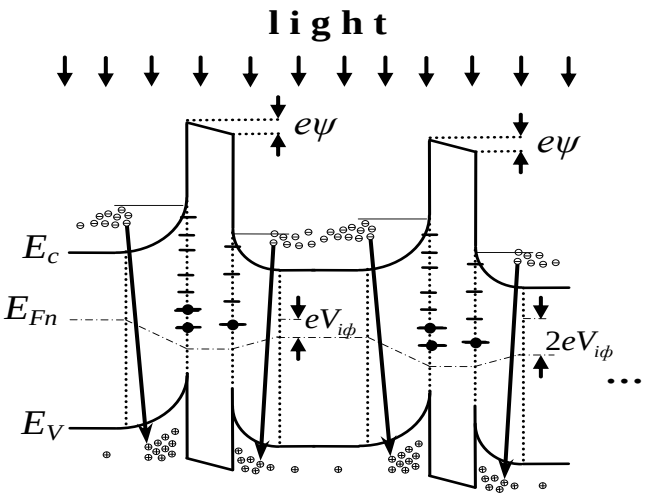

Fig. 2. The banded of diagram energy of the linear chain semiconducting crystalline grains with asymmetric potential barriers among intergranular interface (*DS)*, at illumination by light, bring to *ABP* and *PL* generation.

At illumination of each elementary cell SDS in favor of the light absorption in asymmetric AVC and spatial division of photocarriers generate the small surface photo-EMF $V_{iP} = \psi_0 - \psi$ (Fig. 2), where $\psi_0 = (\varphi_{01} - \varphi_{02})/e$, $\psi = (\varphi_1 - \varphi_2)/e$ - contact differences of potentials between nearby grains in the dark and under the action of light, $e-$ electron charge, φ_{01}, φ_{02} and φ_1, φ_2 -heights of subsurface potential barriers with left and right sides of dielectric layer (DL) to and after illumination. Then, of course, we see that linear chain SDS generates high voltage photo-EMF $V_{APV} = N \cdot V_{iP}$ (N -number of SDS cells). It is evident, that if surface potential barriers on the grains borders symmetrical or the film is enough thick or possesses the high photoconductivity, so APV - effect will be absent in favor of shunting SDS by resistances R_{sh} or r_{sh1}, r_{sh2} on Fig.3.

Appears the natural question, how are the processes of the shaping $LTPL$ and APV -properties of slanting spraying and fine grained films interconnected? How can we explain the short-wave offset of the red border *A*-lines and change its full width on half maximum in the result of alloyage and TP films?

It is known, that the surface of photo- EMF appears in favour of photogeneration of free electronic-hole steam and their spatial division by internal field only in AVC that prevents the process of excitons formation. On the other hand, exactly such process brings to accumulation of electrons in bordering area between QNA and AVC, but holes near the grains borders with DL *i*n specified on Fig. 2 in the case of curving energetical level in AVC. Moreover in our high-resistance samples of Maxwell time of relaxation $\tau_M = \frac{\varepsilon \varepsilon_0}{\sigma}$ it is enough big and so, the time of life band radiating recombination photocarriers in corresponding band of energy according to (2) are defined basically between bands of radiating recombinations $(\tau \approx \tau_r \le \tau_0)$. But this is probably the main reason of the inflammation of own photoluminescence and suppression of exciton radiation in fine grained polycrystalline semiconductors of the $CdTe$ type. Consequently, surface PL and photo-EMF in determined conditions always are associated with each other. So, in fine grained polycrystallines $(d \sim \ell_{Di})$ at weak surface recombination of the contribution AVC in PL can become dominant. Just such situation and, probably, exists in investigated $CdTe$ films (Fig.1, A -line).

Proceeding from the equivalent energy scheme of the SDS structure on Fig. 3 we shall notice that at $r_{sh} \to 0$ (the event of the metallic substrate) in conditions of the short circuit the photocarriers will participate in carrying current, consequently, the surrface photo-EMF and undoubtedly own PL do not appear (a separate article will be dedicated to this interesting question). In the case, when $R_{sh} \to 0$, but r_{shi} has enough great value (comparatively thick film), though $V_{APV} \to 0$, however in areas AVC can be formed elementary photo-EMF and PL. In slanting spraying big grained films $(d >> \ell_{Di})$, though the

contribution of the surface PL surrenders before QNA contribution , however, anomalous big photo-EMF all the same can generated. On the contrary though in the case of symmetrical surface barrier of the fine-grained film APV does not appear, that the less role of the surface PL can become essential. Thereby, we can conclude that the appearance of the own band of the radiation in PL spectrum of slanting spraying fine grained polycrystalline $CdTe$ thinfilm is conditioned by the generation of the surface photo-EMF near the grain borders. Naturally, that widths of spectrum radiations from areas of asymmetric potential barriers with both sides DL a little differ. This reveals in unusual spreading of resulting fundamental band of the radiation, but sharp long wave border which is conditioned made by ideal crystalline structure of separate grains.

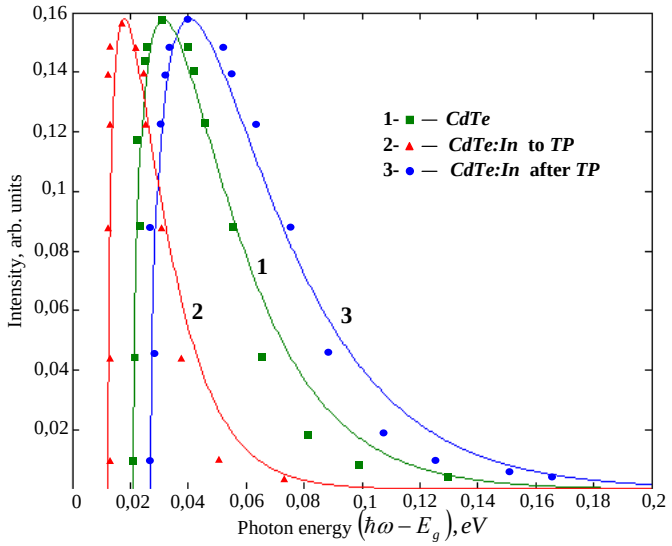

Fig. 4. The comparison of theoretical (the utter curves, calculated on formula (4)) and experimental (points) $LTPL$ spectrums fundamental band of fine grained APV films $CdTe$ at $T = 4.2\ K$ (the explanation in the text).

Strictly speaking, PL of polycrystalline film is formed from different depths and microareas on the base of different mechanisms of radiating recombination. The exact analytical calculation of PL spectrum presents the significant difficulties. However on the base of the formula (1) and stated above physical considerations we can do certain rough approaches. So, preliminary quantitative analysis of spectrums A - lines radiation shows that in the first its approximation it is possible to describe the following formula:

$$L(\omega) = A_0 \sqrt{\hbar\omega - (E_g + \Delta E_r)} \cdot \exp\left(- \frac{\hbar\omega - (E_g + \Delta E_r)}{kT_{eh}} \right), \quad (3)$$

where A_0 - constant, depending on the type of the film and its condition of photoexitation, E_g - a width of the forbidden band of $CdTe$ monocrystalline, k -constant of Bolicmana, T_{eh} - an average typical temperature of photocarriers, powerfully differring from the temperature of the lattice T , $\Delta E_r = \hbar\omega_r - E_g$ - a difference between red border A - lines and E_g . Naturally, the second and the third multipliers in right part of the formula (3) are conditioned by the density of the conditions in simple bands and near-equilibrium functions of distribution photocarriers.

On Fig. 4 the comparison of theoretical (on formula (3)) and experimental spectrums of the fundamental band $LTPL$ of fine grained APV films of $CdTe$, $CdTe:In$ are presented. The values of parameters $\Delta E_r \approx kT_{eh}$ are chosen on the short-wave offsets of the red border $A-$ lines from experimental spectrums Fig. 1, a, b, c: $\Delta E_r = 21\ meV$ (curve 1 for no alloying $CdTe$ films), $17\ meV$ (curve 2, $CdTe:In$ without TP), $29\ meV$ (curve 3, $CdTe:In$ after TP). It is seen, that rudely calculated spectral lines 1-3 satisfactorily conform with the results of the experiment. However there are essential divergences on the short-wave edge spectrums. The experiment shows more strong thermalization of hot photocarriers with typical temperature $T_{eh} < \Delta E_r / k$, that speaks of additional channels of the dissipation high-energetic non-equilibrum free carriers.

The physical meaning of the value ΔE_r we can explain as follows. Since the laser excitation of the semiconductor is realized on enough big frequency $\hbar\omega = 2.60\ eV$ in contrast with $E_g = 1.606\ eV$ at $T = 4.2\ K$, that high-energetic photoelectrons and

photoholes having relaxated on energy and approach to corresponding borders of the energetic bands with a certain remaining temperature T_e and T_h completely not cooled before the temperature of the crystalline lattice. This also promotes to the internal electrostatic fields AVC ("built-in" fields $\vec{E}_i$), spacely separating generated electronic-holed steam and accelerating photocarriers. In the last case the electrons are in addition warmed on energy to equal height of the subsurface potential barrier φ_i. Then considering that energy of hot electrons concerning of the bottom band conductivity equals $\Delta E_e \approx \varphi_i + kT_e$, but for holes - $\Delta E_h \approx \varphi_i + kT_h$, we shall get

$$\Delta E_r = \Delta E_e + \Delta E_h \approx 2\varphi_i + kT_{eh} \quad , \quad \text{where} \quad T_{eh} = T_e + T_h \ . \qquad (4)$$

According to formula (4) the value ΔE_r is defined by a kinetic energy of hot photocarriers and modulated height of subsurface potential barrier φ_i under the light action. Here we deal with the effect of the edge offset own $LTPL$ at intensive laser excitation of the hot carriers in fine grained polycrystalline and straightbanding semiconductors depending on structured defects, defining parameters of subbordering potential barriers of monocrystalline grains.

From the formula (3) formally it is possible to define spectral full width on half maximum A-lines as follows. We shall enter the non-dimensional value $x = (\hbar\omega - (E_g + \Delta E_r))/kT_{eh}$. Then formula (3) takes the following functional type

$$L(x) = A_0^{'}\sqrt{x}\cdot\exp(-x)$$

with maximum $L_{\max} = A_0^{'}/\sqrt{2e}$ at $x = 1/2$, where $e = 2.718\ldots$, - a base of the natural logarithm. Full width on half maximum A - lines we shall define as differences of two solution of the transcendental equation $x\cdot\exp(-2x) = (8e)^{-1}$, i.e. as

$$\Delta_A = kT_{eh}\cdot(x_2 - x_1) \approx 0.67kT_{eh} \ . \qquad (5)$$

Thence we shall draw a conclusion, that spectral full width on half maximum A-lines Δ_A straight proportionally the temperature of photocarriers, which is determined by the short-wave offset of its red border ΔE_r. This qualitatively corresponds to the changes of the spectral characteristics A - lines on Fig.1, *a-c*. Since the alloyage of the $CdTe$ films by In brings to reduction φ_{0i} and kT_{eh}, thereby, we see on Fig. 1, b reduction ΔE_r on $3-5\ meV$, but Δ_A - nearly in three times (before 6 meV). Herewith according to Fig. 3 resistances R_{sh}, r_{shi}, R_{sh}, r_{shi} also decrease, but the film moves to more low-resistance condition, in the result the photocurrent of the short circuit I_{sh} increases, but maximum value of photo-EMF V_{APV} falls. The following optimum TP in the result of processes self-compensation [5] moves the film in high-resistance condition not only at the expense of the growing microresistance R_{sh}, r_{shi} and R_D, but also because of increasing φ_{0i} and expansion AVC. From Fig. 1,c accordingly we shall get that Δ_A increases before $17\ meV$, but ΔE_r - to $29\ meV$, i.e. the formula of the estimation (5) is executed with specific error 8% if consider the equitable condition $\Delta E_r \approx kT_{eh}$.

Conclusions. So, on the basis of above results from the analysis of $LTPL$ spectrums fine grained slanting spraying films $CdTe$, $CdTe:In$, with APV properties we can do the following findings:

1. In $LTPL$ spectrums of the fine grained $CdTe$ monocrystalline films at excitation on wavelength $\lambda = 476.6\ nm$ by light unceasing gazocharging Ar^+ - a laser with the fundamental band of the radiation with full width on half maximum $\Delta_A \approx 10-20\ meV$ (A-line) and its LO - and $2LO$ - phonon repetitions are observed.

2. The effect of the short-wave offset of the red border A - lines is discovered, bounded $e-h$ - a recombination of hot photocarriers, divided by electric field bordering AVC of crystalline grains. Value of the offset ΔE_r is correlated with spectral full width on half maximum, which depend on structural film defects.

3. In $LTPL$ spectrums of fine grained polycrystalline films $CdTe$ $CdTe:In$, with APV properties unlike monocrystallines and large-block polycrystallines do not reveal exciton and DAS - channels of the radiation, which reason is a process of generation photo-EMF in subbordering areas of crystalline grains, bring about stimulation of the own luminescence and inflammation its LO - phonon repetitions in pure samples.

4. The correlation between $LTPL$ spectrum $(T = 4.2\ K)$ and APV properties of polycrystalline slanting spraying films $CdTe$, $CdTe:In$ are found. In the spectrum of pure samples is dominated the band of own luminescence, conditioned by the presence of potential barriers on the borders grains, generating surface photo-EMF, which asymmetry brings about formation ABP. The alloyage by donor impurity In suppresses the role LO - phonons in relaxation processes of hot photocarriers on energy and, hereunder, brings to stewing of doublet band. The most further TP of slanting spraying films stimulate the asymmetry of potential barrier on border grains, which is adequately reflected in inhomogeneous spreading and sharp activation of the own band, the full width on half maximum Δ_A of which and its offset edge ΔE_r are connected with maximum value of photovoltage V_{APV}.

In conclusion we would like to make a note that offered here optical method of the analysis $LTPL$ spectrums with photoelectric properties of fine grained polycrystalline $CdTe$ films greatly supplements the known electro physical methods and can be used with success for studying properties of other semiconductor film structures and, consequently, the most further study its new possibilities with the purpose of technology modernization of the development efficient film photo converters is required.

REFERENCES

1. V.S. Bagaev, YU.V. Klevlov,S.A. Kolosov, V.S. Krivobok, A.A. Shepeli, Fiz. Tverd. Tela **52**(1), 37 (2015).

2. V.V.Ushakov, YU.V. Klevkov, Semiconductors **37**(9), 1067 (2017).

3. B.Z.Polvonov, Yu.I.Gafurov, U.A.Otajhonov, M.Kh.Nasirov, B.B.Zaylobiddinov The specificity of photoluminescence n-CdS/p-CdTe in semiconductor heterostructures// International Journal of Mathematics and Physics (SCOPUS)- Al-Farabi Kazakh National University, 2022, 13(2), C. 12-19

4. B.Z.Polvonov // The specificity of photoluminescence in CdTe and n-CdS/p-CdTe semiconductor structures//Monography-2023. Generis Publishing 9798886767254. Maldova.

5. B.S.Ruzimatova, B.Z.Polvonov. "The formation of creative thinking in teaching physics."//International Engineering Journal For Research & Development 5 (2020) 5-5.

6. B.Z.Polvonov, N.K. Yuldashev, M.H.Nasirov, F.K. Mirzarakhimova. "Diagnostics of semiconductor materials such as Cadmium chalcogenides by the method of low-temperature polariton luminescence"//Journal of International Scientific Review, Boston, USA 11(53).(2018):24.

7. B.Z.Polvonov, M.Kh.Nasirov, O.Z.Polvonov, B.K.Tuychibaev "Osobennosti povisheniya moshnosti fotovoltaicheskikh plenochnix struktur chalkogenidov cadmiya"// Oriental renaissance: Innovative, educational, natural and social sciences 1(11).(2021):1046