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DEPOSITION OF THE CADMIUM TELLURIDE FILMS FOR BASE LAYERS OF FLEXIBLE PHOTOELECTRIC CONVERTERS BY THE MAGNETRON SPUTTERING METHOD ON THE DIRECT CURRENT

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Abstract

In order to create thin-film photovoltaic converters based on cadmium sulfide and telluride experimental studies of the process of cadmium telluride magnetron sputtering with direct current, and the impact of a magnetron sputtering mode on CdTe films crystalline structure were carried out. CdTe films for the base layers of film photovoltaic converters were obtained on flexible polyimide substrates by magnetron sputtering with direct current for the first time. It was found that increasing the magnetron discharge current up to 80 mA leads to increase in coherent scattering regions what is due to an increase in the thickness of the cadmium telluride films of the hexagonal modification having a columnar structure. A further increase in the discharge current leads to a decrease in the size of coherent scattering regions what is caused by the thermodynamical output formation of low-angle boundaries. It was shown experimentally that the "chloride" processing of the obtained cadmium telluride layer leads to the transformation of the metastable hexagonal modification cadmium telluride in a stable cubic modification. At the same time, due to the eutectic recrystallization, increase in the sizes of coherent scattering regions by a decade and the microstrain level reduction in 1.5 times are observed.

Keywords: film photoelectric converter based on cadmium sulfide and telluride, method of magnetron sputtering with direct current, "chloride" processing, hexagonal and cubic modification.

1. Introduction

Film photovoltaic converters (PVC), based on cadmium sulfide and telluride, represent an alternative to the most widespread silicon crystalline photovoltaic converters in the capacity of autonomous sources of electric energy in terrestrial and space conditions. Modern high efficiency film PVCs based on CdS / CdTe are manufactured in the back configuration of the glass substrate through which solar radiation enters the base layer [1]. In terrestrial conditions PVCs based on CdS / CdTe, in accordance with the optimum band gap of cadmium telluride, have the greatest theoretical coefficient of performance (COP) - 29%, and in space applications, due to the nature of the chemical bonds of CdTe are the most resistant to radiation [2]. In addition, lower material and energy consumption of manufacturing process of film photovoltaic converters based on CdS / CdTe provides a lower cost compared to crystalline silicon photovoltaic converters. For example, in the conditions of industrial production, First Solar company which manufactures photovoltaic converters based on CdS / CdTe said about reaching "grid parity" when the cost of electricity produced by photovoltaic converters equals the cost of electricity produced by conventional power sources [3]. It should be noted that conventional PVCs based on CdTe photovoltaic converters essentially concede to PVCs based on crystalline silicon in power density (value of electric power generated per unit weight of a PVC).

Substitution of glass substrates which are conventional for photovoltaic converters based on CdS / CdTe to a flexible substrate allows the reduced power to increase by several orders of magnitude, and to surpass by this parameter not only silicon-based photovoltaic converters, but also photovoltaic converters on the basis of A_3B_5. However, in addition, due to the lower thermal stability of the polyimide substrate it is necessary to reduce the deposition temperature of the cadmium telluride films below 400 °C what is impossible for methods of close-spaced sublimation [4, 5] and vapor phase transport deposition [6, 7] which are conventionally used to produce high performance photovoltaic converters based on CdS / CdTe. When implementing these methods forming the base layer of cadmium telluride is carried out at a deposition temperature of 550 °C.

Low temperature techniques for production of cadmium telluride films that can be realized in mass production includes magnetron sputtering method [8, 9]. The main technological challenge of getting the semiconductor films by magnetron sputtering with direct current is a low rate of film growth. This is because during sputtering a low-conducting substrate accumulation of positive charge takes place, and this charge does not have time to drain off. This creates a counterfield inhibiting the argon ions which bombard the substrate what causes a decrease in the discharge current.

Therefore, obtaining of cadmium telluride films for base layers of flexible photovoltaic converters by magnetron sputtering with direct current is an urgent technological problem for which solution experimental studies of the process of cadmium telluride magnetron sputtering with direct current and of the impact of the magnetron sputtering modes on the crystalline structure of CdTe films have been carried out.

2. Experimental Technique

In the work we have used deposition of cadmium telluride films by magnetron sputtering with direct current. We used an experimental vacuum plant VUP-5M with original magnetron systems what important design feature was their cooling circuit which includes only a magnetic system. This made it possible to vary quite widely the surface temperature of the target. The target was made by cold pressing of cadmium telluride powder intended to produce semiconductors of grade "ch" (TU 6-09-01-429-77). The target diameter was 76 mm, thickness - 2 mm. Target cold pressing pressure was 100 MPa. The dwell time of the target at this pressure was 15 hours. After pressing the target its vacuum annealing was performed at a residual pressure of at least 10^{-4} mm Hg and a temperature of 80 °C. When depositing CdTe layers thermostable polyimide film manufactured by Upilex firm with thickness up to 10 microns was used in the capacity of a substrate. The flexible substrate was positioned in a movable substrate holder of VUP-5M vacuum chamber in close contact with the front surface of the thermocouple. Before the process of applying the cadmium telluride layers pumping in the working volume to a pressure of 10^{-5} Pa was carried out. Argon puffing in the capacity of a working gas was carried out using an automated puffing system SNO.

Taking of X-ray diffractograms for the cadmium telluride films was carried out by θ-2θ scanning method with Bragg-Brentano focusing procedure using X-ray diffractometer DRON-4 with a step 0.01-0.02 degrees in Kα radiation of a cobalt anode ($\lambda_{CoK\alpha}$ = 1.78897Å).

Under these conditions, the diffraction pattern was formed by the grains with reflecting planes parallel to the surface of samples *(hkl)* [10]. Identification of the phase composition of the samples was carried out by comparing the angles 2θ of clearly defined peaks obtained when shooting, with filed reference data from JCPDS (Joint Committee on Powder Diffraction Standards) which have been obtained by means of an electronic database "PCPDFWIN" for the respective phases.

Processing of single peaks in X-ray diffractograms (smoothing, background separation, separation of the doublet Kα1 - Kα2) and calculation of the profile parameters of the diffraction lines (peak position, interplane distance, integrated intensity of the peak, and integral width) were carried out using the computer program "New_Profile. Sizes of coherent scattering regions (L_i) and the microstrain level (ε) were determined with regard to the physical broadening of the diffraction maxima (β). The diffraction distribution β was estimated by calculation by approximation of the diffraction profiles with use of Gauss-Cauchyfunction [10]. To identify structural features of the cadmium telluride base layers the method of so-called "oblique" shooting was used where in the radiation of the cobalt anode by 2θscanning there were detected and pointwisely registered the diffraction reflections from the planes of sphalerite and wurtzite modifications of cadmium telluride that are not found when using the registration method set forth above, because the texture is available on the sample [11].

To do this, the sample was rotated relative to the initial position at an appropriate angle (the angle between the plane which formed the most intense diffraction peak when focusing with regard to Bragg-Brentano, and the target plane).

3. Results and their Discussion

3.1 Study of the cadmium telluride magnetron sputtering with direct current

In the course of studying the process of magnetron sputtering with direct current to produce cadmium telluride films, five technological modes have been implemented (see the table 1); they differed by argon pressure (P_{arg}), the magnetron voltage (V), and substrate and the target heating mode. When conducting researches, the dependence of the discharge current of the magnetron (I) on the sputtering time (t) was measured.

It was found that in the process of magnetron sputtering of a cadmium telluride target the change of discharge current is observed (Figure1). Firstly, upon implementation of the first mode when the magnetron was switched off conducted the substrate has been pre-heated to a temperature of 200 °C. Upon that, the substrate was moved away from the magnetron. Then 800 V voltage was applied to the magnetron, an argon pressure was 2.5 Pa, and after that the substrate was transferred to a position above the magnetron. Measurement of discharge current dependence on the sputtering time (Table 1) shows that during the first four minutes of sputtering the discharge current does not exceed 1.2 mA. It was visually found that upon such a current discharge cadmium telluride film on a flexible substrate surface has not been formed as target sputtering hardly occurred. However, since 4 to 8 minutes of sputtering discharge current has increased to 60 mA (curve 1, Figure 1) and then during the subsequent sputtering time the current has not changed. Thus, active formation of cadmium telluride film on the substrate surface was visually observed.

Table 1 - Magnetron Sputtering Process Parameters.

Mode No.	Parameters \ t, min	0	2	4	5	7	10	12	15	17	20
1	P_{arg}, Pa	2.5									
	I, mA	1.2	1.7	2.94	15	50	59	58	57	62.7	57.7
	U, V	800	800	800	750	700	650	600	600	600	600
2	P_{arg}, Pa	2									

	I, mA	3.13	7	20	62	83	82	85	81	82	77
	U, V	600	600	600	600	600	600	600	600	600	600
3	P_{arg}, Pa	1.8									
	I, mA	56	69	57	55	52	52	50	51	48.5	50
	U, V	600	600	600	600	600	600	600	600	600	600
4	P_{arg}, Pa	1.7									
	I, mA	62	60	61	64	60	62	62	63	66	60
	U, V	600	600	600	600	600	600	600	600	600	600
5	P_{arg}, Pa	1.5									
	I, mA	75	72	68	70	71	72	63	62	61	59
	U, V	600	600	600	600	600	600	600	600	600	600

When implementing the second mode, simultaneously with the start of heating the substrate which was away from the magnetron a voltage V = 600 V was applied to the magnetron, with P_{arg} = 2 Pa. Target pre-heating temperature was 200 °C. Then without interrupting the magnetron discharge the substrate was moved to a position above the target. It was found that the magnetron sputtering process starts with an initial discharge current 3.1mA (Table 1). By increasing the sputtering time to 4 minutes it was detected experimentally that discharge current increases to 20 mA, then with a further increase of sputtering time to 8 minutes the discharge current has increased to 85 mA (curve 2, Figure 1). With further increase in sputtering time from 8 minutes to 20 minutes there was a slight decrease in the current by 10%.

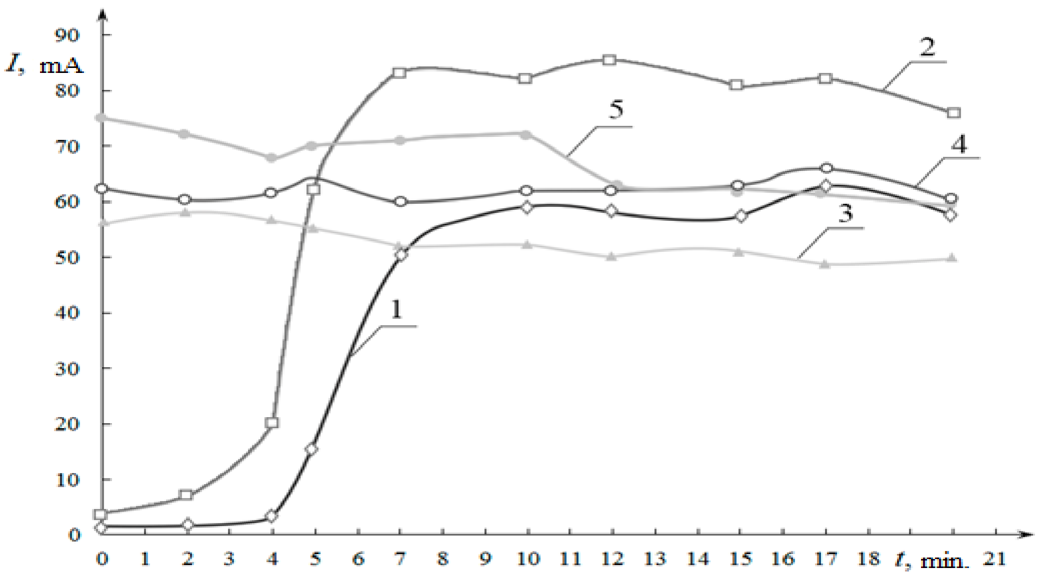


Figure 1 - The discharge current dependence on the sputtering time for various processes.

In the third mode in a position when the substrate was spaced away from the magnetron, firstly, it was heated to 200 °C, then for 3 minutes the substrate was heated at a position above the magnetron. Then 600 V voltage was applied to the magnetron at argon pressure of 1.8 Pa. This change in process conditions led to an increase of the initial discharge current up to 55 mA (Table 1). In the process of sputtering there was a slight monotonous decrease in discharge current to 50 mA (curve 3, Figure 1).

In comparison with the third process mode, in the course of implementation of the fourth mode, the heating temperature of the substrate both at the side of the magnetron and above the magnetron surface was increased to 230 °C. Voltage of 600 V was applied to the magnetron at an argon pressure of 1.7 Pa. As a result of this mode the initial discharge current increased to 62 mA (see Table 1). In the process of sputtering there was a slight decrease in monotonous discharge current to 60 mA (curve 4, Figure 1).

When implementing the fifth mode the substrate heating temperature was increased to 240 °C, and the time of preheating the substrate surface of the target was decreased to 5 minutes. This led to an increase in initial current to 75 mA (Table 1) at a voltage of 600 V and argon pressure of 1.5 Pa. In the process of sputtering a monotonic decrease in the discharge current to 60 mA (curve 5, Figure 1) was observed.

The carried out research of the magnetron sputtering process with direct current of the cadmium telluride target has shown that changing the magnetron sputtering current in the process of CdTe film deposition is related to target material surface heating. Experiments show that this can occur due to thermal radiation from the substrate surface. Indeed, it has experimentally demonstrated that with increasing of substrate temperature and, particularly, its heating time over the target surface, an increase of the initial discharge current of 1.2 mA to 75 mA (Table 1) is observed. The temperature of the target surface also increases with magnetron sputtering time due to the bombardment of the target by ions of the working gas. This is confirmed experimentally by the presence of areas with rapid growth of the discharge current with the discharge time (see data on modes 1 and 2 in Table 1).

From our point of view, heating up of the target surface causes increase in the intensity of the thermal emission of secondary electrons from the target surface in the magnetron discharge zone and reducing the electric resistance of the target as a result of the thermal generation of the main charge carriers. Increase in the concentration of the secondary electrons increases the probability of ionization of the argon molecules what in turn causes increase in the intensity of the argon ion bombardment of the target surface and therefore the target sputtering rate. Generation of main carriers lowers the target resistivity and decreases the intensity of the accumulation of positive charge that leads to formation of the electric counterfield retarding accelerated argon ions which bombard the target. Availability of a charge accumulation process is confirmed by experimentally observed decrease in the discharge current (see, for example, mode 5). The experimentally observed stabilization of the discharge current irrespective of the technological process of magnetron sputtering indicates the occurrence of the heat balance mode in the target.

3.2 Studying the influence of modes for obtaining the cadmium telluride films on their crystalline structure

Based on the analysis of the process of magnetron sputtering cadmium telluride films with direct current we have selected deposition modes what provide intensive sputtering of a target. For this purpose we pre-heated the substrate up to 410 - 420 °C.

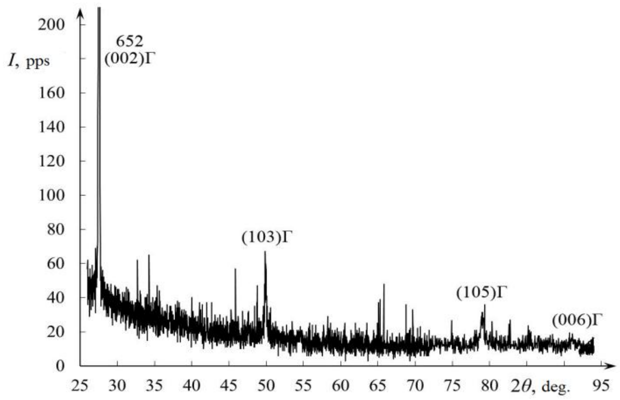
After reaching this temperature, the movable substrate holder was transferred to the mode above the target, as a result the target was also heated for 5-8 minutes. A voltage was applied to the magnetron, and the process of deposition of cadmium telluride films has started. Upon that, the discharge current varied within the range of 40 mA to 100 mA for different samples by variation of the magnetron power ranging from 600 V to 650V, and of an argon partial pressure from 1 Pa to 0.8Pa (Table 2). Thus, discharge current was almost not changed in the process of sputtering. The substrate temperature during the deposition was also virtually unchanged and was 300 ^{o}C. The duration of the films deposition process ranged from 15 to 25 minutes.

Table 2 - Technological modes for production of CdTe films.

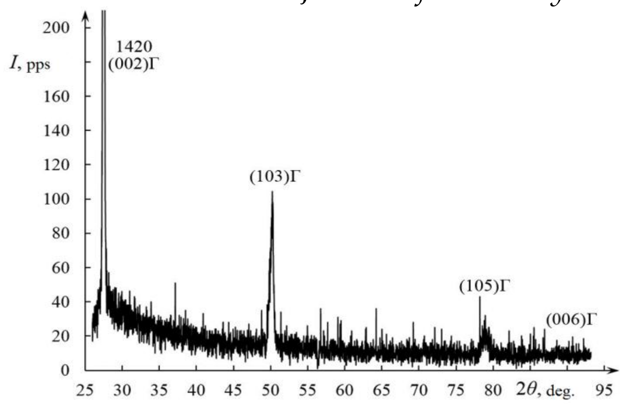
Sample	t, min	P_{apr}, Pa	U, V	I, mA	D, nm	V, nm / min
CdTe3	25	0.8 - 1	600	40	1030	41
CdTe4	25	0.8 - 1	600	60	2360	94
CdTe6	25	0.9 - 1	650	80	5200	208
CdTe7	15	0.8 - 0.9	650	100	5500	367

The increase in the average growth rate of the cadmium telluride films from 41nm / min to 367 nm / min with increasing discharge current from 40 mA to 100 mA was established experimentally, so the selected modes of the magnetron operation do not fall in the saturation region what provides good process control and film deposition rate sufficient for mass production.

The crystalline structure of the cadmium telluride films has been investigated using the method of X-ray diffraction. Figure 2 shows the X-ray diffractograms of samples 3 and 6. Analytical processing of the experimental X-ray diffractograms made it possible to determine the position of the diffraction peaks, their intensity and half-width (Table 3).



a)



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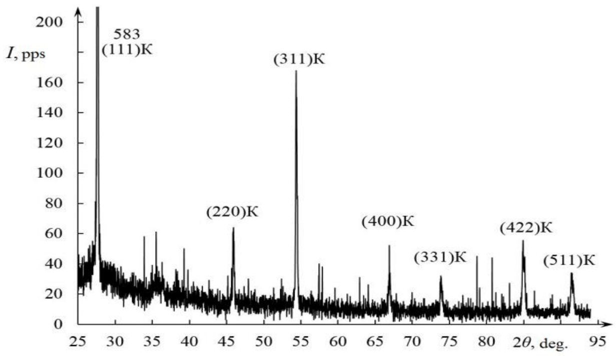


c)

Figure 2 - X-ray diffractograms of CdTe films:

a - I = 40 mA, b - I = 80 mA, c- I = 80 mA after the "chloride" processing.

Table 3 - Analytical processing of X-ray diffractograms for cadmium telluride films obtained by magnetron sputtering with direct current.

Sample	I, mA	Peak position, degree	(hkl)	Interplanar distance, Å	Intensity, pulses / s	Half-width, degree
CdTe3	40	27.52	(002)	3.760	419	0.15
		49.89	(103)	2.121	23	0.30
		78.98	(105)	1.407	20	0.59
		91.07	(006)	1.253	10	0.24
CdTe4	60	27.49	(002)	3.764	1787	0.14
		91.03	(006)	1.254	24	0.33
CdTe6	80	27.48	(002)	3.770	944	0.18
		50.14	(103)	2.110	52	0.54
		78.89	(105)	1.410	8	1.07
		91.01	(006)	1.254	93	0.26
CdTe7	100	27.53	(002)	3.759	2750	0.14
		78.95	(105)	1.407	17	0.98
		91.05	(006)	1.254	117	0.27

In all X-ray diffractograms there are two distinguishable double peaks at angles 2θ 27.05 ° and 91.05 ° what may belong to both hexagonal and cubic CdTe modifications: a reflection (002) and (006) for wurtzite and reflection (111) and (333) **for** sphalerite, respectively. High intensity of these peaks indicates that the films have a preferred direction. This direction is [111] in the case of cadmium telluride sphalerite modification or [0001] in the case of CdTe wurtzite modification. As the X-ray diffractogram demostrate peak reflections at the angles 2θ 49.89° and 78.98° what may belong to the wurtzite planes (103) and (105), it becomes evident that the studied cadmium telluride films have hexagonal modification. To determine whether there is a cadmium telluride sphalerite modification in the test layers we have carried out "oblique" shooting. To carry out "oblique" shooting by the formulas (1) and (2), we have calculated the angles between planes (111) and (620) for the cubic modification (002), and (105) and (002) for the (515) hexagonal modification:

$$\cos\theta_1 = (h_1h_2+k_1k_2+l_1l_2) / (\sqrt{h_1^2+k_1^2+l_1^2} \cdot \sqrt{h_2^2+k_2^2+l_2^2}), \quad (1)$$

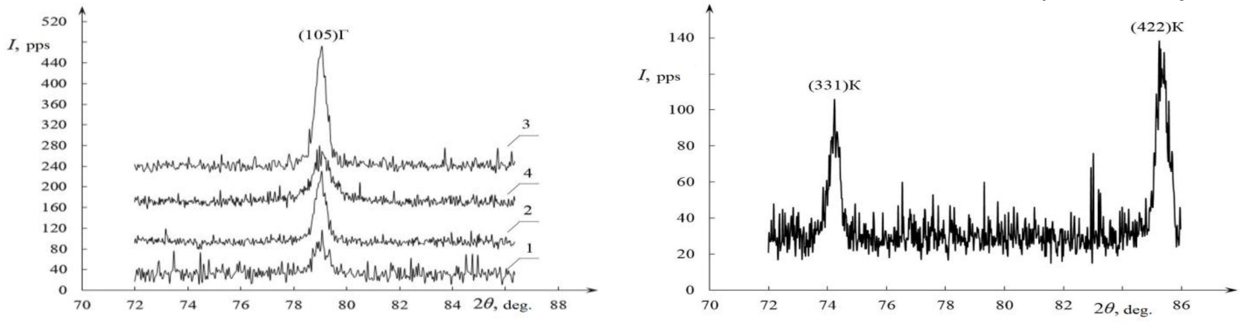
where h_1, k_1, l_1 - plane indices (111), h_2, k_2, l_2 - plane indices (620)

$$\cos\theta_2 = (h_1h_2+k_1k_2+1/2\,(h_1k_2+h_2k_1+3/4\,(a^2/c^2)\, l1l2)) /$$

$$/ ((h_1^2+k_1^2+h_1k_1+3/4\,(a^2/c^2)\, l12)^{1/2} \cdot (h_2^2+k_2^2+h_2k_2+3/4\,(a^2/c^2)\, l22)^{1/2}), \quad (2)$$

where h_1, k_1, l_1 - plane indices (002); h_2, k_2, l_2 - plane indices (105) or (515); a, c - hexagonal lattice parameters of cadmium telluride.

Calculations demonstrate that the angle between the planes (111) and (620) of a cubic phase is about 43.08°, the angle between the planes (002) and (105), and (002) and (215) of the hexagonal phase - 20.7° and 78.46°, respectively. Based on the calculations, X-ray surveys were conducted to determine the phase composition of the produced films at the angles 2θ of 72-85° by rotating the sample at an angle of 20.7°. Selection of the sample rotation angle value was caused by the fact that the angle between the direction of [001] and [105] of the hexagonal modification is 20.68°, and the angles between the directions [331] and [422] to direction [111] are 22 to 19.47°. Therefore, if to turn to the specified angle the reflection of [105] for the hexagonal modification and the reflections [331] and [422] for the cubic modification should occur. Results of oblique shooting are shown in Figure 3. For the films studied, in the area of 2θ 72-85° only the diffraction peak (105) of the hexagonal phase is observed and diffraction peaks (331) and (422) of the cubic modification can not be detected. Thus it can be concluded that in this case the tested films are formed of hexagonal CdTe modification and further calculations were carried out for this phase.



a) **b)**

Fig. 3- X-ray patterns for basic CdTe layers during the "oblique" shooting:

a) 1- I = 40 mA, 2- I = 60 mA, 3 - I = 80 mA, 4 - I = 100 mA;

b) I = 80 mA, after the "chloride" processing

Proceeding from the positions of diffraction peaks calculations of the interplanar distances (Table 3) were carried out. Data analysis shows that at the start with increasing the discharge current from 40 mA to 80 mA, an increase of interplanar distances for all identified planes is observed. A further increase in the discharge current from 80 mA to 100 mA reduces the interplanar distances. By the physical broadening of the diffraction peaks by approximation of their profiles using the Gauss-Cauchy function there were investigated the effect of the magnetron sputtering modes on the size of coherent scattering regions (CSR) and microstrain level (Table 4) for grains oriented in the direction (002). It was found that by increasing the sputtering current from 40 mA to 80 mA, an increase in CSR size from 52 nm to 132 nm is observed. From our perspective, this is primarily due to the increase in the cadmium telluride film thickness from 1.0 micron to 5.2 microns with an increase in film growth rate which is caused by the growth of the sputtering current. Increasing the CSR size with increasing the film thickness is a natural physical process. Traditionally, in the course of cadmium telluride film deposition on a nonoriented substrate initially fine crystalline defect layer is formed in which grains have random crystallographic orientation. Then, as the film thickness growth due to different rates of growth of grains with different crystallographic orientation a columnar structure is formed with grains oriented in the crystallographic directions which are characterized by the maximum growth rate [12]. Upon that, grain growth with another crystallographic orientation is suppressed.

Table 4 - Results of calculation of coherent scattering regions sizes (L_i) and the microstrain level (ε)

Sample	Cauchy approximation		Gaussian approximation		Average value	
	L_i, Å	ε, relative units	L_i, Å	ε, relative units	L_i, Å	ε, relative units
CdTe3	55	$7\cdot10^{-2}$	48	$8.5\cdot10^{-2}$	52	$7.8\cdot10^{-2}$
CdTe4	120	$5\cdot10^{-2}$	95	$5.3\cdot10^{-2}$	108	$5.2\cdot10^{-2}$
CdTe6	165	$4\cdot10^{-2}$	98	$7\cdot10^{-2}$	132	$5.5\cdot10^{-2}$
CdTe7	105	$5\cdot10^{-3}$	87	$5.5\cdot10^{-3}$	96	$5.3\cdot10^{-2}$

For hexagonal modification of cadmium telluride maximum growth rate belongs to crystallographic direction (002). According to the results of structural studies, the obtained cadmium telluride films are oriented in this crystallographic direction, as evidenced by the high values of the intensity of the corresponding diffraction peaks (see table 3) and the presence of multiple peaks (004). For a columnar structure with increasing thickness a grain size is also grows, and the boundaries between them have high angle values. In addition, inside grains the degree of development of low angle boundaries also decreases due to the decrease in number of defects what leads to an increase in CSR size.

Further growth of the sputtering current from 80 mA to 100 mA reduces CSR sizes from 132 nm to 96 nm, in spite of the continued growth of the film thickness of cadmium telluride to 5.5 microns. This indicates an increase of defects number in the growing layers with increasing the sputtering current. In our view, the experimentally identified increase of film growth rate from 208 nm / min to 367 nm / min reduces the mobility of atoms deposited on the substrate what in turn increases the number of point structural defects. The defect density growth leads to an increase in free energy to such an extent that there becomes thermodynamically favorable the formation in the growing layer of low angle boundaries which are the drain point structural defects.

Research of microstrain level shows that with the growth of the sputtering current from 40 mA to 60 mA, there is a decrease in the level of microstrains, and then the level of microstrain practically unchanged.

Thus, from the standpoint of obtaining cadmium telluride films with a minimum number of structural defects, optimal discharge current is 80 mA.

For the cadmium telluride film received in these modes there was carried out "chloride" processing which is convenient for the formation of basic layers of cadmium telluride for high-efficiency film photovoltaic converters on their basis. [13] To perform the "chloride" processing, cadmium chloride layers were deposited on the surface of cadmium telluride films by vacuum evaporation without heating the substrate. Then annealing in air at 430 °C for 25 minutes was carried out [14].

According to the literature [15] at this temperature base layers of cadmium telluride recrystallize without phase separation due to the presence of low-temperature eutectic in CdTe-$CdCl_2$ system.

The diffractogram of the cadmium telluride film after the "chloride" processing shows the peaks belonging to the cubic modification CdTe (Fig. 3, Table 5). Only peaks (331) and (422) of cubic modification are observed on the diffraction pattern obtained by the method of "oblique" shooting angle within the range of 2θ from 72.5° to 87.5°at

20.5° turn of the sample, and the peak (105) of hexagonal modification is not detected there. Thus, after the "chloride" processing a cadmium telluride film contains the hexagonal phase. After "chloride" processing there is also observed reduction of peak width (111) and (333) as compared with the peaks (002) and (006) of hexagonal phase in the samples before the "chloride" processing (compare tables 3 and 5). Calculations of CSR sizes and the level of microstrain showed an increase of CSR to 230 nm and a decrease in the level of microstrain up to $3 \cdot 10^{-2}$

Table 5 - Results of processing the diffraction pattern of CdTe6 sample after "chloride" processing.

Peak position, degree	Index hkl	Interplanar distance, Å	Peak intensity, pulse / s	Half-width, degree
27.59	(111)	3.751	402	0.15
45.88	(220)	2.295	34	0.19
54.35	(311)	1.959	128	0.15
66.89	(400)	1.623	20	0.23
73.83	(331)	1.489	18	0.22
84.90	(422)	1.325	76	0.25
91.44	(511)	1.249	40	0.32

3. Conclusions

For the first time, the cadmium telluride films of hexagonal modification by thickness of 1-5 mm have been produced on flexible polyimide substrates by magnetron sputtering with direct current due to heating the target surface to intensify the thermal emission of the secondary electrons in the magnetron discharge zone and to reduce the electrical resistance of the target as a result of thermal generation of main charge carriers; that allows the films to be used as a base layer in film photovoltaic converters.

It was found that upon increasing the magnetron discharge current to 80 mA the rise of CSR sizes is observed what is caused by an increase in the thickness of the cadmium telluride films having a columnar structure. Further growth of the discharge current leads to a decrease in CSR sizes due to thermodynamically favorable formation of low-angle boundaries what is the physical mechanism compensating the increase in number of radiation point defects upon intensification of the magnetron sputtering process.

It is shown, that a decrease in the level of microstrains is observed with an increase in the discharge current to 60 mA, and a further increase has no significant effect.

It was shown experimentally that the "chloride" processing of cadmium telluride layers carried out by deposition of cadmium chloride films followed by annealing in air at 430 °C for 25 minutes leads to the transformation of the metastable hexagonal modification cadmium telluride in a stable cubic modification. At the same time due to the eutectic recrystallization, CSR size growth by an order of magnitude is observed and decrease of a microstrain level

in 1.5 times. This article was prepared within the framework of the implementation of applied research and experimental development (PNIER) under the Agreement on the provision of grants dated October 27, 2015 №14.607.21.0137 at the financial support of the Ministry of Education and Science of the Russian Federation. Unique PNIER identifier is RFMEFI60715X0137.

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