ELECTROPHYSICAL PROPERTIES OF MnHgTe EPITAXIAL LAYERS OBTAINED BY PULSED LASER ASSISTED EVAPORATION AND DEPOSITION[1]

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Thin (2—3 μm) epitaxial $Mn_xHg_{1-x}Te$ (MMT) layers have been obtained by the pulsed laser assisted evaporation and deposition. The peculiarities of the deposition of those layers onto CdTe (111) substrates have been studied. The influence of technological parameters on the structural and electrophysical properties of MMT layers has been investigated. The epitaxial growth of MMT layers has been found to occur in a narrow range of the substrate temperature, from 180 to 210 °C. The as-grown layers are of the n-type with the electron concentration and mobility of $(0.6 \div 3) \times 10^{17}$ cm^{-3} and $(3.5 \div 6.5) \times 10^3$ cm^2/(V × s), respectively, at 77 K. The two-stage thermal treatment of the specimens in Hg vapors induces a drastic increase of the current carrier mobility (by a factor of 30—50).

1. Introduction

Semiconductor solid solutions MMT are a perspective material for modern electronic technics [1, 2]. While manufacturing high-quality photodetectors of IR radiation, it is of special importance to produce thin MMT layers with a homogeneous distribution of components across the thickness and on the surface of a layer, a perfect structure, and a small concentration of defects. The following methods of thin MMT layer epitaxy from the vapor phase are known: vapor phase epitaxy [3], metal-organic vapor phase epitaxy [4], and molecular beam epitaxy [5].

The method of pulsed laser evaporation and deposition is widely used for making thin layers of multicomponent $A^{II}B^{VI}$-based semiconductor compounds. In particular, this method was applied to the growing of MMT epitaxial layers [6–8]. The electrical parameters of the epitaxial layers obtained meet the requirements for the production of detectors in the IR range.

In this work, we demonstrate an opportunity to produce the epitaxial MMT layers on CdTe (111) substrates making use of the method of pulsed laser evaporation and deposition. The features of the formation of the MMT layer structure and their dependence on the growth conditions have been studied. The MMT epitaxial layers with $x = 0.10 - 0.13$ and n-conductivity were produced, provided that the temperatures of the substrate was sustained in a narrow interval $T_s = 180 \div 210$ °C. The influence of a thermal treatment on the physical properties of MMT layers has been studied. The best results were achieved provided a two-stage thermal treatment of specimens in mercury vapors. In this case, the MMT layers preserved their conductivity of the n type, the current currier concentration became lower to some extent, and their mobility increased by a factor of 30—50.

2. Experimental Method

Thin MMT layers were grown by the method of pulsed laser evaporation and deposition in a dynamic vacuum [9]. Single-crystal MMT slabs with the Mn content of about 12 at.% served as targets. To evaporate the material of the target, a neodymium laser with a wavelength of 1.06 μm operating in the free generation mode was applied. Thin MMT layers were deposited provided the average power of laser emission of 0.03 – 0.6 W, the pulse duration t of about 10 μs, and the pulse repetition frequency of 12.5 – 25 Hz. The beam was focused to a 0.05-cm point on the target surface. To provide the uniform evaporation of the target material, we used a device which scanned the laser beam. The evaporated material was deposited onto single-crystal slabs of cadmium telluride oriented in the [111] direction; the substrate temperature T_s extended from room one up to 265 °C. The deposition rate was 4—6 μm/h, when the target–substrate distance was 4—5.5 cm. The thickness of the layers obtained was 2—3 μm. Typical values of the technological parameters, which we used for depositing thin MMT layers, are quoted in Table 1.

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The peculiarities in the formation of the structure of thin MMT layers were studied making use of the RHEED method. The electrophysical parameters were measured following the standard methods of measuring in the dc mode, in the magnetic field $B = 0.1$ T, and in the temperature range $80 - 300$ K.

3. Results and Discussion

Electron-diffraction studies of the produced thin MMT layers showed that structurally perfect epitaxial layers grew in a narrow interval of the substrate temperature $T_s = 180 \div 210$ °C and with a deposition rate of 4 μm/h [9]. The main defects of those layers included microtwins and stacking fault dislocations. At elevated temperatures, the structural perfection of MMT layers became worse, which is explained by losses of mercury from the layer growing on the substrate. According to the data of X-ray microprobe analysis, the distribution of the components over the surfaces of the MMT epitaxial layers was uniform.

Electrophysical measurements were performed on untreated specimens and specimens annealed in mercury vapors. The procedure of thermal annealing in mercury vapors included two stages: a short-term high-temperature annealing at 400 °C and a long-term low-temperature one at 210 °C. The electrophysical parameters of the researched specimens are listed in Table 2. The energy gap width E_g and the content x of Mn were determined from the transmission spectra at room temperature, by using the dependence [1]

$$E_g(x,T) = -0.253 + 3.44x +$$

$$+4.9 \cdot 10^{-4}\, T - 2.55 \cdot 10^{-3} xT.$$

In the range of optical transparency of the MMT layers with various thicknesses, the transmission spectra reveal interference, which evidences for a high homogeneity of the layer across its thickness, an unruffled surface, and a sharp substrate–layer interface.

The temperature dependences of the Hall constant R_{H} and the Hall mobility $R_{\mathrm{H}}\sigma$ are exhibited in Fig. 1. The temperature behavior of the Hall mobility of current curriers in the MMT layers testifies to that electrons are mainly scattered by thermal fluctuations of the crystal lattice at the temperature of epitaxial growth $T_s = 180 \div 210$ °C ($R_{\mathrm{H}}\sigma \sim T^{-3/2}$) (Figure,*d*). If the growth temperature goes beyond this interval (i.e. $T_s < 180$ °C or $T_s > 210$ °C) and the structural perfection of the MMT layers becomes worse, the scattering by structural defects and ionized impurities manifests itself, becoming dominating at $T_s < 150$ °C ($R_{\mathrm{H}}\sigma \sim T$) (Figure,*c*).

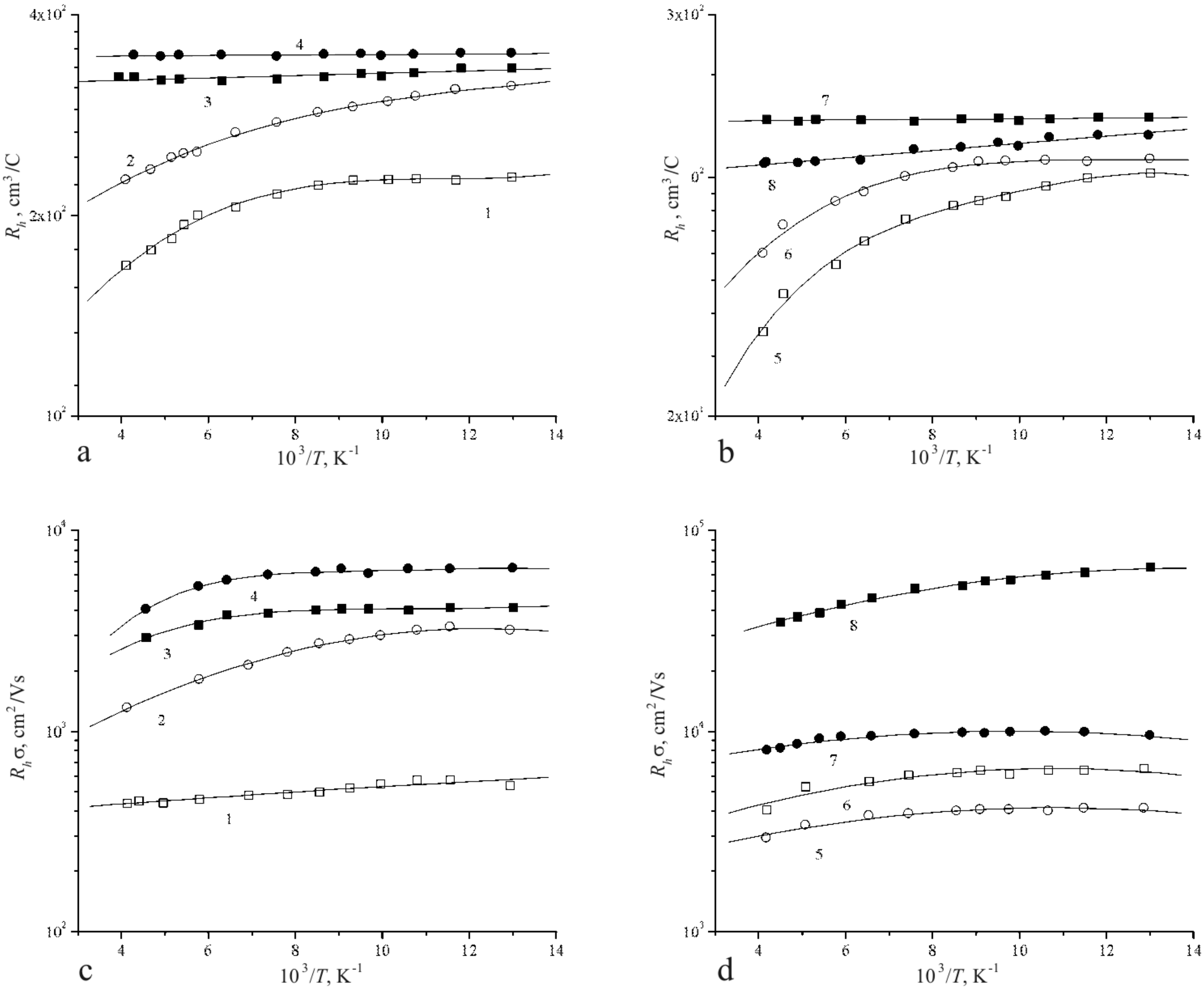
The *n*-conductivity of the MMT layers can be explained by the fact that the atomization of the target proceeds in the laser erosion plasma consisting of high-energy neutral admixtures and ions, which is the reason for the generation of radiation-induced defects that act as donors in the growing film. The Hg—Te bounding forces are the weakest in the MMT solid solutions; on the other hand, since the own MMT defects such as Te vacancies and interstitial Hg atoms are donors, one may put forward the assumption that it is the defects of this type that are formed when the deposition of thin MMT layers from the laser erosion plasma takes place. A similar assumption was made in [7], while obtaining thin CdHgTe layers by the method of pulsed laser evaporation and deposition.

Table 1. Conditions of producing thin $Mn_xHg_{1-x}Te$ layers

Laser	pulsed Nd:YAG laser
The wavelength	$\lambda = 1.06$ μm
The pulse duration	$\tau \sim 10$ μs
The average power of laser emission of	0.03—0.6 W
The pulse repetition frequency	$f = 12.5 \div 25$ Hz
Target	$Mn_{0.12}Hg_{0.88}Te$
Linear speed of scanning	$V = 1.25$ cm/s
Substrate	CdTe (111)
Target–substrate distance	$d = 4 \div 5.5$ cm
Term of deposition	$t = 0.5 \div 1$ год
Substrate temperature	$T_s = 25 \div 265$ °C

Table 2. Electrical parameters of thin $Mn_xHg_{1-x}Te$ layers

N	x	d, μm	T_s, °C	T, K	E_g, eV	R_h, cm^3/C		$R_h\sigma$, cm^2/(V·s)	
						before annealing	after annealing	before annealing	after annealing
71	0.101	2.1	150	300	0.164	170	320	450	1700
				77	0.113	230	330	535	4100
72	0.123	2.2	190	300	0.223	225	345	1300	3500
				77	0.184	310	350	3200	6500
73	0.128	2.0	200	300	0.237	35	150	4000	35000
				77	0.200	103	145	6500	66000
74	0.133	2.1	230	300	0.250	53	110	2940	8000
				77	0.217	113	135	4150	10000



Temperature dependences of the Hall constant (*a* and *b*) and the Hall mobility (*c* and *d*) for the MMT layers before (curves *1*,*2*,*5*, and *6*) and after their two-stage annealing (curves *3*,*4*,*7*, and *8*): specimen 71 (*1* and *3*), specimen 72 (*2* and *4*), specimen 74 (*5* and *7*), and specimen 73 (*6* and *8*)

After the two-stage annealing, the electrical parameters of the layers change drastically, especially the value of the Hall mobility $R_{\rm H}\sigma$ – by a factor of 30—50 (Figure,*c* and *d*). It can be explained by the annealing of structural defects, as well as radiation-induced point ones which are formed during the growth of a layer.

It should be noted that a single-stage isothermal treatment in mercury vapors at 210°C does not bring about a similar result [9]. The value of the Hall constant after the two-stage annealing in mercury vapors is not changed substantially (Figure,*a* and *b*). It may be a result of the high electron concentration $n \sim 10^{17}$ cm^{-3} in the target used, which can be connected to the uncontrollable availability of a dopant inserted in the course of the growth of MMT single crystals.

4. Conclusions

The experimental studies of MMT layers obtained by the method of pulsed laser evaporation and deposition have showed that single-crystalline MMT layers can be produced in a narrow range of the substrate temperature, $T_s = 180 \div 210$ °C. In this case, their conductivity is of the n-type, the current currier mobility is $(3.5 \div 6.5) \times 10^3$ cm^2/(V × s), and the current currier concentration amounts to $(0.6 \div 3) \times 10^{17}$ cm^{-3} at 77 K. A two-stage thermal treatment in mercury vapors enhances the mobility by a factor of 30—50 and insignificantly reduces the concentration of electrons in the layers.

The results of studies concerning the features of the growth of thin $Mn_xHg_{1-x}Te$ layers obtained by the method of pulsed laser evaporation and deposition evidence for good capabilities of this method in the production of high-quality thin epitaxial layers $Mn_xHg_{1-x}Te$ without additional insertion of Hg during the deposition.

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ЕЛЕКТРОФІЗИЧНІ ВЛАСТИВОСТІ ЕПІТАКСІЙНИХ ШАРІВ MnHgTe, ОТРИМАНИХ МЕТОДОМ ІМПУЛЬСНОГО ЛАЗЕРНОГО ВИПАРОВУВАННЯ І КОНДЕНСАЦІЇ

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Резюме

Тонкі епітаксійні шари $Mn_xHg_{1-x}Te$ (2 – 3 мкм) отримано методом імпульсного лазерного випаровування і конденсації. Вивчено особливості їхнього осадження на підкладки CdTe з орієнтацією (111) та досліджено вплив технологічних параметрів на структурні та електрофізичні властивості шарів $Mn_xHg_{1-x}Te$. Встановлено, що епітаксійний ріст шарів $Mn_xHg_{1-x}Te$ спостерігається у вузькому діапазоні температури підкладки — від 180 до 210 °C. Після росту шари мали n-тип провідності з концентрацією носіїв $(0,6 \div 3) \cdot 10^{17}$ см$^{-3}$ і рухливістю $(3,5 \div 6,5) \cdot 10^3$ см^2/(В·с) при 77 K. Різке зростання рухливості носіїв (в 30—50 разів) відбувається після двостадійної обробки в парах ртуті.