Electrical characteristics of $Hg_{1-x}Cd_xTe$ epilayers subjected to ultrasonic influence

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The degradation of electrophysical characteristics of $Hg_{1-x}Cd_xTe$ thin films grown by LPE and MBE as a consequence of the high-frequency and high-intensity elastic deformation effect was investigated. It was determined that parameters of $Hg_{1-x}Cd_xTe$ thin films grown by MBE are stable to ultrasonic influence whereas for $Hg_{1-x}Cd_xTe$ thin films grown by LPE the mobility decrease and the change of the conductivity type at low magnetic field were observed. The best agreement between experiment and calculation was obtained in the frame of assumption about forming of the thin layer with opposite conductivity. The possible mechanism of the observing effects was analyzed.

1. Introduction

$Hg_{1-x}Cd_xTe$ (MCT) remains the most important material for infrared photodetectors despite numerous attempts to replace it with alternative materials such as closely related mercury alloys, Schottky barriers on silicon, SiGe heterojunctions, GaAs/AlGaAs quantum wells, InAs/GaInSb superlattices, etc. At present efforts in infrared detector research are directed towards improving the performance of single element devices, large electronically scanned arrays and higher operating temperature [1-3]. At the same time the stability of the electrical parameters of the most used for FPA arrays MCT epitaxial layers under the external actions is an important factor of reliability of the infrared FPA MCT detector.

It is known that the quality of MCT based devices can be dramatically changed as a result of degradation processes connected with active transformation of the defect system in this material. It is thought that the high-frequency elastic vibration is a good tool for driving semiconductor material into high nonequilibrium states, for transformation of the defect system and for degradation process modeling thus.

2. Experiment

In this study our efforts were focused on investigation of the degradation of MCT electrophysical characteristics as a consequence of the high-intensity ultrasonic treatment. The *n*- and *p*-type MCT (x=0.23÷0.24) thin films for 8÷12 μm spectral region FPAs were grown by liquid-phase and molecular-beam epitaxy. Semi-insulating CdZnTe plates and GaAs plates with CdZnTe buffer layer were used as a substrate respectively.

Hall coefficient R_H and resistivity $\Delta\rho_\perp/\rho_0$ measurements were made by van der Pauw method at T=78°K. High substrate resistivity excluded any influence of the one on results of electrical measurements. An optical microscope was used to determine the thickness of grown layers which was about 10÷20 μm. Some parameters of the typical investigated MCT epilayers have been presented in the Table 1.

The samples of MCT thin films were treated during 30÷60 min at T=300°K by the longitudinal ultrasonic (US) vibrations with frequency f_{US}=7.5MHz and intensity W_{US} which was kept below 10^4W/m^2.

3. Results and discussion

The initial dependencies of the Hall coefficient from the magnetic field $R_H(B)$ were typical for n- and p-type MCT crystals and were analyzed by using a next expression [4]:

$$eR_H(B) = \frac{\sum a_i \mu_i c_i(B)}{\left(\sum c_i(B)\right)^2 + B^2\left(\sum a_i \mu_i c_i(B)\right)^2} \quad (1)$$

where e is the electric charge, $c_i = n_i\mu_i/(1+\mu_i^2B^2)$, n_i is the concentration of the ith type of carrier, μ_i is the mobility of the ith type of carrier, a_i is the sign of carrier (-1 for electrons, +1 for holes), and B is the magnetic flux density. In addition, the zero magnetic field electrical conductivity is given by $\Sigma(0)=e\Sigma c_i(0)$. From the analysis carried out electron and hole concentration and mobility were obtained before and after ultrasonic treatments (Table 1).

We observed the increase of the electron contribution to the conductivity and the decrease of the charge carrier mobility after ultrasonic treatment of MCT epilayers. It was found also that the change of the conductivity type $p \rightarrow n$ at low magnetic field took place for p-type MCT grown by LPE (see Fig.1). It was determined that parameters of MCT thin films grown by MBE (I group) are more stable to US influence than MCT thin films grown by LPE (II group). For the first group of samples the charge carrier mobility and concentration changes were an essential only after second US treatment (see the Table 1).

For clarification of the possible mechanism of observing effects we have carried out some experiments with bulk MCT crystals at *in-situ* ultrasonic loading with pre-threshold intensity. In order to prevent irreversible effects, the US intensity W_{US} was kept below 5 10^3 W/m^2 and the temperature was T≤200°K. The effect of US loading manifests itself as an increase of the electron concentration n in the impurity-conductivity temperature range (T<120° K). The change of the measured parameter had the reversible character with relaxation during 10^2÷10^3s.

Table 1 Some parameters of typical investigated $Hg_{1-x}Cd_xTe$ epilayers, T=78°K.

MCT samples		d, μm	μ_H, cm^2/V c	μ_{H1}, cm^2/V c	μ_{H2}, cm^2/V c	ρ, Ohm cm	ρ_1, Ohm cm	ρ_2, Ohm cm
			initial	after first dose of US	after second dose of US	initial	after first dose of US	after second dose of US
I group	p-type	12	500	500	370	2.1	1.9	1.55
	n-type	14	3500	3400	1100	1.87	1.85	1.6
II group	p-type	19	540	300	200	0.89	1.6	0.54
	n-type	15	3500	1700	1400	0.25	0.13	0.1

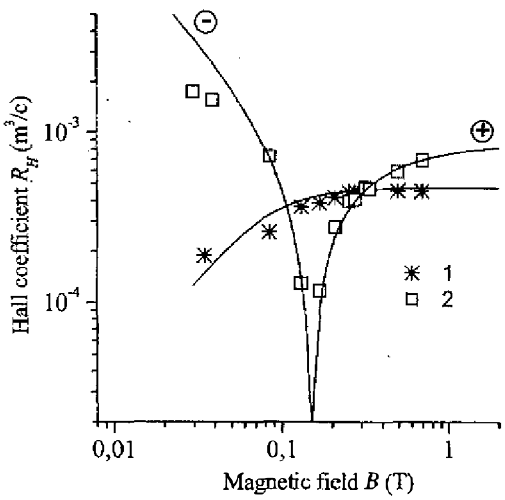

Fig. 1 Hall coefficient magnetic field dependencies at 78K in $Hg_{1-x}Cd_xTe$ thin films grown by LPE: curve 1 – for initial sample, curve 2 – for sample subjected to ultrasonic treatment. Solid lines present the results of the fitting procedure

Considering the sonic-dislocation mechanism as dominant in the ultrasonic-wave interaction with crystal [5], we suggest that the presence of impurities and intrinsic defects "bounded" at dislocations is the main factor that determines sonic-stimulated processes in MCT. Obtained values of the relaxation time of the electron concentration for bulk MCT sample after switching off the US loading confirm the ionic nature of the ultrasonically stimulated processes in this material.

The concentration of "bounded" defects can be expressed as $N=N_0exp(-W_b/kT)$, where W_b is their binding energy, N_0 is the total defect concentration in the crystal [5]. Absorption of the US energy by dislocations during ultrasonic loading results in W_b decrease and some of these "bounded" defects can be released and become electrically active [6]. As a consequence an increase in the effective electron concentration occurs.

Fitting procedure to the experimental data of the p-type MCT sample N3 from the Table 1 was applied (Fig.1). The best agreement between experimental and calculated $R_H(B)$ dependence was obtained in the frame of the assumption about forming of the thin layer with n-type of conductivity as a result of US treatment. Layer thickness d and charge carrier parameters were determined for this sample (Table 2). The analysis of Hall effect measurements in magnetic field for n-MCT epilayers has shown that the initial $R_H(B)$ dependencies can be described with the help of the two-layer model and two types of electrons with high and low mobilities. The contribution of the thin layer with low mobility of electrons is magnifying after US treatment.

Table 2 Charge carrier parameters of $Hg_{1-x}Cd_xTe$ epilayer grown by LPE; n_d, μ_{nd} are the electron concentration and mobility in layer with thickness d, T=78°K.

	p, cm^{-3}	μ_p, cm^2/V c	n, cm^{-3}	μ_n, cm^2/V c	d, μm	n_d, cm^{-3}	μ_{nd}, cm^2/V c
before US treatment	$1.3\cdot10^{16}$	540	$2\cdot10^{10}$	160000			
after first US treatment	$7\cdot10^{15}$	300	$3.5\cdot10^{10}$	52000	~1	10^{11}	20000

We suppose that an effictive US stimulated defect system transformation, which results in the change of charge carrier parameters, takes place in the region berween substrate and epilayer both for *n*-MCT and for *p*-MCT samples. It is worth underlining also that ultrasonically stimulated phenomena in MCT epilayers depend on many factors (for example, growth condition, initial state of material, type of substrate etc.) and require further investigation.

4. Conclusion

The degradation of electrophysical characteristics of MCT thin films grown by LPE and MBE as a consequence of the ultrasonic influence was investigated. It was determined that parameters of MCT thin films grown by MBE are more stable to the high-frequency and high-intensity elastic deformation effect than MCT thin films grown by LPE. It was concluded that the MBE MCT layers are much more suitable for producing of infrared FPA arrays with stable characteristics compared to LPE layers.

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