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Acoustodynamic transformation of the defect structure in $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ alloys

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Abstract. The results of the investigations of transport properties of n - and p - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ semiconductor crystals exposed to intensive ultrasound ($\approx 6\text{MHz}$) are represented. Acoustostimulated phenomena of concentration change (increase in n -type and decrease in p -type) are observed in the region of impurity conductivity. The possible mechanism of the acoustodynamic processes (electrical activation/disactivation of the crystals defects) are analyzed. For the first time the phenomenon of acoustostimulated $p \rightarrow n$ conversion have been detected in p - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ at $T < 120\text{K}$.

Keywords: II-VI semiconductors, ultrasound, dislocation, acoustodynamic influence.

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1. Introduction

It is known that solid solutions $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ are frequently used material for producing of detectors of infrared radiation. This aspect has made sure stable interest to these during a few ten-year periods.

Low threshold of plasticity and, as a consequence, essential number of the point and linear structural defects are the reason of the considerable sensitivity of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ to external influences. So, high-frequency intensive ultrasound (US) is an effective mean of the influence on defect structure of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ crystals.

It was determined that the nature of acoustostimulated (AS) effects which take place in $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ is connected with acoustodislocation interaction and transformation of the absorbed US energy to the internal vibration states of crystal. The intensification of the point defects diffusive redistribution between block bulk and its boundaries and irreversible change of the electrophysical (EP) properties of crystals are the result of such acoustodislocation interaction during US treatment [1,2]. However, AS effects at dynamic prethreshold US loading and peculiarities of that in crystals of n - and p -types conductivity are not well understood yet.

So, in this paper the results of investigations of the AS transformation of the defect structure in n - and p - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ ($x = 0.2 \div 0.22$) crystals at dynamic pre-

reshold US loading has been presented and the possible mechanism of AS effects has been discussed.

2. Samples and experiment

AS changes of EP parameters of n - and p - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ ($x = 0.2 \div 0.22$) crystals with the dislocations density $10^4 \div 10^6\text{cm}^{-2}$ had been researched on the samples which were cut, polished and etched in solution of 8% Br - 92% HBr. Contacts were made of In. The standard Hall scheme of experiment was completed with acoustic elements for realization of the dynamic US loading regime as described in Ref. [3]. The longitudinal US oscillations with frequency $f = (5 \div 7)\text{MHz}$ and US intensity $W_{US} \leq 5 \cdot 10^3\text{W/m}^2$ were used, but the biggest intensity was applied at $T < 200\text{K}$ for prevention of the irreversible processes. Samples were US loaded in [111] direction. The temperature control was realized especially with care, keeping in the mind a possibility of US heating. The accuracy of a temperature fixing reached approximately 0.1 K.

3. Results

We investigated the temperature ($T = 77 \div 300\text{K}$), amplitude (from US intensity $W_{US} \leq 5 \cdot 10^3\text{W/m}^2$) and relaxa-

tion dependences of the Hall coefficient, R_H , and resistivity, ρ , of the n - and p - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ crystals. Calculated values of concentration $(eR_H)^{-1}$ and Hall mobility μ_H at $T=77$ K for all investigated samples are represented in Table.

Temperature dependencies of $(eR_H)^{-1}$ without (white symbols) and at US loading (dark symbols) are presented in Fig. 1 for samples of the n -type of conductivity and in Fig. 2 for samples of the p -type of conductivity. In region of the impurity conductivity ($T < 120$ K) the value of $(eR_H)^{-1}$ have increased at US loading for all samples of n - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$. It's necessary to underline that the value of AS change of $(eR_H)^{-1}$ differs from sample to sample at the same US intensity. For p - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ it can be different for two groups of samples. For the first group AS changes of $(eR_H)^{-1}$ are absent. For the second group AS decreasing of $(eR_H)^{-1}$ and the reversible $p \rightarrow n$ conversion at increasing US intensity (see typical amplitude dependence of R_H (σ_{US}) on inset of Fig. 2) in the region of impurity conductivity ($T < 120$ K) take place. The more detailed investigation discovered that AS change of the conductivity type is a consequence of AS shift of the main $p \rightarrow n$ conversion ($\Delta T_{con} = 40 \div 80$ K, $W_{US} = (1 \div 5) \cdot 10^3$ W/m²) and is not connected with surface effects [4]. It is necessary to note the reversible character of all AS effects. After US off, the relaxation of R_H and μ_H to initial state takes place for $10^2 \div 10^3$ c. The value of the relaxation time increased with increasing US amplitude and reducing the work temperature.

4. Discussion

As it was noted in introduction, it's known that all acoustostimulated effects in $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ alloys are determined by state of the linear structural defects (dislocations, low angle boundaries, block boundaries, etc.) and are consequence of the acoustodislocation interaction. Really, the structural investigations have indicated that the value of the AS changes of measured parameters depends directly on a density of the linear structural defects. Both for n - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ and for p - $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ crystals maximum AS effect at the same US intensity takes place in the sample

with the biggest density of dislocations and with block structure (see Table).

Taking into account this aspect, a possible mechanism of the observed AS effect of concentration change in $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ crystals can be supposed. It's known that the dislocations are surrounded by atmospheres of the intrinsic defects and impurities which are «bound» and do not participate in transport processes [5]. Such bound defects can be activated into the electrically active state by external factors disturbing thermodynamic equilibrium in crystal. We assumed that US loading can play a role of such factor, and both acoustoactivation of a part of bound defects to an electrically active state with its thermal ionization as well as capture of the donor and acceptor defects from block bulk by the dislocation atmosphere vibrating in US field are possible. The direction of this process is determined by the initial defect state of block bulk and boundaries.

We can express the complete carriers concentration for sample of n -type of conductivity without US loading as:

$$n = n_o + n_b = (N_d^o - N_a^o) + N_o^b \exp(-U_o / kT) \quad (1)$$

where $n_o \equiv N_d^o - N_a^o$ is the concentration of charge carriers, $n_b \equiv N_o^b \exp(-U_o/kT)$ [5] is the concentration of charge carriers from the thermoactivated bound defects, N_o^b is full bound defects concentration; U_o is an activation energy.

We have analyzed the US influence on behavior of EP parameters according to dislocation mechanism [6], i.e. we ascertained that U_o can be considered, on the one hand, as binding energy of the defect coupling with dislocations and, on the other hand, as an energy of dislocation vibration. It is known that external loading can reduce binding energy of dislocation and point defects with linear regularity [5]. So, if $U_{US} = U_o - \gamma_n \sigma_{US}$, then the concentration of charge carriers during US loading can be described as follows:

$$n_{US} = n_o + N_o^b \exp[-(U_o - \gamma_n \sigma_{US}) / kT] \quad (2)$$

where γ_n is an effective coefficient of US field interaction with crystal defects, $\sigma_{US} = (2\rho v_{US} W_{US})^{1/2}$ is an US

Table. The electrophysical parameters ($(eR_H)^{-1}$ and m_H at $T=77$ K) of the investigated samples and their densities of the structural defects: N_{dis} - dislocations density, N_{lab} - low angle boundaries density.

Sample	Type of conductivity	x	$(eR_H)^{-1}_{77K}$, cm ⁻³	$\mu_H = (R_H/\rho)$, cm ² /V c	N_{dis} , cm ⁻²	N_{lab} , cm ⁻¹
1	n-type	0.2÷0.22	$7 \cdot 10^{14}$	10^5	10^5	absent
2			$3.5 \cdot 10^{14}$	$5 \cdot 10^4$	10^5	1÷2
3			$3.5 \cdot 10^{14}$	$3 \cdot 10^4$	10^6	15
4			$9 \cdot 10^{14}$	$1.5 \cdot 10^4$	$3 \cdot 10^6$	25
5	p-type	0.2	$4 \cdot 10^{16}$	150	$5 \cdot 10^4$	absent
6			$1.2 \cdot 10^{16}$	200	$3 \cdot 10^5$	35

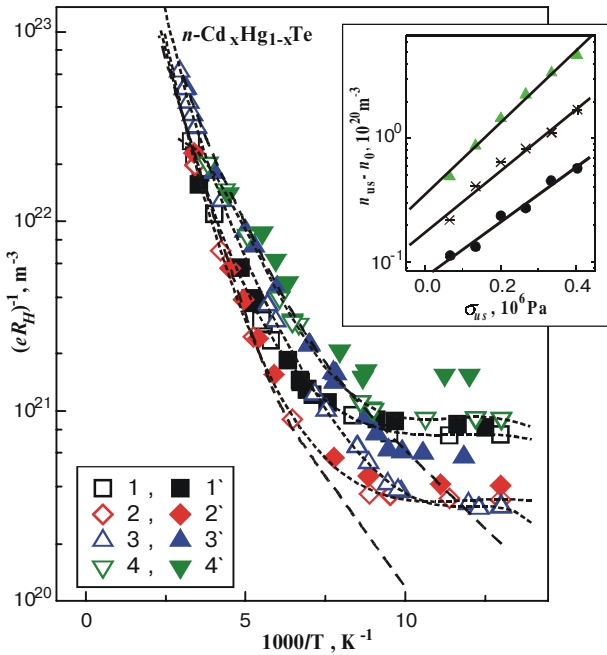


Fig. 1. Temperature dependences of the charge carrier concentrations $(eR_H)^{-1}$ of n -HgCdTe crystals without (white symbols) and at US loading (black symbols), $f_{US} = 5.6$ MHz, $W_{US} = 5 \cdot 10^3$ W/m². The curves numeration is conformed to sample numbers in Table. Dotted lines are the temperature dependences of the intrinsic concentration for $x = 0.2$ and for $x = 0.22$. Inset. The amplitude dependences of the $n_b(\sigma_{US}) = n(T_i, \sigma_{US}) - n_o(T_i, 0)$ of sample N3: curve 1 – γ_n (87 K) = $6.2 \cdot 10^{-27}$ m³, curve 2 – g_n (93 K) = $7.4 \cdot 10^{-27}$ m³, curve 3 – γ_n (103 K) = $9.7 \cdot 10^{-27}$ m³.

strength, ρ is a material density, v_{US} is a longitudinal US wave velocity, W_{US} stands for US intensity. In dislocation theory $\gamma = abl$ is activation volume [5], where parameters a and l are displacement amplitude and length of the vibrating dislocation section, respectively, b is the Burgers vector.

Note that the average value of $n_b(\sigma_{US}) = n(T_i, \sigma_{US}) - n_o(T_i, 0)$ during period of US wave have not been equaled to zero at $\gamma_n \sigma_{US} / kT_i \geq 1$ because $\sigma_{US} = \sigma_o \cos(2\pi ft)$ are located in exponent of Eq. (2). It means that the increase of the ionized defects concentration during straining period was not compensated during compression period [6].

According to Eq. (2) the value of parameter γ_n can be calculated at different temperatures from slopes of the experimental dependencies $\lg[n_b(\sigma_{US})] = f(\sigma_{US})$ (see typical dependences on inset of Fig. 1). The increasing of γ_n with temperature have confirmed thermoactivation character of dislocations oscillation in A_2B_6 crystals [7,8].

We have decided that a presence of the bound defects atmospheres and possibility of their thermoactivation are characteristic both for n -Hg_{1-x}Cd_xTe and for p -Hg_{1-x}Cd_xTe. But the observed experimentally changes of carriers concentration in p -Hg_{1-x}Cd_xTe can not be explained by the thermoactivation of bound donor defects

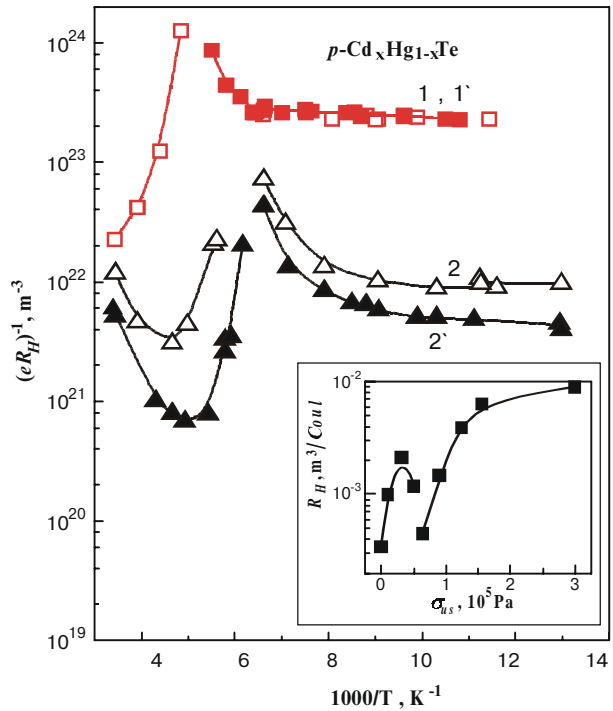


Fig. 2. Temperature dependences of the charge carrier concentrations $(eR_H)^{-1}$ of p -HgCdTe crystals without (white symbols) and at US loading (black symbols), $f_{US} = 5.6$ MHz, $W_{US} = 5 \cdot 10^3$ W/m². Curves 1, 1' – sample N5, curves 2, 2' – sample N6. Inset. Amplitude dependences of the Hall coefficient $R_H(\sigma_{US})$ of p -HgCdTe sample N6 at $T = 87$ K..

only. Really, the AS decreasing of carriers concentration in impurity conductivity region in p -Hg_{1-x}Cd_xTe is $\Delta p \equiv \Delta(N_a - N_d) \sim 10^{16}$ cm⁻³, but in n -Hg_{1-x}Cd_xTe is $\Delta n \equiv \Delta(N_d - N_a) \sim 10^{14}$ cm⁻³. It is possible that the process of the point defects («free» acceptors N_a) capture by vibrating dislocations field from block bulk (or $V_{Hg^+} \rightarrow V_{Hg^-}$ reionization) have determined EP parameters changes in p -Hg_{1-x}Cd_xTe at US loading. At this the increasing of intrinsic component contribution have occurred and $p \rightarrow n$ conversion has taken place at significant US intensity.

So, we have analysed the mechanism of acousto-thermo-activation of point defects bound in dislocations atmosphere. At the same time, as it is wellknown the dislocations creates energy levels in a band gap. The change of the charge state of such levels under external impact can influence on EP parameters of material, too. Certainly, such mechanism has recombination, electronic character as against previous mechanism, which has diffusive, ionic nature. Thus, various characteristic times corresponds to these mechanisms. The investigation of R_H and ρ relaxation after US loading off had indicated relaxation time $t = 10^2 \div 10^3$ s (Fig. 3). Such values of the time are characteristic for ionic processes, whereas the recombination processes are characterized by values of the time

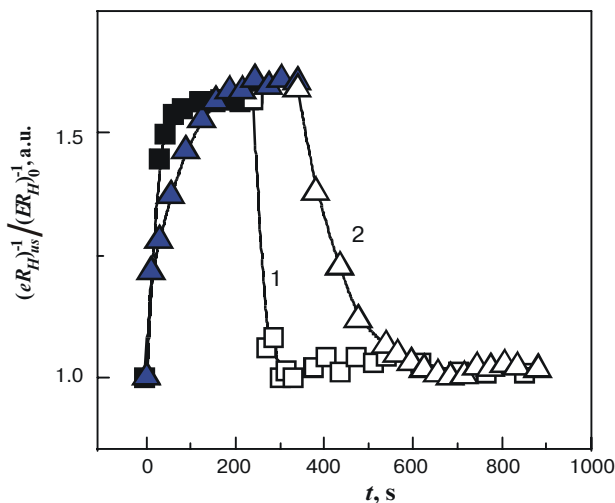


Fig. 3. Typical for investigated material (*n*-HgCdTe) relaxation curves of the carriers concentration $(eR_H)^{-1}$. White symbols – at US off, black symbols – at US on ($W_{US}=5 \cdot 10^3$ W/m²). Curve 1 – $T=110$ K, curve 2 – $T=80$ K.

$10^{-7} \div 10^{-6}$ s. Therefore, the ionic nature of the AS mechanism of the concentration change in investigated material is more probable.

At last it is necessary to note the role of temperature in AS processes of defect structure transformation. The increase of the temperature near the linear structural defects is a consequence of primary absorption of the US energy by vibrating dislocations in US field. This is followed by the increase of the intrinsic transitions probability and of the intrinsic component contribution. The characteristic time of such mechanism of charge carriers concentration change is determined by processes of system returning to the state of thermoequilibrium.

Conclusions

Thus, in our report the results of the investigations of the electrophysical parameters of *n*- and *p*-Hg_{1-x}Cd_xTe behavior in high-frequency intensive ultrasound field are presented. On this base we have analyzed the possible mechanisms of the acoustodynamic processes. We have suggested that the acoustostimulated phenomena of the concentration change in HgCdTe alloys is a consequence of the acoustodislocation interaction and thermoacousto-activation of bound point defects in dislocation atmosphere. The ionic nature of such processes has been proved by experimentally indicated times of the electrophysical parameters relaxation after US off.

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