

Sonic-Stimulated Change of the Charge Carrier Concentration in $n\text{-Cd}_x\text{Hg}_{1-x}\text{Te}$ Alloys with Different Initial State of the Defect Structure

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(Received July 27, 2001; accepted September 30, 2001)

Subject classification: 43.35.+d; 61.72.Ji; 61.72.Lk; 61.72.Mm; 72.20.Jv; S8.13

Sonic-stimulated change of electron concentration in $n\text{-Cd}_x\text{Hg}_{1-x}\text{Te}$ alloys was investigated. The possible mechanism of the observed effects was analyzed. It was shown that the **ultrasonic-induced increase of carrier concentration in $n\text{-Cd}_x\text{Hg}_{1-x}\text{Te}$ alloys could be connected with the activation of donor-like bound defects by acoustic wave. The value of such effect grows with increasing dislocation and low-angle boundary densities** in the crystals. The resonance character of the ultrasonic influence was determined.

Previous studies of the effect of ultrasonic loading on electrical and photoelectric parameters of $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$ alloys which were focused primarily on residual effects after ultrasonic processing have shown that the nature of the sonic-stimulated (SS) effects in this material was connected with the interaction between acoustic waves and crystal defects. This leads to a conversion of the absorbed ultrasonic energy into internal vibration states of the crystal, and the material characteristics changes as consequence. **The dislocations are the agent which accumulates the ultrasonic energy** [1].

Processes of ultrasonic-induced transformation of crystal defect structure and the modification of charge-carrier scattering conditions in $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$ crystals treated by ultrasonic loading were studied by us in [2, 3]. In this work, correlation between the value of the SS changes of the electron concentration n and the state of the defect system in $n\text{-Cd}_x\text{Hg}_{1-x}\text{Te}$ ($x = 0.2\text{--}0.22$) solid solutions is established in order to clarify the peculiarities of the SS effects in crystals with different degree of structural perfection.

The electron concentration was obtained by Hall effect method. Its value varies from 3×10^{14} to $5 \times 10^{14} \text{ cm}^{-3}$ at $T = 77 \text{ K}$ for all samples. The investigation of the sonic-stimulated change of n was carried out **during ultrasonic loading at the pre-threshold intensity**, referred as dynamic ultrasonic loading. The change of the measured parameter had reversible character. Switching off the ultrasonic loading led to a **relaxation** of the concentration to its original value of $10^2\text{--}10^3 \text{ s}$. In order to prevent irreversible effects, the ultrasonic intensity W_{US} was kept **below $5 \times 10^3 \text{ W/m}^2$** .

In order to measure the dynamic ultrasonic loading, we added acoustic elements to the setup for a standard Hall experiment. Longitudinal ultrasonic vibrations with frequency $f_{\text{US}} = 7 \text{ MHz}$ were generated by a lithium niobate (35° Y-cut) transducer and fed to the sample through a quartz buffer. The scheme for ultrasonically loading sample is shown in the inset of Fig. 1.

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Table 1

Parameters of the investigated n-Cd_xHg_{1-x}Te crystals: the value of the sonic-stimulated concentration change $\Delta n = n_{US}/n_0$ ($\sigma_{US} = 2 \times 10^5$ Pa) and values of the structural defect density N_{DIS} , N_{LAB} . First group of samples is characterized by small constant density of low-angle boundaries, second group of samples is characterized by a constant value of dislocation density

sample	first group of samples $N_{LAB} \leq 3 \text{ cm}^{-1}$, $F_R \leq 0.5 \text{ MHz}$		second group of samples $N_{DIS} \sim 10^5 \text{ cm}^{-2}$		
	$\Delta n = n_{US}/n_0$	N_{DIS} (cm^{-2})	$\Delta n = n_{US}/n_0$	N_{LAB} (cm^{-1})	F_R (MHz)
1	1.17	$\sim 10^5$	1.2	2	0.34
2	1.2	10^5	1.7	15	2.55
3	1.25	3×10^5	2.1	25	4.25
4	1.5	10^6	3.1	50	8.5

The structural perfection of the samples was determined by the method of selective etching. The density of the structural defects, dislocations and low-angle boundaries, was determined by the universal optic microscope NV2E (Carl Zeiss Jena).

We investigated two groups of crystals with different structural defects (see Table 1). The effect of ultrasonic loading manifests itself in an **increase of the electron concentration n in the impurity conductivity temperature range ($T < 120$ K)** for all samples. The dependence of carrier concentration on the effective ultrasonic stress amplitude σ_{US} ($\sigma_{US} = (2\rho v_{US} W_{US})^{1/2}$, where $\rho = 7.6 \times 10^3 \text{ kg/m}^3$ is the Cd_xHg_{1-x}Te density and $v_{US} = 3.4 \times 10^3 \text{ m/s}$ is the velocity of a longitudinal acoustic wave for Cd_xHg_{1-x}Te), is plotted in Fig. 1.

Considering the sonic-dislocation mechanism as dominant in the ultrasonic-wave interaction with the crystal [1], we suggest that the presence of impurities and intrinsic defects “bounded” at dislocations and low-angle boundaries is the main factor that determines sonic-stimulated processes in Cd_xHg_{1-x}Te. The obtained values of relaxation time of the electron concentration after switching off the ultrasonic loading confirms the ionic nature of the SS processes in Cd_xHg_{1-x}Te crystals. The concentration

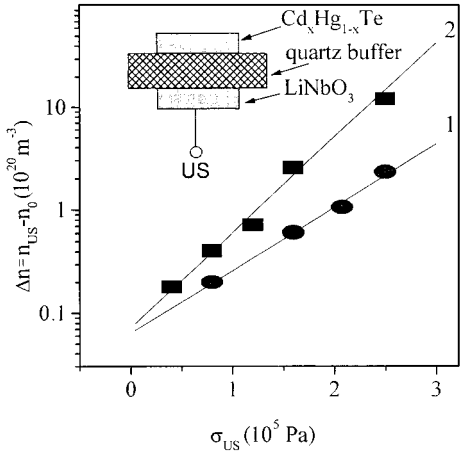


Fig. 1. Plots of the change in concentration $\Delta n = n_{US}(T, \sigma_{US}) - n_0(T, 0)$ versus the stress of ultrasonic vibrations σ_{US} , measured at $T = 85$ K for (1) a sample from the first group of n-Cd_xHg_{1-x}Te crystals, (2) a sample from the second group of n-Cd_xHg_{1-x}Te crystals. Insert: scheme of ultrasonic loading of the investigated Cd_xHg_{1-x}Te crystals

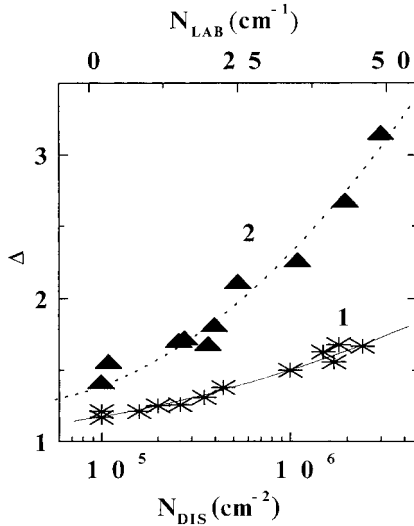


Fig. 2. Plot of the sonic-stimulated change in concentration $\Delta = n_{US}/n_0$ versus structural defect density for the two groups of n-Cd_xHg_{1-x}Te samples, $\sigma_{US} = 2 \times 10^5$ Pa, for (1) first group samples versus the dislocation density, (2) second group samples versus the low-angle boundary density

of “bounded” defects can be expressed as $N = N_0 \exp(-W_b/kT)$, where W_b is their binding energy, N_0 is the total defect concentration in the crystal [1]. The absorption of sonic wave energy by dislocations during ultrasonic loading results in a decrease of W_b and some of these “bounded” defects can be released and become electrically active [2]. An increase in the effective electron concentration occurs. It is useful to note that in p-Cd_xHg_{1-x}Te crystals we observed a decrease of the effective hole concentration p in the impurity-conductivity temperature range [4]. Such experimental fact confirms the donor-like nature of sonic-stimulated released defects.

We determined that the value of the sonic-stimulated change of electron concentration in Cd_xHg_{1-x}Te depend on the density of crystal structural defects, dislocations and low-angle boundaries. Figure 2 shows the dependence of Δ ($\Delta = n_{US}/n_0$, where n_{US} is the carrier concentration measured during ultrasonic loading, n_0 is the carrier concentration measured without ultrasonic loading) on the structural defect density for the two groups of investigated samples, the dislocation density N_{DIS} (curve 1) and the low-angle boundary density N_{LAB} (curve 2). It noteworthy that all measurements were carried out at the same ultrasonic intensity. It is clear that the increase of the structural defect density (N_{DIS} or N_{LAB}) leads to the growth of the electron concentration change Δ stimulated ultrasonically.

While analyzing the experimental data, observed SS effects with an efficiency of interaction between acoustic waves and linear structural defects in Cd_xHg_{1-x}Te alloys must be considered. For example, the dislocation mobility determines the efficiency of sonic-dislocation interaction in the crystals. The dislocation motion is limited by the crystal potential, Peierls relief [1] and the structure and state of point defects, the dislocation pinning points (for Cd_xHg_{1-x}Te, Hg vacancies are predominant [5]). However, since the concentration of Hg vacancies does not change after p → n conversion during high-temperature annealing of Cd_xHg_{1-x}Te crystals in saturated vapor of Hg [5], the structure and state of the dislocation pinning points is practically the same for the investigated samples. It was also determined by the calculation that the value of Peierls potential does not differ for the investigated samples.

It was noticed that the maximum effect of ultrasonic influence on crystal parameters has been observed for samples with a high concentration of low-angle boundaries. According to the model of forced oscillations of low-angle boundaries in the ultrasonic

wave field maximum SS effects in Cd_xHg_{1-x}Te crystal can be obtained when ultrasonic frequency f_{US} is approximately equal to the natural frequency of a crystal block structure F_R . This parameter is connected with the geometrical dimensions of the blocks, $F_R = v_{US}/2L$ [6], where $L = (N_{LAB})^{-1}$ is the linear dimension of a sample sub-block. So, the ultrasonic influence is of resonant character. A similar SS effect in Cd_xHg_{1-x}Te solid solutions was observed after ultrasonic processing [6]. If the sonic processing of Cd_xHg_{1-x}Te crystals is carried out in resonance condition, the transformation of the point defects is dominant due to the interaction between ultrasonic waves and low-angle boundaries. But, if the values of F_R and f_{US} differ essentially the SS defect system transformation in the crystal is realized with the individual dislocations participating. In the latter case the value of the sonic-stimulated effect is significantly smaller than in the first case.

Apparently the similar model can be attractive in our case. The calculated values of natural frequency F_R for the investigated samples are shown in Table 1. For the first group of samples the resonance condition of the sonic–dislocation interaction is not realized (see Fig. 2, curve 1 and Table 1). The value of $F_R \leq 0.5$ MHz is significantly smaller than the frequency of the ultrasonic loading and the maximum value of $\Delta = n_{US}/n_0 \leq 1.5$. For the second group of samples with a grid of the low-angle boundaries (see Fig. 2, curve 2 and Table 1), the value of the SS change of electron concentration is significantly higher. The condition nearest to resonance ($F_R = 8.5$ MHz is the nearest to $f_{US} = 7$ MHz) and, as consequence, the maximum SS effect is realized for the sample 4 (see Table 1, first group of samples).

In this paper, we report the results of an experimental study of the ultrasonic-stimulated effects in n-Cd_xHg_{1-x}Te crystals with different degree of structural perfection. It has been shown that the value of ultrasonic-induced change in carrier concentration of n-Cd_xHg_{1-x}Te alloys is connected with the density of dislocations and low-angle boundaries in the crystal. The effect of ultrasonic influence is resonant in character. The change of the concentration is the largest when the value of the natural frequency F_R of the crystal sub-block structure is nearly equal to the external ultrasonic loading frequency f_{US} .

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