Contributed paper

Temperature depedence of the amplitudes of the magneto-phonon oscillations in the $Hg_{1-x-y}Cd_xZn_yTe$ solid solutions

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The magnetophonon resonance (MPR) was studied in $Hg_{1-x-y}Cd_xZn_yTe$ with the aim to determine the band structure and phonon spectrum of this solid solution. The effect of temperature on the oscillations of the transverse magnetoresistance in the epitaxial layers of $Hg_{1-x-y}Cd_xZn_yTe$ with x = 0.11, y = 0.08, mobility = 9×10^4 cm²/Vs and concentration n = 4×10^{15} cm⁻³ has been studied. In the result of the interpretation of temperature dependence of peaks in the measured oscillations it was concluded that some peaks can be related to the MPR with subtracted LO phonon frequencies and the other as one phonon MPR. It was concluded that the presence of Zn in the crystal lattice increases the electron – two phonon interaction, while an increase of temperature suppresses this effect.

1. Introduction

$Hg_{1-x}Cd_xTe$ are the basic materials for infrared devices. However, their wide applications are limited due to the weak Hg-Te bond which is a source of instability of their properties. Recently alternative materials with better mechanical properties have been looked for. Recent research has shown that a four-component $Hg_{1-x-y}Cd_xZn_yTe$ (MCZT) compound may become a good alternative to $Hg_{1-x}Cd_xTe$ [1] (editor's remark – see also: Opto-Electronics Rev. **4** (1996) 140.). The introduction of Zn atoms allows to considerably reduce defects concentration and stabilizes Hg-Te bond without simultaneous losing the required physical properties. Studying the band structure and phonon spectrum of the new solid solutions MCZT seems to be very important. The excellent method for this is magnetophonon resonance (MPR) [2]. In our previous paper [1], the parameters of the band structure and their temperature dependences in the range of 4.2-200 K for several compositions MCZT were determined on the basis of cyclotron resonance and MPR in the range of magnetic field 2-6 T. In the present paper we are mainly concerned with the temperature behaviour of the oscillations of magnetoresistance in the weak magnetic fields (B < 2T).

2. Experimental results

The effect of temperature on the oscillations of the transverse magnetoresistance in the epitaxial layers $Hg_{1-x-y}Cd_xZn_yTe$ at x = 0.11, y = 0.08, with mobility $\mu = 9 \times 10^4$ cm²/Vs and concentration $n = 4 \times 10^{15}$ cm⁻³ has been studied. The second derivative of the transversal magnetoresistance as a function of pulsed magnetic field ρ_{xx}, obtained in the temperature range 77-200 K has been registered. Pulsed magnetic field allows us to obtain a number of curves $\delta^2 r_{xx}(B)/\delta B^2$ for different temperatures and in various range of the magnetic field. Typical experimental curves in two different scales of magnetic field are presented in Figs. 1, 2, 3. From the multitude of presented peaks we

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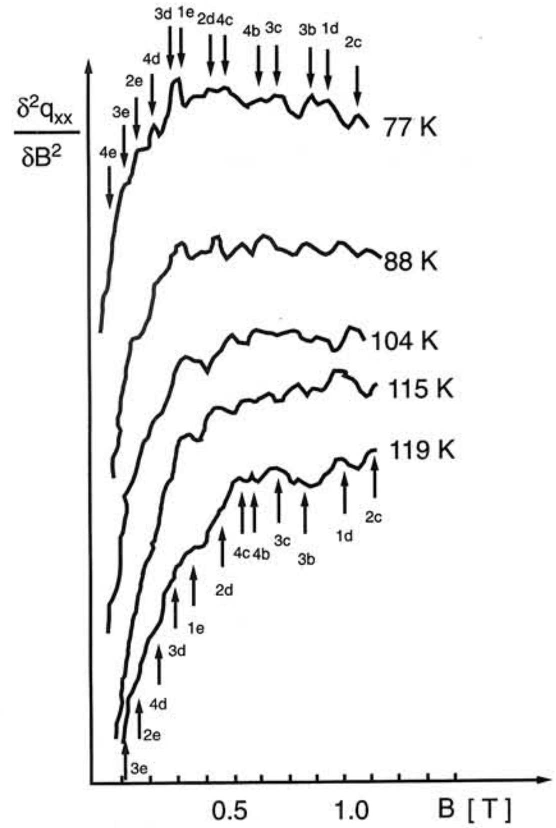

Fig. 1. Experimental traces of $\frac{\delta^2 q_{xx}}{\delta B^2}$ for n – $Hg_{0.81}Cd_{0.11}Zn_{0,08}Te$ – on a weak magnetic fields scale at temperatures 77 K, 88 K, 104 K, 115 K, 119 K

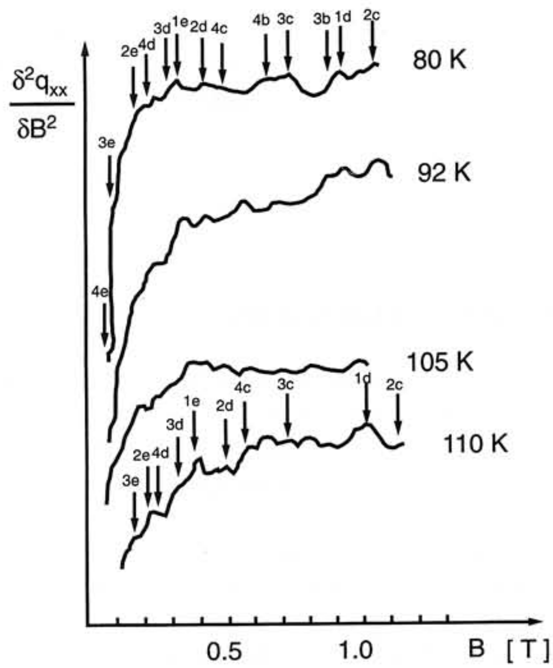

Fig. 2. Experimental records of $\frac{\delta^2 q_{xx}}{\delta B^2}$ for n – $Hg_{0.81}Cd_{0.11}Zn_{0,08}Te$ – in weak magnetic fields at temperatures 80 K, 92 K, 105 K, 110 K

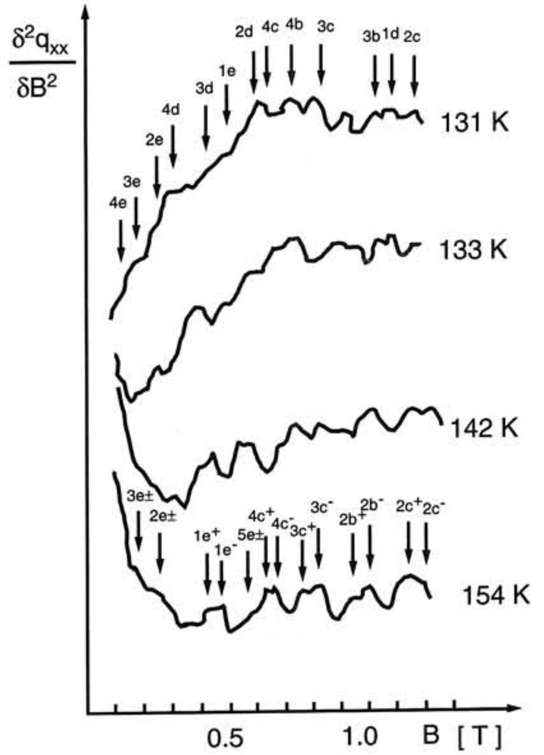

Fig. 3. Experimental records of $\frac{\delta^2 q_{xx}}{\delta B^2}$ for n – $Hg_{0.81}Cd_{0.11}Zn_{0,08}Te$ – in weak magnetic fields at temperatures 131 K, 133 K, 142 K, 154 K

select the most distinctive peak c1. This peak, as well as the other peaks of the same series c2, c3, c4, were interpreted earlier [1] as MPR peaks with absorption of LO phonon of HgTe sublattice. This interpretation made possible to determine the band-structure parameters of solid solution MCZT for any given composition. Complicated structure of peaks in weak magnetic field is of special interest, because it cannot be interpreted only by participation of one type phonons in MPR.

At 77 K in magnetic field 0.35 T a "1e" peak appears, which cannot be interpreted as a harmonic of resonances described earlier. Looking at the MPR curve for 77 K in Figs. 1, 2, 3 one can see that for 1/2, 1/3 and 1/4 fractions of magnetic field at which peak 1e appears, the other peaks indicated as "2e", "3e" and "4e" can be observed, correspondingly. Observation of the change of peak position in the magnetic field B depending on temperature leads to the conclusion that peaks shift to the higher magnetic fields with increase of the temperature. The peaks of "c", "b" series and peak "1e" also undergo the spin splitting.

In Figs. 4 and 5, the experimental curve for 77 K and 154 K and theoretical dependence of Landau levels as a function of magnetic field B has been presented.

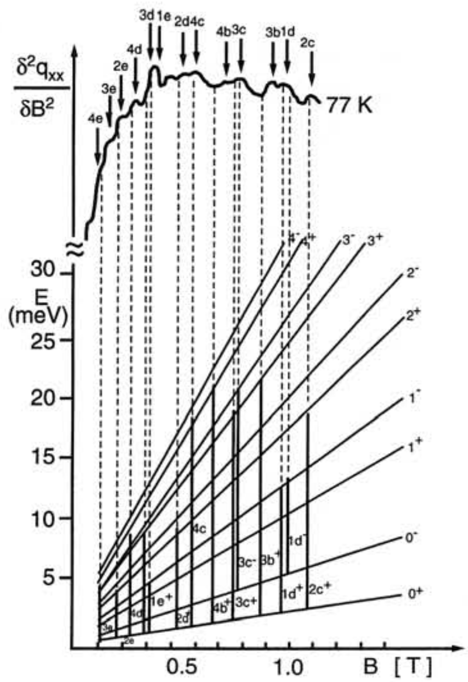

Fig. 4. Experimental records of $\frac{\delta^2 q_{xx}}{\delta B^2}$ for n – $Hg_{0.81}Cd_{0.11}Zn_{0,08}Te$ – in weak magnetic fields and corresponding transition at temperature 77 K

Transitions between Landau levels responsible for experimental peaks are given too. One can see a good agreement of peaks of series "c" with position of magnetic field transitions with absorption of LO(HgTe) phonon.

The energy of LO(HgTe) phonon, well known for solid solution CdHgTe [5], hardly changes with the composition (most probably in $Hg_{1-x-y}Cd_xZn_yTe$ also at $x + y \leq 0.3$ and is equal to 17.0 meV. However, for the interpretation of peaks in series "b", transition energy equal to 20 meV is needed. This is very close to the phonon energy of CdTe sublattice in the solid solution CdHgTe [3] (it is possible that introduction of 8% Zn will not change this energy very much). Hence, one should interpret peaks in series "b" as MPR with participation of LO(CdTe) phonons. As it has been mentioned above, a new series begins from peak "1e" or, in other words, this peak is caused by transition between Landau levels $0^{\pm} \rightarrow 1^{\pm}$. As was shown earlier [4], this series of peaks is caused by MPR with subtracted phonon energies: LO(CdTe) – LO(HgTe).

Also we may suppose that resonance series "d" was caused by transitions of electrons between Landau levels with absorption of phonon LO(ZnTe) and emission of LO(HgTe).

As was shown earlier [4] it is possible to interpret the series "e" as MPR with subtracted LO phonon

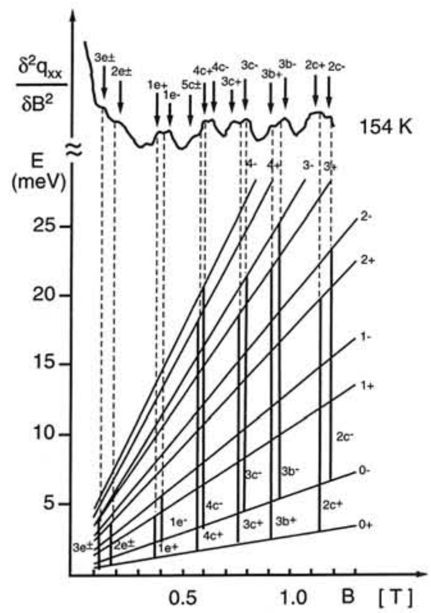

Fig. 5. Experimental records of $\frac{\delta^2 q_{xx}}{\delta B^2}$ for n – $Hg_{0.81}Cd_{0.11}Zn_{0,08}Te$ – in weak magnetic fields and corresponding transition at temperature 154 K

frequencies (MPR_{SPF}) in sublattice HgTe and CdTe which has been observed for the first time in [5] for solid solution $Hg_{1-x}Cd_xTe$. As can be seen, resonances of series "e" are more visible than series "d", what may be explained by the fact that CdTe contents is greater than ZnTe in this solid solution.

3. Temperature dependence of amplitude

Let us consider how before-mentioned interpretation of peaks agrees with temperature dependence of their amplitude. The amplitude of MPR peaks depends on three factors:

- Broadening of the Landau levels,
- Occupation numbers of phonons,
- Occupation of Landau levels by electrons.

First factor may be expressed by a multiplier:

$$\exp\left[-\left(\frac{\omega_{LO}}{\omega_c}\beta^2\right)^{1/3}\right] \qquad (1)$$

where ω_{LO} – is the frequency of optical phonon ω_c – is a cyclotron frequency, β – is the damping factor responsible for broadening of Landau levels (caused by scattering of carriers and by ordinary temperature broadening kT).

In the temperature range 77-154 K mobility will change only slightly, due to transition from the scattering on ionized centers to preferably elastic scattering on phonons. Consequently, the temperature broadening is the main reason of nonzero β and the broadening of Landau levels.

The occupation number of phonons increases with the increase of temperature and is proportional to the factor;

$$\exp\left[-h\omega_{LO}/kT\right] \quad (2)$$

in the case of one phonon resonance.

In the case of two phonon resonance, when simultaneous absorption of two phonons takes place, we have the following expression for this factor:

$$\exp\left[-2h\omega_{LO}/kT\right] \quad (3)$$

Therefore, the increase of temperature causes an increase in ratio of peak heights of two phonon resonance and one phonon resonance.

Another situation occurs in the two phonon resonances with simultaneous absorption and emission of phonons, because in this case one phonon will be absorbed despite two phonon participation in resonance transition [5].

Experimental data (see Figs. 4 and 5) confirmed this conclusion and even show, that relation of amplitude MPR_{SPF} to amplitude of one-phonon MPR decreases with increase of the temperature. We suppose that it is caused by factor (1).

Since we can observe MPR_{SPF} in smaller magnetic fields, its amplitude is more sensitive to temperature broadening of Landau's levels (than in the case of series "c"). When there is a superposition of two-phonon peaks MPR_{SPF} and one-phonon MPR, as in the case of series "d", with increase of temperature the first should appear clearly, because transition takes place on Landau's level with a small number. This conclusion is confirmed by experimental data at 77 K (peak "1e" has greater amplitude than "4c", and 1d is comparable with "2c" and "3b"), whereas at 154 K peak "1e" is comparable with "4c", and "1d" is not observed in the background of "2c" and "3b". If we limit ourselves only to transition from lower to upper Landau levels, this experimental fact can be explained with the help of change of the occupation number of Landau levels by electrons with the increase of temperature. Therefore, due to occupation of Landau levels at increasing temperature from 77 to 154 K in magnetic field of 1 T, the probability of transition from 0^+ on 1^+ decreases by 1.6 times. However, the same probability of transition from 0^+ to 2^+ under this magnetic field decreases only by 1.3 times. This means that increase of temperature makes worse the condition of resonance "1d" in comparison with "2c" due to occupation of Landau's levels. But, together with this, MPR_{SPF} may occur also in the reverse direction: an electron found on upper Landau's levels absorbs a phonon of a lower energy [LO(HgTe)], causing it to undergo a transition to a lower level, releasing a phonon of higher energy [LO(CdTe)] or [LO(ZnTe)]. With the increase of temperature, probability of these transitions should increase, compensating the decrease of probability of transitions from lower Landau's level to upper.

4. Conclusions

In this manner, temperature behaviour of peak series "e" and "d" principally agrees with the interpretation as MPR_{SPF}. However, neither factor (1) (broadening of Landau's level), nor factor (2) (occupation number of phonons), nor changes in occupation of Landau levels by electrons allowed us to completely explain faster extinction of peaks of these series with temperature in comparison with one phonon MPR. Therefore it seems to be necessary to include into consideration the influence of temperature on the same mechanism of electron interaction with two phonons with their simultaneous absorption and emission. It can be assumed that the presence of Zn in the lattice, on the one hand increases this interaction, however, on the other hand, an increase of temperature suppresses this advantage.

References

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