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Photoluminescence excitation spectroscopy in narrow - gap $\text{Hg}_{1-x-y}\text{Cd}_x\text{Mn}_y\text{Te}$

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Abstract. New results on infrared photoluminescence and photoluminescence excitation spectroscopy around the fundamental energy gap in $\text{Hg}_{1-x-y}\text{Cd}_x\text{Mn}_y\text{Te}$ single crystal are presented. A very strong electron-phonon coupling influencing the optical spectra of this narrow-gap semiconductor is found. An indirect «hot exciton» absorption under participation of longitudinal optical phonons occurs to be the main absorption mechanism. It was shown, that knowledge about the excitonic processes in wide gap semiconductors also can be applied to high-quality narrow-gap materials.

Keywords: photoluminescence excitation, «hot exciton», monitor position, longitudinal optical phonon.

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I. Introduction

Up to date narrow-gap semiconductors, i.e. materials with a positive energy gap (E_g) smaller than ≈ 0.5 eV, have not been considered as attractive model substances for optical spectroscopy. This is mainly due to the lack of pronounced excitonic lines as well as to the technical difficulties accompanied with spectroscopical work in the mid-infrared (IR) spectral region. However, for a number of reasons new experiments performed with the semimagnetic $\text{Hg}_{1-x-y}\text{Cd}_x\text{Mn}_y\text{Te}$ mixed crystal system could change this situation. The E_g -value of this material can be tuned within a wide range from negative values in the semimetallic phase up to more than 2 eV by changing the mole fractions x and y [1, 2]. Independently from the actual E_g -value, the x - y -ratio allows to adjust the magnetic properties, i.e., the concentration of semimagnetic Mn^{2+} ions. Besides, the effects caused by a compositional variation the electronic spectrum in addition becomes strongly affected by external parameters such as temperature and magnetic field [3]. These parameters substantially influence both transport and optical properties of the material, providing flexibility for applications. Furthermore, it was experimentally shown, that also the exciton binding energy (R_x) as well as the density of states in the edge region, cf. Karpov and Tsidil'kovskii [4], become influenced by these external parameters in an unusually significant way [5].

These interesting features are interfered by another effect inherent to multinary compounds – the high degree of disordering. However, it seems that this effect can be ruled out, at least in part, by finding appropriate x - y -ratios [6]. A «small amount» of Mn^{2+} ions is expected to stimulate the relaxation of 0- and 1-dimensional native defects. This relaxation effect is assumed to be accompanied and promoted by the exchange interaction between the localized spins in the Mn^{2+} ions and the free carriers, i.e. by the electronic subsystems of localized and free carriers. Thus, the *localized* ions produce something like a *delocalization* of the defect related effects in both electronic subsystems and the lattice. In addition to these assumptions, there exists serious experimental indication of improving the structural properties by adjusting the magnetic component (Mn mole fraction) to well-defined values: defect related features in the far-IR phonon absorption and reflectance spectra disappear and the photoluminescence (PL) becomes narrower and brighter [7, 8].

Due to the direct gap of the material most of the near-to-edge optical properties of $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ can be explained *without any phonon participation*. However, since the energies of the electron and the phonon elementary excitation here (typically for the present sample set $E_g \approx 332$ meV, $R_x \approx 1.0$ meV, $E_{\text{LocTe}} \approx 19.4$ meV) are

generally closer to each other than in wide-gap materials, one should expect a stronger electron-phonon coupling in particular for narrow-gap materials. Thus, $\text{Hg}_{1-x-y}\text{Cd}_x\text{Mn}_y\text{Te}$ should be good model substance to study electron-phonon coupling.

This report is devoted to the results obtained by spectroscopic investigations in narrow-gap $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ and mainly focuses on effects due to exciton-phonon interaction obtained by photoluminescence excitation spectroscopy (PLE). Thus, an unusual combination of experimental method and object of investigation was chosen, and the first report on PLE investigations in a narrow-gap semimagnetic material is presented. These excitation experiments reveal a strong interaction between electron-hole pairs and longitudinal optical (LO) phonons.

A qualitative theoretical interpretation of the results is provided starting from the basic scenarios of exciton creation such as introduced e.g. by Gross et al. when studying free-exciton luminescence excitation spectra in CdS [9,10]. For photon energies above E_g , Gross distinguished between two kinds of exciton creation processes:

- (i) The exciton gets created from non-correlated states of free electrons and holes by relaxation processes. According to this concept, excitons can be formed from free electron-hole pairs, generated after interband absorption.
- (ii) An alternative mechanism includes the creation of correlated electron-hole states by indirect exciton absorption acts resulting in excitons holding the kinetic energy of one or two phonons [11,12]. Then the kinetic energy of the exciton decreases through LO phonon emission. Exciton-exciton scattering as well as relaxation caused by interaction with acoustic phonons leads to an equilibrium energy distribution among excitons, non-radiative decay and radiative recombination.

All elementary processes mentioned have their characteristic time constants. In the hierarchy of time constants the largest is the time of radiative recombination (10^{-8} - 10^{-7} s) and the smallest is the time of LO phonon relaxation ($\approx 10^{-13}$ s). If the time of exciton relaxation by LO phonon generation is substantially smaller than the thermalization time in the exciton band, the energy distribution of excitons is a non-equilibrium one, and the emission of 'hot' excitons will dominate. In this case, the peak of the excitonic absorption should be excess energy dependent and consequently the peak position of the PLE should also depend on the photon energy of the excitation light.

In order to learn more about these processes, PLE spectroscopy and PL with resonant excitation seem to be the appropriate tools. An important methodical step was done by Fuchs et al. by introducing the Fourier-Transform (FT) PLE as a new experimental technique to the mid-infrared range [13]. Applying this technique, the potential was obtained to present here the first successful study employing FT PLE in a diluted narrow-

gap semiconductor – $\text{Hg}_{1-x-y}\text{Cd}_x\text{Mn}_y\text{Te}$ – providing new proofs for excitonic nature of the low-temperature near edge emission. Furthermore, the resonant excitation experiments exhibit a lot of similarities with the experimental findings by Ouadjaout and Marfaing for wide-gap $\text{Hg}_{1-x}\text{Zn}_x\text{Te}$ ($E_g \approx 2.3$ eV) with less than 1 % Hg-content [14-16]. Thus, this report could be a step forward to an unified view on the luminescence behavior on both wide-gap and narrow-gap Hg-alloyed semiconductors.

II. Experimental

Zinc blende $\text{Hg}_{1-x-y}\text{Cd}_x\text{Mn}_y\text{Te}$ single crystals were grown by a modified traveling heater method. X-ray microprobe investigations have proved homogeneous Cd and Mn distributions over the whole wafer of $\varnothing = 10$ mm with x - and y -fluctuations within the limits $\Delta x = \Delta y = 0.002$. Sample characterization by means of standard optical and Hall measurements provided the following parameters for one of the samples, which will be exemplarily discussed in this report: Cd-content $x = 0.335$ mol %, Mn-content $y = 0.014$ mol %, $E_g = 332$ meV, $n_e = 1.41 \times 10^{15}$ cm $^{-3}$, electron mobility $\mu^g = 1.1 \times 10^5$ cm 2 V $^{-1}$ s $^{-1}$ (all at $T = 4.2$ K).

Fourier-transform photoluminescence excitation spectroscopy of $\text{Hg}_{1-x-y}\text{Cd}_x\text{Mn}_y\text{Te}$ was performed with the set-up described in detail earlier by Fuchs et. al. [13]. Basically, the FT IR spectrometer serves as excitation source and all the polychromatic light from the glowbar, which becomes modulated by the Michelson interferometer, reaches the sample surface. In order to select a narrow luminescence band (i.e., the so-called monitor energy) and for suppressing stray light arising from the excitation source itself, a grating monochromator serves as a spectral filter. The luminescence signal was detected by a liquid nitrogen cooled InSb photodetector. In order to choose the appropriate spectral range for the FT PLE investigation PL was measured, too. It was excited by a He-Ne laser at 1.96 eV. A double modulation technique – locking of interferometer mirror motion and modulation of the excitation light – was applied for performing the PL measurement [17].

III. Results and discussion

A. Photoluminescence excitation spectra

Luminescence spectra from $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ measured at $T = 12$ K are shown in Fig. 1. One can easily distinguish between three features: The *high energy line*, which depends superlinearly on the excitation density, vanishes for low pumping levels (see both the PL spectra on the top). An earlier magnetoluminescence study on the same sample set has demonstrated its sophisticated nature [8]. At low temperatures (less than 30 K) the main contribution appears from initially free excitons which

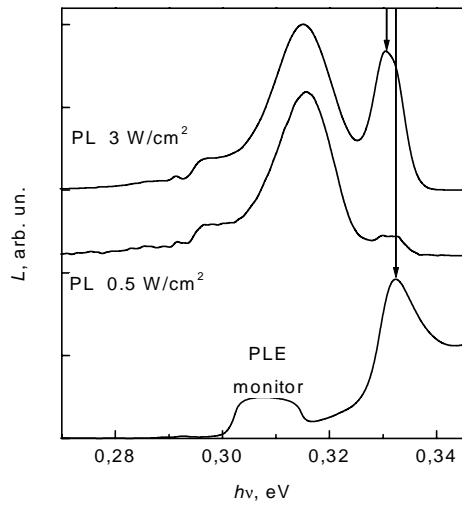


Fig. 1. PL spectra (top) from $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ measured at $T = 12$ K. The parameter is the excitation density. At the bottom a PLE spectrum is added. The PLE monitor position was 308 meV. Arrows indicate the peak positions of PL and PLE.

get localized within potential wells under participation of a magnetopolaron effect [5]. With increasing temperature this PL line transforms its nature more and more into band-to-band ‘plasma’ recombination, connected with direct transitions and is surely described in the framework of a modified Anderson model [18]. The *second line* does not change substantially its spectral shape even when the excitation density is varied by three orders of magnitude. The changes caused by a variation of the temperature or by applying magnetic field are more pronounced. Both dependencies show a non-monotonic behavior of the peak position and provide strong arguments in favour of impurity-related nature of these transitions, probably donor-acceptor pairs (DAP). The feature situated at the low energy tail (290-295 meV) of the spectrum is induced by the strong CO_2 absorption in air. Our discussion will focus exclusively to both near band-edge transitions mentioned.

At the bottom of Fig. 1 a PLE spectrum is added. Note the 2 meV Stokes shift between PL and PLE (cf. arrows) which is due to exciton localization in potential wells probably created by fluctuations of the band edge energetic positions [4]. This effect is well-known for II-VI multinary compounds. The value of 2 meV was experimentally verified by thermal delocalization of the excitons for different magnetic fields (B). Using this technique it was possible to obtain both $R_x(B)$ as well as the

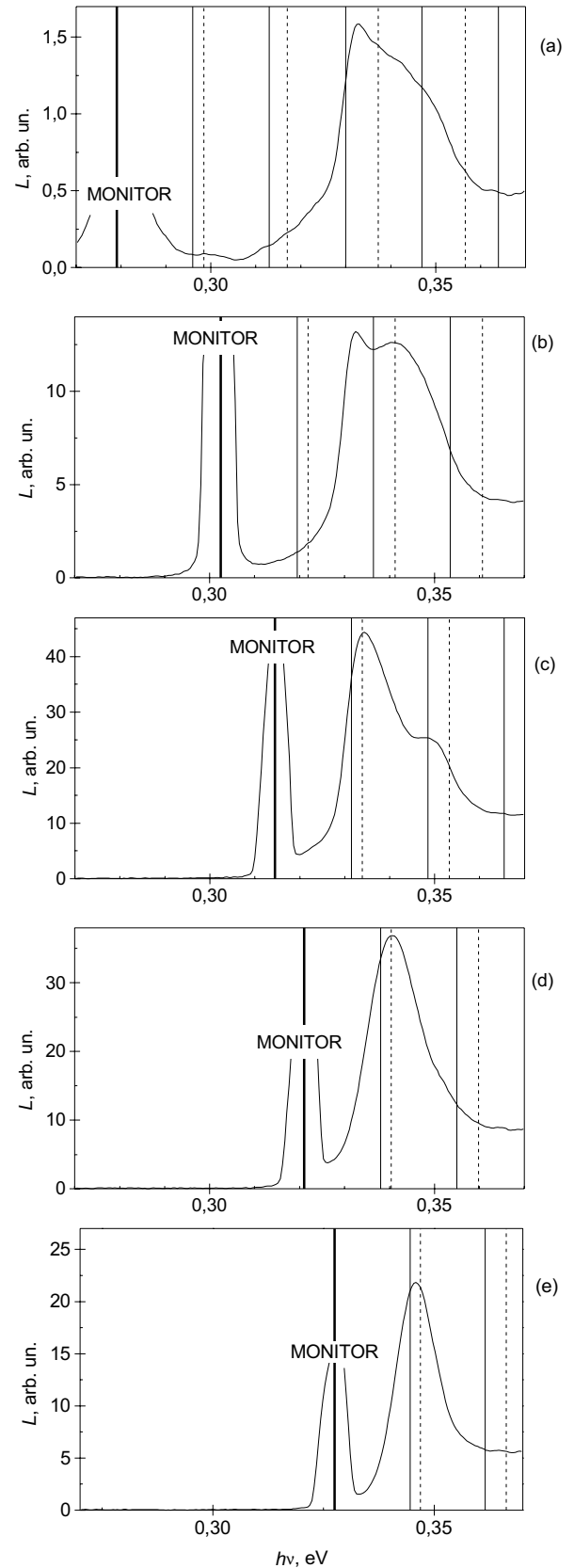


Fig. 2. PLE spectra of $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ for various monitor positions. The monitor positions are: (a) 279.0 meV; (b) 302.5 meV; (c) 314.5 meV; (d) 321.0 meV and (e) 327.5 meV. Full and dashed vertical grid lines in Fig. 2 mark the positions of phonon replicas of the monitor line ($E_m + nE_{\text{LO}}$, n integer number), caused by phonons of the HgTe and CdTe sublattices, respectively.

localization energy and determined the latter to about 2 meV [8]. This is in a remarkable agreement with the Stokes shift in Fig. 1 a.

Figure 2 depicts a series of FT PLE spectra from the same $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ sample. The spectral position of the monitor line is marked in each of the spectra. The monitor peak itself is predominantly caused by excitation light. The monitor position starts (Fig. 2a) on the low energy side of the PL spectrum at 279 meV and was moved towards E_g (subsequently Fig. 2b-e). The main transformation in the FT PLE spectrum appears within the spectral range of excitonic absorbance. The main PLE peak marking the exciton position does not move when the monitor is situated in the spectral range below the impurity related transitions (Fig. 2 a,b). If the monitor passes through the maximum of the impurity related band in the PL spectrum the exciton related feature starts shifting towards higher energies with subsequent transformation of the shape of the whole PLE spectrum.

Fig. 3 depicts this behavior. The data are extracted from PLE spectra which are in part displayed in Figs. 1 and 2a-e. Furthermore, a PL spectrum is added. The distinct onset of the shift in center of the DAP line as well as the slope of unity are the main information from this figure.

Fig. 4 shows the evolution of the FT PLE spectrum monitored at the exciton peak position (E_x) for various

temperatures. The peak shifts to higher energies and disappears when the temperature exceeds 40 K. This is a strong argument for the excitonic nature of the transitions observed but also allows to estimate the temperature dependence of E_g for the given sample. Thus the positive temperature coefficient dE_g/dT is verified.

In order to interpret the FT PLE data one has to take into account the multicomponent structure of the $\text{Hg}_{1-x}\text{Cd}_x\text{Mn}_y\text{Te}$ system. As a result of this structure, the phonon spectra of the compound exhibit a so-called three-mode behavior: each of the binary components HgTe, CdTe and MnTe gives the origin to one particular set of longitudinal and transverse phonons, corresponding to HgTe-, CdTe- and MnTe-like modes in far infrared (FIR) transmission and reflectance spectra [6,7].

Using our previous data [19-21] on FIR reflection measurements for $\text{Hg}_{1-x}\text{Cd}_x\text{Mn}_y\text{Te}$ of proper composition, Kramers-Kronig analysis and a fitting procedure based on the approximation of non-coupled oscillators, it was possible to identify the active phonon modes for our samples. The results are collected in Table 1.

B. Discussion

Before discussing details the PLE signal generation process should be briefly spelled out: the dependence of the PL intensity at a fixed photon energy (monitor) on the wavelength of the exciting light – i.e. the PLE spectrum – is roughly proportional to the product of the absorption spectrum and the probability of the optically pumped states to decay into the states contributing to the lumi-

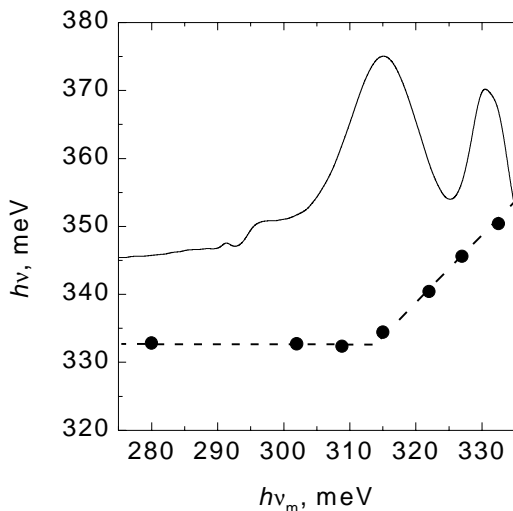


Fig. 3. PLE peak position versus monitor position at $T = 12$ K for $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$. For comparison a PL spectrum was added. The dashed line is an eyes guide. Note, that the slope of the dashed line in the right part is unit, indicating the coupling between PLE peak and monitor position. The difference between the two energies in this spectral range is (19.4 ± 0.3) meV or (156 ± 3) cm^{-1} , corresponding to the CdTe-like LO phonon mode (cf. Table 1).

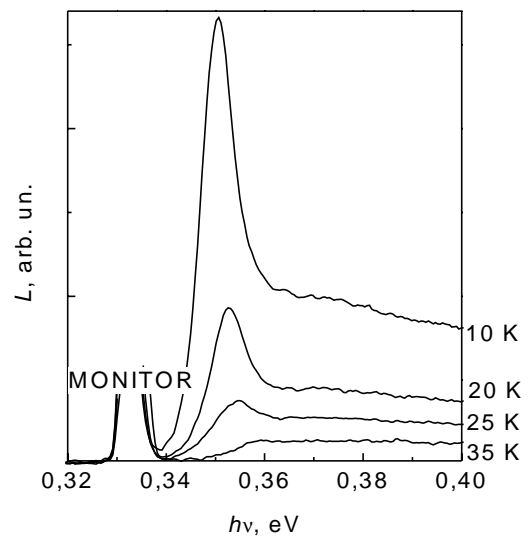


Fig. 4. PLE spectra from $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ for various temperatures. The monitor position is $E_x(10 \text{ K})$.

Table 1. Data of the active phonon modes for $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$.

		5 K	100 K	300 K
Gap mode	TO (cm^{-1})	98.0	95.0	94.0
	(MnTe) LO (cm^{-1})	99.0	96.2	95.3
Defect mode	TO (cm^{-1})	105.0	103.0	101.0
	LO (cm^{-1})	106.4	104.5	102.8
CdTe-like impurity activated	TO (cm^{-1})	112.0	110.5	108.0
	LA-mode LO (cm^{-1})	113.3	112.4	109.7
HgTe-mode	TO (cm^{-1})	121.5	122.5	124.0
	LO (cm^{-1})	138.7	139.8	140.8
Clustering mode at 135 cm^{-1}	TO (cm^{-1})	137.0	135.0	135.5
	LO (cm^{-1})	137.6	135.8	136.2
CdTe ₁ -mode	TO (cm^{-1})	151.0	150.0	146.0
	LO (cm^{-1})	153.0	152.5	147.8
CdTe ₂ -mode	TO (cm^{-1})	155.5	154.5	150.0
	LO (cm^{-1})	157.1	156.4	151.5
MnTe-mode	TO (cm^{-1})	191.0	190.0	187.0
	LO (cm^{-1})	191.3	190.6	187.8

nescence at the particular spectral position of the monitor. The latter process proceeds under interaction with other excitons as well as under participation of optical and acoustic phonons. Furthermore, trapping processes of excitons, and single electrons and/or holes by impurities are relevant.

The broad impurity-related luminescence band around 315 meV was tentatively assigned to DAP recombination [8]. The energies of shallow donor levels in this material are estimated to be less than 1 meV, whereas the hydrogen-like acceptor ground state energy amounts to 11.5 meV. The acceptor levels are strongly broadened (about 10 meV). Therefore the low energy tail of the corresponding PL feature is formed by far of DAPs. The FT PLE spectra of this PL part (Fig. 2a,b) demonstrate a regular behavior, i.e., the exciton transition is accompanied by a wide shoulder on the high energy side. For very low excitation densities, recent experiments on excitation dependent PL carried out with the present sample set revealed an infrared shift when lowering the excitation density further. This is expected even for DAP (Coulomb term) and earlier has been already demonstrated for narrow-gap $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ [22]. Thus, an additional and independent argument in favor of the explanation as DAP was provided.

In Fig. 2 full and dashed vertical grid lines mark the positions of phonon replicas of the monitor line ($E_m + nE_{\text{LO}}$, n integer number), caused by LO phonons of the HgTe and CdTe sublattices, respectively. The LO phonon energies were taken from Table 1. In Fig. 2a the $E_m + 3E_{\text{LO}}$ and $E_m + 4E_{\text{LO}}$ energies fall within the high energy tail of the PLE spectrum. A similar behavior can be observed in Fig. 2b where the range $E_m + 2E_{\text{LO}}$ and $E_m + 3E_{\text{LO}}$ is situated within the main PLE resonance. It undermines the concept that the radiative transitions in this spectral range can be feed either by the excitons *resonantly excited* or by those arising after an indirect ab-

sorption act, or the electrons and holes trapped by impurities when they recombine with LO phonon participation. Additionally it should be pointed out that the LO phonons of both sublattices contribute roughly with the same efficiency in the PLE spectrum. The flat background in each plot of Fig. 2 can be assigned to contributions of free electron-hole pairs which are scattered by impurities into states producing a signal within the PL monitor band.

The situation basically changes when the monitor passes the spectral position of impurity band maximum (cf. Fig. 3). In Fig. 2c the monitor is located 1-2 meV above the energy $E_x - E_{\text{LOCdTe}}$. Now the PLE peak corresponding to the exciton transition starts shifting toward higher energies and becomes located *exactly* at $E_m + E_{\text{LOcdTe}}$. The second well pronounced shoulder is located again *exactly* at $E_m + 2E_{\text{LOHgTe}}$. The PL spectrum at this particular monitor position (314.5 meV) originates from those DAP which are situated closer to each other. In Fig. 2c we observe the $E_m + E_{\text{LOcdTe}}$ and $E_m + 2E_{\text{LOHgTe}}$, whereas the $E_m + E_{\text{LOHgTe}}$ and $E_m + 2E_{\text{LOCdTe}}$ replicas vanish within the spectral envelope. Thus, both the HgTe and the CdTe sublattices contribute, however, there is a tendency for the domination of the phonon related absorption via CdTe sublattice phonons. This tendency becomes even more pronounced for monitor energies above 314.5 meV towards E_x (cf. Fig. 2d, e and Fig. 3).

Such "above bandgap phonon replica" have been discussed before for wide-gap materials such as CuCl and CdTe [23, 24]. But to the best of our knowledge, up to date such direct observation of exciton-phonon coupling has been never reported for a narrow-gap material. Furthermore, present experiments demonstrate the interplay between the action of the HgTe and CdTe similar modes. This behavior is a typical feature of multicomponent solid solutions.

The plots d and e in Fig. 2 give evidence for the non-

equilibrium character of the excitonic luminescence which is generated by exciton-phonon interaction. Considering them in terms of an exciton band, the position of the excitonic peak in the PLE spectrum is strongly dependent on the wavelength of exciting light shifted by the energy of one LO phonon. Thus, the luminescence is originated by annihilation of ‘hot’ excitons having energies between E_x and $E_x + E_{\text{LO}}$ and consequently also with *different kinetic energies*. The kinetic energy is determined as the energy difference between the position of the monitor and the position of $E_x - E_{\text{LOCdTe}}$ line. Assuming that free excitons are created mainly as a result of indirect exciton transitions in the spectral range just above the fundamental edge, the maximum of the PLE spectrum should not move. After an indirect absorption act the free “hot” excitons and a number of LO phonons are created. “Hot” excitons with a certain kinetic energy relax predominantly by emitting LO phonons and a non-equilibrium distribution becomes generated within the excitonic band. The kinetic energy of excitons strongly differs from the mean kinetic energy corresponding to the lattice temperature and the exciton distribution is shifted towards higher energies. As a result, the peak of the exciton emission also moves towards higher photon energies. It becomes located near the energy E' which is connected with the photon energy of the pump light E_p by

$$E' = E_p - nE_{\text{LO}} \quad (1)$$

where $E' < E_x + E_{\text{LO}}$ and n is again an integer number.

Radiative decay from this state will result in a PL signal shifted towards the high energy side of the LO phonon replica of the exciton monitored in the experiment. The magnitude of the PL signal is determined by the rates of radiative and non-radiative decay (relaxation) of the excitons which accompanies the transition from the non-equilibrium distribution into an equilibrium one by emission and absorption of acoustic phonons as well as by exciton-exciton scattering. The time of non-radiative decay basically determines the lifetime of free excitons and strongly depends on the defect structure of the sample. Because of the small value of the excitonic lifetime being of the order of 10^{-10} s in comparison with the thermalization time, estimated to be less than 10^{-9} s, the equilibrium distribution is not realized during the relaxation processes and the PL becomes substantially a non-equilibrium effect (for time constants cf. Refs. [25, 26]).

An alternative understanding of the phenomena observed could also be found in a single-particle picture where electrons and holes are separately considered. The results obtained have shown a strong coupling between electrons (holes) and LO phonons. If the free excitons can be described in analogy to localized centers a Franck-Condon effect in PL would be expected [27]. The peculiarities of the PLE spectrum are found then to be caused by the structure of the excitonic absorbance. It includes a series of equidistant peaks, separated from each other

by one LO phonon energy. Such spectrum was detected for CuCl where the excitons are self-confined [23]. Following the theoretical criteria given by Dykman and Pekar [28], an excitonic self-confinement can be expected in materials with a large difference between the effective masses of electrons (m_e) and holes (m_h). For $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ which is discussed here, the ratio $m_h/m_e \approx 30$ was found versus 40 in CuCl. Consequently, one could have reason to consider the exciton here to be self-localized in a such way as known for the CuCl. In this case, the intensity ratios of the LO replicas are given by the Huang-Rhys-factor which varies inversely with the exciton size. For bound-to-bound transitions it varies with the donor-acceptor spatial separation. The LO phonon energy derived from the PLE experiments depends on the distance between the absorbing and emitting center as well as from mirrors the dispersion of the LO phonon branch [27]. However, our previous magnetoluminescence experiments [5, 8] as well as the observed dependence of the FT PLE peak on the monitor position (cf. Fig. 3), show that the model of non-equilibrium exciton kinetics is more preferable here.

Fig. 4 depicts the temperature dependence of the PLE spectra. The monitor band remained fixed at the spectral position of $E_x(10\text{K})$. One can see the LO phonon replica connected with the HgTe sublattice for different temperatures. The temperature induced shift of the phonon peak (E_{ph}) is quantitatively described by the known empirical $E_g(x,y,T)$ relation [8]

$$E_g(x,y,T) = -0.302 + 6.3 \times 10^{-4} \times (1-2q) \times T + 1.93q - 0.81q^2 + 0.832q^3 \quad (\text{eV}), \quad (2)$$

where $q = x + 2y$.

This finding is consistent with the former discussion: in the low-temperature region ($T < 30$ K) the dominant PL mechanism is of excitonic nature. Consequently, the spectral position of the emission follows roughly $E_g(x,y,T)$. More thorough considerations indicate that the localization of the hole component within potential wells created by band edge fluctuations should be additionally taken into account.

IV. Summary

For the first time experimental material on PLE investigations in $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ is presented. It was found, that in a small spectral region around the fundamental energy gap ($E_x - E_{\text{LO}} < E < E_x + E_{\text{LO}}$) in this *direct* narrow-gap semiconductor *indirect* “hot exciton” absorption is the main absorption mechanism.

Thus, after earlier magnetoluminescence results [5], an additional and *independent verification* of the excitonic nature of the near to edge optical transitions in a narrow-gap material was found.

To the best of our knowledge, a direct observation of exciton-phonon coupling has never been reported before for a narrow-gap material. Furthermore, present experiments demonstrate the interplay between the phonon

modes arising from the HgTe and CdTe sublattices.

The optical properties of $\text{Hg}_{0.651}\text{Cd}_{0.335}\text{Mn}_{0.014}\text{Te}$ exhibit a number of features such as the LO phonon related resonances in PLE and resonant PL, which are very similar to corresponding effects observed for wide-gap II-VI materials such as $\text{Hg}_{1-x}\text{Zn}_x\text{Te}$ and $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$. This result should encourage to explain the very similar PLE behavior of these materials by a unified theoretical description.

Of course, above presented discussion sounds very similar to discussions done earlier about PLE-results obtained in wide gap II-VI materials. Even this similarity can be considered as a big step forward. It seems, that all knowledge about the behavior of the excitonic processes in wide gap materials can be really applied to high-quality narrow-gap materials.

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