Magneto-Photoluminescent Structure of HgCdTe

Liang Zhu*, Zhen Qi*, Xiren Chen*, Lu Chen†, Liangqing Zhu‡ Fangxing Zha§, and Jun Shao*¶
*National Laboratory for Infrared Physics, Shanghai Institute of Technical Physics CAS, Shanghai, China
† Research Center for Advanced Materials and Devices, Shanghai Institute of Technical Physics CAS, Shanghai, China
‡ Key Laboratory of Polar Materials and Devices, Ministry of Education, East China Normal University, Shanghai, China
§ Department of Physics, Shanghai University, Shanghai, China
¶ Email: jshao@mail.sitp.ac.cn

***Abstract*—Photoluminesence(PL) and magneto-optics are classical routines to characterize electronic structures of semiconductors. We incorporated magnetic field with infrared (IR) PL based on a Fourier transform infrared spectrometer, such that thermal background disturbance is well eliminated and signal-to-noise ratio significantly improved. By resolving closely-spaced PL components in $Hg_{1-x}Cd_xTe$ at various magnetic induction intensities, effective masses, shallow level types and energetic positions are deduced. It's demonstrated that magneto-PL is powerful in resolving IR-PL structure, and able to provide accurate parameters like effective masses and ionization energies of band-edge levels, along with the impurity types.**

I. INTRODUCTION AND BACKGROUND

ALLOY $Hg_{1-x}Cd_xTe$ (MCT) is a critical material system for infrared (IR) detection, which possesses exclusive advantages than other narrow-gap materials [1]. The band-edge levels affect crucial factors, e.g. carrier mobility, minor carrier lifetime, recombination channels and dark current mechanisms. Photoluminescence (PL) is classic and effective in studying band-edge structure. Under varing magnetic field, band-edge components in PL profiles evolve distinctively to each other in energy and intensity, which facilitate identifications of near band-edge features and parameter deductions by analyzing PL profiles. However, thermal background emission centering at 10 μm overwhelms PL signal above 3 μm [2], thus deteriorating the signal quality and hindering fine analysis of PL profiles.

In this work, via a method based on a step-scan Fourier transform infrared spectrometer [3], PL spectra with sufficient signal-to-noise ratio and spectral resolution were recorded at various magnetic field. Low temperature PL profiles of MCT are mostly composed of donor-related processes and those donors are dispersivenessless in k-space. It's demonstrated that magneto-PL is efficient to determine PL structure, effective mass and near band-edge level types.

II. RESULTS

Figure 1 depicts typical spectra. PL profiles are clearly consisted of component E0, E1, E2 and TA. Above 7 T, high energy feature LL emerges. The energy dependence on magnetic field is linear, indicating that negligible Coulomb interaction. With rising magnetic field, the relative weight of higher energy features in the PL profiles enhance, such that E0 is stronger than E1 above 6 T, and LL starts to emerge above 6 T.

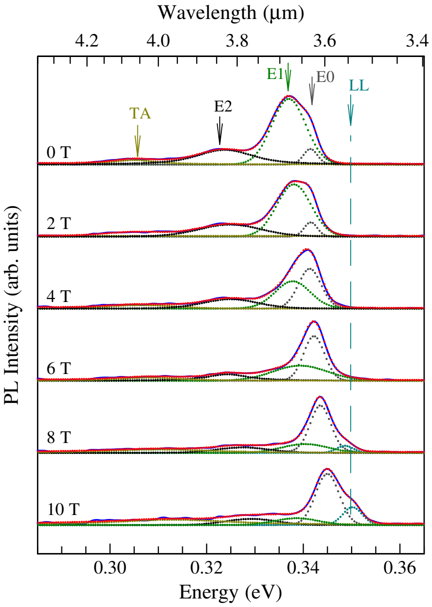

Fig. 1. Typical PL spectra and fitting results at different magnetic induction densities. Each component of PL profile is labeled with arrow. The energy dependences against field are all linear.

The energetic evolutions of peak LL, and E0-E2 are illustrated in Fig. 2, along with linear fittings. The evolutions of E0-E2 are nearly parallel to each other; while that of LL is much faster, and share the same energetic position at zero field with E0.

For direct semiconductors, the energy evolution against magnetic field is given by

$$E_n(B) = E_0 + \frac{1}{2}(n+1)\hbar\omega_{e(h)} \pm \frac{1}{2}g^*\mu_B B, \qquad (1)$$

$$\omega_{e(h)} = \frac{eB}{m^*_{e(h)}C}, \qquad (2)$$

$$\mu_B = \frac{e\hbar}{2m_0}, \qquad (3)$$

where E_0 is transition energy at zero field, n the Landau level index, $m^*_{e(h)}$ the reduced effective mass of electron (hole), B the magnetic field, and g^* the effective Landè g-factor. Since the excitation power densities in PL measurements are in the order of 10-100 W/cm^2, the photo-generated carriers filling in extend bands are negligible, thus n is usually not greater than unity; however, when Landau level splitting is comparable with k_bT, higher n should be taken into consideration.

In MCT, which is a typical narrow-gap semiconductor, effective Landè g-factor of free electron can be expressed as [4]

$$g_e^* = 2 + 4N_1 - \frac{2}{3}E_p(\frac{1}{E_g} - \frac{1}{E_g+\Delta}), \qquad (4)$$

$$E_p = \frac{2m_0}{\hbar^2}P^2, \qquad (5)$$

As an estimate, when E_g is about 0.3 eV, E_p is 18.5 eV , N_1 is zero, Δ equals 0.96 eV, then g_e^* is about -28 [5]. If free electron involved in PL profiles, the energetic shifts should be 22.3∓8.3 meV at 10 T; in contrast, energetic shifts of E0-E1 in the present work are only of several meV as depicted in Fig. 2. Therefore, processes involved free electron, and even those bound to hydrogenic impurities, can be safely ruled out in analysis; the only possibilities for those processes are related with non-hygrogenic donors, that are dispersivenessless in k-space. The same arguments are true for light-hole-involved processes. The energetic shift of LL is about 10 meV, which is about three times faster than those of E0-E2, and it may be the due to higer order Landau level transition compared with E0.

For heavy holes, the contributions of energetic shifts from g$_{hh}^*$ can be neglected compared with those from the Landau splitting [6]. Therefore, Eq. 1 can be reduced to

$$E_n(B) = E_0 + \frac{1}{2}(n+1)\hbar\omega_{hh}, \qquad (6)$$

$$\omega_{hh} = \frac{eB}{m_{hh}^*C}, \qquad (7)$$

where m$_{hh}$ is effective mass of heavy hole. By curve-fitting with Eq. 6, m$_{hh}^*$'s are about 0.16 m_0, larger than that of free electron and light hole. Therefore, E0, E1 and E2 originate from non-hydrogenic-donor-to-heavy-hole transitions, and recombination energies are 340.7, 336.9, 323.3 and 308.0 meV, respectively. The feature LL shifts nearly three times faster and shares the same energy position with E0 at zero field, thus is from non-hydrogeinc-donor-to-second-heavy-hole-Landau-Level transition. Since the MCT sample is as-grown without intentional doping, those donors are likely from intrinsic defects or residual impurities, and may contribute to background n-type conductivity.

For E1 and E2, only the first Landau splitting level related transitions are observed. It is understandable, since E1 and E2 is nearly completely eliminated in PL profiles when the second Landau splitting level component of E0 is observed. The competitions among E0,E1 and E2 are clear and out of expectation if they are independent impurities or defects. Further experimental and theoretical investigations are required to understand those competition behaviors against magnetic field.

It is also noted that though V$_{Hg}$ is the domain intrinsic acceptors in HgCdTe, no signs are observed for them. It indicates that all the photo-generated electrons are immediately captured by donors, so that no recombinations with V$_{Hg}$ can happen, and the recombination between donors and V$_{Hg}$ is very weak and negligible compared with those like E0-E1.

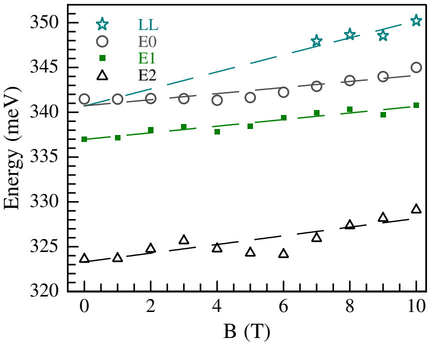

Fig. 2. Energy evolution of feature LL-E2 against magnetic induction intensity. The energy of the feature LL blue-shifts about three times faster than those of E0, E1 and E2.

III. CONCLUSION

To conclude, PL measurements were performed on MCT with various magnetic induction intensities. By recovering PL profiles with Gaussian-Lorentzian functions at different magnetic fields, closely-spaced and overlapped PL features are resolved. Analysis of the energy evolutions of those PL components indicates they are donor-related processes. The very large effective mass evidences those donor levels are not hydrogenic and nearly dispersivenessless in k-space. The competitions among those PL components indicate those donor levels are not independent. Parameters, i.e. effective mass of heavy hole, ionization energies of donors, are deduced. Therefore, magneto-PL is demonstrated to be powerful in resolving components of IR-PL, and able to give accurate parameters like effective masses and ionization energies of closely-spaced near band-edge levels.

ACKNOWLEDGMENT

The author (ZL) thanks Dr. K. He for fruitful discussions. This work is supported by the MOST 973 program (2014CB643901), STCSM (11JC14138) and NSFC (61176075, 11274329 and 61290301) of China.

REFERENCES

[1] A. Rogalski, *Rep. Prog. Phys.* **68**, 2267 (2005); A. Rogalski, J. Antoszewski, and L. Faraone, *J. Appl. Phys.* **105**, 091101 (2009)

[2] A. Fuchs, A. Lusson, J. Wagner, and P. Koidl, *Proc. SPIE* **1145**, 323 (1989); A. R. Reisinger, R. N. Roberts, S. R. Chinn, and T. H. Myersell, *Rev. Sci. Intrum.* **60**, 82 (1989)

[3] J. Shao, W. Lu, X. Lü, F. Y. Yue, Z. F. Li, S. L. Guo, and J. H. Chu, *Rev. Sci. Instrum.* **77**, 063104 (2006); J. Shao, F. Y. Yue, X. Lü, W. Lu, W. Huang, Z. F. Li and S. L. Guo, and J. H. Chu, *Appl. Phys. Lett.* **89**, 182121 (2006)

[4] V. Lòpez-Richard, G. E. Marques, and C. Trallero-Giner, *Solid State Commun.* **114** 649 (2000)

[5] A. J. Syllaios, C. L. Littler, X. N. Song, V. C. Lopes, C. R. Christensen, J. A. Grisham and F. W. Clarke, *Semicond. Sci. Technol.* **8**, 953 (1993)

[6] B. Li, Y.-S. Gui, Z.-H. Chen, H. J. Ye, J. H. Chu, S.L. Wang, R. B. Rong, and L. He, *Appl. Phys. Lett.* **73**, 1538(1998)