Photoluminescence Spectral Features of CdTe on InSb Grown by Molecular Beam Epitaxy

Z. C. Feng[1]*, J. W. Yu[1], W. Y. Chang[2], and J. Lin[2]

[1] Graduate Institute of Electro-Optical Engineering & Department of Electrical Engineering, National Taiwan University, Taiwan, ROC

[2] Department of Physics, National University of Singapore, Singapore

* E-mail address: zcfeng@ee.cc.ntu.edu.tw

Abstract

CdTe is an important optoelectronic material in the IR range application. CdTe was grown on InSb(001) by molecular beam expitaxy (MBE). Low temperature (2K) photoluminescence (PL) spectra were measured at different excitation power level while laser beam was focused on the same spot of the sample. From our experiment, we can obtain that the spectral features in the 1.4-1.5 eV range consist of three sets of DAP recombination emissions with different values of Huang-Rhys constants. Their peak positions are shifted with the excitation power at different rates. As expected, the Huang-Rhys factor is larger for the broadband feature than other two processes, i.e. this DAP transition involves different mechanisms from the two others.

CdTe semiconductor is intensively studied for the purpose of use in optoelectronic devices, in particular, solar cells, detectors of electromagnetic radiation and other elements of optoelectronic systems, because this material is characterized by a low thermal noise and large absorption coefficient [1,2]. Its optical, in particular luminescent, properties play an important role for these applications. Here we report a study on the photoluminescence (PL) characteristic of CdTe epitaxial film. The studied CdTe materials were grown on InSb (001) by molecular beam expitaxy (MBE). Low temperature (2K) PL spectra were measured at different excitation power level while laser beam was focused on the same spot of the sample.

From PL spectra, overlapping peaks from excitation, donor-acceptor-pair (DAP) and longitudinal optical (LO) phonon replicas were observed and their relative intensity and spectral shapes varied while changing excitation power. At lower temperature and lower excitation power, four separated peaks were noticeable in the range 1.4 ~ 1.5 eV, just below the fundamental band gap of CdTe. The interval of peaks towards low energy side was about 0.021 eV i.e. a LO phonon energy. With the increase of excitation power, a broad band emerged, first only as a background then as a dominant peak covering the whole range. To quantify this trend, theoretical simulation and curve fitting were applied to distinguish the separated features when they overlapped. PL spectral shape is described by a Poisson distribution. The intensity of PL spectrum is the sum of phonon replicas of DAP emission [3]:

$$I = I_0 \sum_0^3 \frac{e^{-s} s^m}{m!} g(E - E_0 + mE_{LO}, w).$$

The s is the Huang-Rhys factor, I_0 is the overall intensity, E_0 is the center of the zero phonon line (ZPL) and w is the peak width. $g(x,w)$ is a normalized Gaussian centered at $x = 0$ of width of w. The LO phonon energy, E_{LO}, is constrained to be 21 meV. It is found that our experimental results

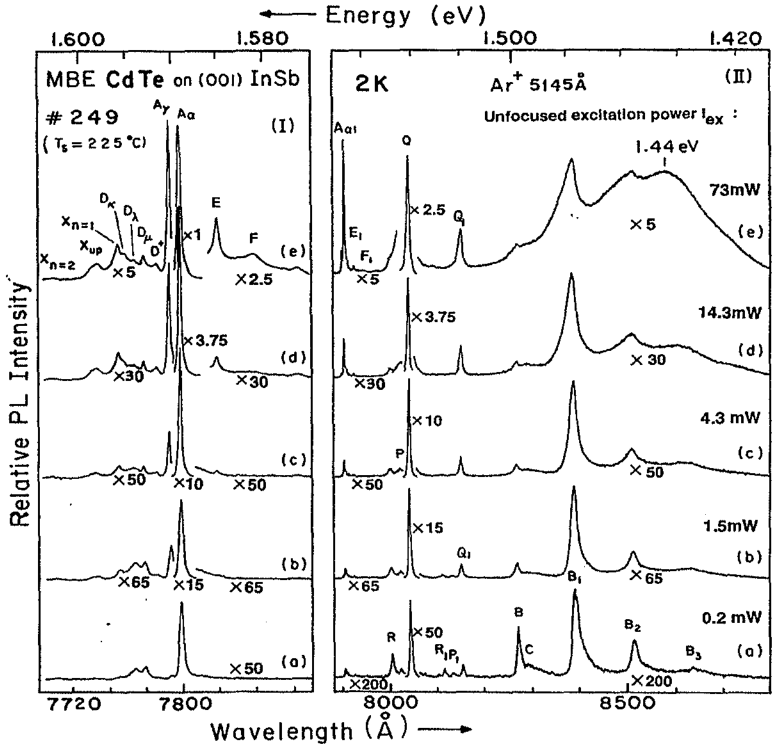
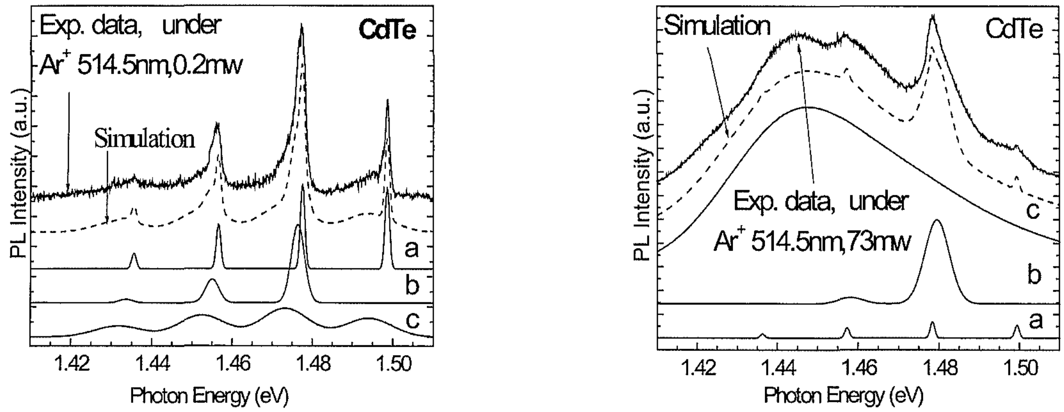


Fig. 1. *2K Photoluminescence spectra of CdTe grown on (001) InSb by MBE versus excitation laser power.*

can be well explained by constant *s*-parameter or unique DAP emission.

The low-temperature photoluminescence (LT-PL) measurement arrangements are similar to what has been described in **Refs. 4** and **5**. An Ar-ion laser with the 514.5 nm line is used as the excitation sources. Samples are immersed in liquid He below the lambda point (< 2K). A SPEX-1400 spectrometer, a cooled RCA C31034 photomultiplier (PM), and a lock-in amplifier are used for the measurements. Two microcomputers are used for instrumental control, data processing, and on-line display. **Fig. 1** shows high-resolution spectra for exciton transitions at 2K for the CdTe film grown InSb substrates by MBE. The high-resolution LT-PL exciton spectra show clear free-exciton (FE) features, and sharp and strong bound exciton (BE) lines. The line D_μ , D_λ ,and D_κ are assigned to recombination of excitons bound to donor impurities or complexes. The relative positions among D_μ , D_λ , and D_κ and their excited states are very similar. A_i with $i = \alpha, \beta, \gamma$ belongs to (A_i , X), the exciton bound to a neutral acceptor. The donor-acceptor-pair (DAP) transition R, **P**, and Q, and the deep transitions B, C, and J, including their phonon replicas, in MBE CdTe/InSb have been reported by us previous [5,6].

We suggest that it is a sum of numerous bands with different ZPLs corresponding to different intra-pair separation. Three series of DAP transitions were revealed from our experimental data. Good agreement is reached between experimental data and theoretical calculation which is shown in **Fig. 2**. Three DAP series, component A, B and C, spaced with the Zero Phonon Line (ZPL) peaked at 1.5, 1.48, 1.49 eV, respectively, as determined from the fine structure of PL spectra at lower temperature and lower excitation power. We refer to component A as a shallow DAP and the other two components are under discussion. With



(A) *PL spectra and simulation under the excitation power of 0.2mW*

(B) *PL spectra and simulation under the excitation power of 73 mW*

Fig. 2. *PL spectra of CdTe at 2K under different excitation power,* **(A)** *0.2 and* **(B)** *73 mW, with the top for experimental ones. Three calculated components a, b and c are displayed vertically for clarity. Dashed lines are the sum of three components.*

the increase of excitation power, the intensity of shallow donor DAP transition decreased significantly accompanied with the increase of the component C, which evolved into a dominant feature over the whole range. Blue shifts of peak positions occurred for all individual components.

The effect of excitation intensity on the PL spectral peaks at low temperature is studied to determine the recombination process involved. The spectral shift is explained as follows [4,5]. According to Configuration-Coordination model, the emission energy and transition probability of DAP emission depend on spatial intra-pair separation, *r*. With the increase of excitation intensity, intensities of emission lines located at longer wavelength with larger *r* should be saturated. Therefore, the peak of a band composed of unresolved pair lines should shift to short-wavelength side. In comparison with small shifts for shallow donors, large shift is observed for deep donors. For example, C. Thomsen *et al*. reported the 2.8 eV band shifted more 200meV in M-doped GaN [6].

Fig. 3 shows the peak shifts of three components. It is evident that three DAP features are shifted with excitation power at different rates. It indicates

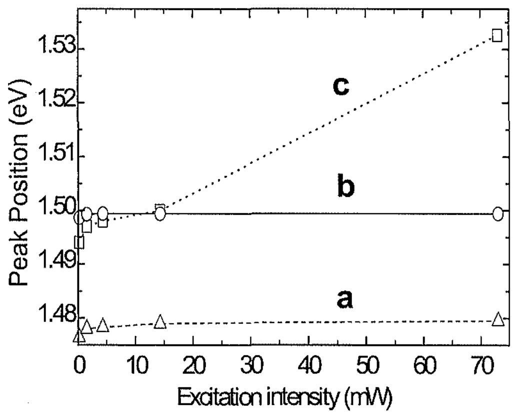


Fig. 3. *Dependence of the peak position of three components on excitation intensity.*

that the recombination process for broadband is quite different from those of two others. This interpretation is also supported by the behavior of the Huang-Rhys factor under varied excitation intensity, which is shown in **Fig. 4**. It is known that the electron–phonon interaction related to impurity such as donor and acceptor becomes stronger with an increase of the donor or acceptor energy level. For component C, s-value deduced from curve fitting, is greater than 6, which is expected for stronger phonon-electron coupling. It is reasonable to conclude that broadband transition is related to deep level donors or acceptors.

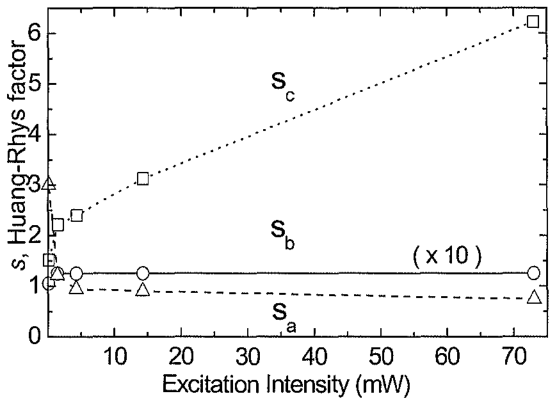


Fig. 4. *Dependence of the s-parameter of three components on excitation intensity.*

In summary, LT PL spectra of CdTe grown on InSb are studied. Our work reveal that the spectral features in the 1.4 - 1.5 eV range consist of three sets of DAP recombination emissions with different values of Huang-Rhys constants. Their peak positions are shifted with the excitation power at different rates. As expected, the Huang-Rhys factor is larger for the broadband feature than other two processes, i.e. this DAP transition involves different mechanisms from the two others.

Reference

[1] I. S. Virt, M. Bester, M. Kuzma, V. D. Popovych, Thin Solid Films 451-452, 184 (2004)

[2] P. Capper (Ed.), Properties of Narrow Gap Cadmium-based Compounds, INSPEC, London p399 (1994)

[3] A. L. Chen, W. Walukiewicz and E. E. Haller, Appl. Phys. Lett, 65, 1006 (1994).

[4] Z. C. Feng, A. Mascarenhas, W. J. Choyke, R. F. Farrow, F. A. Shirland, and W. J. Takei, Appl. Phys. Lett, 47, 24 (1985)

[5] Z. C. Feng, A. Mascarenhas, and W. J. Choyke, J. Lumim. 35, 329 (1986)

[6] Z. C. Feng, M. J. Bevan, W. J. Choyke, S. V. Krishnaswamy, J. Appl. Phys. 64, 2595 (1988)

[7] M. A. Reshchikov, F. Shahefipour, R. Y. Korotkov, B. W. Wessels, and M. P. Ulmer, J. Appl. Phys. 87, 3351 (2000).

[8] Shigeo Shionoya, *Luminescence of solids,* edited by D. R. Vij, Plenum Press, New York, 1998.

[9] C. Thomsen, B. Schineller, K. Heime, M. Heuken, O. Schon, and R. Beccard, J. Appl. Phys. 84, 5828 (1998).