

Resonant Raman Spectra of CdTe/ZnTe Self Assembled Quantum Dots

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In this paper we present Raman scattering and photoluminescence spectra measured on CdTe/ZnTe self assembled quantum dots. The photoluminescence spectrum has shown two main emission peaks, both connected with existing of quantum dots. One presents direct deexcitation to ground state and the other is optical phonon ($\omega = 207.3 \text{ cm}^{-1}$)-assisted deexcitation. The registered multiphonon emission process depends on temperature. At low temperature phonon spectra shows line at 450 cm^{-1} (TA+2LO in ZnTe) and 595 cm^{-1} (2LO+TO(T) in ZnTe).

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1. Introduction

Great interest has been observed recently in studying the properties of layers of semiconductor materials with a mismatch between their lattice parameters. Favourable conditions for the formation of self-assembled quantum dots (QDs) are created in such layers [1]. The wide band-gap CdTe/ZnTe system is of current interest because of its potential applications in short-wavelength optoelectronic devices, but the large lattice mismatch (6.4%) makes it very difficult to grow CdTe/ZnTe structure of high quality [2].

Raman scattering has been widely used to study the phonons in low-dimensional semiconductor systems. For II–VI semiconductor, first order Raman scattering, multiphonon (MP) Raman scattering has received less attention [3]. For better understanding of optical and structural properties of CdTe/ZnTe structures, in this paper we focused our attention to Raman and photoluminescence (PL) spectroscopy of CdTe/ZnTe self organized quantum dots.

2. Samples and characterization

Investigated samples were grown by molecular beam epitaxy on GaAs substrate. CdTe buffer layer, $5 \mu\text{m}$ thick, was deposited on the substrate. After a $0.8 \mu\text{m}$ thick ZnTe layer, 12 monolayers (ML) of CdTe were deposited to form a random distribution of quantum

dots. High mismatch of lattice parameters of CdTe (6.482 \AA) and ZnTe (6.104 \AA) provokes gathering of CdTe molecules and forming of quantum dots. The dot layer was covered by $0.1 \mu\text{m}$ ZnTe capping layer. Further details of the samples growth can be found in Ref. [1]. The Raman and photoluminescence spectra were excited by several lines of argon-laser line and measured using a Jobin Yvon model U-1000 monochromator, with a conventional photocounting system.

3. Results and discussion

The electronic band structure was characterized by a PL spectrum which showed two main emission peaks. Typical PL spectra, recorded at 200 K, are presented in Fig. 1. The peaks positions are 2.307 eV (E_1) and 2.11 eV (E_2) at $T = 200 \text{ K}$, and 2.337 eV (E_1) and 2.13 eV (E_2) at $T = 20 \text{ K}$. Their energies decrease with temperature increase, as presented in Fig. 2. The first peak, E_1 , is related to optical phonon ($\omega = 207.3 \text{ cm}^{-1}$) assisted emission. MP resonant processes are registered at temperature below 200 K. This process is dominant for QDs with high emission energy, i.e. presumably with smaller size. The second one, E_2 , is related to direct excited state–ground state transition. This process is important for all QDs.

Calculation of electronic transitions is done in common effective-mass approximation [4]. Parameters, effective masses and conduction and valence offsets are transferred from literature. In our case we use approximation that supports the assumption which leads from PL spectra. We suppose that electrons and holes from QD are

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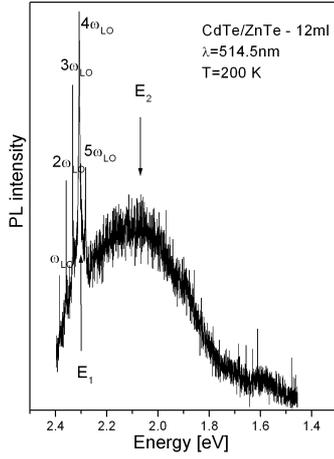


Fig. 1. Typical PL spectra of sample with 12 ML of CdTe in the finishing layer; PL spectra are excited by $\lambda = 514.5$ nm Ar-laser line and recorded at 200 K.

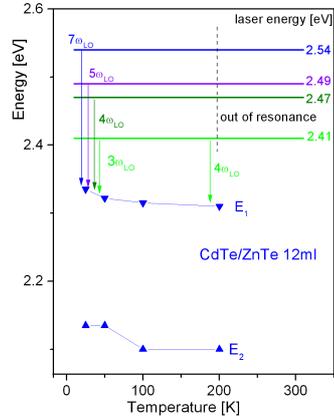


Fig. 2. Schematic presentation of multiphonon resonance and temperature dependences of PL emission peaks.

in step-like energy well. CdTe is in the core and the concentration of CdTe in the surrounding $\text{Cd}_x\text{Zn}_{1-x}\text{Te}$ gradually decreases to 10% ($x = 0.1$), step by step. For measured E_2 the dimension of the well core, related with dimension of QD, is 1.55 nm and the external diameter of the energy well is 6.48 nm. Broad E_2 band in this sample suggests the great dispersion in dimensions of QDs, i.e. the great variations in relief of CdTe layer.

In principle, registered MP resonant process (see Fig. 3) can be described by the following equation: $E_{\text{in}} - K\hbar\omega = E$; E_{in} and E are the incident photon energy and electron transition energy, respectively. $\hbar\omega$ is the phonon energy and K is the MP order. MP emission is not registered at $T = 300$ K. MP emission processes are registered at temperature below $T = 200$ K (for 2.41 eV laser energy, $K = 4$). The equation means that when the energy of the scattered photon approached the energy E , the Raman line becomes strongly enhanced. At $T = 20$ K resonance order depends on excitation energy

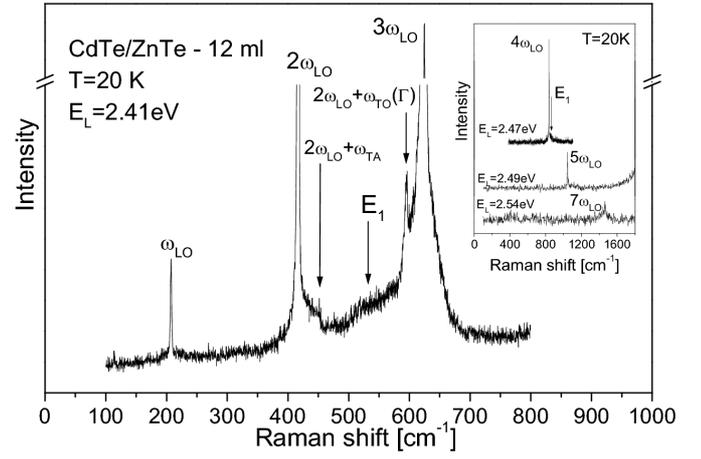


Fig. 3. Raman spectra of CdTe/ZnTe self assembled QD at $T = 20$ K. Inset: PL spectra excited by different excitation energies at $T = 20$ K.

and its values are 3, 4, 5 and 7 for laser lines 2.41 eV, 2.47 eV, 2.49 eV and 2.54 eV, respectively (see inset in Fig. 3), which is schematically presented in Fig. 2.

Phonon spectra depend on temperature. More complicated spectra are registered at $T = 20$ K, Fig. 3. Beside the phonon at 207.3 cm^{-1} , its harmonics, which participate in MP processes, lines at 450 cm^{-1} and 595 cm^{-1} can easily be observed. These modes can be assigned in this way: we attribute the peak 207.3 cm^{-1} to confine longitudinal-optical (LO) phonons from bulk ZnTe (209 cm^{-1}) [5]. We identified the peaks at 450 cm^{-1} and 595 cm^{-1} as ZnTe (TA + 2LO) modes and $(2\text{LO} + \text{TO}(\Gamma))$ modes, respectively.

4. Conclusion

In this paper we investigated structural and optical properties of CdTe/ZnTe self-assembled quantum dots growth by molecular beam epitaxy. Photoluminescence spectra consist of two main emission peaks: direct excited state-ground state transition (E_2) and optical phonon assisted emission (E_1). The registered multiphonon emission processes depend on temperature. When the energy of the scattered photon approaches the energy E_1 , the corresponding Raman line becomes strongly enhanced. At low temperature phonon spectra shows ω_{LO} line at 207.3 cm^{-1} , its higher order harmonics and multiphonon modes at 450 cm^{-1} (TA + 2LO in ZnTe) and 595 cm^{-1} ($2\text{LO} + \text{TO}(\Gamma)$).

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References

- [1] S. Mackowski, *Thin Solid Films* **412**, 96 (2002).
- [2] S. Mackowski, G. Karczewski, T. Wojtowicz, J. Kossut, S. Kret, P. Dluzewski, *Appl. Phys. Lett.* **78**, 3884 (2001).
- [3] A.A. Arora, M. Rajalakshmi, T.R. Ravindran, V. Sivasubramanian, *J. Raman Spectrosc.* **38**, 604 (2007).
- [4] M. Tkach, V. Holovatsky, O. Voitsekhivska, M. Mikhalyova, *Phys. Status Solidi B* **203**, 373 (1997).
- [5] S.L. Zhang, Y.T. Hou, M.Y. Shen, J. Li, S.X. Yuan, *Phys. Rev. B* **47**, 12937 (1993).