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Optical characteristics of InAs/GaAs double quantum dots grown by MBE with Indium-Flush method

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1. Introduction

The semiconductor quantum dots (QDs) has been studied energetically due to attractive physical properties. The research has moved to phase for application and already very low threshold current laser is actualizing [1]. Recently, it is revealed experimentally that carrier coherence in QDs is kept for several hundred psec [2], QDs catches attention as medium for quantum computing. Actually coherent control of exciton in single quantum dot has been reported [3]. Interaction between two QDs and coherence control of electronic state in each QD are essential for realizing control NOT gate as unit of quantum computation. As examples of double QDs in 3-5 semiconductor, strain- induced dots [4] and InAs/InAlAs dots [5] have been reported.

In this paper, we report optical characteristics of InAs/GaAs double quantum dots structure fabricated by MBE with Indium-Flush method.

2. Experiments

We used vertically coupled growth method for double QDs growth [6]. Studying interaction between dots needs distinction between the two dots in photoluminescence (PL) spectra. Therefore we fabricated double dots where size differs in the upper and lower as pilot experiment. 150nm GaAs buffer layer, 1.65ML InAs as 1st dots layer, 6nm GaAs barrier layer, 1.4ML InAs (sample A) or 1.6ML InAs (sample B) as 2nd dots layer and 150nm GaAs capping layer were grown on GaAs(100)A substrate successively. As shown PL spectra in Fig.1, we confirmed that it is possible to distinguish between 1st and 2nd layer dots in 1.4ML sample A contrary to 1.6ML sample B that has only overlapped single peak.

With the result above, we fabricated three samples which have different barrier thickness each other, using Indium-Flush (I-F) method [7]. After 1.65ML InAs as 1st dot layer was grown, we executed I-F at GaAs 4nm grown. And then, three variations, 6nm (sample C), 4nm (sample D), 2nm (Sample E), GaAs layer as barrier, 1.5ML 2nd InAs layer and finally 150nm GaAs cap layer were grown sequentially. We estimated effective burrier thickness of sample C, D, E at 7nm ,5nm, 3nm respectively following Ref[7].

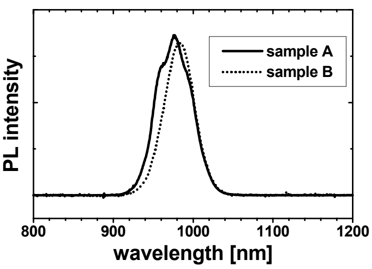

Fig.1 PL of double QDs at 10K excited by Argon laser. Sample A is 1.65ML/1.4ML InAs and Sample B is 1.65ML/1.6ML InAs. Both samples have 6nm GaAs barrier layer.

3. Results

In Fig.2, We show excitation power dependence of PL spectra of double dots samples with different barrier thickness at 10K. Also inset shows PL of single dots layer sample for reference. Comparing with single dots sample, all double dots samples has two main peaks assigned to luminescence from upper and lower dots layer respectively. And remarkable difference of power dependence among three double dots samples is observed. This indicate enhancement of tunneling probability between double dots with decrease of barrier thickness.

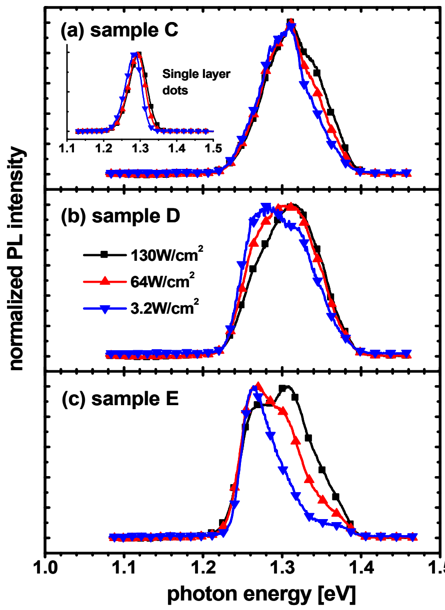

Fig.2 PL of double QDs at 10K excited by laser diode 1.95eV. Barrier layer thickness of Sample C, D, E is 7nm, 5nm, 3nm respectively. Inset shows PL of single layer dots.

In order to separate detail peaks from PL spectra, we measured PLE spectra and performed Gaussian fitting to PL spectra for each samples. Fig.3(a) shows PL and PLE spectra of sample E with fitting carve. All spectra are fitted by 4 Gaussian and each peaks agree PLE peaks. We assigned lower 2 peaks(named X1, X2) to 1st layer dots and higher 2 peaks(Y1, Y2) to 2nd layer. Then we plotted each peak energy to barrier thickness as shown Fig.3(b). Energy sprit between main X1 peak and Y1 is increased with barrier thickness decrease. This suggested that wave function coupling between double dots is enhanced with decrease of barrier thickness.

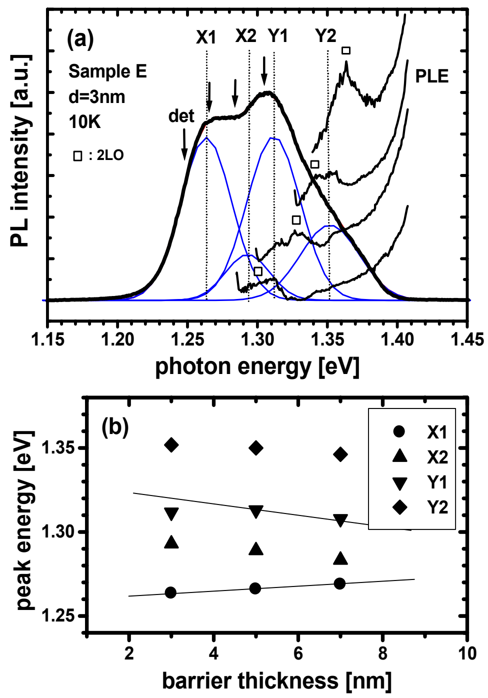

Fig.3 (a) PLE and Gaussian fitting carve of PL for sample E. Arrows indicate PLE detection energy. Square symbol indicate 2LO resonant peaks. (b) PL peaks energy of each sample are plotted to barrier layer thickness.

Actually, calculating coupled state for simply 1D confinement conditions as shown Fig.4, we conformed that energy separation is increased by bonding, anti-bonding wave function coupling between different energy state.

4. Conclusions

We have fabricated InAs/GaAs double quantum dots structures by MBE which have different barrier thickness. We observed luminescence from two dots layer individually. Excitation power dependence of PL spectra indicated enhancement of tunneling probability between double dots with decrease of burrier thickness. We confirmed peak energy shift due to wave function coupling between double dots.

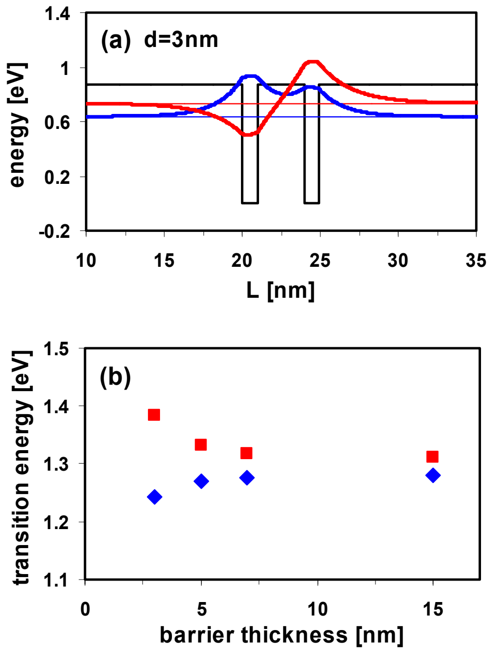

Fig.4 (a) calculated wave function of coupled asymmetric QWs, where barrier thickness=3nm. (b) transition energy are plotted to barrier layer thickness.

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