DLTS Study on Self-Assembled InAs/GaAs Quantum Dots Grown by MBE

E.K. Kim[1], J.S. Kim[1], J.H. Kim[1], S.J. Lee[2], S.K. Noh[2]
[1]*Dept. of Physics, Hanyang Univ., Seoul 133-791, Korea*
[2]*KRISS, Daejeon 305-600, Korea*

The quantum dot (QD) is a very interesting structure in viewpoint of theoretical physics and applications because band structure of QD system is a kind of potential well just like hydrogen atom or particle in a box. Thus, property of the QD bears resemble to an atom. Its energy state is a discrete, density of the state is like delta function and band transition follows selection rule. Most of all, discrete energy state of QD is a very important property from a applied point of view. The properties give us high quantum efficiency in optical device such as laser diodes and light emitting diodes, and useable to information unit in information devices such as single electron memory and more over qubit of quantum computation. However, the control and characterization of the energy state of QD are not easy.

Recently, photoluminescence (PL) methods are widely used in optical characterization. The methods are comparably convenience and produce direct band-to-band transition information. However, PL can't determine offset of energy state of QD related to the band edge of the host matrix. This information is important to application of not only optical devices but also electrical devices such as single electron transistor and information devices. It is characterized by several methods for instance electrical methods of I-V, C-V, admittance spectroscopy, deep level transient spectroscopy (DLTS), and temperature dependent PL, etc. Especially, DLTS is very useful and powerful tool to find out not only energy state of QDs but also deep levels in epilayers.

In this study, we find the confined energy levels of QDs from the analysis of DLTS measurement for molecular beam epitaxy (MBE) grown InAs/GaAs QD system. Through DLTS measurements under various filling pulse width the capture barrier height of QDs is estimated also. The all kinds of InAs QD structures used in this study were grown on n^+-GaAs substrates by self-assembled method using MBE system. The GaAs buffer layer with a thickness of 300 nm was grown at 560 ^oC and then the InAs QDs were grown at temperatures range from 480 ^oC to 505 ^oC with 2.3 MLs. The 100nm of GaAs capping layer was grown at low temperature just like growth temperature of the QDs, and then the rest GaAs capping layer was grown at 560 ^oC until with a thickness of 500 nm. From atomic force microscope measurement the density of QDs appeared order of 10^{10} cm^{-2}. The highest density was appeared high 10^{10} cm^{-2} at growth temperature of 495 ^oC. As the growth temperature becomes higher or lower compared to 495 ^oC the density becomes lower to low 10^{10} cm^{-2}. The height and lateral size of QD were about 7~8 nm and 25 nm, respectively.

Fig. 1 and 2 are the result of PL measurement and the depth dependence of DLTS spectra in InAs/GaAs QDs at temperature of 480 ^oC. From the PL measurements, we confirm that two quantum energies in QDs exist and the difference between two levels is about 80~100 meV. DLTS can measure not only the confined level of QDs but also a point defect of epilayer. From the reason, there are many signals in the spectra. After analysis of DLTS signals, we strongly expect that signals of B and C are confined energy level of QDs. The activation energies of QDs signals are consistent with PL result. The activation energies and emission cross sections of B and C levels are 0.32 eV and 0.24 eV, 5.68 X $10^{-14}cm^2$ and 1.88 X 10^{-14} cm^2, respectively. The difference of two activation energies is about 80 meV. On the other hand, it is considered that origins of signals A and D may be related to defect state of GaAs layer and interface state InAs/GaAs structure.

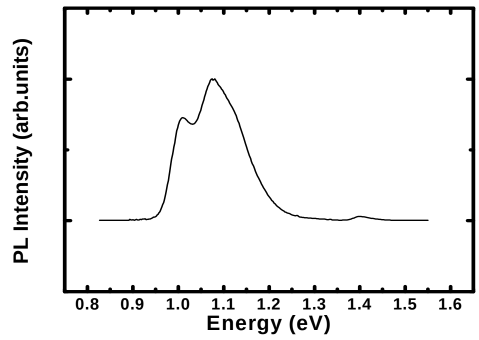

Fig. 1 PL spectra of MBE grown InAs/GaAs QDs at temperature of 480 ^oC

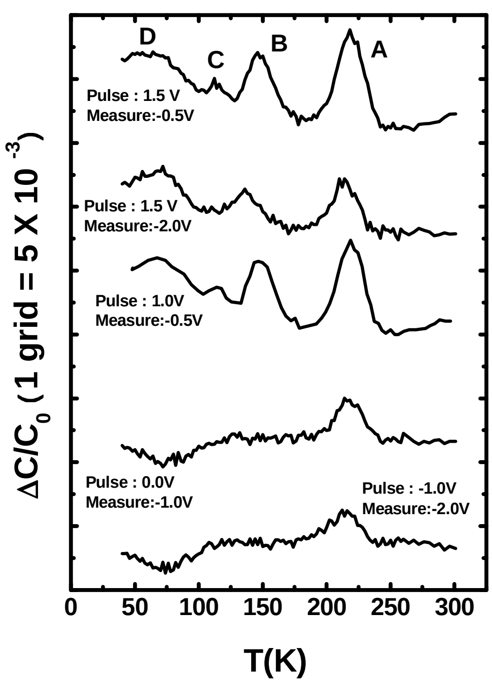

Fig. 2 DLTS spectra of MBE grown InAs/GaAs QDs at temperature of 480 ^oC