Quantum Size and Alloying Effects of InGaAs Single Quantum Dots on GaAs(001) Studied by Scanning Tunneling Spectroscopy

T. Yamauchi[1*], M. Tabuchi[2], and A. Nakamura[1,3]
[1]CREST, Japan Science and Technology Corporation
[2]Graduate School of Engineering, Nagoya University
[3]Center for Integrated Research in Science and Engineering, Nagoya University
*yamauchi@cirse.nagoya-u.ac.jp

InAs and InGaAs self-assembled quantum dots (QDs) grown on a GaAs substrate have been intensively investigated for optoelectronic device applications as well as fundamental understanding of quantum size effects (QSEs). Structural studies on InGaAs QDs have recently shown that the actual In composition in a QD is different from the nominal composition and the distribution is nonuniform in a QDs. Here, we represent a correlation between the gap energy and size of single InGaAs QDs. [1].

The InGaAs QDs were grown on a Si-doped GaAs(001) substrate by molecular-beam epitaxy (MBE). An InGaAs layer with a nominal thickness of 4.8 ML and In composition x of 0.46 was deposited. The dot height varies from 1.3 to 7.1 nm, and the lateral size is in the range of 8.5-37 nm. The mean values of the height and diameter are 2.9 and 16.4 nm, respectively. Height h and diameter d measured for each dot are related to the following equation in the unit of nm: $d = 5.1h + 1.7$.

A correlation between the gap energy and dot size was investigated by measuring a tunneling current with a current imaging tunneling spectroscopy (CITS) mode. Figure 1 shows the measured gap energies as a function of dot height. The gap increases with decreasing dot height: 1.18 eV for 1.7 nm and 0.54 eV for 6.6 nm. These data can be compared to the energy range of the PL spectrum, and the data for $h < 5$ nm correspond to the observed spectrum in which the energy scale is displayed by shifting the scale by 78 meV due to the temperature variation of the band gap.

We have calculated the gap energies between the lowest bound states of the conduction and valence bands using a one-dimensional quantum well model with finite barrier potentials. The solid curve in Fig. 1 shows the dependence of the gap energy on the dot height calculated for x = 0.46. The calculated energy is larger than the experimental data, and the discrepancy is found to be significant for large height. Taking In composition x as an adjustable parameter, we calculated gap energies. When we take x in the range of 0.75-1, the observed gap energy is well reproduced by the calculation. Therefore, we have found that In enrichment takes place during InGaAs MBE growth and the In composition is 0.75-1.

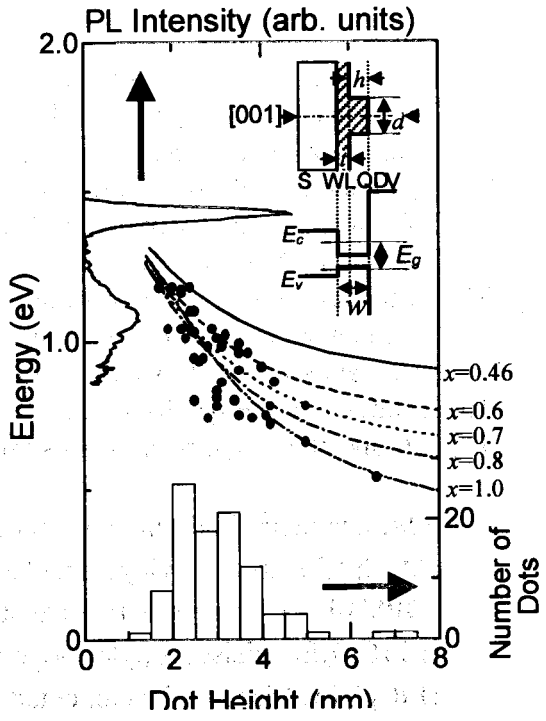

Fig.1: Dot-height dependence of gap energy for InGaAs QDs at room temperature, histogram of dot height, and PL spectrum at 80 K.

[1] T. Yamauchi et al., Appl. Phys. Lett. 79, (2001) No. 15.