Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 338-339

Size Quantization in InAs/GaAs Self-Assembled Quantum Dots by Gas-Source Molecular Beam Epitaxy

Hong-Wen Ren,[1], Kenichi Nishi,[2] Shigeo Sugou[1,2] and Yasuaki Masumoto[1,3]

1. Single Quantum Dot Project, ERATO, JST, c/o NEC Corporation, Miyukigaoka 34, Tsukuba 305, Japan
Tel: +81-298-50-1174, Fax: +81-298-56-6140, E-mail: ren@obl.cl.nec.co.jp
2. Opto-electronics Research Laboratories, NEC Corporation, Miyukigaoka 34, Tsukuba 305, Japan
3. Institute of Physics, University of Tsukuba, Tsukuba 305, Japan

1. Introduction

Semiconductor quantum dots exhibit distinct electronic properties that are originated from the 3-dimensional size confinement of electrons or excitons [1]. They are interesting not only in physics but also in fabricating novel quantum devices.

Many studies on InAs/GaAs self-assembled quantum dots (SADs) displaying excited quantum states have been reported [2-4]. However, the geometrical structures and strain distributions that determine the number and energies of the quantum states in SADs are subjects of further investigations. It has been reported that, with increasing InAs coverage from 1.6ML to 2ML, the average diameter of SADs decreases from 25 to 20nm and the average height shows little or no increase [5]. This suggest that the SAD size is not always proportional to the amount of InAs deposition, or the monotonous decrease of the PL peak energy with the increase of InAs coverage may not be originated from the increase of the quantum dot size, but from other origins such as strain relaxation and increase of the actual indium content in SADs.

In contrast, it was reported that the average size of InAs self-assembled islands can be controlled easily by the growth temperature of InAs deposition [6]. In this study, InAs SADs with fixed coverage of 1.7ML but different dot sizes were obtained by suppressing indium segregation. We found that the indium segregation is the most influencing factor to alter the geometry and composition of SADs. The number and energies of confined states, state filling in SADs and difference between large and small dots are studied.

2. Experimental results and discussion

Growth of InAs SADs on GaAs (100) vicinal surfaces was carried out in a gas-source molecular beam epitaxy with Ga, In and cracked AsH_3 at 950°C as sources. The substrates were GaAs (100) vicinal surfaces inclined by 0.5° toward the $[0\bar{1}1]$ direction. While growing the InAs layer, the amount of InAs deposition was controlled to be 1.7ML by observing the RHEED transition from streaky to spotty. By varying the InAs deposition temperature to be 520°C, 500°C, 480°C and 450°C, the average diameter of the 3D islands decreased from 35nm down to 28nm, 22nm and 15nm, respectively as was measured by AFM. The height to diameter ratio decreased from 0.28 down to 0.2. In compensation, the surface density of SADs increased by one order. To make samples for the optical study, InAs islands were formed at different temperatures but all are capped by GaAs at 450°C. Such low temperature is crucial to suppress indium segregation and still maintain the GaAs quality. 77K PL of the resulted SADs formed at different temperatures are shown in Fig. 1. All the four PL spectra showed multiple peaks. The emission at 1.42eV is identified to be from the wetting layer. Excitation intensity dependence and Gaussian fit of the PL spectra reveal that the number of confined states from the dots are five, three, two and one for the samples where InAs was deposited at 520°C, 500°C, 480°C and 450°C, respectively. The energies of the Gaussian components for the four samples are plotted in Fig. 2. With the decrease of the dot diameter from 35nm to 15nm, the ground state appear at 1.15eV, 1.22eV, 1.26eV and 1.34eV, respectively. For InAs SADs grown at 520°C and 500°C, state filling to the higher levels is clearly observed. The distinct peaks keep constant energies under different excitation intensities with the energy separation of 50meV.

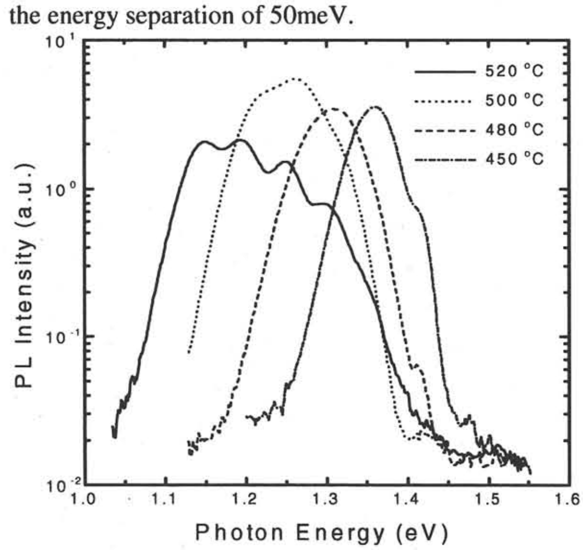

Fig. 1. 77K PL of 1.7 ML InAs/GaAs SADs excited by 514.5nm laser at 600W/cm^2. InAs were deposited at 520°C, 500°C, 480°C, 450°C, respectively and all of them were capped by GaAs at 450°C.

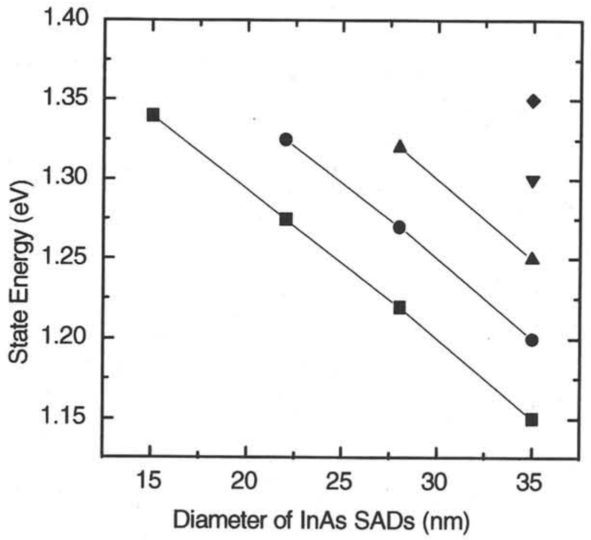

Fig. 2. Peak positions of the Gaussian components in the 77K PL spectra of the four samples with different dot sizes.

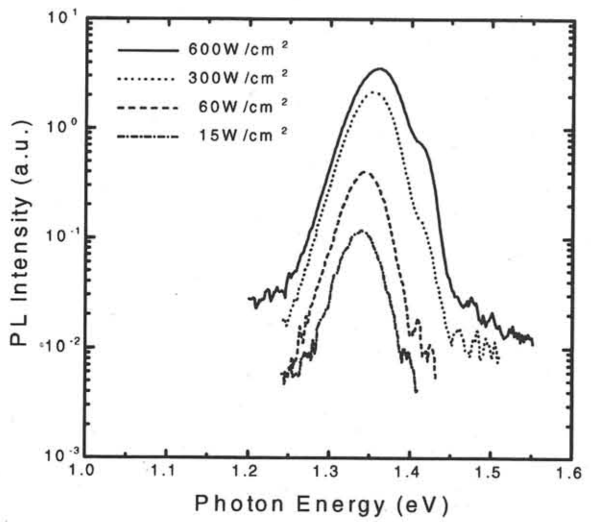

Fig. 3. 77K PL of 1.7 ML InAs/GaAs SADs excited by 514.5nm laser at different excitation intensities. Both InAs dots and GaAs cap layer were grown at 450°C.

On the contrary, the excitation intensity dependence of PL spectra for the smaller InAs SADs grown at 480°C and 450°C showed blue-shift of the peak positions with increasing excitation. The PL from the sample grown at 450°C is manifested in Fig.3. By increasing excitation from $15W/cm^2$ to $600W/cm^2$, the blue-shift is about 18meV but the half-width does not increase obviously. The origin causing the difference between large and small dots is under further investigation.

3. Conclusions

By controlling the growth temperature for 1.7ML InAs deposition and that for GaAs cap layer, different sized SADs under suppressed indium segregation were obtained. The number of confined states in the dots varies from five to one with the decrease of the dot sizes. State filling effect is easily observed in 77K PL for large SADs and the energy separations between the states are about 50meV. For the smaller dots where only one or two confined states remain, the PL peak showed blue-shift with increasing excitation intensity.

Acknowledgments

The authors would like to thank Mr. T. Anan and Mr. K. Tokutome for their help, and to thank Dr. K. Kasahara and Dr. T. Yuasa for their encouragement.

References

1). A.D. Yoffe, Adv. Phys. 42 (1993) 173.
2). S. Fafard, R. Leon, D. Leonard, J.L. Merz and P.M. Petroff: Phys. Rev. B 52 (1995) 5752.
3). K. Mukai, N. Ohtsuka, H. Shoji and M. Sugawara: Phys. Rev. B 54 (1996) R5243.
4). M. Grundmann, N.N. Ledentsov, O. Stier, J.Bohrer and D. Bimberg: Phys. Rev. B 53 (1996) R10509.
5). D. Leonard, K. Pond and P.M. Petroff: Phys. Rev. B 50 (1994) 11687.
6). T. Nishinaga, I. Ichimura and T. Suzuki, Control of Semiconductor Interfaces, I. Ohdomari, M. Oshima and A. Hiraki eds, 1994 Elsevier Science B.V. 63.