Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 336-337

Vertical Quantum Confinement Effect on Optical Properties of Strain-Induced InGaP Quantum Dot Structure

S.J. Kim, H. Asahi, M. Takemoto, K. Asami and S. Gonda

The Institute of Scientific and Industrial Research, Osaka University
8-1, Mihogaoka, Ibaraki, Osaka 567, Japan
Phone/Fax:+ 81-6-879-8407 / 8509, E-mail:asahi@sanken.osaka-u.ac.jp

1. Introduction

Quantum dot (QD) structures with three-dimensional quantum confinement are attracting great interest for novel device applications and physical studies. In previous papers [1], we have reported the self-formation of QD structures in the GaP/InP short period superlattices (SLs) grown on GaAs(N11)A substrates by gas source molecular beam epitaxy (MBE). However, the full width at half-maximum (FWHM) of the photoluminescence (PL) peak for the $(GaP)_{1.5}(InP)_{1.88}$ SL(18 periods=20 nm) /InGaP(20 nm:barrier) multilayer QD structures showed large broadening with temperature. In this paper, we report the dependence of optical properties on the SL period (SL thickness).

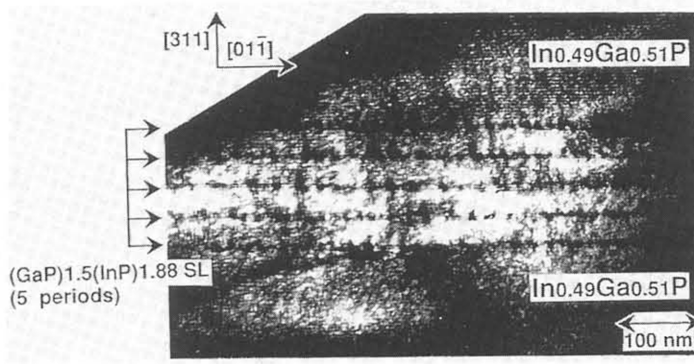

Fig.1 (011) plane cross-sectional TEM image for the $(GaP)_{1.5}(InP)_{1.88}$ SL(5-periods))/InGaP(20 nm) multilayer QD structure grown on GaAs(311)A.

2. Experimental and Results

Two types of self-organized QD structures were fabricated on GaAs(411)A and (311)A substrates. First type of QD samples are multi-stacked QD structures fabricated by growing 5 cycles of x-periods of $(GaP)_{1.5}(InP)_{1.88}$ SL/InGaP(20 nm) multilayers (x=1, 3, 15, 18 and 30). Second type of QD samples are 4-QD-layers-stacked structures fabricated by growing 1, 5, 18 and 30 periods of $(GaP)_{1.5}(InP)_{1.88}$ SLs sandwiched with 30 nm InGaP layers. Plan-view transmission electron microscope (TEM) images showed the self-formation of dot/columnar structures with a period of about 10~20 nm along the [011] and [01$\bar{1}$] direction. Cross-sectional TEM images for the multilayer structures showed the formation of QD structures with [100] and [211] direction columnars (Fig. 1) [2].

For these structures, 77 K PL peak energy showed a shift toward higher energies by decreasing the period of SL mainly due to the quantum size effect along the vertical direction (columnar direction) (Fig. 2). Reduction in the temperature variation of FWHM was observed for the 5~10 periods (5~10 nm) samples (Fig. 3). This small broadening for the QDs with short SL periods is considered to come from the zero-dimensional density of states in QDs. The saturation of the broadening at high temperatures is due to the enhancement of quantum confinement along the columnar direction as well as lateral direction. The temperature-insensitive PL peak energies were observed from the QDs with 18-periods SL on GaAs(311)A. This temperature dependence is considered to be caused by the multiaxial strain existing in the QD regions. The temperature insensitive characteristic is considered to be one of the candidates to fabricate the temperature insensitive wavelength laser diodes [3].

Photoluminescence excitation (PLE) spectra showed well-resolved peaks (Fig. 4). Stokes-shift in PL spectrum was observed to be very small. Average indium composition of the Ga-rich region in QDs was estimated be 0.33 ($In_{0.33}Ga_{0.67}P$) from PLE spectrum.

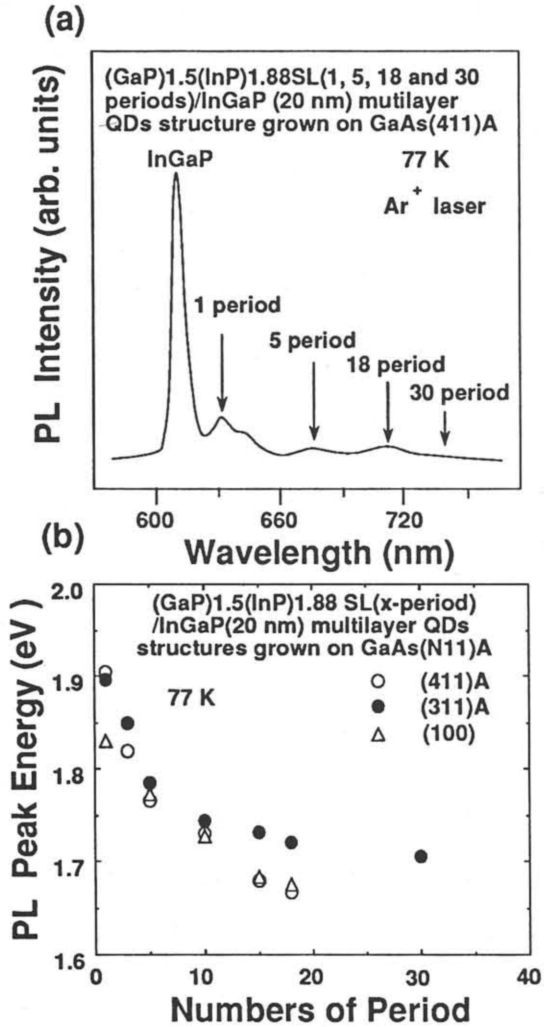

Fig. 2 (a) 77K PL spectrum for the 4-QD-layers-stacked QD structures fabricated on GaAs(411)A substrate. (b) Variation of PL peak energy with SL period for the QDs formed in the $(GaP)_{1.5}(InP)_{1.88}$ SL(x-period)/InGaP (20 nm) multilayer structures.

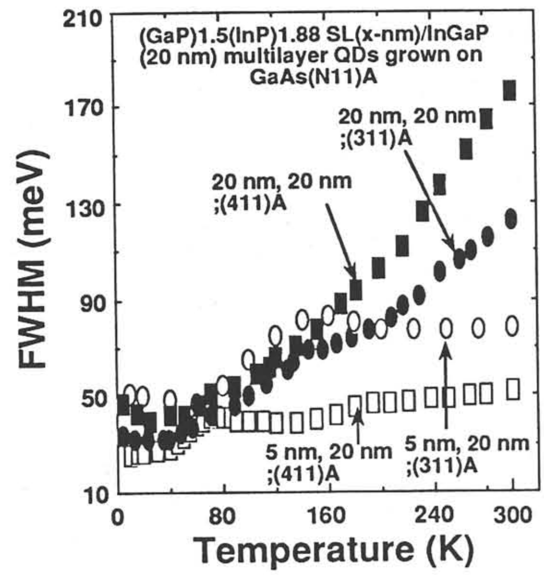

Fig. 3 Temperature variation of FWHM as a function of the SL period for the QDs formed in the $(GaP)_{1.5}(InP)_{1.88}$ SL(x-period)/InGaP (20 nm) multilayers.

3. Summary

Superlattice (SL) period dependence of optical properties of the quantum dots self-formed in GaP/InP short period SLs sandwiched with InGaP layers is studied. Small temperature variation of the PL halfwidth was achieved for 5-10 periods. Temperature insensitive PL peak energy and very small Stokes shifts were also observed.

Reference

1) S.J. Kim, H. Asahi, M. Takemoto, K. Asami, M. Takeuchi and S. Gonda: Jpn.J.Appl.Phys.35 (1996) 4225.
2) S.J. Kim, H. Asahi, M. Takemoto, K. Asami and S. Gonda: Appl.Surf.Sci. (1997) in press
3) H.Asahi, K.Yamamoto, K.Iwata, S.Gonda and K.Oe: Jpn.J.Appl.phys. 35 (1996) L876.

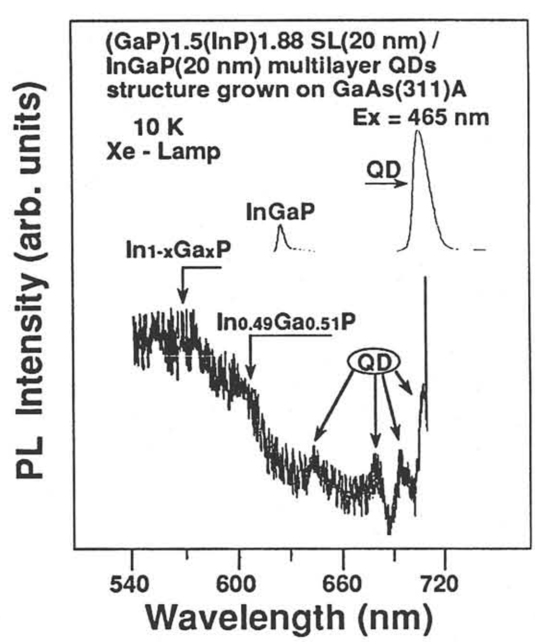

Fig. 4 PL and PLE spectra for the QDs formed in $(GaP)_{1.5}(InP)_{1.88}$ SL(18-periods) /InGaP(20 nm) multilayers.