Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 234-235

Superlattice Cycle (p) Dependence of the Quantum Dot Structures Self-Formed in {(GaP)n(InP)m}p Superlattices Grown on GaAs (311)A Substrates

J.H. Noh, H. Asahi, M. Fudeta, S. J. Kim, K. Asami and S. Gonda
The Institute of Scientific and Industrial Research, Osaka University
8-1, Mihogaoka, Ibaraki, Osaka 567, Japan
Phone: +81-6-879-8406, Fax: +81-6-879-8509, E-mail: noh21@sanken.osaka-u.ac.jp

III-V semiconductor quantum dot (QD) structures are gathering great interest from the view points of physical studies and their novel device applications. Recently, we found that due to the strain-induced lateral composition modulation, the high density QD structures are self-formed in the $(GaP)_n$ $(InP)_m$ short-period superlattices (SLs) grown on the GaAs (N11) substrates by gas source molecular beam epitaxy (MBE) [1].

We have already reported on the scanning tunneling microscopy (STM)/scanning tunneling spectroscopy (STS) study of QD structures self-formed in GaP/InP short-period superlattices and found that the high density QD structures are observed as bright areas in the STM images. The dot size of these structures ranged from 15 nm to 25 nm with a dispersion of ± 10 % depending on the n and m values of $(GaP)_n$ $(InP)_m$ SLs. In the STS measurement, the voltage width for dI/dV=0 varied periodically along the lateral direction on the sample surface. This voltage width variation corresponds to the lateral variation of the bandgap energy [2].

In this paper, we report the self-formation process and optical properties of high density QD structures in the $(GaP)_n$ $(InP)_m$ short-period SLs grown on the GaAs (311)A substrates. SLs were grown by gas source MBE with elemental Ga and In and thermally cracked PH_3. The gas source MBE and STM are connected through ultrahigh-vacuum (UHV) tunnel.

The STM image for the only 0.5 cycle SL (1.5 monolayer GaP layer) revealed the elongated structures along the $[0\bar{1}1]$ direction (group V dimer direction), but the periodic structures along the $[\bar{2}33]$ direction were not completely formed (Fig. 1(a)). For the sample of the 1 cycle of SL (1.5 monolayer GaP and 1.88 monolayer InP), we found that the QD structures are aligned along both $[\bar{2}33]$ and $[0\bar{1}1]$ directions indicating the occurrence of the self-formation of QDs at this stage. On the 2 cycle SL grown surface, very clear QD structures (an average size of 20.4 nm for both directions) were observed (Fig. 1(b)). Furthermore, this surface also showed the fine periodic structures parallel to the $[0\bar{1}1]$ direction with a period of 1.6 or 4.0 nm, which seems to be group V dimer rows on the self-formed QD structures. This observation shows the flatness of the QD surface.

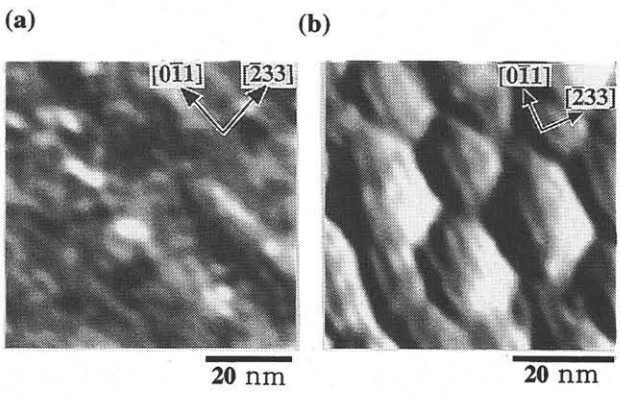

Fig. 1 STM images for the self-formed structures of different SL cycle number of $(GaP)_{1.5}$ $(InP)_{1.88}$ SL grown on GaAs (311)A substrates. **(a)** 0.5 cycle of SL (1.5ML (monolayer)-GaP), **(b)** 2 cycles of SL (1.5 ML-GaP, 1.88 ML-InP, 1.5 ML-GaP and 1.88 ML-InP).

AFM observation for the sample of the 5 cycles SL, showed the flatness of the sample surface with a roughness of ± 0.2 Å .

Observed bright and dark images are mainly caused by the variation of bandgap energy (composition variation) due to the lateral composition modulation and the voltage width of dI/dV=0 in dI/dV vs. V curves varied periodically along both [$\bar{2}33$] and [$0\bar{1}1$] directions. The amplitude of this periodic variation increased with the SL cycle number and saturated at the 2 SL cycles (Fig. 2).

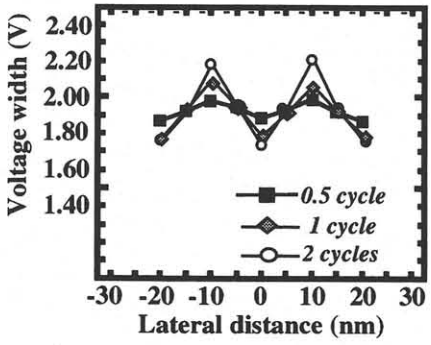

Fig. 2 Lateral variation of the voltage width for dI/dV=0 along the [$0\bar{1}1$] direction as a function of SL cycle number (0.5, 1 and 2).

Optical properties of multilayer quantum dots (MQDs) self-formed by growing the $(GaP)_{1.5}$ $(InP)_{1.88}$ SL (***p*** cycles)/InGaP (***B*** nm) multilayers on GaAs (N11)A (N=3, 4) substrates were investigated by changing SL cycle (***p***).

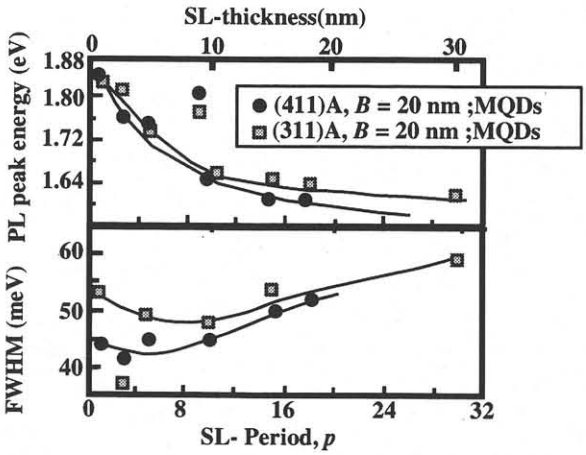

Fig. 3 SL-cycle (***p***) dependence of PL peak energy and FWHM for the MQDs self-formed in the $(GaP)_{1.5}(InP)_{1.88}$ SL(***p*** cycles)/InGaP multi-layers (***B***=20 nm) on GaAs (N11)A .

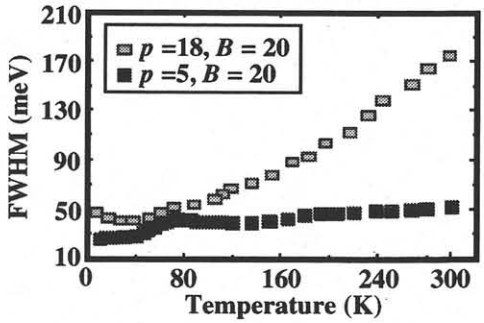

Fig. 4 Temperature variation of the FWHM for the MQDs self-formed in the $(GaP)_{1.5}$ $(InP)_{1.88}$ SL (***P*** cycles)/InGaP (***B*** nm) multi-layers as a function of SL cycle (***P***) and barrier thickness (***B***).

PL peak energy for the MQDs self-formed by growing the $(GaP)_{1.5}$ $(InP)_{1.88}$ SL (***P*** cycles)/InGaP (***B*** nm) multilayers on GaAs (N11)A (N=3, 4) shifted toward higher energy by decreasing ***P*** due to the quantum size effect along the growth direction (Fig. 3). The minimum full width at half-maximum (FWHM) was observed at p=3~5. The temperature dependence of PL FWHM for the self-formed MQDs was also improved by decreasing ***P*** as shown in Fig. 4.

References

[1] S.J. Kim, H. Asahi, M. Takemoto, J. H. Noh, K. Asami and S. Gonda : Appl. Surf. Sci.113/114 (1997) 97.

[2] J.H. Noh, H. Asahi, S.J. Kim and S. Gonda : Jpn. J. Appl. Phys. 36 (1997) 3818.