THE EFFECT OF THIN GAP INSERTION LAYER ON INP NANOSTRUCTURE BY METAL-ORGANIC VAPOR PHASE EPITAXY

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Keyword: InP, InGaP**,** Self-assembled Quantum Dots (SAQDs), Metal-Organic Vapor Phase Epitaxy (MOVPE), Atomic Force Microscopy (AFM), Photoluminescence (PL)

ABSTRACT

The influence of thin GaP insertion layers (0 – 4) monolayers (MLs) on the properties of InP self-assembled quantum dots (SAQDs) embedded in $In_{0.49}Ga_{0.51}P$ on GaAs (001) substrate grown by metal-organic vapor phase epitaxy was reported. The growth of thin GaP insertion layer between $In_{0.49}Ga_{0.51}P$ buffer and InP QDs layer reduced the mean height and size fluctuation and slightly increased the density of InP QDs. A maximum QDs density of 4.2×10^9 cm^{-2} and smaller QDs size and better uniformity had been achieved at 2 ML GaP insertion layer. The blue-shift of the PL peak was enhanced with thicker GaP insertion layer. A blue-shift of the peak emission wavelength of InP QDs from 814 nm to 780 nm was also observed as the GaP insertion layer thickness from 0 ML to 2 ML but there was no further blue-shift with further increase of the GaP insertion layer thickness.

EXPERIMENTAL DETAILS

In this study, quantum dots composed of InP embedded in $In_{0.49}Ga_{0.51}P$ matrix were carried out in a horizontal MOVPE reactor _AIXTRON, AIX200/4 with a rotating substrate holder on nominally (001) oriented GaAs substrate. During MOVPE growth, GaAs substrates were placed at the center of the susceptor. For InP and GaAs growth, trimethylgallium (TMGa) and trimethylindium (TMIn) were used as the group-III precursor with a hydrogen carrier and tertiarybutylarsine (TBAs) and tertiarybutyl- phosphine (TBP) were used as the group-V precursor.

Epitaxial growth conditions were a total pressure of 100 mbar, H_2 total flow rate of 13,000 sccm_sccm denotes cubic centimeter per minute at STP_, temperature of 610 °C, and V/III ratio of source precursors of 18 for InP. 120 nm GaAs buffer layers were grown on semi-insulating GaAs (001) substrates at 610 °C. After the growth of GaAs buffer, growth of 150 nm lattice-matched $\mathrm{In_{0.49}Ga_{0.51}P}$ layers was followed at the same temperature. In all growth process, the growth temperature was fixed at 610 °C. Then 0 - 4 MLs GaP insertion layer was deposited to improve QDs size uniformity. Finally, self-assembled InP QDs was grown at a growth rate of 0.5 ML/s by depositing 4 ML of InP. After the growth of InP QDs, 50 nm cap of InGaP followed in the case of samples planned for PL measurements. Insertion of GaP layer in the materials system InP/InGaP/GaAs by the Stranski-Krastanow technique in MOVPE technique is less well studied than other material systems. We here review the structural, morphological and optical properties of InP QDs due to insertion of 0 – 4 MLs GaP insertion layer by using atomic force microscopy (AFM) and photoluminescence (PL) measurements. Schematic representation of the InP QDs growth structure was depicted in Fig. 1.

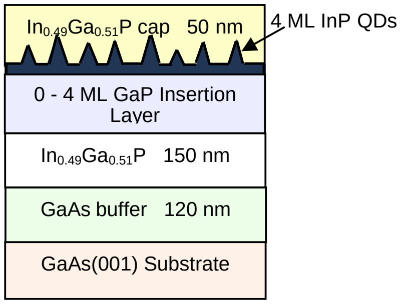

Figure 1. Schematic diagram of the vertical layer structure of InP QDs embedded in InGaP barrier grown on (001) GaAs Substrate.

RESULTS AND DISCUSSION

EFFECT OF GAP INSERTION LAYER ON SIZE AND DENSITY OF INP SAQDS

In order to investigate the role of GaP insertion layer on the characterization of size and density of InP SAQDs, we performed the measurement of AFM. Fig. 2 (a), (b), (c), (d) and (e) show 1 × 1 μm^2 area AFM images of InP quantum dots grown with 0 - 4 ML GaP insertion layer. Both size and height are generally decrease by increasing the thickness of GaP insertion layer. The sample with 2 ML GaP insertion layer showed a significantly improved size, height dispersion and homogeneity.

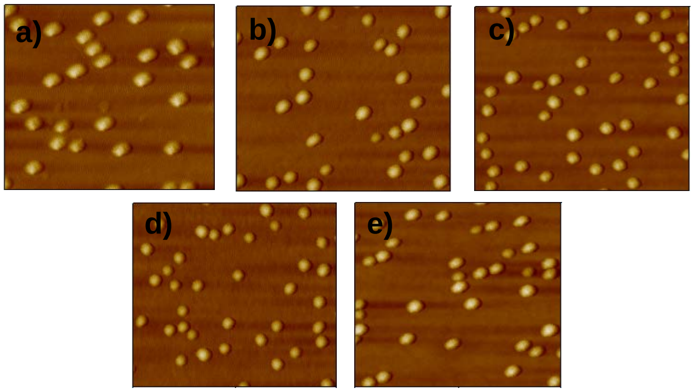

Figure 2. Typical (1μm × 1μm) scan range AFM images of InP QDs embedded in InGaP barrier with (a) 0 ML (b) 1 ML (c) 2 ML (d) 3 ML (e) 4 ML GaP layers.

Fig. 3 summarizes the changes in the QDs density and QDs mean height with the GaP insertion layer thickness. The dot density increases from 2.3 $\times10^9$ cm^{-2} to 4.2$\times10^9$ cm^{-2} due to the insertion of 0 ML - 2 ML GaP layers and then decrease again to 3.3 $\times10^9$ cm^{-2} due to inseriton of 3 ML- 4 ML GaP layer. The improvement of GaP insertion layer effect on InP QDs can be seen at 2 ML GaP layer thickness. The maximum density in 4.2 $\times$ 10^9 cm^{-2} and smallest uniform InP QDs were obtained with 2 ML thickness of GaP insertion layer. After insertion of 2 ML GaP layer thickness, the QDs size was quite increase and density was decrease again. This observation indicated that QDs density first increased with increasing of GaP insertion layer thickness and then it saturated at 2 ML GaP insertion layer thickness. Such behavior showed the nuclei centers first increased with the increase of GaP insertion layer thickness from 0 ML to 2 ML, afterwards nucleation was completed and further increased in the thickness did not significantly increase the density of QDs. However, it was seen that GaP insertion layer caused a reduction in the QDs size fluctuation. Since the growth conditions were the same in all samples, decrease in QDs height, diameter and slightly increase in density with GaP insertion layer indicates that the insertion of thin GaP layer resulted in less material deposition. It is also likely that the incorporation efficiency of In during the deposition of GaP layer reduces as the strain increases.

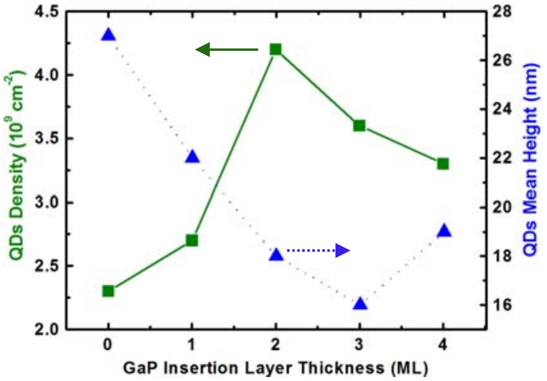

Figure 3. Effect of GaP insertion layer on QDs average size and density for InP SAQDs embedded in InGaP grown at 610 °C.

OPTICAL CHARACTERIZATION

The evolution of the photoluminescence (PL) spectra of InP QDs as a function of the thickness of the GaP insertion layer is shown in Fig. 4. It was found that the InP QDs gave strong photoluminescence (PL), which in fact dominated the spectra from the samples. The InP QDs without any GaP insertion layer shows PL peak at 814 nm and this InP QDs PL peak is overlapping with GaAs buffer photoluminescence peak. After insertion of 0-4 ML GaP layers, InP QDs photoluminescence peaks were observed separately with GaAs buffer layer photoluminescence peaks. When a 1 ML GaP insertion layer is introduced, the PL intensity decreases and blue-shift noticeably with a peak at 786 nm.

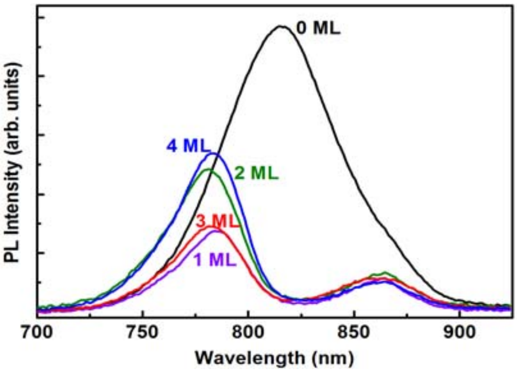

Figure 4. The room temperature PL spectra of the InP QDs grown on the InGaP barrier with 0 – 4 ML thick GaP insertion layer between the InP QDs and the InGaP barrier.

As the GaP insertion layer thickness increases from 1 ML to 2 ML, the PL intensity increases again and the PL peak blue shifts to 781 nm. But the InP QDs with a 3 ML GaP insertion layer show slightly red shifted PL centered at 780 nm and intensity is decrease again. The insertion of 4 ML GaP insertion layer thickness, the PL peak intensity is red-shifted at 783 nm and PL intensity is higher than other GaP insertion layers thickness. The observed blue and red shifts with GaP insertion layer thickness are due to the reduction and increase in the QDs height respectively.

CONCLUSION

Dependence of GaP insertion layer on structural properties of MOVPE grown InP quantum dots (QDs) has been studied by atomic force microscopy and photoluminescence. The combination of structural and optical results for a given sample is very useful to analyze the properties of those nanostructures. The insertion of 0 - 4 ML GaP layer achieves slightly increase density and it also reduces the size and height of QDs that were the better conditions for InP QDs. The QDs density increment of 2.3×10^9 cm^{-2} to 4.2×10^9 cm^{-2} has been achieved at a growth temperature of 610°C with a growth rate of 0.5 ML/s. A thin GaP insertion layer on InP QDs led to a blue-shift of the PL peak. By depositing ultrathin GaP layers on the InGaP barrier before InP QD growth, the PL peak wavelength is continuously reduced with increase of the GaP insertion layer thickness from 0 ML – 2 ML. And then there was no further blue-shift with further increase of the GaP insertion layer thickness from 3 ML to 4 ML. We find that under the same growth conditions, a GaP insertion layer thickness of 2 ML is the optimum where QDs mean size and fluctuation are minimum while giving the higher PL intensity than other thickness of GaP insertion layers.

ACKNOWLEDGEMENTS

The author wishes to thank ASEAN University Network/Southeast Asia Engineering Education Development Network (AUN/SEED-Net), Chulalongkorn University and University of Tokyo for the support of this work.

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