Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 908-909

**G-10-3**

# Continuous Wavelength Tuning of InAs/InP Quantum Dots in the 1.55 μm Region by Inserting Ultra-Thin GaAs and GaP Interlayers

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## 1. Introduction

Self-assembled InAs quantum dots (QDs) grown on InP substrates have great potential for QD lasers and semiconductor optical amplifiers (SOAs) operating in the 1.55 μm wavelength region for fiber optical telecommunication systems. However, it is still a major challenge to tune the QD emission wavelength into this important range since InAs/InP QDs usually emit at wavelengths longer than 1.6 μm at room temperature (RT).

We have recently solved this problem by inserting ultra-thin GaAs interlayers between the InAs QDs and underlying lattice-matched Q1.3 GaInAsP buffer on InP (100) substrates [1]. A thorough comparison with ultra-thin GaP interlayers is the topic of this report. The emission wavelength of the InAs QDs, when embedded in Q1.3 GaInAsP, which is a standard waveguide core material for InP based photonic devices, is continuously tuned from above 1.6 to below 1.5 μm at RT by solely changing the GaAs as well as the GaP layer thicknesses. This is due to an effective suppression of As/P exchange and consumption of segregated In by the GaAs and GaP surface termination, and is most efficient for GaP interlayers where the 1.55 μm wavelength region at RT is realized already for submonolayer coverages.

## 2. Experimental details

The samples were grown by chemical-beam epitaxy (CBE) using trimethylindium (TMI), triethylgallium (TEG), $AsH_3$, and $PH_3$ as precursors on InP (100) substrates, mis-oriented by 2$^o$ towards (110). The structures, grown at 500 $^o$C, consist of a 200-nm InP buffer, 100-nm lattice-matched $Ga_xIn_{1-x}As_yP_{1-y}$ (x = 0.280, y = 0.617), the ultra-thin GaAs (0.3 – 2.5 monolayers (MLs)) or GaP (0.3 – 1.1 MLs) interlayers, the InAs QD layer, and a 100-nm GaInAsP cap. The InAs QDs were formed by nominal deposition of 3.2 MLs InAs at a rate of 0.4 ML/s, and 5 seconds growth interruption under As flux. A second QD layer was grown under the same conditions on the surface for atomic force microscopy (AFM) measurements carried out in tapping mode in air. For photoluminescence (PL), the samples were excited by a Nd:YAG laser in a cryostat (4.8K) with an excitation power density of 256 mW/cm$^2$.

## 3. Results

Fig. 1 (a-f) shows the AFM images of the InAs QDs grown on the thin GaAs interlayers on the surface of the GaInAsP cap. With increasing GaAs interlayer thickness from 0 to 2.5 MLs, the average QD height gradually decreases from 7 – 8 to 4 – 5 nm. A very similar QD height reduction is observed for the GaP interlayers with thicknesses, or better coverages between 0 and 1.1 MLs. The QD height decrease directly leads to the blue-shift of the low-temperature PL peak wavelength in dependence on the GaAs and GaP interlayer thicknesses, depicted in Fig. 2. When the GaAs interlayer thickness is increased from 0 to 2.5 nm, the InAs QD PL peak wavelength shifts from 1556 to 1401 nm. The same wavelength shift is achieved in the case of GaP interlayers already for coverages up to 1.1 MLs. The integrated PL intensities and line widths are not degraded either for GaAs or GaP interlayers.

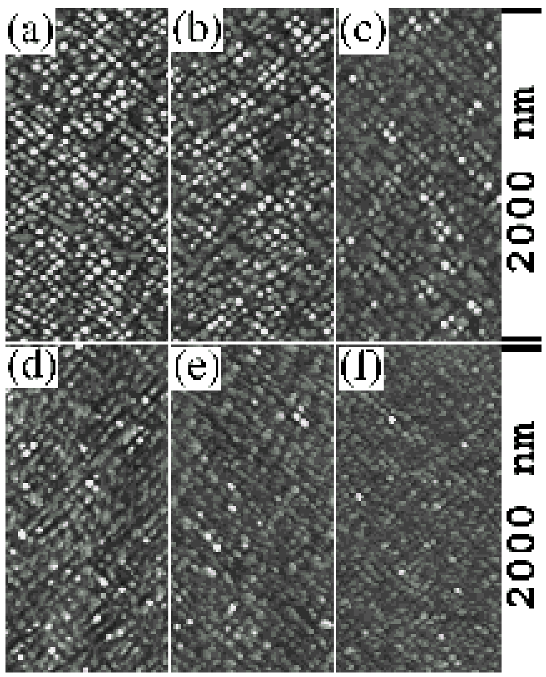


Fig. 1 AFM images of the InAs QDs on thin GaAs interlayers on lattice-matched GaInAsP. The GaAs layer thickness is (a) 0, (b) 0.3, (c) 0.8, (d) 1.2, (e) 1.9, and (f) 2.5 MLs. The black-to-white height contrast is 10 nm for (a-c) and 5 nm for (d-f).

The PL spectra measured at RT of the InAs QDs on the GaAs and GaP interlayers are shown in Fig. 3 (a,b). For the GaAs interlayers the PL peak wavelength at RT is reduced from 1560 to 1496 nm for thicknesses between 1.2 and 2.5 MLs. With the GaP interlayers this wavelength range at RT is covered for 0.62 to 1.1 MLs and the 1.55 μm wavelength region is reached for submonolayer coverages between 0.6 and 0.7 MLs.

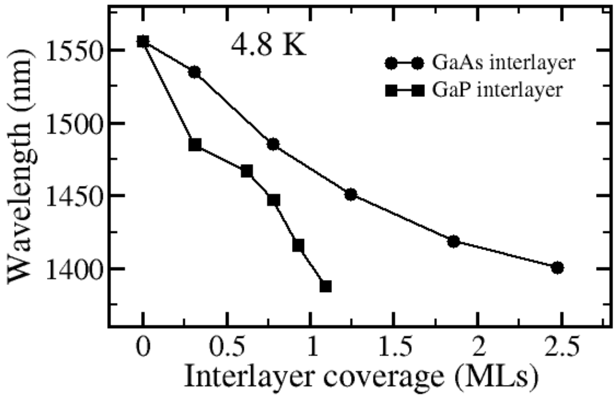


Fig. 2 Low-temperature PL peak wavelength as a function of the GaAs and GaP interlayer coverages.

## 4. Discussion

The reduction of the InAs QD emission wavelength is mainly attributed to the suppression of As/P exchange reactions during InAs deposition and following growth interruption under As flux, supported by the consumption of surface segregated In by the GaAs and GaP interlayers. The suppression of As/P exchange is explained by the relation of the binary compound bond strengths: The Ga-P bond strength (54.9 kcal/mol) is larger than the GaAs bond strength (50.1 kcal/mol) while the smaller In-P bond strength (47.3 kcal/mol) is even smaller than the In-As bond strength (48.0 kcal/mol). Hence, both GaAs and GaP surface termination prevents the substitution of P by As. For GaAs interlayers on GaInAsP, however, As/P exchange takes place at the initial stage of growth for P bound to In. Therefore, GaP interlayers with the largest binary compound bond strength are most effective in suppressing As/P exchange reactions and, hence, in tuning the InAs QD emission wavelength at RT over the 1.55 μm region for submonolayer coverages.

## 5. Conclusions

Continuous wavelength tuning of InAs QDs embedded in GaInAsP on InP (100) has been achieved by inserting ultra-thin GaAs and GaP interlayers between the QDs and the underlying GaInAsP buffer. The important 1.55 μm wavelength region is covered for GaAs layer thicknesses between 1.2 and 2.5 monolayers, and GaP coverages already in the submonolayer range. This is due to a drastic suppression of As/P exchange reactions, being most effective for GaP terminated surfaces.

Applications of InAs/InP QDs for fiber optical communication systems are now possible and an ultra-low power all-optical switch has already been demonstrated [2].

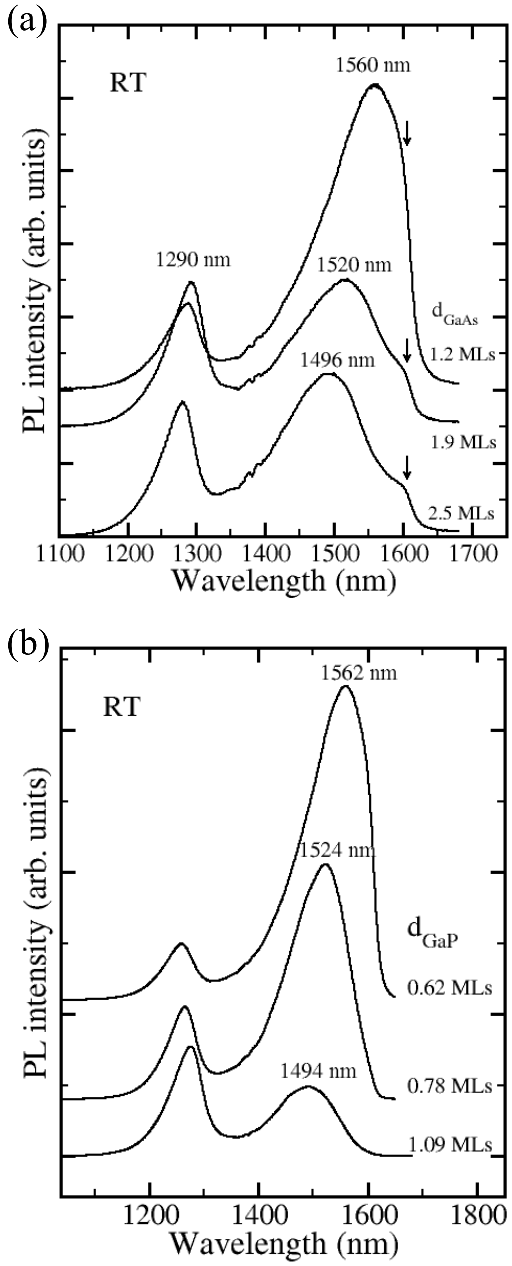


Fig. 3 Room-temperature (RT) PL spectra as a function of (a) the GaAs and (b) the GaP interlayer coverages.

## Acknowledgements

The authors thank P.J. van Veldhoven and G.J. Eijkemans for their cooperation in sample preparation and characterization.

## References

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