InP Self-Assembled Quantum Dots Embedded in $In_{0.5}Al_{0.3}Ga_{0.2}P$ Grown on GaAs Substrates by Metalorganic Chemical Vapor Deposition

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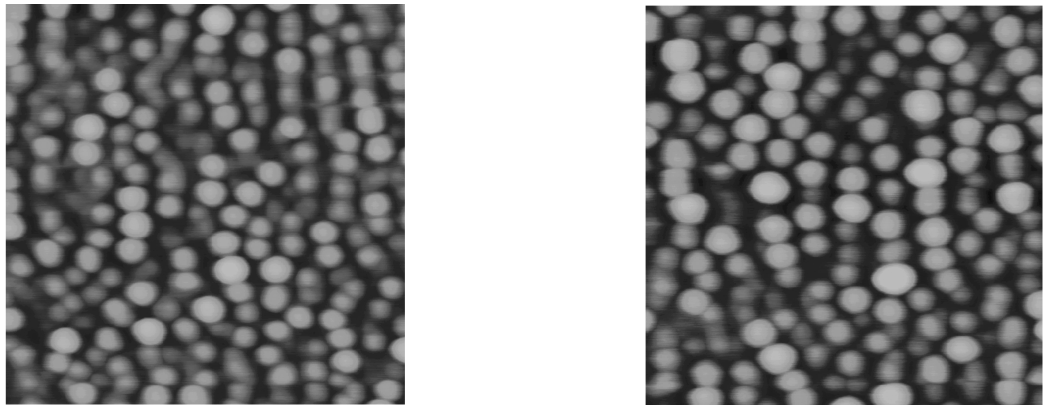
III-Phosphide self-assembled quantum dot (SAQD or simply QD) structures offer a potential to realize injection lasers operating in wide-bandgap visible regions with improved performance characteristics such as low threshold current densities, high characteristic temperature, and high differential gain. Also, SAQD growth can overcome the limitation of lattice matching between the substrate and the epitaxial active region due to the intrinsic nature of growth mode (i.e., strain-induced S-K growth). InP quantum dots have been grown on direct-bandgap $In_{0.49}Ga_{0.51}P$ matrix by several research groups[1,2,3] and on $In_{0.49}Al_{0.51}P$ matrix by the authors[4].

In this study, we report the characteristics of InP SAQDs embedded in $In_{0.5}Al_{0.3}Ga_{0.2}P$, which has the largest direct bandgap lattice-matched to GaAs, on GaAs substrates grown by metalorganic chemical vapor deposition (MOCVD). The InP QD growth is done at the growth temperature of 650°C by altering growth times up to "planar-growth equivalent" 15ML. The morphology of the exposed SAQDs (grown without the upper cladding layer) is characterized by atomic force microscopy (AFM). As growth time increases, dominant QD size increases, while densities remains almost same – densities are $1\sim2\times10^{8}mm^{-2}$ and dominant heights are 10~25nm. Fig. 1 shows the exposed InP AFM image grown on $In_{0.5}Al_{0.3}Ga_{0.2}P$. Low-temperature photoluminescence (PL) is performed to determine the light-emitting characteristics of the $InP/In_{0.5}Al_{0.3}Ga_{0.2}P$ quantum dot heterostructures (QDH). Fig. 2 shows the 4K PL spectra from the InP SAQDs with $In_{0.5}Al_{0.3}Ga_{0.2}P$ claddings, exhibiting PL emission in the visible orange and red regions – 2.10, 1.90, and 1.82eV peak energy for 3.75, 7.5, and 15ML, respectively. Room-temperature emission characteristics are also studied. Since the bandgap of the "active" InP SAQDs is modified by multi-dimensional quantum confinement, bulk material properties like the band offset do not apply in this case. We further study the $InP/In_{0.5}Al_{0.3}Ga_{0.2}P$ SAQDs using ballistic electron emission microscopy (BEEM) techniques to determine the band structure of the dots. Also, transmission electron microscopy (TEM) is used to characterize the microscopic material quality and morphology of the individual QD and the interfaces between SAQD and cladding layers. In summary, we will report on the optical, structural, and electronic properties of InP SAQDs embedded in direct bandgap $In_{0.5}Al_{0.3}Ga_{0.2}P$ layers.

[1] S. P. DenBaars, C. M. Reaves, V. Bressler-Hill, S. Varma, W. H. Weinberg, and P. M. Petroff, "Formation of coherently strained InP quantum islands on InGaP/GaAs (001)", J. Cryst. Growth 145, 721 (1994).
[2] N. Carlsson, W. Seifert, A. Peterson, P. Castrillo, M. E. Pistol, and L. Samuelson, "Study of the two-dimensional – three-dimensional growth mode transition in metalorganic vapor phase epitaxy of GaInP/InP quantum-sized structures", Appl. Phys. Lett. 65, 3093 (1994).
[3] A. Kurtenbach, K. Eberl, and T. Shitara, "Nanoscale InP islands embedded in InGaP", Appl. Phys. Lett. 66, 361 (1995).
[4] J. H. Ryou, R. D. Dupuis, C. V. Reddy, V. Narayanamurti, D. T. Mathes, and R. Hull, "InP and InAlP self-assembled quantum dots grown by metalorganic chemical vapor deposition", Proc. of 20th International Conferences on Indium Phosphide and Related Materials, IEEE Catalog No. 00CH037107, (IEEE, Piscataway, 2000) p.223.



(a) (b)

Figure 1. AFM images (1×1μm) of exposed InP quantum dot on $In_{0.5}Al_{0.3}Ga_{0.2}P$ matrix grown for 7.5ML and 11.25ML at 650°C (maximum height scale is 20 and 25 nm, respectively).

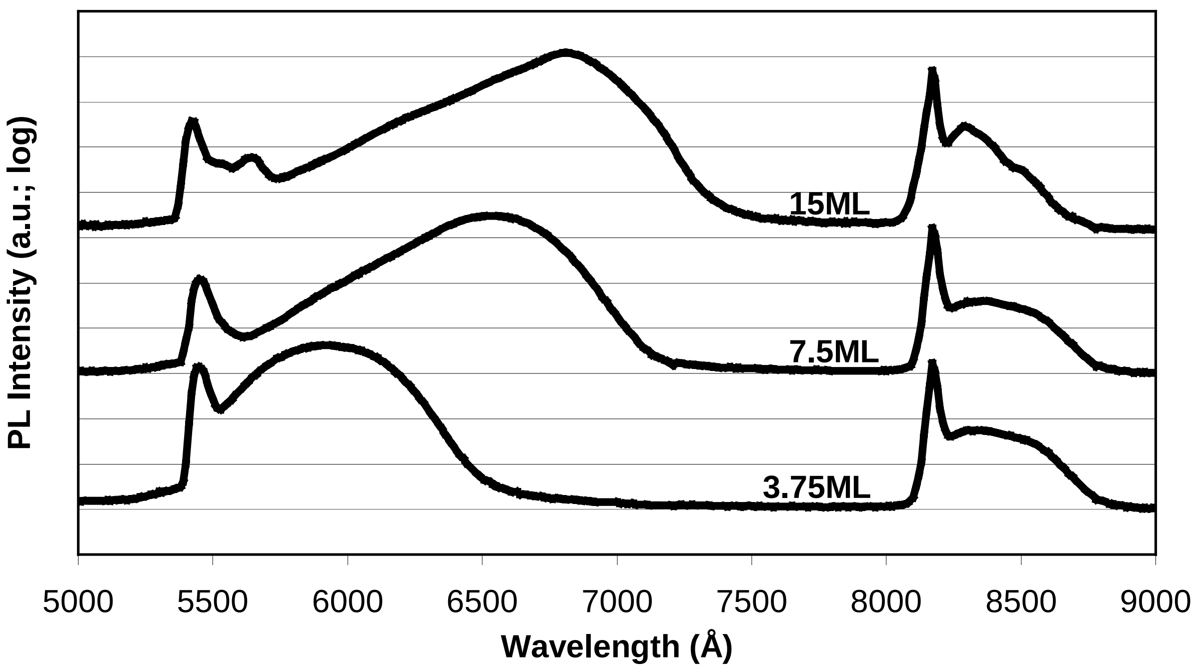


Fig. 2. 4K PL spectra of InP quantum dot embedded in $In_{0.5}Al_{0.3}Ga_{0.2}P$ layers with various quantum dot growth times.