Effects of Antimony (Sb) Surfactant Layer on InAs Quantum Dots

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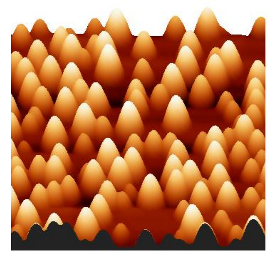
Abstract

In this work, efforts have been devoted to develop high quality InAs QDs for optoelectronic device applications with the help of Antimony (Sb) surfactant layers. The samples are grown by Molecular Beam Epitaxy (MBE) and an Sb flux (BEP=3×10^{-8} Torr) is exposed to the GaAs buffer layer for a soak time of either 15, 30, 45, 60 or 100 seconds before the growth of InAs QDs. The Atomic Force Microscopy (AFM) images show a clear increase of QD density for longer Sb soak time. The best soak time is proved to be 30s as a photoluminescence (PL) intensity increase by over a magnitude and a convergence of $3x10^{10}cm^{-2}$ in the density are seen for the QDs. We also grow one sample with Sb flux during InAs QD growth. A 70 nm redshift of QD PL peak is measured in comparison with the pure InAs QDs, indicating the overall band structure of the QDs is altered after Sb incorporation into the QD growth. In conclusion, we are able to see that the inclusion of a suitable Sb surfactant layer will produce an increase in the InAs QD density and subsequently PL intensity.

Background

❖Many practical QD devices (Lasers, Solar cells, IR detectors) need high density, high quality QDs

❖Antimony (Sb) has been shown to reduce *surface energy* and shorten *diffusion* [1,2] in InAs QD formation

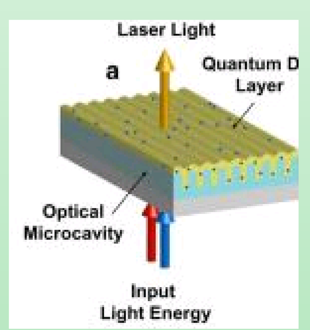


AFM image of InAs QDs

❖Sb surfactant layers lead to an increase in the density of InAs QDs formed on GaAs surface[3]

Motivation & Objective

❖Develop high quality InAs QDs by manipulating QD density via incorporation of Sb



QD laser [4]

❖Correlate the QD performance (density and PL intensity) with the addition of surfactant layers of Sb.

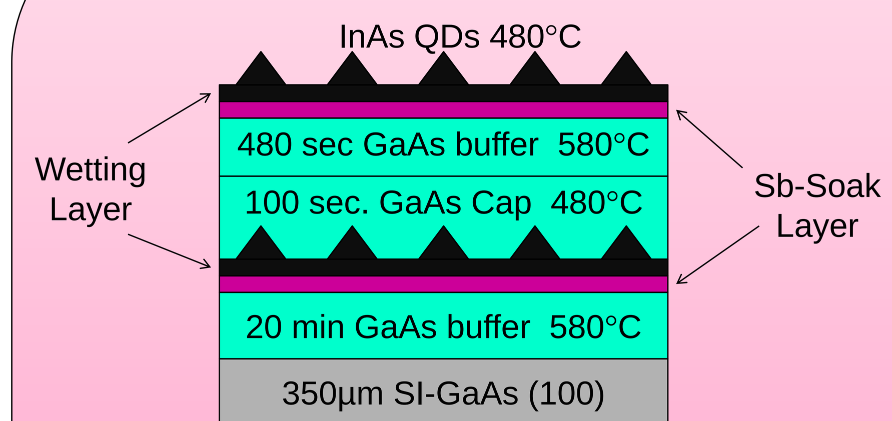
❖Identify the growth condition with Sb incorporation for obtaining the best QD quality

❖Obtain high density and high quality InAs QDs suitable for device applications

References:

[1] D. Guimard, and N. Masao, Applied Physics Letters 89,18 (2006)
[2] K. Yamaguchi, and K. Toru, Journal of Crystal Growth 275 (2005)
[3] P. Aivaliotis, L. R. Wilson, Applied Physics Letters 91, 1 (2007)
[4] http://www.physorg.com/news197224539.html

Sample Fabrication

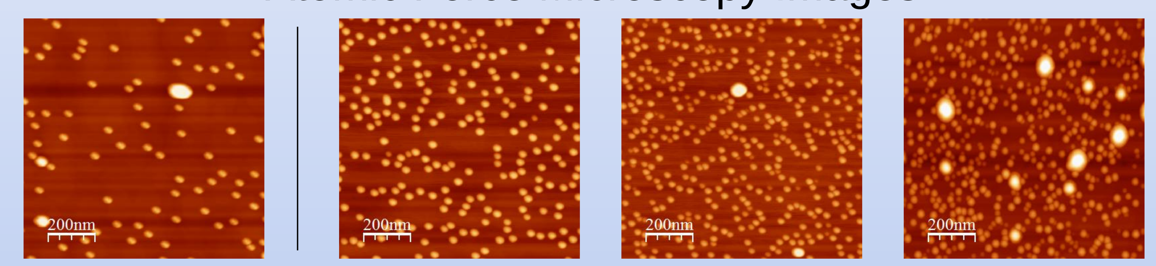


❖Growth by *Molecular Beam Epitaxy* (MBE)
- -InAs growth rate, 0.015 ML/sec
- -Sb flux at BEP = 3×10^{-8} Torr
- -Sb temperature 900/350 °C
- -Substrate temperature 485°C

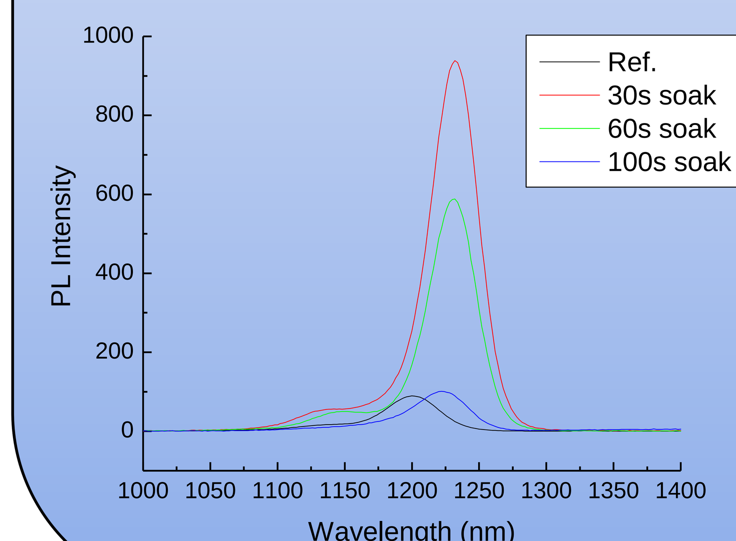
❖Variables
- -Sb-soak layer times of 15, 30, 45, 60, and 100 seconds
- -Sb incorporation into InAs QD growth

AFM & PL Characterization

Atomic Force Microscopy Images

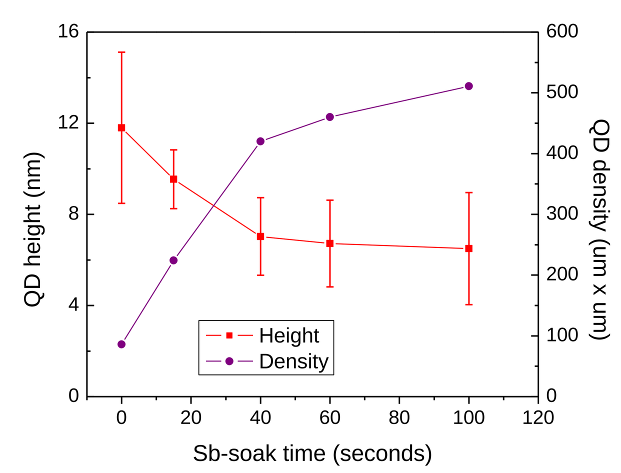


Reference (80 QDs/µm²) | 30 sec. (250 QDs/µm²) | 60 sec. (450 QDs/µm²) | 100 sec. (500 QDs/µm²)



PL spectra of QDs
- -Room temperature
- -Excitation=25 mW
- -Laser λ=659nm
- -InGaAs detector

Sb-Soak Time Effect



❖Saturation was seen in the QD density at 5×10^{10} cm^{-2}

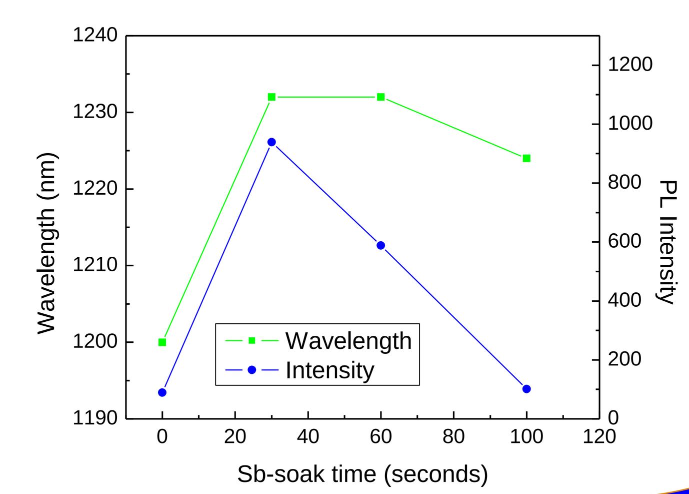
❖QD height decreases from 12nm to 5nm with 100s soak

❖ In diffusion length decreases with longer Sb soak time

❖PL peak red-shift due to Sb-atoms diffuse into QDs

❖A magnitude increase of PL Intensity for 30s Sb-soak QDs

❖PL intensity Increase comes from QD density change and QD quality improvement

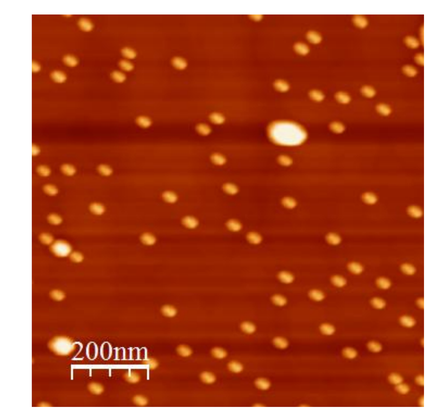


Sb Incorporation Into QD Growth

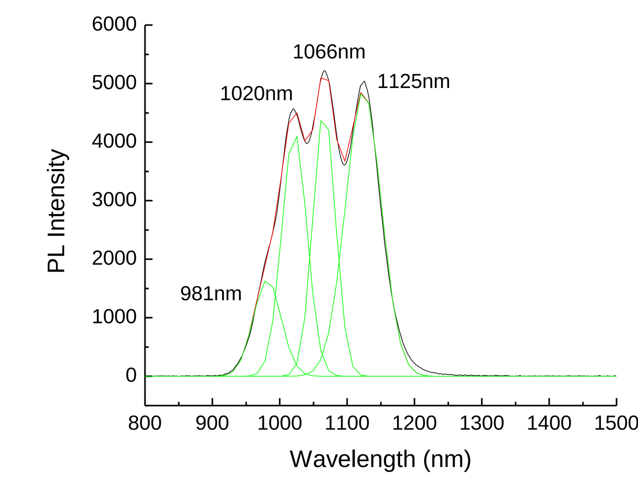
❖70 nm red-shift in QD peak toward to communication wavelength of 1.3µm

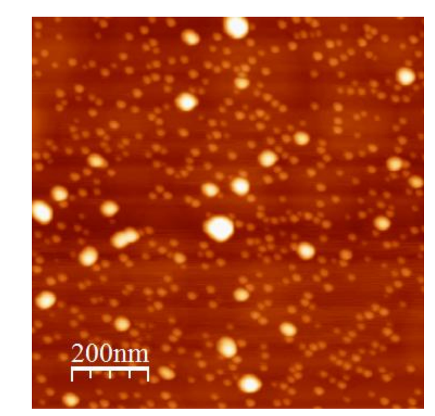
❖Larger separation between ground state and excited states

❖Confirms a change in QD band structure

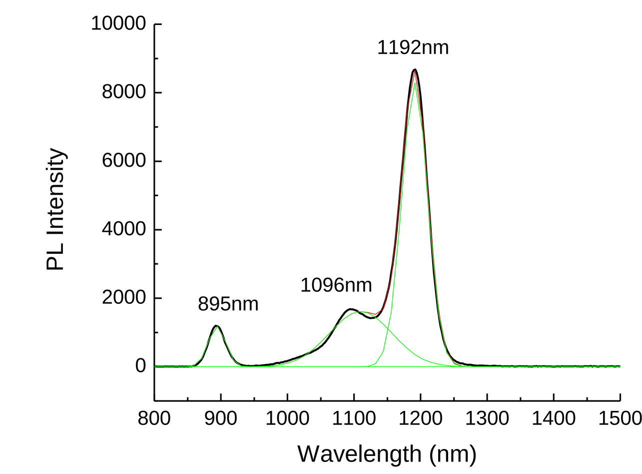


Reference (80 QDs/µm²)





Sb into QD growth (475 QDs/µm²)



Conclusions

❑A suitable amount of Antimony (30sec soak) as a surfactant layer has the capability to increase QD density and subsequently PL intensity

❑Inclusion of Antimony within InAs QDs alters the band structure and elicits a red-shift towards ideal optical communication wavelengths

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