Improving PL properties of self-assembled InAs SQDs by incorporation of Sb

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Motivation

PROBLEM:

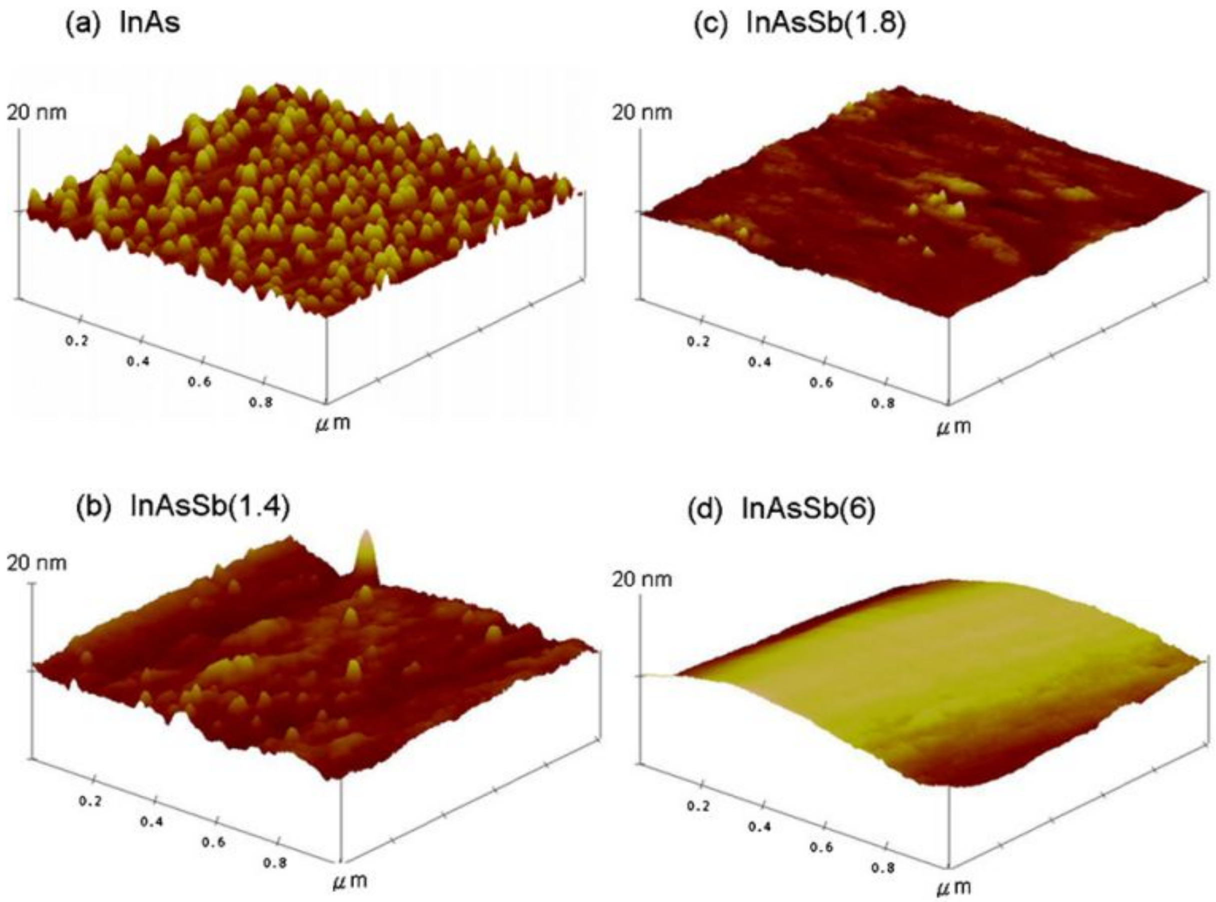
The PL performance of Surface Quantum Dots (SQDs) is worse than that of Buried Quantum Dots (BQDs). This limitation affects the great potential of uncapped In(Ga)As quantum dots in **biological sensing applications**.

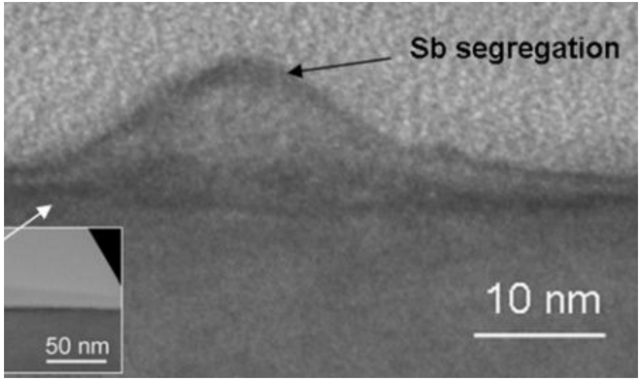
PROPOSED SOLUTION:

Antimony (Sb) in InGaAs quantum wells delayed 3D growth. We can similarly use them to delay dot formation in Surface Quantum Dots, thus reducing dot density and hence giving a PL peak at 0.6-0.7eV AT 300K.

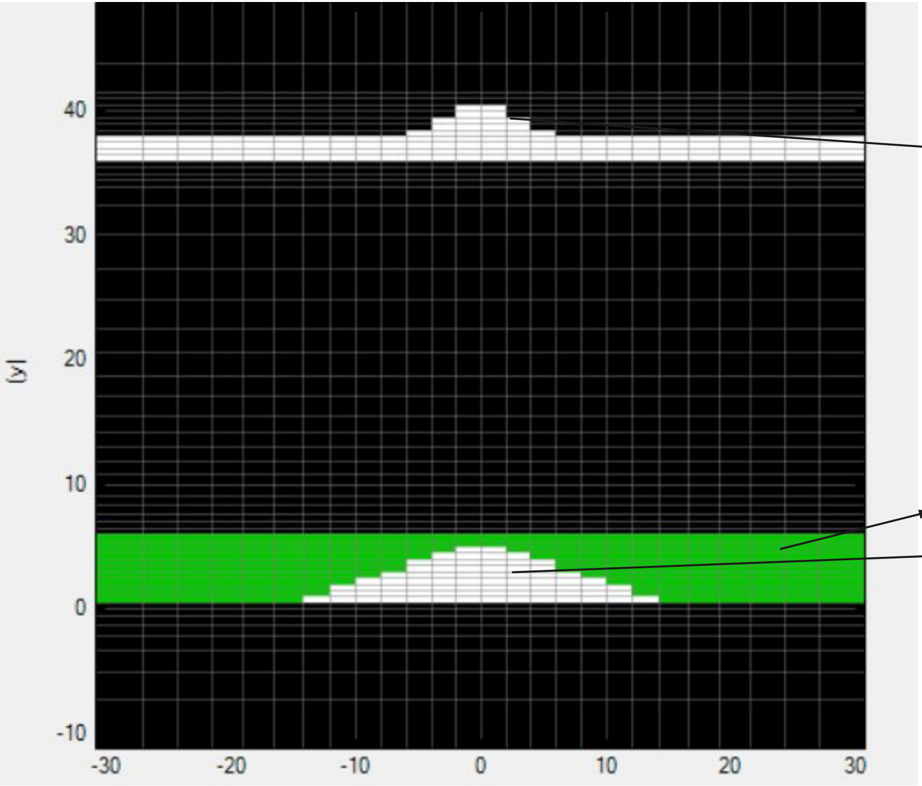
The emission wavelength increases on incorporation of Sb in SQDs due to **surfactant** effect of Sb- reducing the surface faceting and delaying the formation of dislocations. (A surfactant ,molecule segregates to the growth front and decrease surface energy and surface diffusion)

Experimental Results: AFM and TEM





Simulation



Air

$InAs(x)Sb(1-x)$ Surface Dot
(width= 20 nm , height=5 nm)
$InAs(x)Sb(1-x)$ planar growth on surface

300 nm GaAs layer

$In(0.15)Ga(0.85)As$ capping (6 nm)
InAsSb buried quantum dots
(width= 30 nm , height=5 nm)

GaAs Substrate

Results and Discussion (experimental)

1. Incorporating Sb reduced the density of the SQDs by more than two orders of magnitude.

   Without Sb: 3×10^{10} cm−2 InAsSb(1.4) : 3.5×10^{9} cm−2,

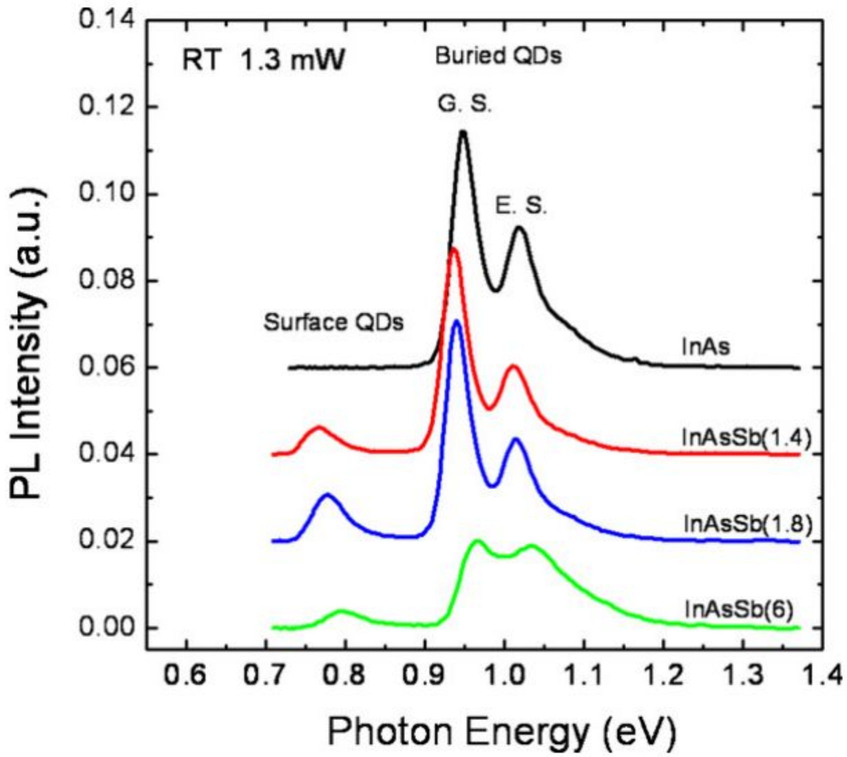
   InAsSb(1.8): 6×10^{8} cm−2.

2. A large Sb BEP **worsens** the surface morphology as a significant amount of the deposited material tends to form these **thick terraces**, rather than a thin wetting layer.

3. The AFM results indicate that the Sb-free SQDs have an average lateral diameter of 50 nm and a height of 10 nm. The dimensions **reduce as Sb BEP increases.**

4. When the QDs are covered by a 0.3 m-thick GaAs cap layer, the emission from the BQDs is blue-shifted by about 171 meV

PHOTOLUMINESCENCE (experimental results)



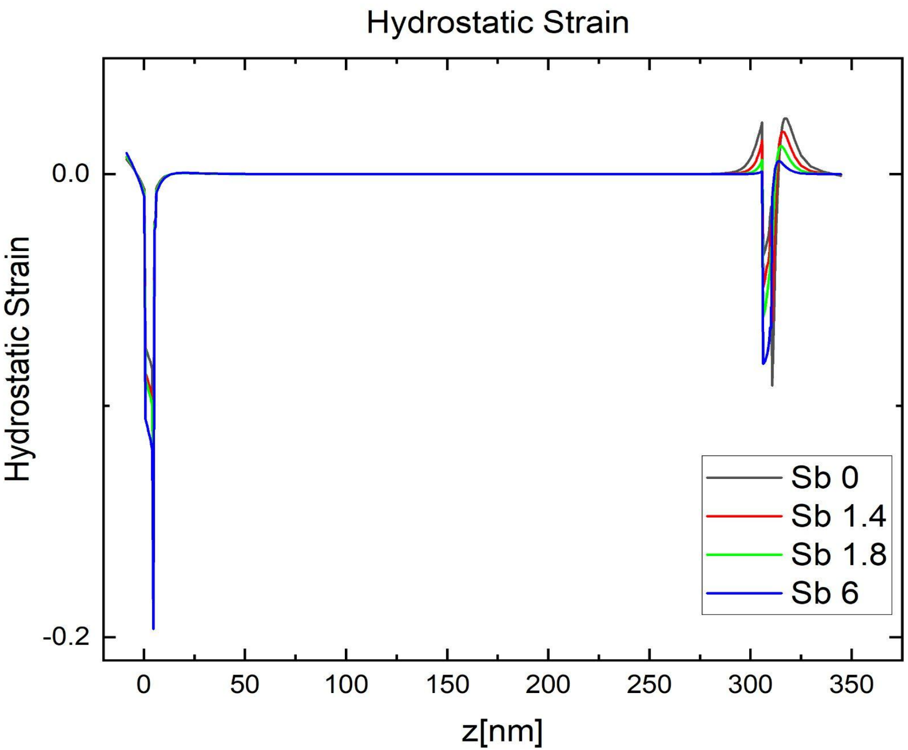
Results and Discussion

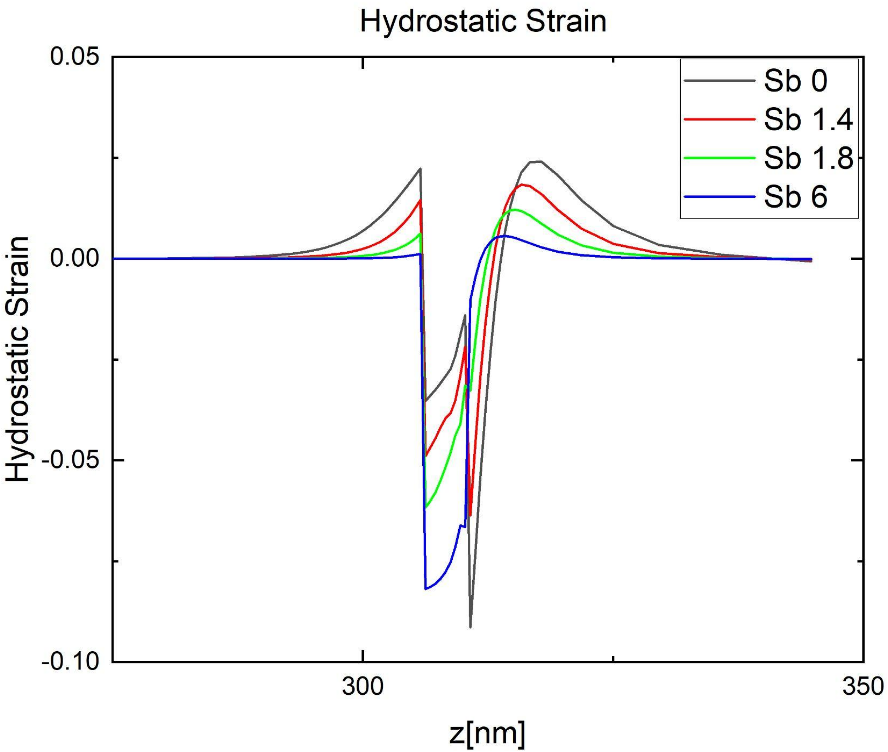
5. Capping the QD with an InGaAs layer has been shown to reduce the strain and **extend the range of emission wavelength** .

6. The PL intensity **increases as the Sb BEP is increased** further.

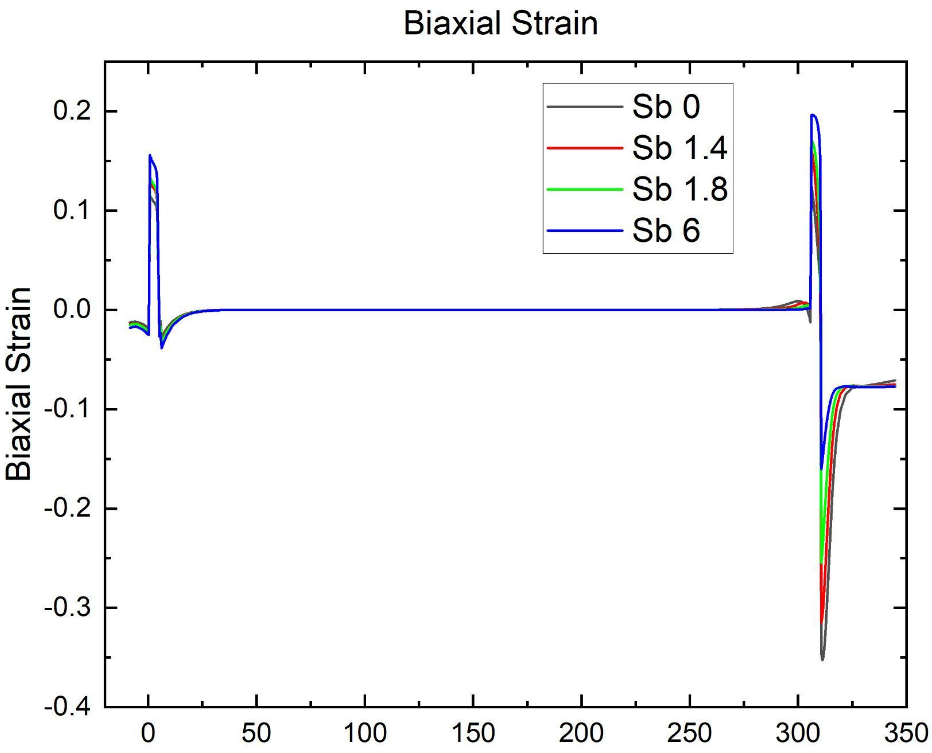
8. The AFM measurements reveal that the incorporation of **Sb effectively reduces the density** of the SQDs by an Sb **surfactant** effect, which enhances layer-by-layer growth and suppresses dot formation.

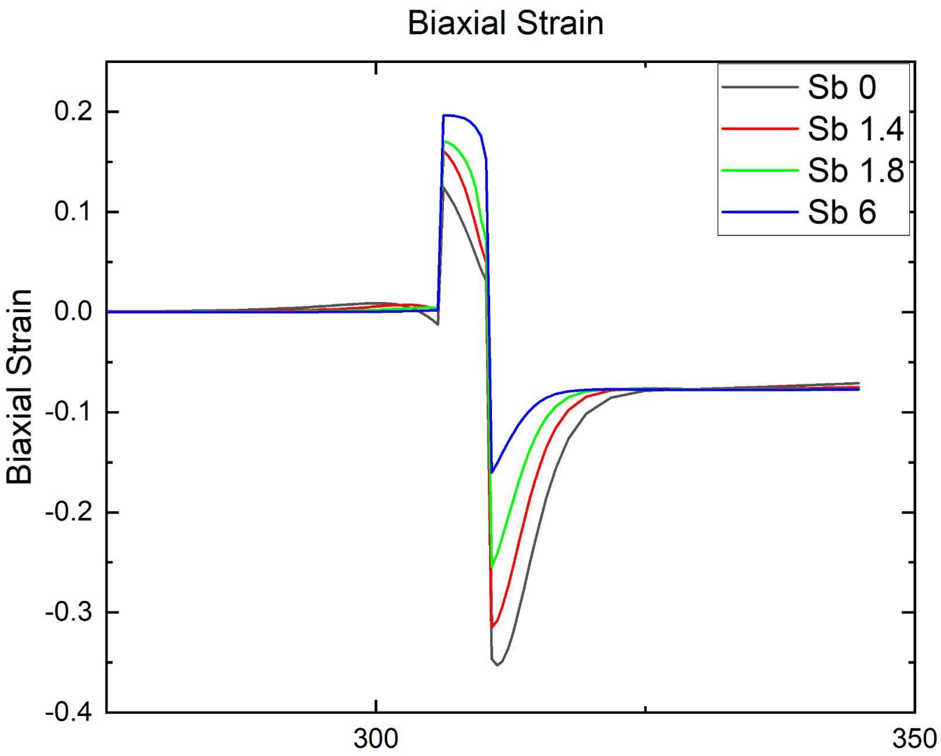
Simulation Results: Hydrostatic Strain





Simulation Results: Biaxial Strain

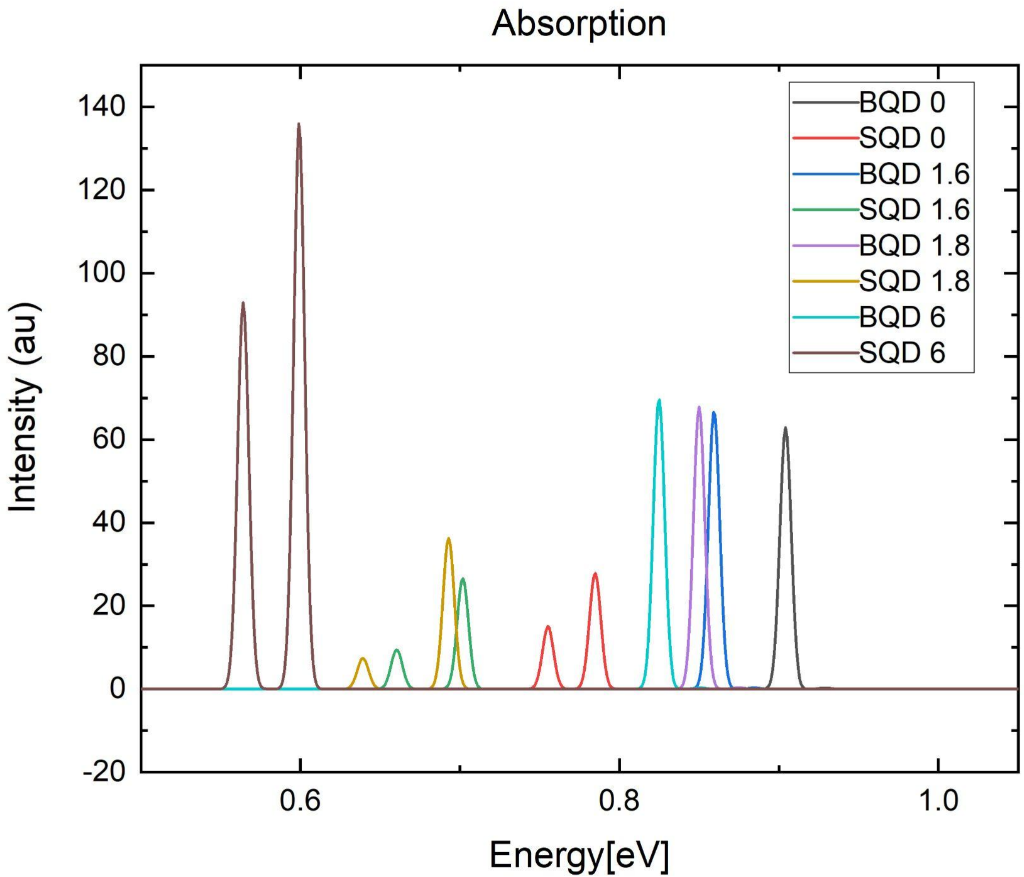




Strain Discussion

- Low hydrostatic strain implies in deeper conduction band, higher electrostatic potential and thus, **improving carrier confinement.**
- Higher biaxial strain reduces the degeneracy of valence sub-bands, causes an upward movement of heavy hole band reducing the energy band gap and therefore, leading to the **redshift** in PL emission.
- With increase in Sb concentration, hydrostatic strain reduces and Biaxial Strain increases.
- Anticipated Result: **improved carrier confinement, lower energy band gap and longer emission wavelength.**

Simulation Results: Absorption



Conclusion

- The Sb surfactant effect can extend planar growth and suppress dot formation. The findings in this study suggest that the PL of InAsSb SQDs is strengthened by increasing Sb BEP.
- The enhancement of the integrated intensity of PL is attributable to Sb segregation close to the surface of SQDs, and reduces non-radiative recombination.
- The transfer of carriers from the BQDs to the SQDs may not be responsible for the improvement, because a 300 nm thick GaAs blocking layer separates the BQDs from the SQDs. Rather, the enhancement is believed to be strongly related to the incorporation of Sb into the QD layers.