Structure of InAs/GaAs Quantum Dots grown with Sb surfactant

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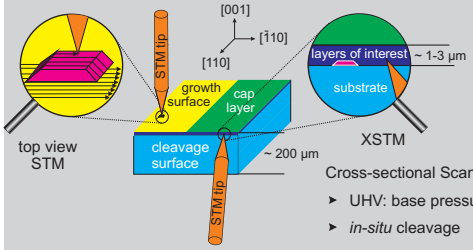
MSS-12
Albuquerque, New Mexico
July 10-15, 2005

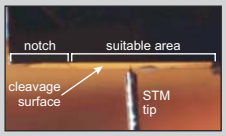
PB1 232

Motivation

goal:	Quantum dot lasing at 1.3 µm wavelength
strategy:	Supply of Sb during InAs QD growth leads to redshift of luminescence
model:	Sb acts as surfactant: Increasing the In mobility, increasing the critical thickness of dot formation, increasing the dot size
experiment:	Growth of InAs QDs with and without Sb supply during different growth stages structural analysis with cross-sectional scanning tunneling microscopy

XSTM Experiment





Cross-sectional Scanning Tunneling Microscopy (XSTM)

- UHV: base pressure < 1 x 10^{-10} mbar
- *in-situ* cleavage

Conclusion

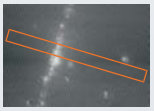
- Quantum dots with rather pure InAs stoichiometry, no Sb found in the dots
- flat, truncated pyramidal shape
- large size variation in monolayer steps: base lengths from about 10 to 35 nm, heights from about 1 to 5 nm.

➤ **Sb acts as surfactant**

In the case of Sb supply already during GaAs stabilization and during InAs deposition:

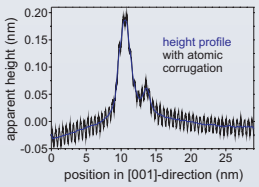
➤ **Incorporation of Sb within the wetting layer**

Stoichiometry

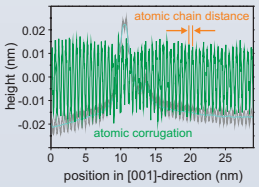


example for stoichiometry analysis: evaluation of local lattice constant

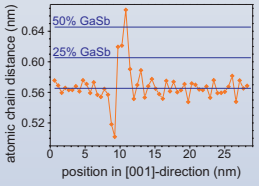
height profile across the dot in growth direction



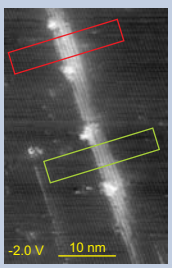
background subtraction → atomic corrugation

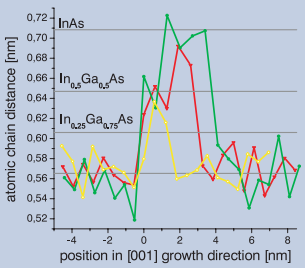


variation of distance between neighboring atomic chains



Experimental results are compared with calculations of the strain relaxation based on continuum mechanics on an atomic scale.



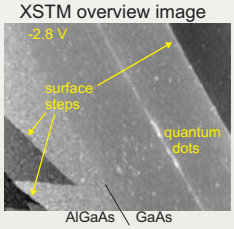


stoichiometry of quantum dots: up to pure InAs

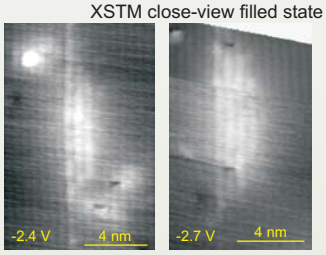
wetting layer: 40 % maximum InAs content

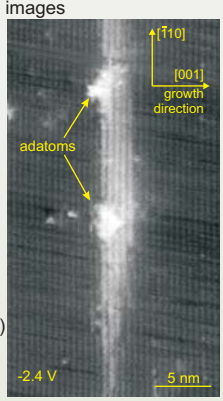
Quantum Dot Structure

XSTM overview image



XSTM close-view filled state images

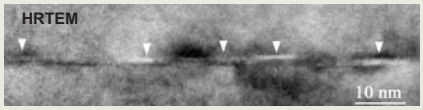


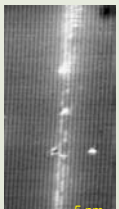


InAs quantum dots, grown with Sb supply during InAs deposition:

- flat, truncated pyramidal dot shape
- large size variation in monolayer steps (shown here: 6, 8, 12 ML height)
- base lengths from about 10 to 25 nm, heights about 1 - 3 nm.
- dot density ~ 6 x 10^{10} cm^{-2}.

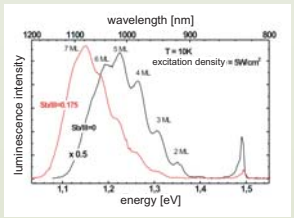
High-resolution Transmission Electron Microscopy image of an equally grown sample

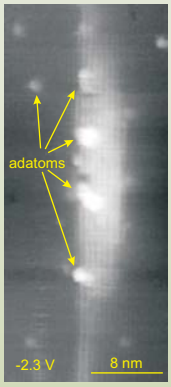




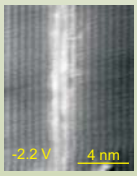
Reference sample without Sb: More segregation observed than in sample with Sb supply ➤confirmation of surfactant

Photoluminescence spectrum of an equally grown sample and a reference sample without Sb, both showing monolayer splitting





XSTM close-view filled state images



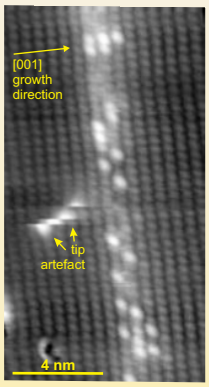
InAs quantum dots, grown with additional Sb supply of 15 sec before InAs deposition.

- even larger size variation:
- base lengths up to 35 nm
- heights up to ~ 5 nm (>15ML)
- dot density ~ 3 x 10^{10} cm^{-2}
- inhomogeneous In composition within largest dots: In-rich center with truncated reversed cone-shape.

➤ Higher mobility of In due to Sb surfactant.

Sb Incorporation

Sample with Sb supply during GaAs stabilization and subsequent InAs deposition:



- atomic resolution: bright balls are individual atoms
- negative sample bias: V_s = -2.3 V
  - ➤ sensitive to group V atoms
  - ➤ InGaAs wetting layer would give smooth structural contrast
  - ➤ sharp chemical contrast must be related to Sb and As

↓

Incorporation of individual Sb atoms into the InGaAs wetting layer

- GaSb content 25 %

Sb incorporation is only observed in the wetting layer, probably due to the larger strain within the InAs dots than within the InGaAs wetting layer

GaAs(110) Surface

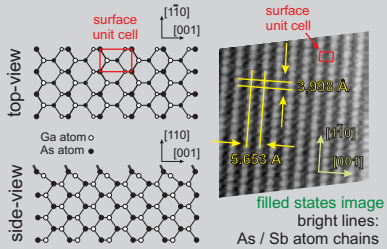
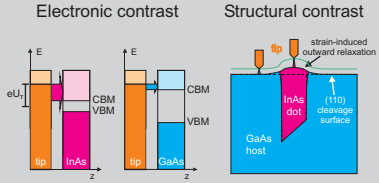


Image Contrast



$I_{tunneling}$ = 80 ... 120 pA for all images shown

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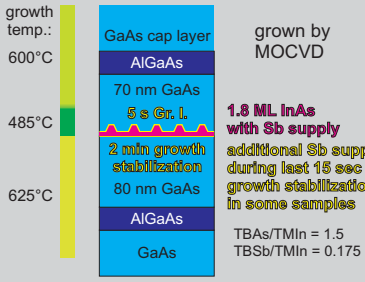
Growth Structure



grown by MOCVD

1.8 ML InAs with Sb supply

additional Sb supply during last 15 sec of growth stabilization in some samples

TBAs/TMIn = 1.5
TBSb/TMIn = 0.175

Acknowledgements

SANDiE

This work is supported by projects Sonderforschungsbereich 296, Da-408/4, and Da-408/8 of the Deutsche Forschungsgemeinschaft as well as by the European Commission in the SANDiE Network of Excellence.

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