Cross-sectional Scanning Tunneling Microscopy of InAs/GaAs (001) SubmonoLayer Quantum Dots

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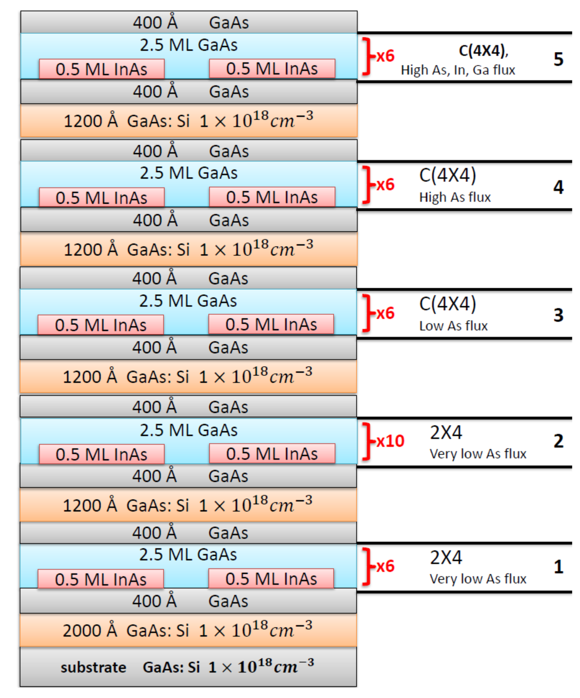
Introduction:

Submonolayer Quantum Dots (SMLQDs) emerged as an alternative for SKQDs in terms of higher dot density[1], smaller aspect ratio (base/height) and the absence of wetting layer. InAs/GaAs SMLQDs are obtained by repeating the deposition of 0.5 monolayer (ML) of InAs followed by a few MLs of GaAs. The small 2D InAs islands of adjacent layers are expected to stack vertically, due to the local strain field from the lattice mismatch, and form structures able to confine carriers as in conventional SKQDs[2]. The optoelectronic properties of such SMLQDs strongly depend on their size, geometry and composition. We employed cross-sectional scanning tunneling microscopy (X-STM) to probe InAs/GaAs SMLQDs on the atomic scale.

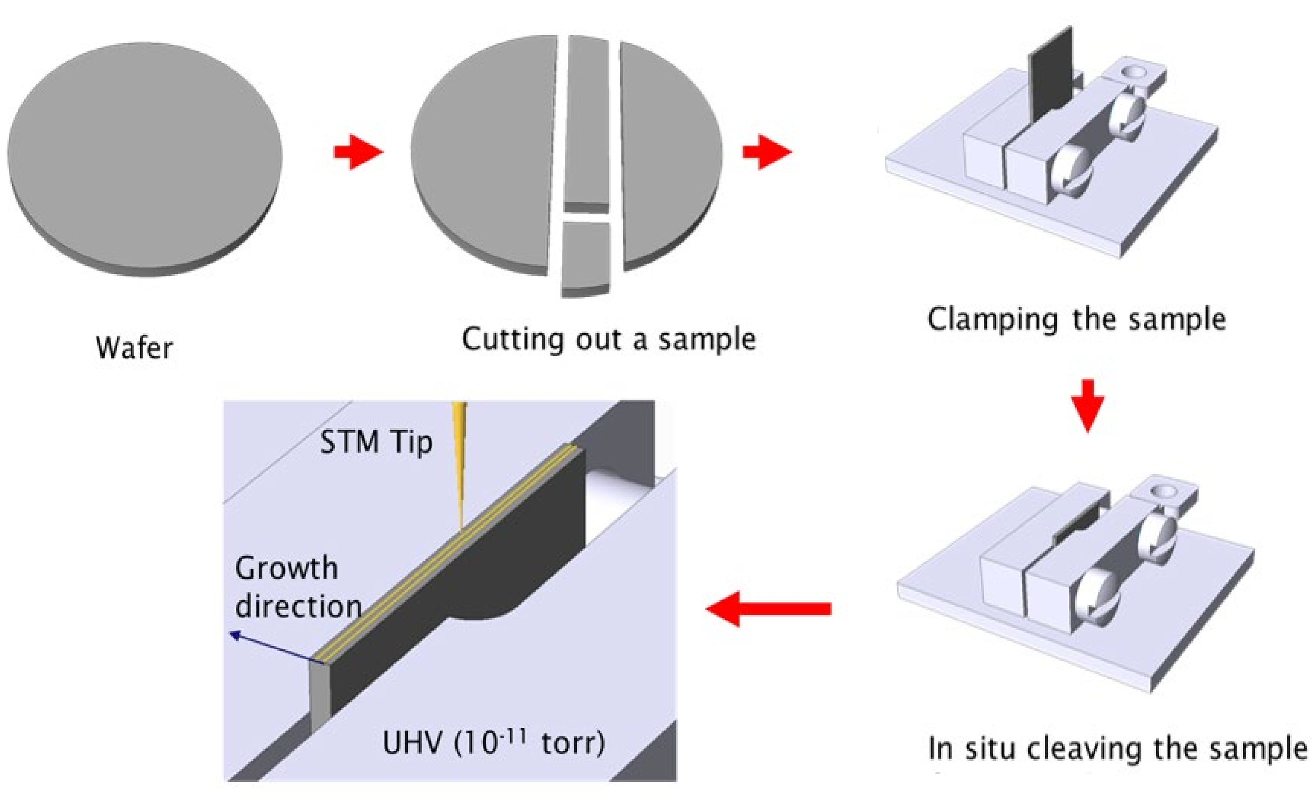
Sample structure:

- ✓ Five layers of SMLQDs grown with different As flux and growth rates to study their effect on the morphology.
- ✓ All the SMLQDs were grown at 490°C.
- ✓ Layer 1&2 grown with very low As flux with a (2 × 4) reconstruction but different thickness
- ✓ Layer 3&4 were grown with increasing As flux and c(4 × 4) reconstruction. Layer 5 was grown with usual SKQDs conditions



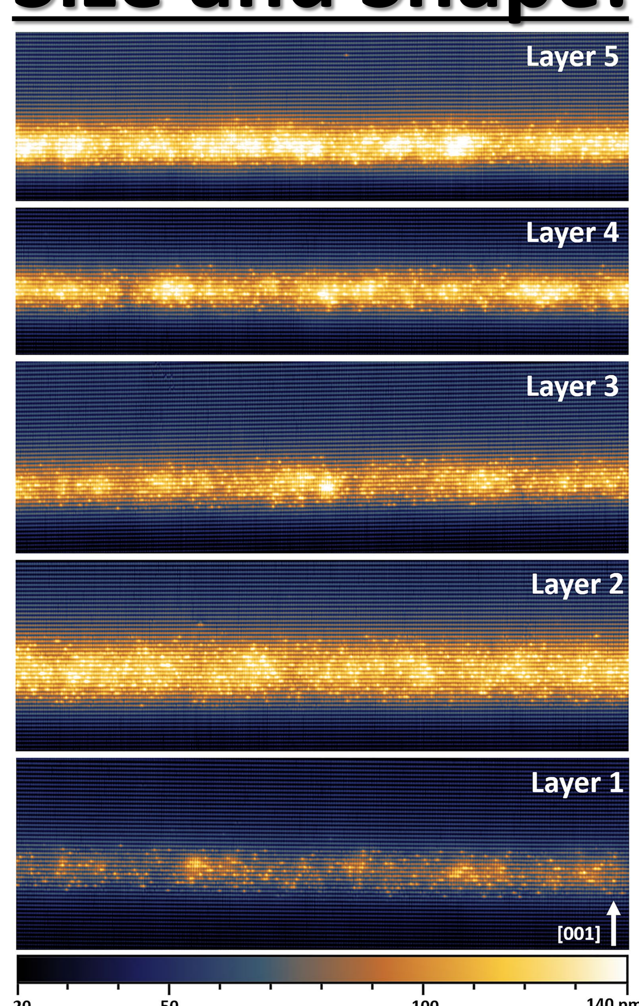
Schematic structure of sample grown by MBE

Cross-sectional STM:

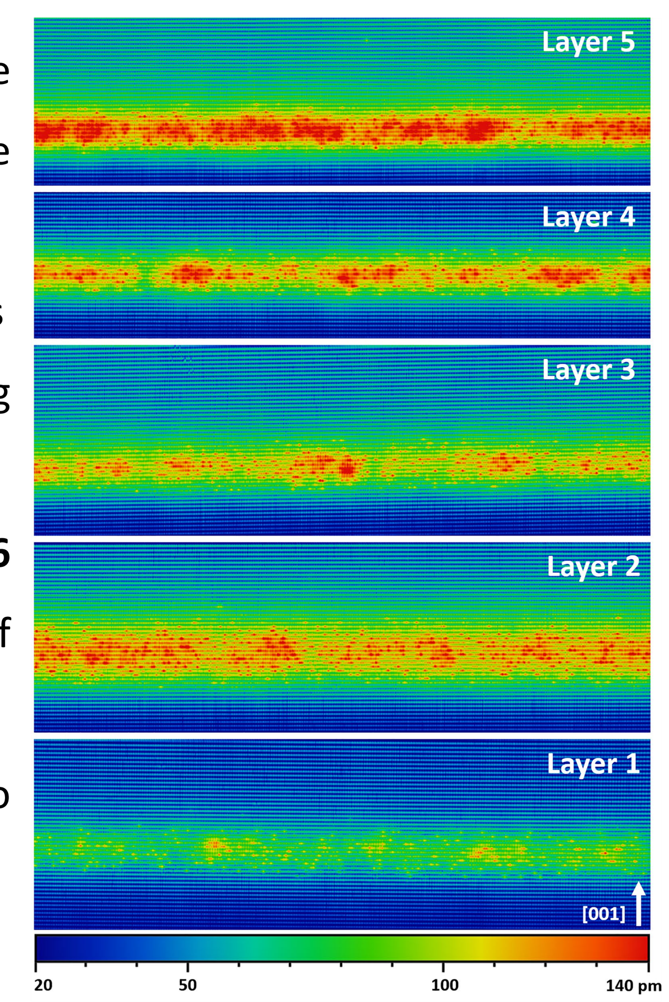


Sample was cleaved in UHV at 77K to reduce the contamination of the freshly obtained {110} surface

Size and Shape:



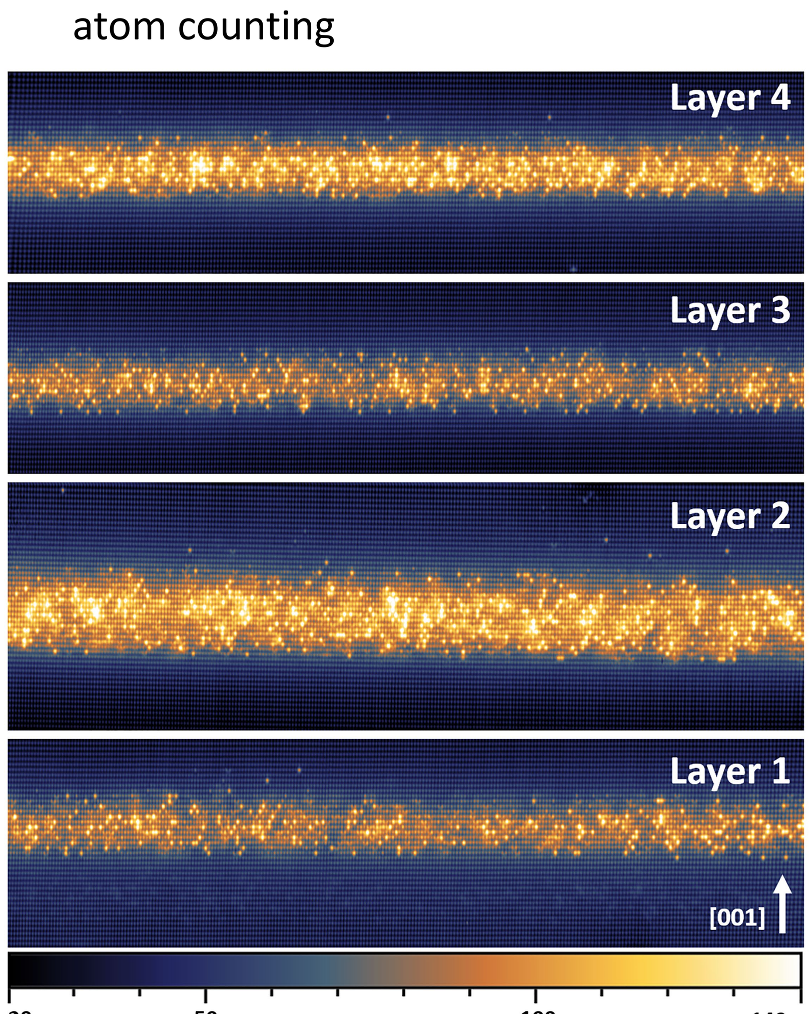
- ✓ Filled state topographic images revealing the structure of SMLQDs; brightness represents the relative height of STM tip from the surface.
- ✓ No 2D stacking observed in any of the SMLQD layers
- ✓ Indium-rich clusters are observed with increasing density from layers 1 to 5 due to increased As flux.
- ✓ Layer 5 has In-rich clusters with base length of **4-6 nm** and height of **3.0-3.5 nm** with a density of **5 × 10^{11} cm^{-2}**.
- ✓ In-rich clusters mimic quantum dots and are able to confine charge carriers.



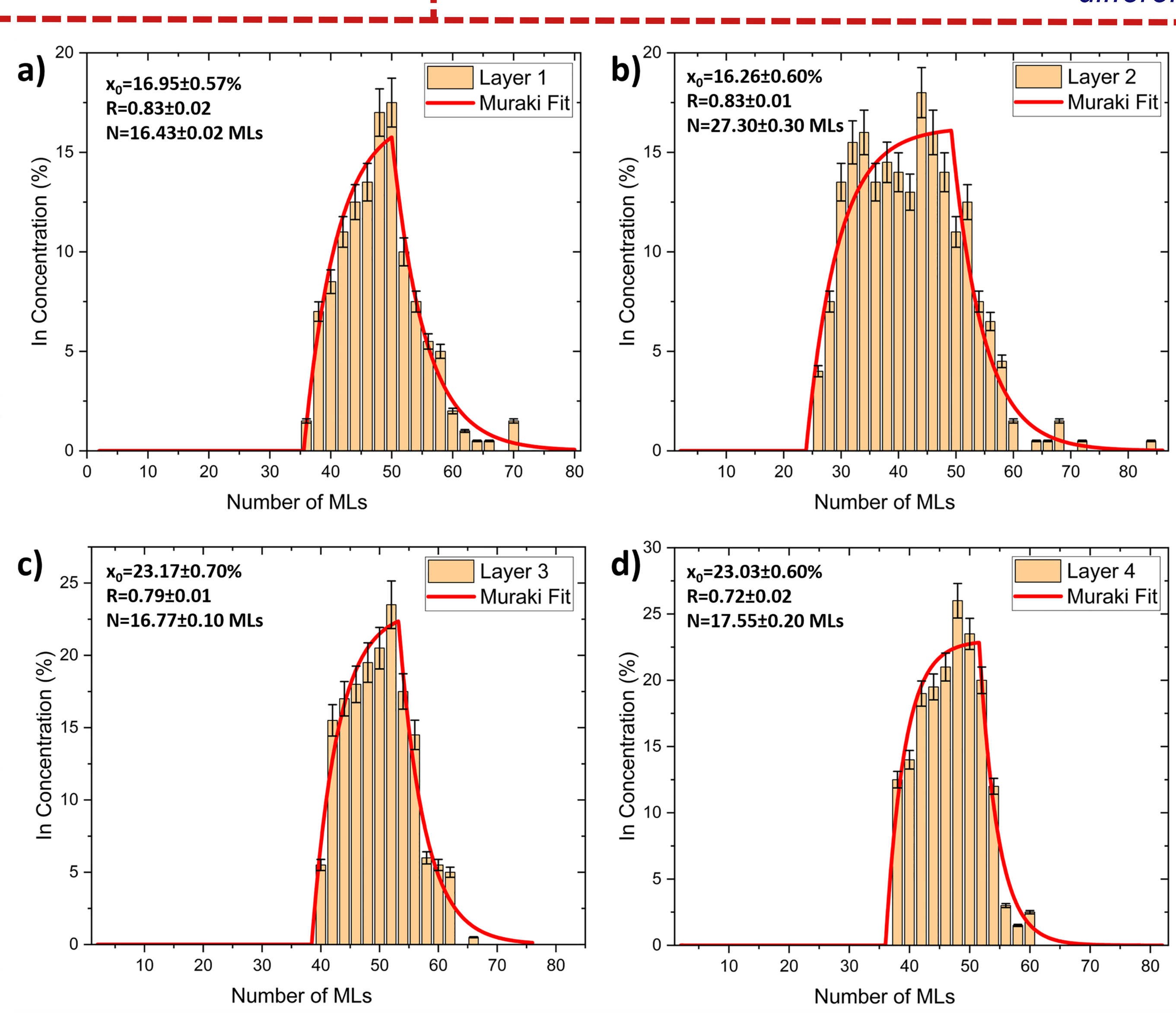
(left) Filled-state topographic (80 × 25 nm^2) images of SMLQDs taken at V_{bias} = -3V and I_t = 50pA, 77K. (right) Same images with a different color contrast to better reveal In clustering.

Composition:

- ✓ Empty-state X-STM images showing In and Ga sublattice
- ✓ Atomic resolution images used for In-atom counting



Empty-state (80 × 25 nm^2) images of SMLQDs taken at 77K with V_{bias} = +2,5V and I_t = 50pA.

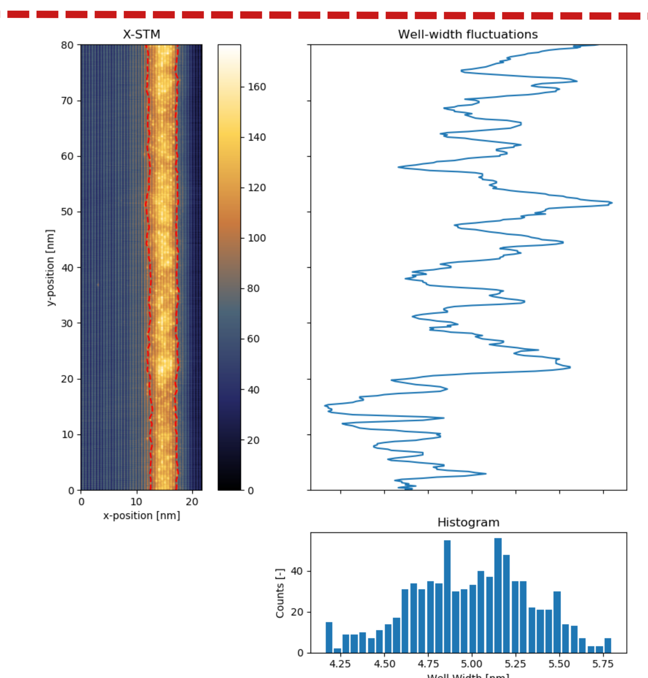


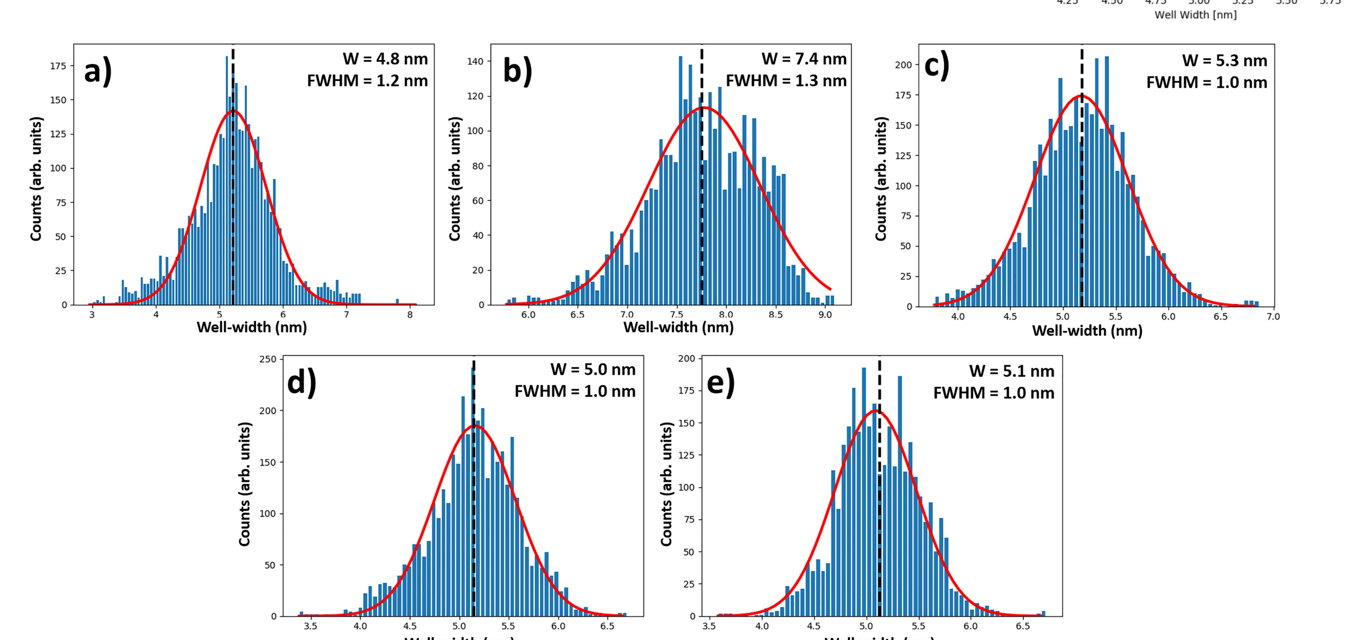
X_0 = Nominal In concentration, R = Segregation Coefficient, N = width of the well (in MLs)

In-concentration profile of the SMLQDs with Muraki's Model[4] to obtain the segregation coefficient (R) and InGaAs well width (N). There is a clear decrease in R with increasing As flux which is also observed in RHEED-oscillations measurements[5].

Well width:

- ✓ Well-width fluctuations are observed.
- ✓ Distribution of well-widths follows a gaussian distribution.
- ✓ The FWHM is similar for all the layers.
- ✓ Well-width fluctuations are independent of growth conditions.





Distribution of well widths summed over a distance of400 nm for each SMLQD layer with a Gaussian fit (red). The average well width (W) and FWHM are indicated: (a) layer 1, (b) layer 2, (c) layer 3, (d) layer 4, and (e) layer 5.

Conclusions:

- ✓ We present the first atomic-scale study of the effect of growth conditions on the formation, morphology and composition of InAs/GaAs SMLQDs.
- ✓ SMLQDs have a base length of 4-6 nm, a height of 3-3.5 nm and a density of 5 × 10^{11} cm^{-2}.
- ✓ Contrary to the expectation, no vertical stacking of 2D islands is observed.
- ✓ As flux has more impact than surface reconstruction.
- ✓ Detailed composition and segregation analysis reveal that In segregation increases while In incorporation decreases with the reduction of As flux.
- ✓ Feedback for further growth optimization to achieve the vertical stacking of 2D In islands.

References:

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