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# Self-assembled growth of epitaxial III-V quantum dots

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## Introduction

### Motivation

Quantum dots (QDs) are semiconductor nanostructures that exhibit quantum confinement of carriers in all three spatial dimensions, resulting in atom-like discrete energy states. Specifically, III-V epitaxial QDs realized by self-assembly have been the subject of intensive research for several years and have proven to be a versatile system with various applications including for:

- **Lasers**
- **Second-harmonic generation**
- **Solar cells etc.**

More recently, their use as **sources of single and entangled photons for quantum applications** has motivated interest in high-quality epitaxial growth of these QDs.

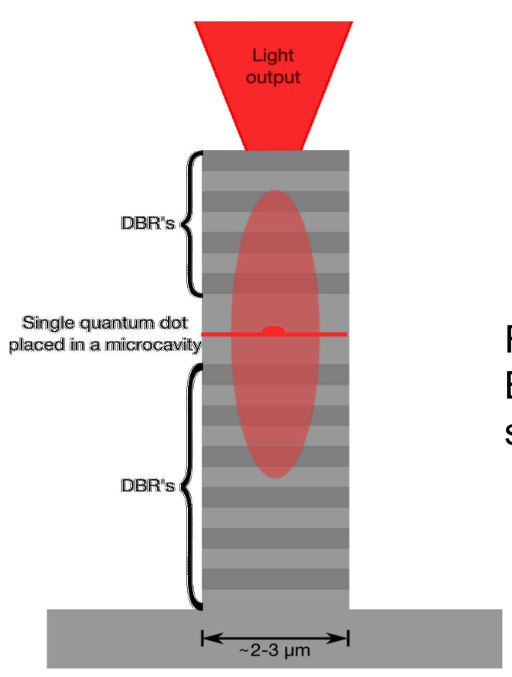


Figure 1: Single QD integrated with Distributed Bragg Reflectors (DBRs) in a microcavity for a single photon source. (Wikiwand)

### Approach

Growth of the QDs shown here is carried out using solid-state **molecular beam epitaxy (MBE)**. Three different approaches are explored towards realizing high-quality QDs :

- **Stranski-Krastanov (S-K) growth mode**
- **Local droplet etching (LDE) method**
- **Submonolayer (SML) QDs**

## MBE capabilities at CINT

- AlInGaAs MBE growth ; Si for n-doping and C for p-doping
- High purity and high mobility materials
- High precision control of thickness and composition

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## Results &

### S-K growth mode

- Strain between the epitaxial layer (QD) and the substrate drives 3-dimensional island formation. Eg: InAs on GaAs (7.16% mismatch)
- QD size, density and consequently emission wavelength can be tuned by modifying growth conditions. (shown in Fig. 2)
- Dimensions: Height – ~8nm ; Width – 50nm (Fig. 3)
- Room-temperature photoluminescence (PL) observed at ~1150nm from samples capped with GaAs.

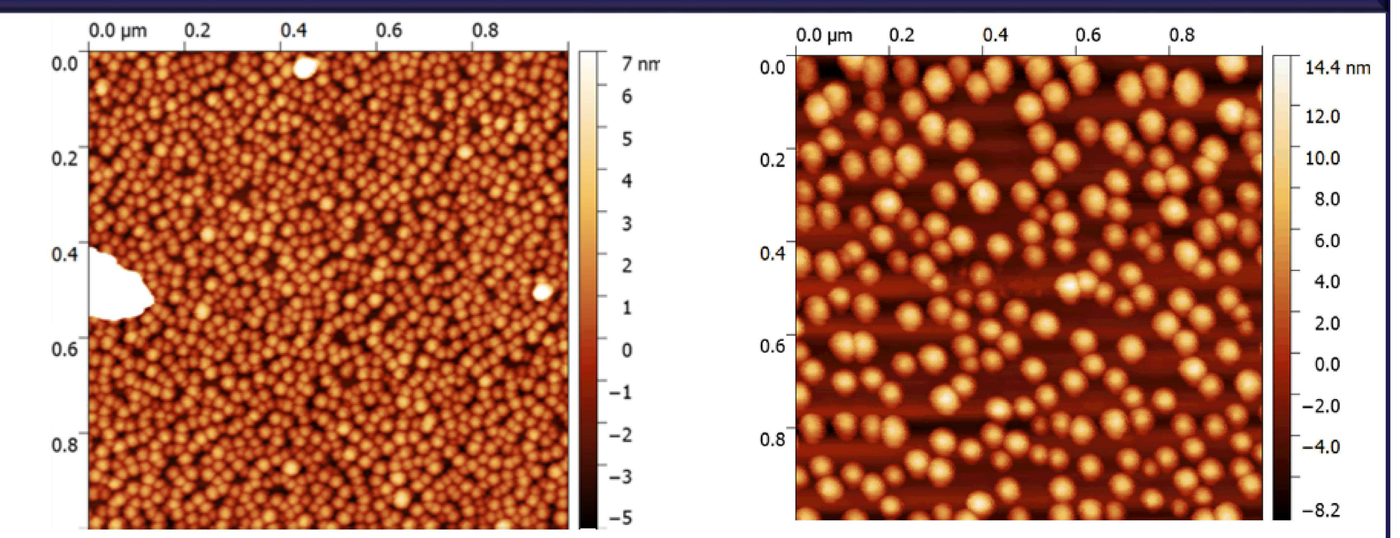

Figure 2: 1 X 1 µm AFM scans showing ability to tune QD size and density by modifying growth conditions such as temperature, growth rate and III-V ratio

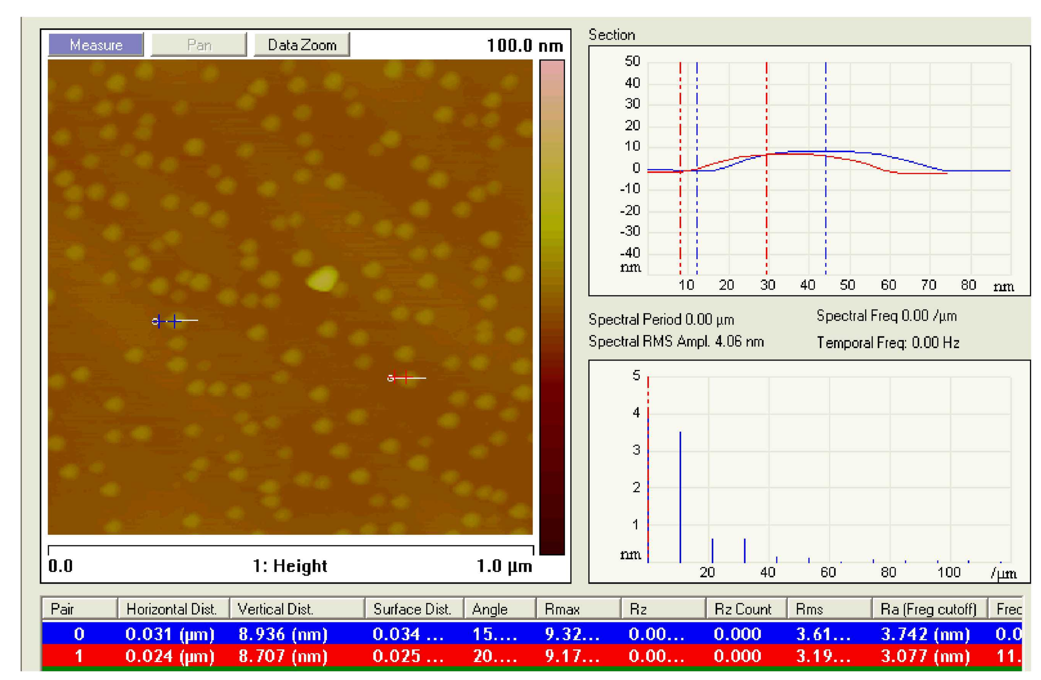

Figure 3: AFM analysis of InAs QDs showing profile and size of typical QDs

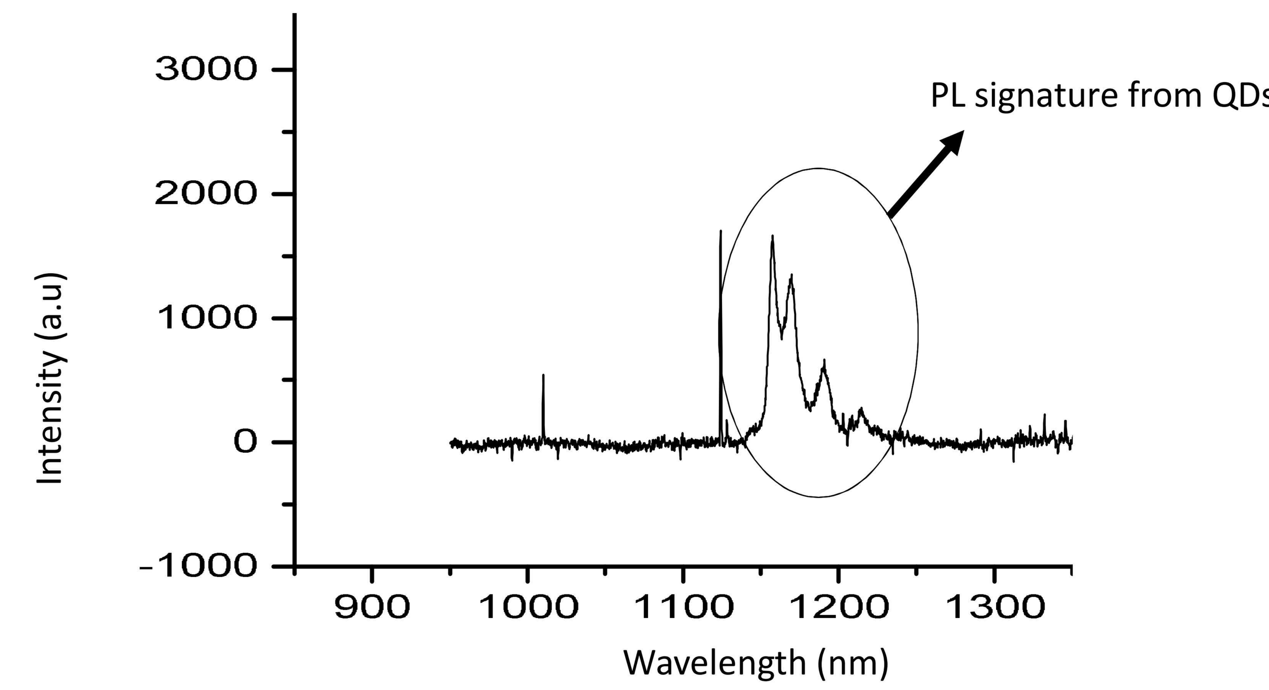


Figure 4: RT PL from capped InAs QDs showing emission around

### SML QDs

- Cycled deposition of submonmolayer InAs in a GaAs matrix (2-4ML).
- Compared to SK QDs, submonolayer QDs show:
  - High areal density → high probability of carrier capture
  - Wider emission wavelength tunability (900-1300nm)
  - Lower lindewidth


Figure 5: Schematic showing difference between S-K (left) and SML (right) QDs

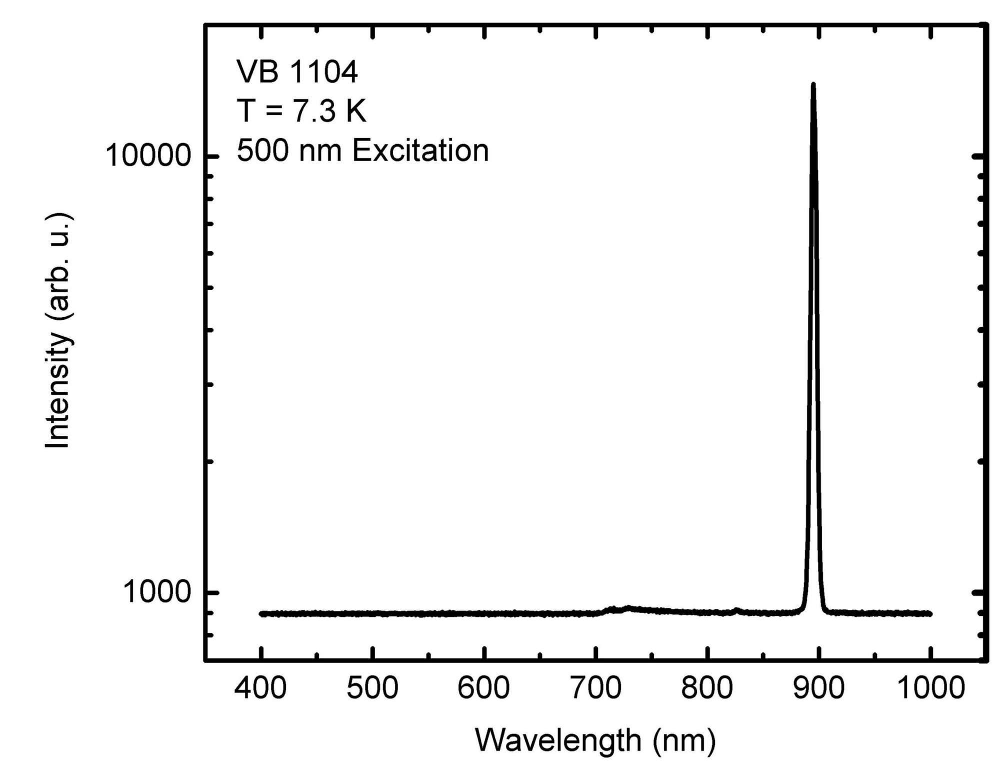


Figure 6: Cryogenic PL results from SML QDs (Pump: 500nm)

### LDE method

- QD formed by etching of substrate to form a nanovoid, followed by filling.
- Dot dimensions (emission wavelength) can be tuned based on growth conditions and thicknesses. (700—900nm)
- Ideal for single photon emitters.

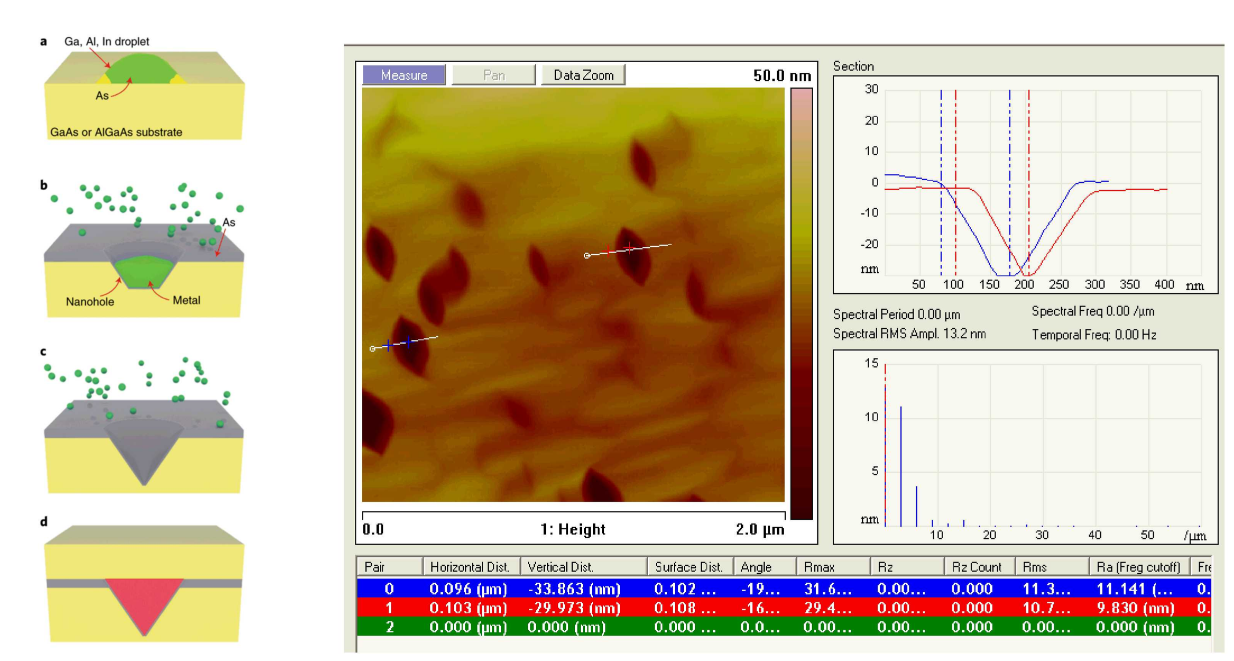

Figure 7: Evolution of LDE method (left) [1]; AFM analysis of nanovoids formed by LDE (right)

[1] Gurioli, Massimo, et al. "Droplet epitaxy of semiconductor nanostructures for quantum photonic devices." *Nature materials* (2019):

LA-UR or SNL number

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