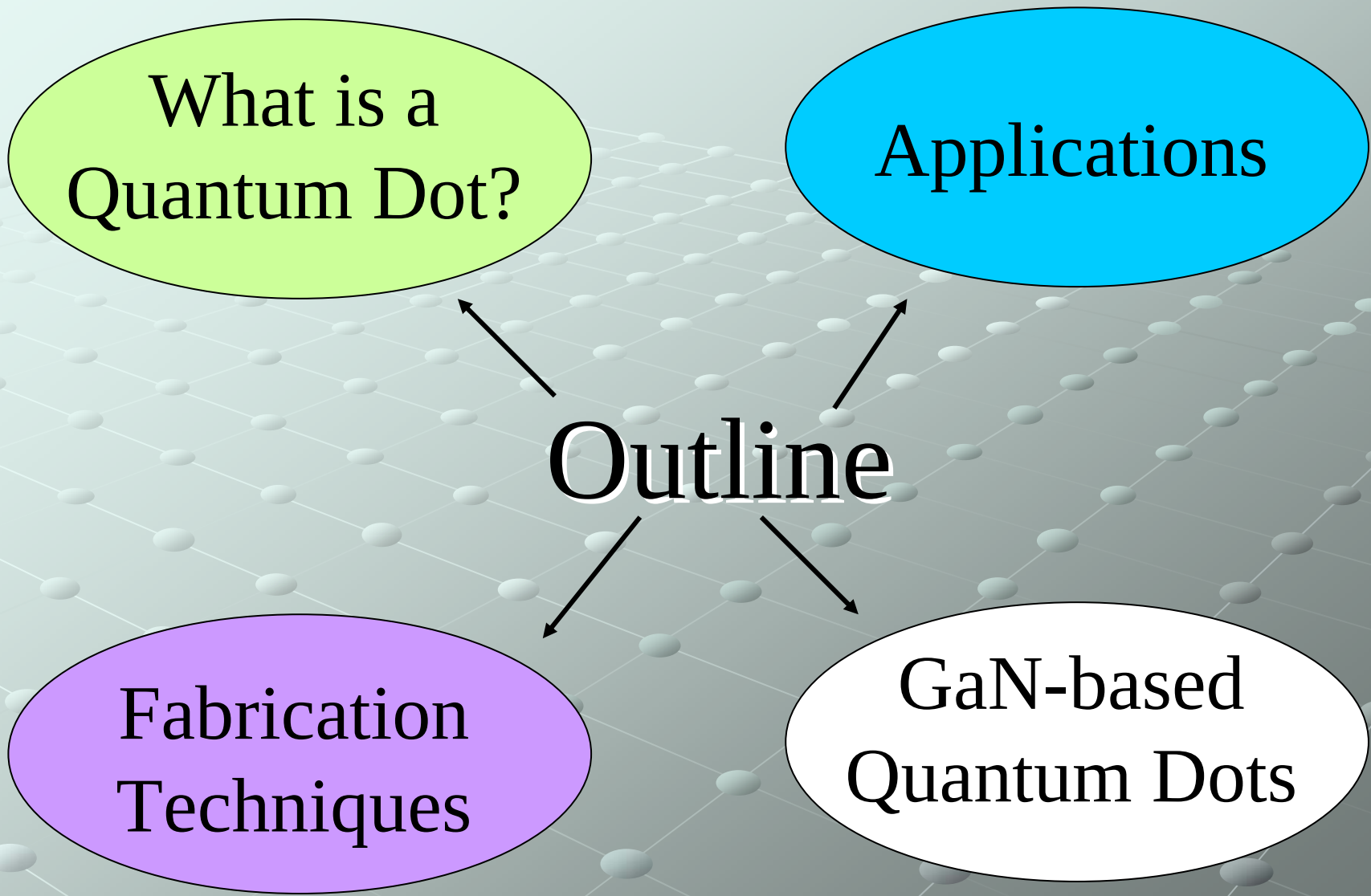
A Quantum Dot: A Quantum What?

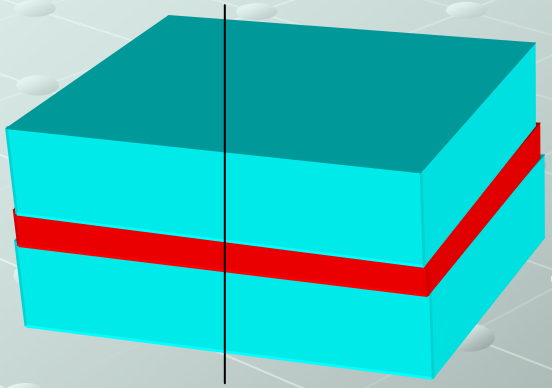
Nicole van der Laak

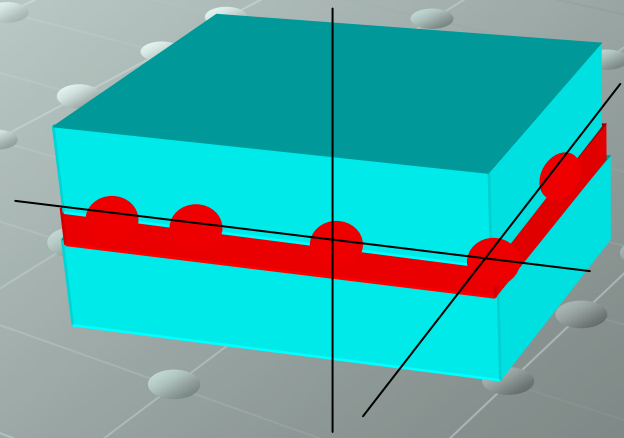

What is a Quantum Dot?
Applications
Outline
Fabrication Techniques
GaN-based Quantum Dots

What is a quantum dot? (1)

"A dot is a synthetic material best described as a giant artificial atom made up of thousands of real atoms"

Kelee Riesbeck





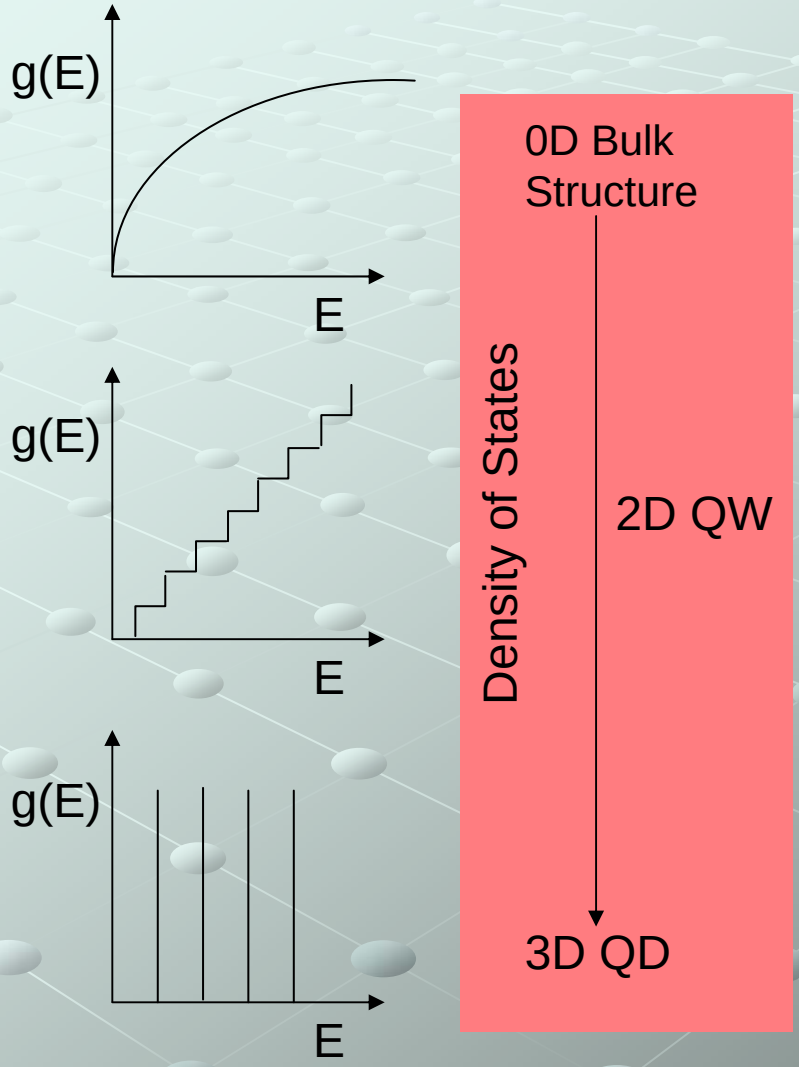
Quantum Well:

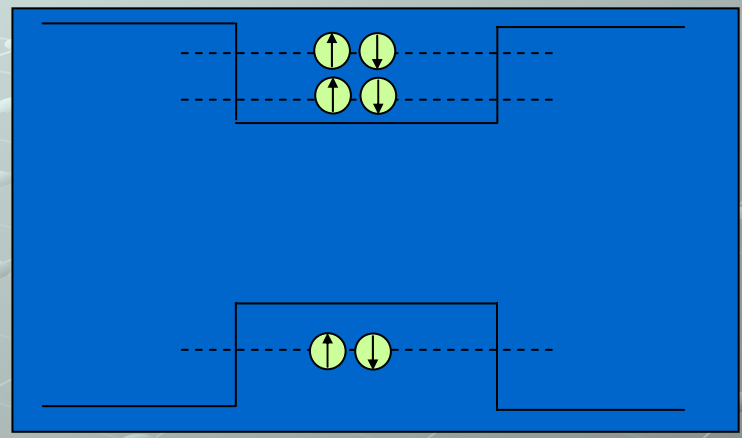
Quantum confinement in one direction

Quantum Dots:

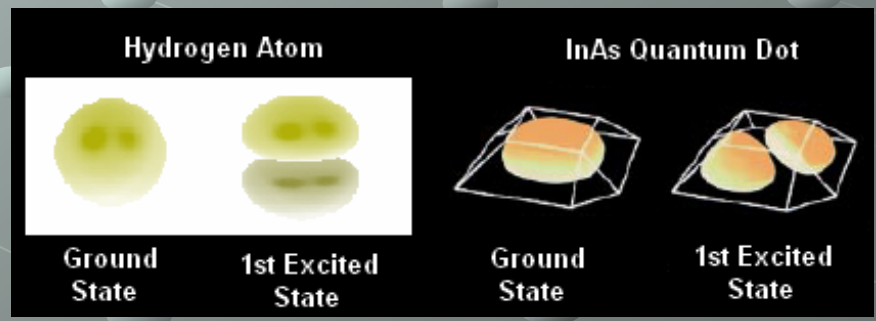
Quantum confinement in three dimensions

What is a quantum dot? (2)





The dot acts to quantum mechanically confine electrons analogous to an 'electron in a box'

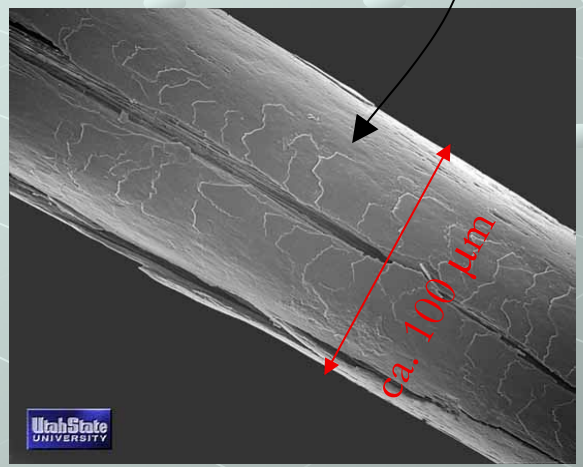


Holm *et al.* (2002) *J. Appl. Phys.* **92**: (2) 932-936

What is the size of quantum dot?

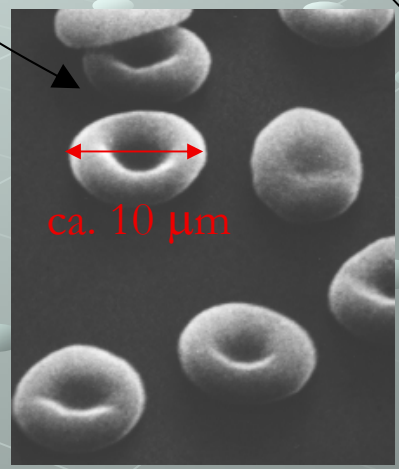
1 m

1 mm



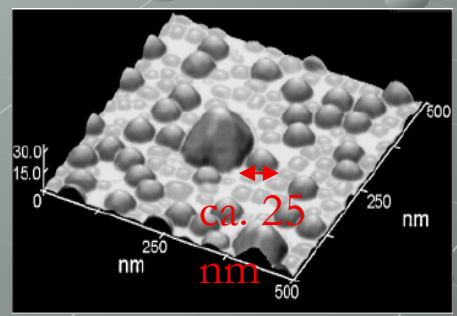
A human hair

1 µm



Red blood cells

1 nm



Ge/Si quantum dots

Williams *et al.* (2000) *Annu. Rev. Phys. Chem.* **51**:527–51

Applications of quantum dots (1)

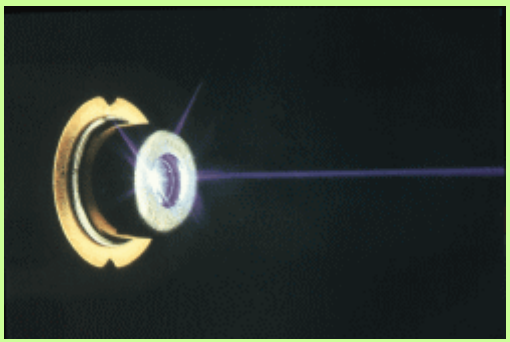
“Ensemble” applications

•Quantum dot lasers

-higher power and great stability

-low threshold currents

-greater efficiency



•Optical detectors

•White light sources

“Single dot” applications

•Quantum computing

- Ordinary (classical) computers process and store information as binary digits called bits.

- The bit is always in states $|0\rangle$ *or* $|1\rangle$

- Quantum bits (qubits) can be in a superposition of states $|0\rangle$ *and* state $|1\rangle$

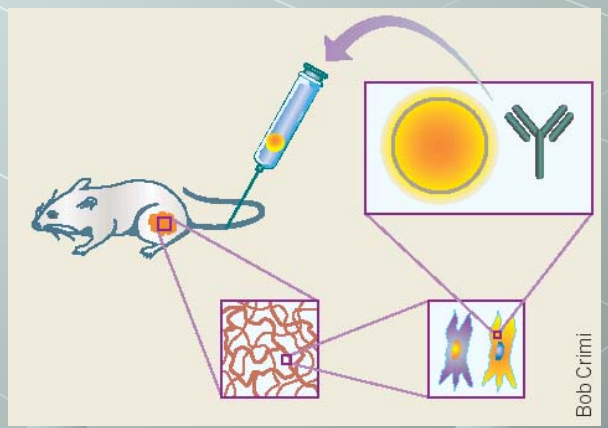
www.ohiou.edu/perspectives/0402/finalfall04.pdf

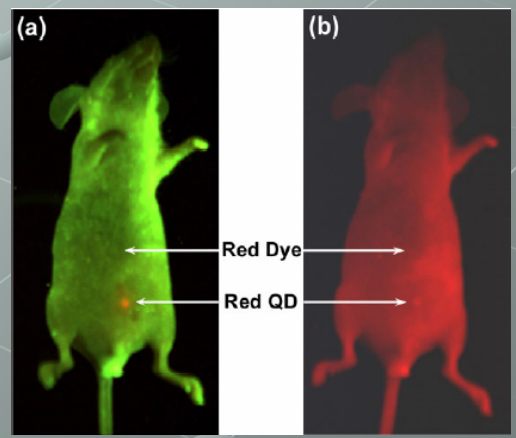
Applications of quantum dots (2)

Solution-based quantum dots

- **Medical research and diagnostics**

-luminescent QDs as biomarkers for selective imaging of tumor cells in living animals

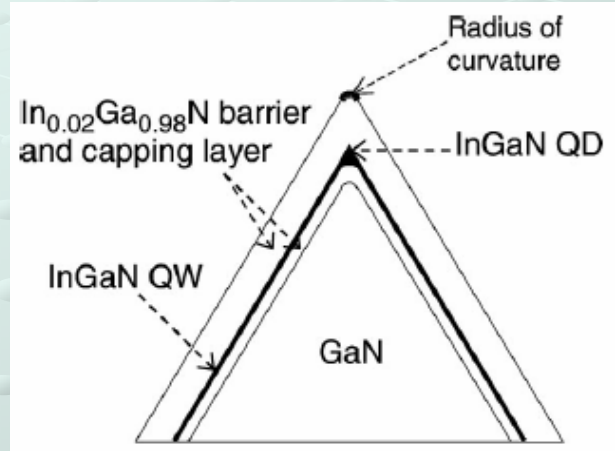




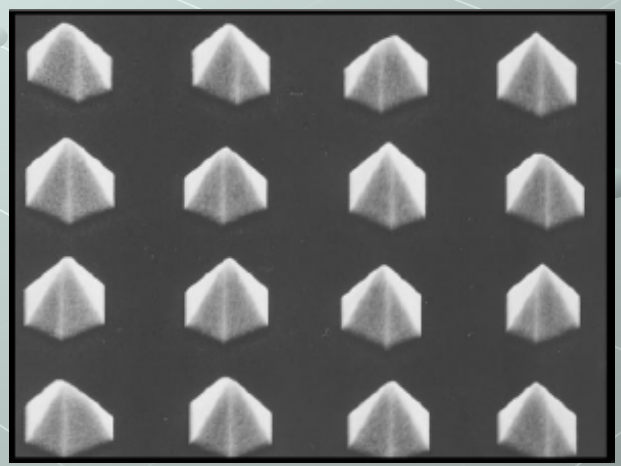
Gao *et al.*, ***Nature biotechnology,*** **22, (8), 969-976, 2004**

Fabrication techniques (1)

Lithographic Techniques: a top-down approach



Using photolithography, a grid-like pattern is created followed by selective growth



Tachibana *et al., Journal of Crystal Growth*, 221 (2000), 576-580

☺ **Compatible with existing processing technologies**

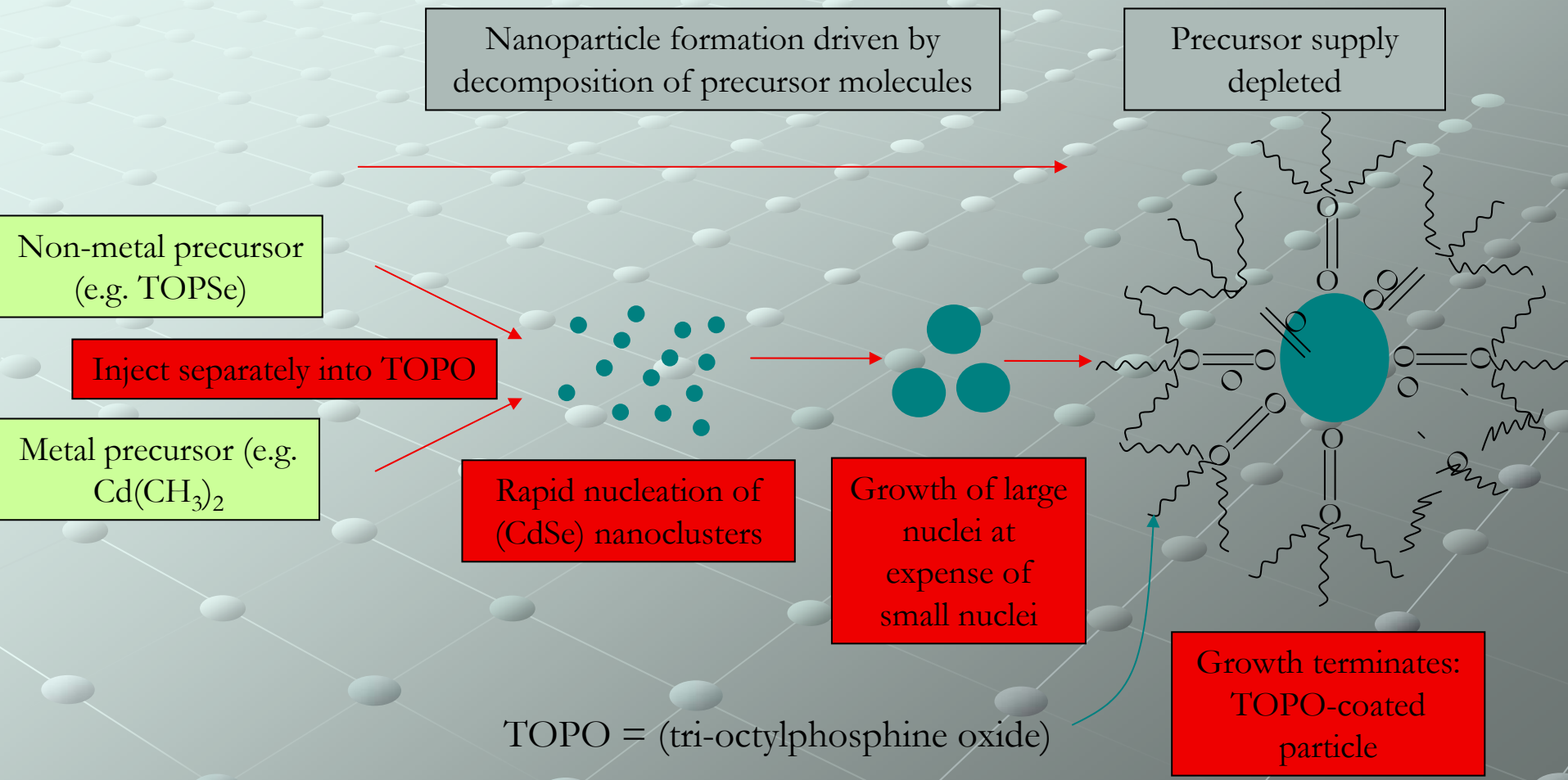
☺ **Lithographic stage is comparatively non-demanding**

☹ **Difficult to achieve small sizes**

☹ **Low dot densities**

Fabrication techniques (1)

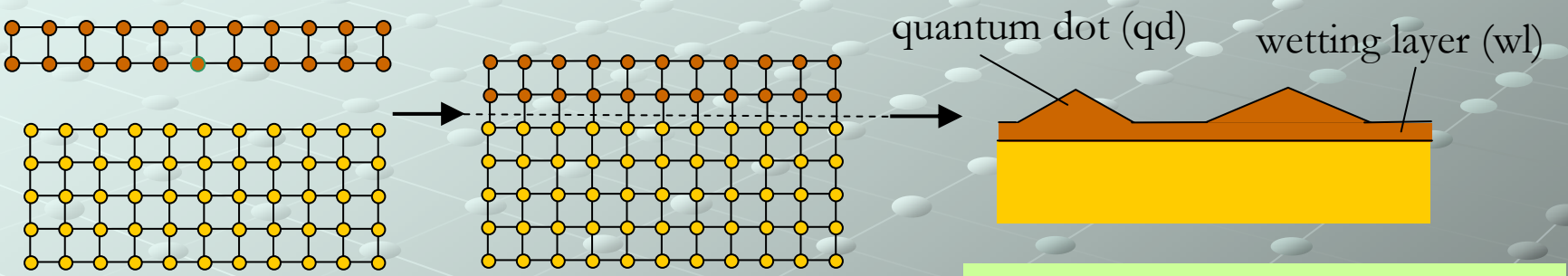
Self-assembly in solution

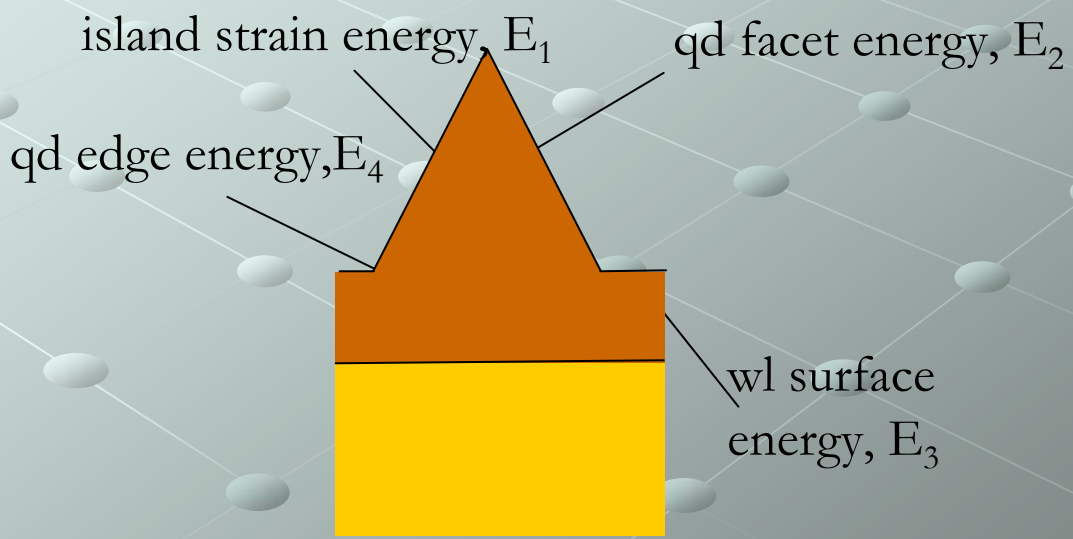


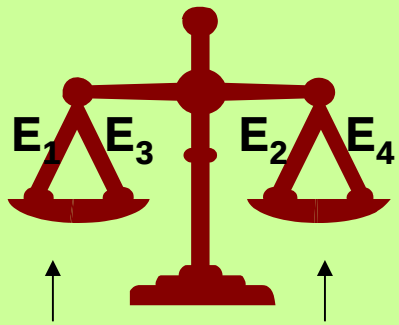
Fabrication techniques (2)

Self-assembly: a bottom-up approach

- via Stranski-Krastanov growth





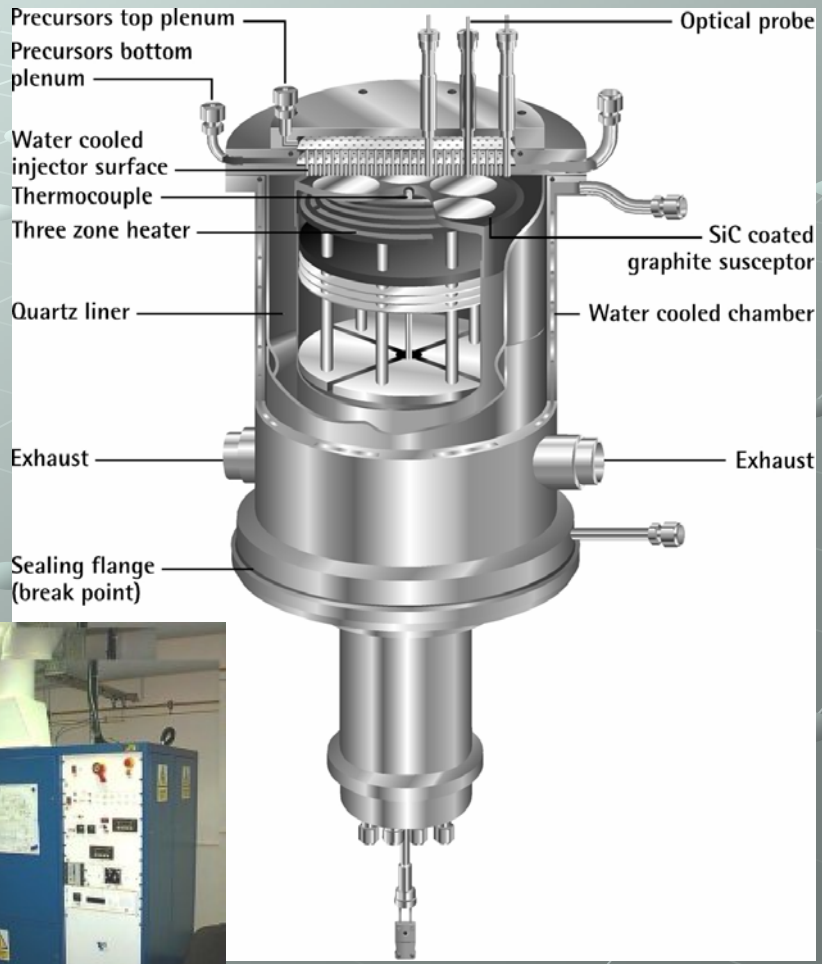


System energy decreased by dot formation

System energy increased by dot formation

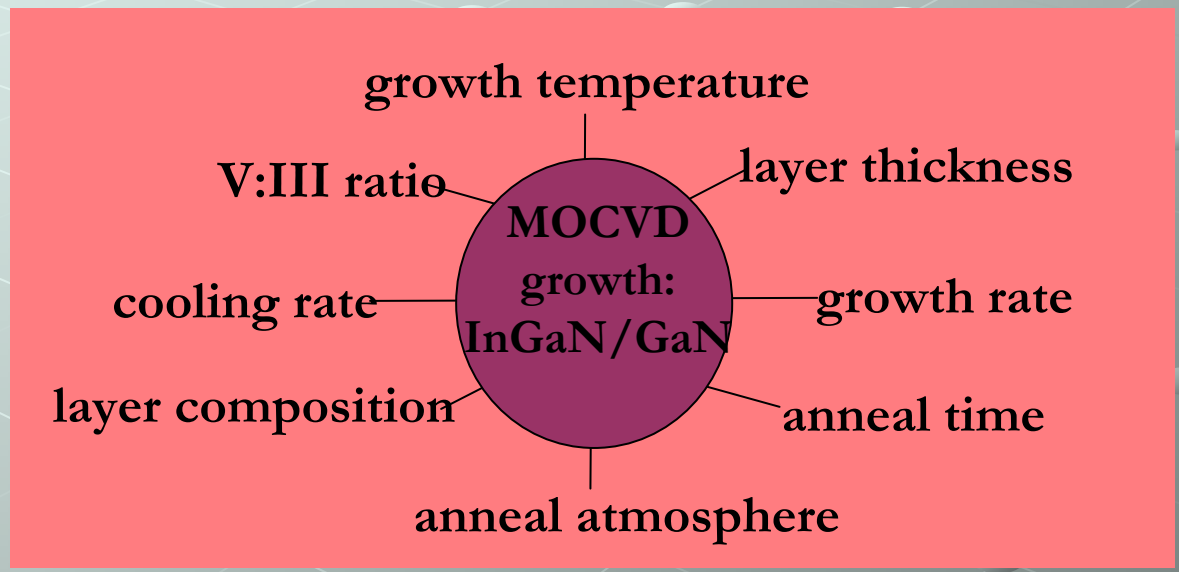
Self-assembled GaN-based Quantum Dots (1)

- Cambridge GaN centre: Thomas Swann 6-wafer MOVPE reactor.
- Gases employed: NH3, TMIn, TMGa



Self-assembled GaN-based Quantum Dots (2)

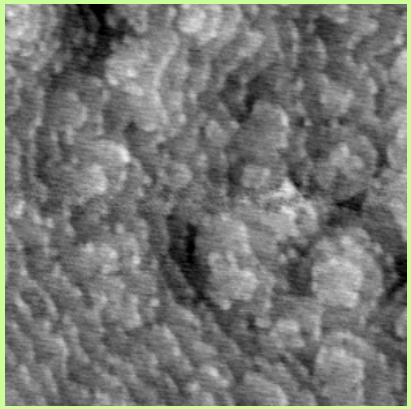
- **Fairly high yields**
- **Good luminescent and electrical properties**
- **Very dependent on growth conditions**



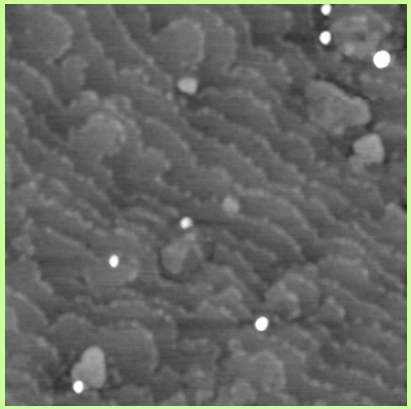
- **We need to understand the growth methodologies (and growth parameters) to improve the dot properties and assess their suitability for potential applications**

Controlling the growth of GaN-based quantum dots

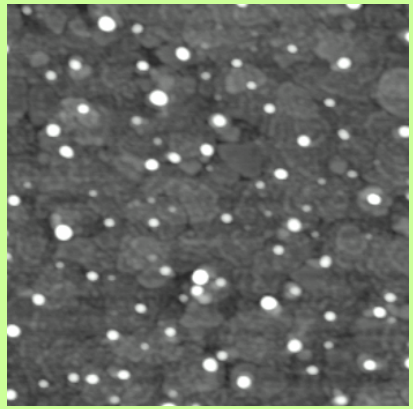
Increasing gas pressure



300 Torr

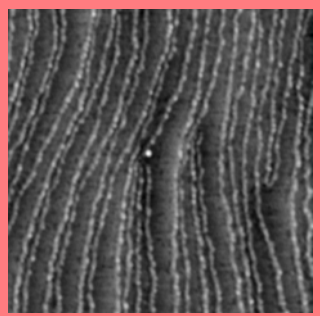


450 Torr

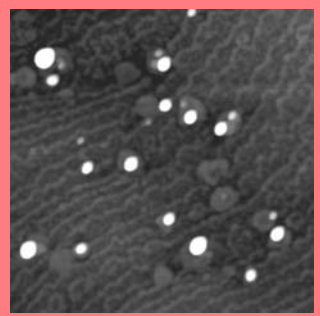


750 Torr

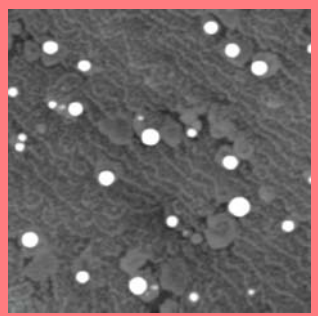
Increasing InGaN growth time



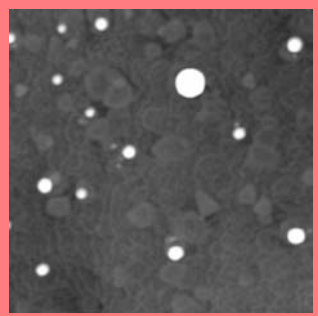
15 s



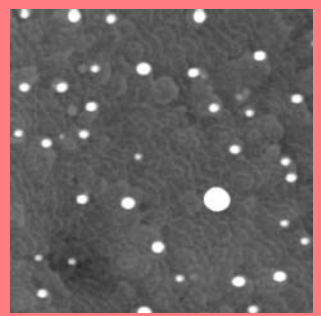
31 s



46 s



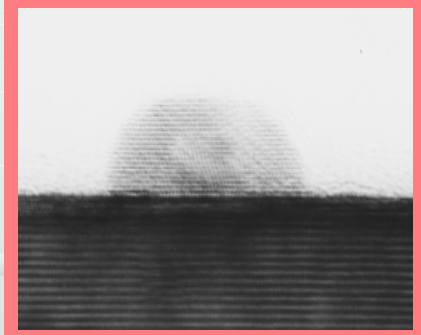
62 s

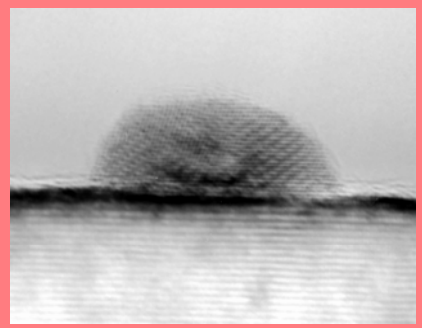


93 s

Understanding the properties of GaN-based quantum dots

What does it look like?





Height: 6.1 nm

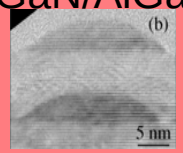
Diameter: 15.9 nm

Height: 6.8 nm

Diameter: 19.6 nm

The quantum dots have rounded sides with truncated flat tops

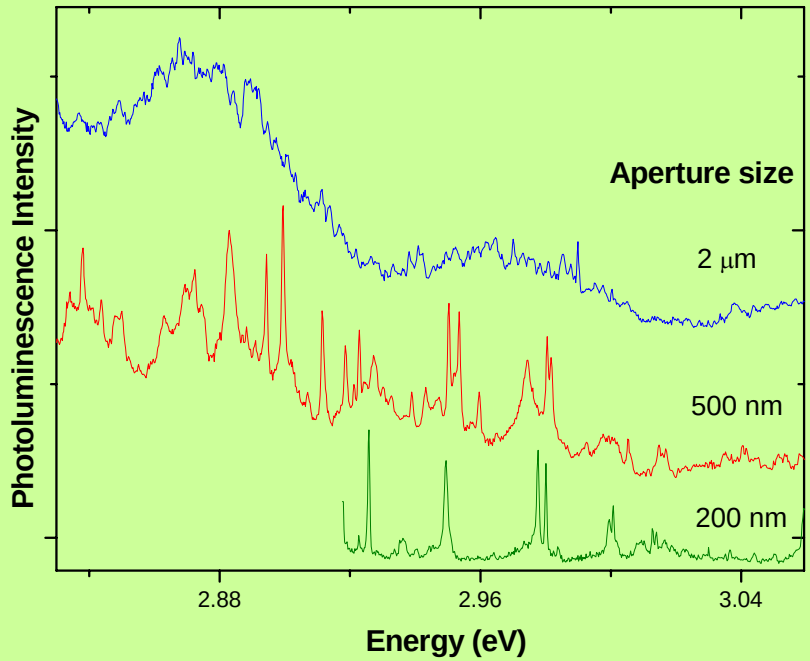
GaN/AlGaN QDs



Charmard V. *et al.*, Phys Rev B, 69, 125327, (2004)

What are its photoluminescence properties?

Low temperature µPL reveals delta-function-like peaks in the spectrum, typical of quantum dots.



A quantum what? – yes that's right a quantum dot

- "A dot is a synthetic material best described as a giant artificial atom made up of thousands of real atoms"
- Applications range from quantum computing to medical applications
- Fabrication routes are application dependent
- Understanding, and controlling dot growth such as self-assembled GaN-based dots is essential for device implementation