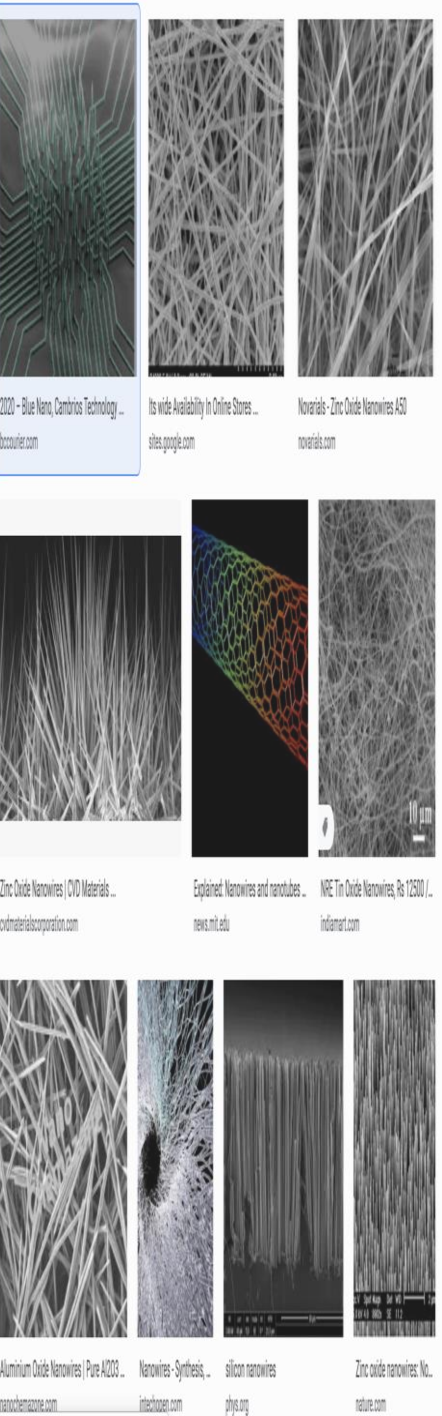


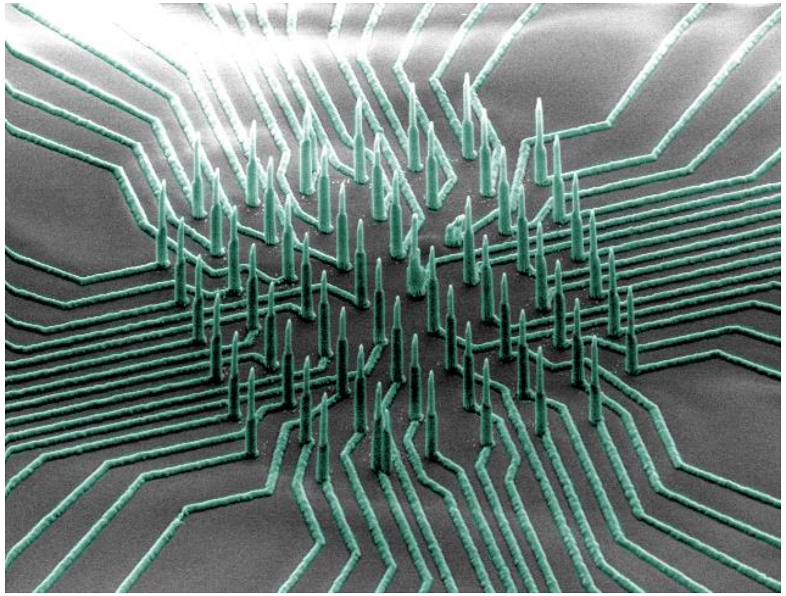
Session 10b

Nanowires

Nanowires—From Basic Materials Research to Real-World Applications

https://www.youtube.com/watch?v=2NUG957W72Q

Report



https://www.bccourier.com/%EF%BB%BFglobal-nanowires-market-2020-blue-nano-cambrios-technology-kemix-novarials/

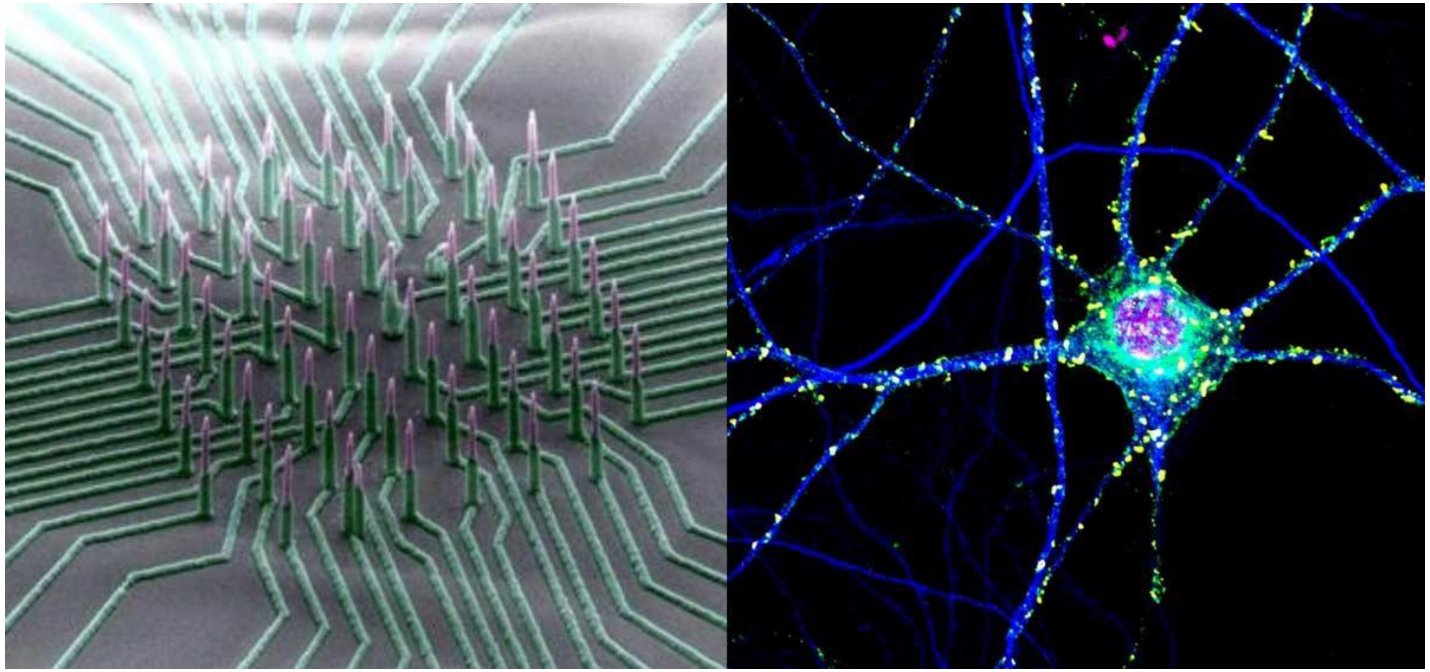
The Global Nanowires market report details in-depth past and present analytical and statistical data about the global Nanowires market. The report describes the Nanowires market in detail in terms of the economic and regulatory factors that are currently shaping the market's growth trajectory, the regional segmentation of the global Nanowires market, and an analysis of the market's downstream and upstream value and supply chains. This report additionally shows the 2015-2026 generation, Consumption, income, Gross edge, Cost, Gross, piece of the overall industry, CAGR, and Market impacting elements of the Nanowires industry. The report gives a far-reaching examination of the Nanowires industry advertise by sorts, applications, players and regions. The worldwide market for Nanowires is expected to grow at a CAGR of roughly over the next five years, will reach XX? million US$ in 2026, from X? million US$ in 2020, according to latest industry study.

Report

Nanowires Market By Type(Metal Nanowires, Semiconductor Nanowires, Oxide Nanowires, Others), Application(Electronics, Healthcare, Research and Development, Others) – Global Insights, Trends and Forecast 2020-2026 *(this report costs $3,300 USD)*

https://www.indexmarketsresearch.com/report/nanowires-market-2/400189/#requestforsample

Research on an application



To examine a neuron's health, activity and response to drugs, scientists record its electrical activity. Current methods of recording are destructive, so they can only be used to study a neuron for a brief period, and can only measure the activity of one cell at a time. But neurons don’t function individually—they act in networks, and commonly used systems for detecting the electrical activity of complex groups of neurons aren’t as sensitive as they could be.

A new technology developed through a collaboration between Anne Bang, Ph.D., director of Cell Biology in the Conrad Prebys Center for Chemical Genomics at the Sanford Burnham Medical Research Institute, and Shadi Dayeh, Ph.D., associate professor at UC San Diego, makes high-sensitivity recording possible in neuronal networks. Publishing in *Nano Letters*, the team describes nanowire arrays that could accelerate drug development for neurological and neuropsychiatric diseases.

"We envision that this nanowire technology could be used on stem-cell-derived brain models to identify the most effective drugs for disorders like bipolar disorder and Alzheimer’s," says Bang.

The nanowire technology developed in Dayeh's laboratory is nondestructive and can simultaneously measure potential changes in multiple neurons -- with the high sensitivity and resolution achieved by the current state of the art.

The device consists of an array of silicon nanowires densely packed on a small chip patterned with nickel electrode leads that are coated with silica. The nanowires poke inside cells without damaging them and are sensitive enough to measure small potential changes that are a fraction of or a few millivolts in magnitude.

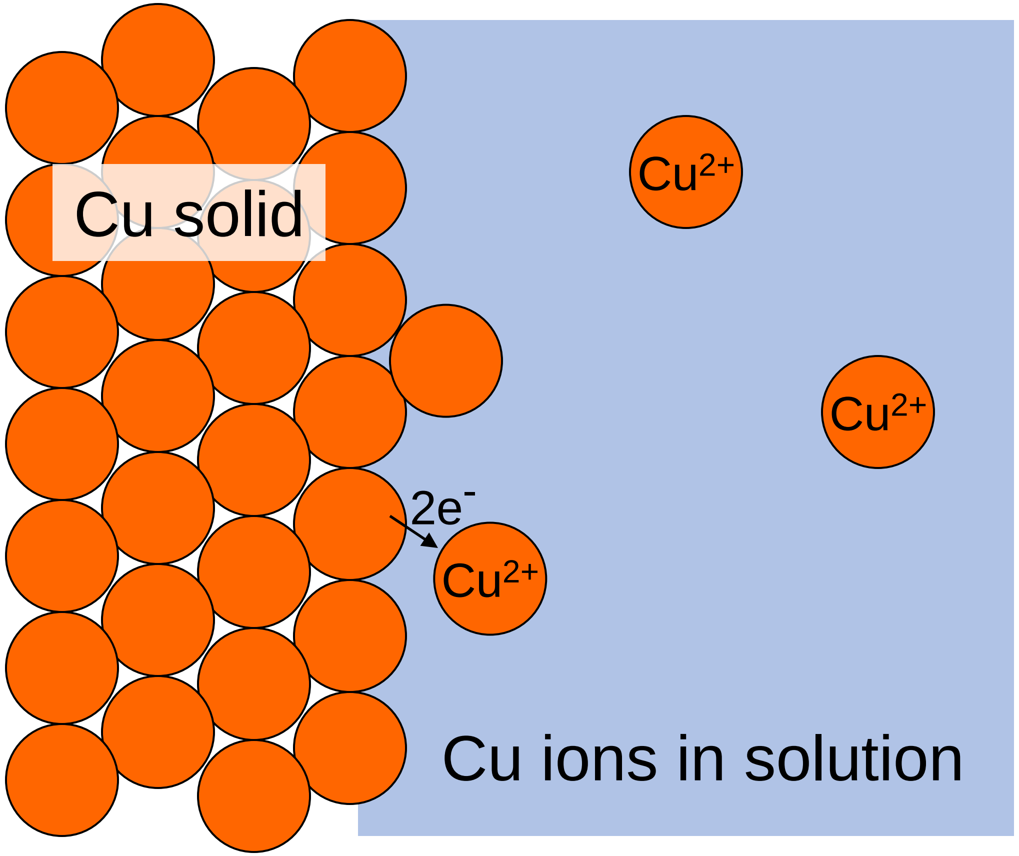
Neurons interfaced with the nanowire array survived and continued functioning for at least six weeks.

Electroplating to make nanostructures

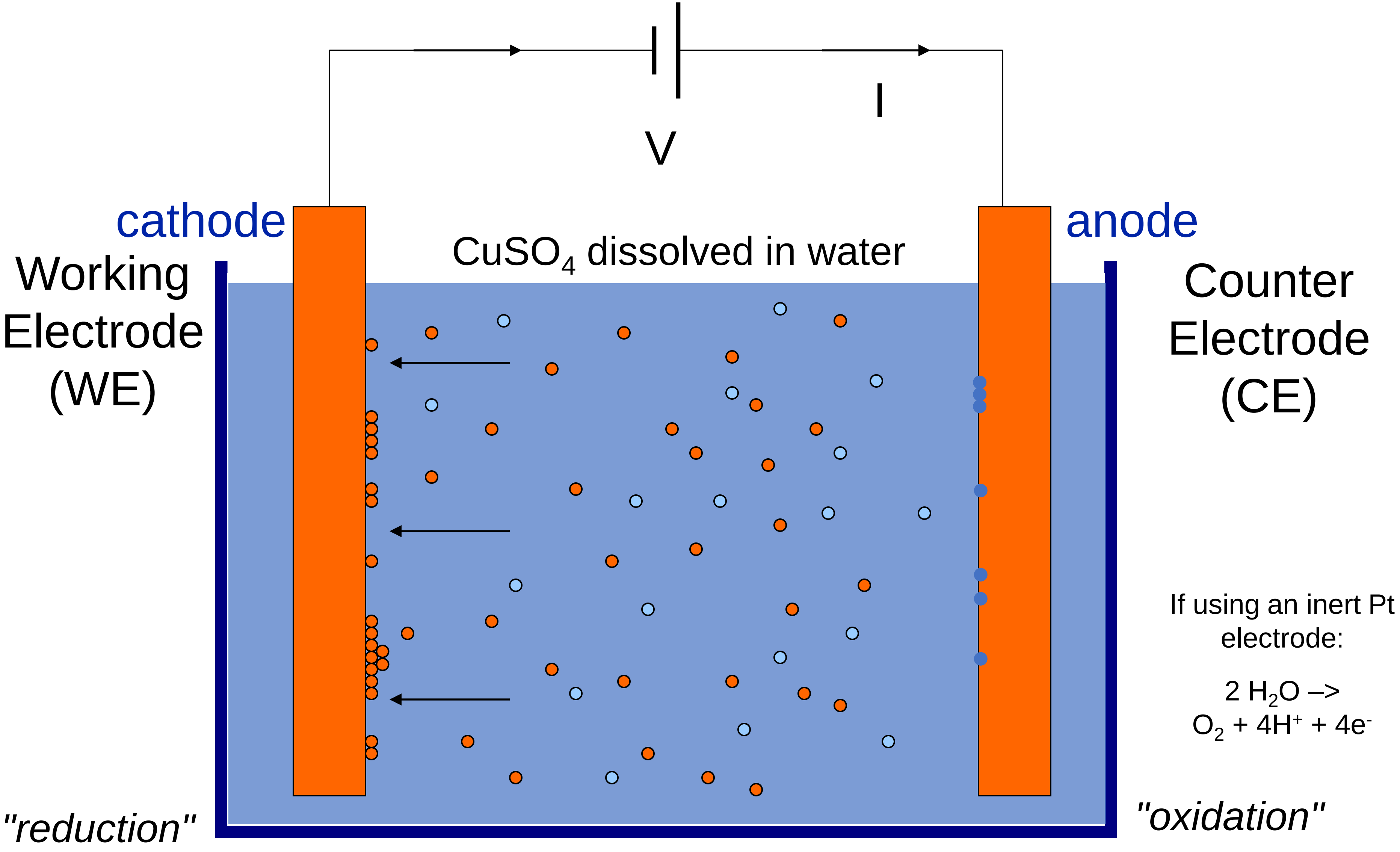
Electroplating

- The chemical conversion of ions in solution into a solid deposit of metal atoms with the work of a electrical power supply

$M^{z+} + ze^- \rightarrow M^{(0)}$ $Cu^{2+} + 2e^- \rightarrow Cu^{(0)}$



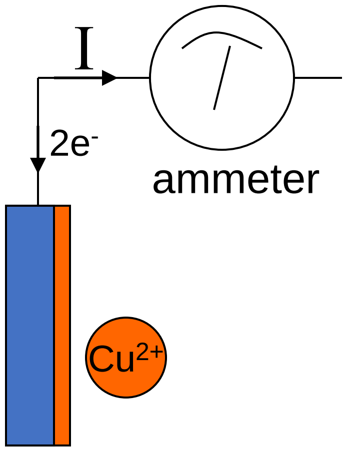
Electroplating Cell



$Cu^{2+} + 2e^- \rightarrow Cu^{(0)}$

$Cu^{(0)} \rightarrow Cu^{2+} + 2e^-$

Amount of Deposition



The number of atoms deposited is proportional to the number of electrons passed through the circuit

- We can determine this by measuring the current

If I is constant

$$I = \frac{dq}{dt} \qquad Q = \int_0^t I\,dt = It$$

\# electrons = Q/e = It/e   where $e = 1.6 \times 10^{-19}$ C

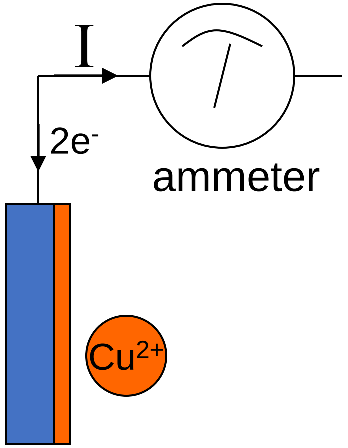
\# atoms = # electrons/z = It/ez

\# moles of atoms = # atoms/N_A = It/ezN_A

$eN_A = (1.6 \times 10^{-19}\ \text{C})(6.02 \times 10^{23}) = 96{,}500\ \text{C} = F =$ "1 Faraday"

\# moles of atoms = It/Fz

Amount of Deposition (cont.)



$$\#\ \text{moles of atoms} = It/Fz$$

$$m = \text{mass} = (It/Fz)(\text{gram atomic weight})$$

e.g., AW_{Cu} = 63.55 g/mole

$$t = \text{film thickness} = (\text{mass})/(\text{density} \cdot \text{area}) = m/(\rho A)$$

Note:
these equations assume 100% current efficiency (CE) - that is, assuming that all of the electrons are used for converting metal ions. However, another reduction reaction may compete for electrons making the CE less than 100%. For example, $2H^+ + 2e^- \rightarrow H_2$. CE must be determined by an independent measurement.

Why choose electroplating to make nanostructures??

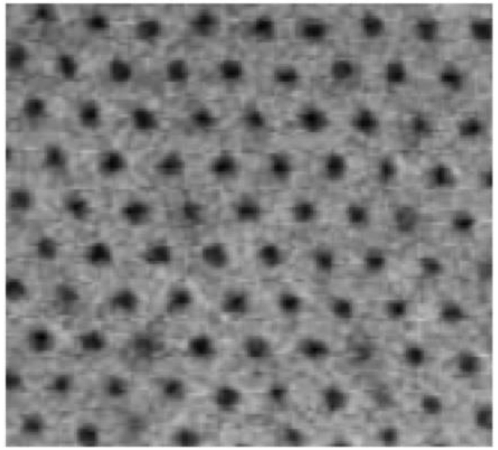
The process is easy to operate and only needs simple equipment.

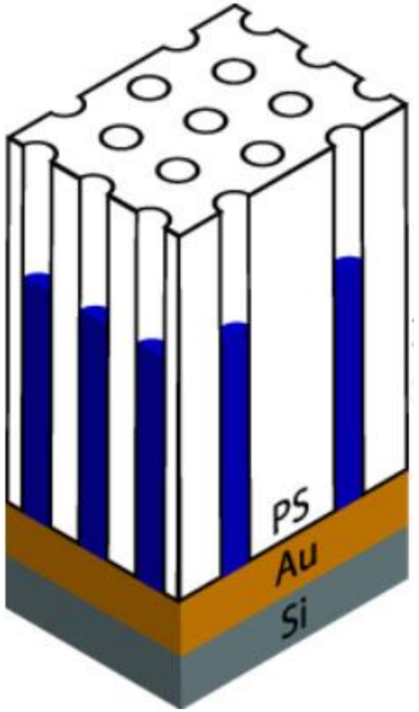
It's simple to control the deposition rate by controlling the voltage or current.

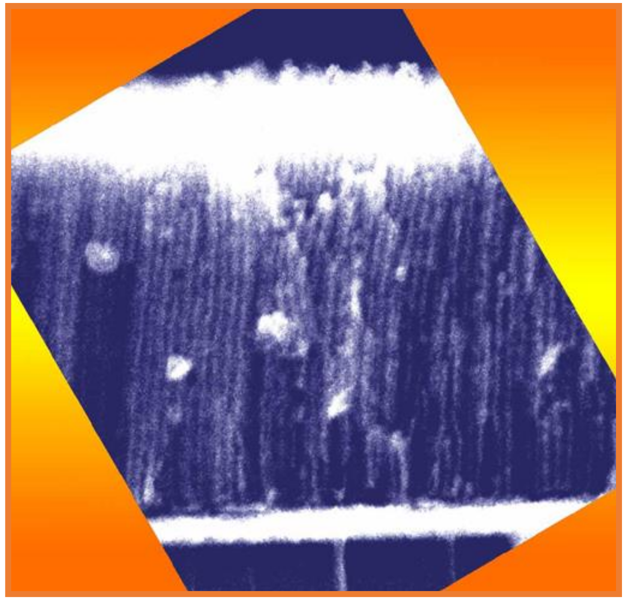
It's a good way to make Nanowires in a porous template.

Electrodeposited Nanowires

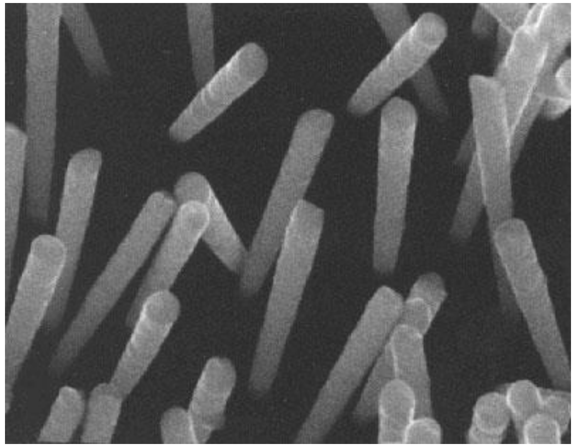
nanoporous template







nanowires in a polycarbonate filter

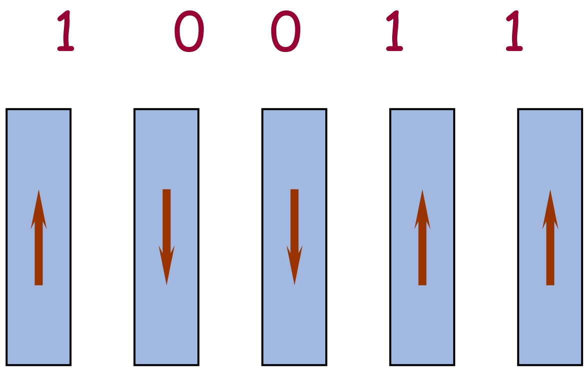


nanowires in a diblock copolymer template

If the nanowires are magnetic, they can be used to store data

Application

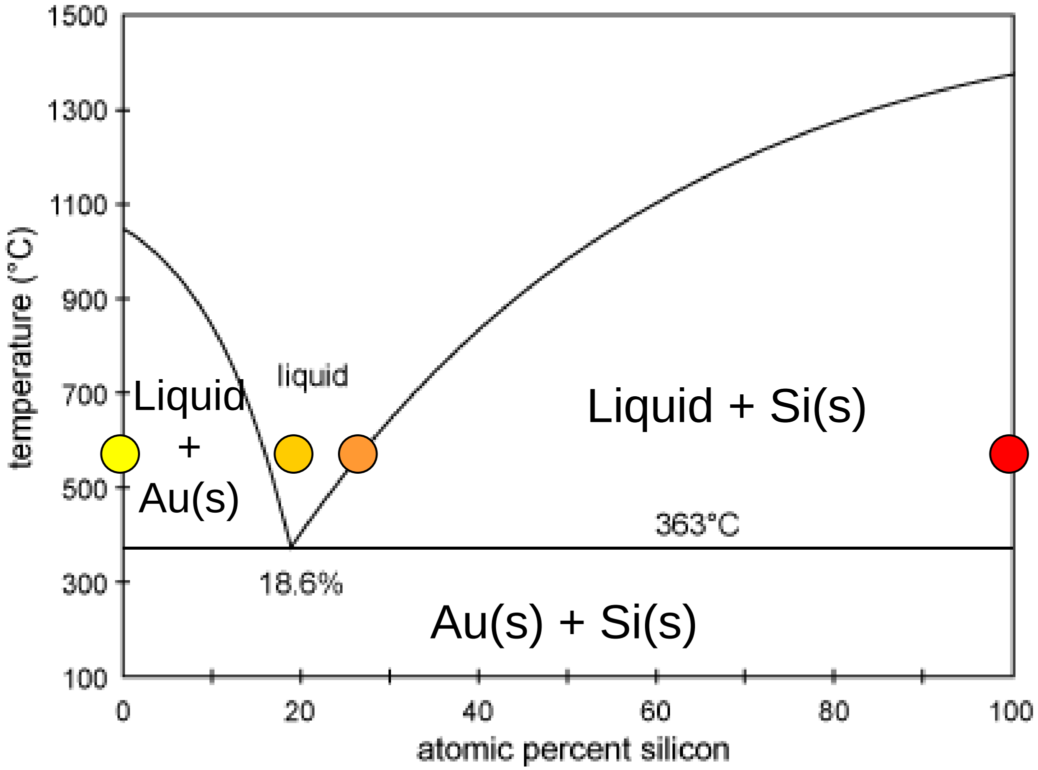
Data storage elements

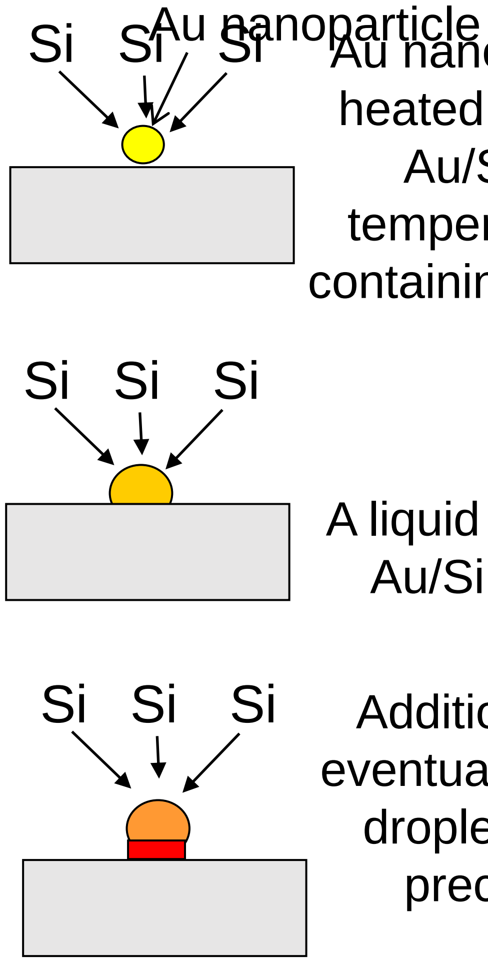


(arrow indicates the direction of magnetization)

Vapor liquid solid (VLS) growth to make nanostructures

Vapour-liquid-solid growth of nanowires: Concept



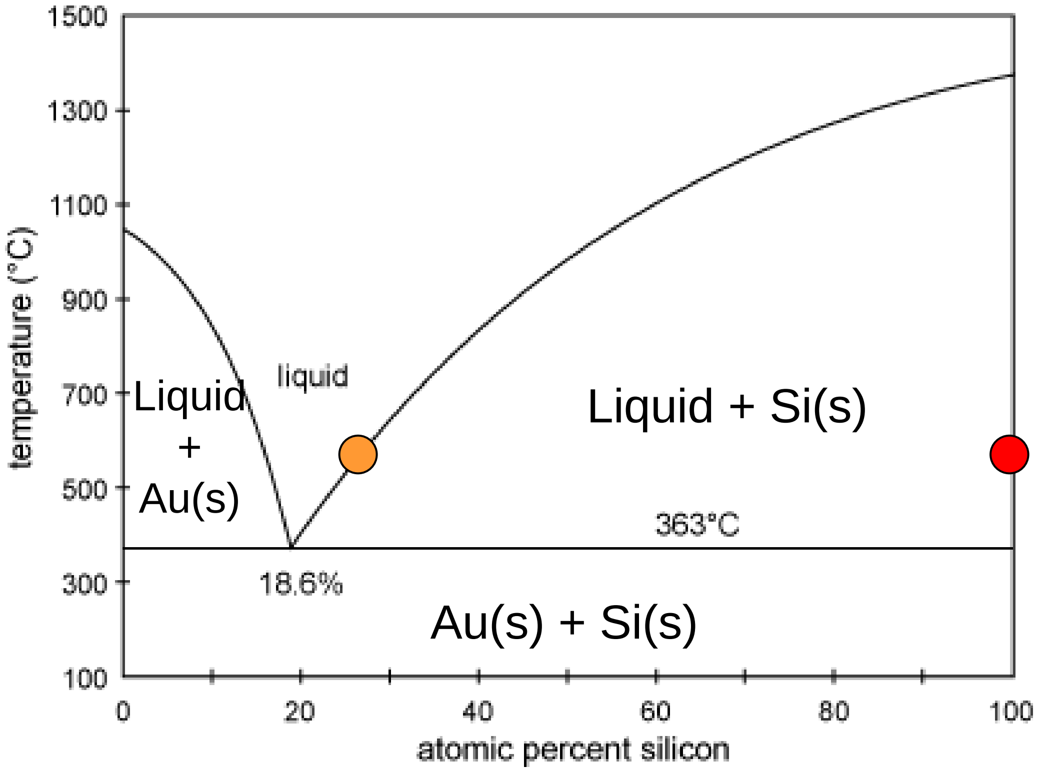


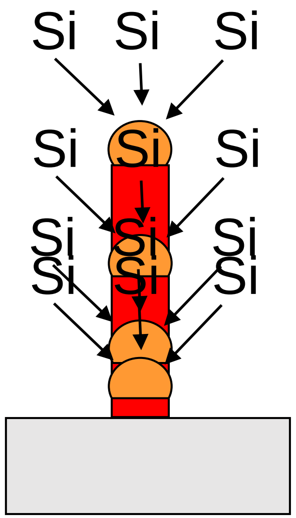
Au nanoparticles are heated to above the Au/Si eutectic temperature in a Si containing atmosphere

A liquid droplet of the Au/Si alloy forms

Addition of further Si eventually saturates the droplet, and solid Si precipitates out.

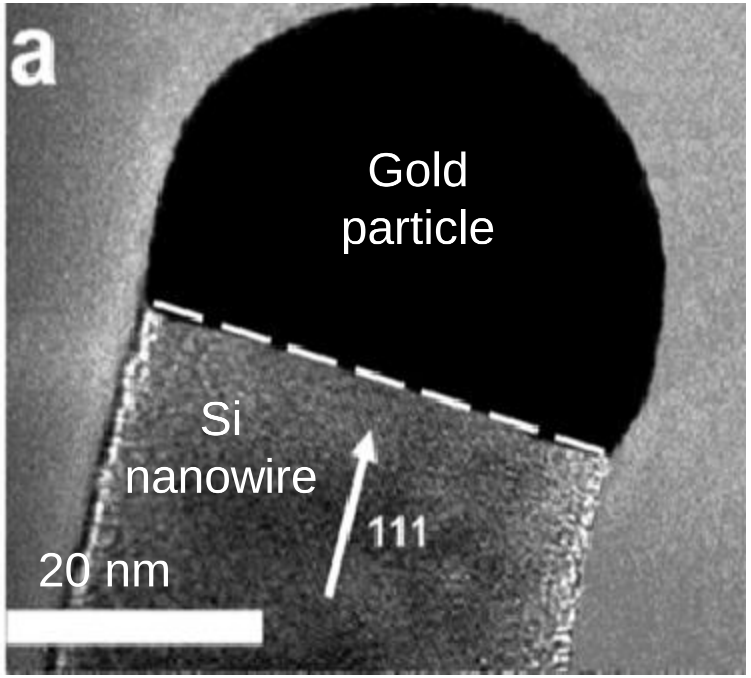
Vapour-liquid-solid growth of nanowires: Concept





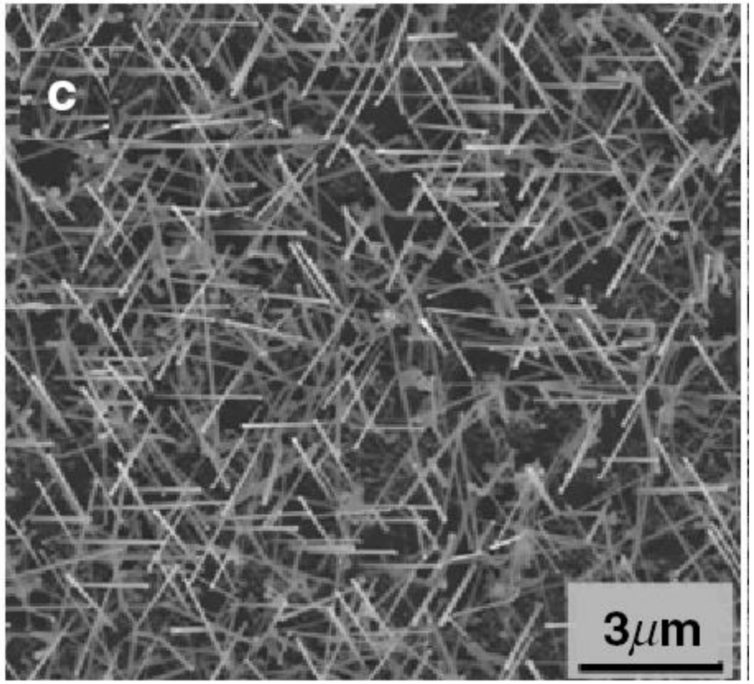
As more Si is added to the droplet, it then precipitates out at the existing solid-liquid interface, so the Si nanocrystal extends, forming a nanowire.

Vapour liquid solid growth of nano-wires: Examples



HRTEM image showing a gold nanoparticle at the end of a Si nanowire after growth

Lu and Lieber, J. Phys. D: Appl. Phys. **39,** R387 (2006)

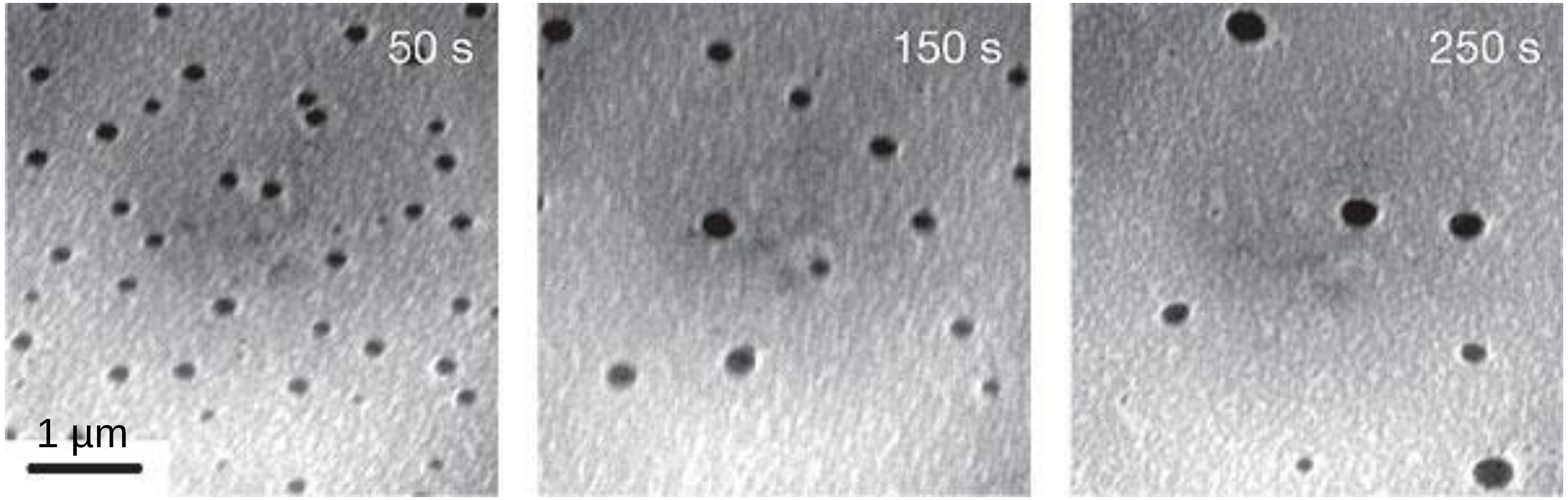


Array of Si nanowires grown using gold nanoparticles on a Si(111) surface

Stelzner *et al.* Nanotechnology **17,** 2895 (2006)

How do we get the Au nano particles?

- Various different methods have been explored.
- Most commonly a thin layer (e.g. 2 monolayers) of gold is deposited on a Si surface and heated in vacuum at ca. 600 °C.
- Dewetting of the surface by the film occurs and gold nanoparticles are formed

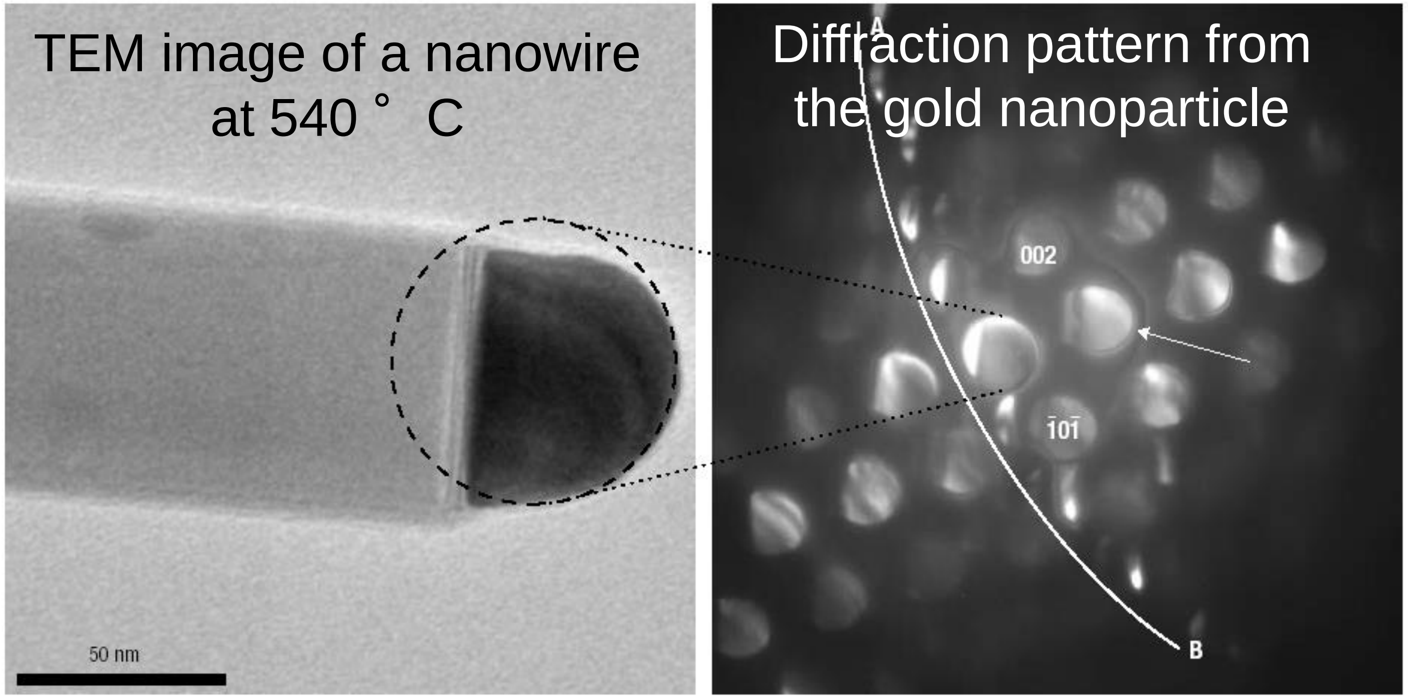


Low energy electron microscopy images of the evolution of gold nanoparticles on Si during annealing

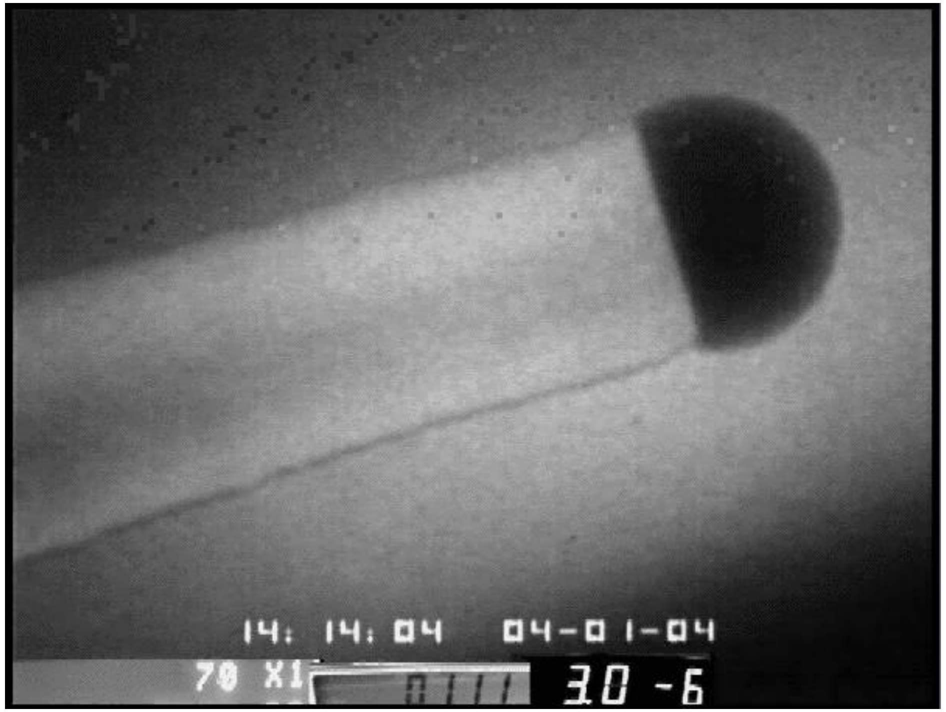
J. B. Hannon *et al.* Nature **440**, 69 (2006)

Challenges to the VLS model

Persson *et al.* (Nature Materials **3,** 677 (2004)) heated a nanowire to the temperatures used in growth *in situ* in a TEM, and took a selected area diffraction pattern from the gold nanoparticle at its apex. A clear diffraction pattern of a crystalline material was seen, leading them to suggest that the nanoparticles may be solid during nanowire growth.



Watching VLS growth as it happens

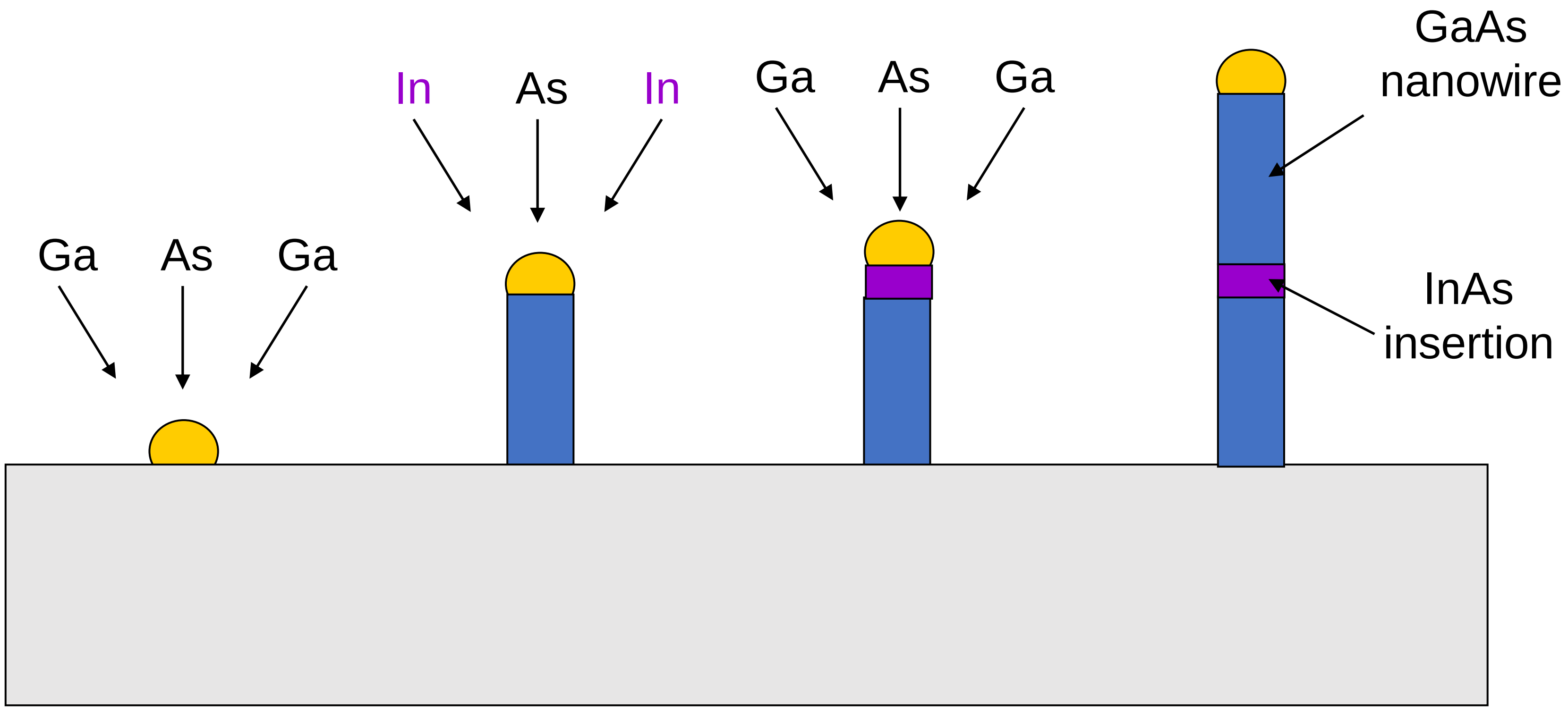


Video courtesy of Dr Frances Ross and IBM

- Frances Ross and her colleagues at IBM were able to image nanowires in the TEM during the VLS growth process.
- They saw that during the growth process the vast majority of catalyst particles were liquid.
- Solid catalyst particles were sometimes seen and exhibited facets. Nanowires with solid catalyst particles grew very slowly.

Nanowire heterostructures: 1: Axial heterostructures

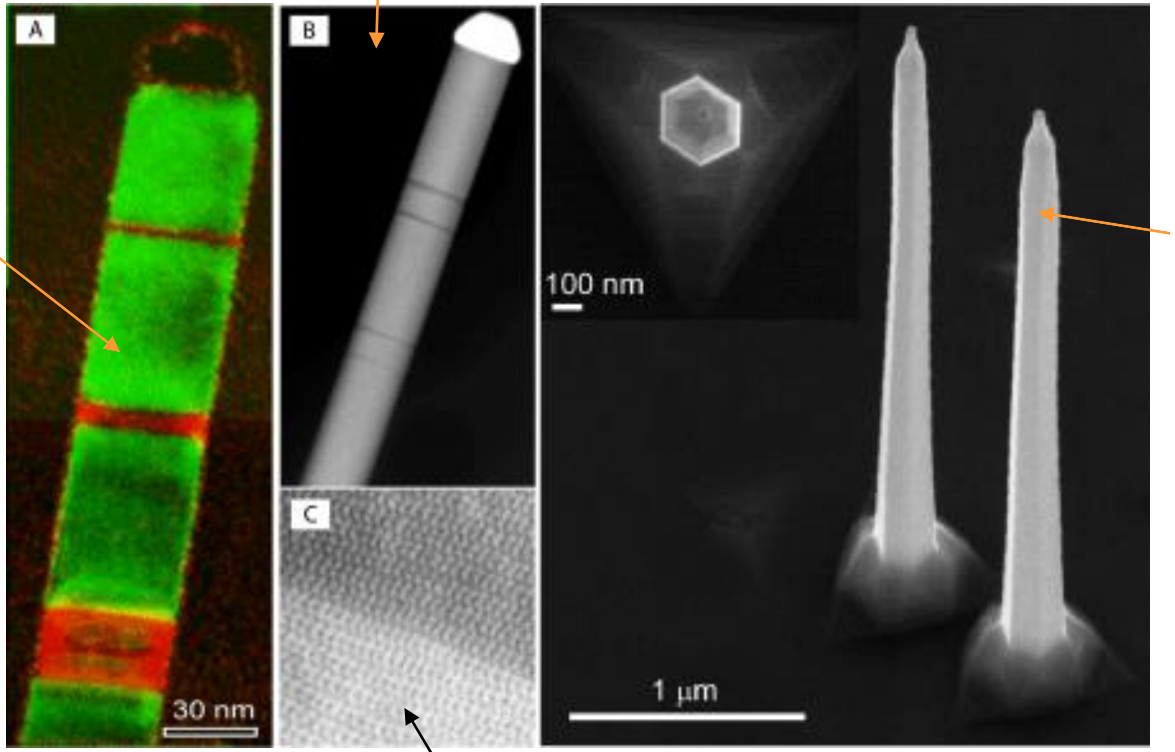
- If a suitable metal nanoparticle “catalyst” is availble for the growth of two different materials, nanowires can be grown which incorporate heterojunctions:



Axial heterostructures: Example

STEM-HAADF
image of a nanowire

Colour coded lattice parameter map of a nanowire: Red = InP, Green = InAs



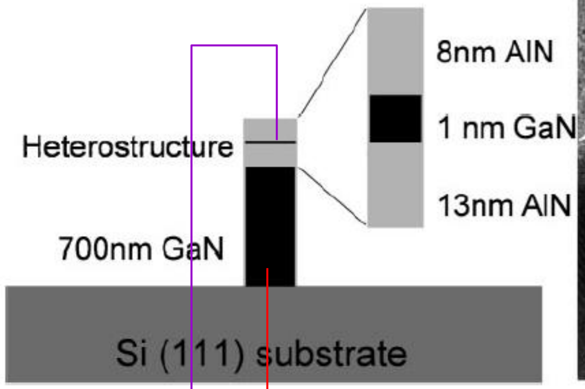
SEM images showing the overall shape of the nanowires

High-resolution STEM image of an InAs (white) /InP (black) interface

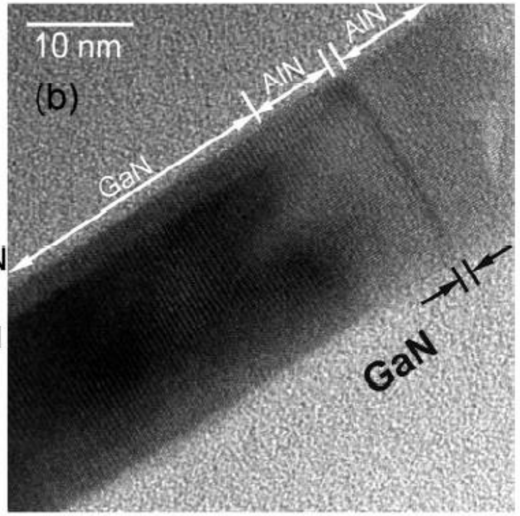
Images from http://www.nano.lth.se/research/epitaxy/project-2

Axial heterostructures:
Thin inclusions in nanowires as quantum dots

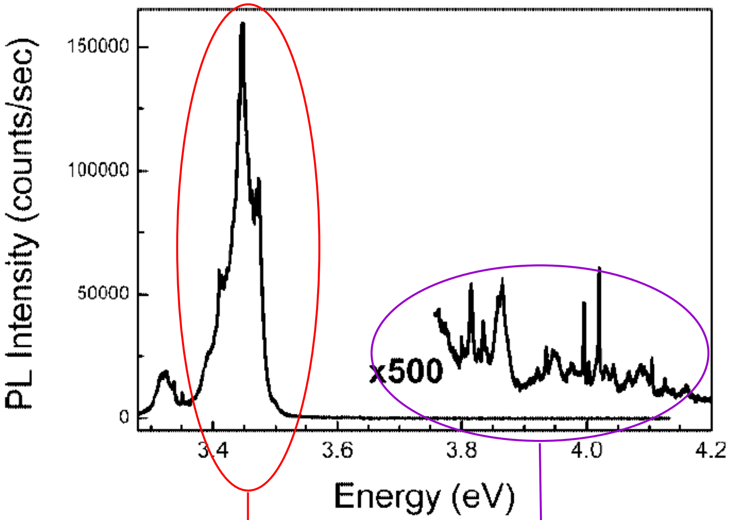
Schematic of GaN/AlN axial heterostructure



HRTEM image of single GaN inclusion



MicroPL data from an ensemble of nanowires



Broad emission from quantum wire region

Sharp lines from quantum dot inclusion; blue shifted due to confinement in smaller region

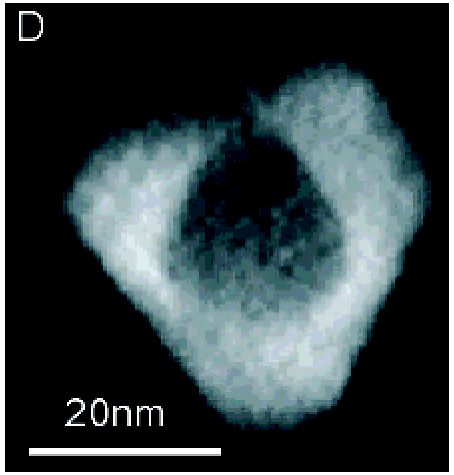
From: Renard *et al.* Nanoletters, **8,** 2092 (2008)

Nano-wire hetero structures: 2: Radial hetero structures

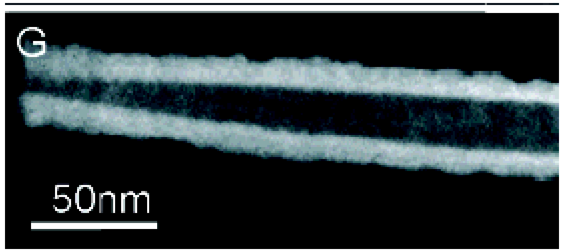
- By altering the growth conditions it is possible to encourage reactants to stick to the nanowire surface, rather than depositing via the metal droplet at the apex.

- If a wider bandgap material is deposited around a narrow bandgap material, this can give rise to better optical and electrical properties, since carriers will be confined in the inner region, reducing the influence of surface states.

These images are extracted from a TEM tomographic (3D) reconstruction of a nanowire with a GaAs shell and a GaP core.



Slice perpendicular to nanowire axis



Slice parallel to nanowire axis

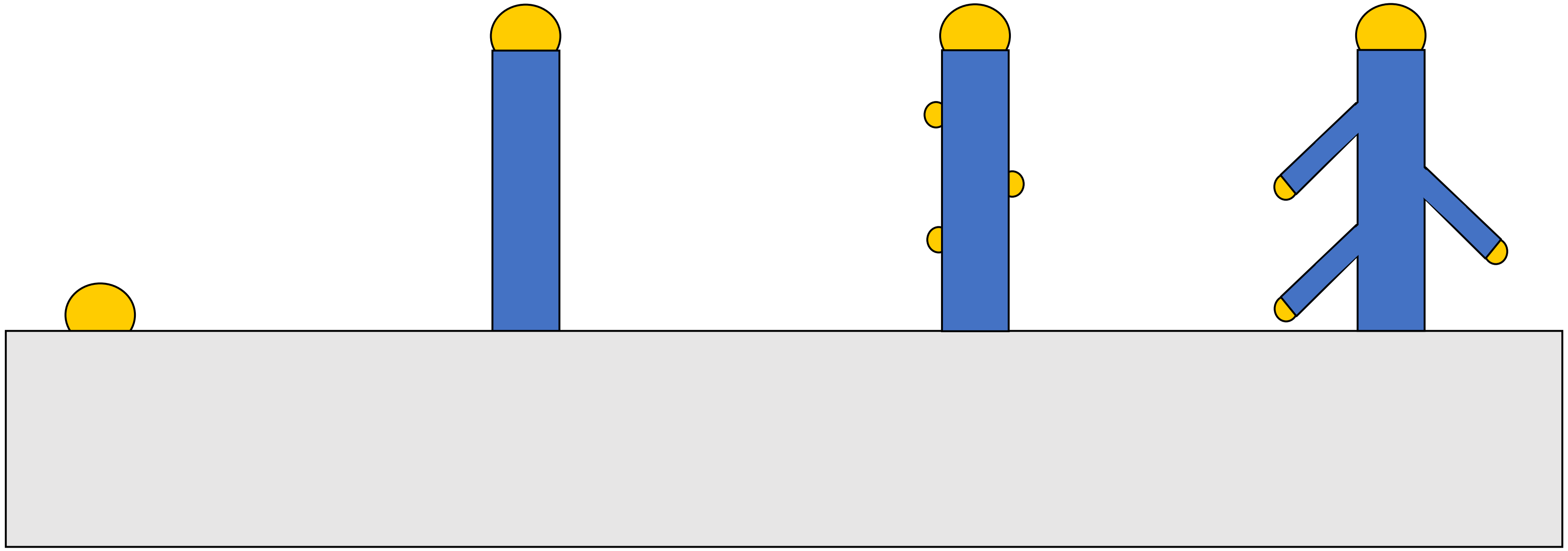
Branched nanowires

Catalyst particle deposition

Reactants for nanowire growth introduced

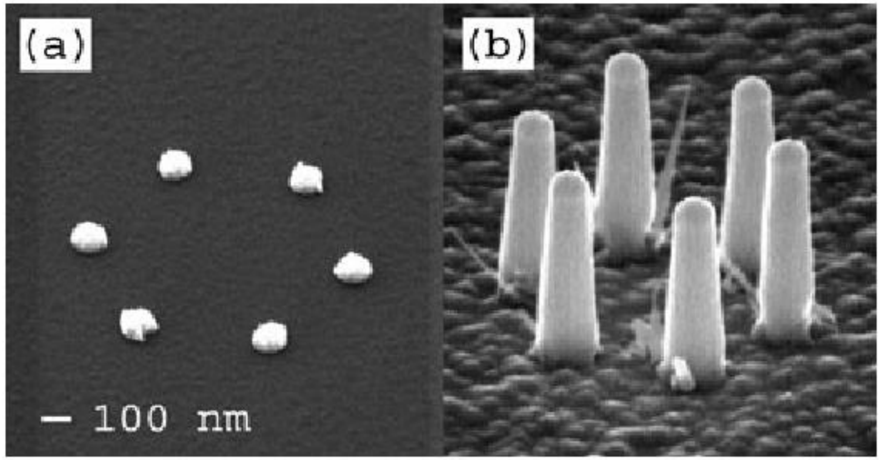
Deposition of further catalyst material

Further nanowire growth reactants introduced



Site-controlled nanowires

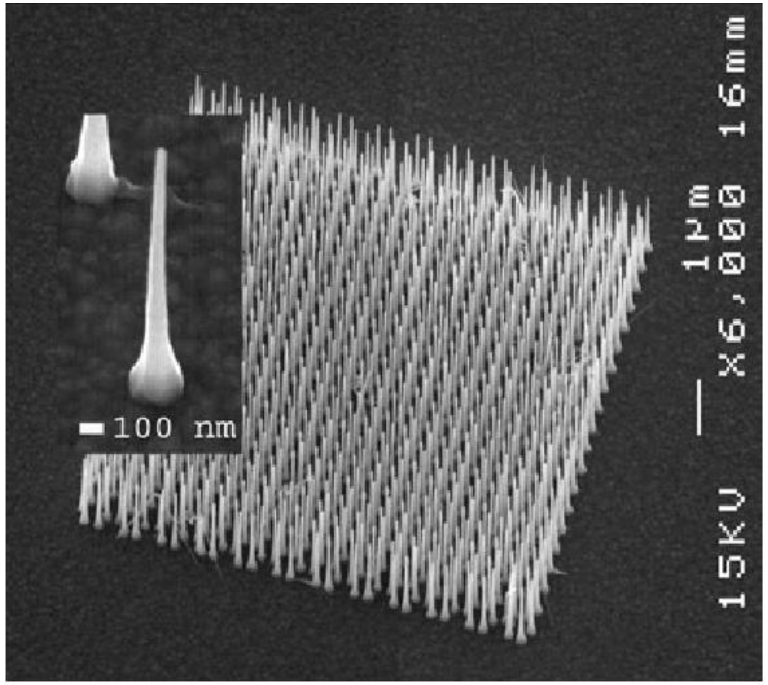
- By defining the positions of the catalyst particles via electron beam lithography or nanoimprinting technology, it is possible to produce an ordered array of nanowires:



Patterned catalyst particles defined by e-beam lithography

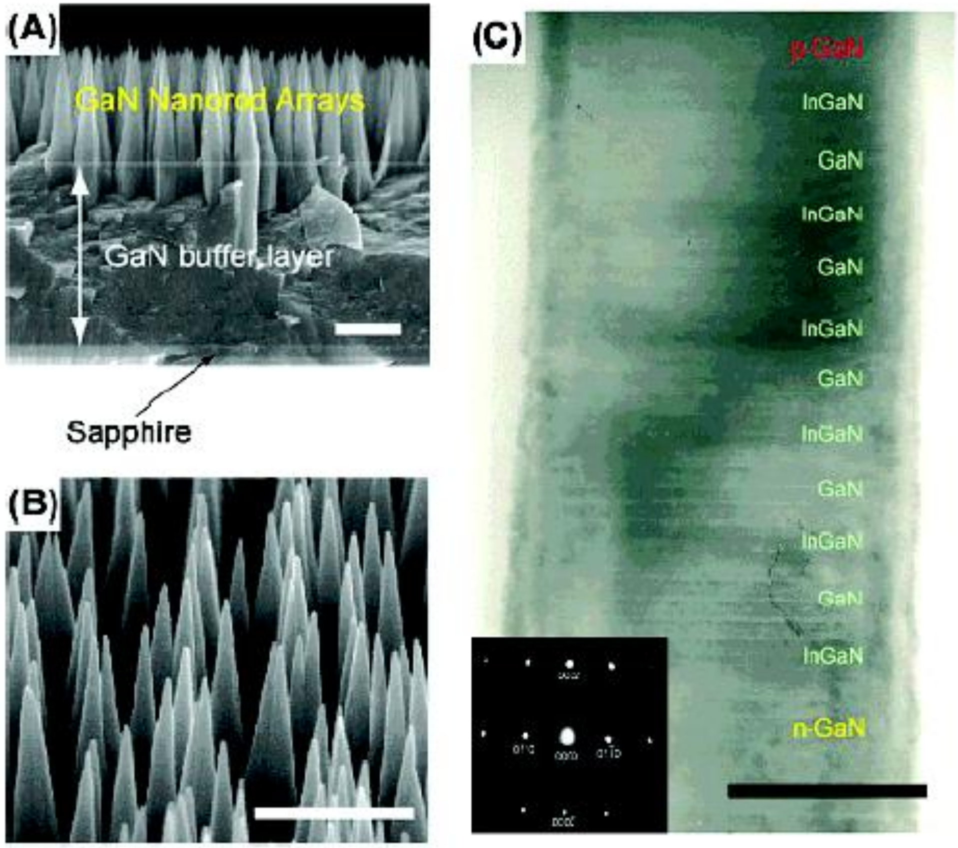
Resulting nanowire pattern

(From Martensson *et al.* Nanotechnology **14,** 1255 (2003))



A larger array of thin nanowires

Example of a potential application of VLS growth: Nanorod LED

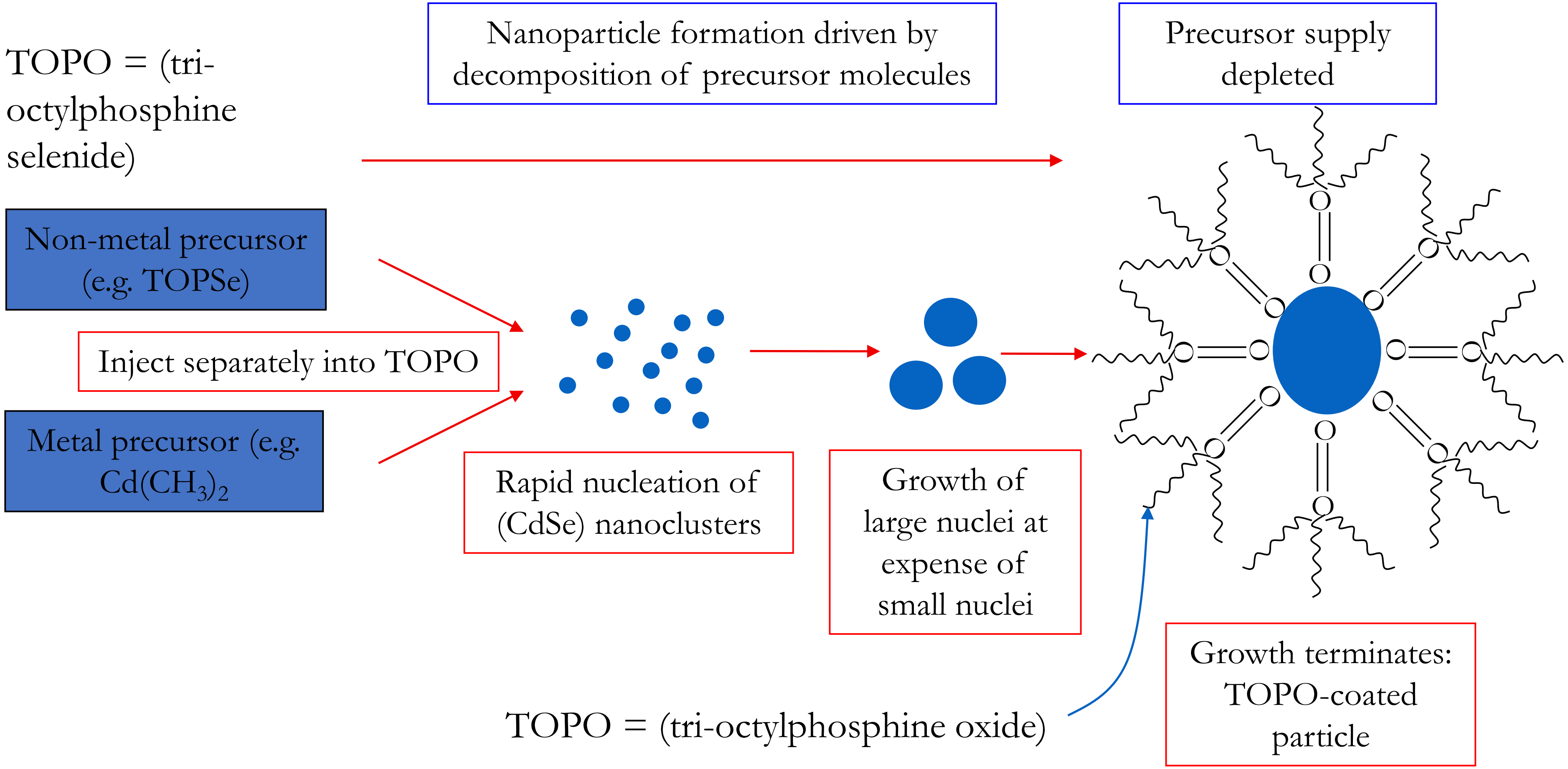


SEM TEM

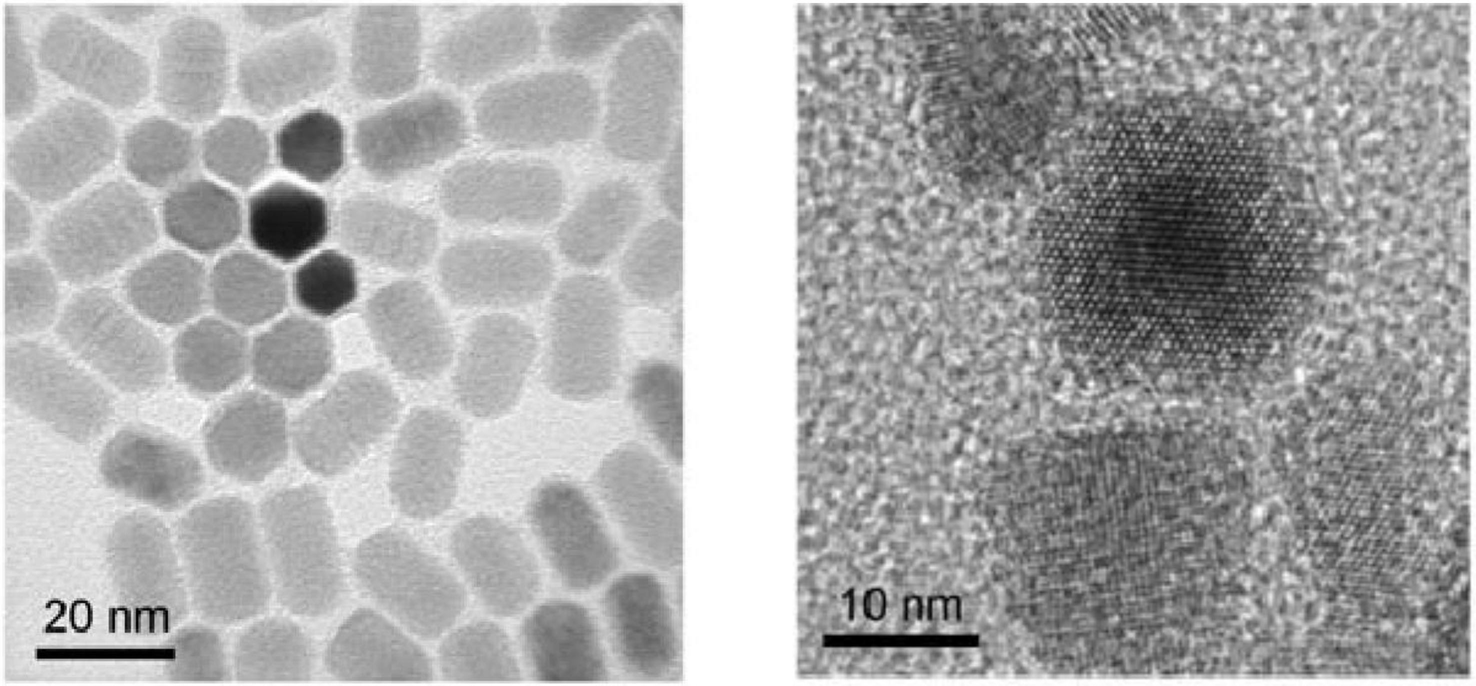
- In GaN, dislocation free nanorods may be grown using an adaptation of the VLS method.
- These nanorods can be doped, to form p-n junctions and InGaN insertions can be included.

(From Kim *et al.* Nano Letters, **4,** 1059 (2004))

Quantum dot self-assembly in solution: Example CdSe



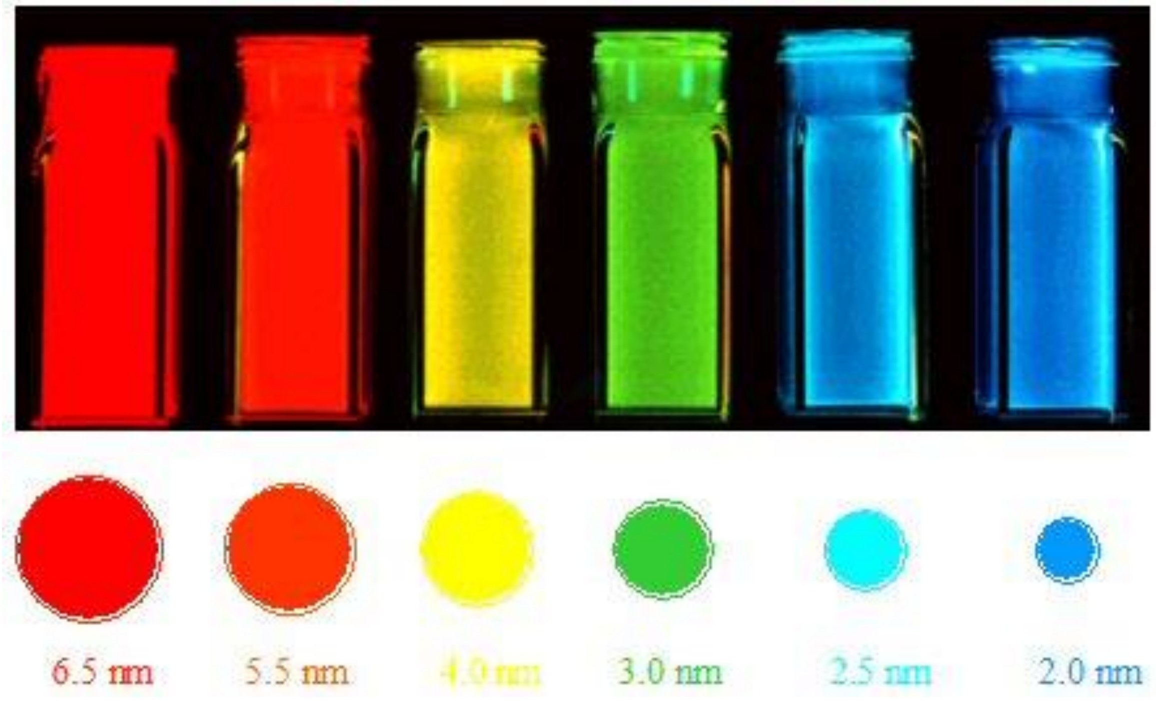
Solution based self-assembly of CdSe nanocrystals: Example



HRTEM images of CdSe nanocrystals

From: Nair *et al.* Small **3**, 481 (2007).

Size dependence of luminescence wavelength



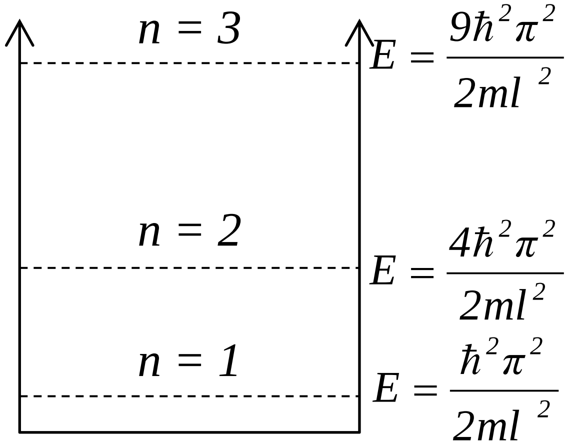
The luminescence wavelength (colour) for the CdSe nanocrystlas is strongly dependent on their size.

http://www.vanderbilt.edu/physics/matphys/research

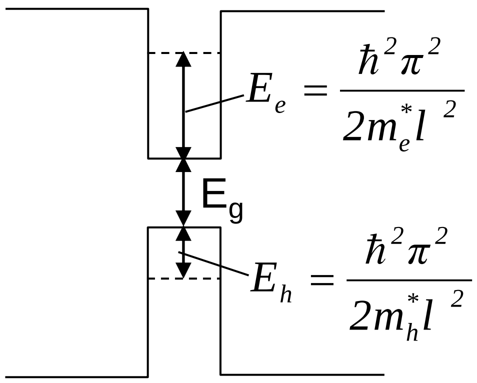
Why does lumine-scence wavelength depend on size?

- Energy of n = 1 state in a quantum dot varies as $1/l^2$, where l is the dot size.

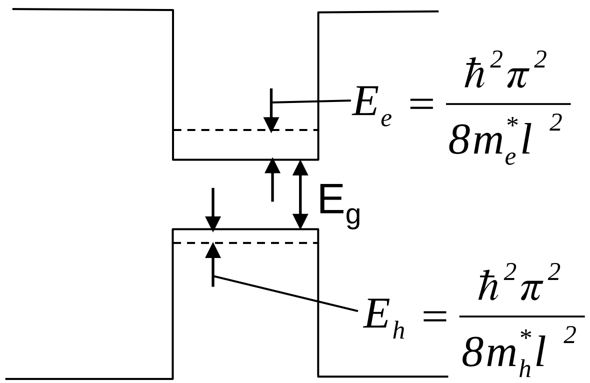
The energy levels vary in a similar way to the energy levels in an infinite potential well:



Particle size = l

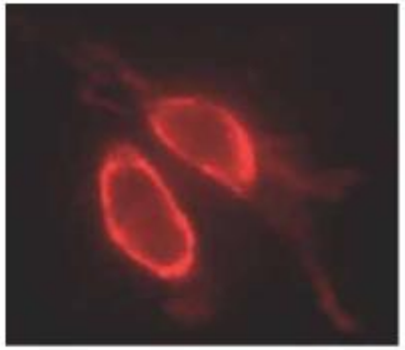


Particle size = $2l$

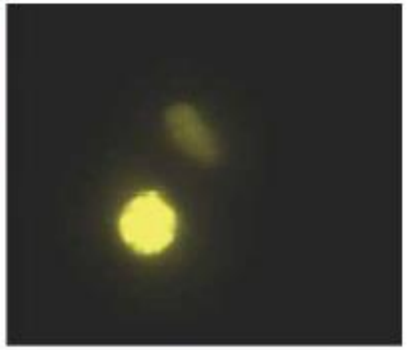


Applications of nanocrystals grown by solution methods: Example 1

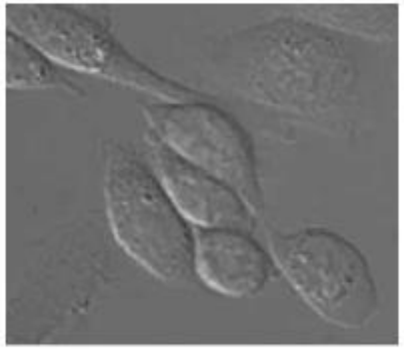
- Nanocrystals can be used a fluorescent tags which bind to biological molecules and can be used to track the binding of those biological molecules to cells or parts of cells.



Luminescence from QD tags



Luminescence from conventional molecular tags

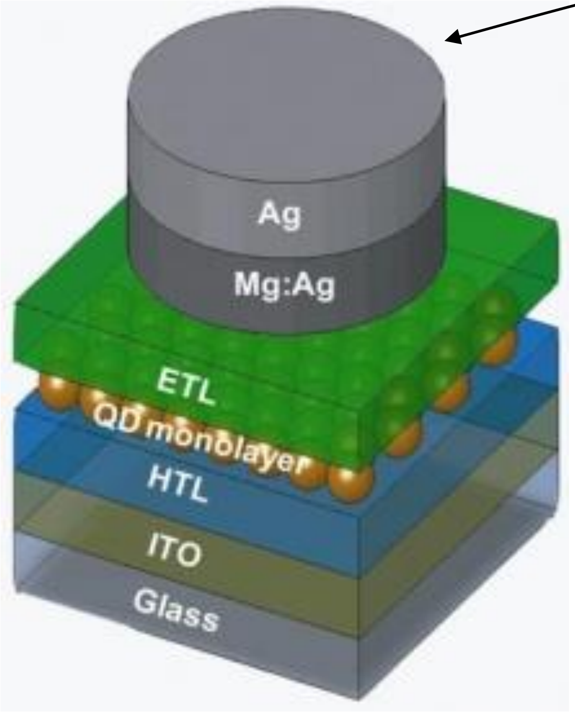


Light micrograph showing all cells

Howarth *et al.* (Nature Methods **5,** 397 (2008)) used QD tags to highlight cells which express a particular peptide. The QDs were shown to highlight the same cells as more conventional tagging methods, but were better distributed throughout the cell, showing the extent of peptide distribution.

Applications of nanocrystals grown by solution methods: Example 2

- Solution-grown nanocrystals may be incorporated into light emitting diodes, for white or coloured light emission.



- Design for an LED based on nanocrystals.
- ETL = electron transport layer
- HTL = hole transport layer
- ITO = indium tin oxide
- Emission at different wavelengths can be achieved using different dot sizes. A mixture of dot sizes gives white light.