

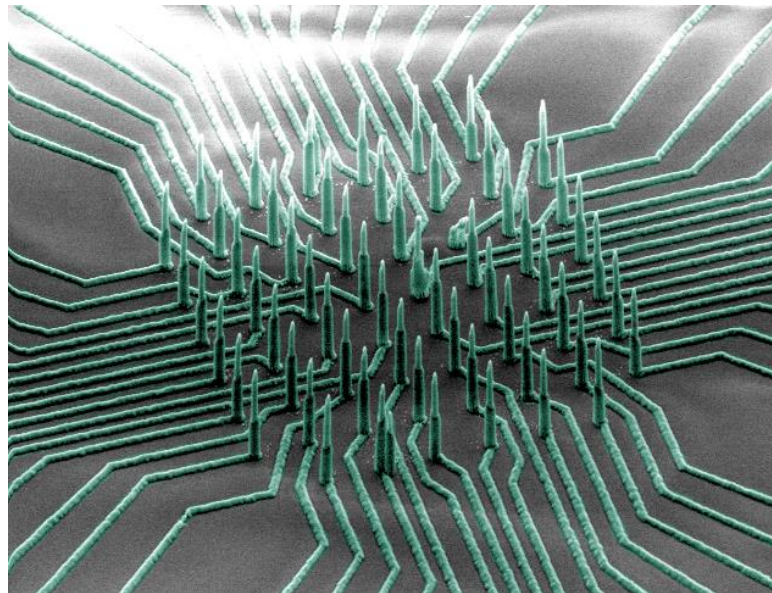
Session 10b

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/>

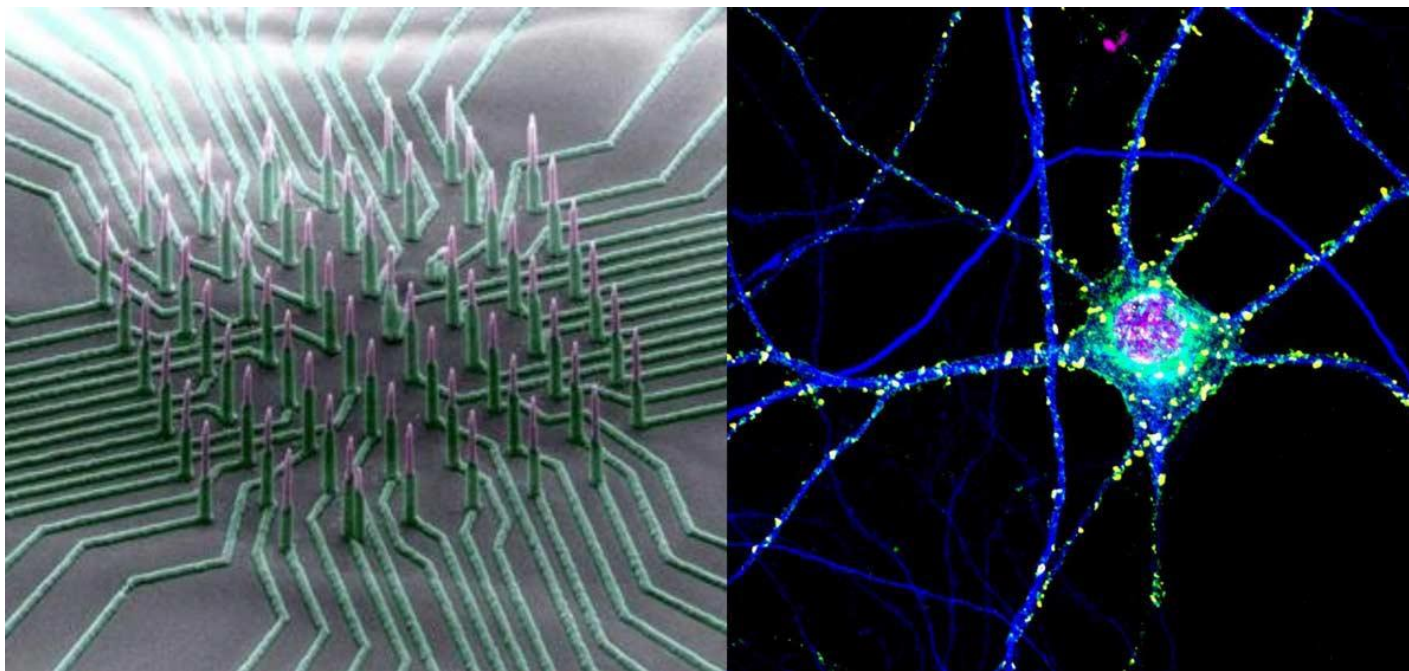
The Global Nanowires market report details in-depth past and present analytical and statistical data about the global Nanowires market. The report describes the Nanowires market in detail in terms of the economic and regulatory factors that are currently shaping the market's growth trajectory, the regional 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



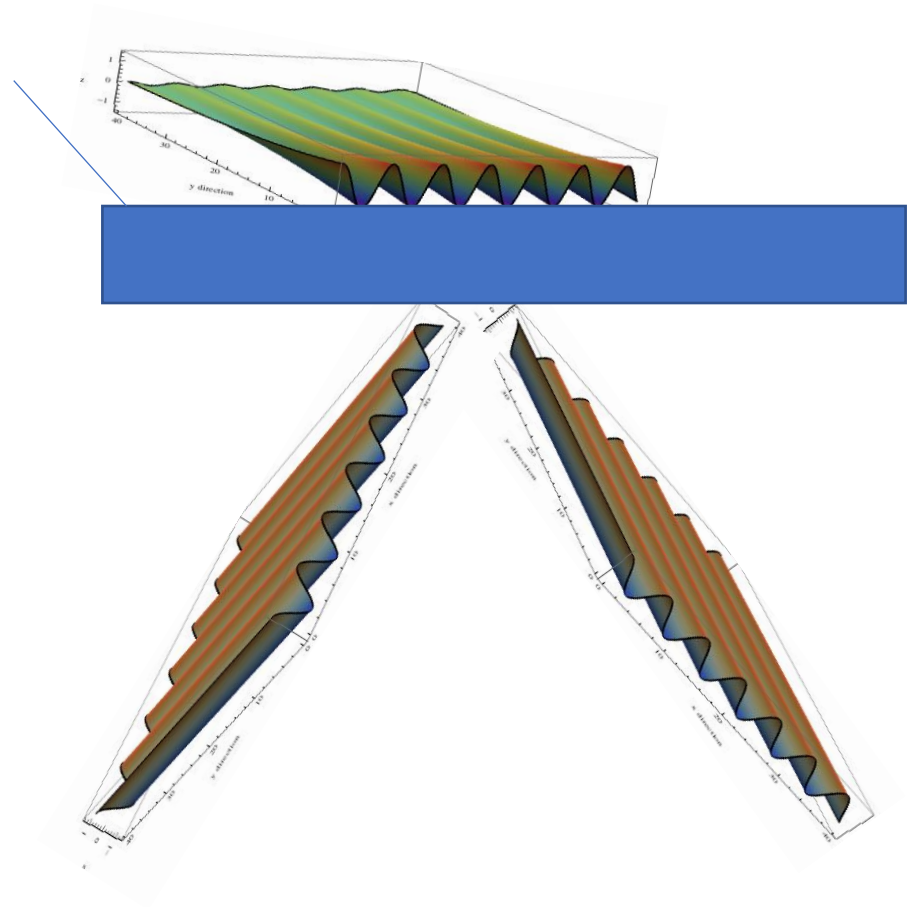
To examine a neuron's health, activity and response to drugs, scientists record its electrical activity. Current methods of recording are destructive, so they can only be used to study a neuron for a brief period, and can only measure the activity of one cell at a time. But neurons don't function individually—they 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.

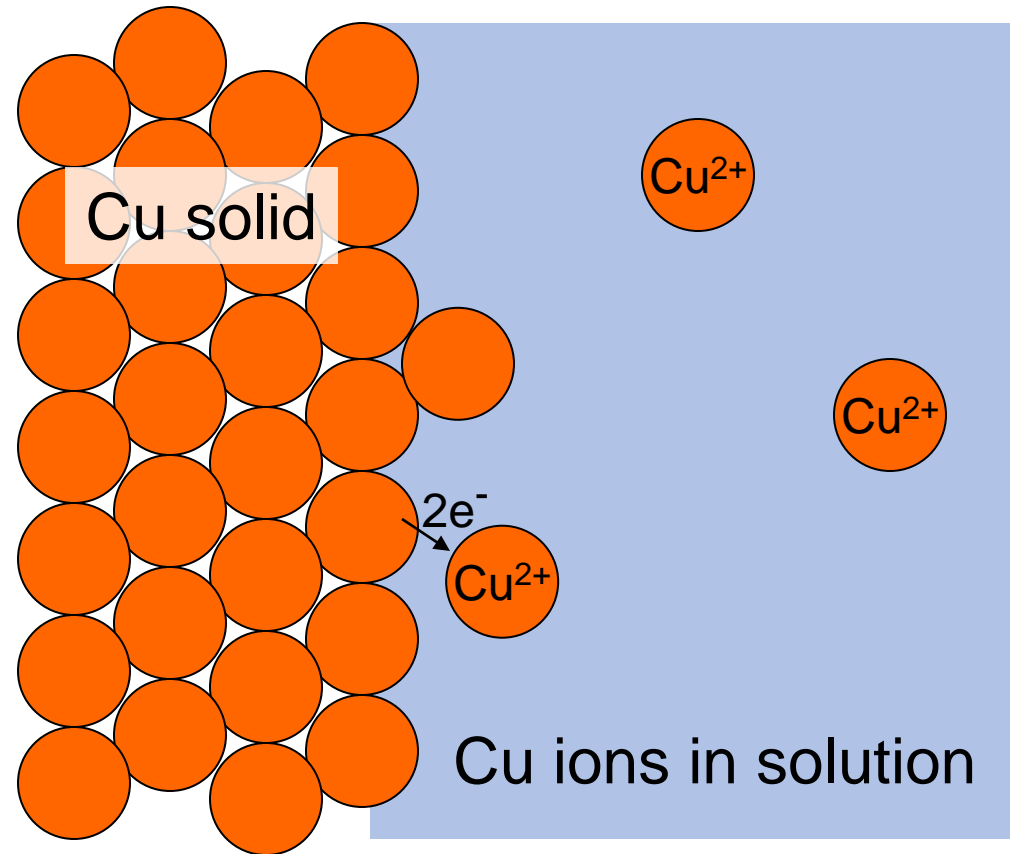
Neurons interfaced with the nanowire array survived and continued functioning for at least six weeks.



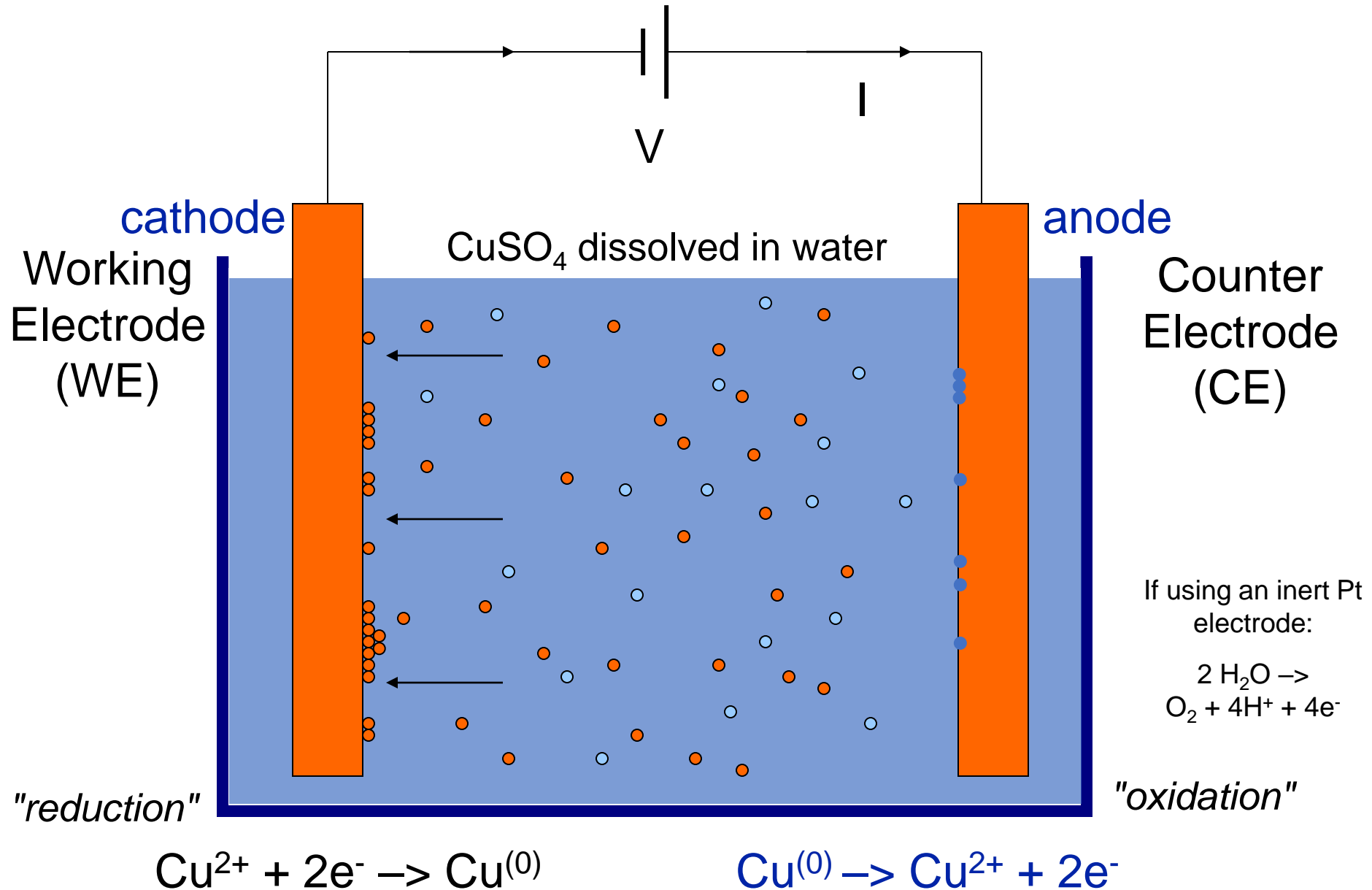
Electroplating to make nanostructures

Electroplating

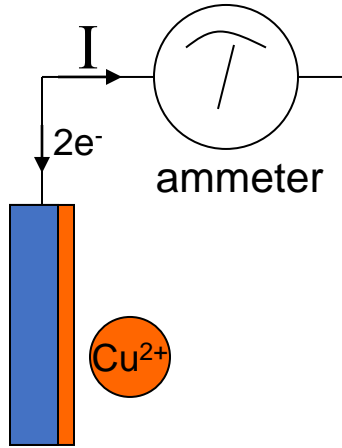
- The chemical conversion of ions in solution into a solid deposit of metal atoms with the work of a electrical power supply



Electroplating Cell



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

$$I = \frac{dq}{dt} \quad Q = \int_0^t I dt = It \quad \text{If } I \text{ is constant}$$

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

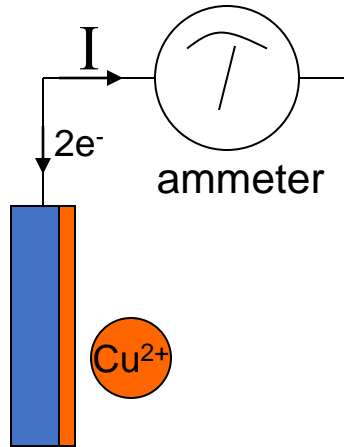
$$\# \text{ atoms} = \# \text{ electrons}/z = It/ez$$

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

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

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

Amount of Deposition (cont.)



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

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

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

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

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, $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$. CE must be determined by an independent measurement.

Why choose electroplating to make nanostructures??

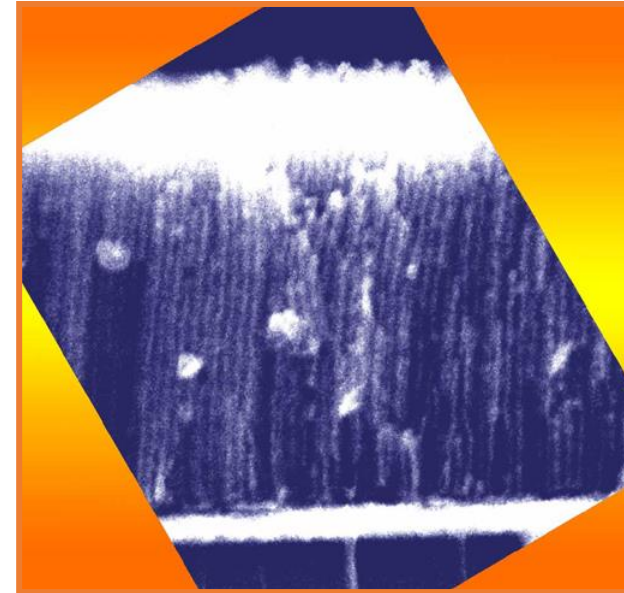
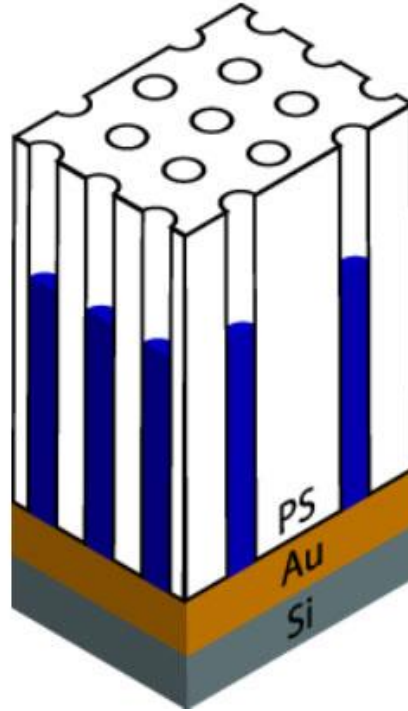
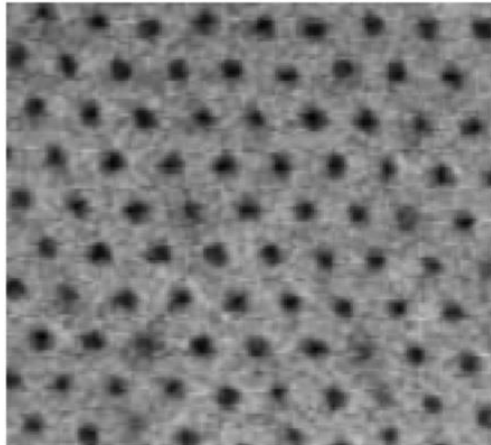
The process is easy to operate and only needs simple equipment.

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

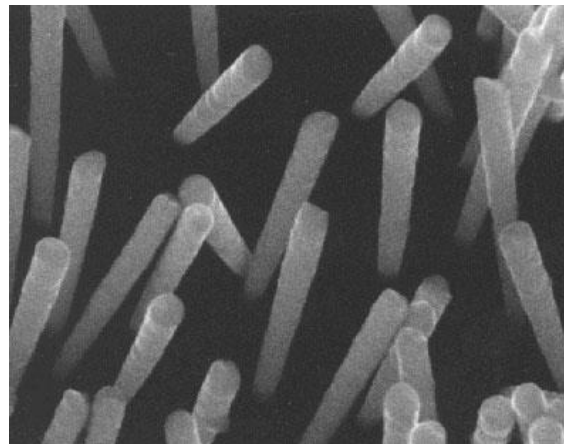
It's a good way to make Nanowires in a porous template.

Electrodeposited Nanowires

nanoporous template



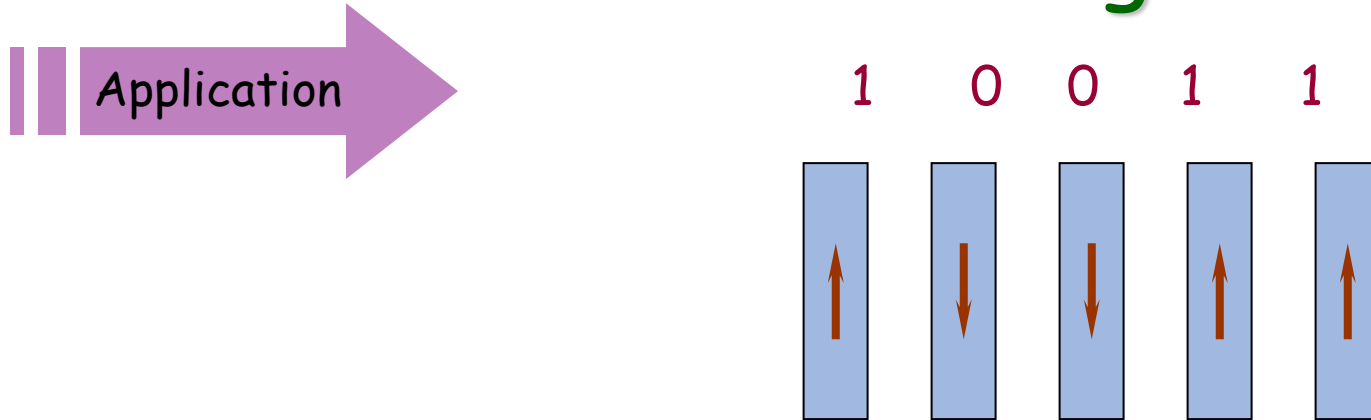
nanowires
in a
polycarbonate
filter



nanowires
in a diblock
copolymer
template

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

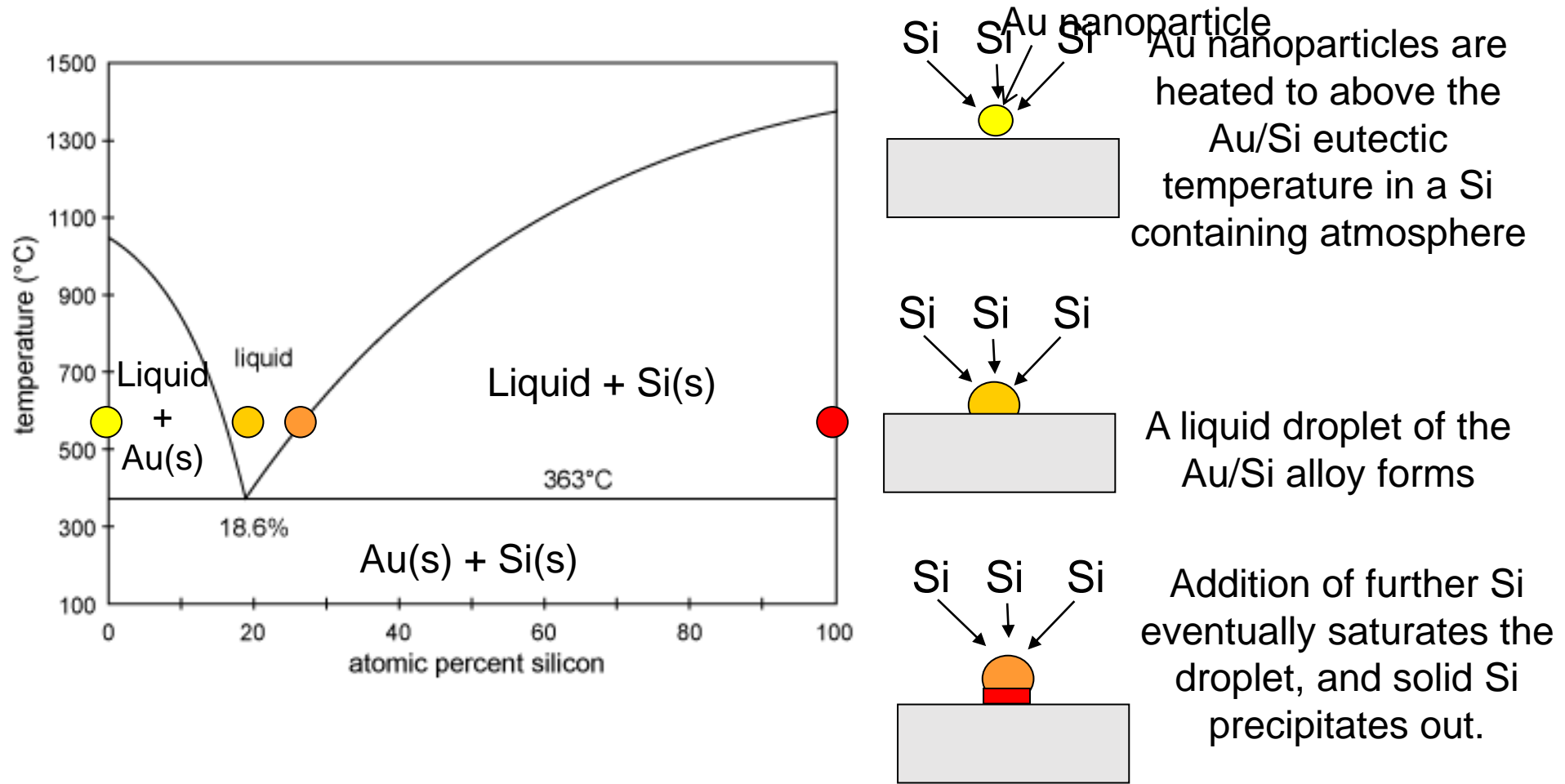
Data storage elements



(arrow indicates the direction of magnetization)

Vapor liquid solid (VLS) growth to
make nanostructures

Vapour-liquid-solid growth of nanowires: Concept



"Vapor-Liquid-Solid Mechanism
of Single Crystal Growth"
Appl Phys Lett 4, 89 (1964)

Vapour liquid solid mechanisms

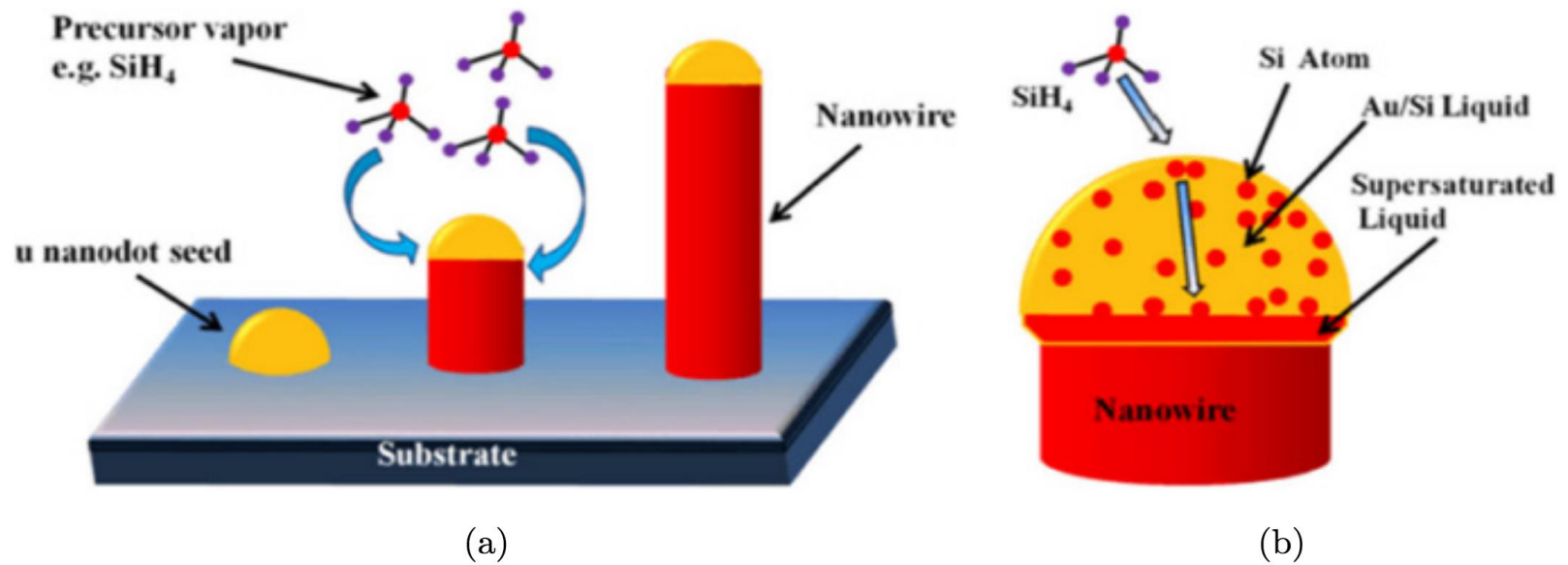
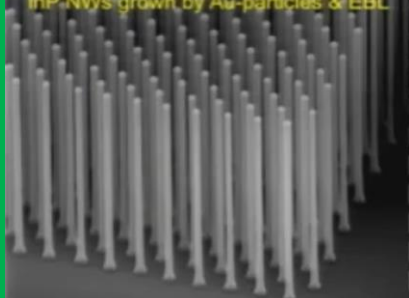
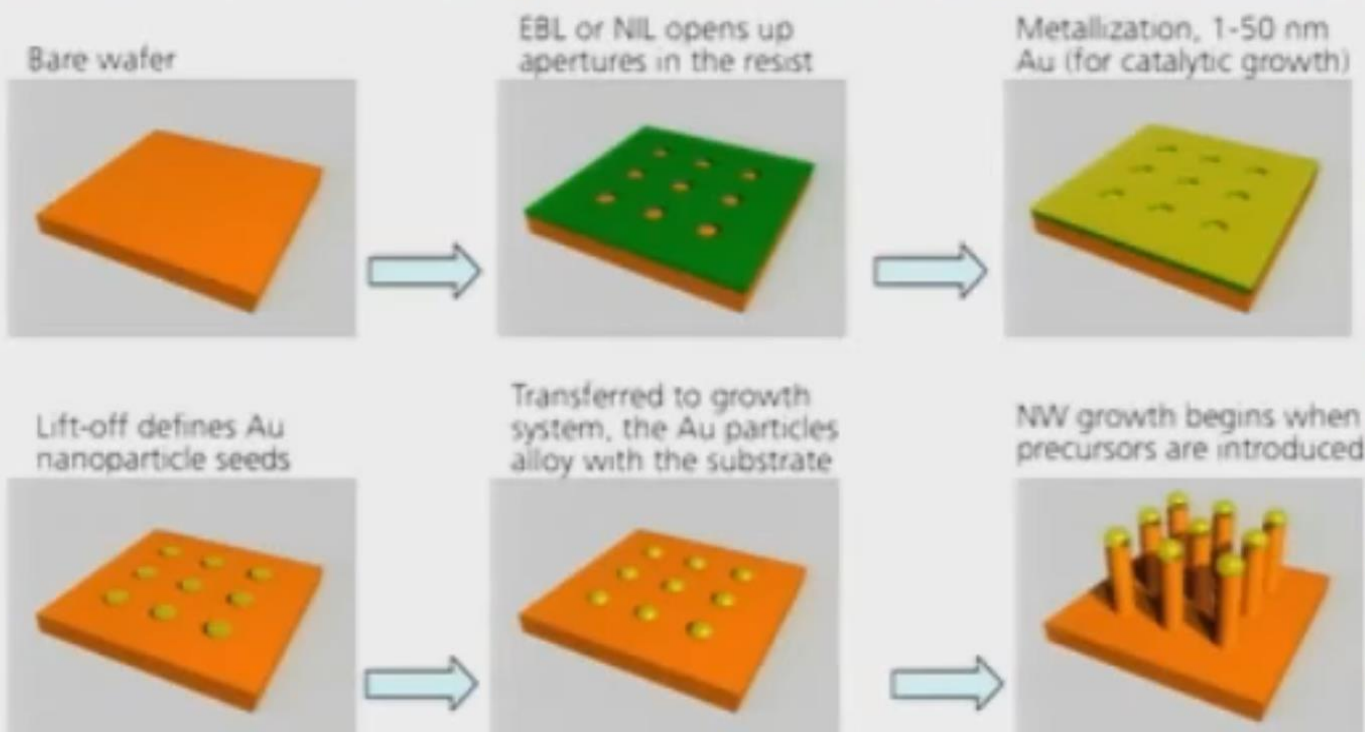


Fig. 1. Vapor–liquid–solid mechanism for nanowire synthesis, (a) schematic of VLS growth of Si NW from a liquid Au catalyst seed, which floats on top of the NW as it grows. (b) Enlarged view illustrating the kinetic steps for NW growth. Reprinted with permission from Ref. 42. Copyright 2010 Chemical Reviews.



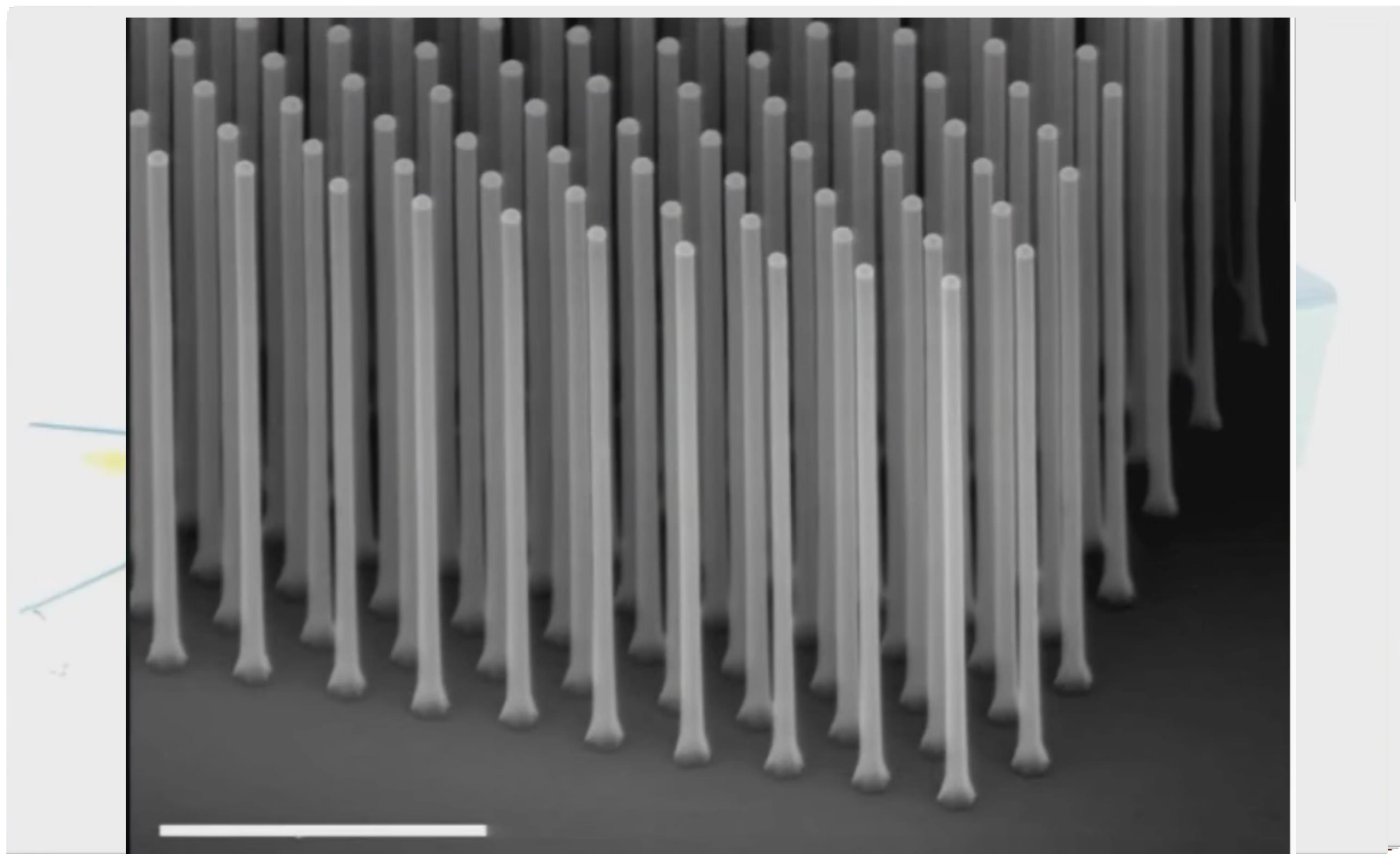
Site control & morphology of NW growth induced by Au patterns or via selective area growth in small mask openings, created either by electron-beam lithography (EBL) or by nanoimprint lithography (NIL):



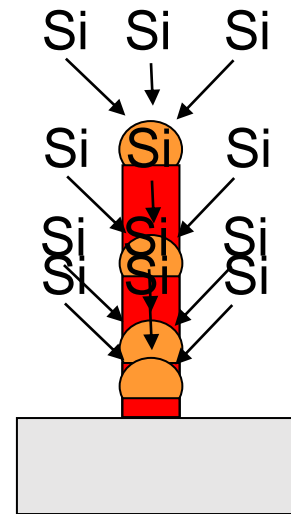
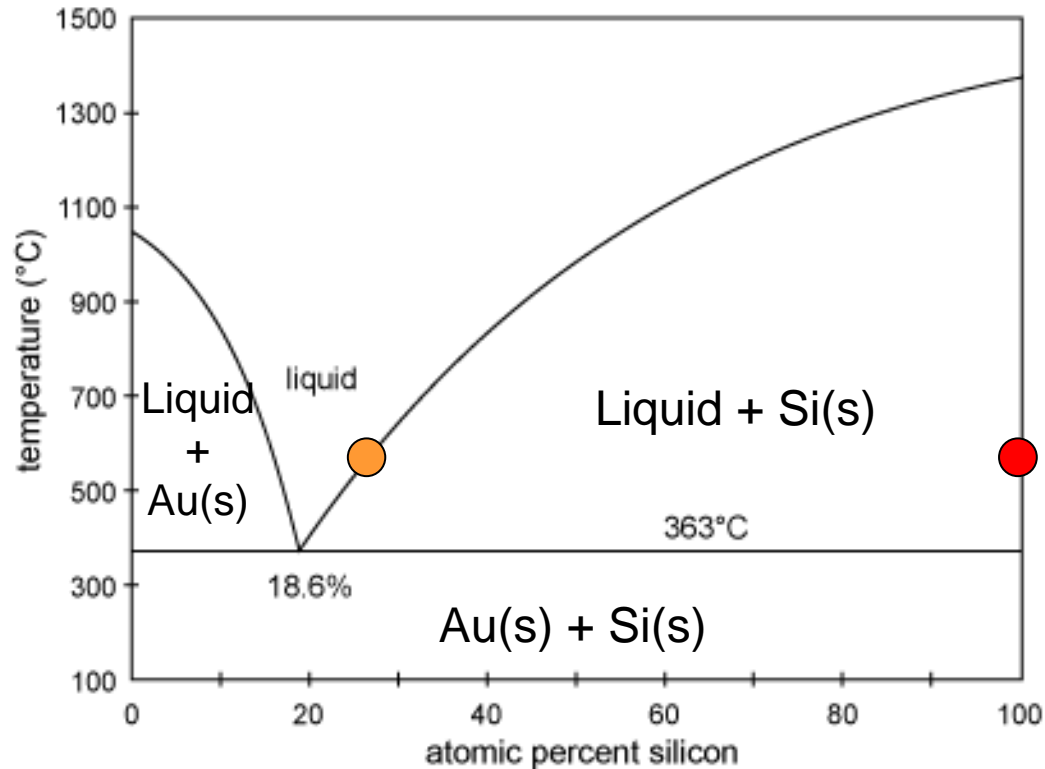
For details of EBL- and NIL-defined nanowire arrays, see for instance:

T. Mårtensson et al., "Fabrication of individually seeded nanowire arrays by VLS growth", *Nanotechnology* 14, 1255 (2003)

T. Mårtensson et al., "Nanowire arrays defined by nanoimprint lithography", *Nano Letters* 4, 699 (2004)



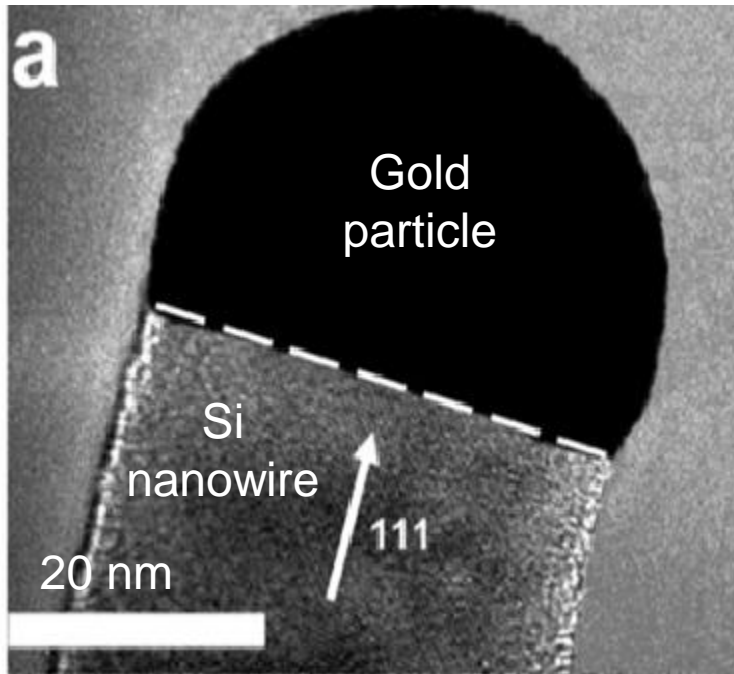
Vapour-liquid-solid growth of nanowires: Concept



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.

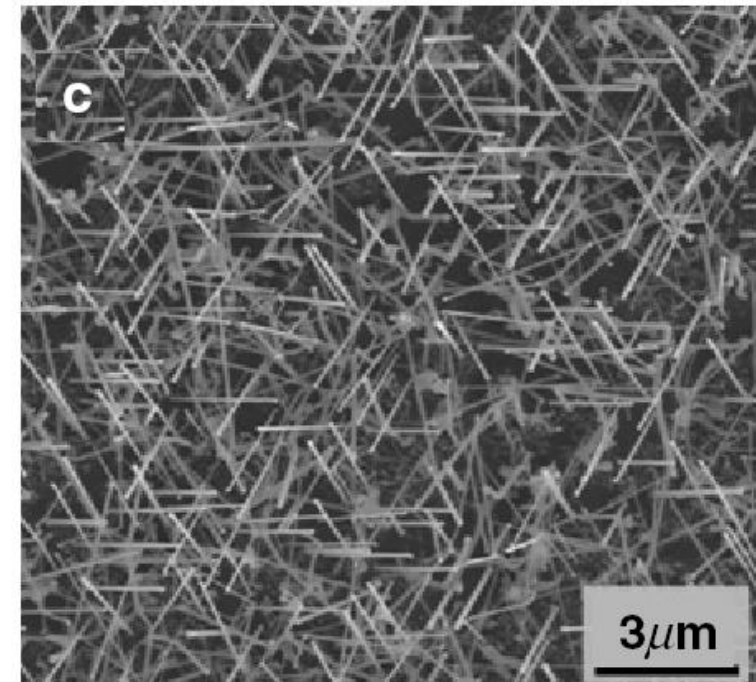
<https://youtu.be/AS06F4YwvnM>

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)

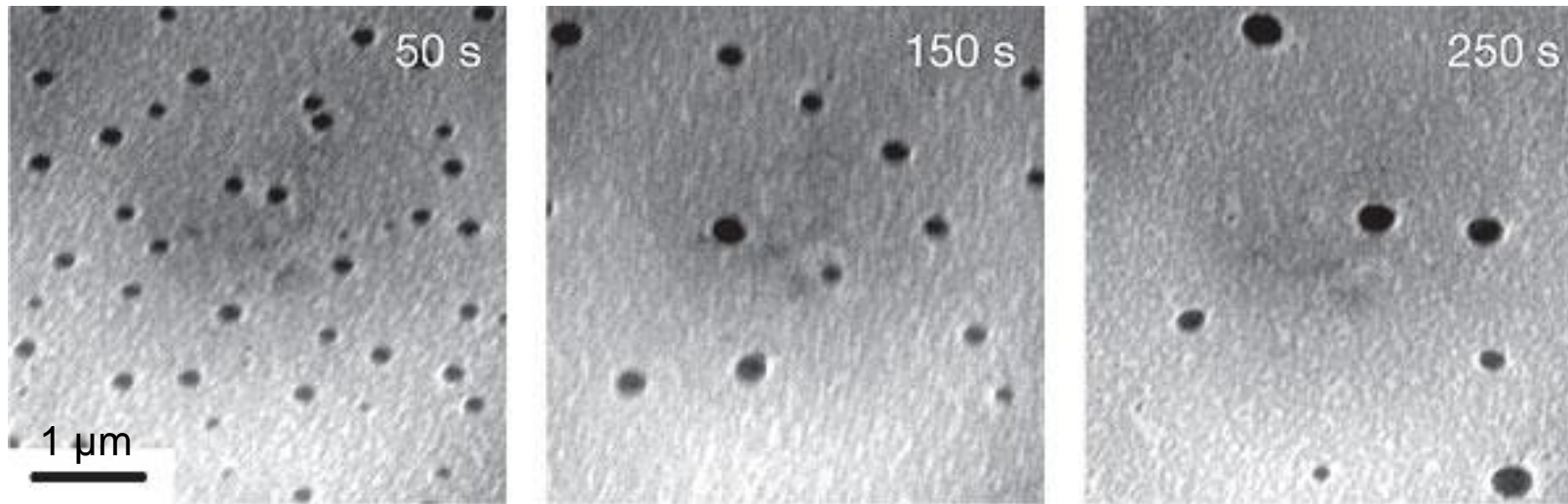


Array of Si nanowires grown using gold nanoparticles on a Si(111) surface

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

How do we get the Au nanoparticles?

- 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

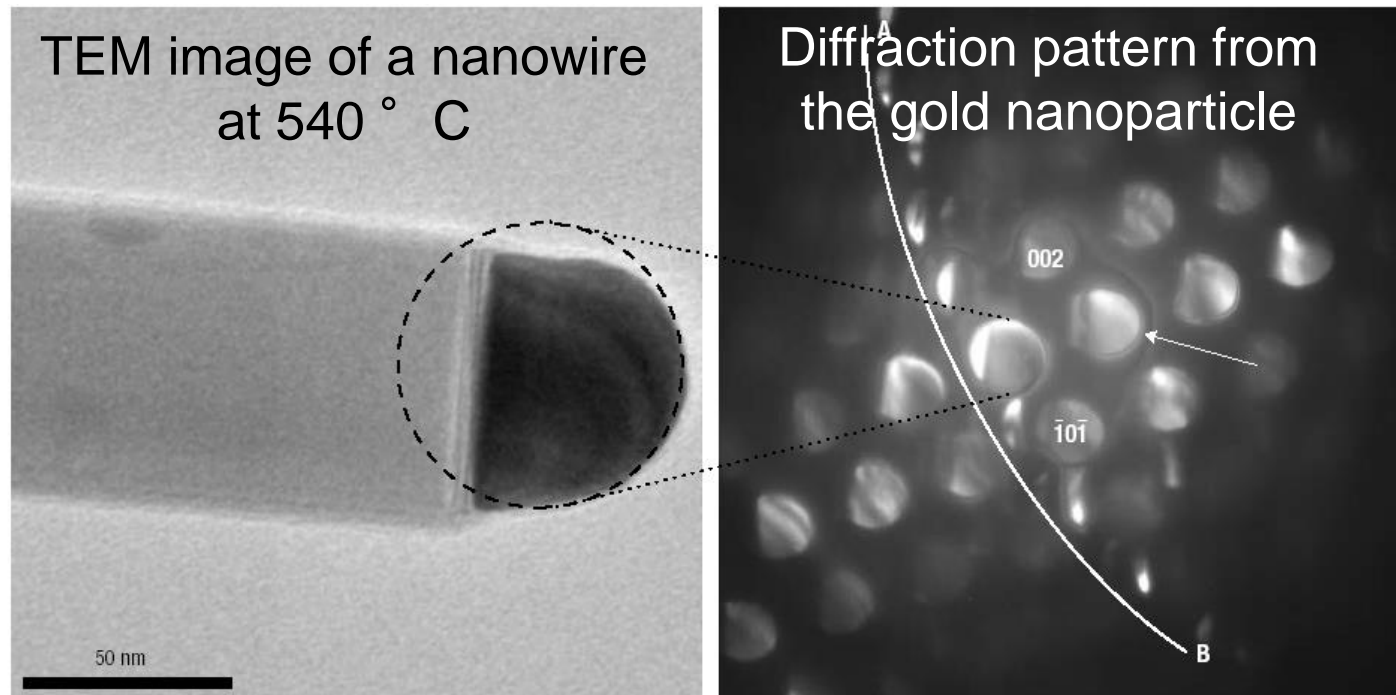


Low energy electron microscopy images of the evolution of gold nanoparticles on Si during annealing

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

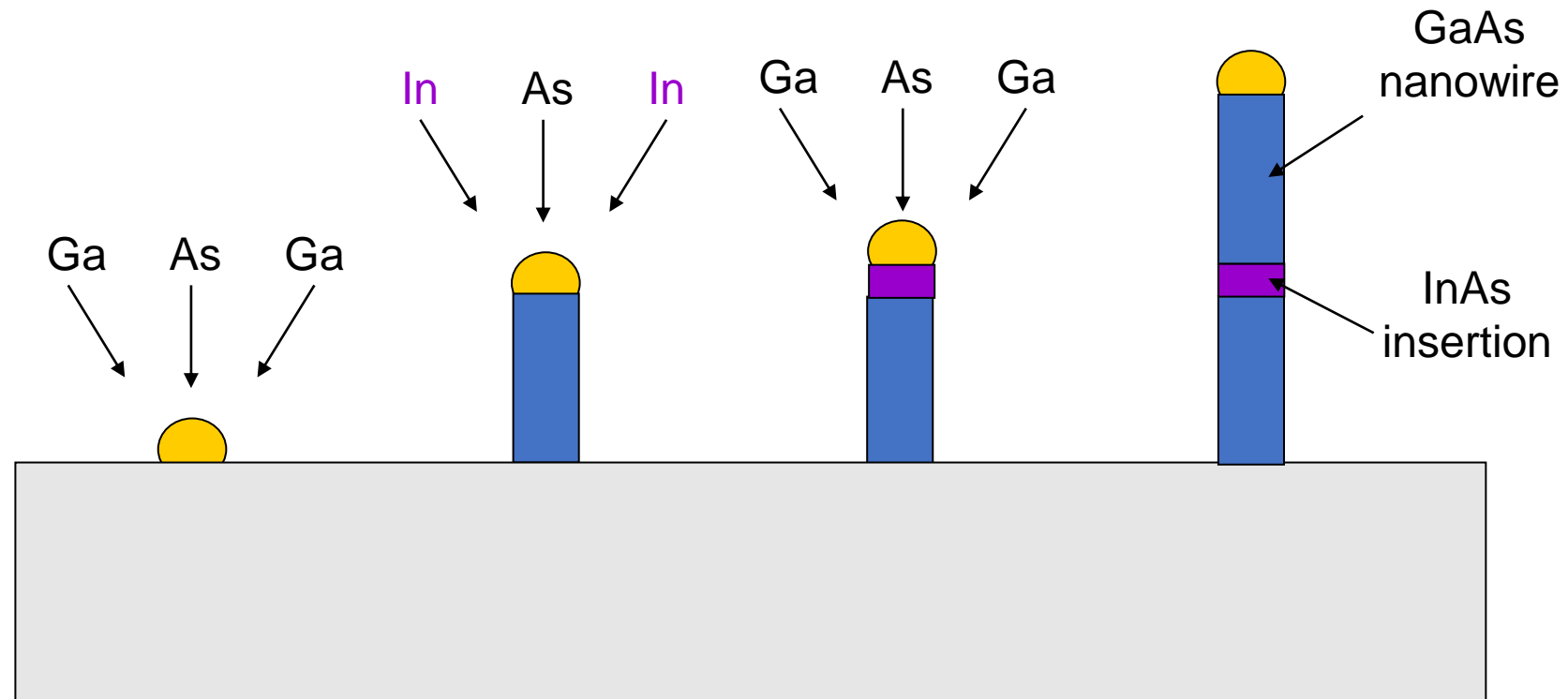


Video courtesy of Dr Frances Ross
and IBM

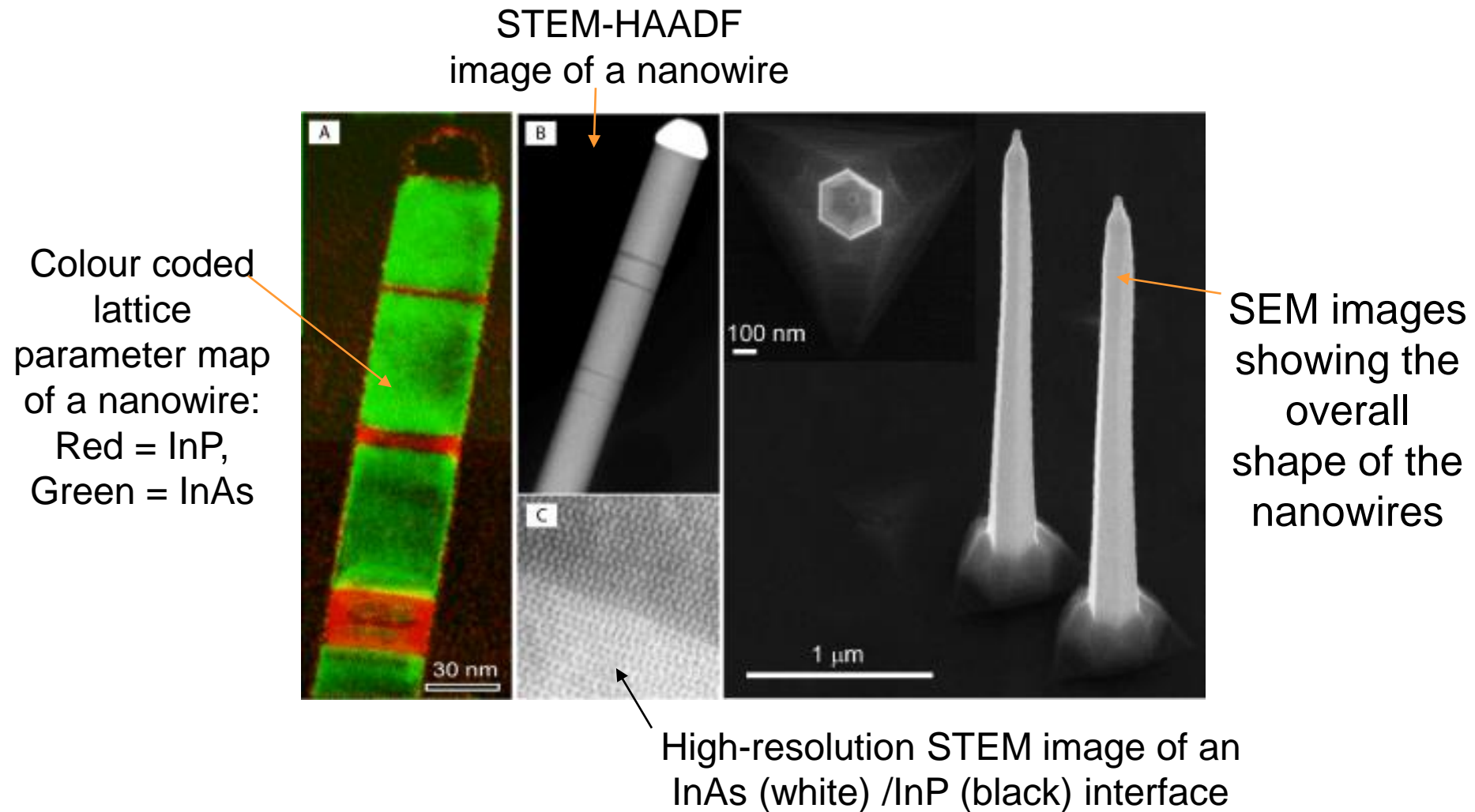
- Frances Ross and her colleagues at IBM were able to image nanowires in the TEM during the VLS growth process.
- They saw that during the growth process the vast majority of catalyst particles were liquid.
- Solid catalyst particles were sometimes seen and exhibited facets. Nanowires with solid catalyst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

Nanowire heterostructures: 1: Axial heterostructures

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



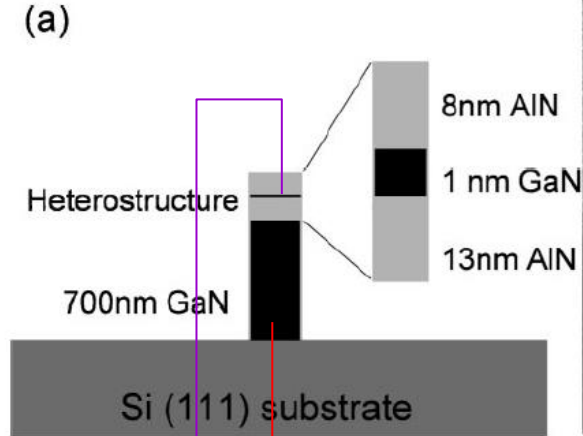
Axial heterostructures: Example



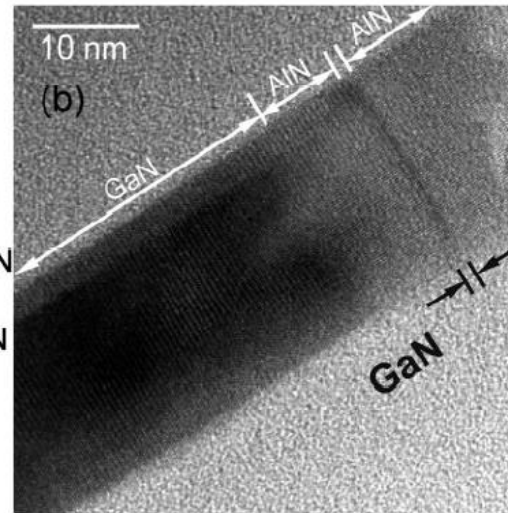
Images from <http://www.nano.lth.se/research/epitaxy/project-2>

Axial heterostructures: Thin inclusions in nanowires as quantum dots

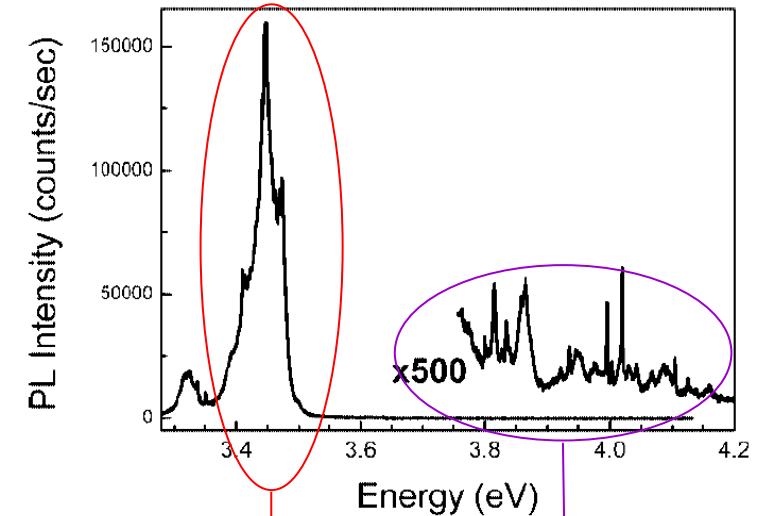
Schematic of GaN/AlN
axial heterostructure



HRTEM image of single
GaN inclusion



MicroPL data from an
ensemble of nanowires



Broad emission from quantum wire region

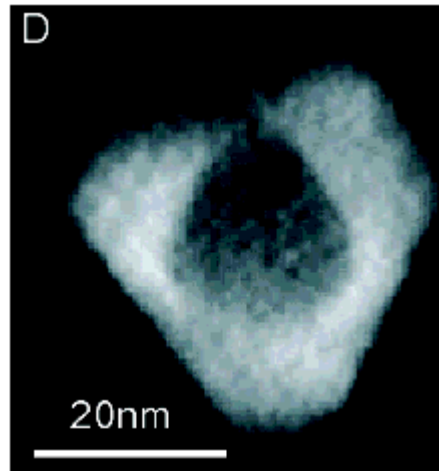
Sharp lines from quantum dot inclusion; blue shifted due to
confinement in smaller region

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

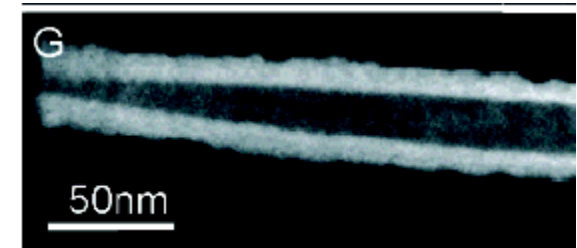
Nano-wire hetero structures: 2: Radial hetero structures

- 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

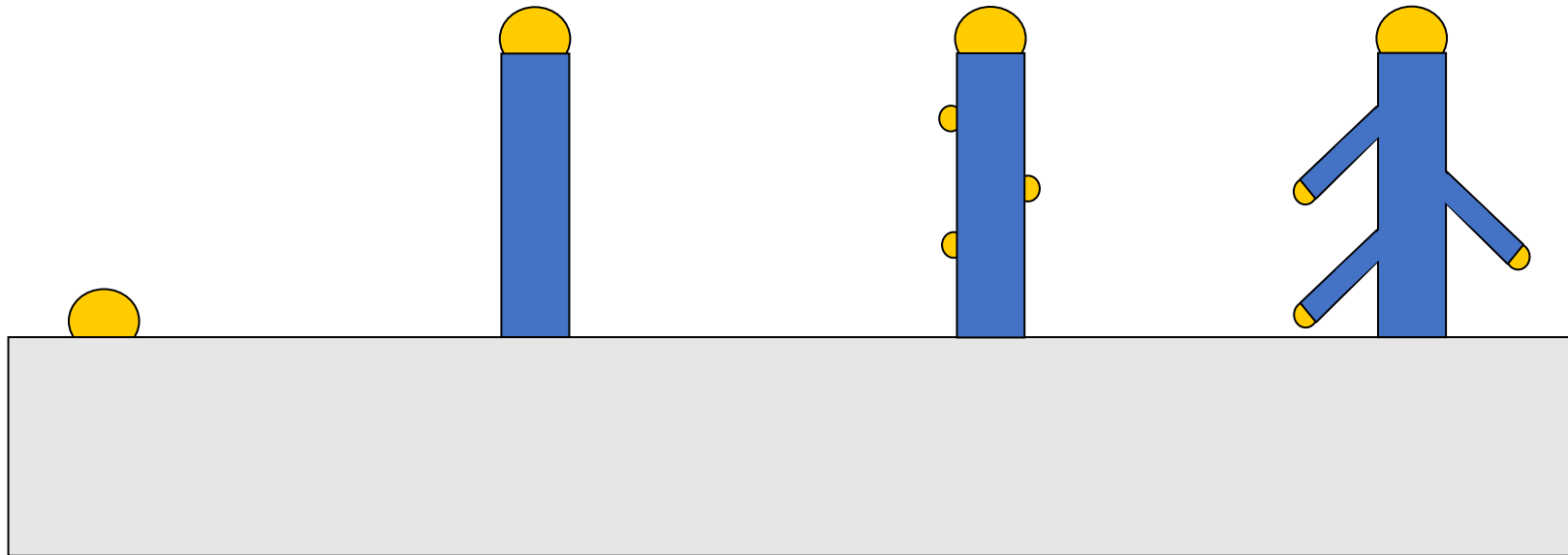
Branched nanowires

Catalyst particle
deposition

Reactants for
nanowire growth
introduced

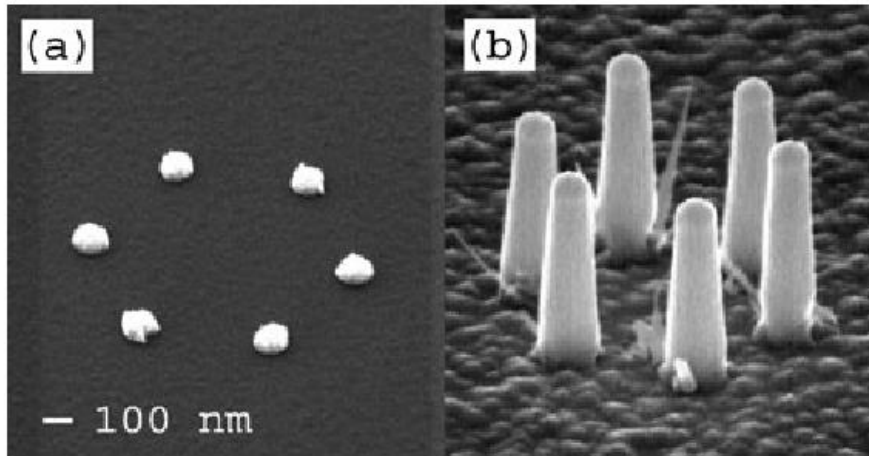
Deposition of
further catalyst
material

Further nanowire
growth reactants
introduced



Site-controlled nanowires

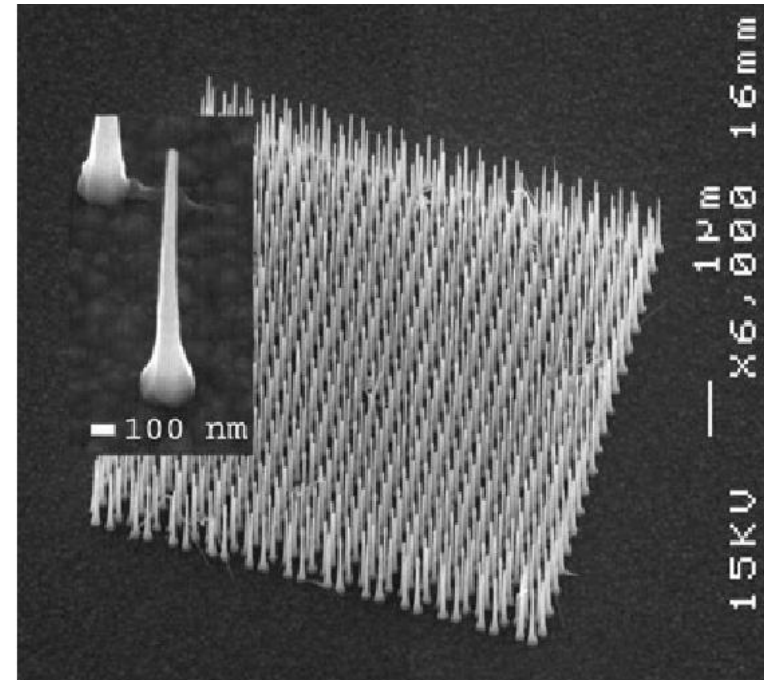
- By defining the positions of the catalyst particles via electron beam lithography or nanoimprinting technology, it is possible to produce an ordered array of nanowires:



Patterned catalyst particles defined by e-beam lithography

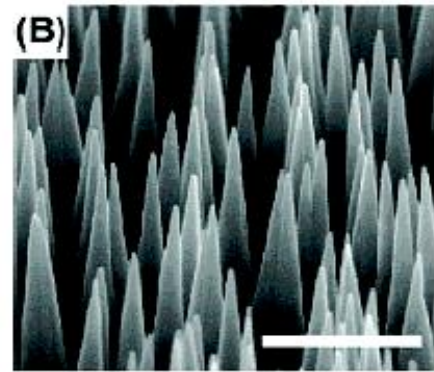
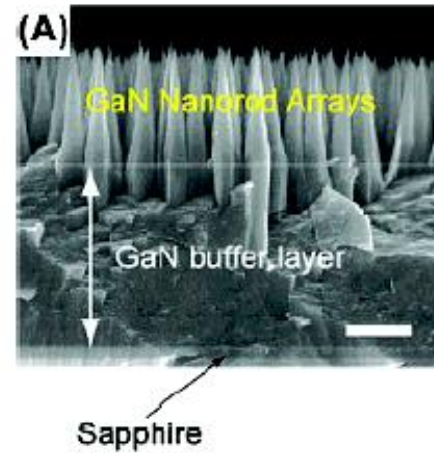
Resulting nanowire pattern

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

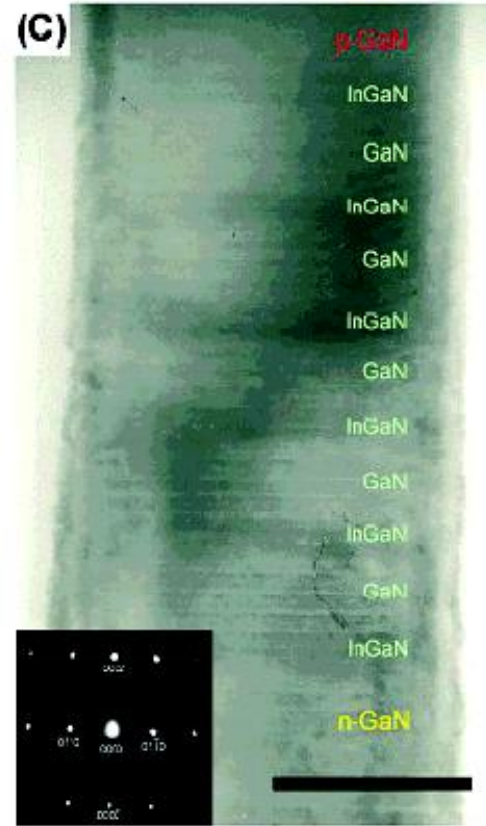


A larger array of thin nanowires

Example of a potential application of VLS growth: Nanorod LED



SEM

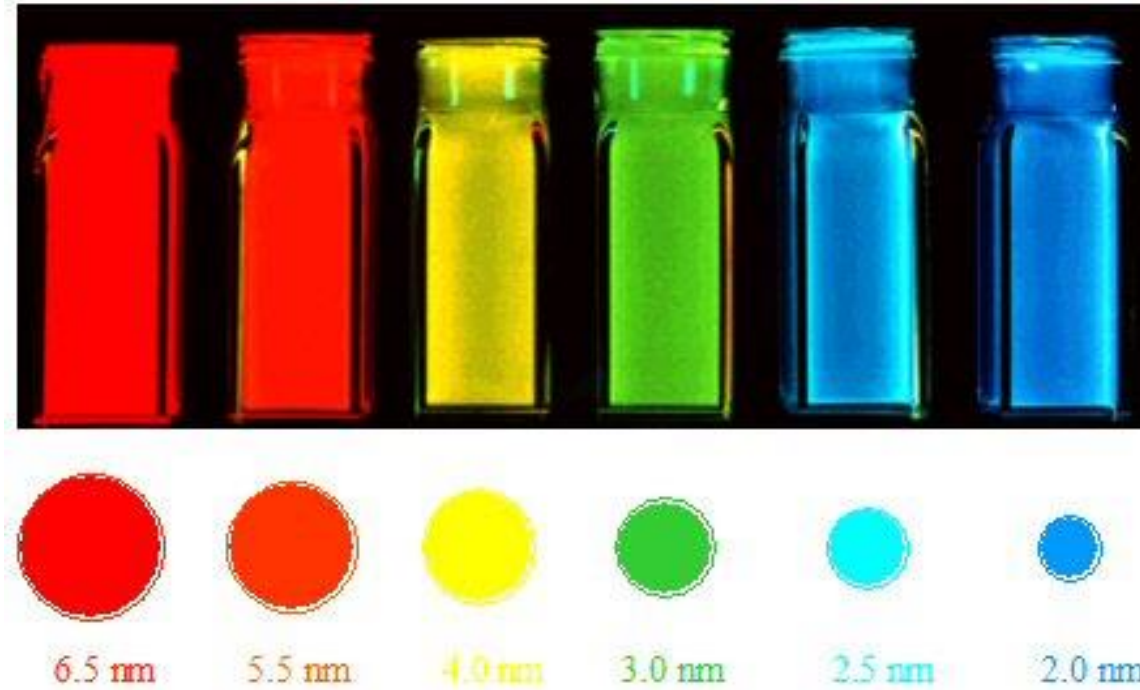


TEM

- 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))

Size dependence of luminescence wavelength



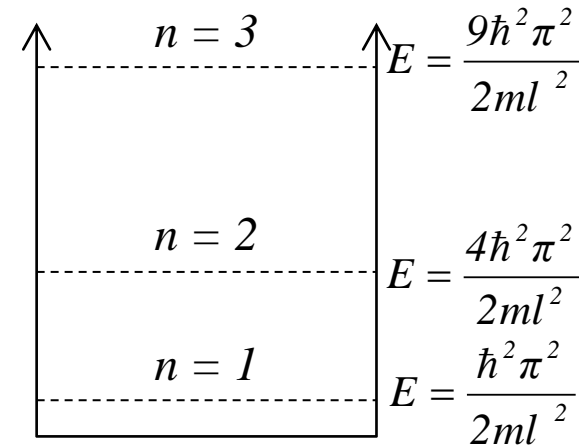
The luminescence wavelength (colour) for the CdSe nanocrystals is strongly dependent on their size.

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

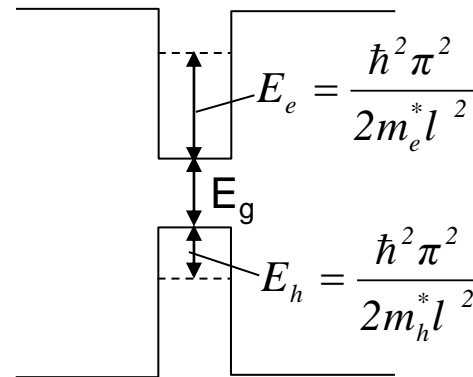
Why does
lumines-
cence
wavelength
depend
on size?

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

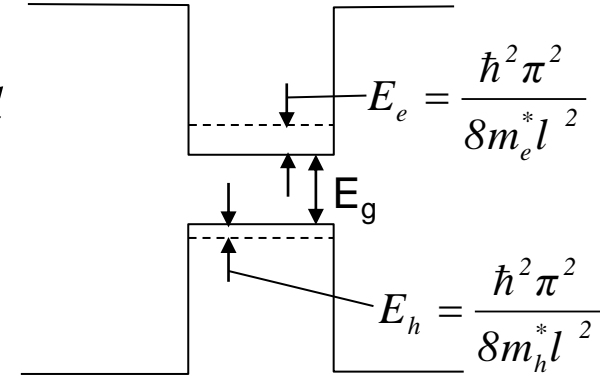
The energy levels vary in a similar way to the energy levels in an infinite potential well:



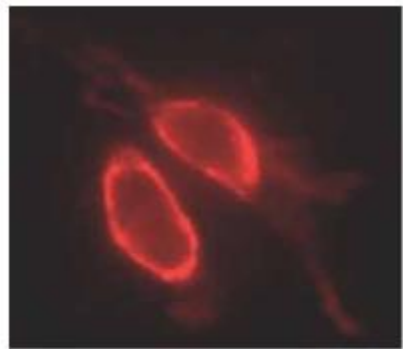
Particle
size = l



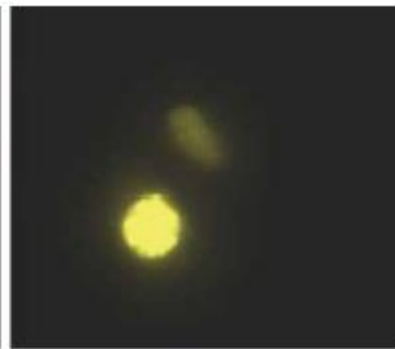
Particle
size = $2l$



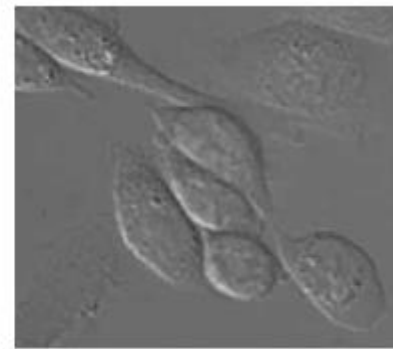
- Nanocrystals can be used as fluorescent tags which bind to biological molecules and can be used to track the binding of those biological molecules to cells or parts of cells.



Luminescence
from QD tags



Luminescence
from
conventional
molecular tags

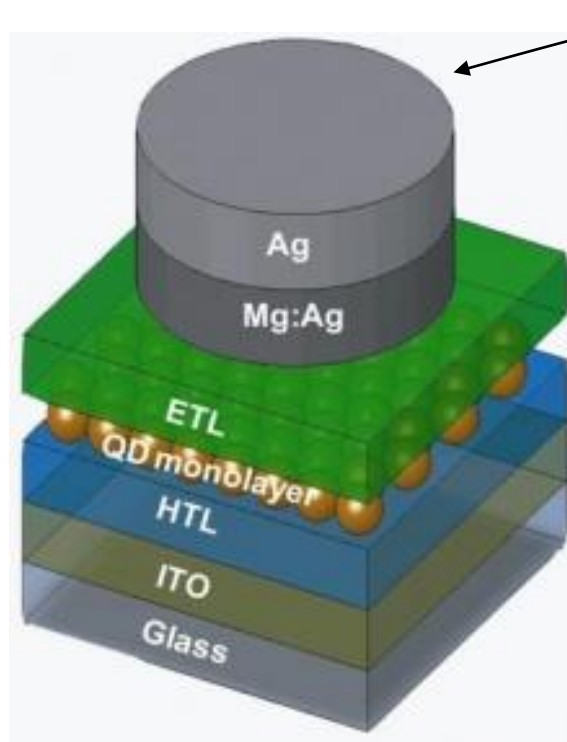


Light
micrograph
showing all
cells

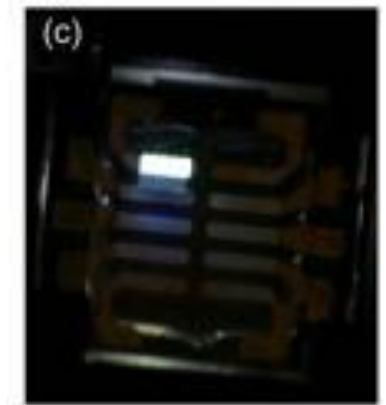
Howarth *et al.* (Nature Methods **5**, 397 (2008)) used QD tags to highlight cells which express a particular peptide. The QDs were shown to highlight the same cells as more conventional tagging methods, but were better distributed throughout the cell, showing the extent of peptide distribution.

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.

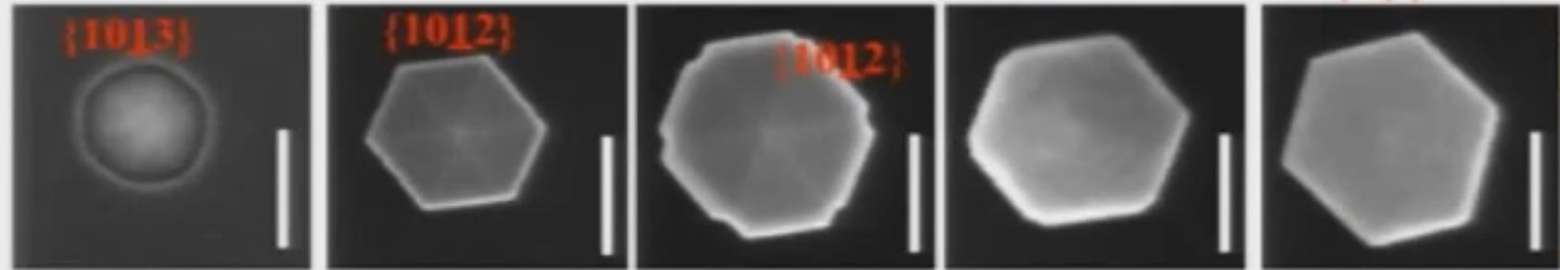


Eptaxial
Growth

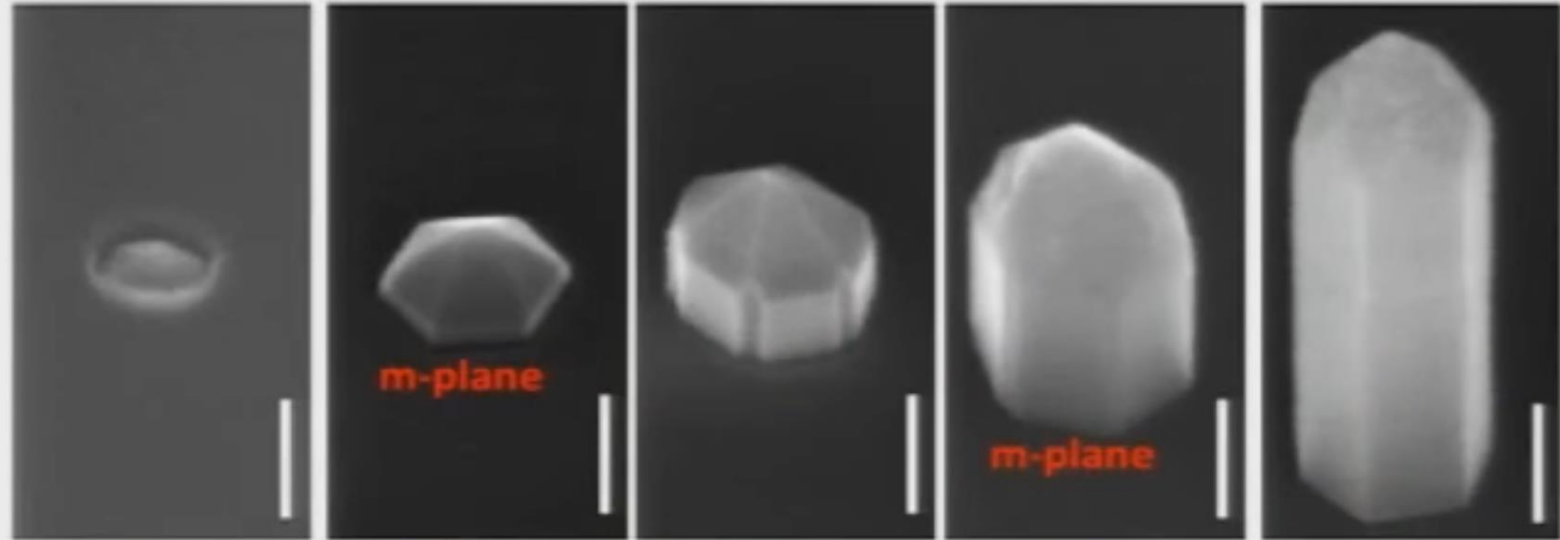
SEM: NW early facet development

Multi-faceted top pyramid

Top view



Tilted view



Scale bar:
100nm

Growth time 5s 15s 30s 60s 120s

Growth transitions observed:

For the first 30s both lateral & vertical growth is observed.

After 30s growth has switched to vertical growth only.

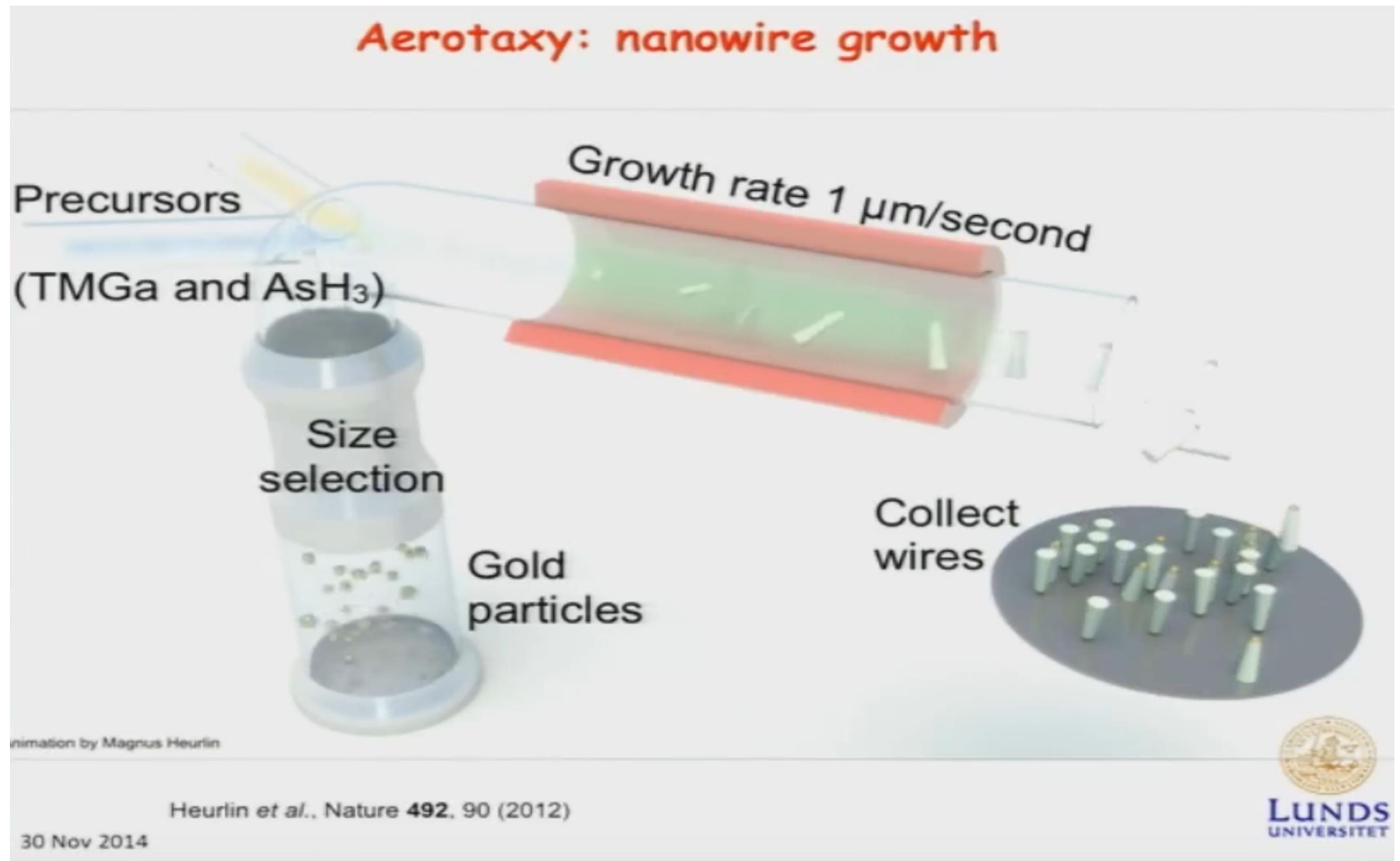


GaN Nanowire growth performed by Dr. Zhaoxia Bi



Epitaxial
growth

Aero Taxy Growth



Nanowires—From Basic Materials Research to Real-World Applications

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

43:25-55:32

44:02

How transistors work (Simple)

<https://www.youtube.com/watch?v=as89B8yPcaE>

Transistors, How do they work ?

<https://www.youtube.com/watch?v=7ukDKVHnac4>

how does a led work

<https://www.youtube.com/watch?v=BH9LI973H8w>

Principle of Semiconductor Laser

<https://www.youtube.com/watch?v=NpePZjTXqRw>

How Lasers Work - A Complete Guide

https://www.youtube.com/watch?v=_JOchLyNO_w

Videos.

Nanowires—From Basic Materials Research to Real-World Applications

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

A review of nanowire growth promoted by alloys and non-alloying elements with emphasis on Au-assisted III–V nanowires

Author: Kimberley A. Dick,

Journal: Progress in Crystal Growth and Characterization of Materials, Volume 54, Issues 3-4, September–December 2008, Pages 138-173

Abstract

Seed particles of elements or compounds which may or may not form alloys are now used extensively in promoting well-controlled nanowire growth. The technology has evolved following the well-known Vapour–Liquid–Solid (VLS) model which was developed over 40 years ago. This model indicates that a liquid alloy is formed from the seed particle and the growth precursor(s), resulting in crystal growth by precipitation from a supersaturated solution. The enhanced growth rate compared to the bulk growth from the vapour is typically attributed to preferential decomposition of precursor materials at or near the particle surface. Recently, however, there has been much interest in further developing this model, which was developed for Au-assisted Si whiskers (with diameter on the micrometre scale), in order to generally describe particle-assisted growth on the nanoscale using a variety of materials and growth systems. This review discusses the current understanding of particle-assisted nanowire growth. The aim is first to give an overview of the historical development of the model, with a discussion of potential growth mechanisms. In particular, the enhancement of growth rate in one dimension due to preferential deposition at the particle–wire interface will be discussed. Then, the particular example of III–V nanowires grown by metal–organic vapour phase epitaxy using Au particles will be revised, with details of the various growth processes involved in this system. The aim of this review is not to provide a conclusive answer to the question of why nanowires grow from seed particle alloys, but to describe the progress made towards this goal of a unified theory of growth, and to clarify the current standing of the question.

- [NanoVol. 14, No. 04, 1930004 \(2019\)](#)
- **Review of the Preparation and Structures of Si Nanowires, Ge Quantum Dots and Their Composites**
- [Xiaokang Weng](#)
- , [Jie Yang](#)
- , [Dongze Li](#)
- , [Rongfei Wang](#)
- , [Feng Qiu](#)
- , [Chong Wang](#)
- and [Yu Yang](#)