Lecture 25 – Recap

EECS 598-002 Winter 2006

Nanophotonics and Nano-scale Fabrication

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Nanophotonics

- What is it?
- What does it really mean?

What is nanophotonics

- Photonics – Study and the use of light-matter interaction. For example, the study of the interaction between light and electrons in ruby crystal leads to the first laser.

- Nanophotonics – Study and the use of photonics in nanoscale materials or technologies.
  - For example optical properties of quantum dots
  - For example the use of photonics in nanoscale CMOS processing or nano-resolution microscopy.

When do we care about nano?

- When the length scale is << optical wavelength → Nano!
  - E.g. near field (evanescent waves, surface EM mode, …)
- When the interaction takes place within a nano length scale
  - E.g. photonics in quantum dots and nanowires

Nanofabrication

Top-down (Miniaturization)

- Electronics circuits (IC)
- Photonics (e.g. lasers)

Bottom-up

- Putting small things together
- Individual manipulation of atoms and molecules

Nanofabrication

Some reminders for you to take away

- Nanophotonic devices are not necessarily in the nano scale.
  - E.g. the photonic crystal device, quantum dot lasers, …

- Always keep in mind what applications you are looking for. Nano is not always “the” solution. For example surface plasmonic wave can be a useful tool for biosensing but still poses great challenge in chip-scale communication due to large loss.

Nanofabrication

- There are many potential technologies.
- But be careful when judging or comparing different technologies. Be fair in benchmarking process and keep in mind that the “current” technology also **will** improve!

Some recap

- The interaction of light and matters can be described by the **macroscopic** version of Maxwell's equations if the length scale that we're interested is > 10 nm.

- For dielectric media, the only quantity we need to determine to fully describe the interaction between light and matters is the dielectric constant $\varepsilon(r)$.

Determination of $\varepsilon(r)$

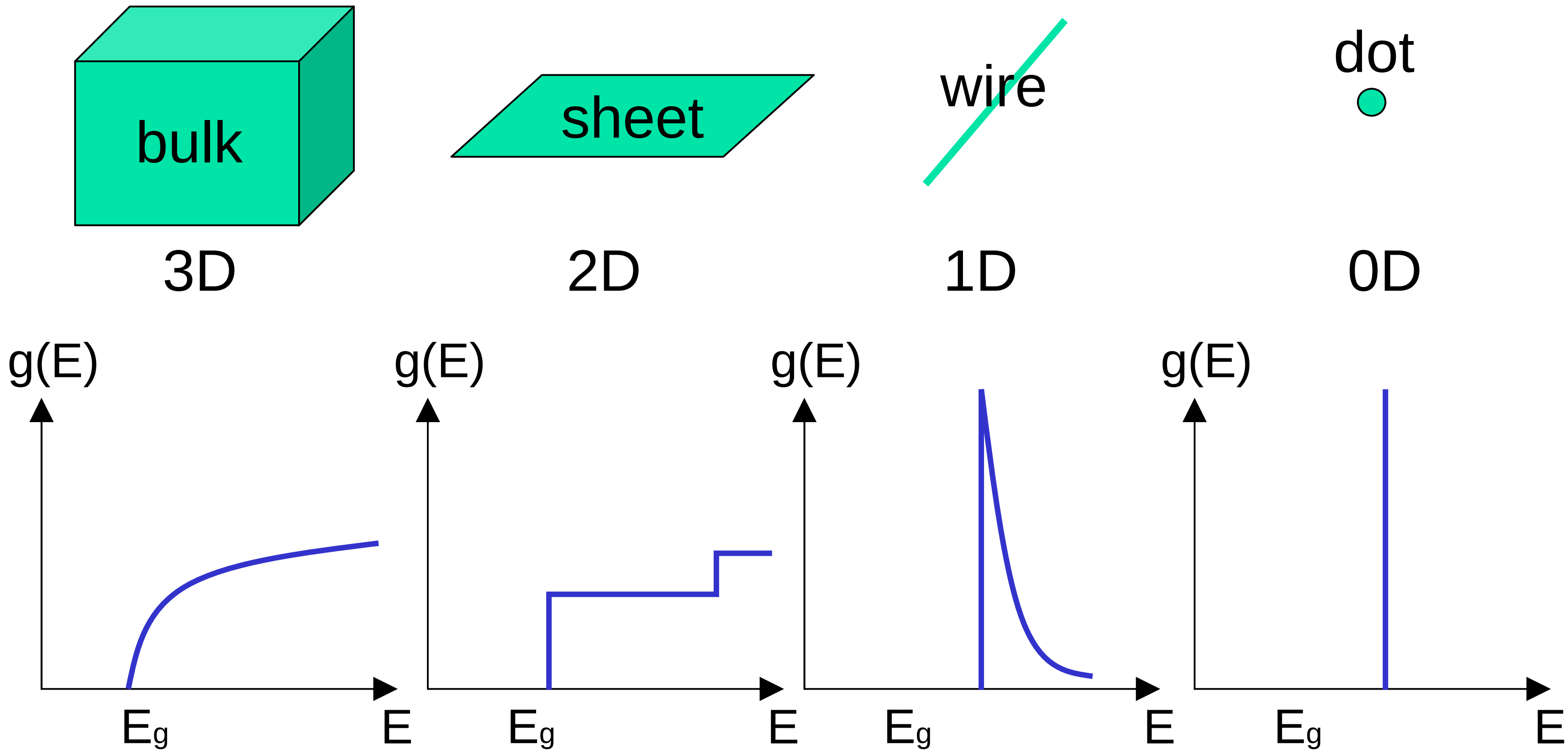
- We only need to measure (or calculate) $\varepsilon(r)$ around resonances of basic excitations in the media. Then we can use Kramers-Kronig relation to evaluate the rest.

- Basic excitations:
  - Plasmons (free electron gas in metals or semiconductors)
  - Phonons (vibration of lattice)
  - Excitons (electron-hole pairs)

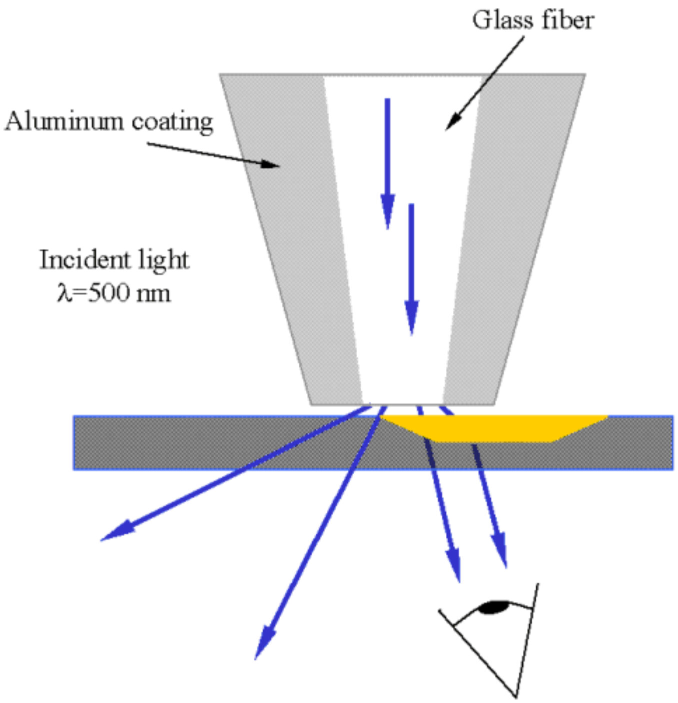
- Lecture 2-6:
  - Behavior of EM waves with known $\varepsilon(r)$ in both near field and far field → described by dispersion curve (ω vs k)
- Lecture 7-10
  - Different excitations and their implications on $\varepsilon(r)$

Quantum confinement

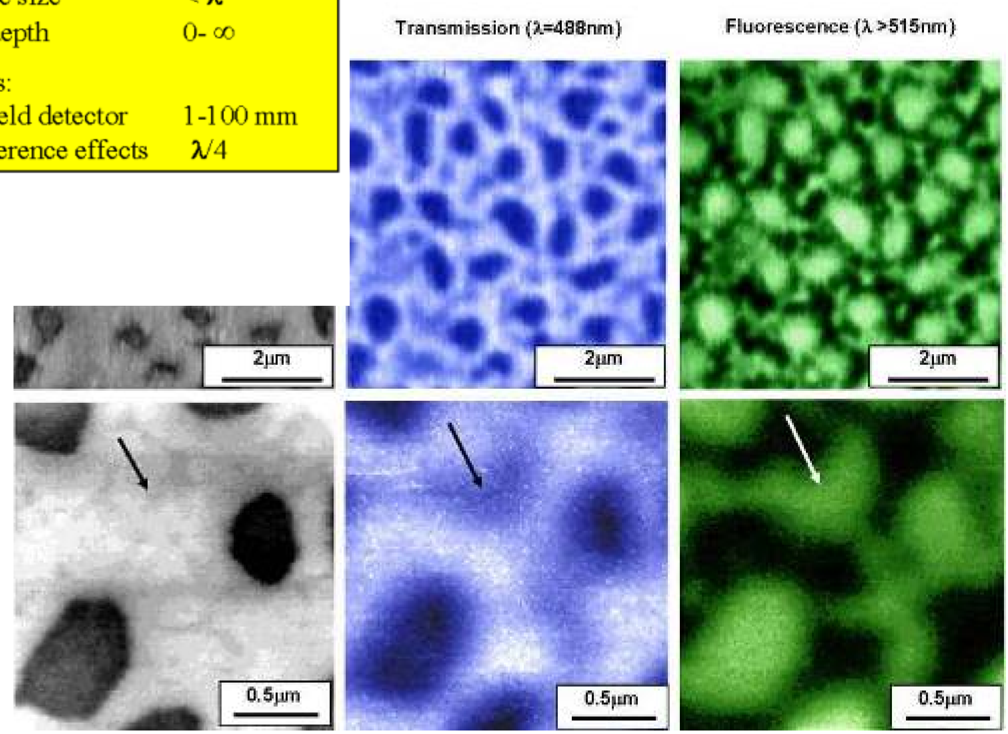
- The change of quantum confinement on electrons and holes leads to the change of the exciton behaviors → change in ε(r)



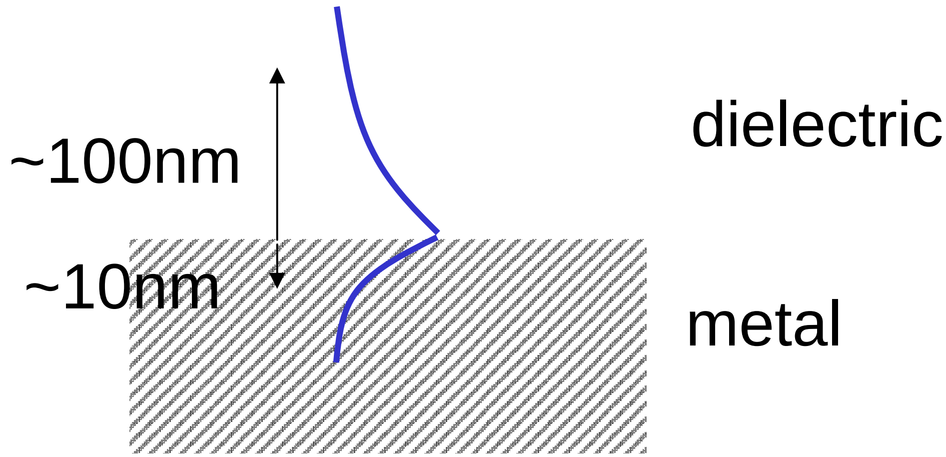
Scanning Near-field Optical Microscope



Light wavelength (λ)	500 nm
Probe:	
aperture size (a)	25-100 nm
evanescent field	a/π
tip-sample gap	5-50 nm
Sample:	
feature size	< λ
skin depth	0- ∞
Optics:	
Far-field detector	1-100 mm
Interference effects	λ/4



Surface plasmon polariton (SPP) confinement



Most of the energy is confined in the dielectric side.

Bio sensing

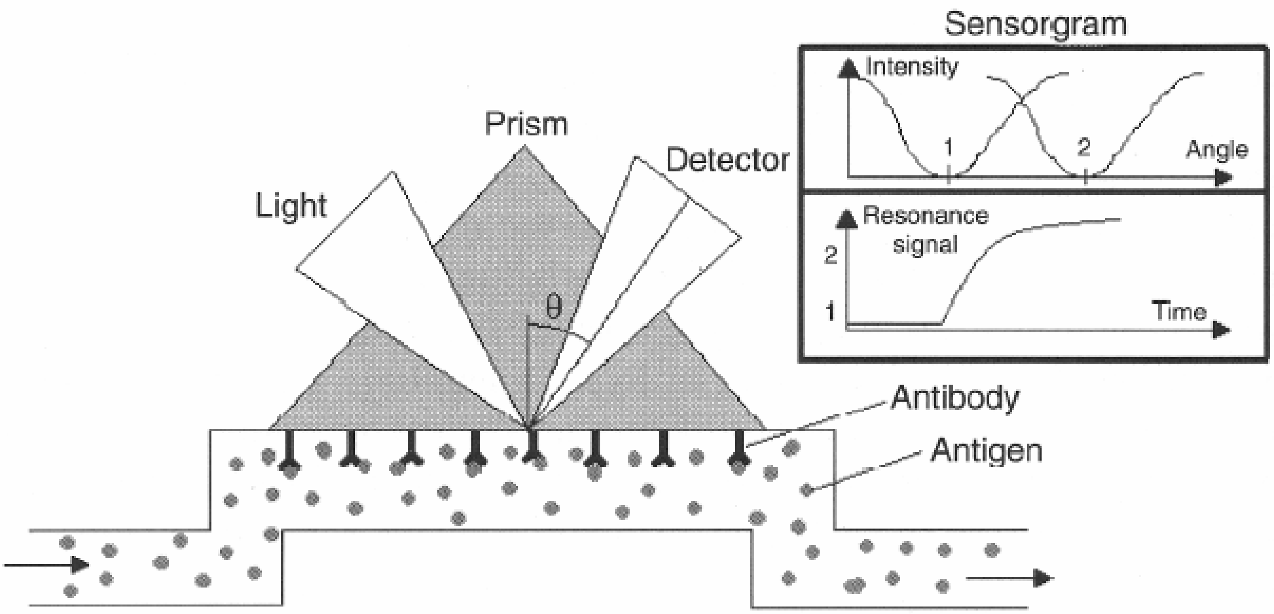


Figure 9.25. Surface plasmon resonance sensor schematic utilizing a CCD or photodiode array (*left*). The inset on the right-hand side shows the sensorgram. The top in the inset shows a shift in the SPR curve from 1 to 2 upon binding with the analyte. The bottom curve is obtained by monitoring the SPR signal at the shifted coupling angle as a function of time when the analyte is introduced. (Reproduced from http://chem.ch.huji.ac/il/~eugeniik/spr.htm.)

Ref: Prasad, *Biophotonics*, figure 9.25.

Dispersion engineering

- The spatial dependence of ε(r) changes the propagation of EM waves and therefore changes the dispersion relation.
  - For example:

    1-D Bragg gratings
    Photonic crystals

- The change in the basic excitation behavior changes the dispersion relation too.
  - For example:

    EIT
    population oscillation

EIT and slow light

Light speed reduction to 17 metres per second in an ultracold atomic gas

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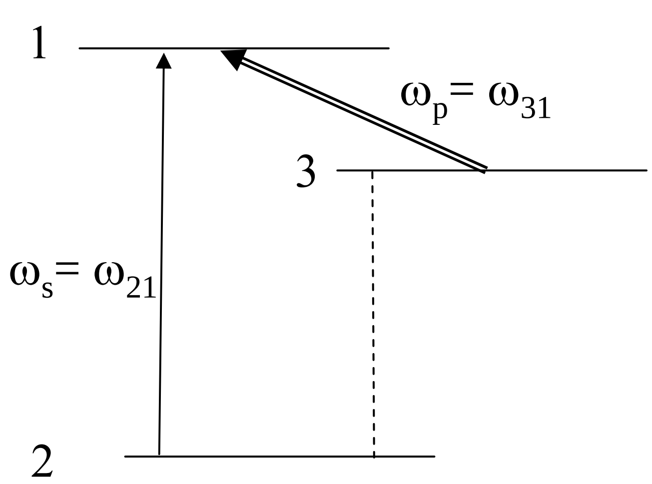
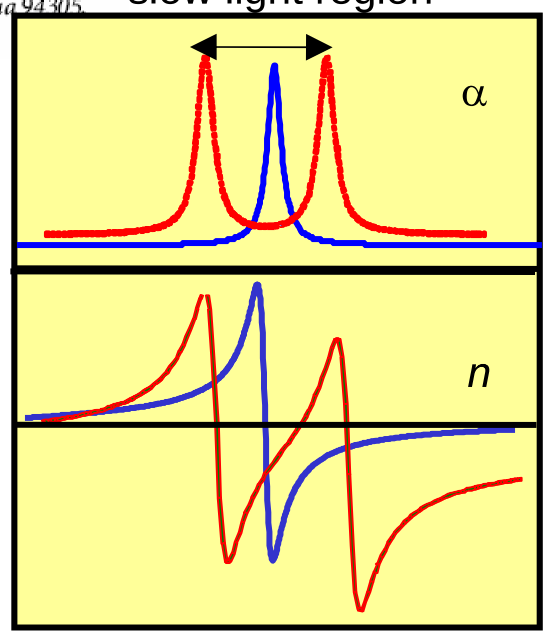
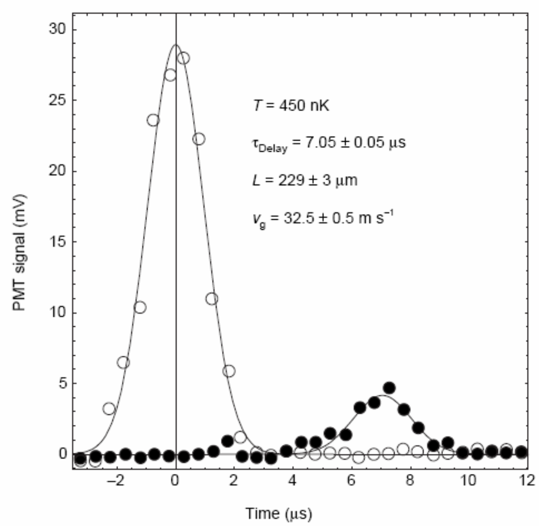
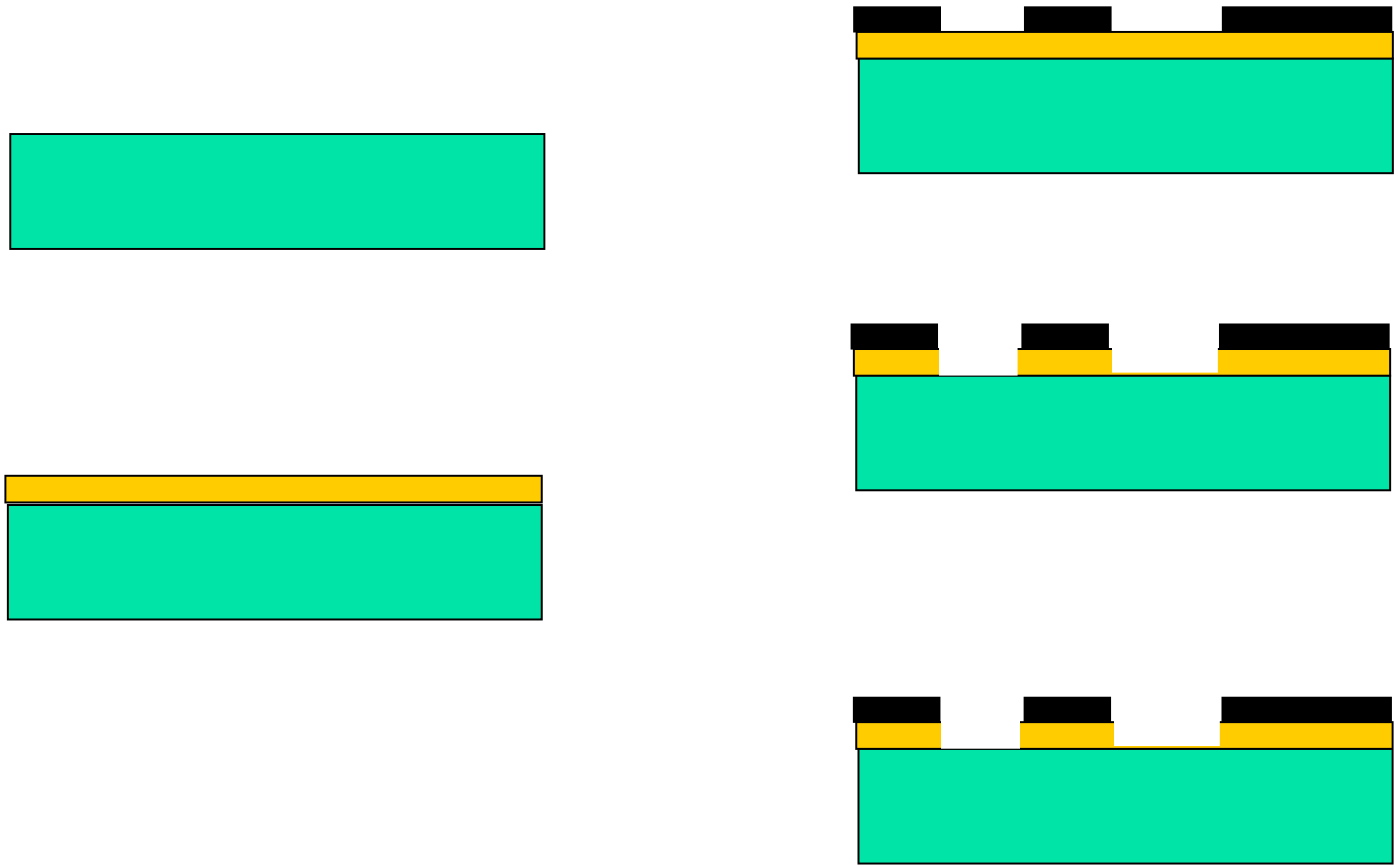






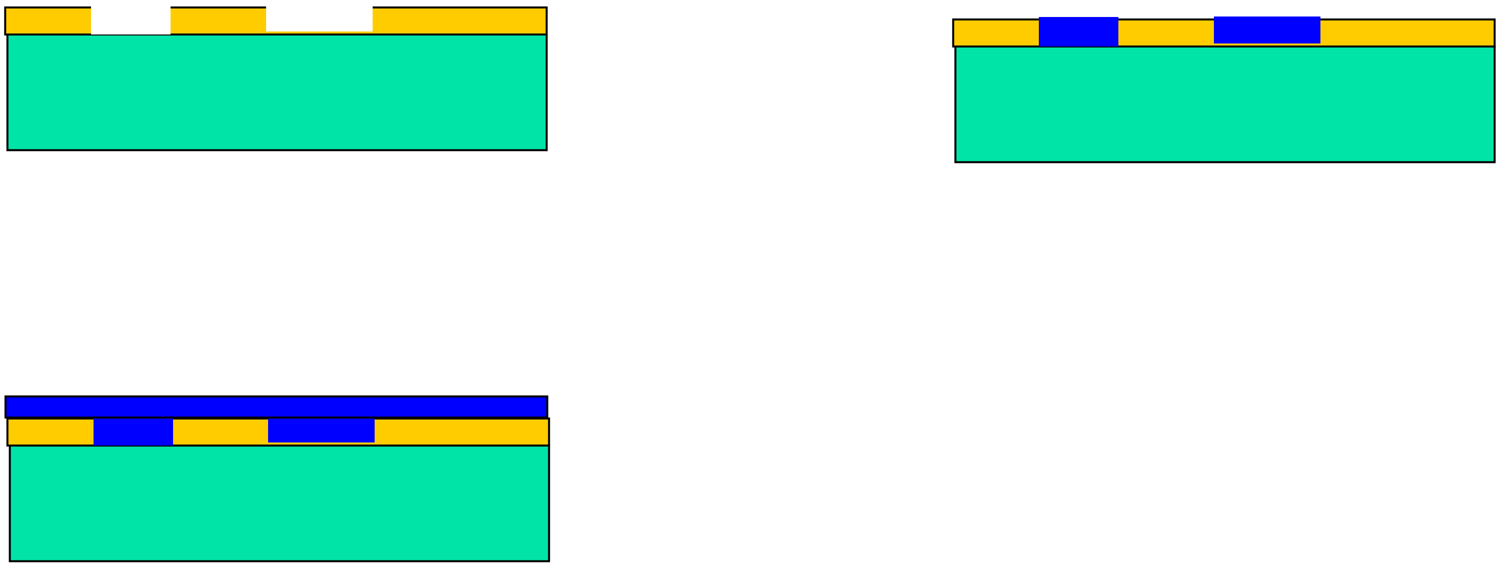
Different approaches

- Top-down (litho/etch)



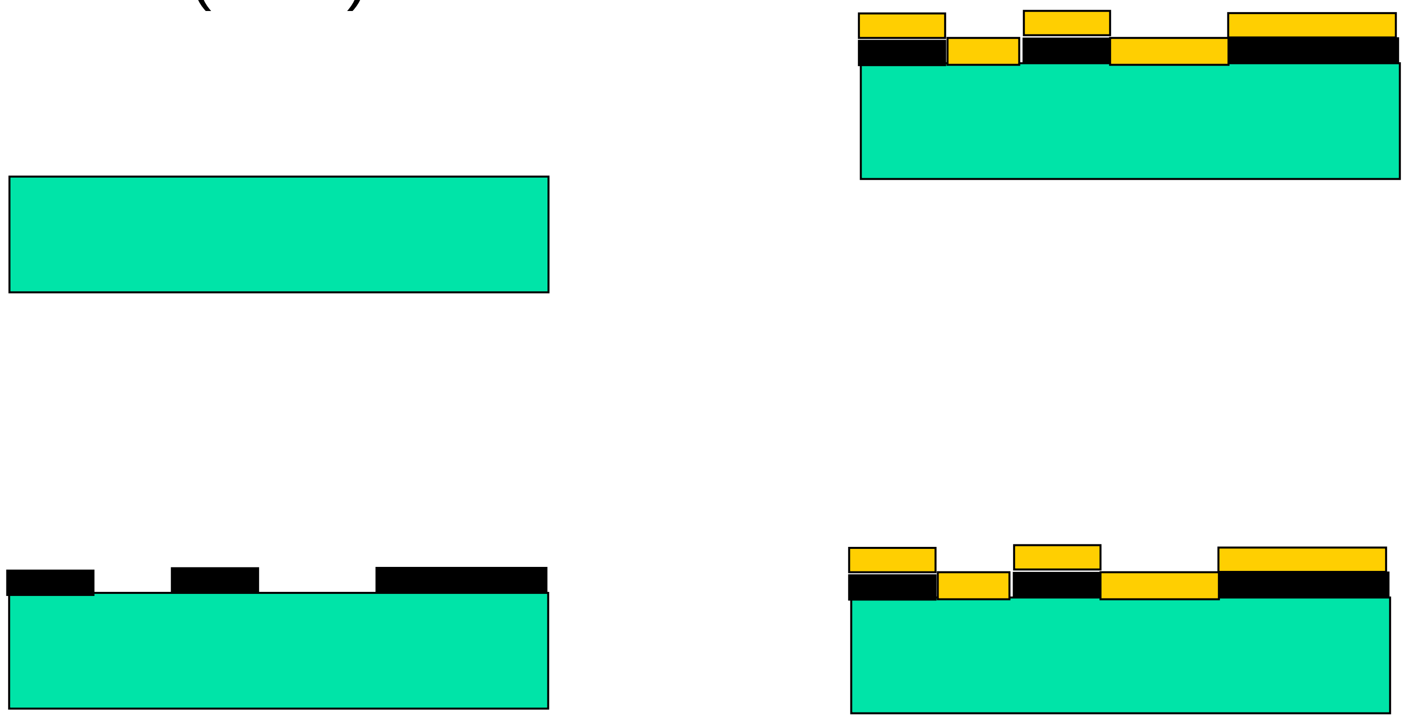
Different approaches

- Top-down (damascene/CMP)



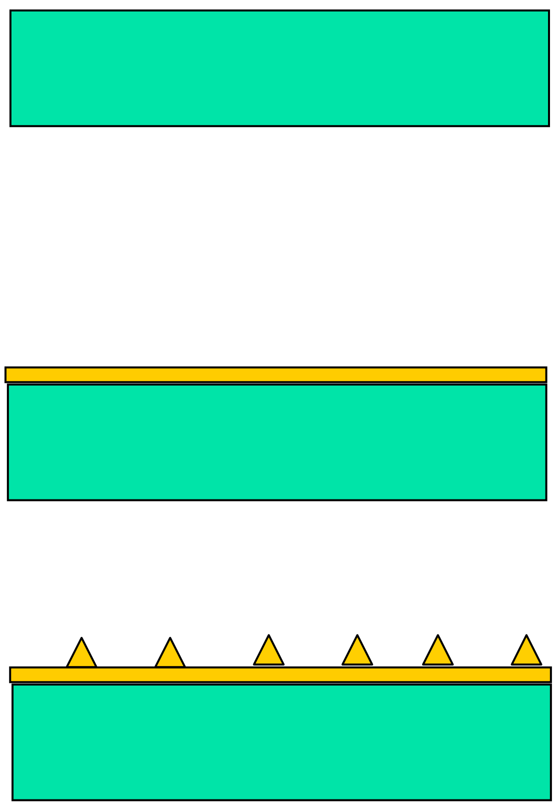
Different approaches

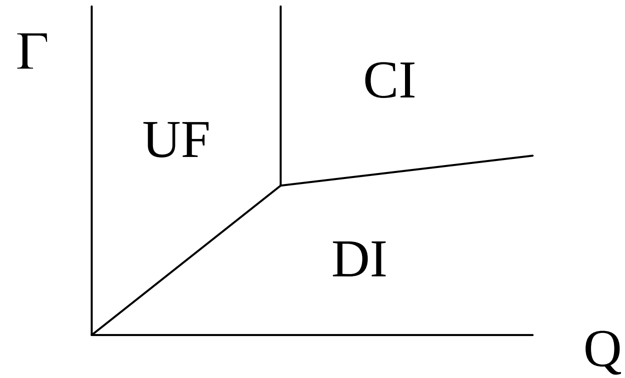
- Top-down (liftoff)



Different approaches

- Bottom-up (strain-induced self-assembly)





Q: amount of deposited material

$\Gamma = \Delta E_{dis} / \Delta E_{surf}$

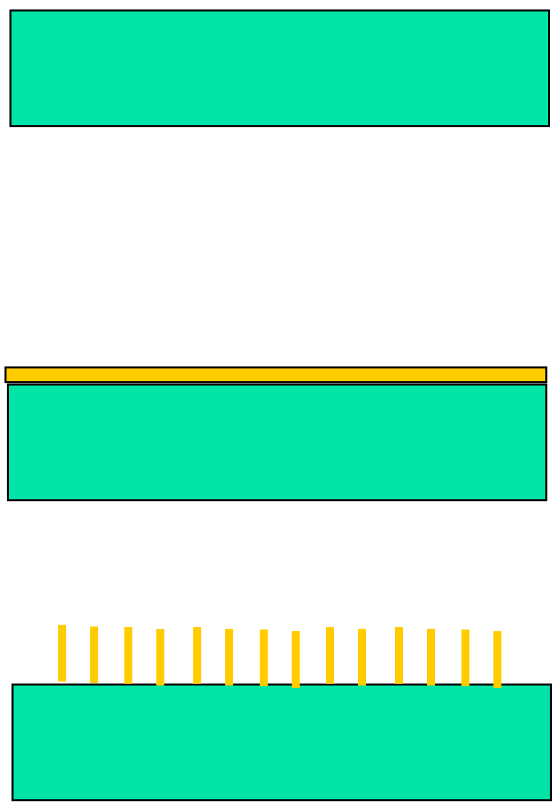
CI = coherent islands

DI = dislocated islands

UF = uniform film

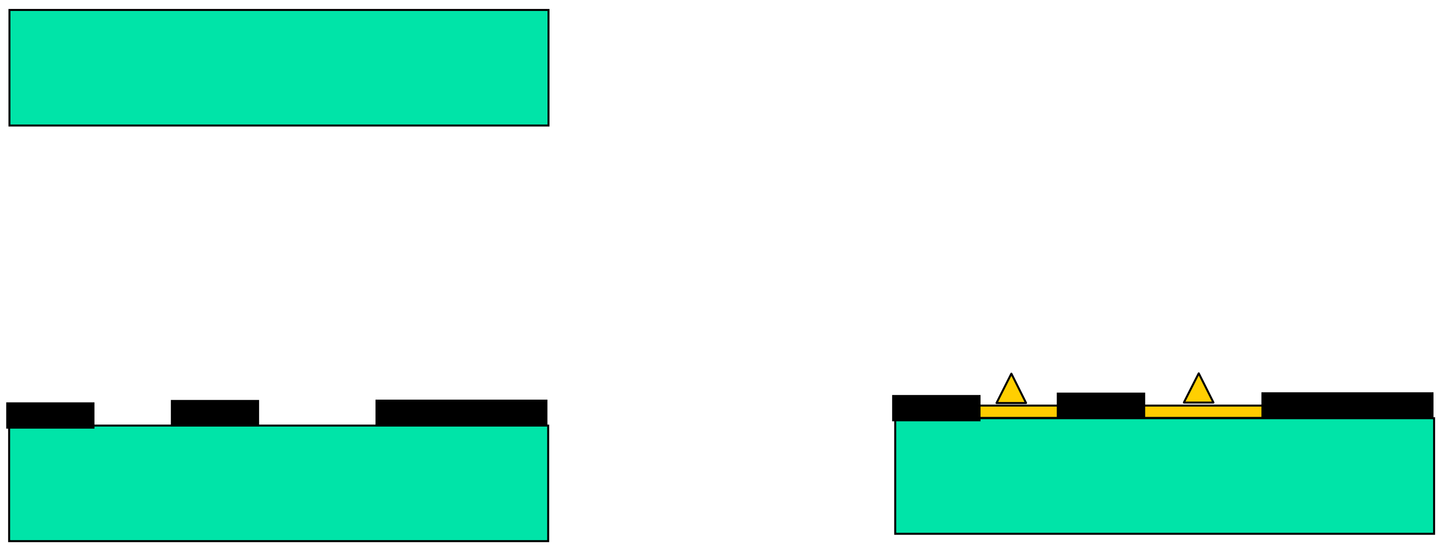
Different approaches

- Bottom-up (catalyst-induced self-assembly)



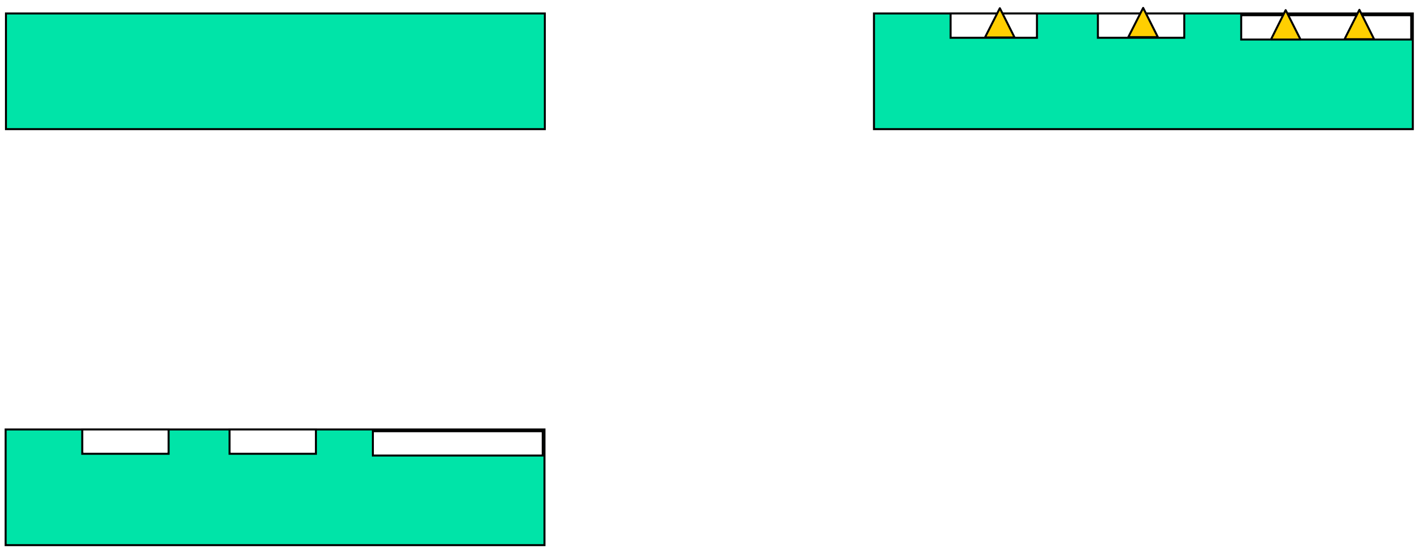
Different approaches

- Hybrid (selective-area growth)



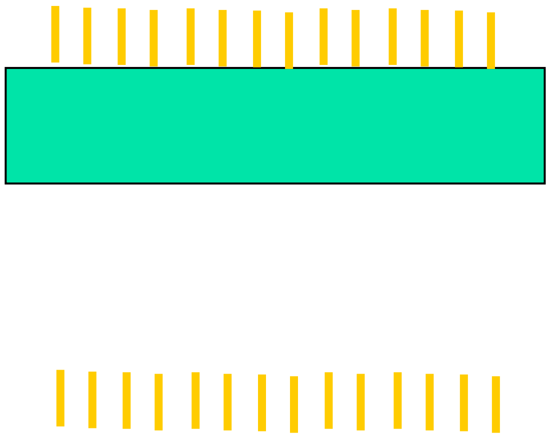
Different approaches

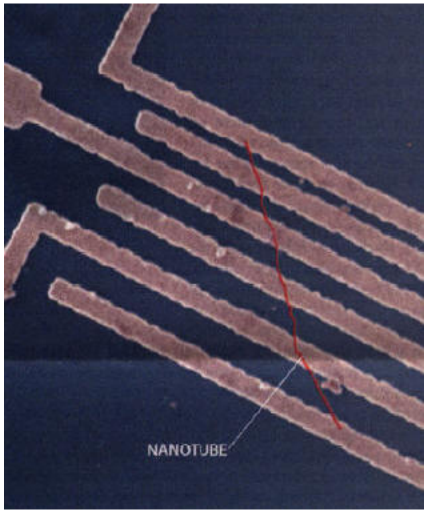
- Hybrid (patterned substrate overgrowth)



Different approaches

- Hybrid (separate assembly)





http://www.mtmi.vu.lt/pfk/funkc_darini
ai/nanostructures/nanotubes.htm

Lithography

- Optical wavelength determines the fundamental limit on resolution but not the minimum feature size.
- Optics + resist + etch determines the patterning performance.
- Many RET have been developed to enhance the performance.

Thin film deposition

- MOCVD, MBE, and ALE are three major technologies that are capable of depositing defect-free single crystalline materials with the atomic-layer precision on thickness control.

Self-assembled growth

- More flexible in growth conditions
- Hard to control size, location, and physical orientation

In addition to miniaturization…

- Technology is meant to improve our life experience and fulfill our curiosity for exploration.

- In addition to making the device smaller and smaller, we also need to focus on several key parameters:
  - Human interface (portability, accessibility, etc)
  - Multi-functionality (e.g. SOC-MT)
  - Lower power consumption
  - Green manufacturing

Is *nano* a hype or the future?