Nanophotonics: an overview

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- Introduction to nanophotonics
    - Broad classification
- Nanoscale confinement of light
- Nanoscale confinement of photoprocesses
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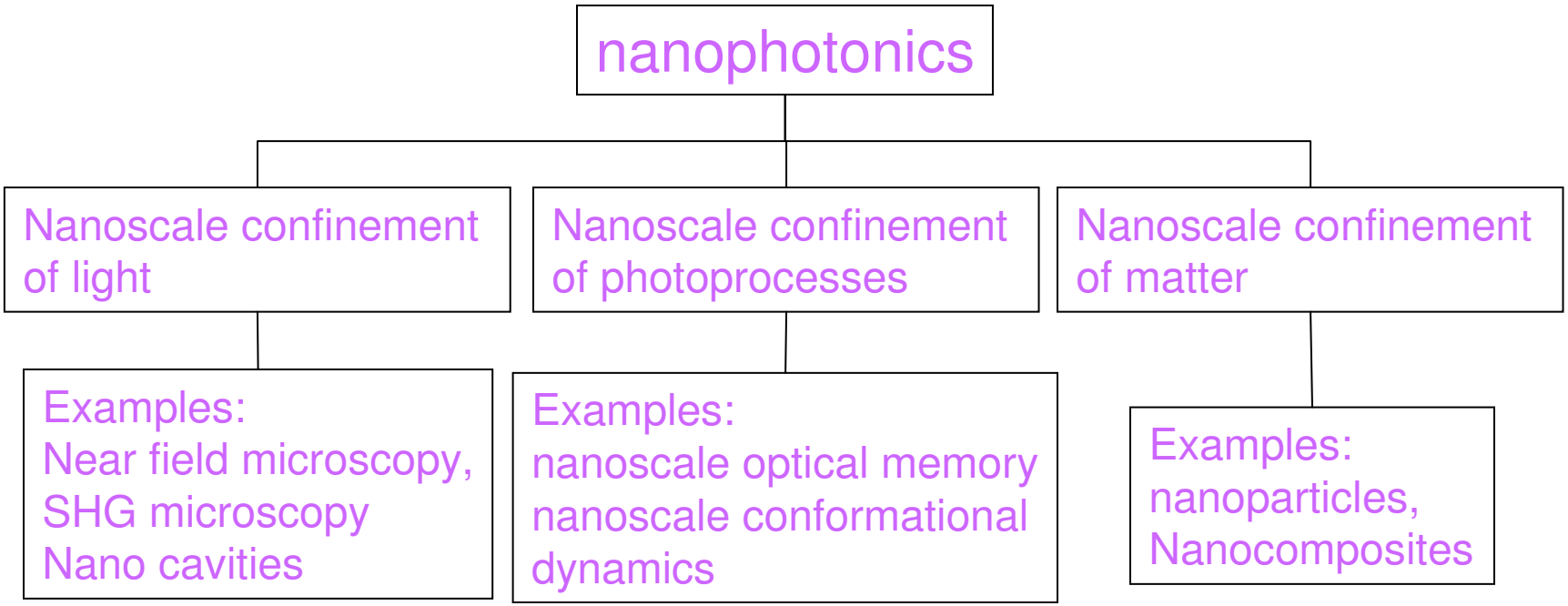
Introduction

Nanophotonics :

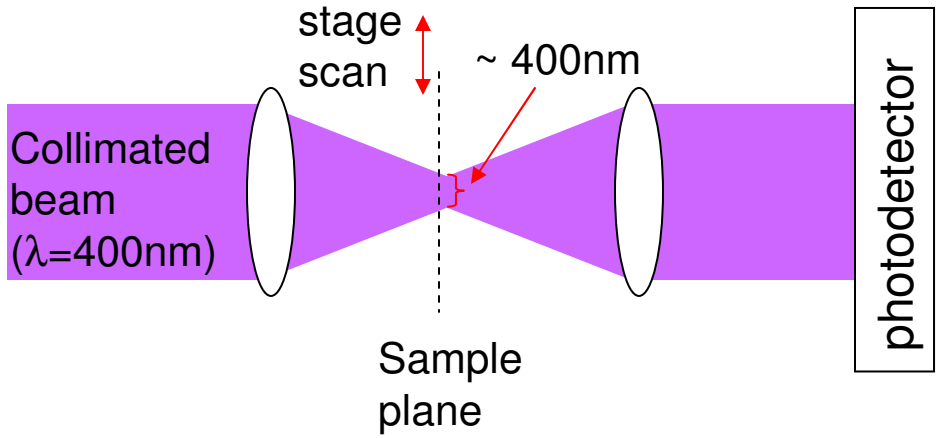
- Nanoscale (of the order of 10^{-9} m) optical science and technology
- Properties of light at nanoscale
- Optical processes and interactions between light and matter at nanoscale

Broad areas of nanophotonics



Nanoscale confinement of light

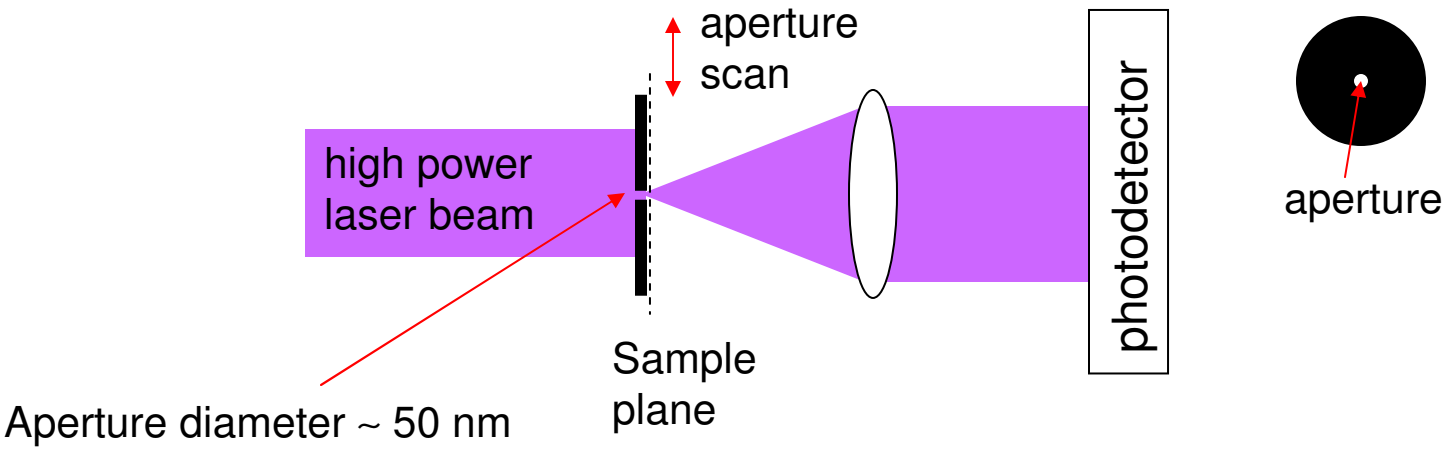
- Far field optical microscopy:



- Focal volume is diffraction limited : not suitable for nanoscale imaging
- Resolution : minimum separation between two points in the sample that can be resolved in the image (>200nm)
- However stimulated emission depletion (STED) microscopy can break the diffraction barrier

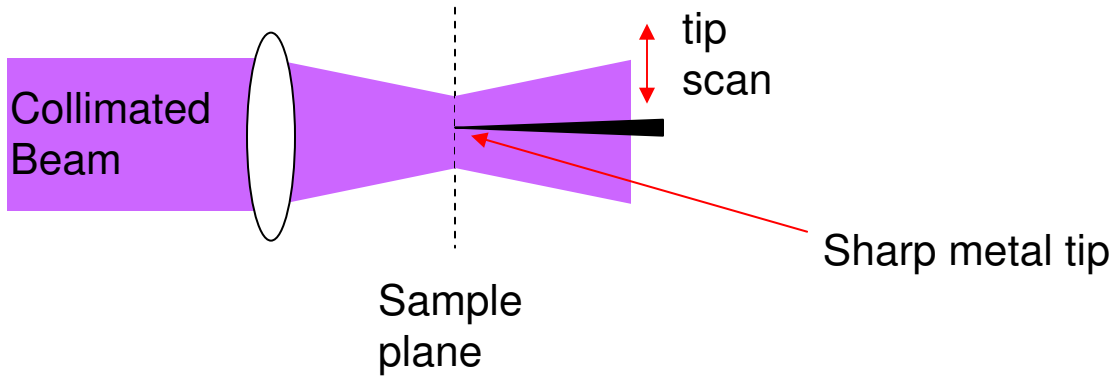
Nanoscale confinement of light

- Near field optical microscopy:



- ❑ Illumination volume is not limited by diffraction effect, rather by the aperture diameter
- ❑ Resolution: ~ aperture diameter
- ❑ Transmitted light $\propto$ (aperture area)$^{-1}$: limit in maximum resolution

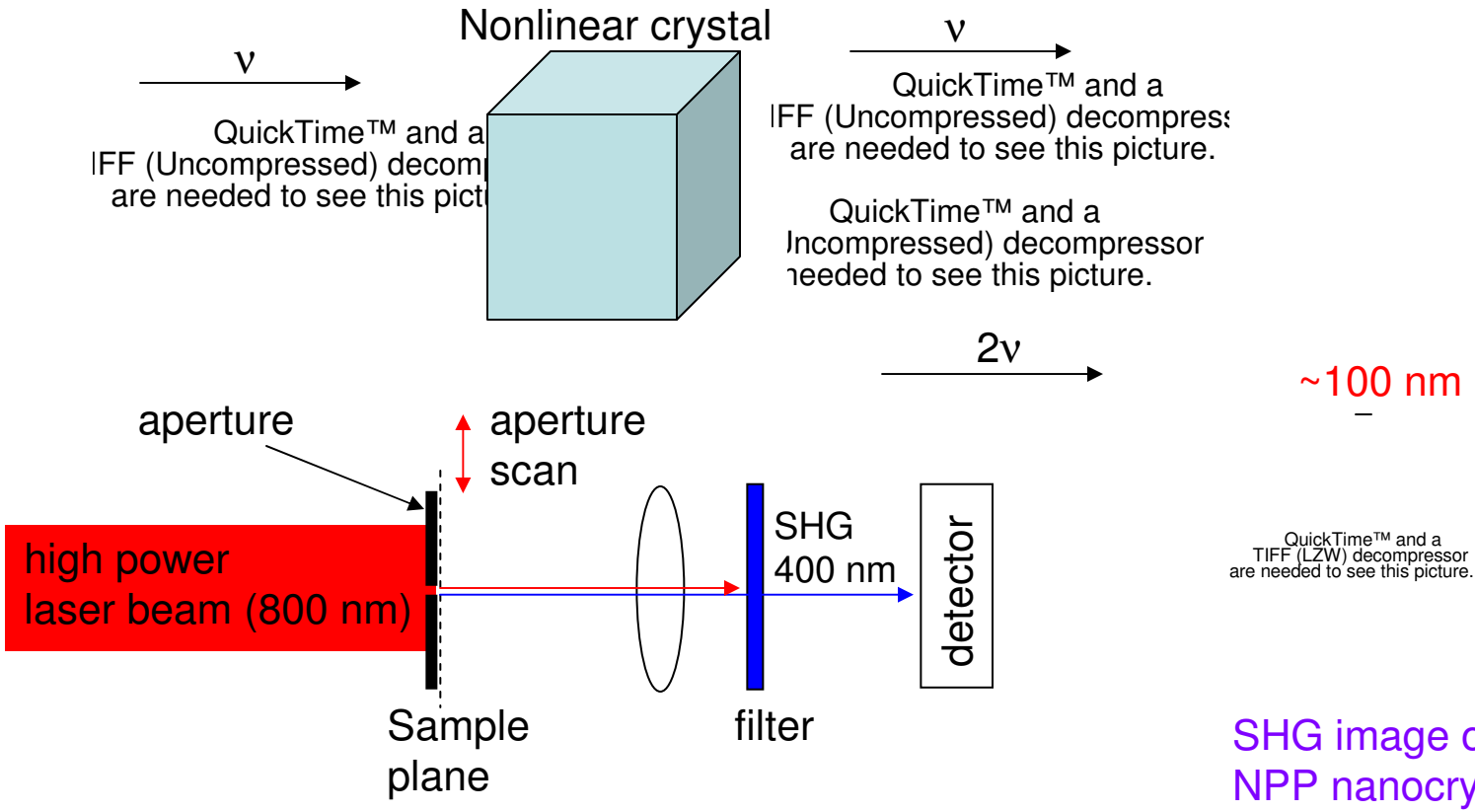
Field enhancement microscopy:



- Electric field enhancement near the tip: ~ 1000 times
- Light detected is mainly from a small region surrounding the metal tip
- Metal tip diameter ~ 10 nm : available resolution

Second harmonic generation microscopy

Second harmonic generation

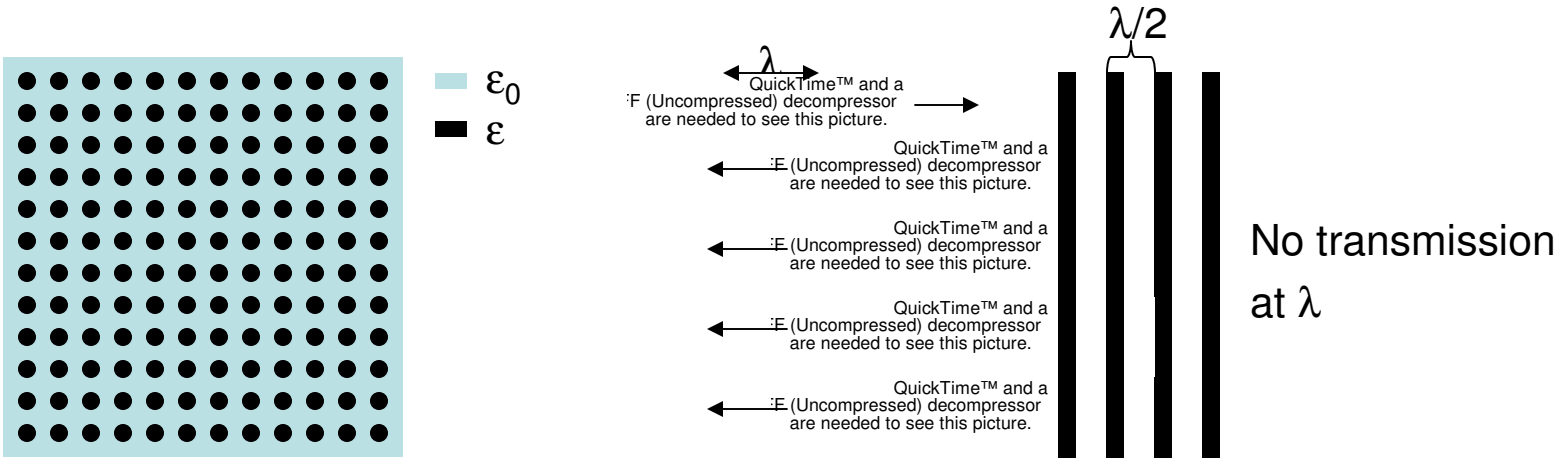


SHG image of NPP nanocrystal

- Shen et al, *J. Phys. Chem. B* **2000,** *104*

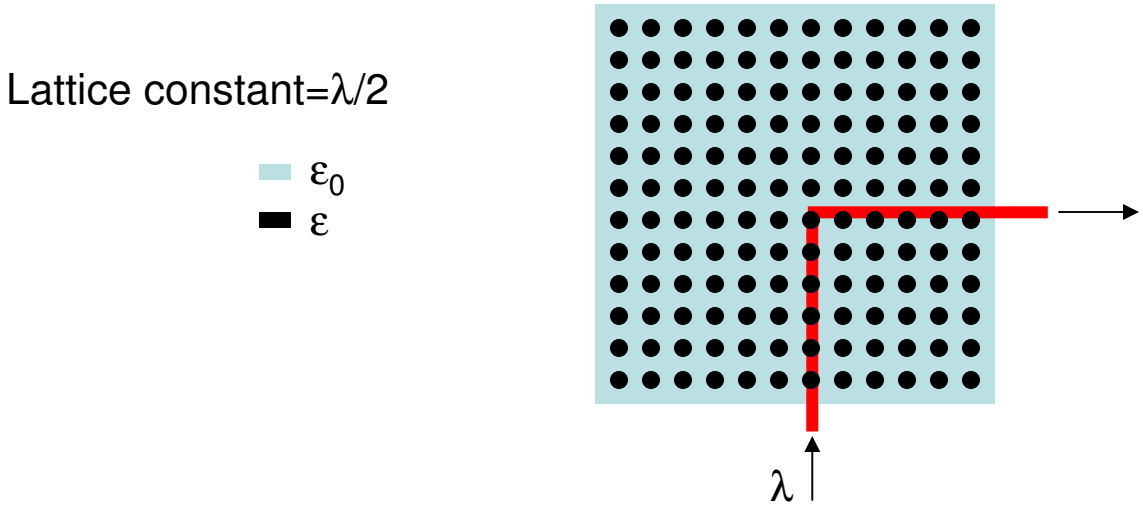
- detector receives SHG light only
- Images localised nonlinearity

Photonic crystal



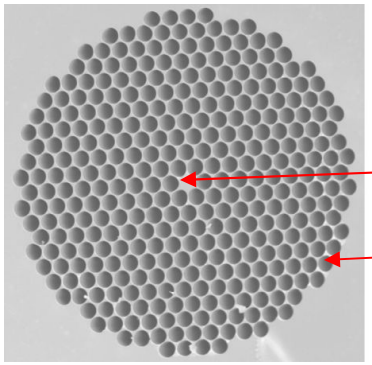
- Period arrangement of dielectric materials (say permittivity ε_0 and ε)
- For lattice constant = $\lambda/2$, light of wavelength λ is prohibited inside the crystal due to Bragg scattering
  - Photonic bandgap
- Bandgap in visible range (λ=400 nm to 700 nm)
  - Lattice constant between 200 nm to 350 nm)

Photon localisation in photonic crystals



- A gap (defect) in the photonic crystal traps light
- A line defect acts as a waveguide
  - Lossless bend around tight corners
- Towards all optical integrated circuits

Supercontinuum in photonic crystal fibre

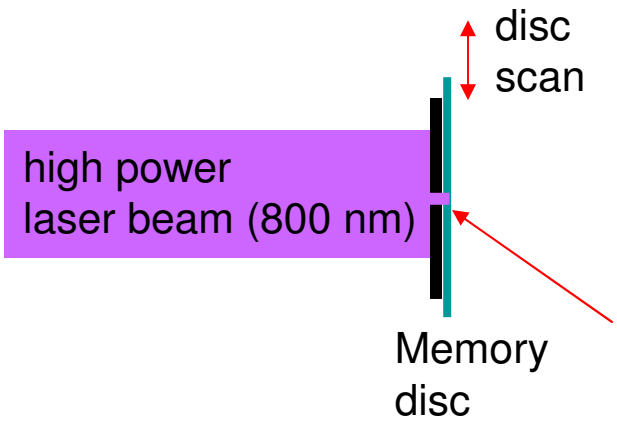


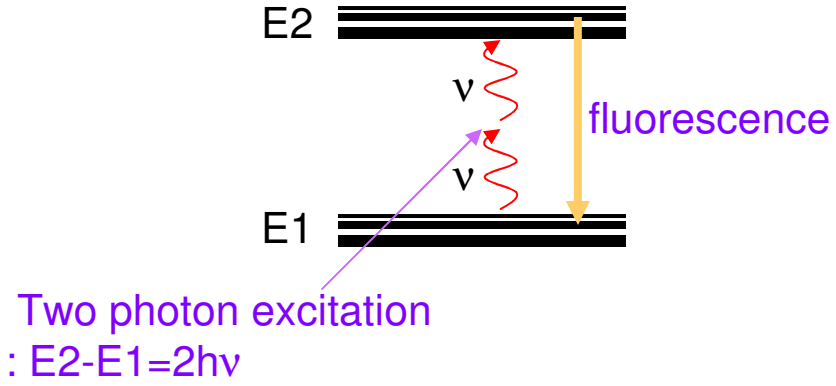
Cross section of a PCF
(source: www.wikipedia.org)

- Properties of photonic crystal confines light to the narrow core
- high intensity of light in the core throughout the length
  - Nonlinear phenomena become prominent
  - Wavelength of an incident laser gets converted into infinite number of smaller components, effectively giving rise to a coherent white light beam (supercontinuum)

Nanoscale confinement of photoprocesses

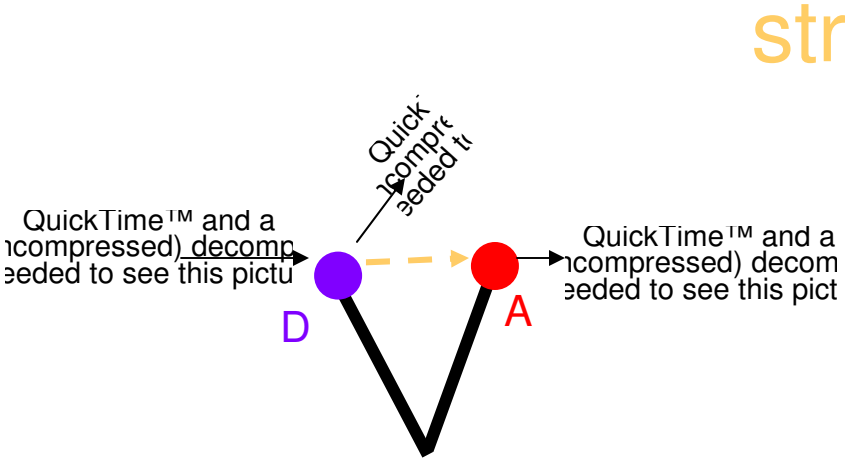
Optical memory



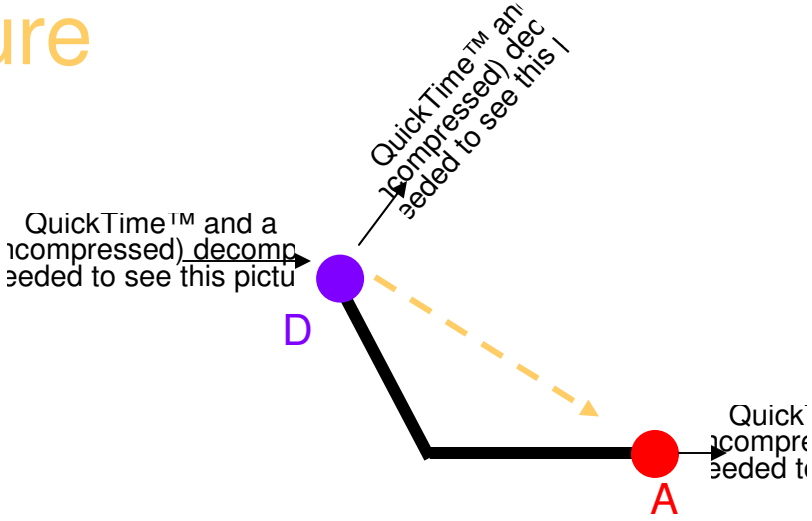


- Two photon excitation leading to photo bleaching
  - No fluorescence emission on further excitation
  - bit value=0
  - quadratic dependence on intensity
- No photo bleaching
  - fluorescence emission on excitation
  - bit value =1
- Bit diameter 70 nm

Nanoscale visualisation of protein structure



Folded protein



Unfolded protein

D : donor fluorescent molecule

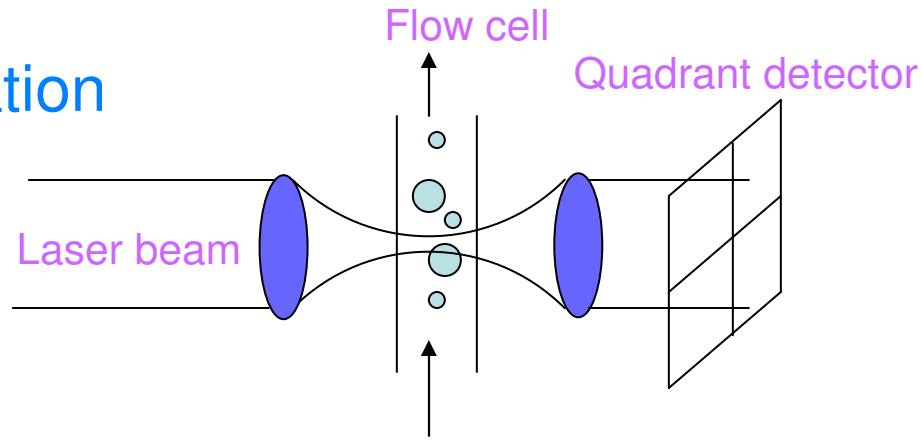
A : acceptor fluorescent molecule

: fluorescence resonance energy transfer (FRET)

- Energy transfer from D to A when they are close by
  - Fluorescence from A
- No energy transfer from D to A when they are far apart
  - No fluorescence from A

Single virus detection

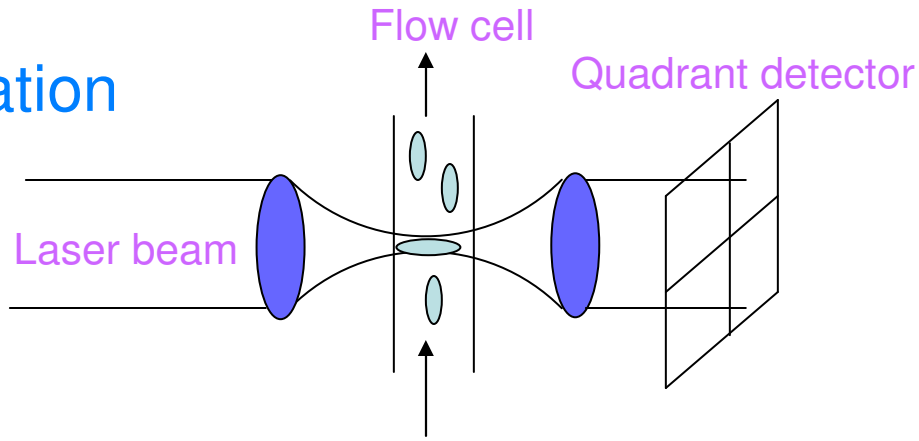
- Size determination



- Particle size dependent pico newton order attractive force towards the focal point
- For smaller particles no attractive force : detector signal vs time is symmetric
- For larger particles strong attractive force : detector signal vs time is asymmetric

Single virus detection

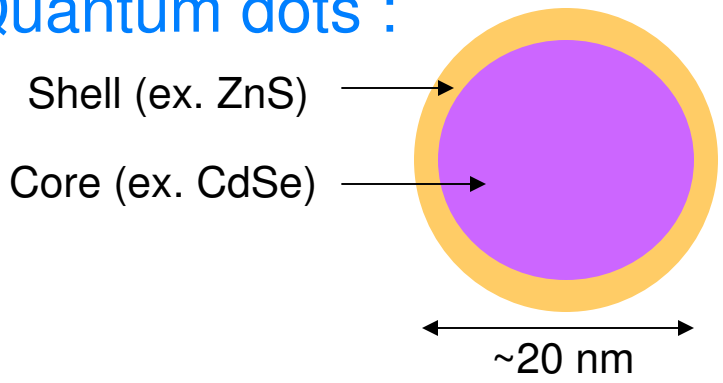
- Shape determination



  - Torque on ellipsoidal particle near focus : aligning it parallel to the optic axis
    - Change in scattering
    - Modulation in differential signal from the quadrant detector
  - No torque on spherical particles

Nanoscale confinement of matter

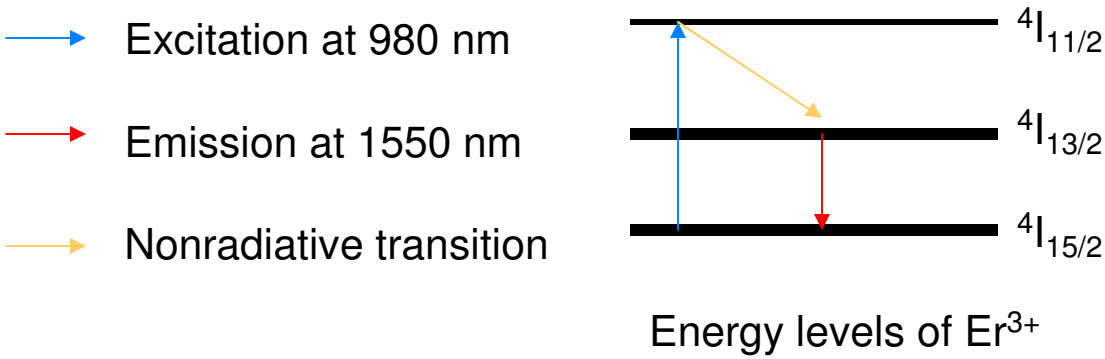
Quantum dots :



Qdots of the same material but of different sizes (source: www.lbl.gov/Science)

- 3D confinement of coulomb-correlated electron-hole pairs
- Properties between semiconductors and discrete molecules
- Size dependent emission wavelength
  - Smaller Qdot emits towards blue
  - Larger Qdot emits towards red
- Application
  - As a fluorescent probe
  - In quantum computers

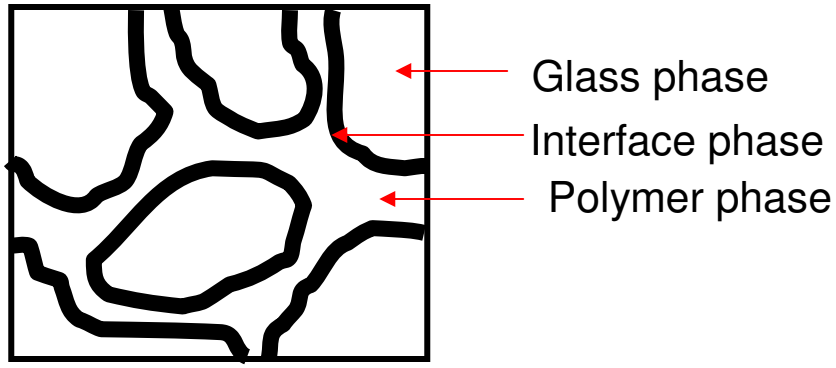
Nanostructured doping

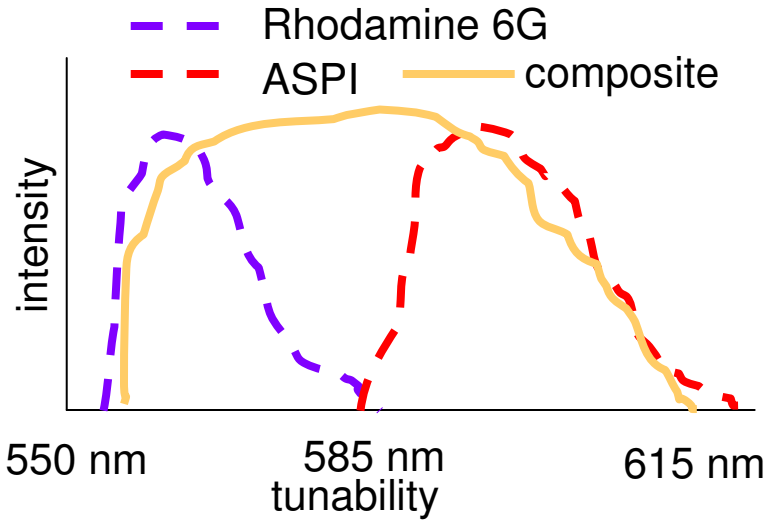


Energy levels of Er^{3+}

- Er^{3+} doped glass: used as lasing and amplifying medium
- Nanostructured Er^{3+} doped glass: Er^{3+} ion is surrounded by low frequency phonon lattice
  - Reduction in nonradiative processes
  - Longer lifetime of the 1550 nm transition

Nanocomposites





- N-methylpyridinium (ASPI) : interface phase
  - Lasing tunability : ~590-610 nm
- Rhodamine 6G : polymer phase
  - Lasing tunability : ~560-572 nm
- Nanocomposite
  - Lasing tunability : 560-610 nm

Conclusion

- Nanophotonics is introduced as the optical science and technology at nanoscale
- Three broad categories of nanophotonics
  - Nanoscale confinement of light, matter and photoprocesses
- A few examples of each category are discussed
- There are ample scopes for further theoretical and experimental works in this area