The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
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IAEA
International Atomic Energy Agency

2328-19

Preparatory School to the Winter College on Optics and the Winter College on Optics: Advances in Nano-Optics and Plasmonics

30 January - 17 February, 2012

SNOM - Scanning near-field optical microscopy

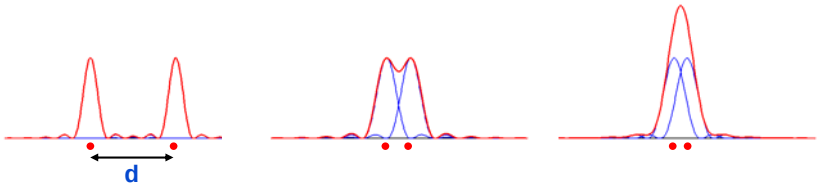
A. Zayats
The Queen's University of Belfast
U.K.

Scanning near-field optical microscopy

- Optical processes on the nanoscale
- Optical properties of materials on the nanoscale
- Light manipulation on the nanoscale

Microscopy

Robert Hooke,
***Micrographia*, 1665**



Diffraction limited resolution: d ~ 0.5 λ/N.A.

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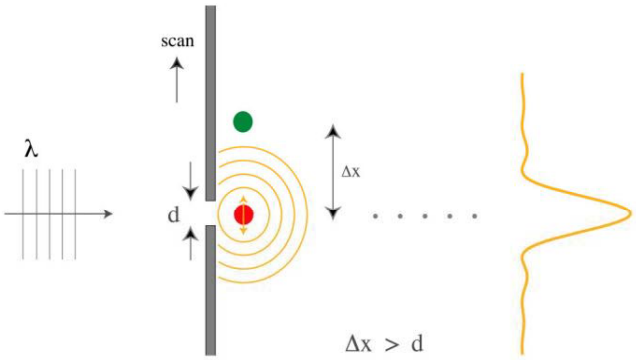
Nanoscopy

Scanning near-field optical microscopy



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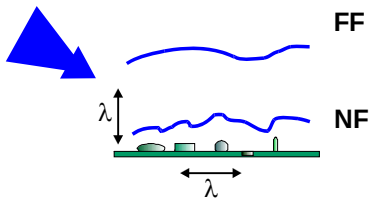
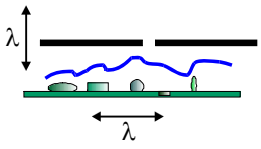
Scanning near-field optical microscopy



First idea

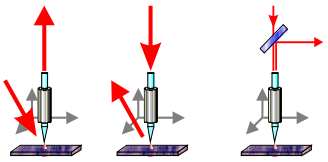


Can access the near-field !!!

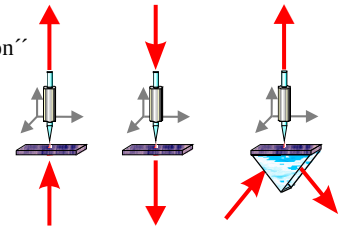
Scanning near-field optical microscopy

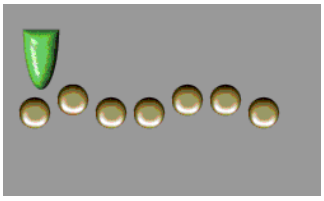
Illumination Modes

``Reflection´´



``Transmission´´





- **Optical image**
- **Topographic image**

Detection Modes

- Reflection
- Transmission
- Photoluminescence
- Harmonic generation
- Raman scattering

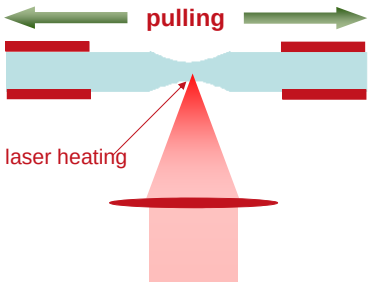
Scanning near-field optical microscopy

How to make it work ?

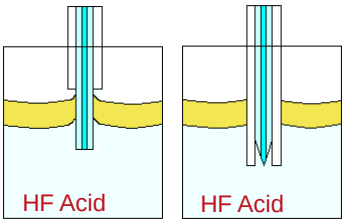
- **Sub-wavelength aperture**
- **Distance control between a tip and a surface**

Scanning near-field optical microscopy

SNOM fibre probe fabrication

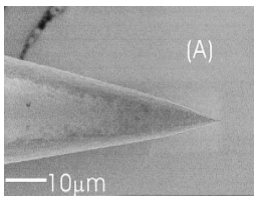


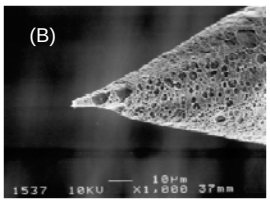
Fibre pulling

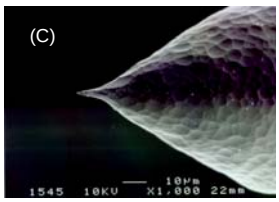


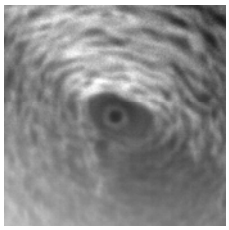
Fibre etching

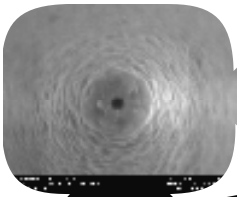
Scanning near-field optical microscopy









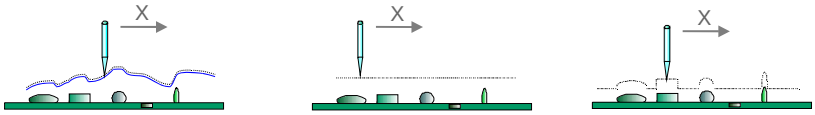


Uncoated fibre tips: ~ 100 nm

Metal-coated fibre tips: ~ 50 nm

Scanning near-field optical microscopy

Distance regulation modes

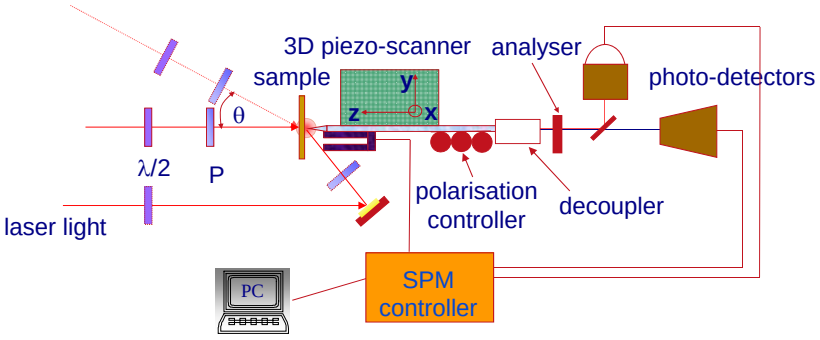


Constant intensity | **Constant height** | **Constant distance**

- **Shear-force**
- **AFM**
- **STM**

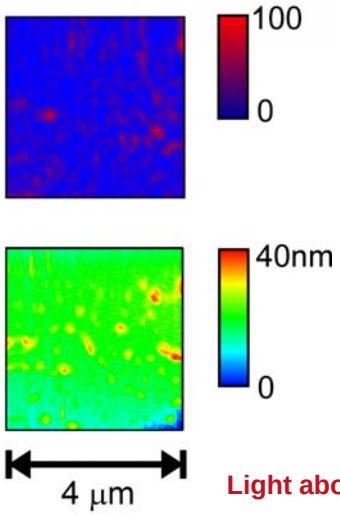
- **Optical image**
- **Topographic image**

Scanning near-field optical microscopy



Scanning near-field optical microscopy

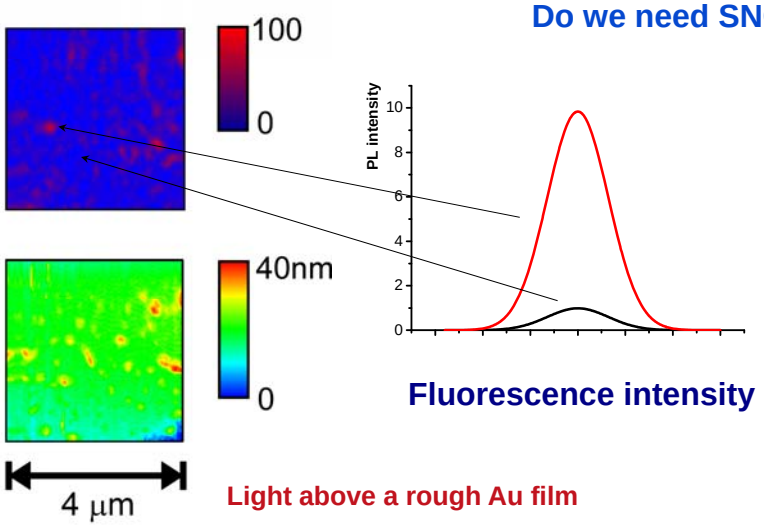
Do we need SNOM ?



Light above a rough Au film

Scanning near-field optical microscopy

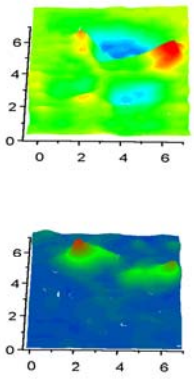
Do we need SNOM ?

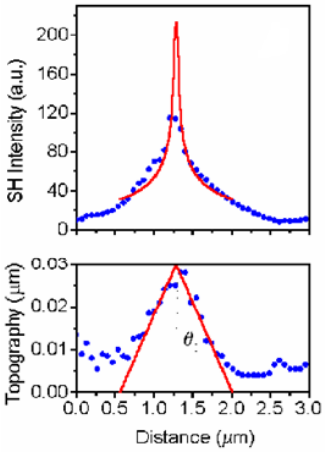


Fluorescence intensity

Light above a rough Au film

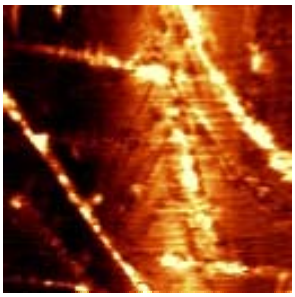
Scanning near-field optical microscopy

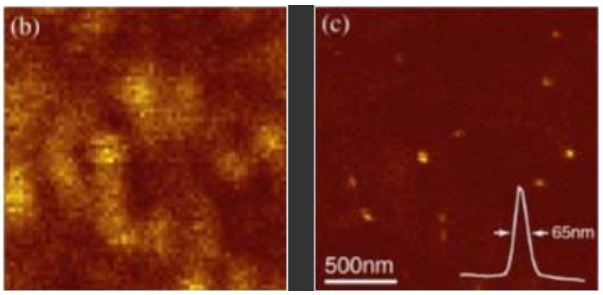




Local enhancement: 20
Average enhancement: 1.2

Scanning near-field optical microscopy





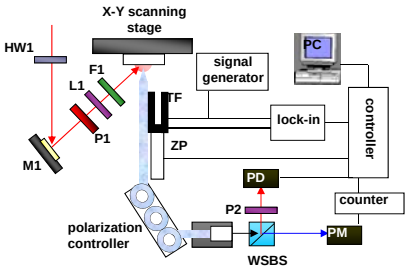
SNOM image:
PL of polymer chains
(Zayats et al)

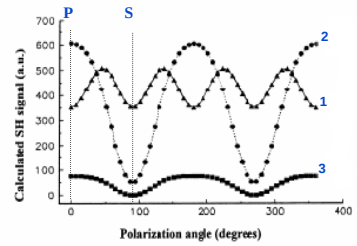
Conventional microscopy

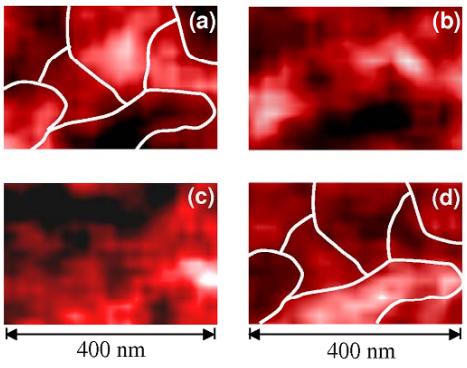
SNOM image

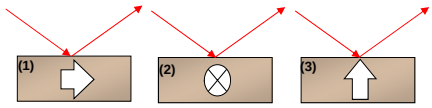
Imaging fluorescence of single molecules (Sandoghdar)

Ferroelectric domain imaging with SHG SNOM

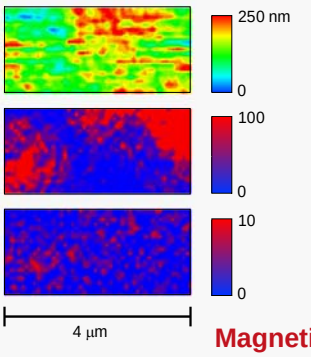




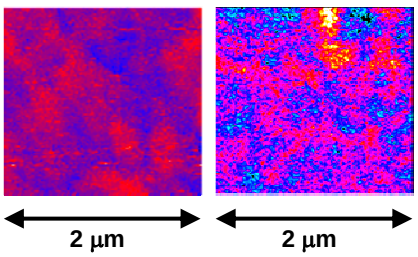




Magnetic and ferroelectric domain imaging



Magnetic domains in Ni single crystal



Domains and domain walls in PZT ceramics

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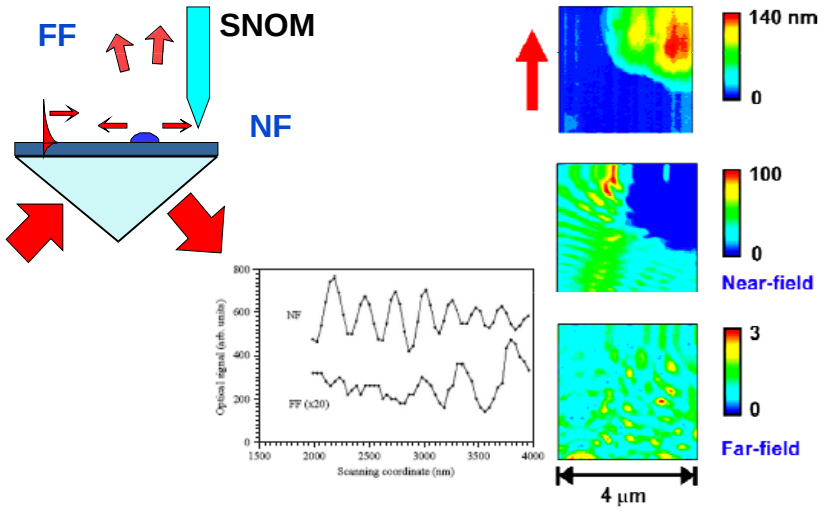
SPP imaging



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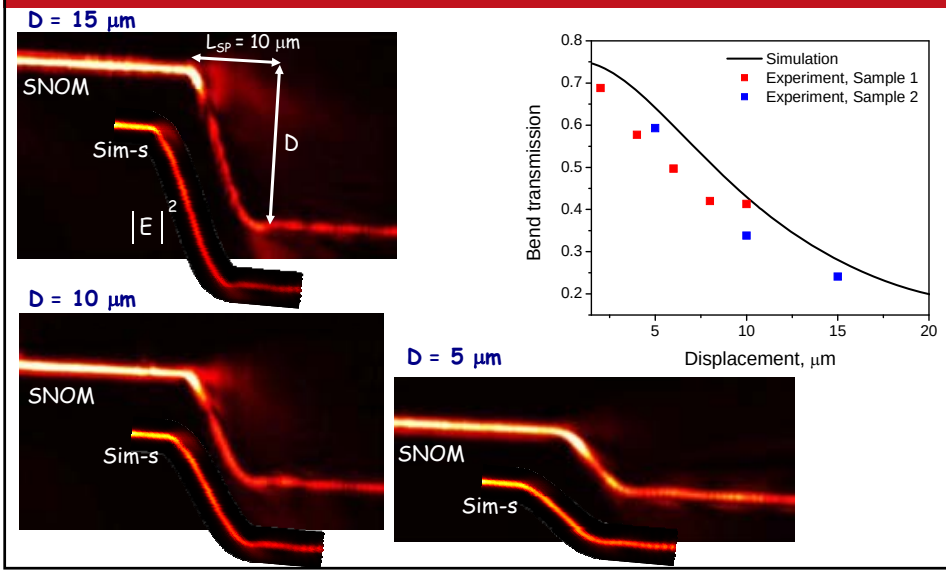
Nanophotonic components



Problems with SNOM

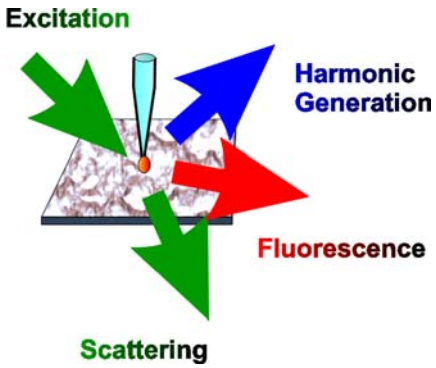
Aperture-based SNOM: resolution limitations

- **Small (sub-wavelength) aperture**
- **Low light throughput**
- **Reproducible and reliable fabrication of SNOM probes**

- **Influence of a probe on the field distribution**

Apertureless SNOM

Aperture less SNOM



Nanoscale metal particle as an optical antennae

Nanoscale light sources

Nanoscopic "light bulb"

Nanosize aperture

Nanoscopic fluorescence

Harmonic generation

- **Strongly confined**
- **Tuneable**

Aperture less SNOM

$I_{SH} \sim [\Sigma \chi_i^{(2)} \alpha_i(2\omega) \alpha_i^2(\omega) + \chi_t^{(2)} \alpha_t(2\omega) \alpha_t^2(\omega)]^2 E^4$

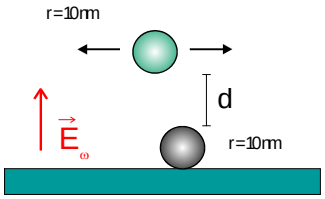
$\alpha_{eff}(\omega) = f(\alpha_i, \alpha_j, d_{ij}, \mathbf{E}/E)$

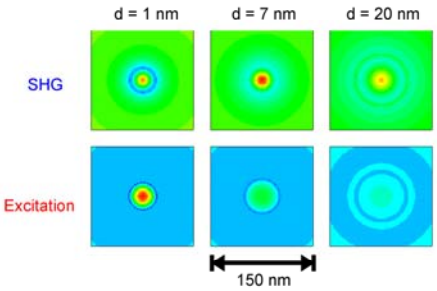
- Resonant field enhancement
- Geometrical field enhancement
- Tip-surface, defect-defect interaction

$\chi_i^{(2)} >> \chi_t^{(2)}$
Aperture less excitation/scattering SHG SNOM

$\chi_i^{(2)} << \chi_t^{(2)}$
Nanoscopic SH light source

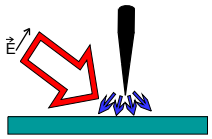
Aperture less SHG SNOM

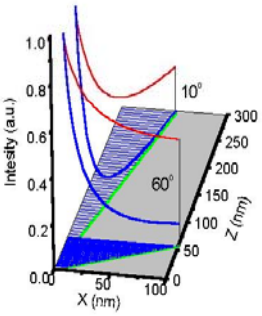


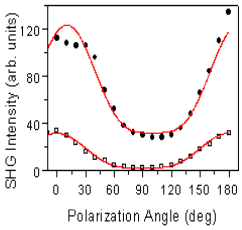


Aperture less SHG SNOM model:
Silver sphere coated with nonlinear molecules
Silver sphere on a dielectric surface
740 nm excitation

Nanoscale light sources

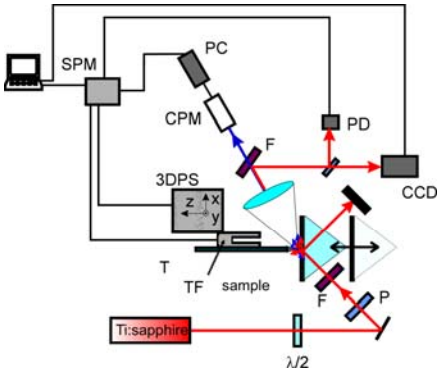






SHG localisation at a conical metal tip apex

Apertureless SHG SNOM



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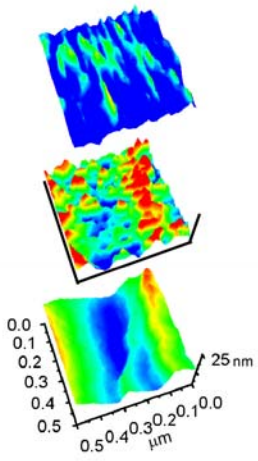
Aperture less SNOM



s-polarised excitation

p-polarised excitation

Rough gold film
Silver coated tip
790 nm Ti:sapphire laser

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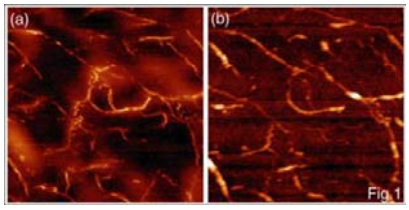
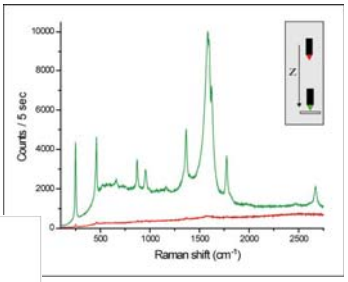
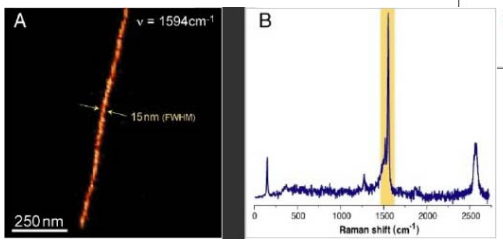
Aperture less SNOM







Optical resolution : ~12 nm
(Novotny et al, 2005)

Hyperspectral SNOM imaging ("white light" SNOM)

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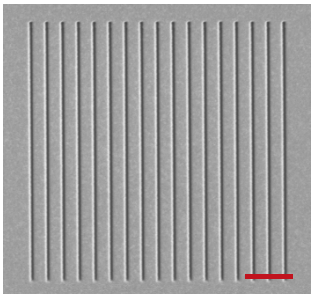
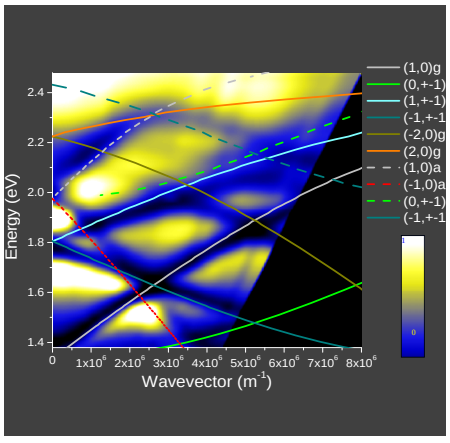
Hyperspectral SNOM





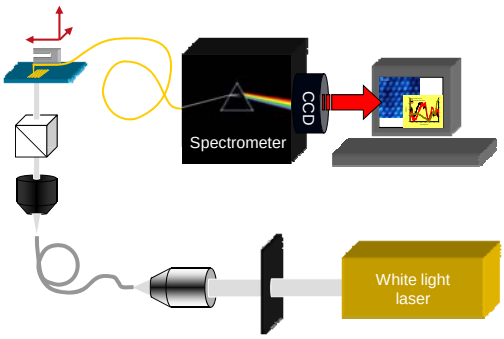
Normal incidence:

- **575 nm: field max on slits**
- **625 nm: field max between**

Plasmonic resonances, fluorescenece etc…

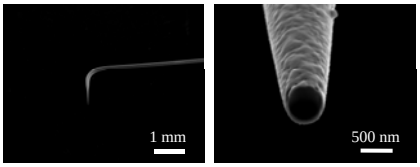
Hyperspectral SNOM

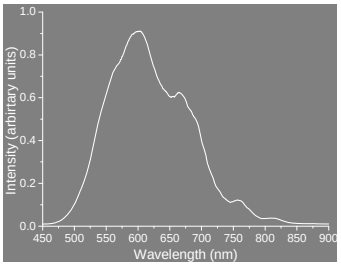
- Broadband laser+ spectrometre + high speed CCD
  - Full spectrum on each pixel of the image
  - 131072 spectra
  - false movie



Hyperspectral SNOM

- SNOM probes
  - Pulled optical fibre
  - Au coated
  - Use FIB to create aperture (50 – 500 nm)
- Normalise near-field signal to the transmission through the probe





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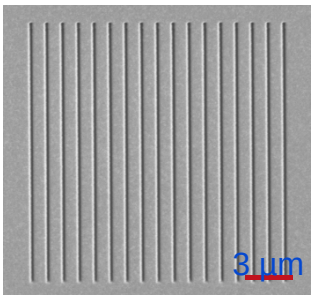
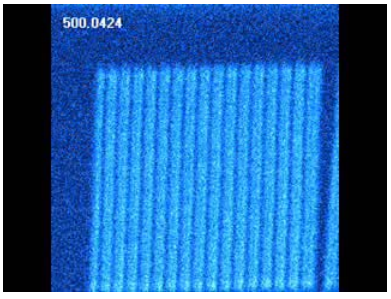
Hyperspectral SNOM

Bloch mode field distribution





polarisation

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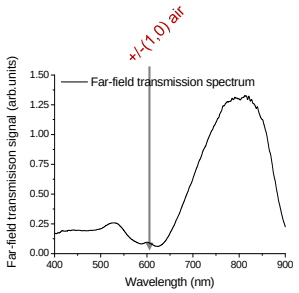
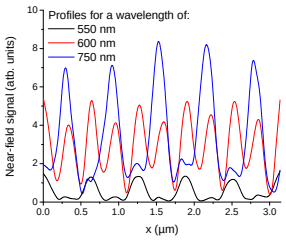
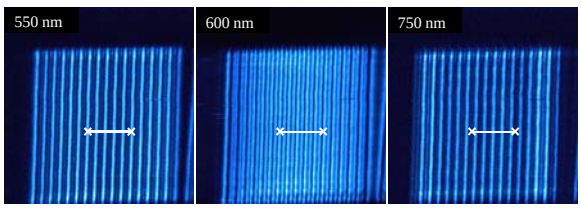
Hyperspectral SNOM







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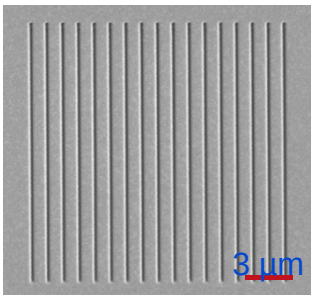
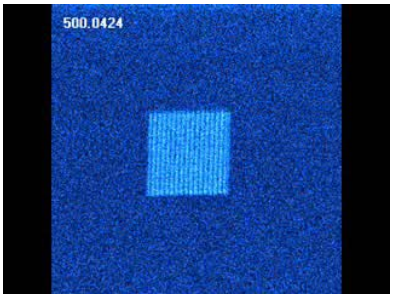
Hyperspectral SNOM

SPP coupling to the smooth metal film





polarisation

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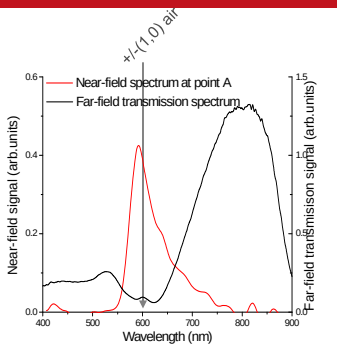
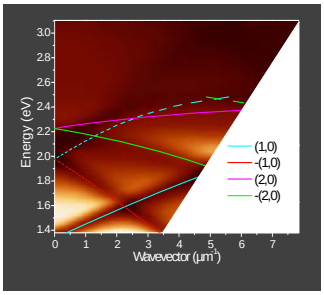
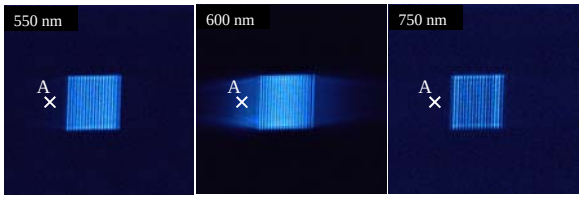
Hyperspectral SNOM







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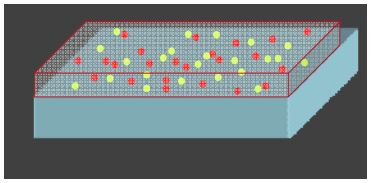
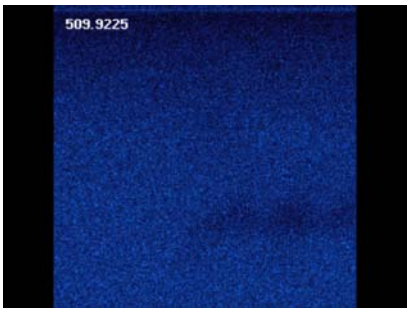
Hyperspectral SNOM





Fluorophores emitting at different wavelengths

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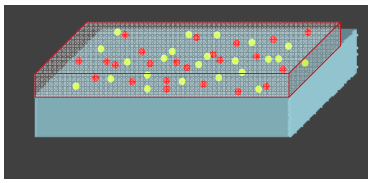
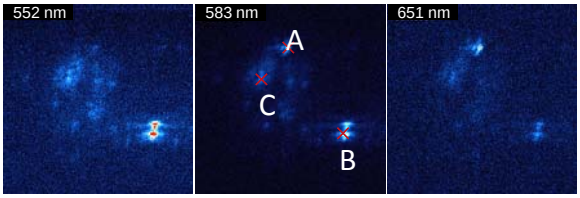
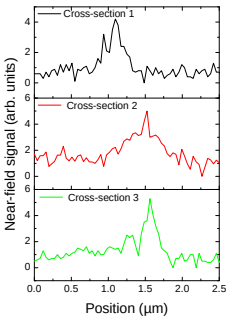
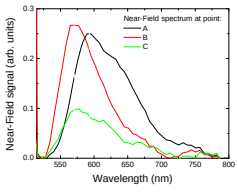
Hyperspectral SNOM









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Take home messages (3):

- Scanning near-field optical microscopy (down to 50 nm resolution)
- Apertureless scanning near-field optical microscopy (down to 10 nm maybe less ?)
- Combination of SNOM and nonlinear optics
- Imaging, Characterisation & Modification on the Nanoscale
  - Surface defects and adsorbates
  - Single molecule imaging and sensing
  - Nonlinear materials and devices
  - Ferromagnetic and ferroelectric materials
  - Nanolithography
  - high density data storage
- Photochemistry and Photobiology on the Nanoscale

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- D. Richards, A.V. Zayats, Eds., *Nano-optics and near-field optical microscopy* (Artech, Boston, 2008), ISBN: 978-1-59693-238-8.
- Hyperspectral imaging with scanning near-field optical microscopy," Optics Express, vol. 18, 2010, 16513.

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