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Patterning of plasmonic structures for (bio) sensing

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Petru Ghenuche, Romain Quidant

Biosensing in the nanoscale

- Confining light to the nanoscale
- Implementing a nanostructured biosensor
  - Fabrication
  - Characterisation
- Enhancing light-matter interaction

Diffraction limit

Light cannot be confined to linear dimensions much smaller than $\lambda/2$ (Abbe 1873)

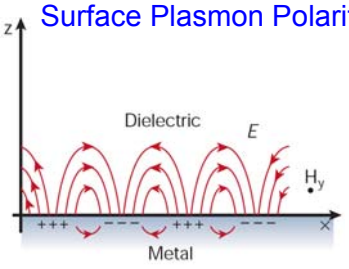
This "diffraction limit" constraint can be expressed as a particular case of Heisenberg's uncertainty principle:

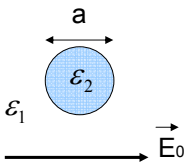
$$\Delta x |\boldsymbol{p}_x| = \frac{h}{2\pi}$$

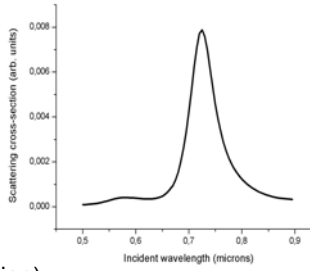
where $p_x = \boldsymbol{\hbar k_x}$

Surface Plasmon Basics

Surface Plasmon Polariton Localised Surface Plasmon



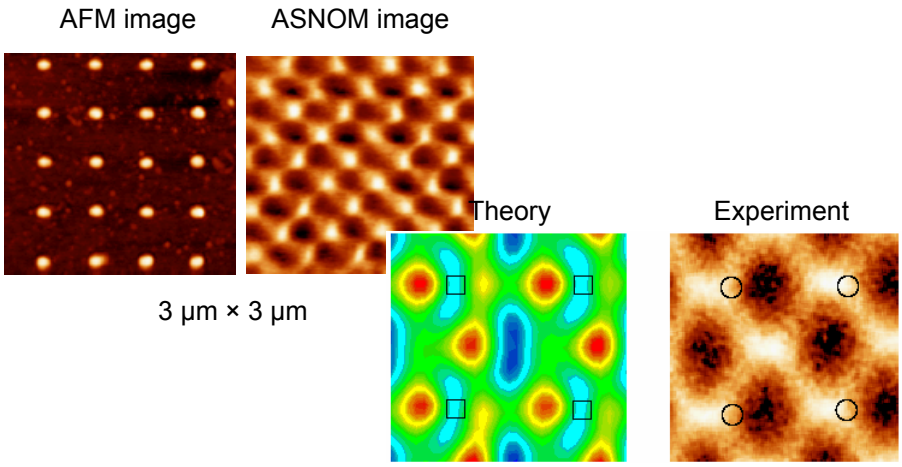




If $a << \lambda \Rightarrow$ dipole:
(electrostatic approximation)

- Field localization and enhancement
- Strong scattering and absorption
- Highly sensitive to changes in the environment

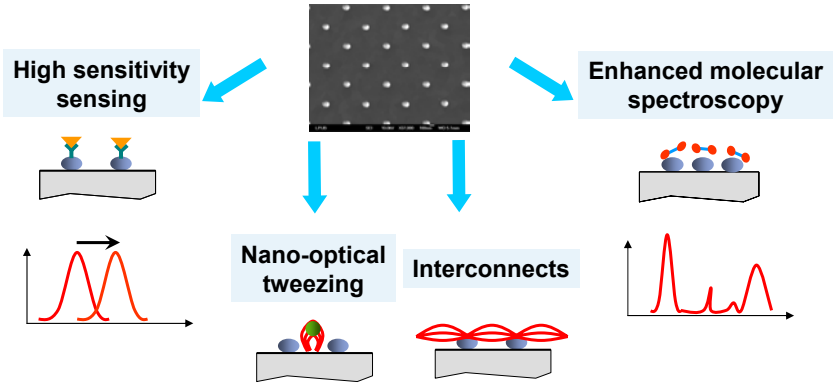
Sub-wavelength patterning of the optical near field



R. Quidant et al., "Sub-wavelength patterning of the optical near-field", Opt. Express **12**, 282-287 (2004)

(Localised) plasmonics

Localised surface plasmons can be used for nano- optics, manipulation, sensing, switching, interconnects…



See e.g. W.L. Barnes et al., "Surface plasmon subwavelength optics," *Nature* **424**, 824 - 830 (2003)

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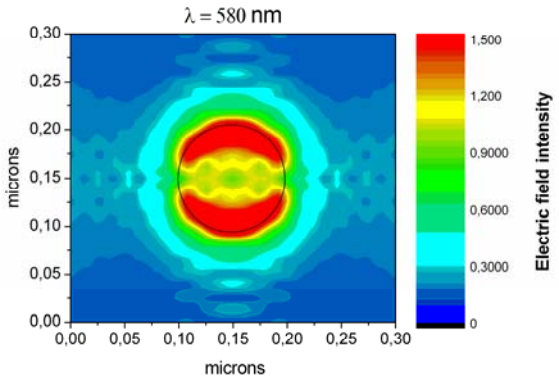
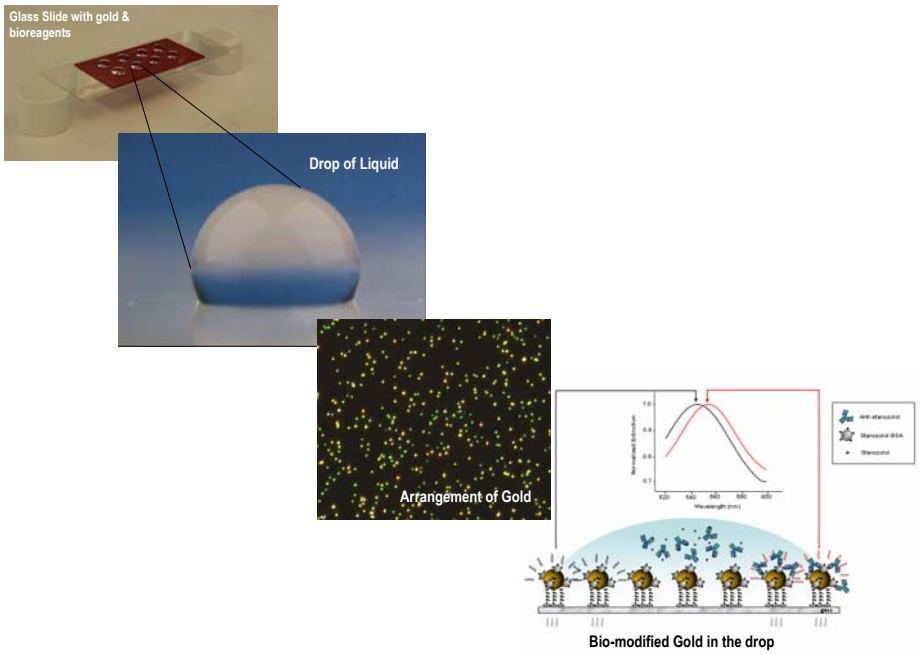
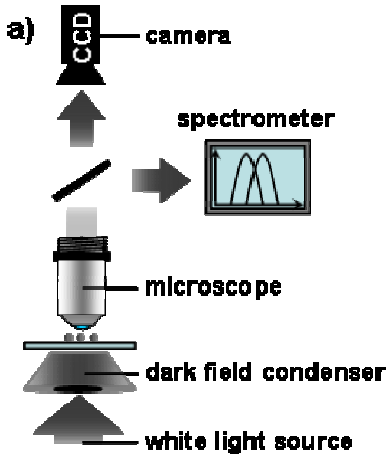
“Single particle” sensing

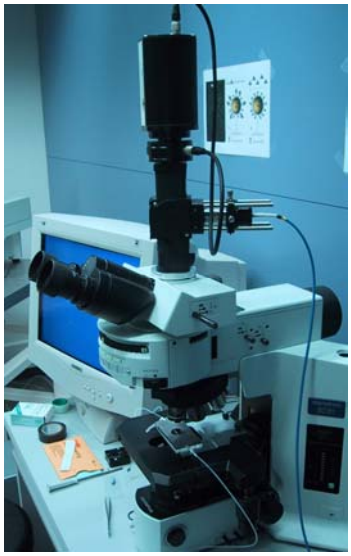
Local field enhancement can be observed around “isolated” metal nanoparticles when the plasmon is excited





Schematic system setup

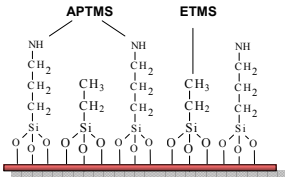




Chemical modification of the glass surface

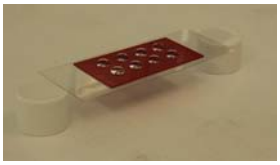
Selective salinization controls density of gold colloid (subsequently bound to surface)

APTMS binds gold, ETMS doesn't

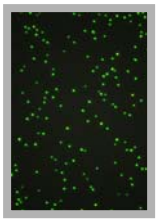


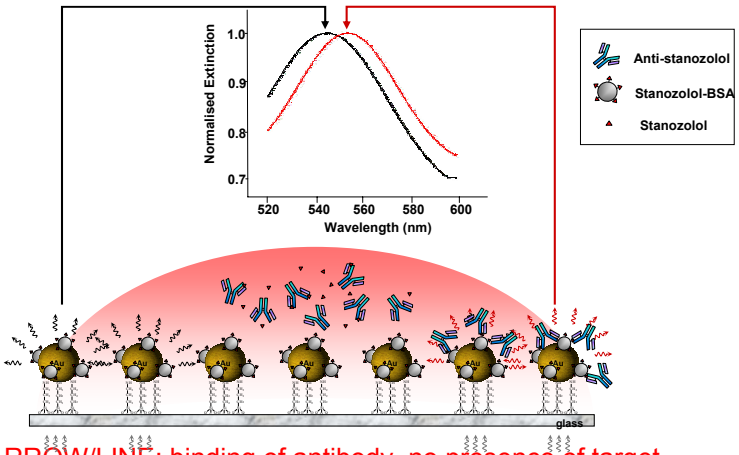
Numerous investigation zones

Each drop can be a different solution
different sensor!



Sensor working principle

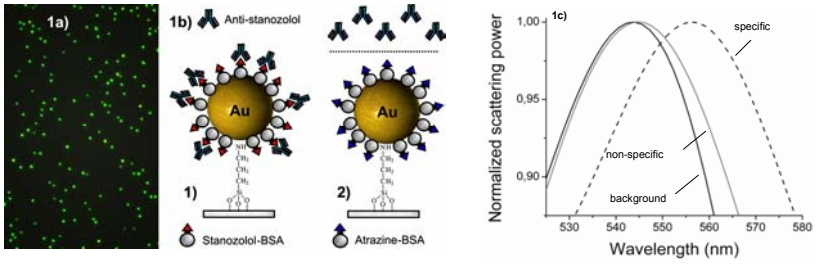




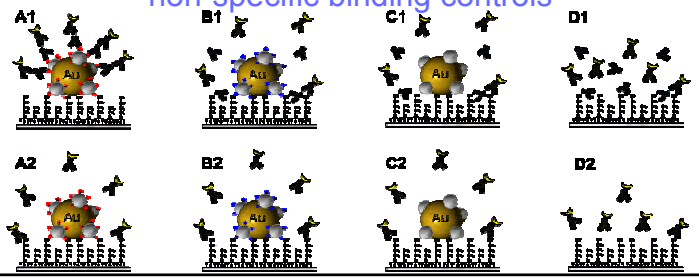
RED ARROW/LINE: binding of antibody, no presence of target stanozolol

BLACK ARROW/LINE: antibody bound by target and washed away

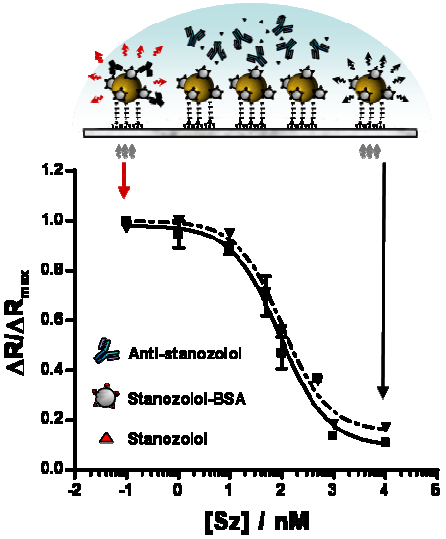
Do we have specific binding?



non-specific binding controls



Quantifying sensor response



RED ARROW/LINE: no presence of target stanozolol

BLACK ARROW/LINE: all antibody bound by target and washed away

(■) LPR

(▼) spectrophotometric

M. Kreuzer et al., *Biosensors & Bioelectronics* **21** (7) (2006)

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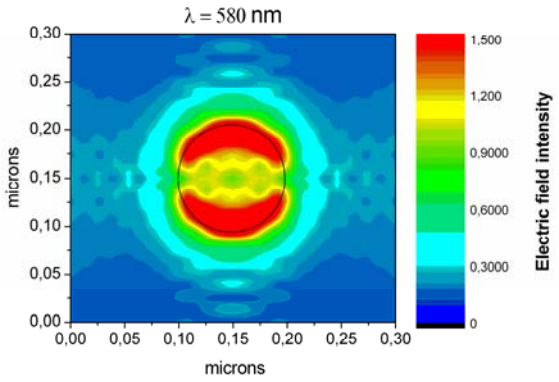
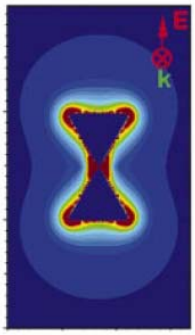
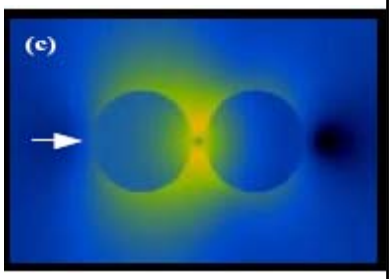


Field enhancement: geometry and separation tuning

E. Hao and G. C. Schatz,
Chem. Phys., 120, 357 (2004)

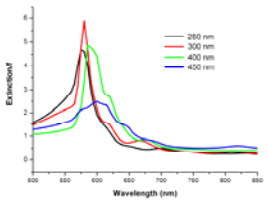


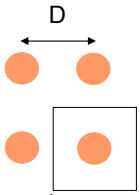
J. Kottmann and O. J. F. Martin,
Optics Express, 8, 655 (2001)



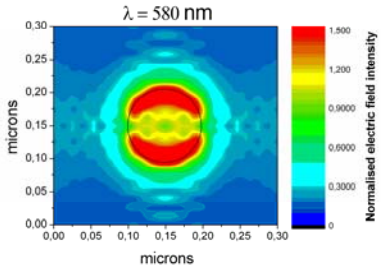
Previous studies (elongated structures, dimers, particles with different shapes)
Field enhancement $\Gamma \approx 10^{3\text{-}4}$

Enhancing sensitivity: arrays

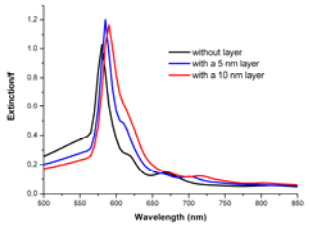




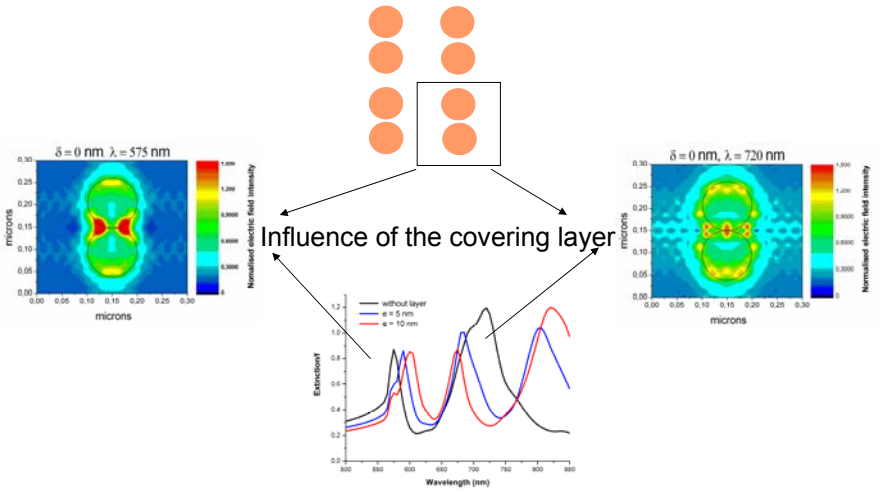
Electric near-field map



Influence of the covering layer

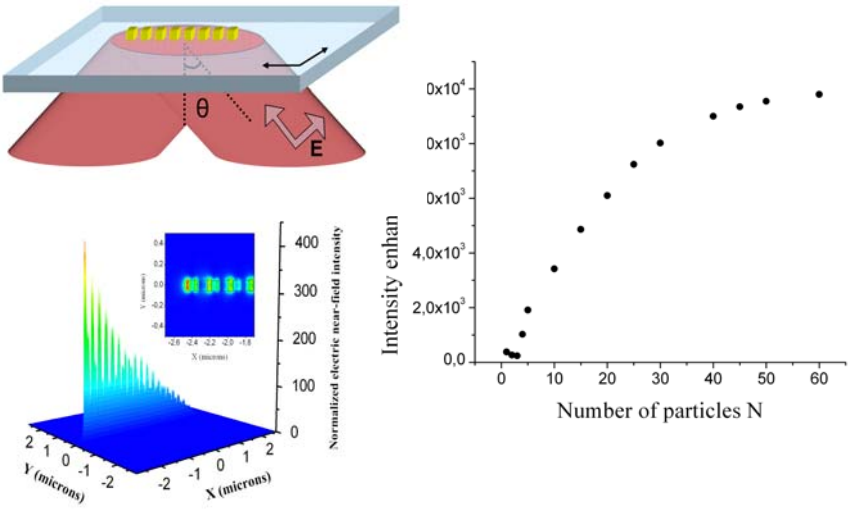


Enhancing sensitivity: dimer arrays



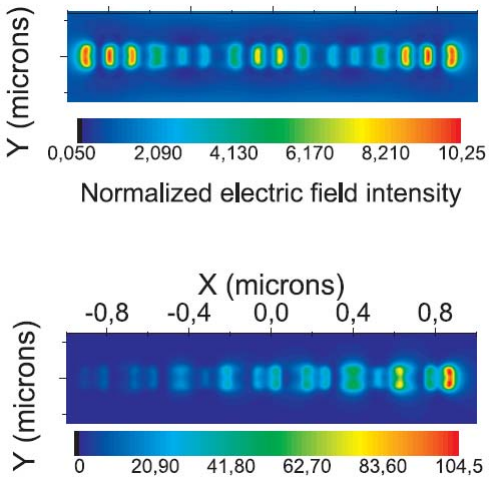
S. Enoch et al., Optics Exp. **12**, (2004)

Field enhancement: particle arrangements

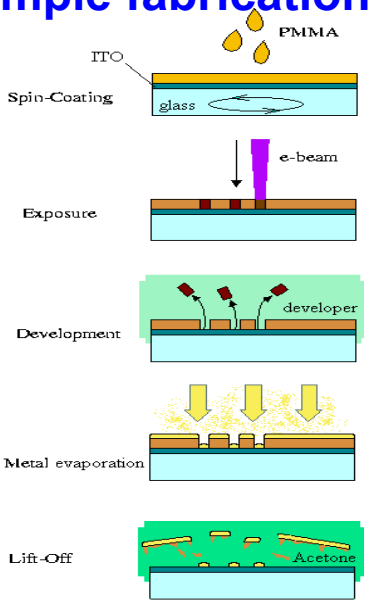


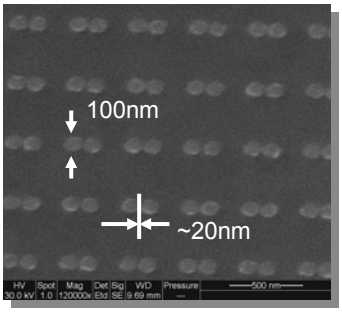
P. Ghenuche et al., Opt. Lett. **30**(2005)

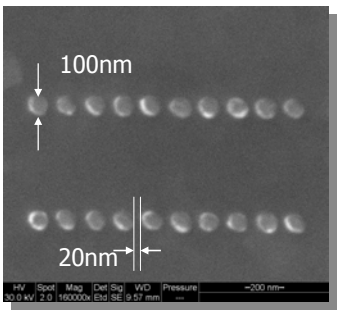
Field enhancement in nanoparticle chains



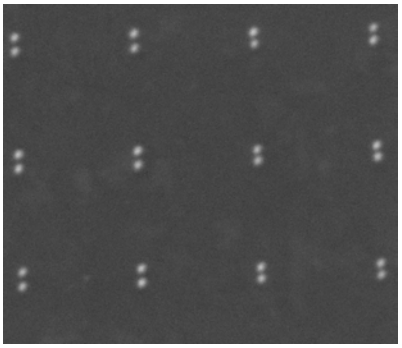
Sample fabrication

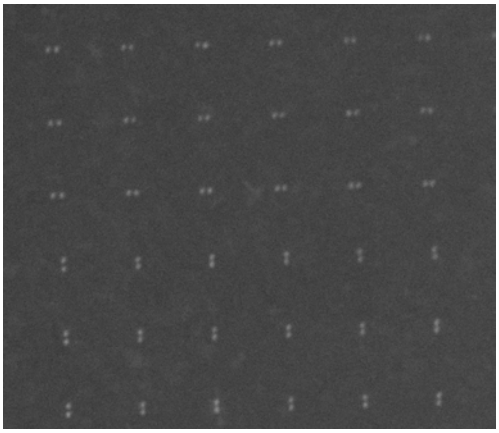




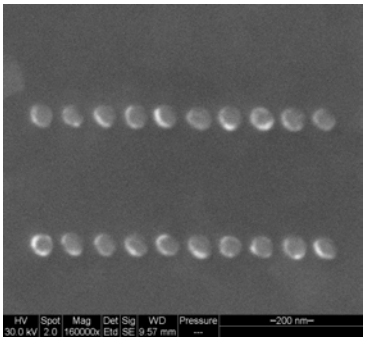


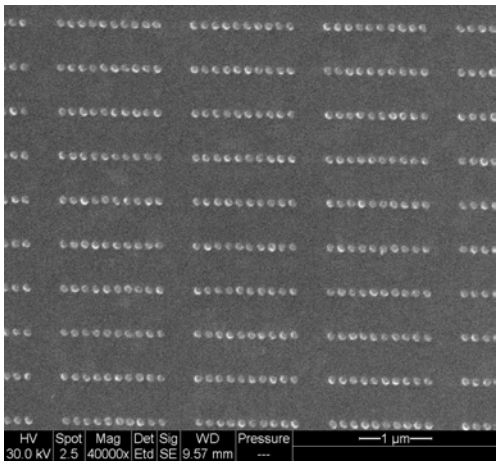
Dimer arrays





Nanoparticle chains





Summary

- Localised surface plasmons are ideal candidates to be used as biosensors
- Random arrangements of gold nanoparticles can achieve competitive sensitivity
- Sensitivity and accuracy can be significantly improved by using lithographically patterned samples

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