

Plasmonique pour la biophotonique

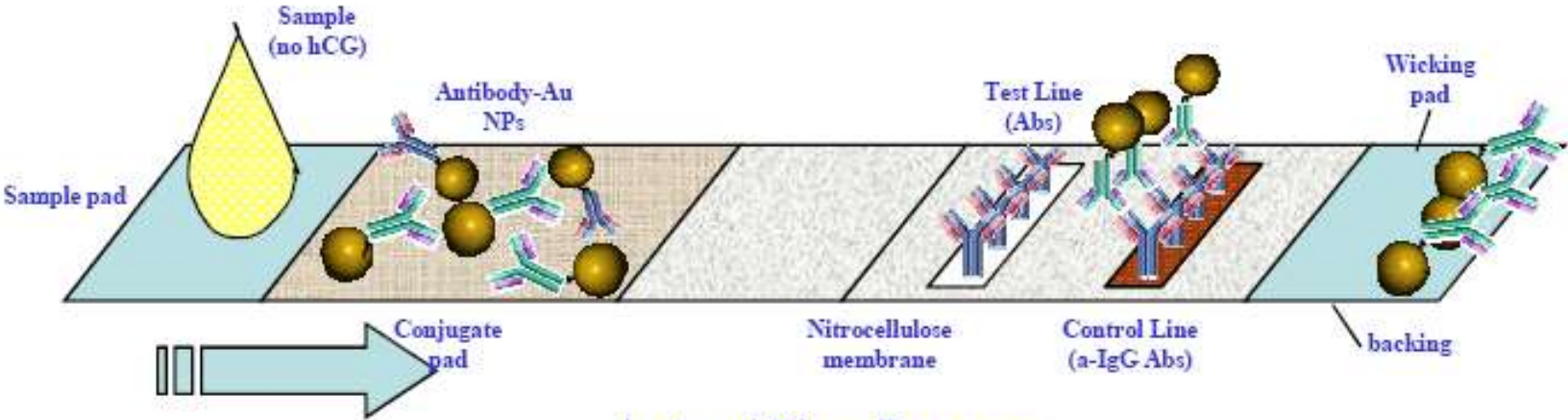
Jérôme Wenger



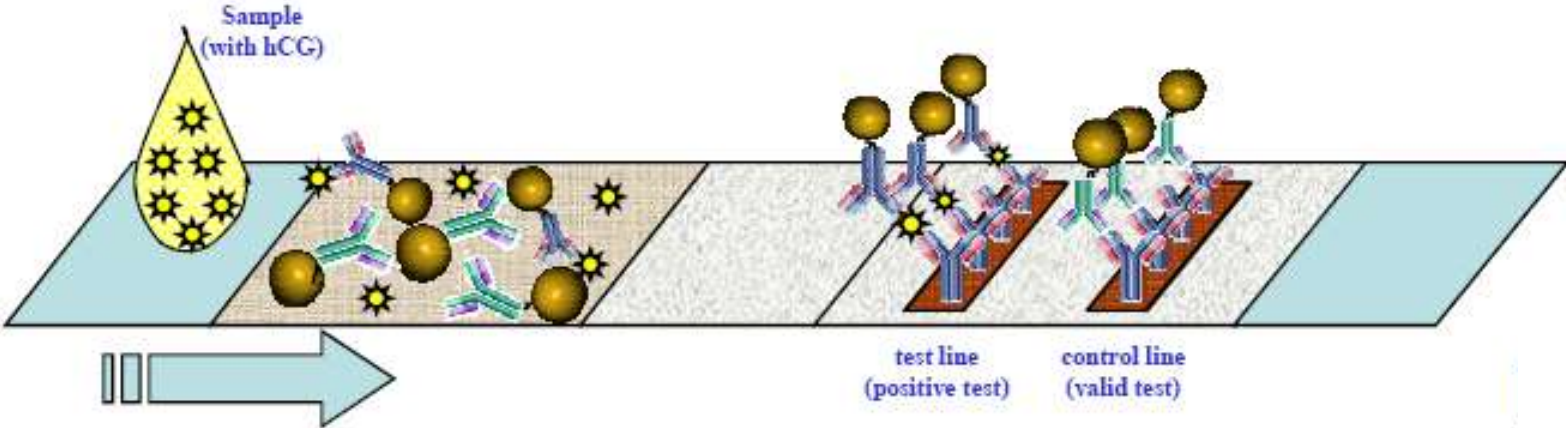
Plasmonique pour la biophotonique

- Capteurs
- Emissions exaltées
- Thermoplasmonique
- Pincés optiques

Le test de grossesse : Première application bioplasmonique



Lateral Flow Process



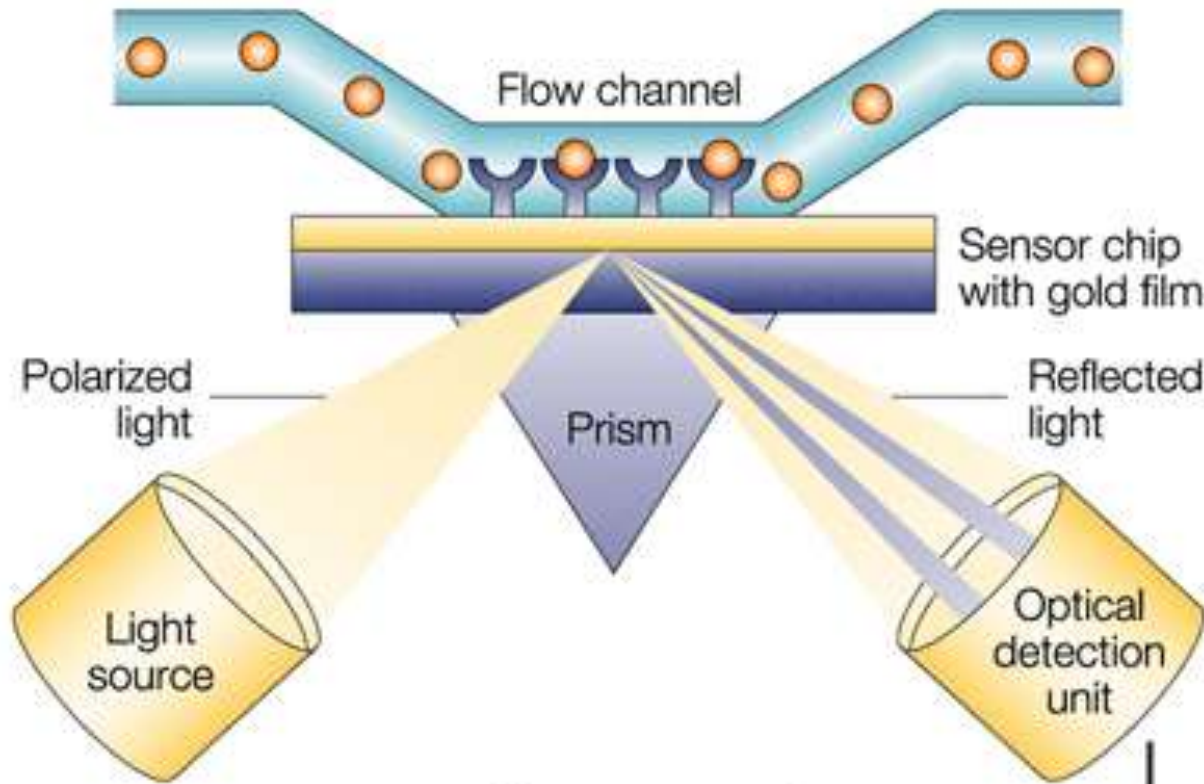
Lateral Flow Process

Capteurs à résonance plasmon de surface

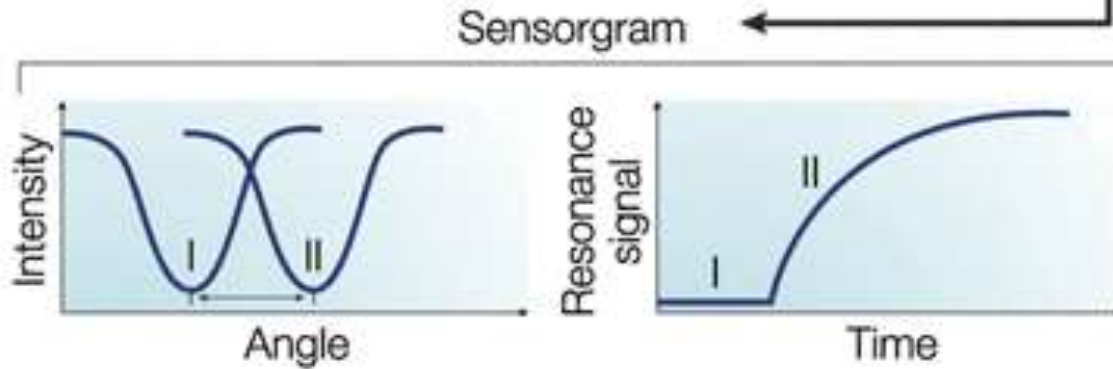


- Détection de molécules sans marquage
- Temps réel
- Accrochage sélectif des molécules sur une surface d'or

Capteurs à résonance plasmon de surface



$$k_{x,SP} = \frac{\omega}{c} \sqrt{\frac{\epsilon_m \epsilon_d}{\epsilon_m + \epsilon_d}}$$



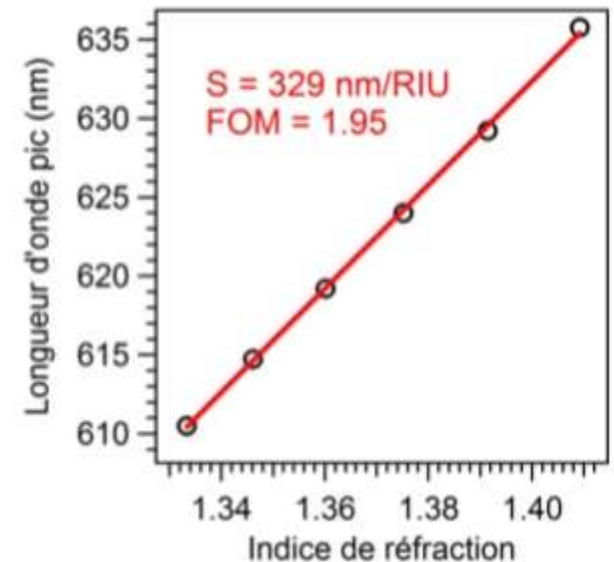
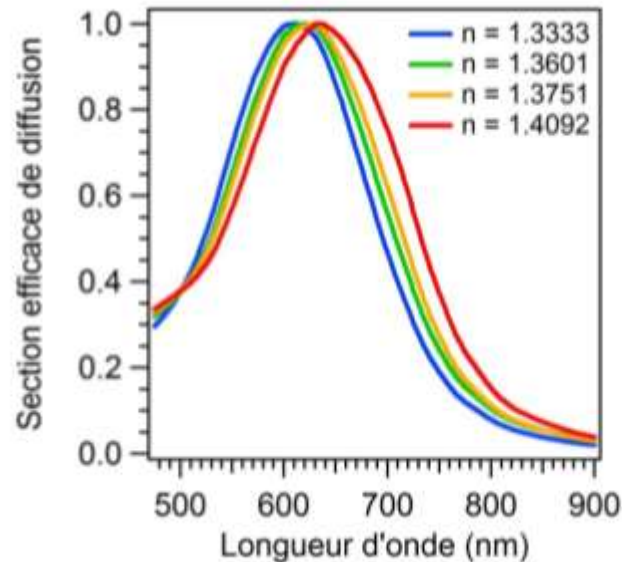
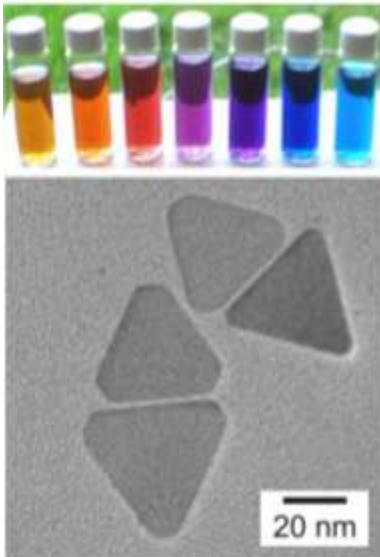
CBW Agents Detectable with SPR

| Type of Agent | Examples of Agents of Interest | Current Direct Detection level | Amplification/ verification |
|-----------------|---|---|---|
| Protein toxins | SEB Ricin Botulinum toxin, | 100 pM (2.8 ppb) 20 nM (600 ppb; current level) <50 nM (7.5 ppm, current level) | Yes (100 fM; 2.8ppt) Not yet done Yes |
| Spores | <i>B. Anthracis,</i> BG spores (simulant) | ~10 ⁵ cfu/ml (prelim) | Not yet done |
| Viruses | Small pox, Marburg, Ebola, Encephalitis, Hemorrhagic fever Flu (as a model system) | ~10 ⁹ pfu (prelim expts) | Yes (prelim) |
| Microbial cells | <i>Y. pestis</i> <i>F. tularensis</i> <i>E. Coll</i> | In progress ~5x10 ⁴ cfu/ml (prelim) In progress | Yes Not yet done Yes |
| CW (organics) | VX Soman Sarin tabun <i>DPMP(stimulant</i> } Domoate Cortisol DNP | Antibodies tested at ECBC 50 nM (15 ppb) 750 pM (271 ppt) ~1 uM (340 ppb) | |

Local Surface Plasmon Resonance Sensor

Nanoparticules individuelles colloïdales

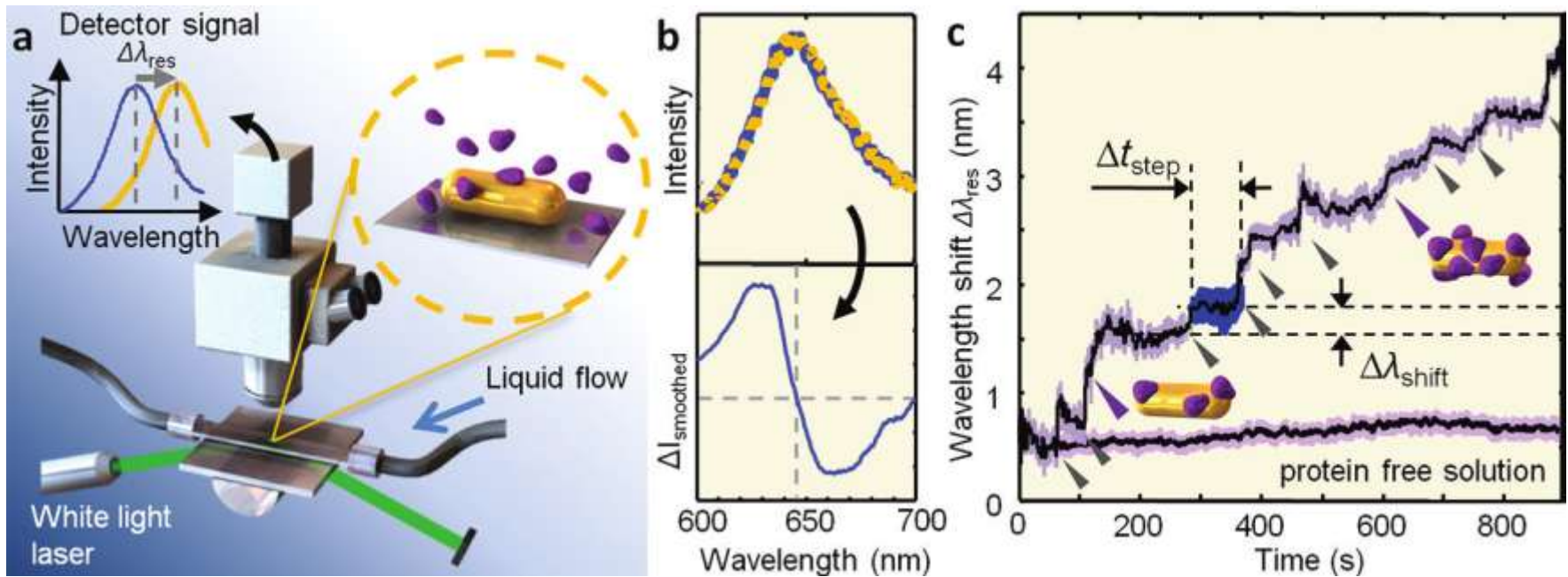
- Plus forte concentration du champ à la surface
- Simplicité d'utilisation et d'intégration



$$\alpha(\omega) = 4\pi\epsilon_{ref}a^3 \frac{\epsilon_{gold}(\omega) - \epsilon_{ref}}{\epsilon_{gold}(\omega) + 2\epsilon_{ref}}$$

Local Surface Plasmon Resonance Sensor

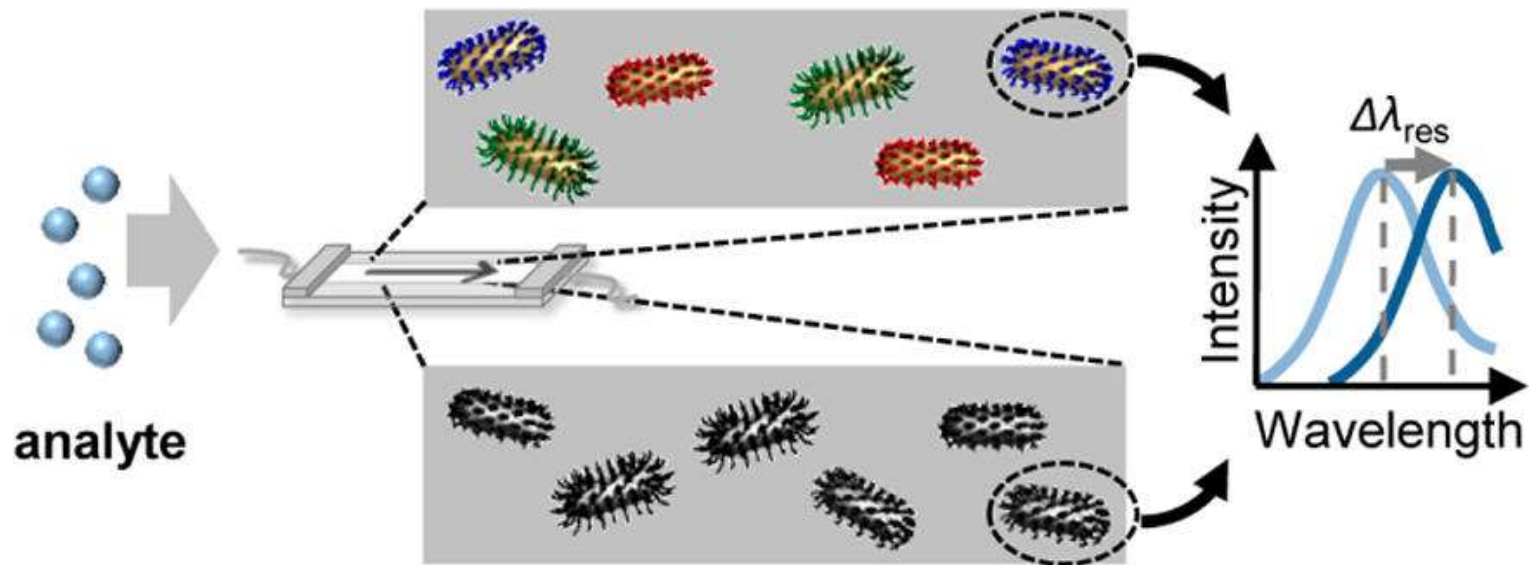
Sensibilité à la molécule unique avec des nanobatonnets d'or



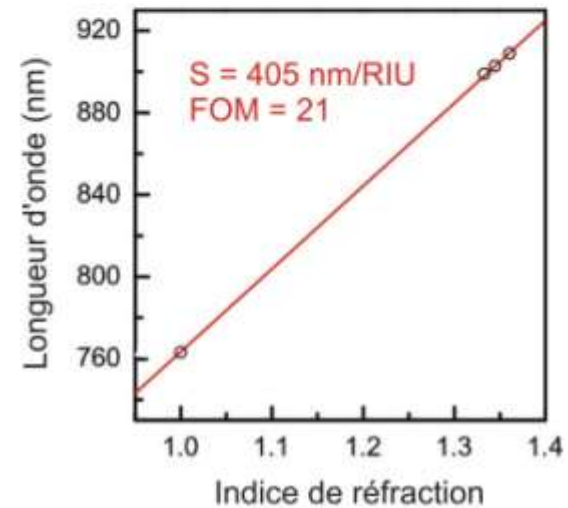
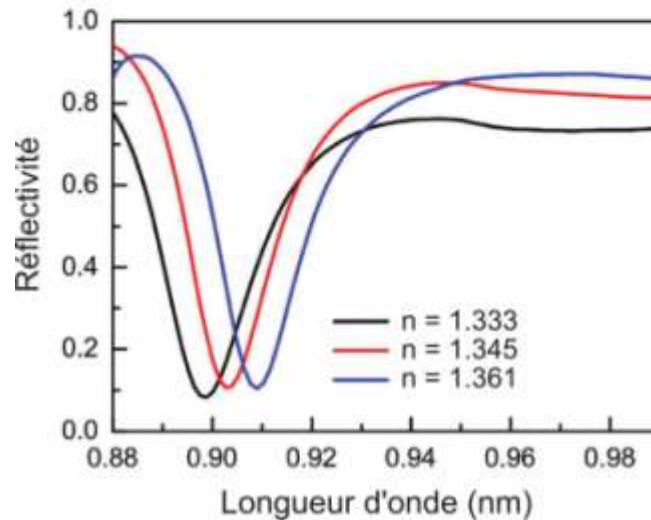
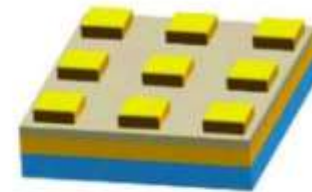
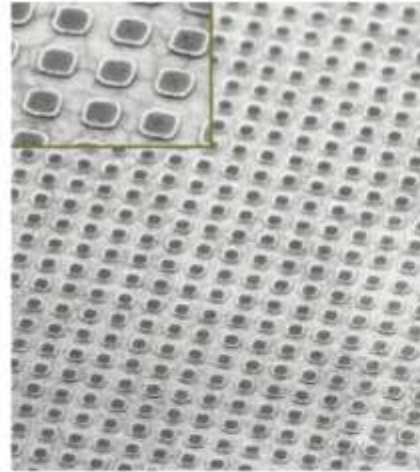
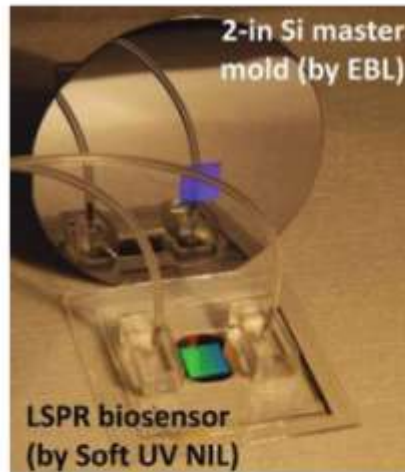
Local Surface Plasmon Resonance Sensor

Défis actuels

- Parallélisation des mesures
- Recyclage des substrats
- Vitesse de traitement



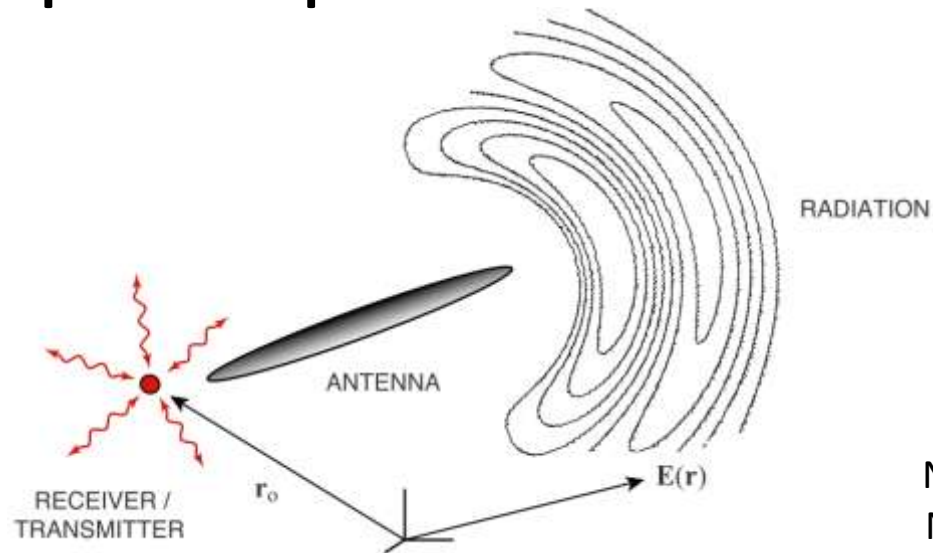
Structures combinées – soft imprint lithography



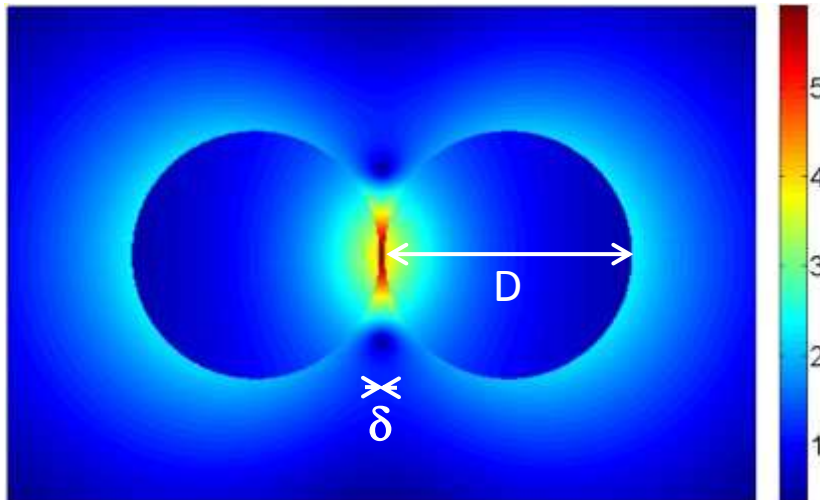
Plasmonique pour la biophotonique

- Capteurs
- **Emissions exaltées**
- Thermoplasmonique
- Pinces optiques

Nanoantennes plasmoniques



Novotny and Van Hulst,
Nat Photon **5** 83 (2011)



Case of a nanoparticle dimer

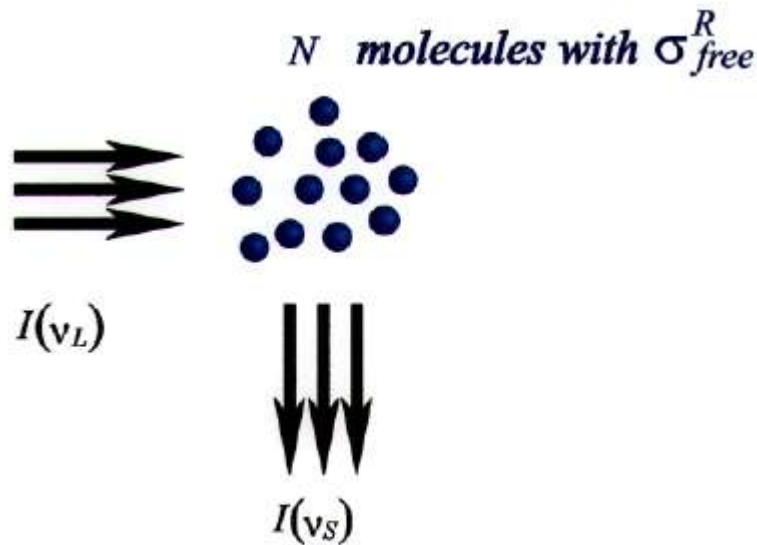
Local electric field enhancement:

$$\frac{E_{\text{loc}}}{E_0} = \frac{-\text{Re } \varepsilon}{\text{Im } \varepsilon} \frac{2D + \delta}{\delta} \sim 500$$

Intensity gain $\sim 2 \cdot 10^5$

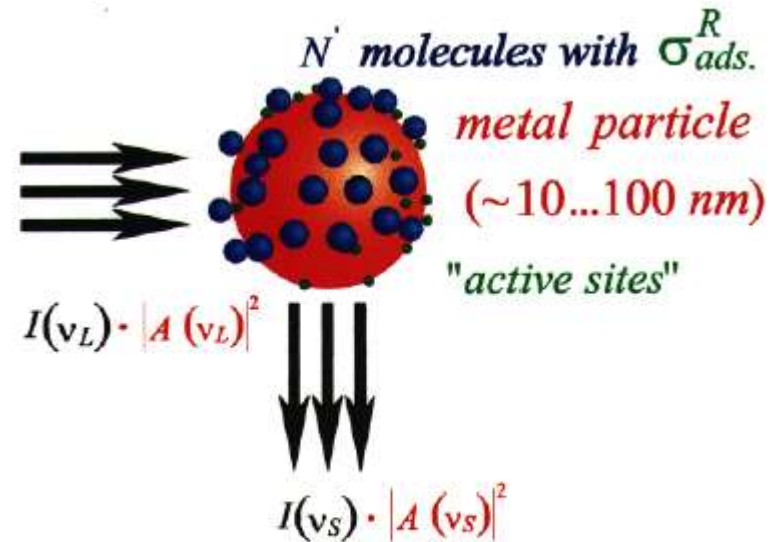
SERS : Surface Enhanced Raman Scattering

Free Molecules



$$I_{NRS}(\nu_S) = N \cdot I(\nu_L) \cdot \sigma_{free}^R$$

Molecules on SERS clusters



$$I_{SERS}(\nu_S) = N' \cdot I(\nu_L) \cdot |A(\nu_L)|^2 \cdot |A(\nu_S)|^2 \cdot \sigma_{ads}^R$$

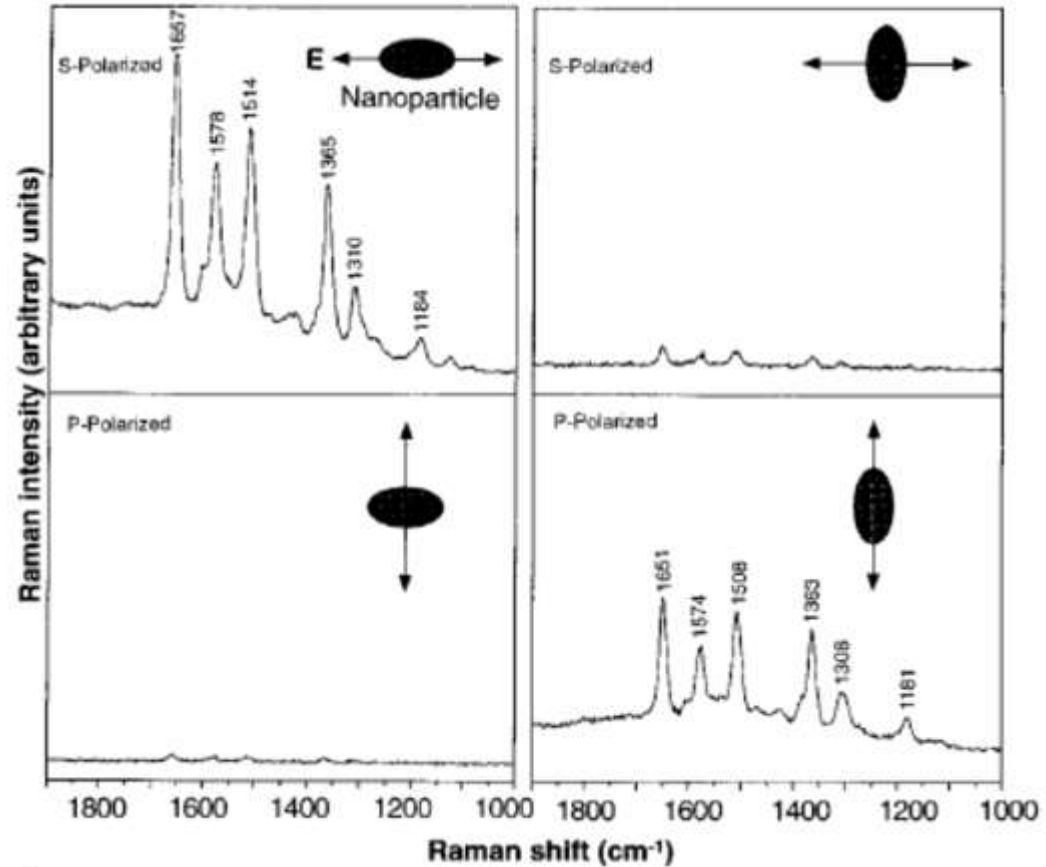
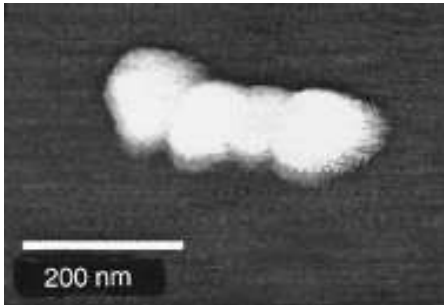
Enhancement of the excitation field

Enhancement of the signal field

Enhancement of the absorption cross section

SERS : Surface Enhanced Raman Scattering

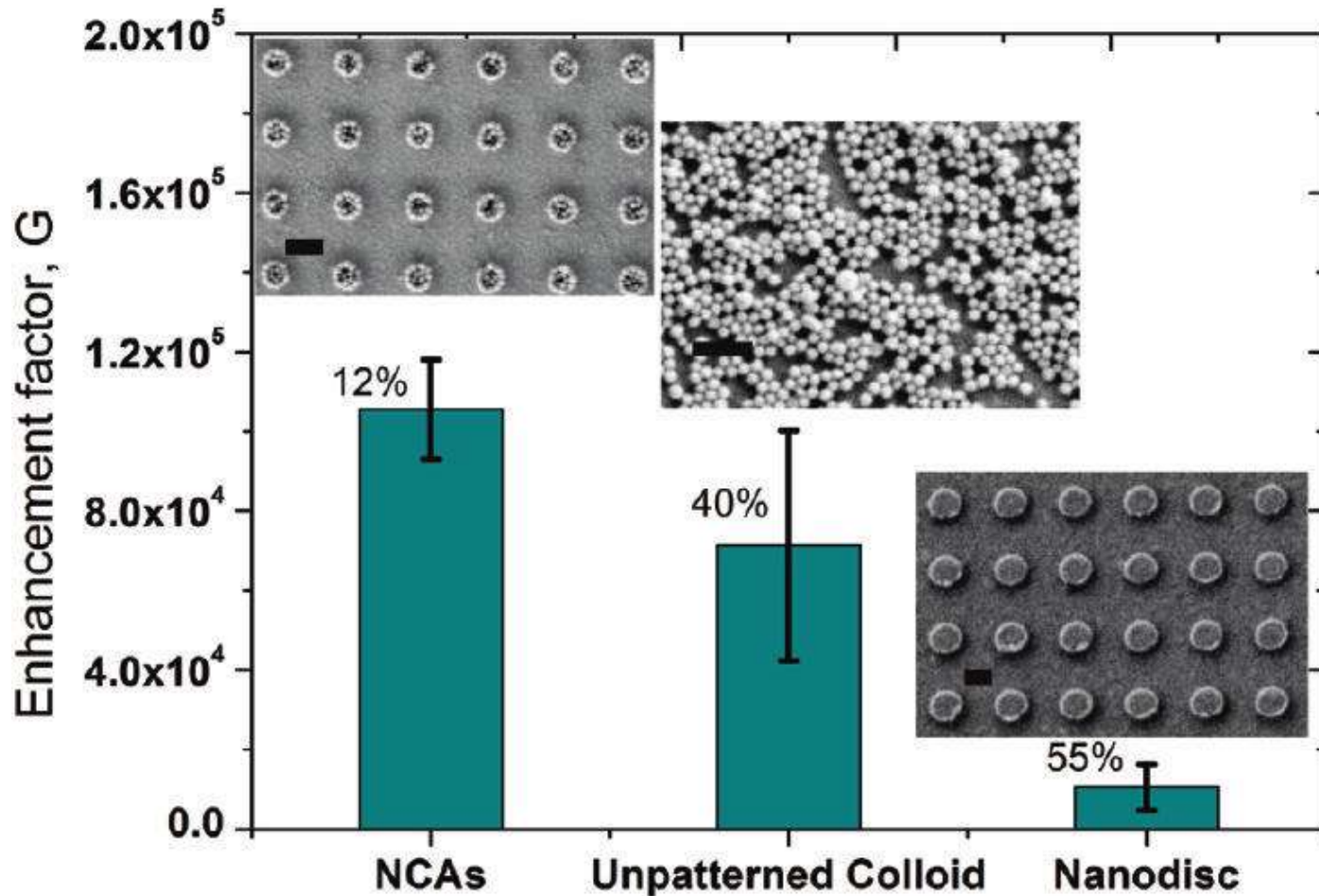
Electromagnetic enhancement → towards single molecule detection



Nie and Emory
Science **275** 1102 (1997)

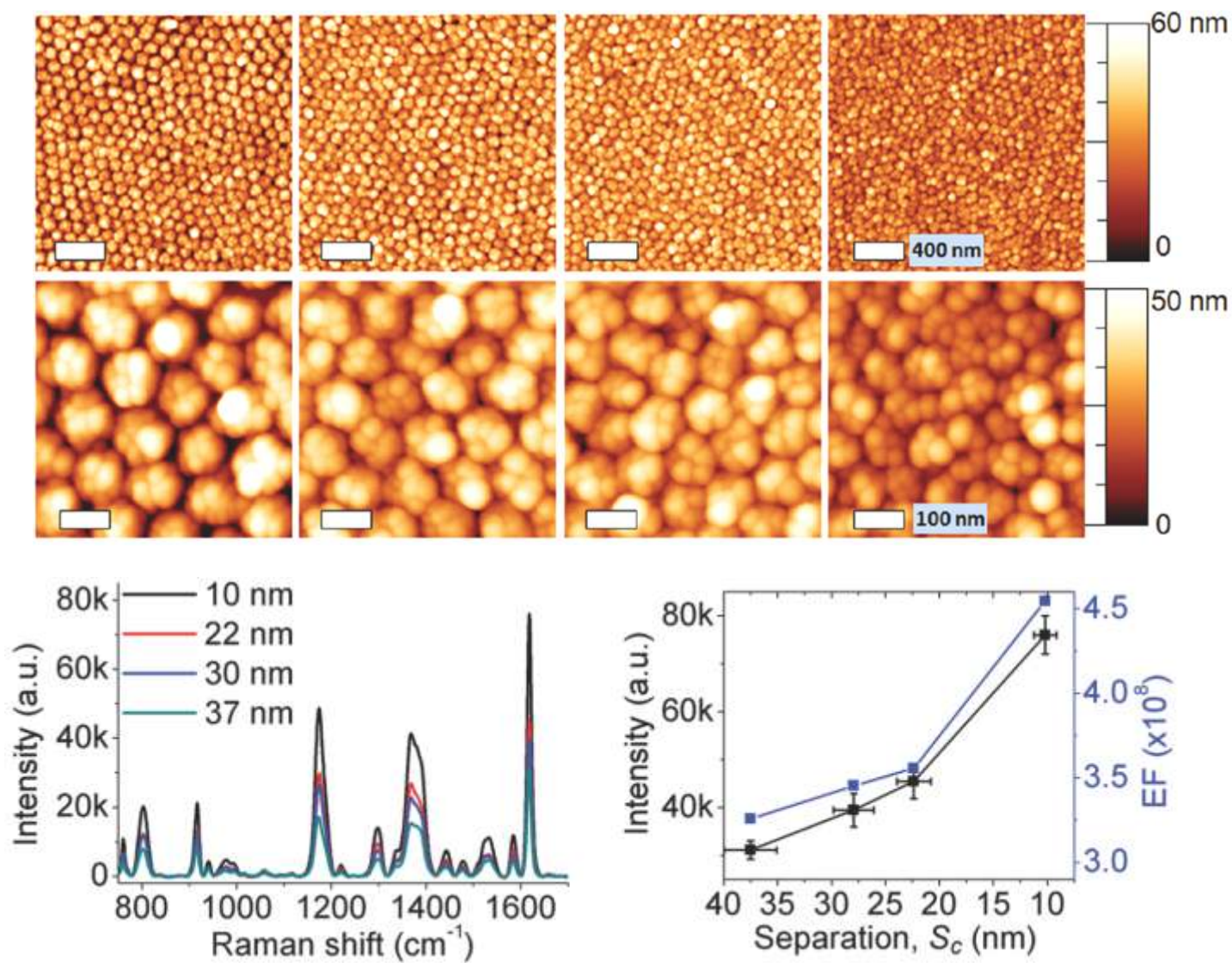
SERS : Surface Enhanced Raman Scattering

Reproducible substrates

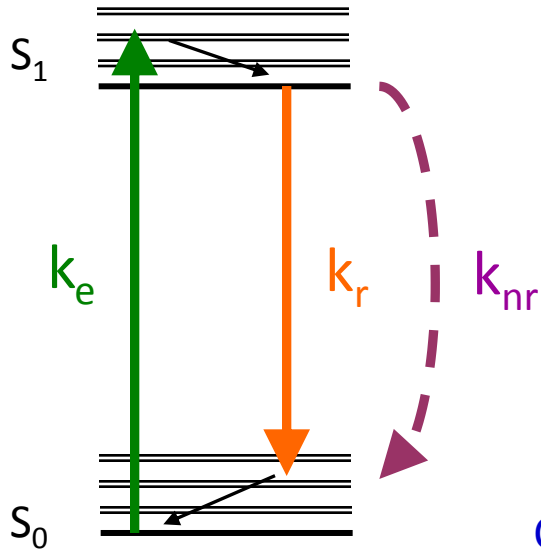


SERS : Surface Enhanced Raman Scattering

Reproducible substrates



Fluorescence



Detected fluorescence

$$F = \kappa k_r N_1$$

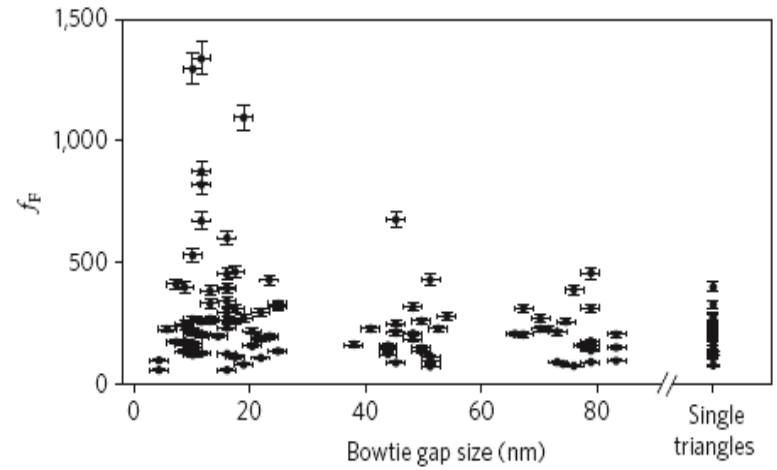
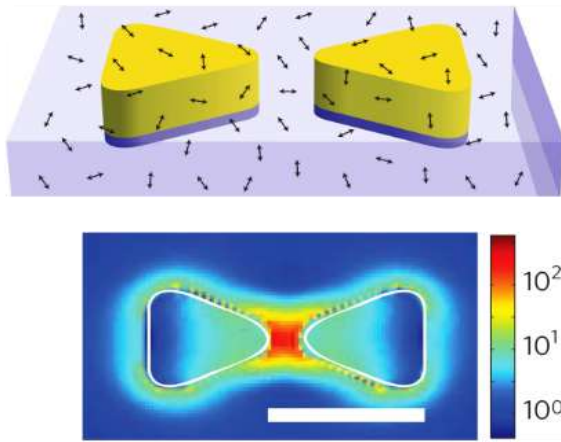
$$= \kappa \frac{k_r}{k_r + k_{nr}} \frac{k_e}{1 + k_e / (k_r + k_{nr})} N_{\text{tot}}$$

Collection efficiency

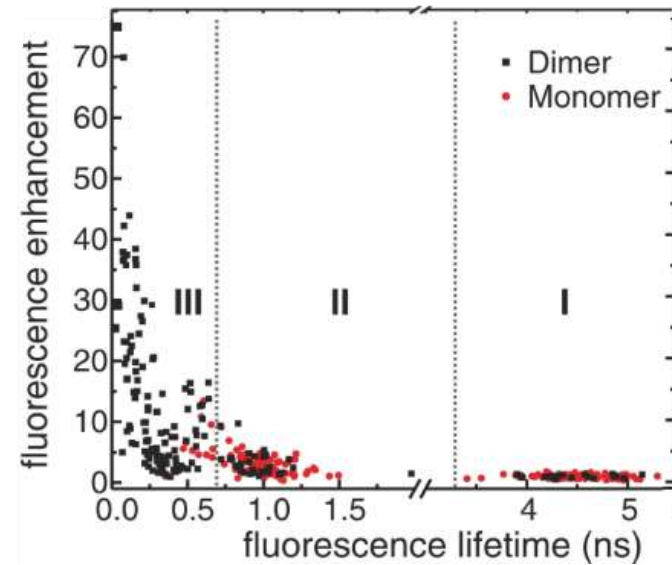
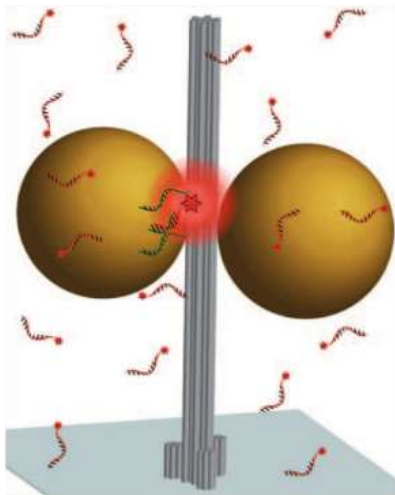
Quantum yield

Excitation intensity

Affected by plasmonic structure

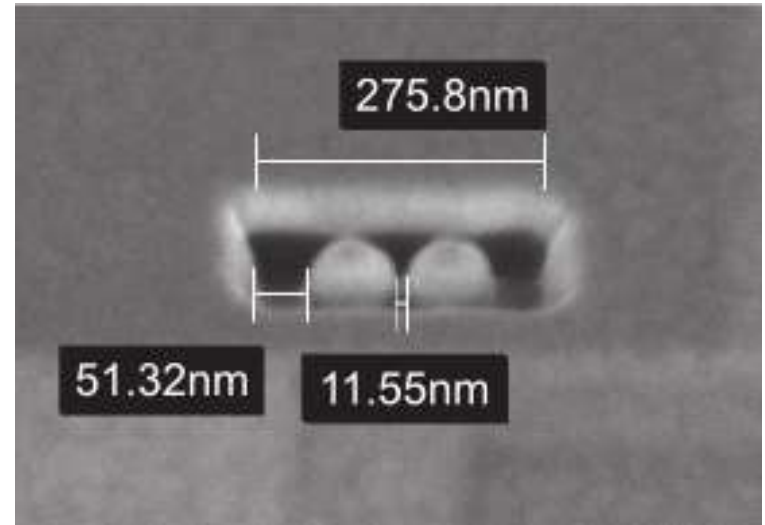
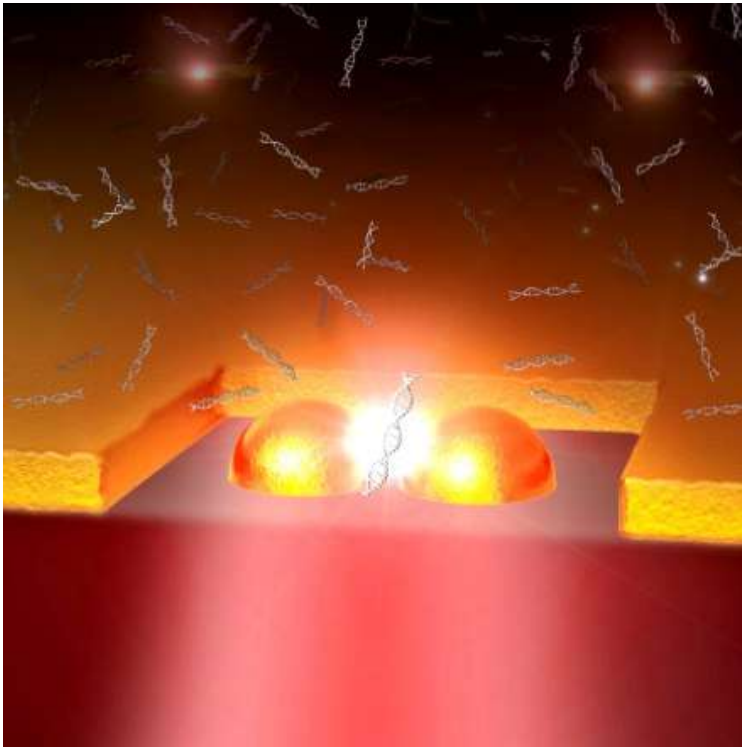


Kinkhabwala *et al*, Nature Phot. **3**, 654 (2009)



Acuna *et al*, Science. **338**, 506 (2012)

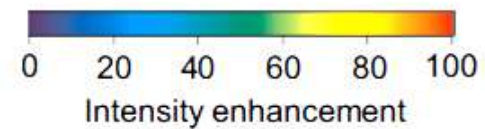
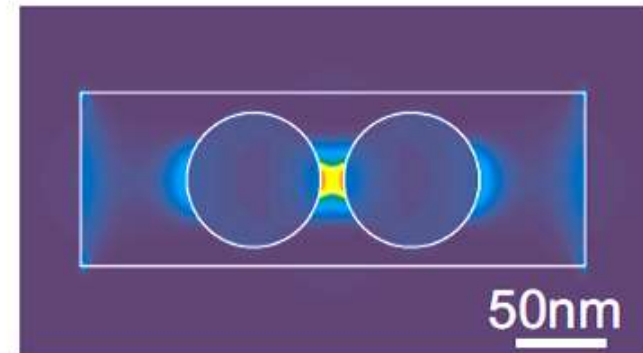
Antenna-in-box



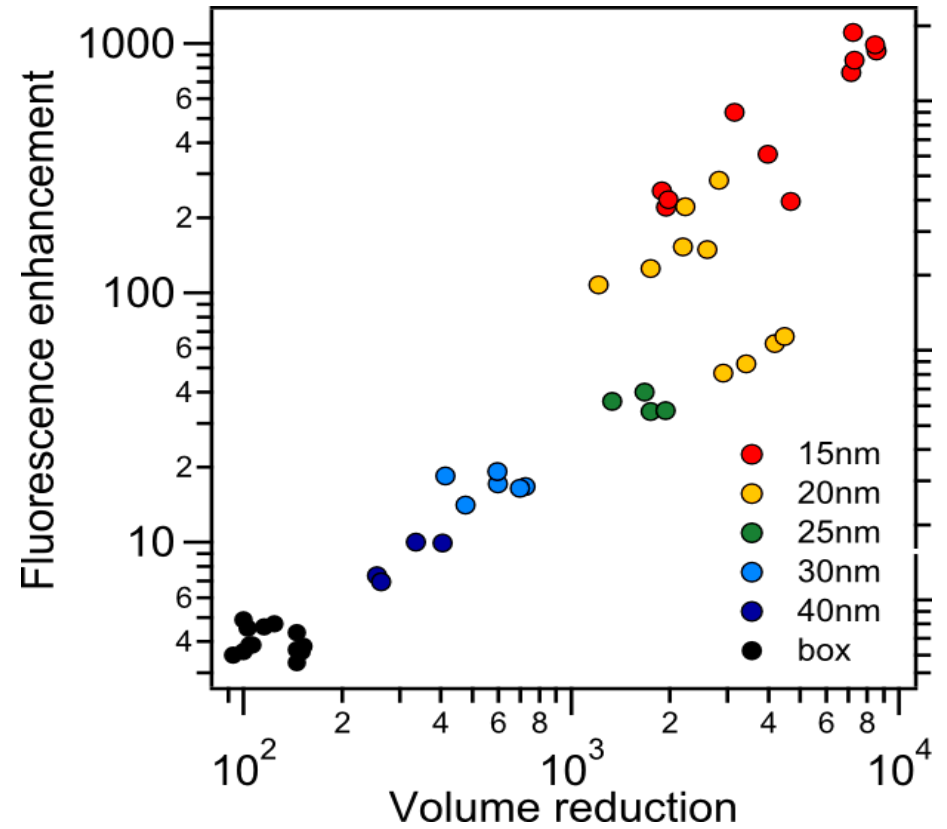
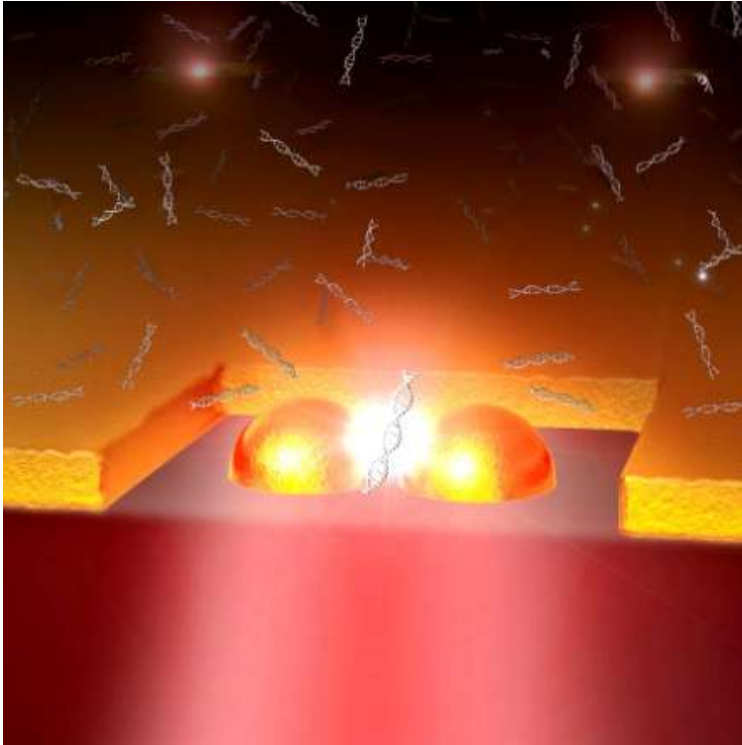
Gap-antenna → Fluo. enhancement

Aperture-box → Background screening

Punj et al, Nat. Nanotech. **8**, 512 (2013)



Antenna-in-box

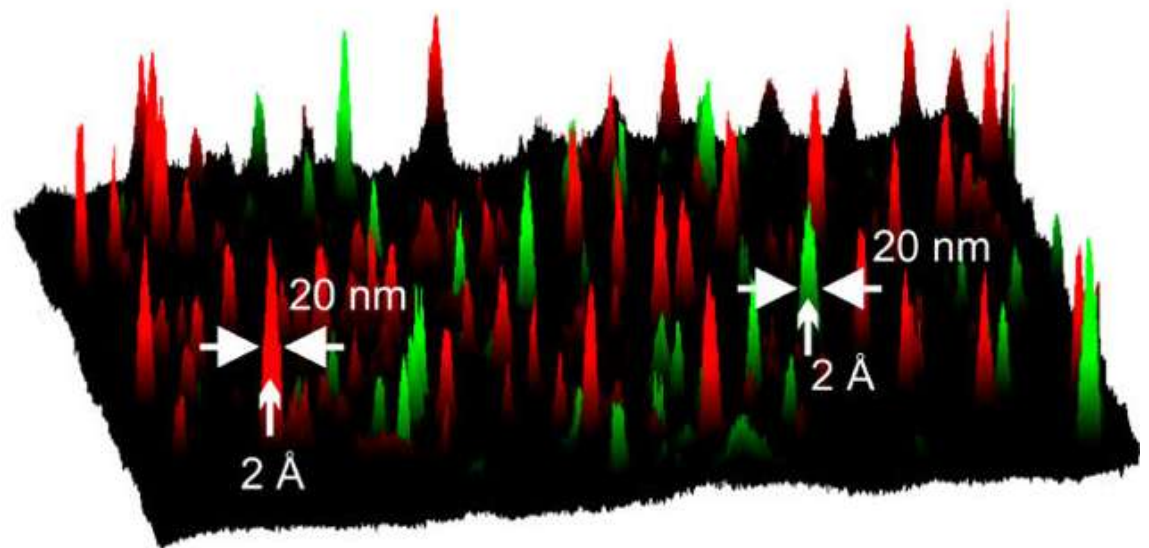
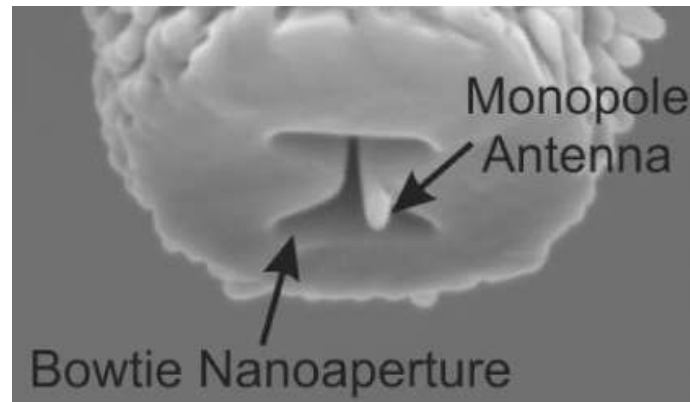
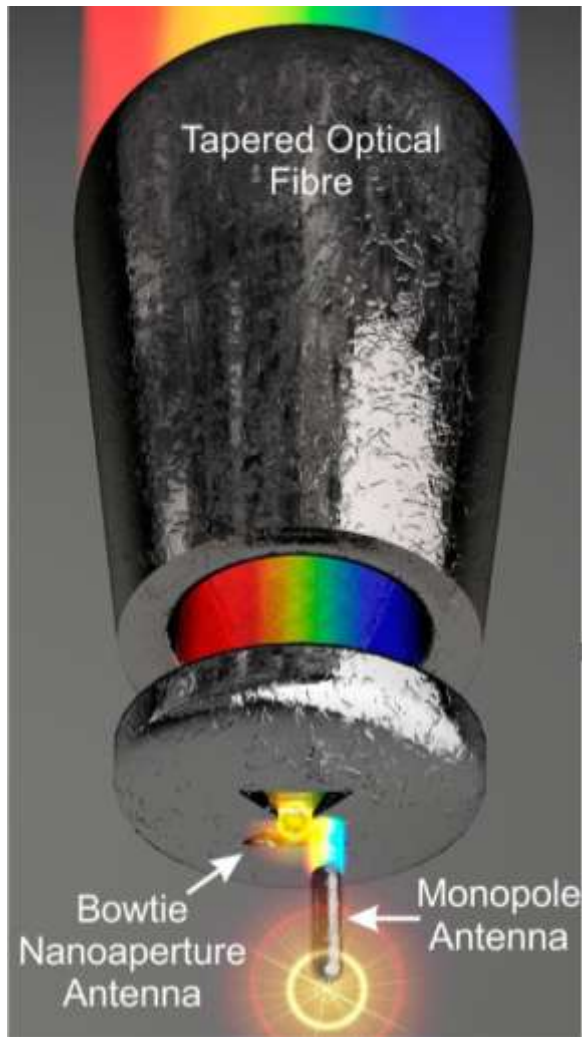


Gap-antenna → Fluo. enhancement

Aperture-box → Background screening

Punj et al, Nat. Nanotech. **8**, 512 (2013)

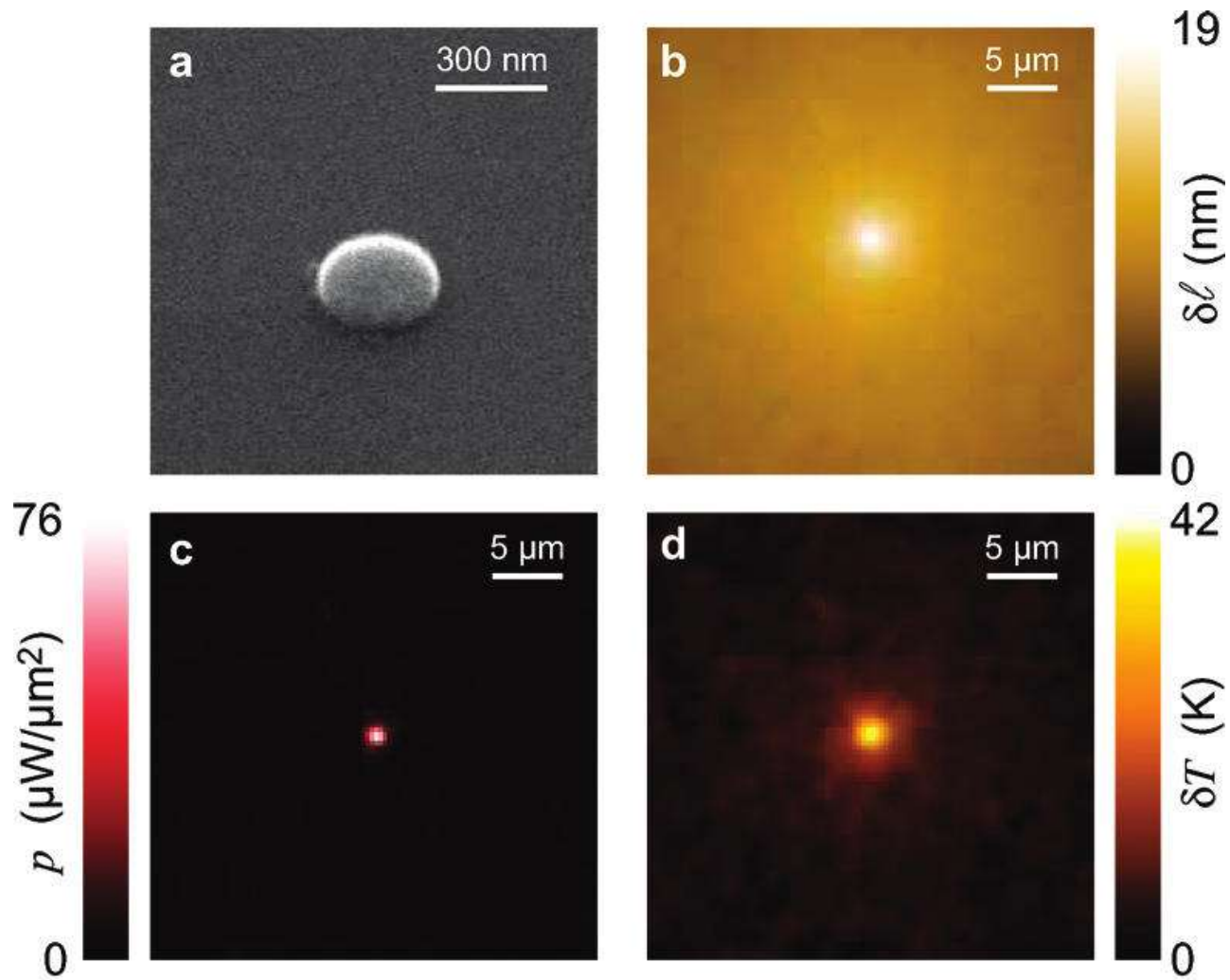
Nanoantennes combinées aux pointes NSOM



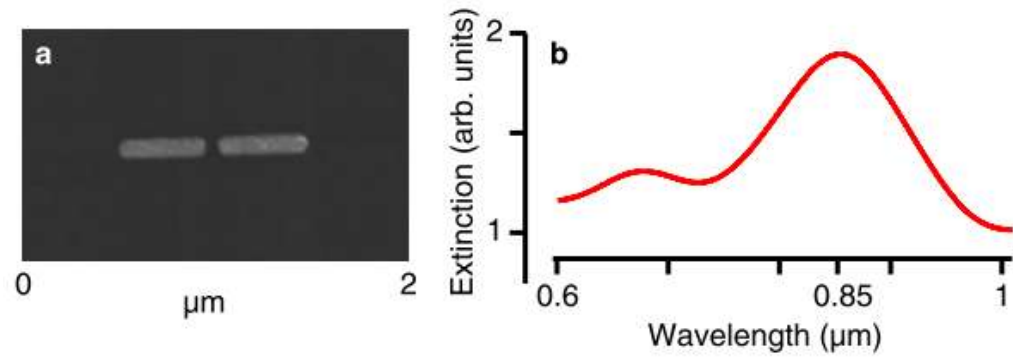
Plasmonique pour la biophotonique

- Capteurs
- Emissions exaltées
- **Thermoplasmonique**
- Pinces optiques

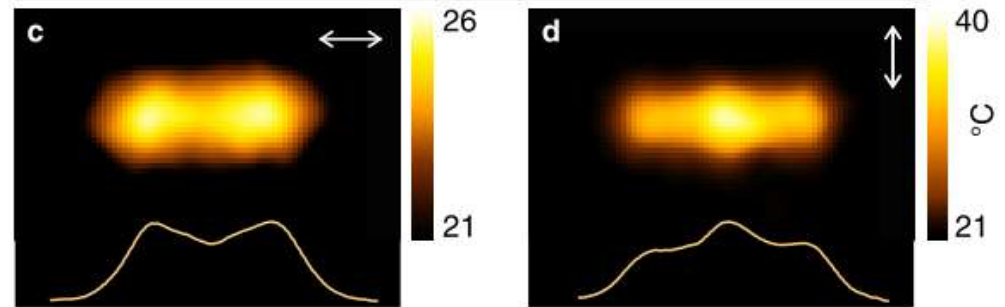
Nanosources de chaleur



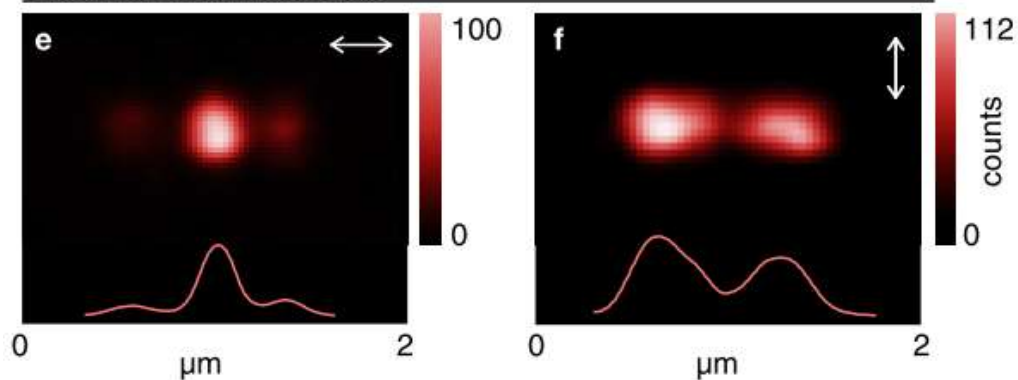
Nanosources de chaleur



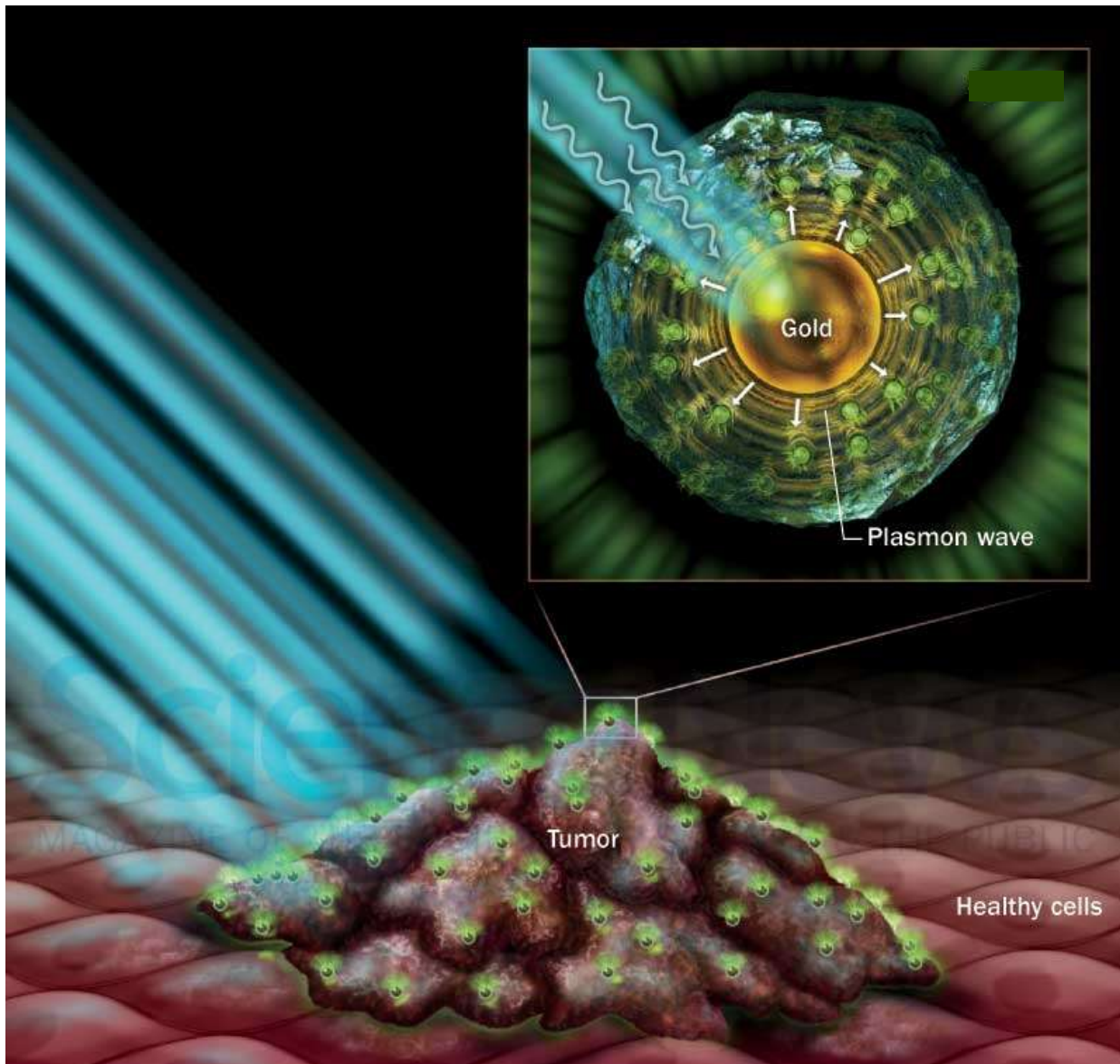
Heat source density $h(r)$



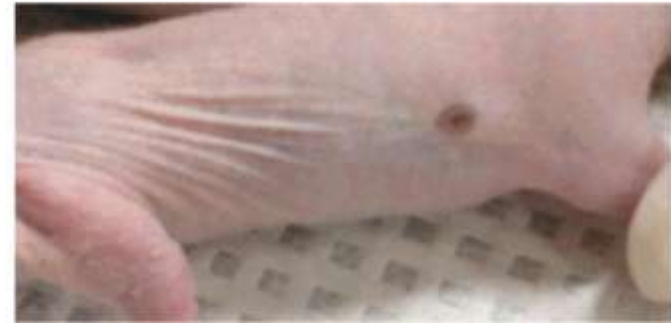
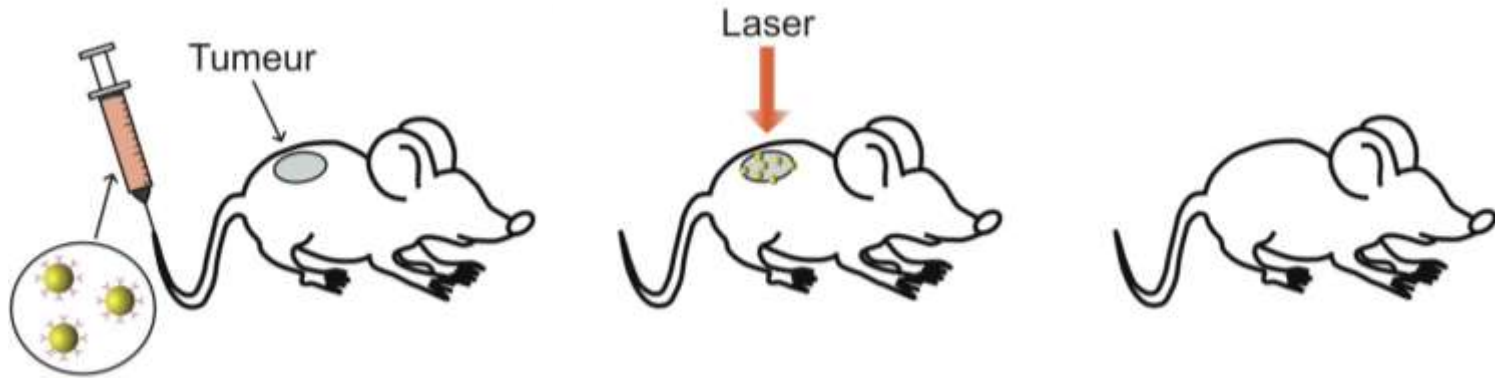
Two-photon luminescence



Traitement photothermique du cancer



Traitement photothermique du cancer

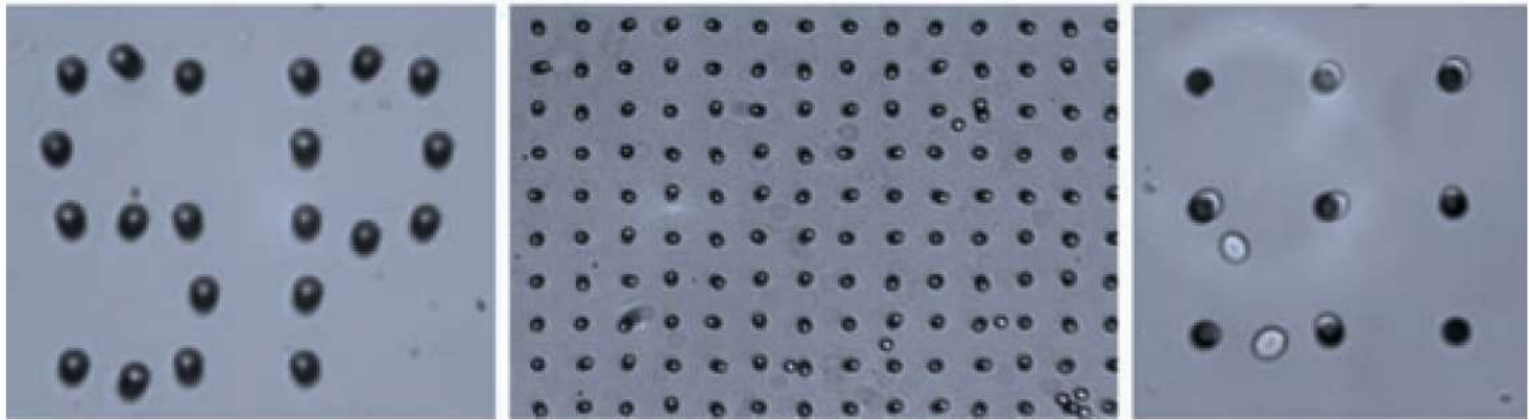
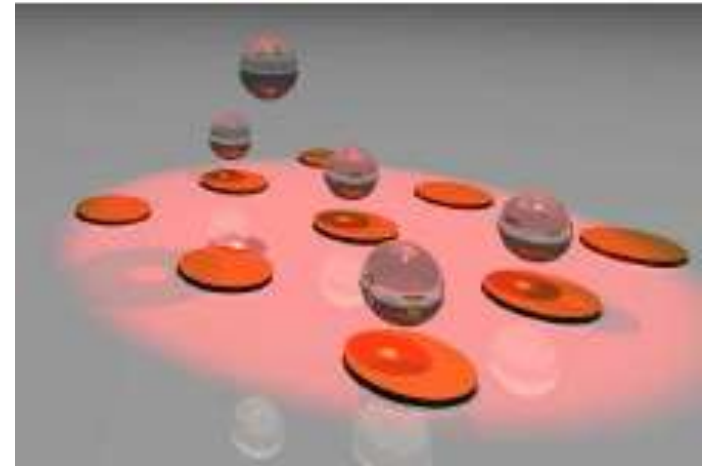
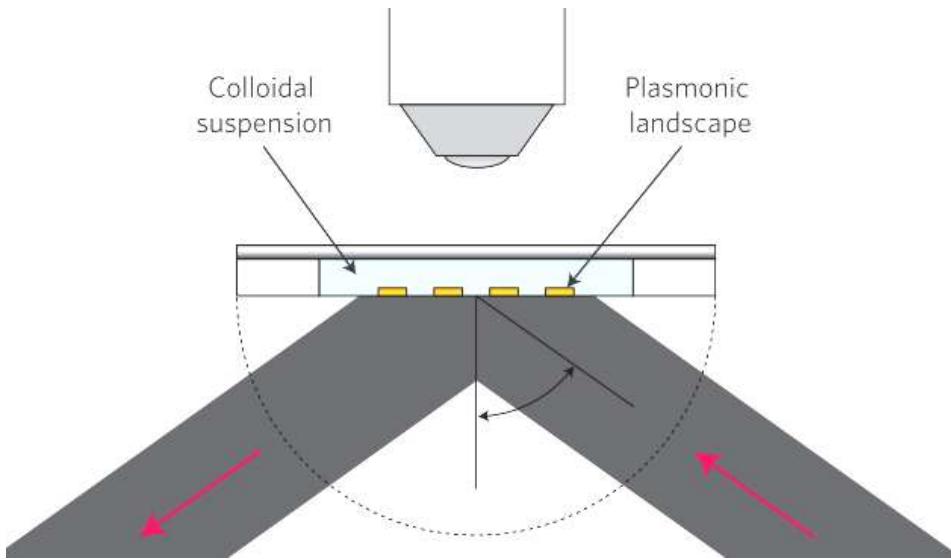


Stern et al, J Urol. **179**, 748 (2008)

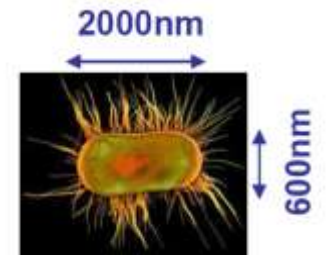
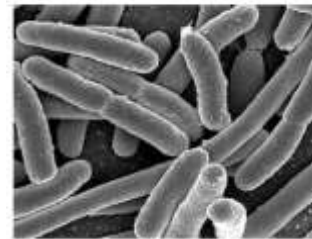
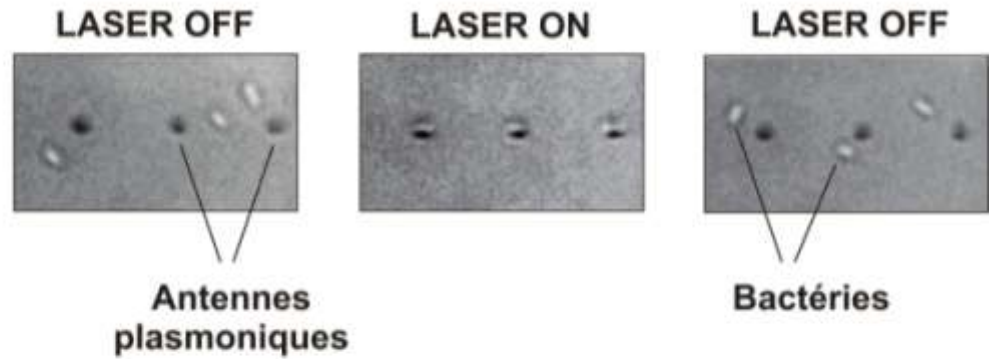
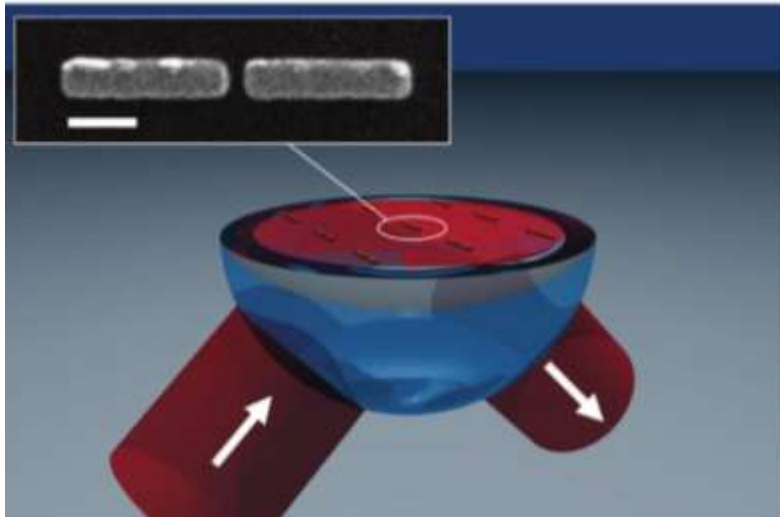
Plasmonique pour la biophotonique

- Capteurs
- Emissions exaltées
- Thermoplasmonique
- **Pinces optiques**

Pinces optiques avec des plasmons localisés

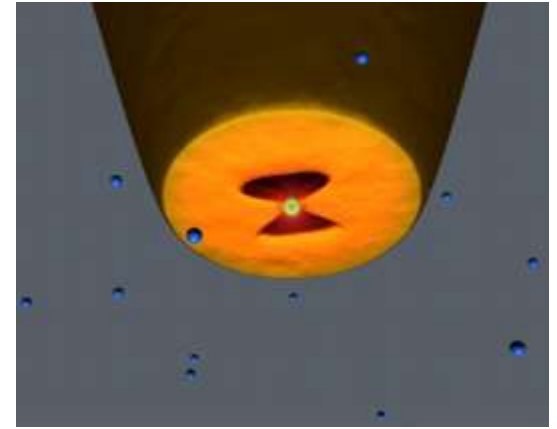
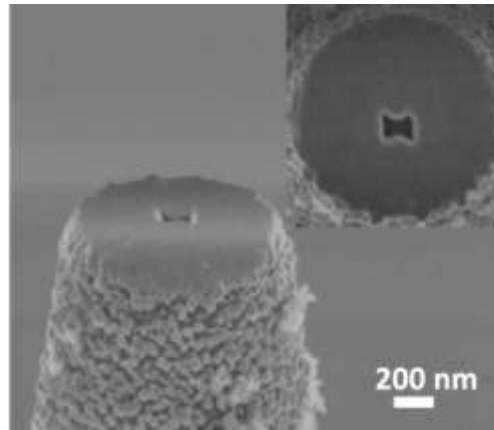


Piégeage de bactéries avec nanoantennes

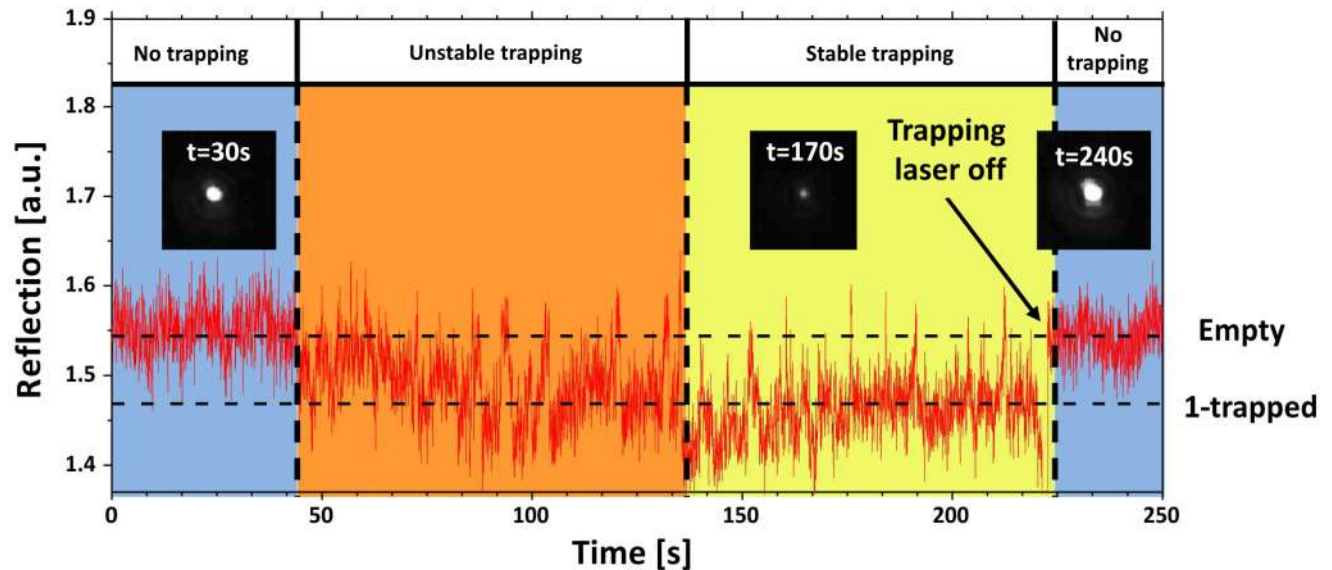


Manipulation 3D avec nanoantennes

Nanooverture en
bout de fibre étirée

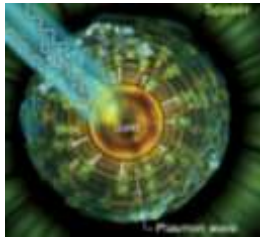


Piégeage de
nanoparticules
diélectriques de
50nm



Plasmonique pour la biophotonique

Propriétés principales et applications :



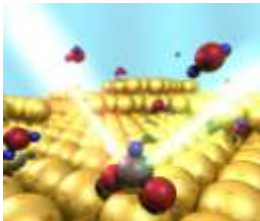
Concentration de la lumière

→ piégeage, photothermie



Exaltation du champ

→ émission optique exaltée



Sensibilité à l'environnement local

→ capteurs sans marquage

