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Nanostructures, nanosources: contrôle de l'émission par le confinement

Agnès Maître

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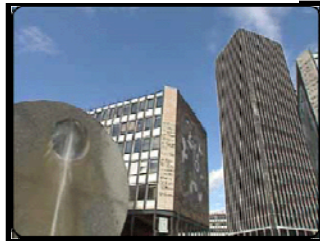
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Submitted on 12 Jan 2012

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Nanostructures, nanosources: contrôle de l'émission par le confinement



Institut des NanoSciences de Paris

Universit  Pierre et Marie Curie

Groupe « nanophotonique et optique quantique »

Membres permanents :

Paul Benalloul, Laurent Coolen, Willy Daney de Marcillac
Jean-Marc Frigerio, [Agn s Ma tre](#), Catherine Schwob

Etudiants en th se:

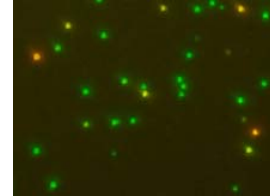
Amaury Avoine, [Cherif Belacel \(INSP/LPN\)](#), [Hugo Frederich](#), Phan Ngoc Hong,

Post-doc : Ikbel Mallek

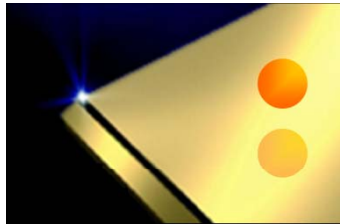
Anciens membres: Carlos Barthou, [C line Vion](#), Julien Laverdant

Nanostructures, nanosources: contrôle de l'émission par le confinement

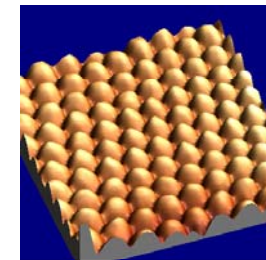
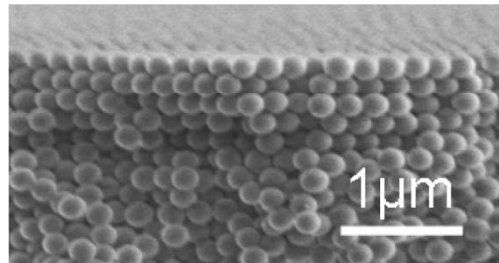
- Photons uniques et nanocristaux de CdSe/ZnS



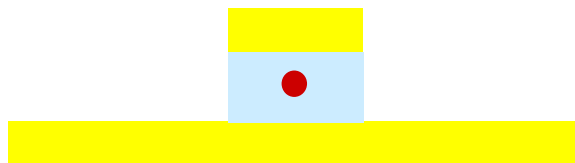
- Modification de l'émission au voisinage d'une surface d'or



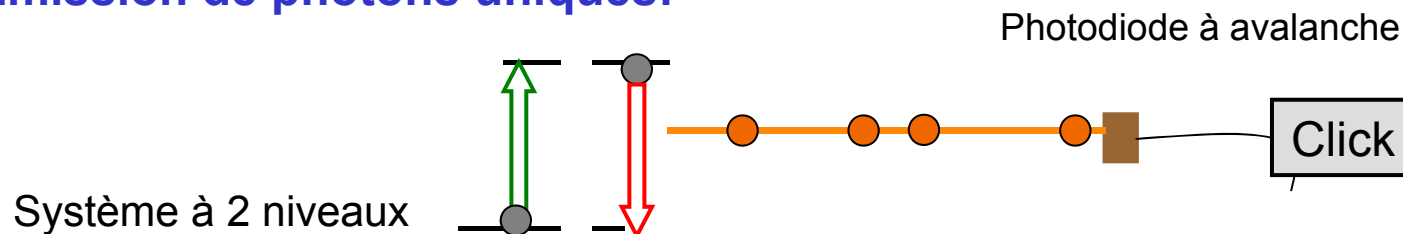
- Cristal plasmonique



- Antenne patch





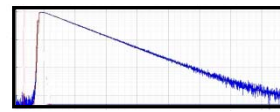
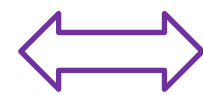
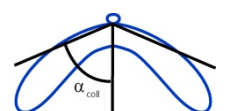
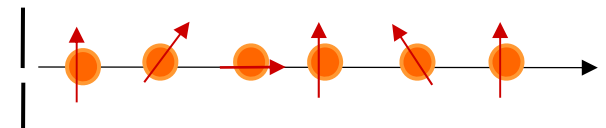
✓ Émission de photons uniques:



Nanocristaux de CdSe/ZnS
B. Lounis et al., Chem. Phys. Lett. 329, 399 (2000)
P. Michler et al., Nature 406, 968 (2000)

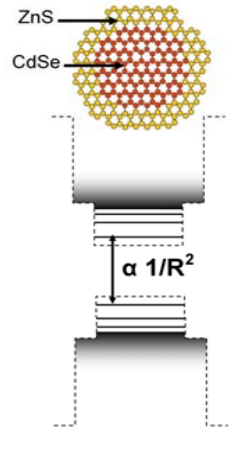
✓ Optimisation de sources de photons uniques pour l'information quantique

1 photon = 1 information quantique

- Flux d'information (temps de vie  flux )
 
- Augmentation de la collection  directivité de l'émission
 
- contrôle de la polarisation
 

« Boîtes quantiques » colloïdales

Nanocristaux de CdSe/ZnS

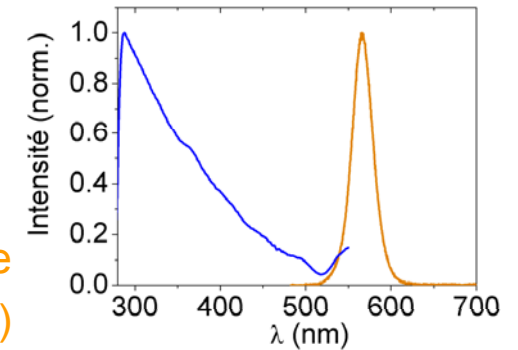


Cœur de CdSe, coquille de ZnS
(R:3,5nm 1000 atomes)

- ✓ synthèse chimique
- ✓ Température ambiante
- ✓ Faible photoblanchiment

- Emission dans le visible
- Largeur de raie (20nm)

Absorption, emission



✓ Caractérisation d'émetteurs à l'échelle collective et individuelle

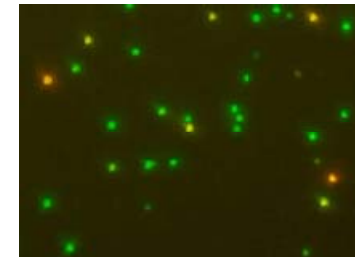
Solution: échelle collective



Qdots©

Propriétés moyennées
Rendement quantique

Forte dilution: échelle individuelle



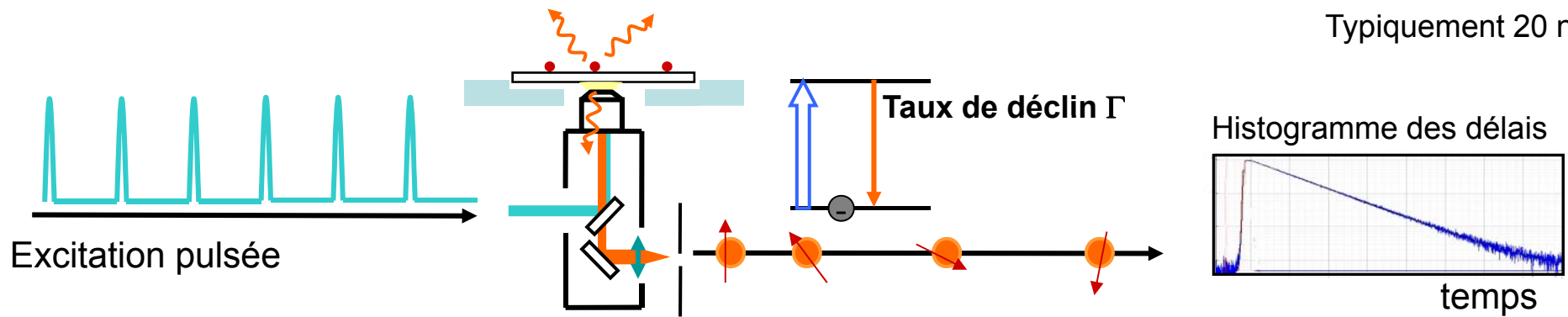
- scintillement
- Efficacité quantique
- Orientation des émetteurs: Analyse de la polarisation

Couplage avec une nanostructure

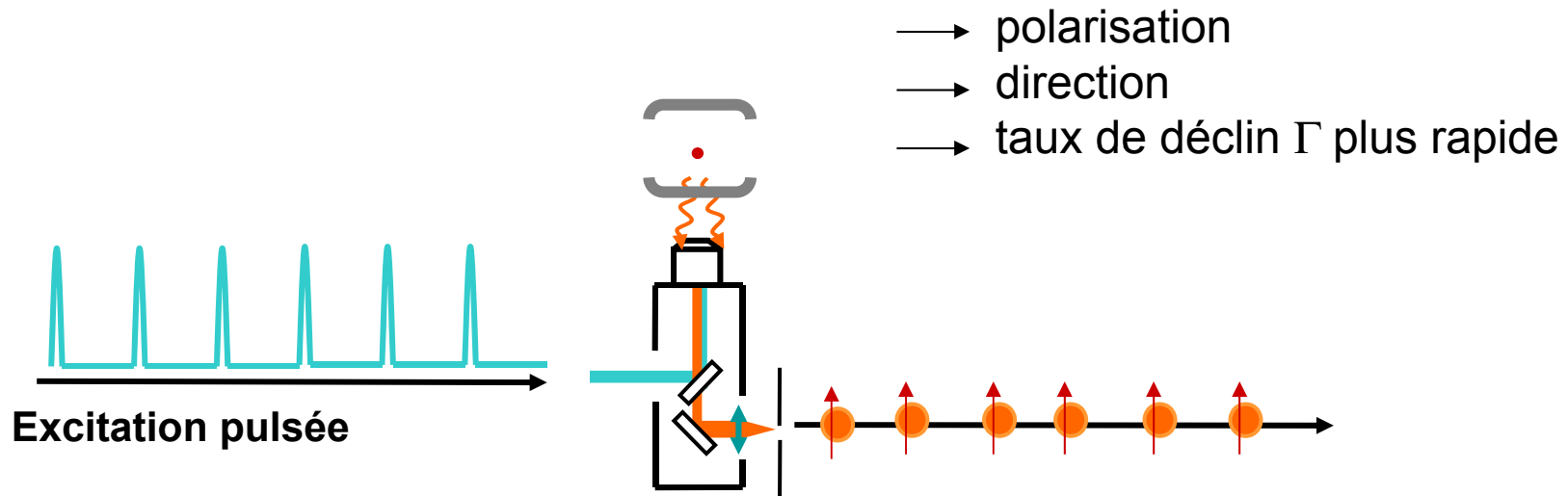
Contrôle de l'émission des photons uniques

Temps de vie ($\tau=1/\Gamma$) (1/taux de déclin)

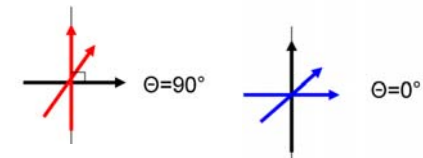
Typiquement 20 ns



Couplage à des structures photoniques

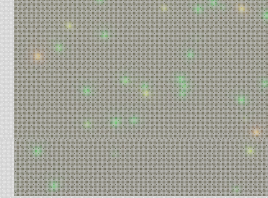


Équivalent à un double dipôle dégénéré rayonnant

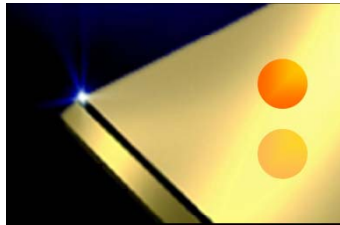


Nanostructures, nanosources: contrôle de l'émission par le confinement

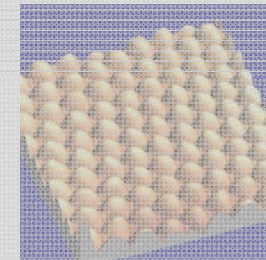
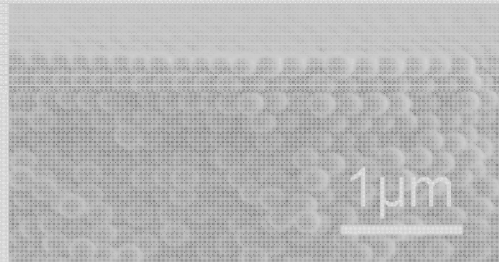
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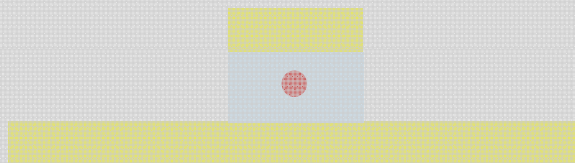
- Modification de l'émission au voisinage d'une surface d'or



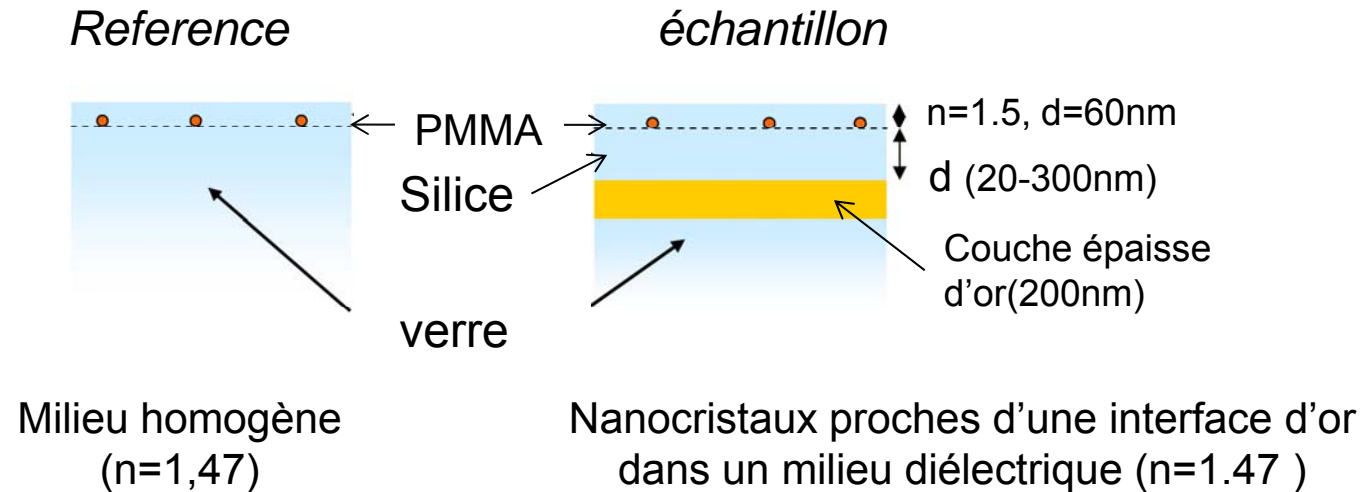
- Cristal plasmonique



- Antenne patch



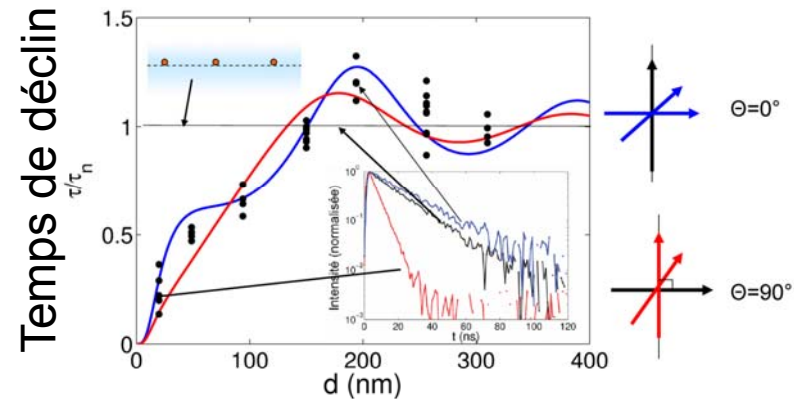
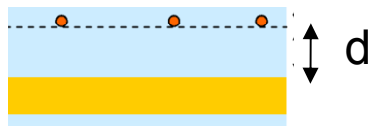
Maximisation du nombre de photons détectés



▪ L'émission est modifiée par l'environnement

- Dynamique
- Emission radiative
- Diagramme d'émission

...en excitation impulsionnelle :

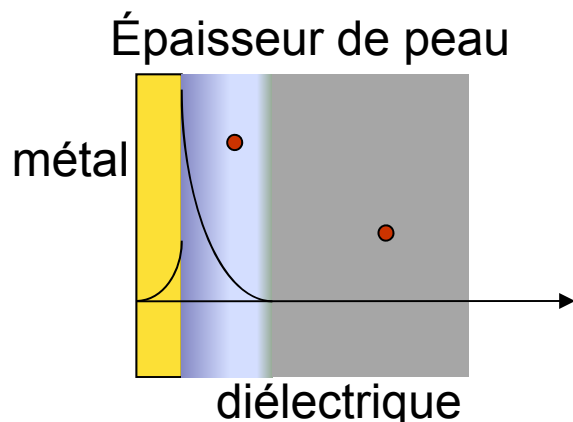
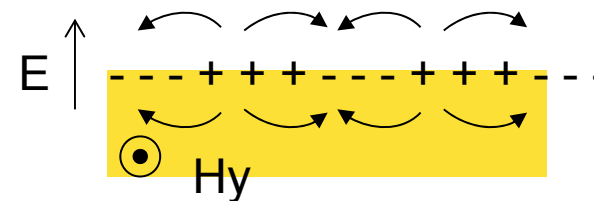


Le temps de vie diminue avec d ➔ la dynamique de l'émission est augmentée

La densité locale d'états (LDOS) est modifiée par l'environnement

Plasmons de surface (SPP)

Oscillation collective d'électrons à la surface du métal



$$k_{SPP} > k_0 = n \omega / c$$

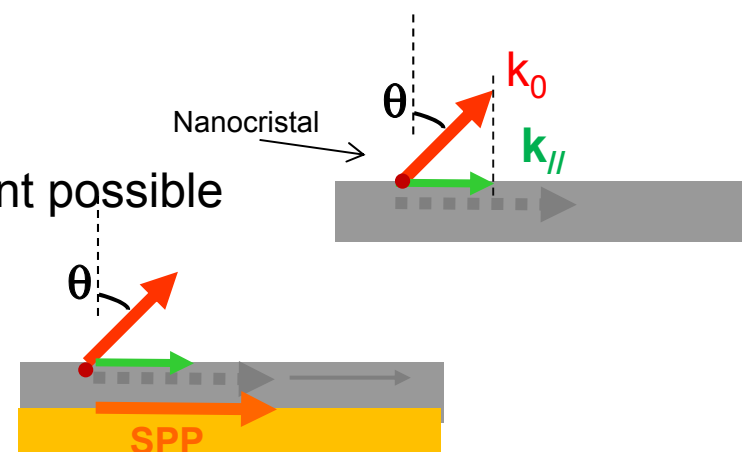
émission du dipôle

- En champ lointain $k_{//} = n \omega \sin \theta / c$
- En champ proche, $k > k_{\text{propagatif}}$ pas de rayonnement possible

Proche d'une interface d'or

Couplage du champ proche du nanocristal aux plasmons de surface

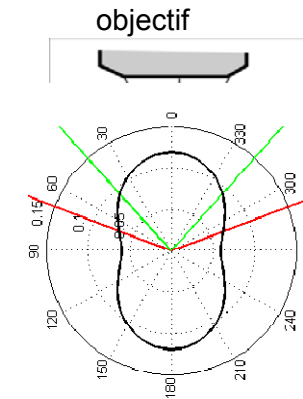
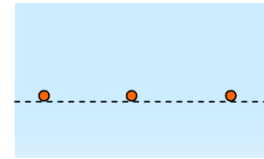
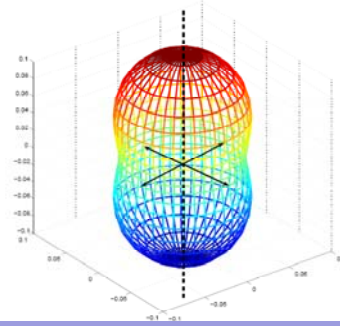
Polarisation P uniquement



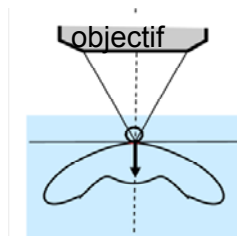
Modification de la LDOS

Diagramme de rayonnement

- En milieu diélectrique homogène **infini**

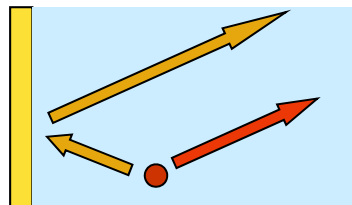


- En milieu diélectrique homogène **semi-infini**

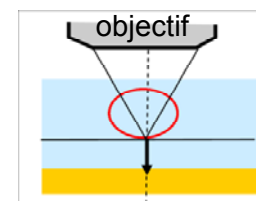


Collection faible

- A proximité d'une surface d'or



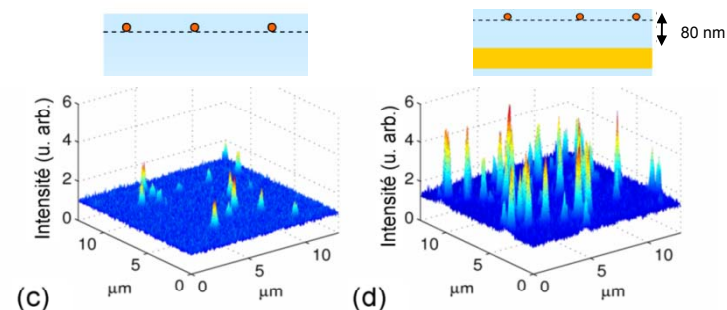
Interférences



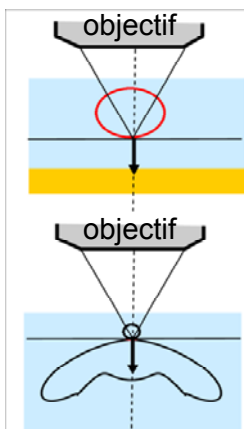
Collection importante

□ sous excitation continue (lampe UV)

Intensité mesurée **x3**



Redirection (effet miroir)



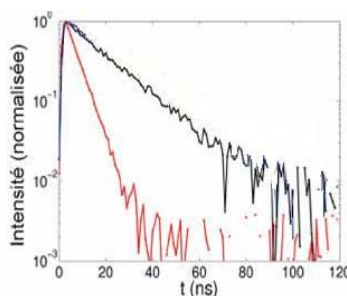
Meilleure collection de la lumière.

Meilleure excitation.

+ Gain

Accélération de l'émission

Déclin de fluorescence



Due au couplage SPP.
Plus de photon/sec.

~ Négligeable

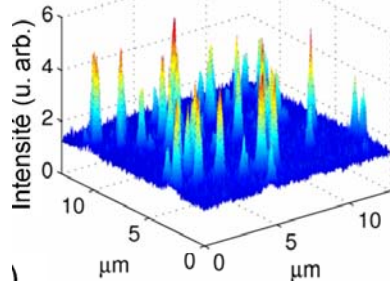
SPP non radiatifs

$$k_{SPP} > k_{photon}$$

SPP restent confinés sur l'or

- Pertes

Augmentation de l'émission détectéemais pertes vers les modes de plasmon :

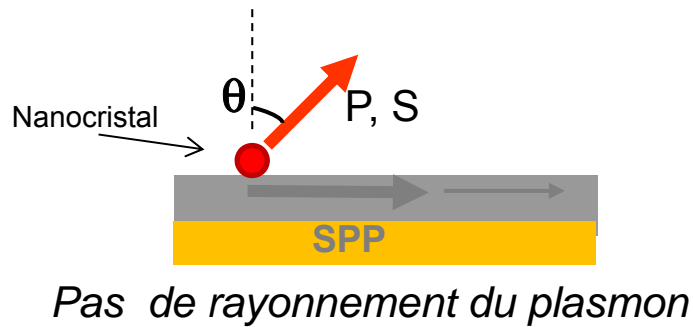


Source plus efficace?

Est-ce possible de récupérer les plasmons de surface qui ont été émis ?

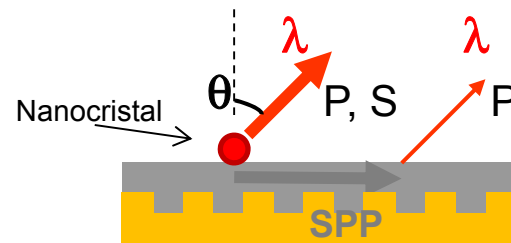
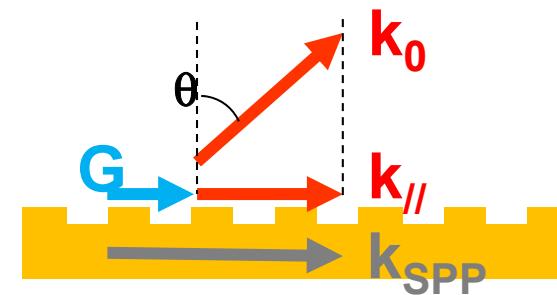
surface métallique nanostructurée

- Réémission possible du SPP par un réseau



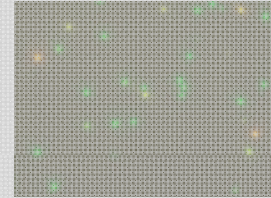
Condition de couplage

$$\vec{k}_{SPP} = \vec{k}_{//} + \vec{G}$$

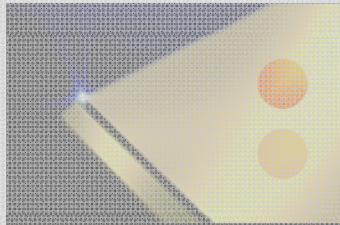


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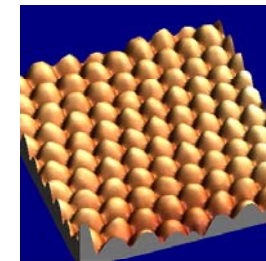
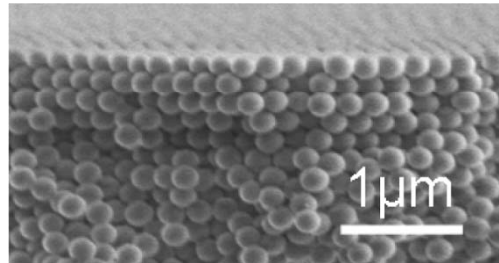
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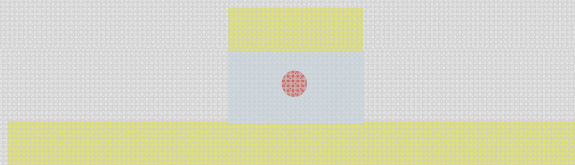
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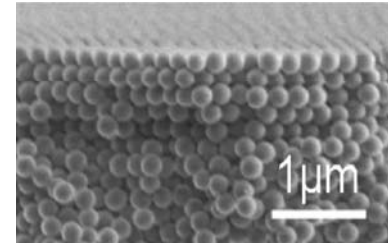
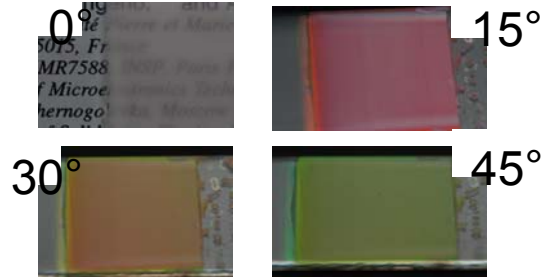
•Cristal photonique: Opales

•artificielle (billes de silice)



•Naturelle

macroscopique



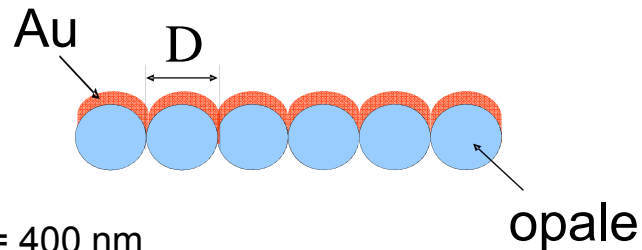
©INSP

microscopique

Frederich et al, optics express, 19, 24424 (11)

•Cristal plasmonique

▪Évaporation d'une couche d'or sur une opale (réseau 2D)



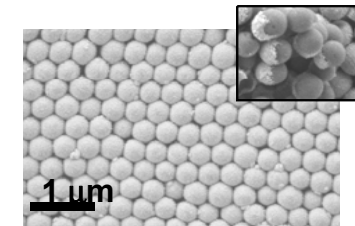
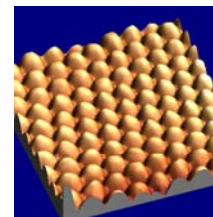
$D = 400 \text{ nm}$

Épaisseur d'or : entre 150 et 500 nm

Bon ordre sur $100 \mu\text{m}$ environ

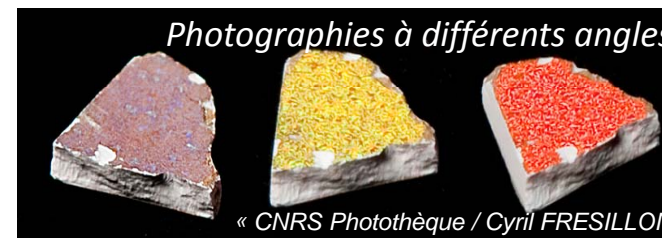
macroscopique

AFM



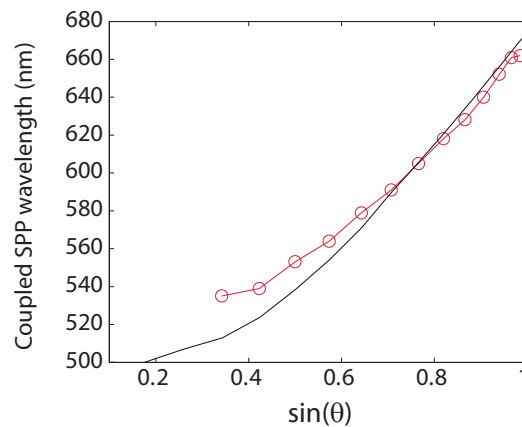
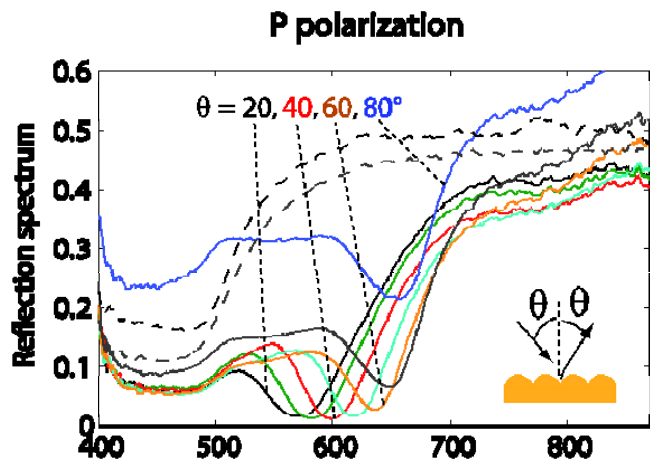
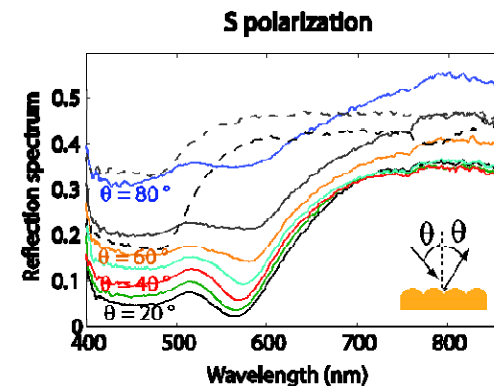
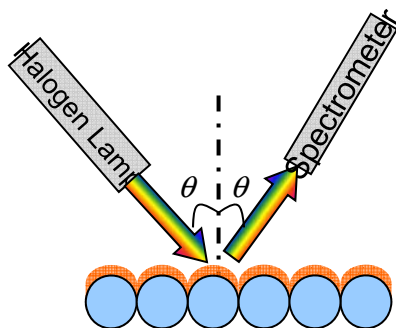
MEB

microscopique



Excitation des plasmons de surface

Cluster de nanocristaux

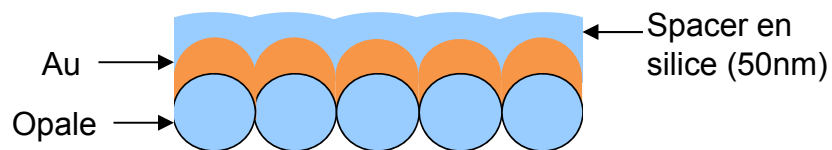


$$\vec{k}_{SPP} = \vec{k}_{//} + \vec{G}$$

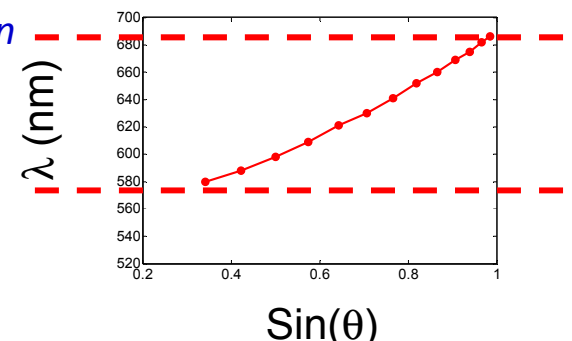
...couplage aux plasmons de surface

Couplage nanocristaux – plasmons de surface

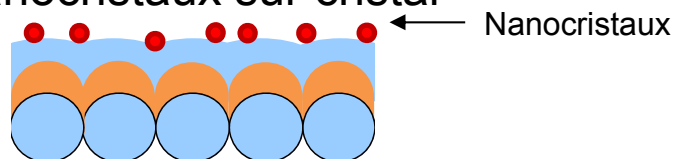
• Cristal « nu »



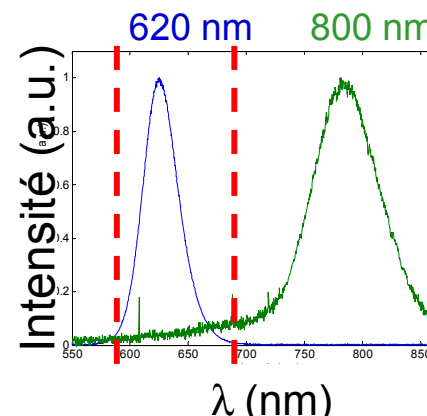
Relation de dispersion



• Nanocristaux sur cristal



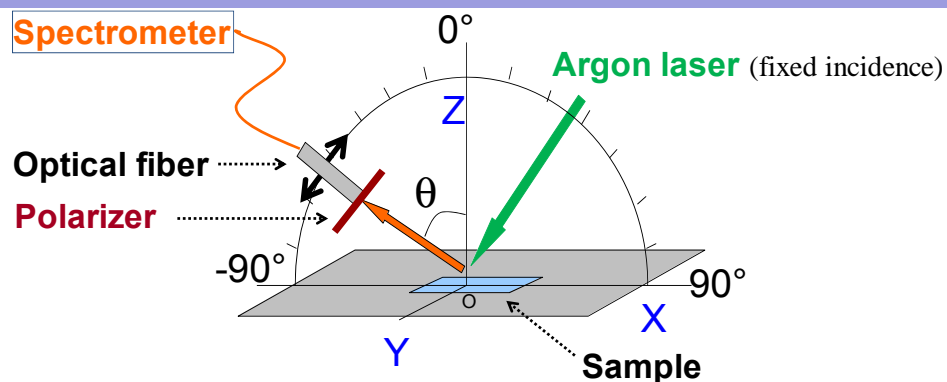
Spectres d'émission des nanocristaux



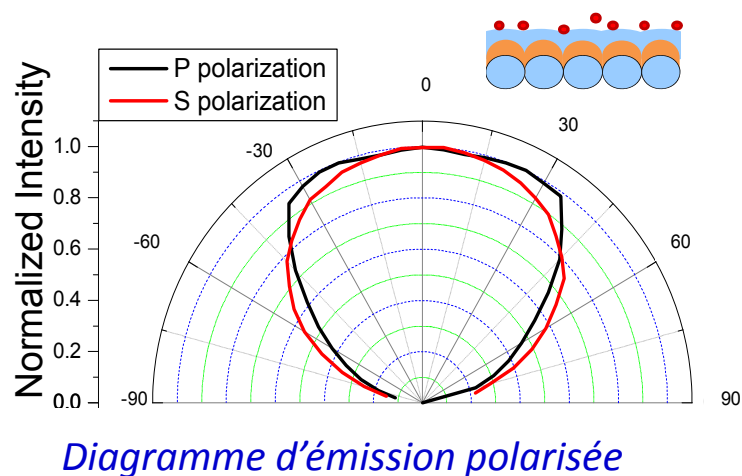
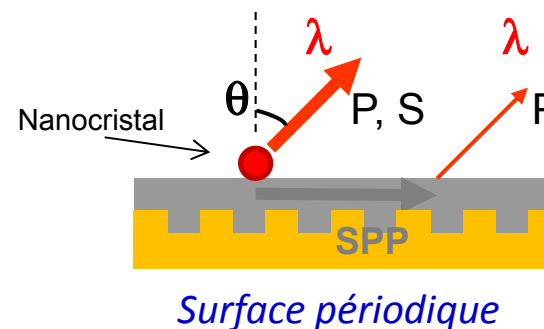
▪ Deux types de nanocristaux déposés:

- Emission à 620 nm, accordés aux SPP
- Emission à 800 nm, désaccordés

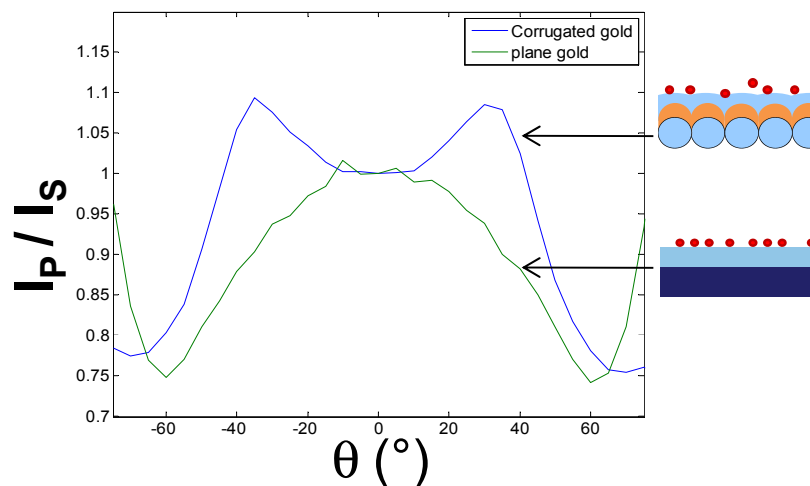
• Spectroscopie résolue en angle



Mesures pour $\lambda = 620$ nm

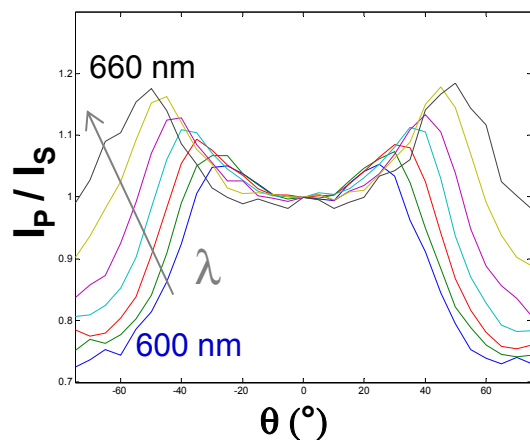


Rapport des émissions polarisées P et S

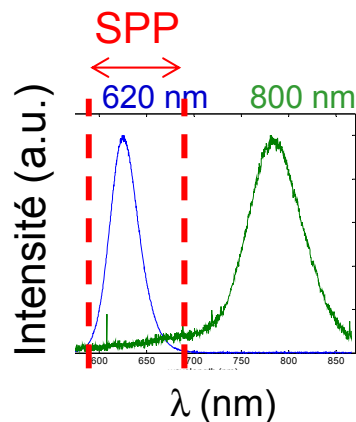


Surplus d'émission polarisée P pour la surface périodique / surface plane

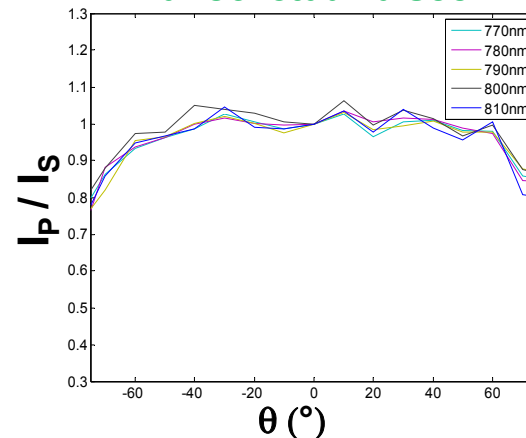
Nanocristaux à 620 nm



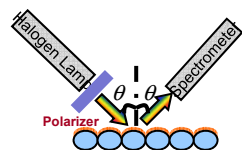
Couplage aux SPP



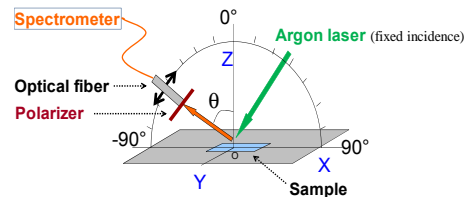
Nanocristaux à 800 nm



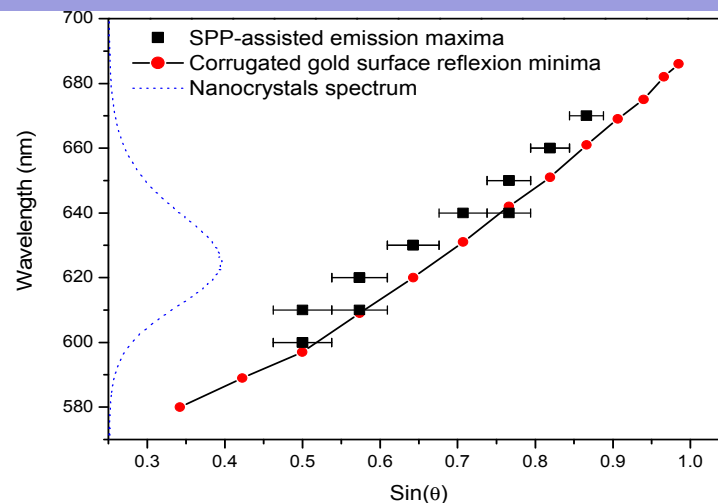
Pas de couplage aux SPP



En **rouge**, minima de réflectivité P



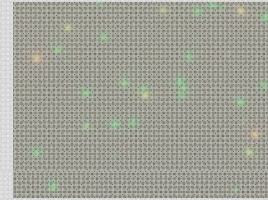
En **noir**, maxima du ratio de fluorescence P/S



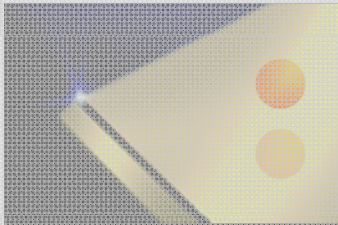
Réémission directionnelle et polarisée des SPP

Nanostructures, nanosources: contrôle de l'émission par le confinement

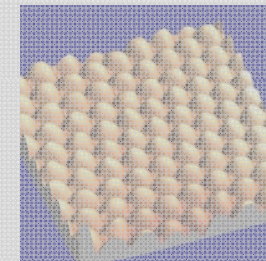
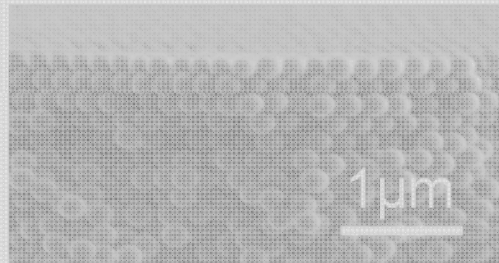
- Photons uniques et nanocristaux de CdSe/ZnS



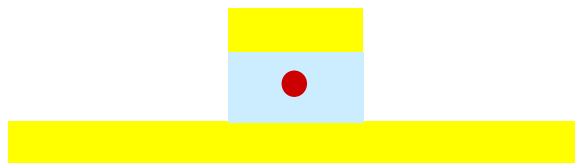
- Modification de l'émission au voisinage d'une surface d'or



- Cristal plasmonique



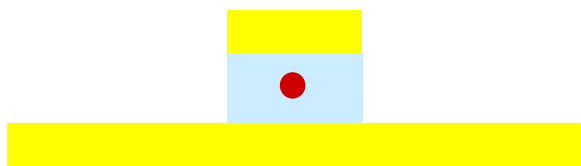
- Antenne patch



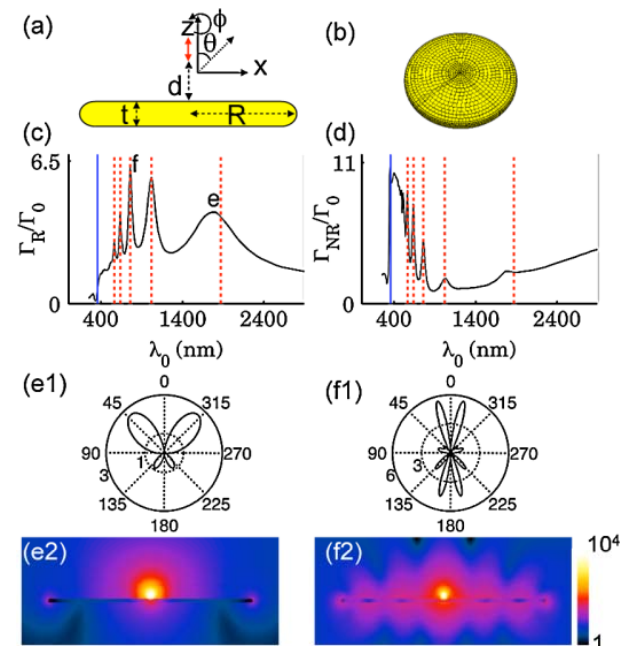
C. Belacel (INSP, LPN), A. Maître (INSP), **P. Senellart (LPN)**
J.J Greffet, F Marquier (LCFIO), B. Dubertret (ESPCI)

• Antenne patch

R. Esteban, T. Teperik, J.J. Greffet, PRL 104, 026802 (2010)



- Diagramme de rayonnement
- Accélération du rayonnement (« Effet Purcell »)

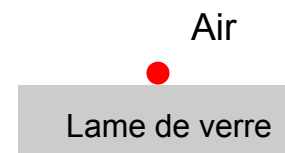


• **Positionnement déterministe** : la structure est gravée autour d'un nanocristal
 (technique développée au LPN : *A. Dousse, P. Senellart et al., Phys. Rev. Lett. 101, 267404*)

• **Nanocristaux de CdSe/CdS** très brillants (LPEM)

Temps de vie

$\langle \tau_{\text{air}} \rangle = 40 \text{ ns}$
 dispersion 30 %

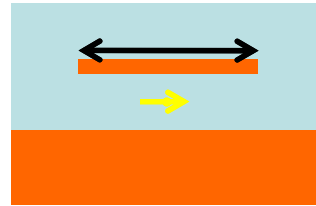
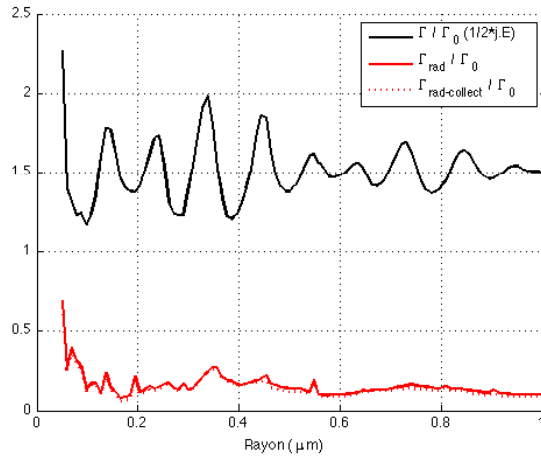


« Purcell » et rayonnement

Simulations (Institut d'optique)

Taux de déclin ($F_p = \Gamma / \Gamma_v$)

Taux de déclin radiatif ($P_{\text{rayonné}} / P_n$)

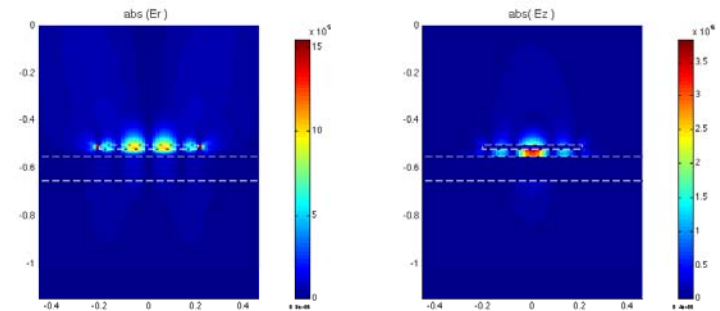
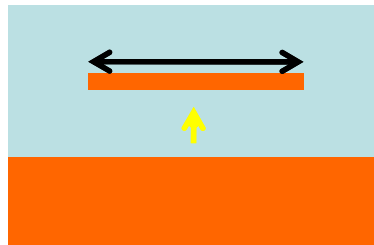
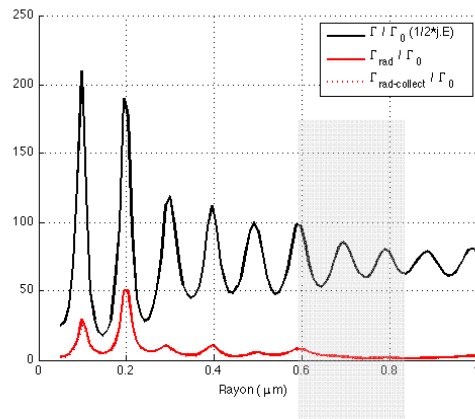


Couplage faible aux plasmons

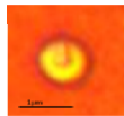
Référence

- milieu diélectrique infini (n)

Couplage fort aux plasmons

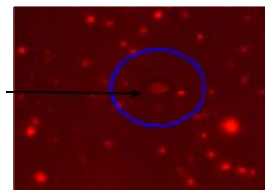
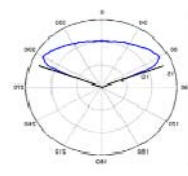
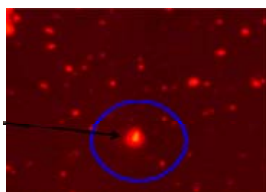
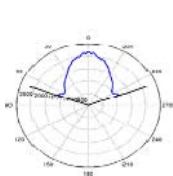


Accélération attendue $\approx 50-100$

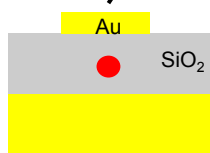
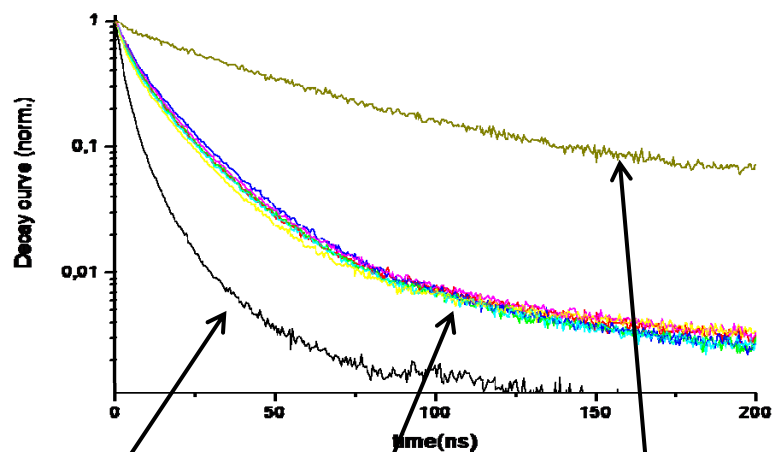


Clusters de nanocristaux

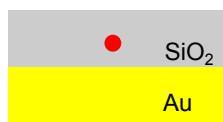
• Diagramme de rayonnement



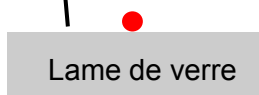
• Temps de vie



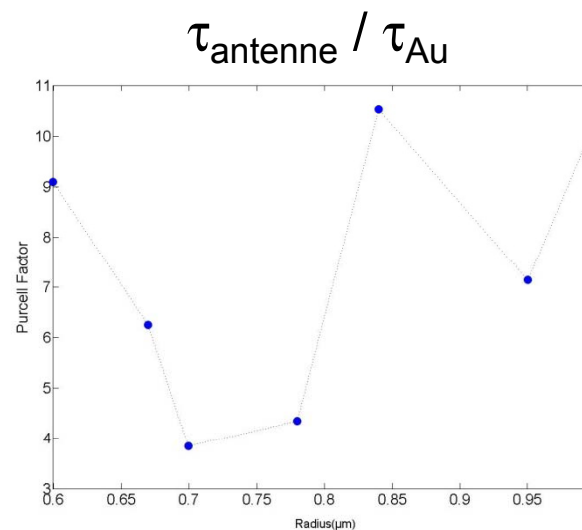
τ_{antenne}



$\langle \tau_{\text{Au}} \rangle = 4 \text{ ns}$
dispersion 10 %



$\langle \tau_n \rangle = 40 \text{ ns}$



$$\tau_{\text{Au}} / \tau_n \approx 10$$

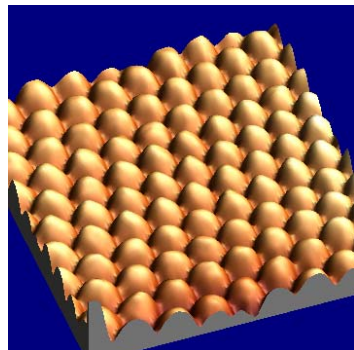
$$F_P = \tau_n / \tau_{\text{Antenne}} \approx 40-100$$

Contrôle de l'émission par l'environnement

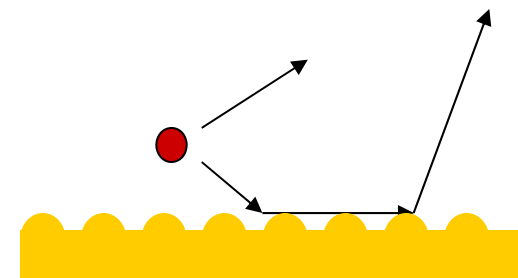
Modification de la densité locale d'états

- **Macroscopique**

Cristal plasmonique

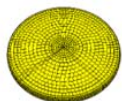


Couplage et réémission par les plasmons

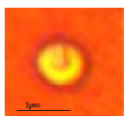


Optimisation de la source de photons uniques

- **Microscopique**



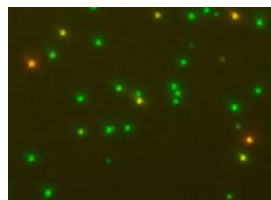
Facteur de Purcell: 40-100



Antenne avec un émetteur unique

Merci de votre attention

- Photons uniques et nanocristaux de CdSe/ZnS



Collaborations

LPEM, B. Dubertret, T. Pons, B. Malher

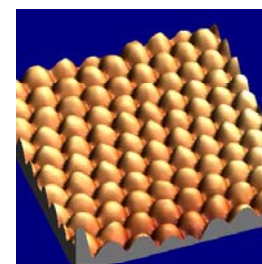
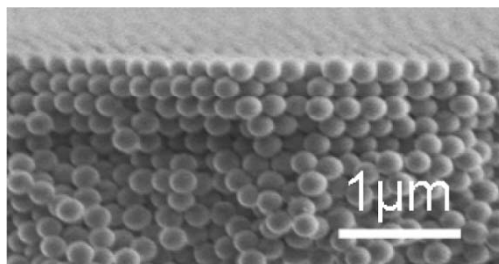
- Modification de l'émission au voisinage d'une surface d'or



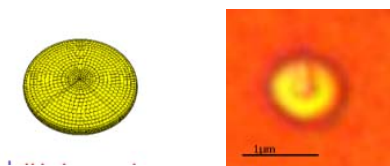
LKB, GEMAC; Jean-Pierre Hermier, Alberto Bramati

- Cristal plasmonique

*Hanoi, Pham Thu Nga
Moscou, A. Grusintsev*



- Antenne patch



LPN: Pascale Senellart

Institut d'optique: J.J. Greffet, F. Marquier, B. Habert