

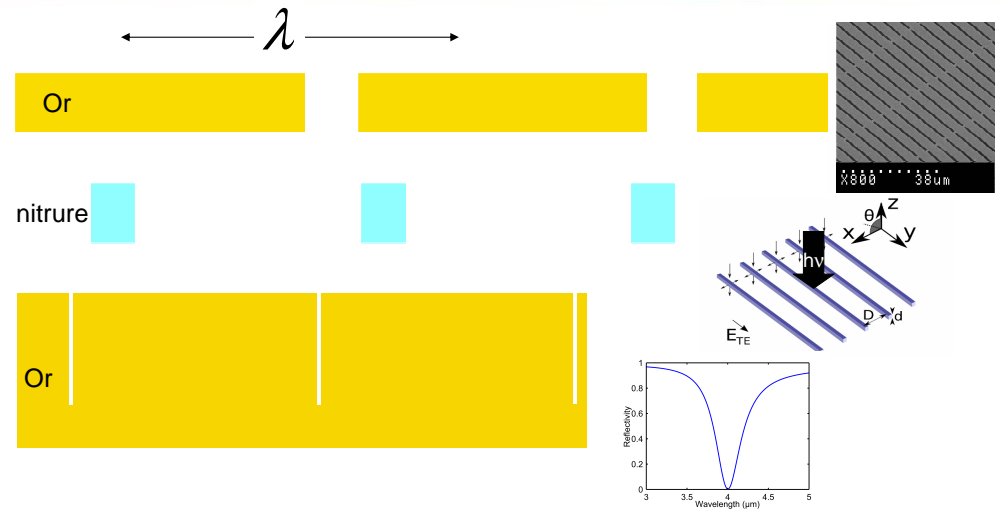
Nanotechnologies pour l'optique infrarouge

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P. Bouchon, P. Chevalier, S. Collin, S. Derelle, J. Deschamps, Th. Estruch, S. Héron, J. Jaeck, Q. Lévesque, F. Pardo, J.-L. Pelouard, B. Portier, E. Sakat, C. Tardieu, M. Verdun, G. Vincent



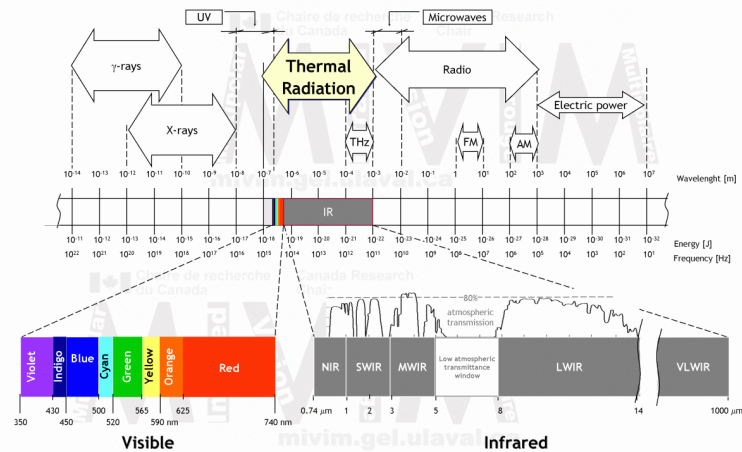
What about nanotechnologies ?



Le sub- λ , source de paradoxes



Infrared light detection



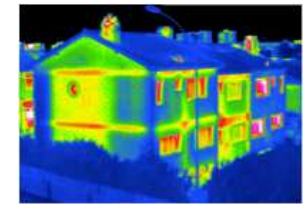
$$\lambda_{max} [\mu m] = \frac{3000}{T[K]}$$

Applications of IR detection

Vision nocturne



Performance énergétique



Maintenance Prédictive



Imagerie Médicale

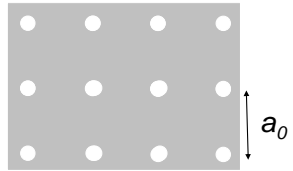


1. Poor spectral selection (wide-band detection)
2. Performances of IR detectors
3. Compacity/ Cost/ multifunctionality of IR camera



What about nanotechnologies ?

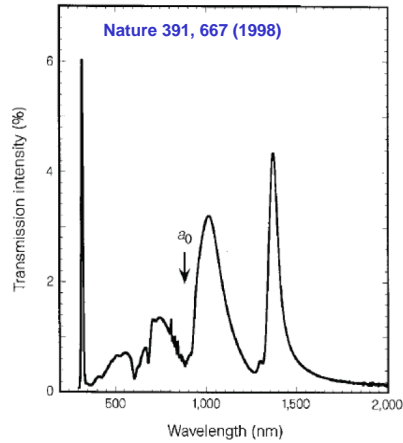
Thomas Ebbesen's experiment



Metal Film
Aperture $d = 150$ nm
Aperture ratio 2%

H.A. Bethe, Phys. Rev. 66, 163 (1966)
Sub- λ transmission

$$T \propto \left(\frac{d}{\lambda}\right)^4 \sim 10^{-3}$$



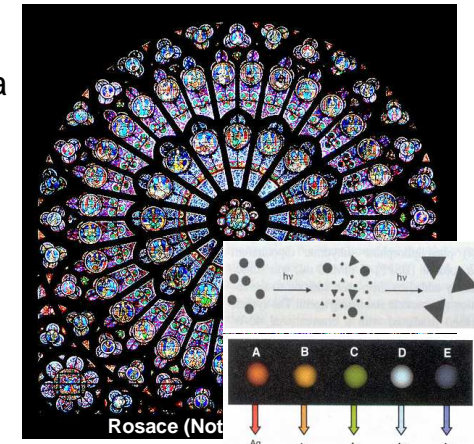
Th. Ebbesen, 1998

... extraordinary transparent to optical radiation

What about nanotechnologies ?

Des plasmons dans l'art... depuis l'antiquité !

Lycurgus cup from Byzantine era Nanoparticles of Gold in glass



Enhancement of absorption

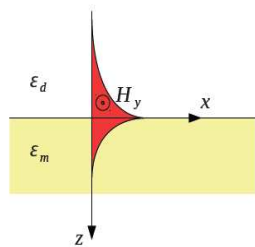
Surface plasmons

Ondes de surface sur les métaux

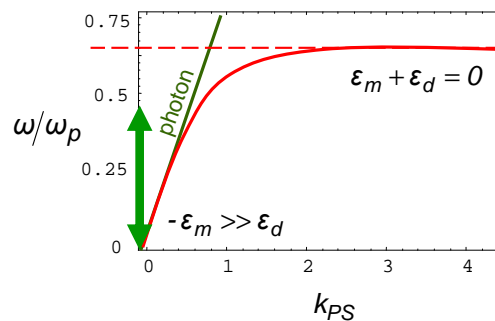
Rayonnement visible et infrarouge

Modèle de Drude des métaux

$$\epsilon_m(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + i\omega\gamma}$$



plasmons de surface



Plasmon de Surface dans le visible et l'infrarouge :
deux ondes planes inhomogènes qui se comportent comme un photon.

Basic architectures

for the application of plasmonics to imaging

Source de lumière \rightarrow

Hublot fonctionnalisé (filtrage angulaire ou spectral) \rightarrow

Optique réfractive (lentilles, prismes) \rightarrow

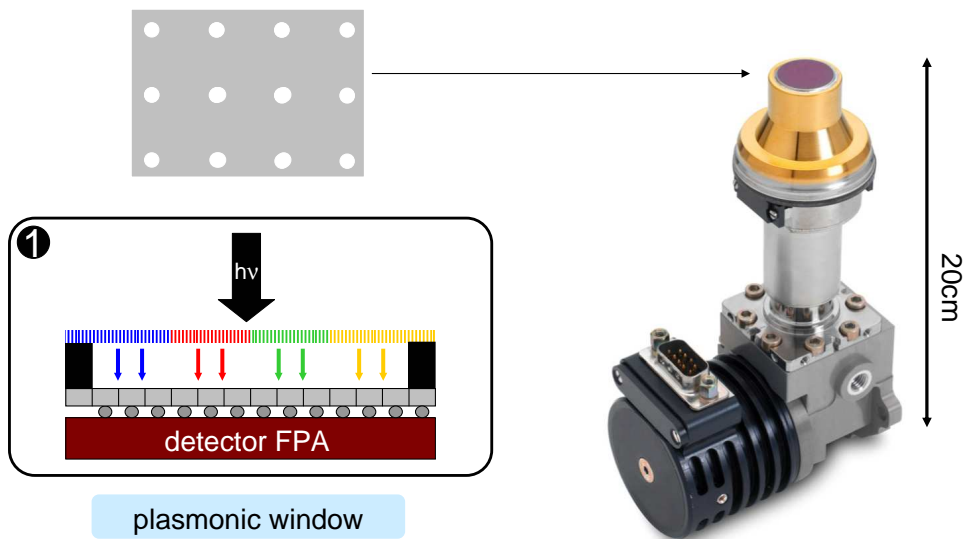
Détecteur (fonctions intégrées, performances) \rightarrow

Besoins :

1. Compacité (embarquabilité, coût cryogénique)
2. Coût
3. Multifonctionnalité
4. Performances

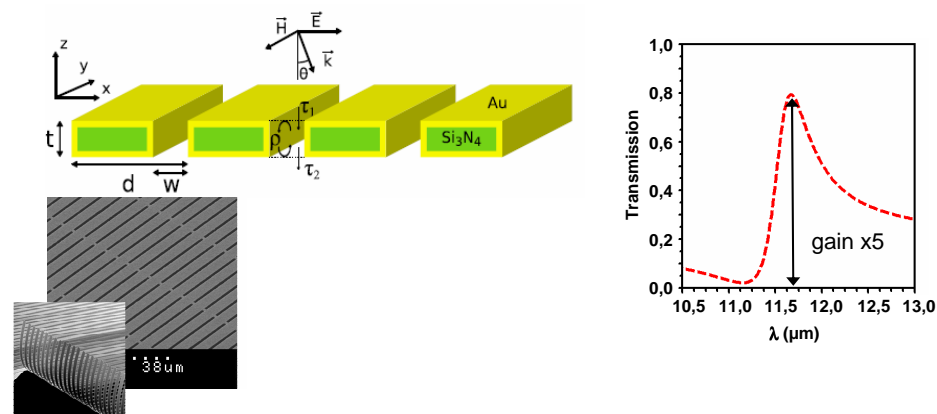


Basic architectures for the application of plasmonics to imaging



Plasmonic window Spectral filtering

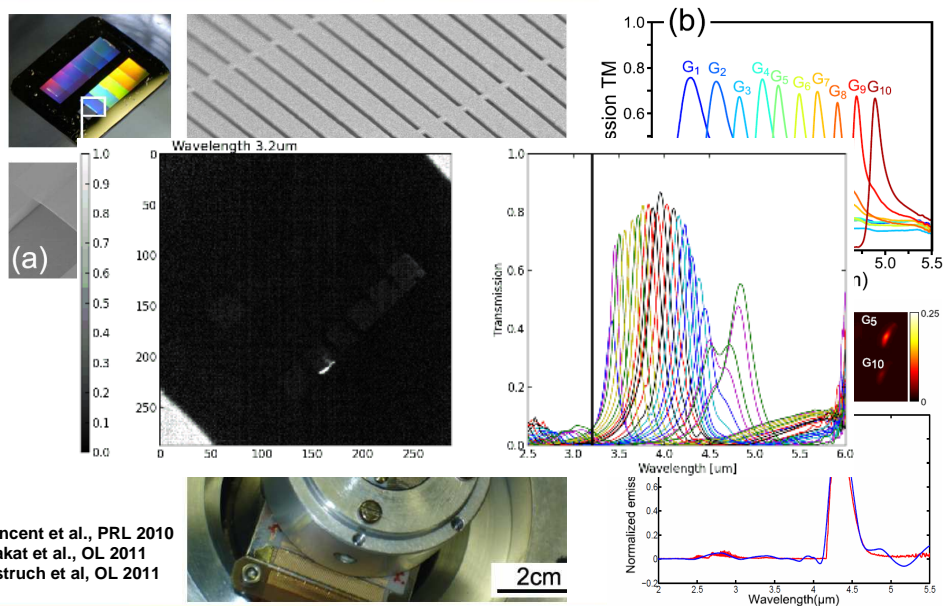
Quasi-perfect transmission through very narrow metallic slits
> Great interest for spectral filtering in the IR



core-shell technology

spectral filtering engineering

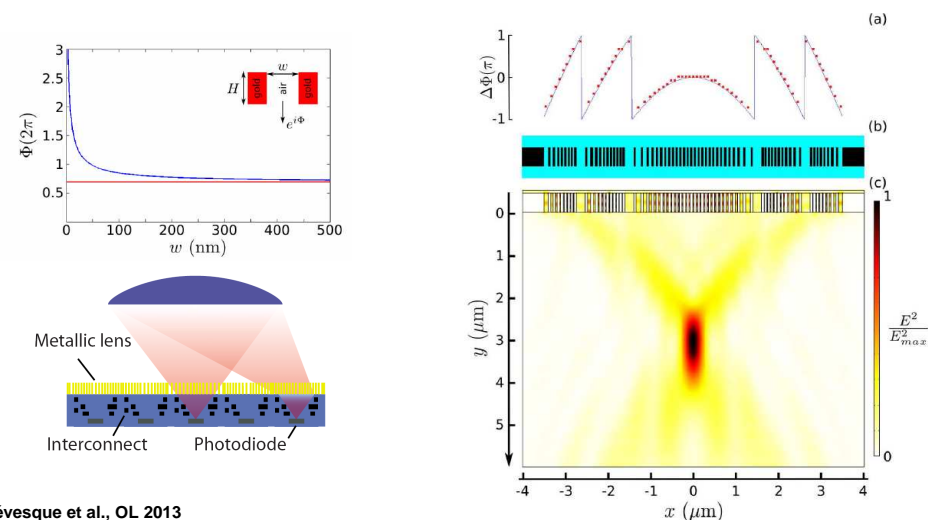
Plasmonic window Spectral filtering



Vincent et al., PRL 2010
Sakat et al., OL 2011
Estruch et al., OL 2011

Plasmonic window Plasmonic micro-optics

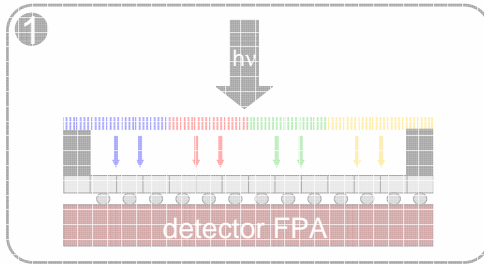
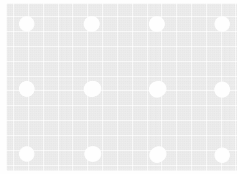
Phase-coding with narrow metallic slits



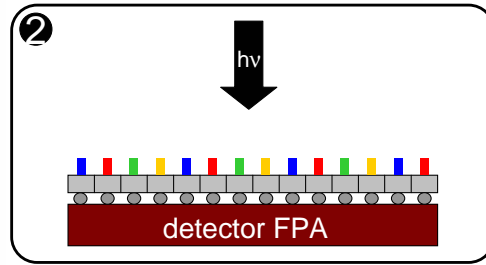
Lévesque et al., OL 2013

Basic architectures

for the application of plasmonics to imaging



plasmonic window

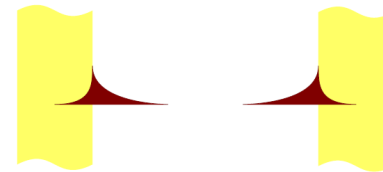


plasmonics on chip
absorption engineering

Plasmonics on chip

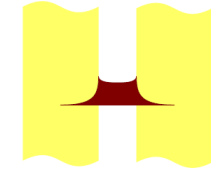
MIM structure

Metal-Insulator-Metal (MIM) structures



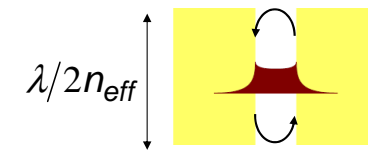
Two plasmons $k > \omega/c$

$$k_{spp} = \frac{k_0}{\sqrt{1/\epsilon_d + 1/\epsilon_m}} > \sqrt{\epsilon_d} k_0$$



Coupled plasmons $k \gg \omega/c$

high effective optical index



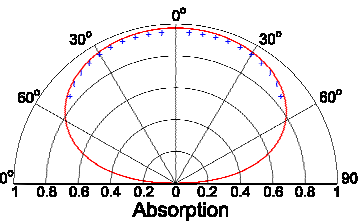
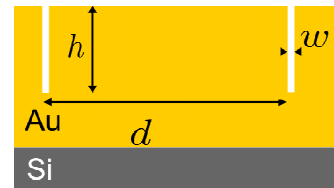
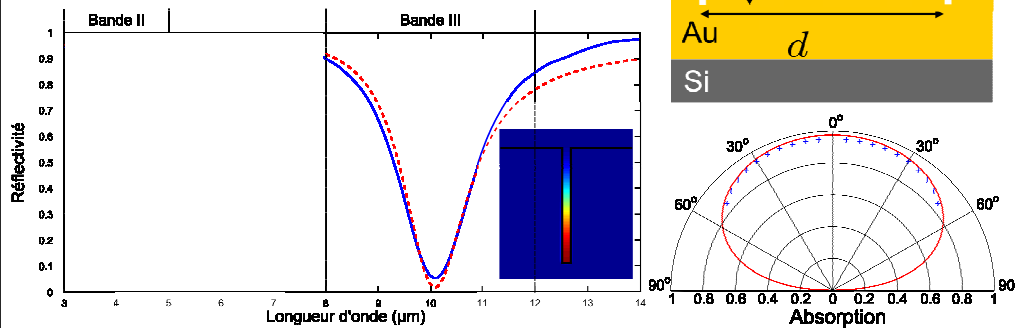
very small optical resonators

Plasmonics on chip

MIM : a perfect nano-antenna

Vertical MIM : experimental results

w = 150nm
d = 2500nm
h = 2000nm



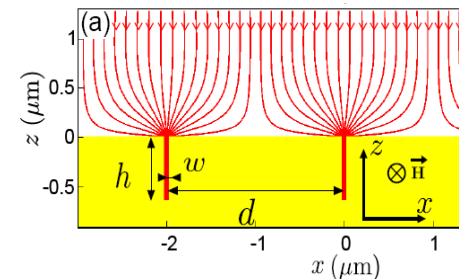
Total and quasi-omnidirectional absorption in nanometric grooves

Plasmonics on chip

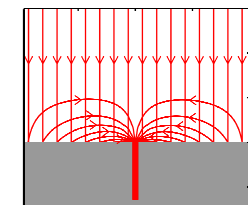
MIM : funneling mechanism

Vertical MIM : funneling mechanism

w = 150nm
d = 2500nm
h = 2000nm



$$E_e \times H_i + E_i \times H_e$$



Plasmonics on chip MIM : funneling and tunnel

ϵ_{air} ϵ_d ϵ_d ϵ_d

Prisme

© wikipedia

© wikipedia

$E_1 \times H_2 + E_2 \times H_1$

Analogie avec l'effet tunnel quantique à travers une barrière de potentiel.

Plasmonics on chip Horizontal MIM

MIM slits

$$\lambda_m \approx \frac{4n_{eff} h}{2m+1}$$

MIM ribbons

$$\lambda_m \approx \frac{2n_{eff} w}{m}$$

Plasmonics on chip MIM for bolometric detection

Principe de la détection thermique

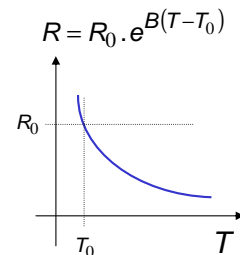
- Phase 1 : Absorption du rayonnement, et échauffement
- Phase 2 : Modification des propriétés physiques



La Tourmaline : un matériau pyroélectrique Le semiconducteur : bolomètre résistif



Theophraste

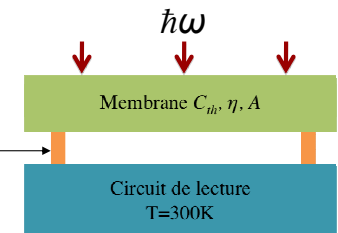


Phase 3 : Mesure d'un signal électrique

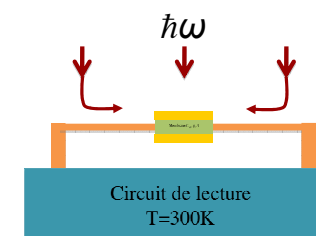
Plasmonics on chip MIM for bolometric detection

MIM pour la détection thermique

$\mathfrak{R} = \frac{\alpha}{G}$ ← Absorption
 $\tau_t = \frac{C}{G}$ ← Isolation thermique
 ← Volume

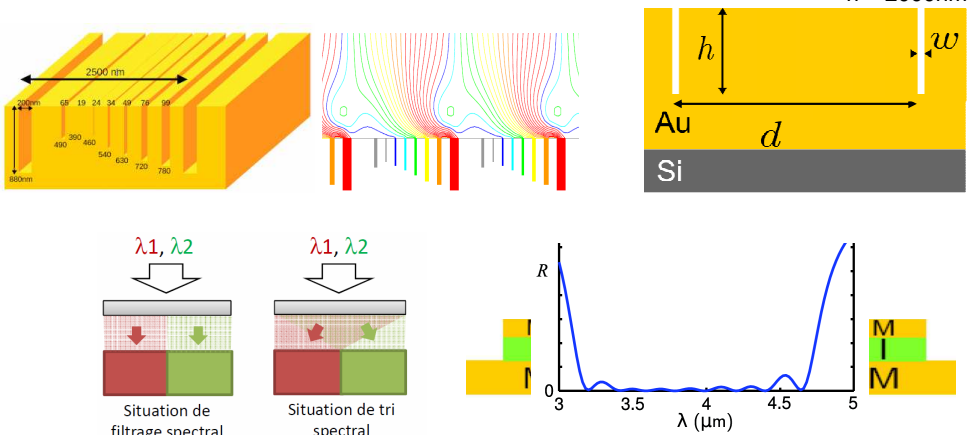


compromis entre vitesse (C) et efficacité (α) : tout absorber dans le plus petit volume...



Plasmonics on chip MIM for rainbow antenna

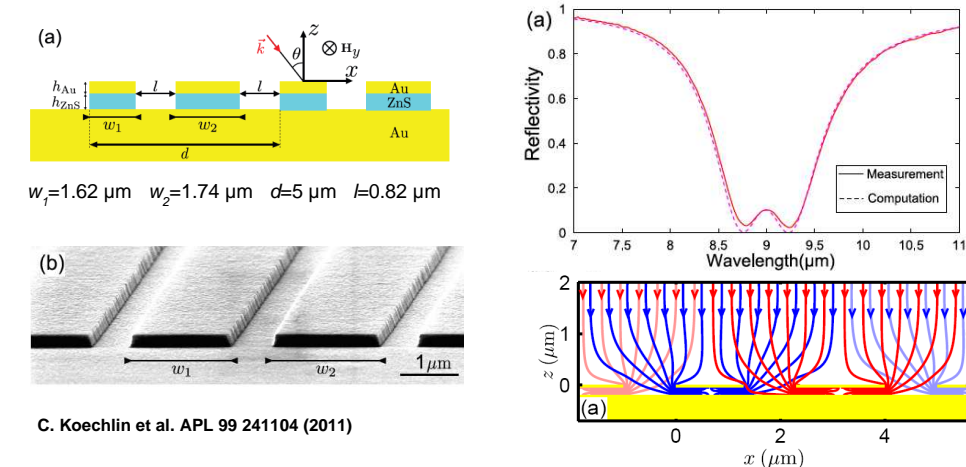
Combinaison d'antennes



Possibilité de tri spectral, sans perte de lumière

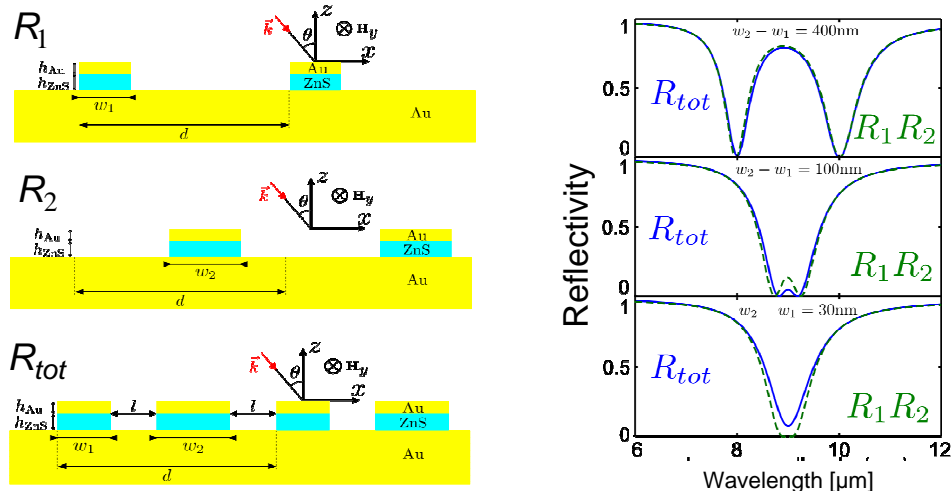
Plasmonics on chip Photons sorting in polarized 1D antennas

biMIM : 2 resonators per sub- λ period



Sorting effect & Wideband detection

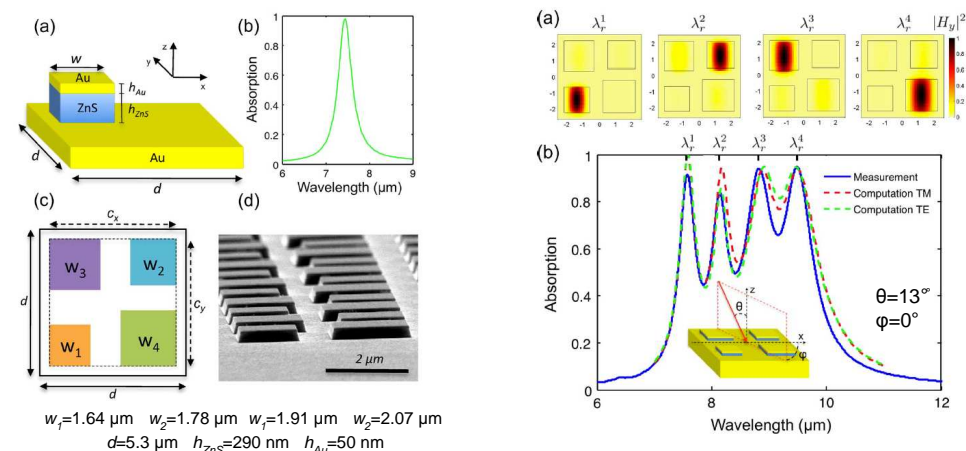
Plasmonics on chip Photons sorting in polarized 1D antennas



Independent antennas : « $R_1 R_2$ » design rule

Plasmonics on chip Photons sorting in 2D unpolarized antennas

quadriMIM : 4 resonators per sub- λ period



wideband unpolarized resonators

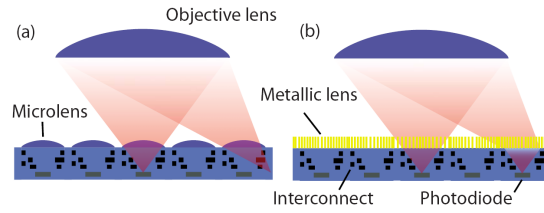
Conclusion

Plasmonics by combination of metals and dielectrics

- Optical functions on window

Camera on chip

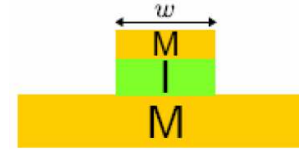
Verslegers et al, APL **95**, 071112 (2009)



- New photodetector structures

- Decrease the detector active area (solar cells, bolometers)
- Colorize the light detection (photons sorting instead of filtering)

MIM for thermal emission



Isotropic total light absorption in tiny volumes

$$\varepsilon(\lambda) = \alpha(\lambda)$$

