Plasmons, Plasmons Polaritons de Surface et application en Nanoptique

Physique de la matière condensée et nano-objets

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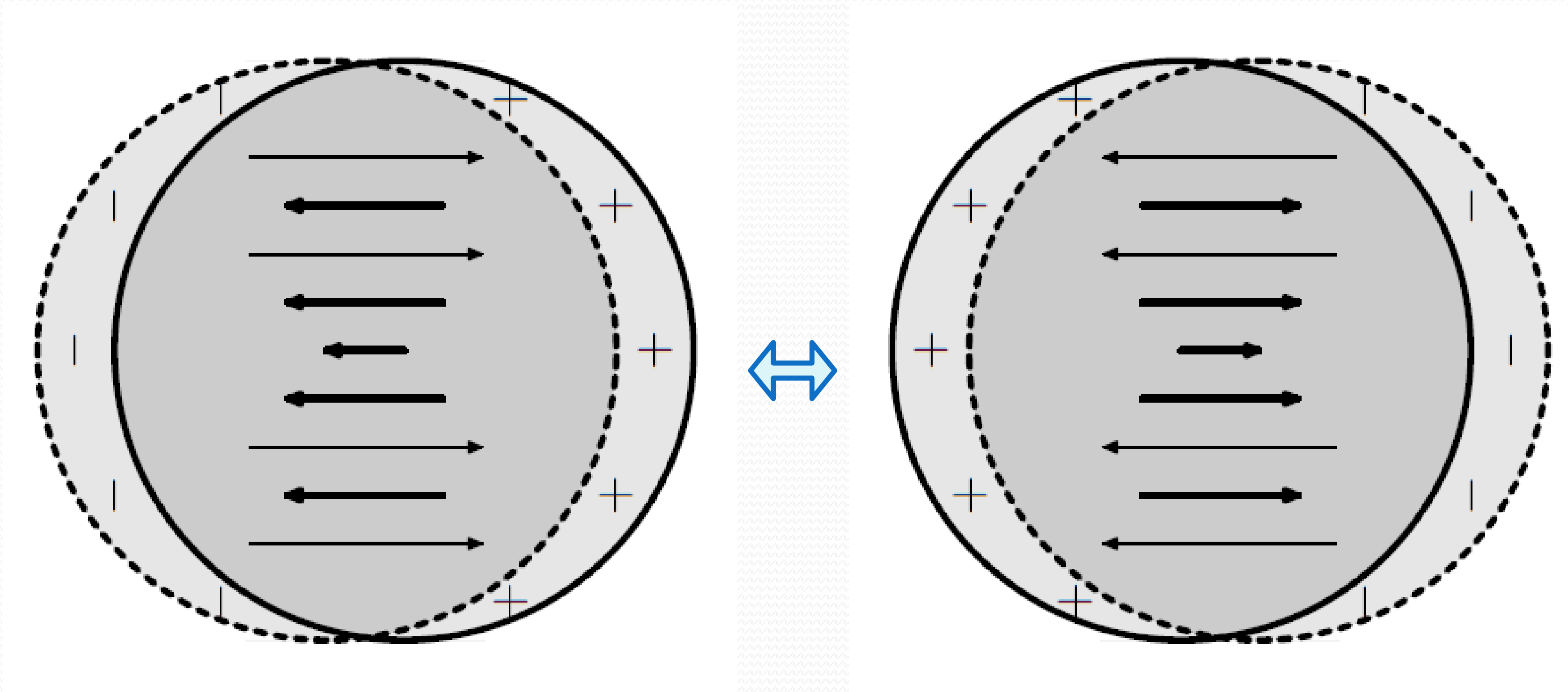
Plasmons

- Quantum d’oscillation du plasma
  (oscillation de densité de charges libres)



- Excitation collective

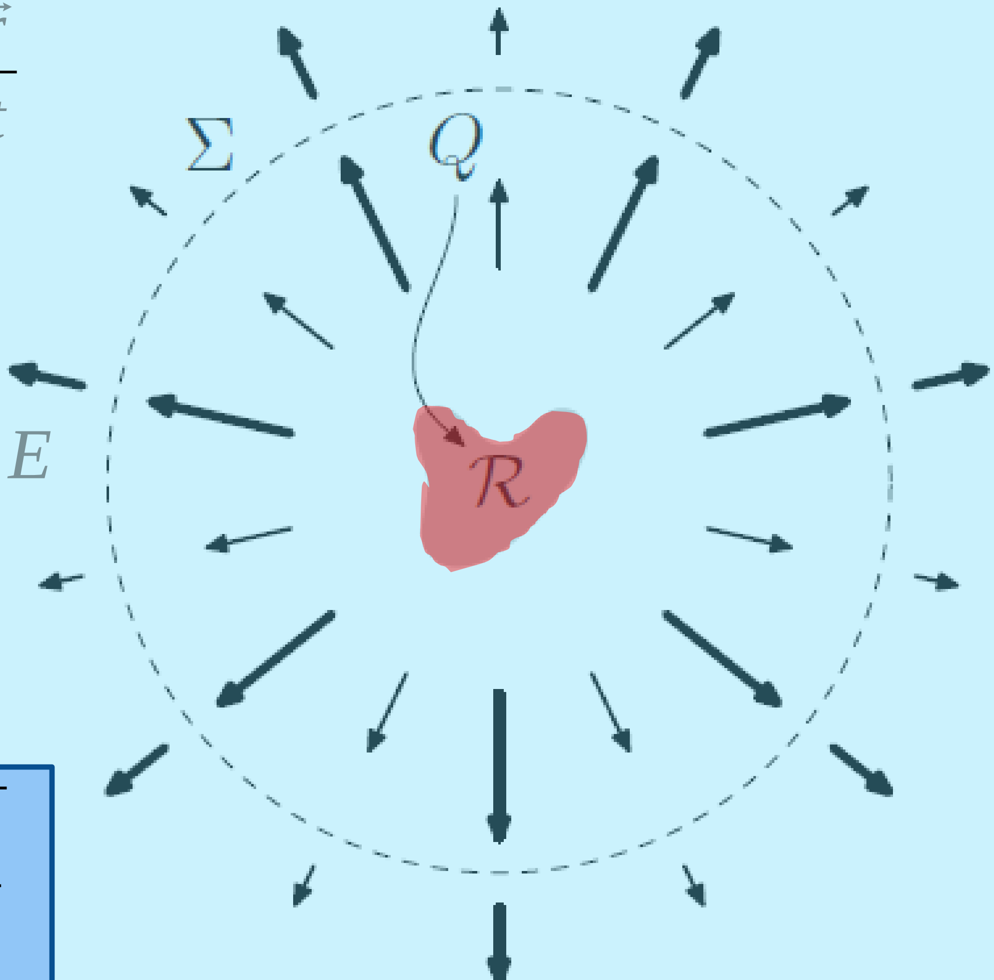
Fréquence Plasma

$$m\frac{d^2\vec{r}}{dt^2} = -eE(\vec{r},t) \qquad \vec{j} = -n_0 e\frac{d\vec{r}}{dt}$$

$$\frac{\partial\vec{j}(\vec{r},t)}{\partial t} = \left(\frac{n_0 e^2}{m}\right)E(\vec{r},t)$$

$$\frac{d}{dt}\int_\Sigma d\vec{a}\cdot\vec{j}(\vec{r},t) = \left(\frac{n_0 e^2}{m}\right)\int_\Sigma d\vec{a}\cdot E$$

$$\frac{d^2Q}{dt^2} = -\frac{4\pi n e^2}{m}Q \qquad Q = Q(0)\,e^{-i\omega_p t}$$



CGS

$$\omega_p = \sqrt{\frac{4\pi n e^2}{m}}$$

SI

$$\omega_p = \sqrt{\frac{n e^2}{\varepsilon_0 m}}$$

$$E_p = \hbar\omega_p \approx 5-15eV$$

Permittivité diélectrique

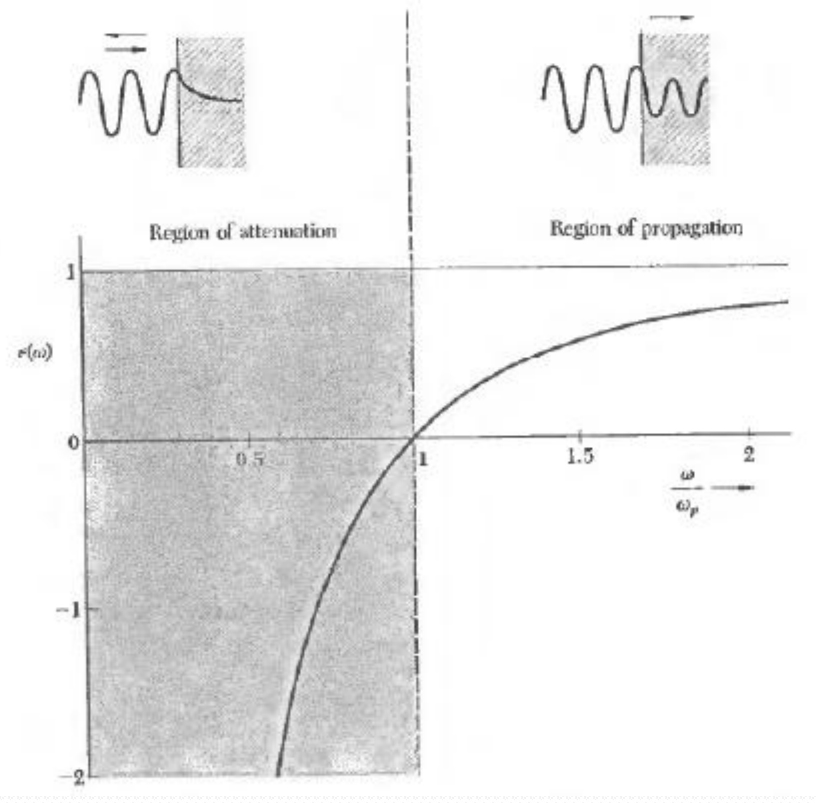
$$\varepsilon(\omega, \vec{k})$$

$$m\frac{d^2\vec{r}}{dt^2} = -e\vec{E} \qquad E \propto e^{-i\omega t} \qquad \vec{r} = \frac{e}{m\omega^2}\vec{E}$$

$$\vec{P} = -n_0 e\vec{r} = -\frac{ne^2}{m\omega}\vec{E}$$

$$\varepsilon(\omega) = \frac{D(\omega)}{E(\omega)} = 1 + 4\pi\frac{P(\omega)}{E(\omega)} = 1 - \frac{4\pi ne^2}{m\omega^2}$$

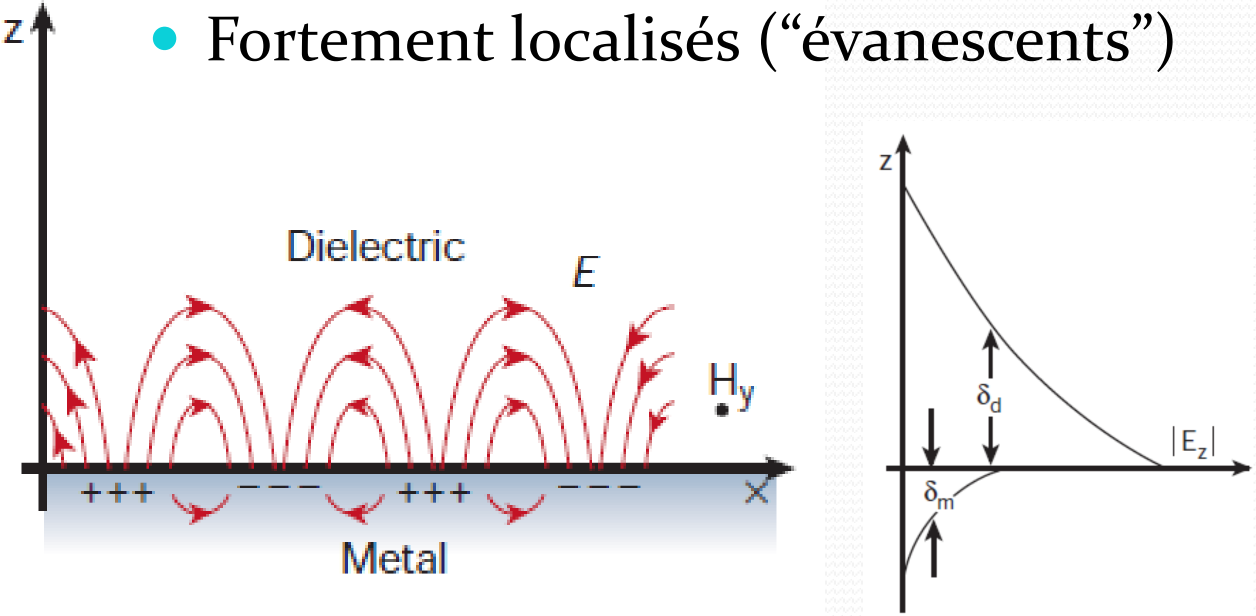
$$\varepsilon(\omega) = 1 - \frac{\omega_p^2}{\omega^2}$$

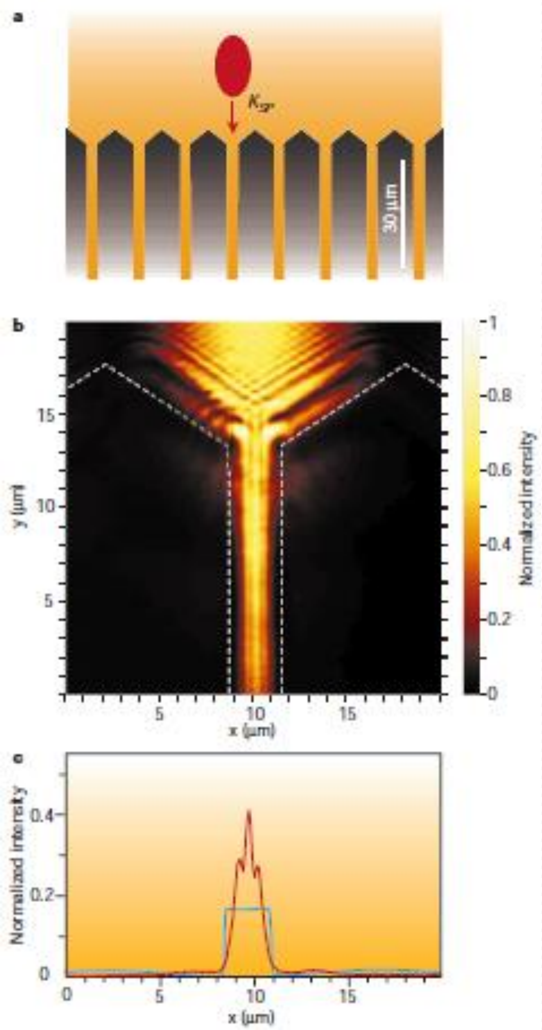


Plasmon Polaritons de Surface

Plasmons de Surface

- Transverse magnétiques
- Fortement localisés ("évanescents")





Plasmon Polaritons

- Couplage photon – plasmon
- propagation jusqu'au mm

Relation de dispersion - Volume

Ondes électromagnétiques dans un gaz d'électrons libres

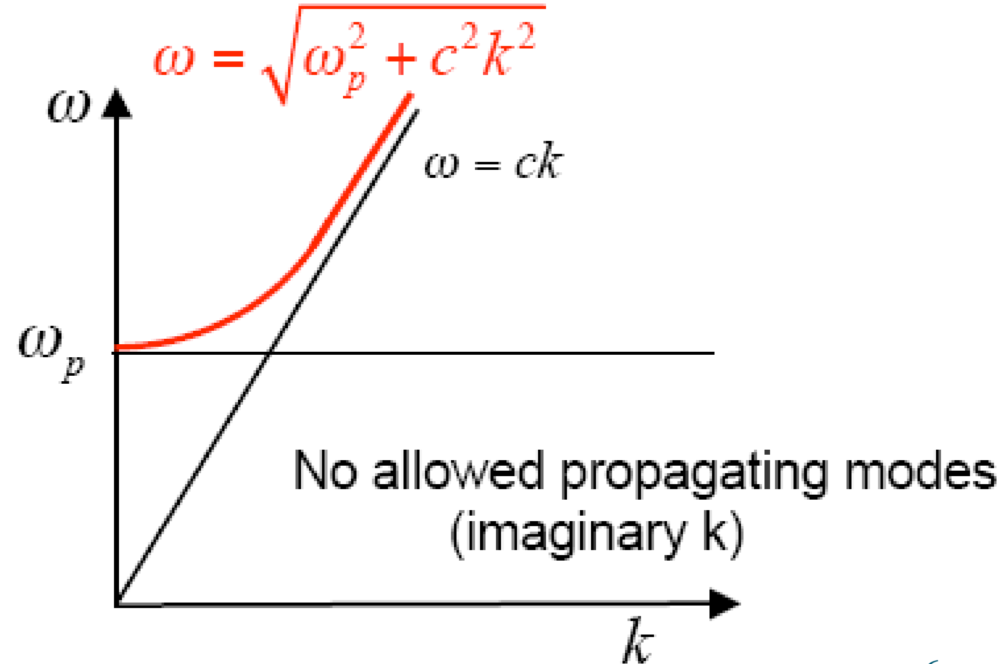
$$\frac{\partial^2 \vec{D}}{\partial t^2} = c^2 \nabla^2 \vec{E}$$

Equation d'onde

$$\vec{E} \propto e^{-i\omega t} e^{i\vec{k}\cdot\vec{r}}$$

$$\varepsilon(\omega, \vec{k})\,\omega^2 = c^2 k^2$$

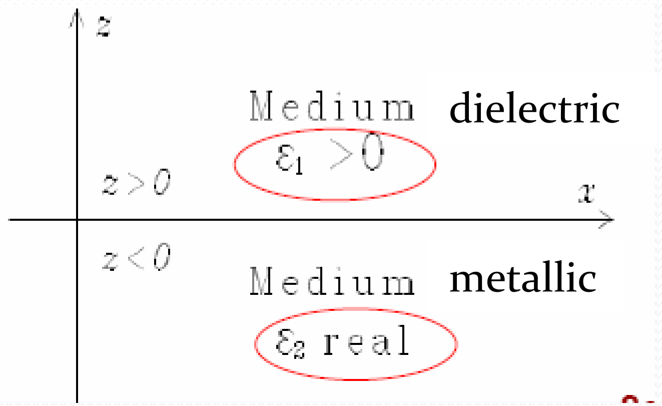
$$\omega^2 - \omega_p^2 = c^2 k^2$$



Relation de dispersion – SPs – 1

z<0 $\begin{cases} \boldsymbol{H}_d = (0, H_{yd}, 0)\exp i(k_{xd}x + k_{zd}z - \omega t) \\ \boldsymbol{E}_d = (E_{xd}, 0, E_{zd})\exp i(k_{xd}x + k_{zd}z - \omega t) \end{cases}$

z>0 $\begin{cases} \boldsymbol{H}_m = (0, H_{ym}, 0)\exp i(k_{xm}x + k_{zm}z - \omega t) \\ \boldsymbol{E}_m = (E_{xm}, 0, E_{zm})\exp i(k_{xm}x + k_{zm}z - \omega t) \end{cases}$



Dans le moyen i :

$$\nabla \times \vec{H}_i = \varepsilon_i \frac{d\vec{E}_i}{dt} \Rightarrow (k_{zi}H_{yi}, 0, ik_{xi}H_{yi}) = (\omega\varepsilon_i E_{xi}, 0, i\omega\varepsilon_i E_{zi})$$

$$k_{zi}H_{yi} = -\omega\varepsilon_i E_{xi}$$

$$\begin{cases} k_{zm}H_{ym} = -\omega\varepsilon_m E_{xm} \\ k_{zd}H_{yd} = -\omega\varepsilon_d E_{xd} \end{cases}$$

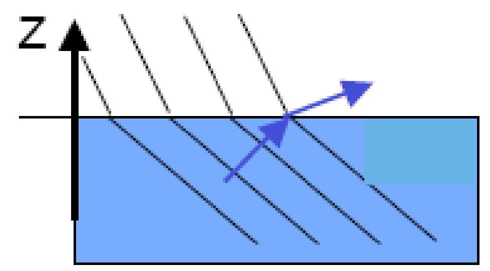
Continuité à la surface $\begin{cases} E_{xm} = E_{xd} \\ H_{ym} = H_{yd} \end{cases}$

$$\frac{k_{zm}}{\varepsilon_m} = \frac{k_{zd}}{\varepsilon_d}$$

Relation de dispersion – SPs – 2

Pour toutes les surfaces :

$$k_{xm} = k_{xd}$$



Si on suppose que μ=1 et k_y=0

$$|k| = \frac{n\omega}{c}$$

$$k_x^2 + k_{zi}^2 = \varepsilon_i \left(\frac{\omega}{c}\right)^2$$

$$\left.\begin{aligned} k_{sp} = k_x = \sqrt{\varepsilon_i \left(\frac{\omega}{c}\right)^2 - k_{zi}^2} \\ \frac{k_{zm}}{\varepsilon_m} = \frac{k_{zd}}{\varepsilon_d} \end{aligned}\right\}$$

$$k_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_d \varepsilon_m}{\varepsilon_d + \varepsilon_m}}$$

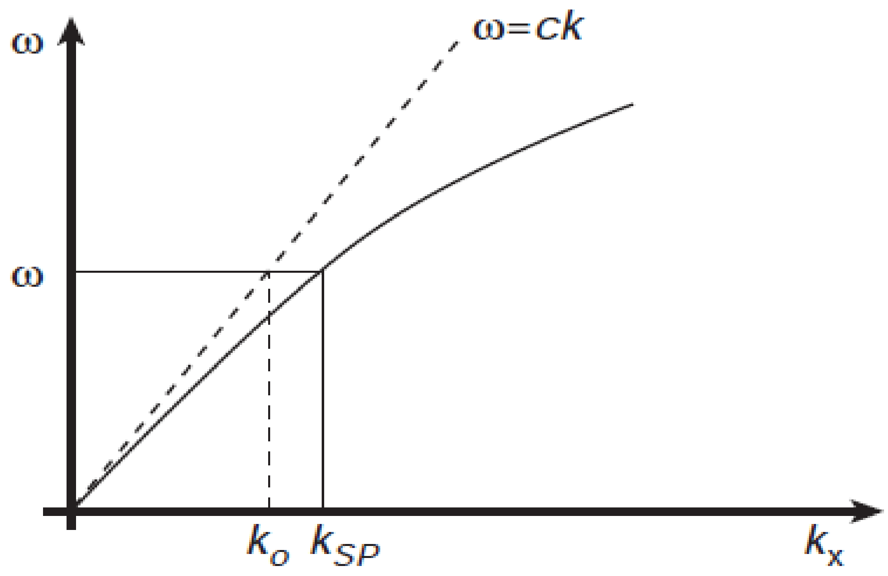
Relation de dispersion des plasmons surfaciques

Couplage photon-plasmon

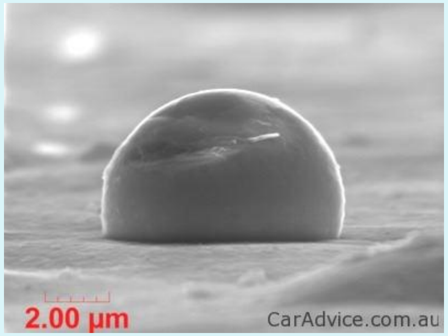
- Différent moment:

$$\hbar k_{sp} \neq \hbar k_0$$

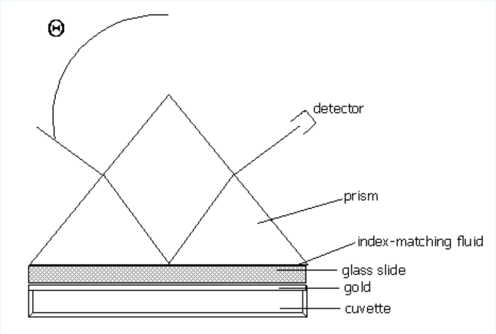
$$k_{sp} = k_0 \sqrt{\frac{\varepsilon_d \varepsilon_m}{\varepsilon_d + \varepsilon_m}}$$



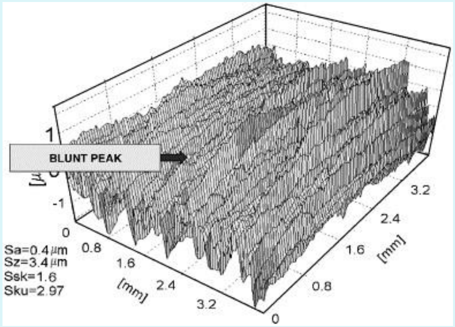
diffusion par un défaut



couplage avec prismes

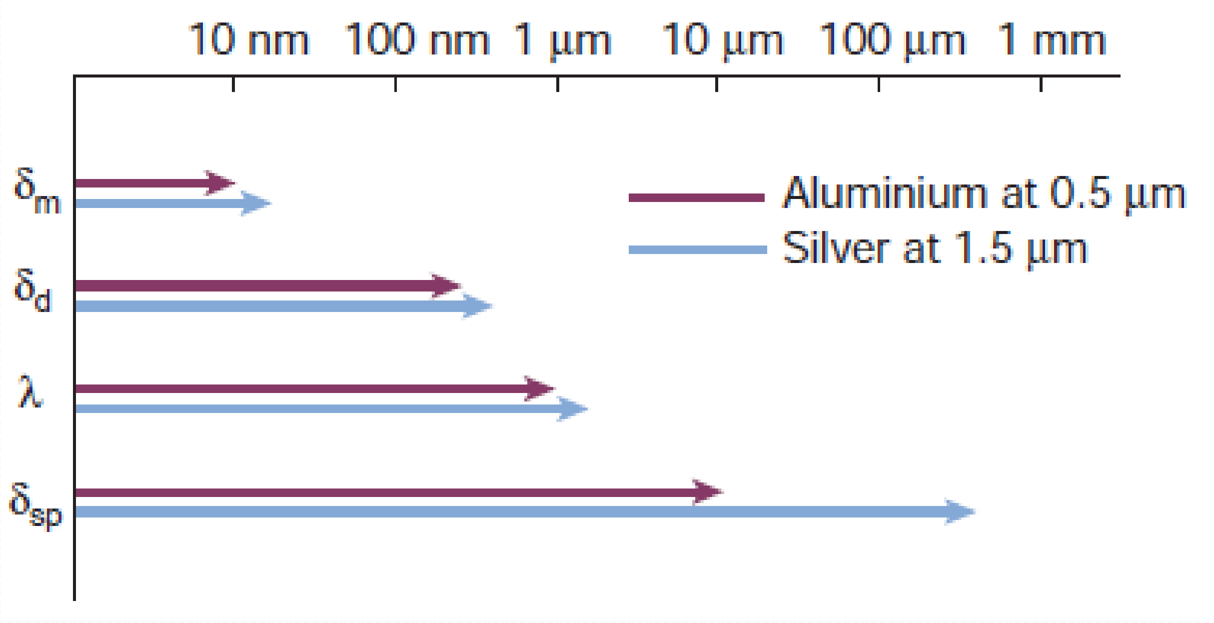


rugosité périodique



Couplage photon-plasmon

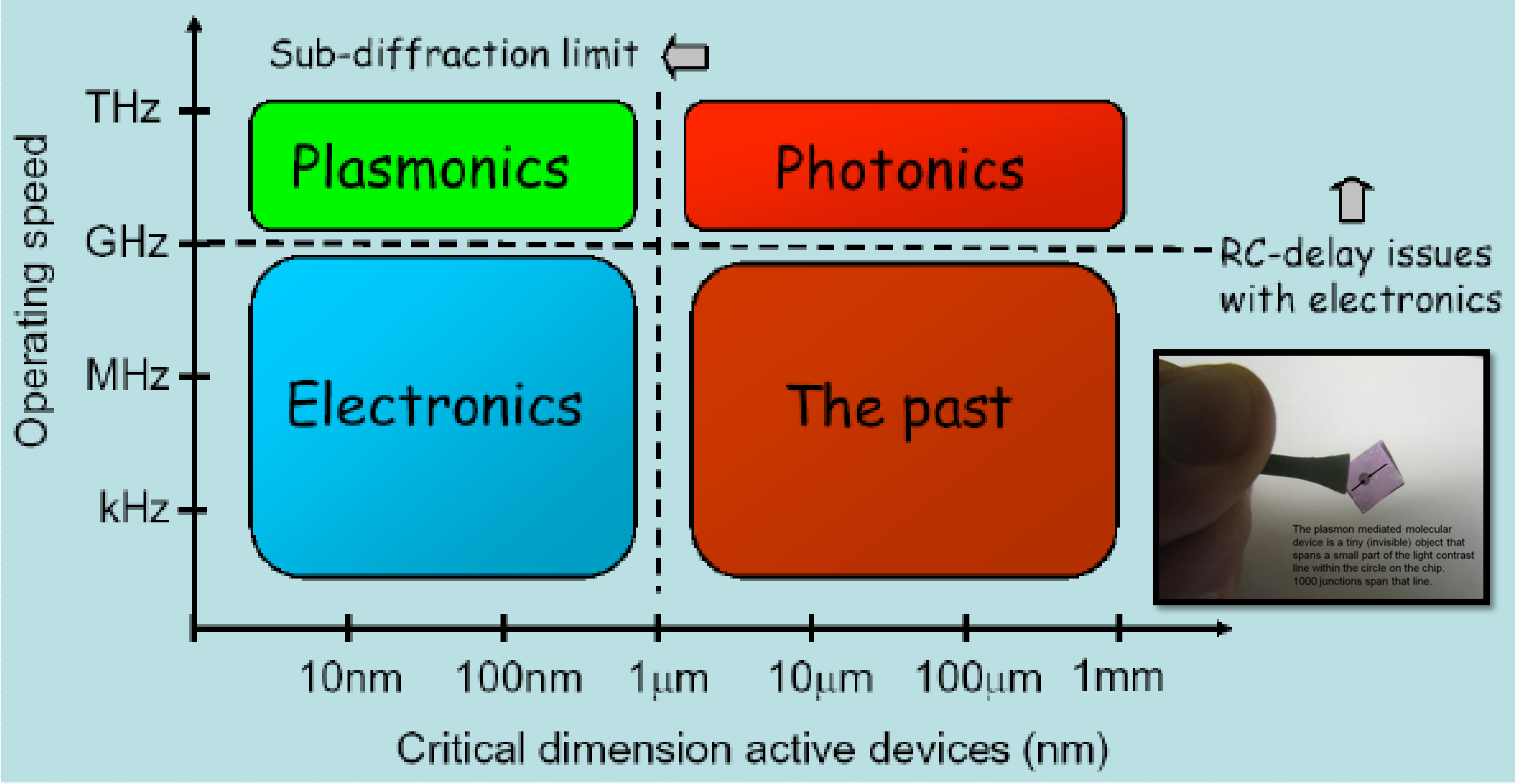
- Décadence exponentielle perpendiculairement à la surface



- Atténuation par absorption dans le métal

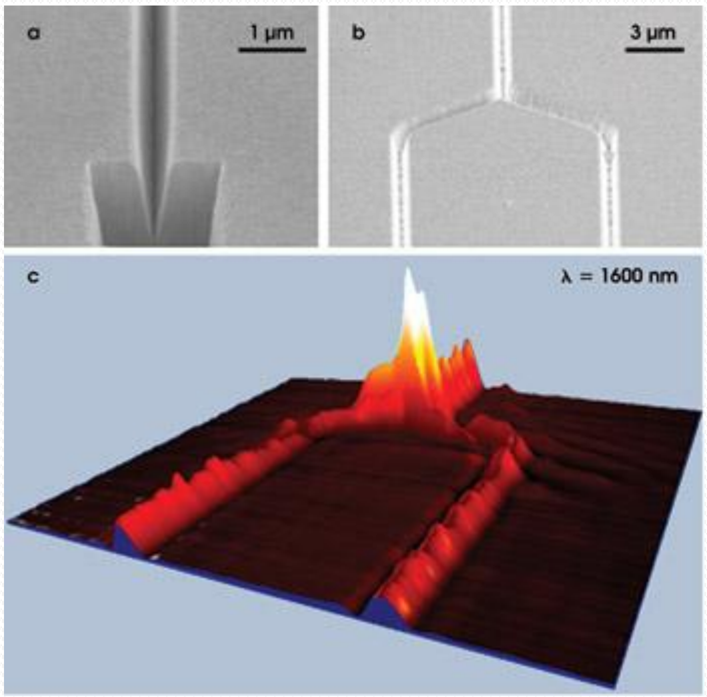
$$\delta_{SP} = \frac{1}{2k''_{SP}} = \frac{c}{\omega}\left(\frac{\varepsilon'_m + \varepsilon_d}{\varepsilon'_m \varepsilon_d}\right)^{\frac{3}{2}} \frac{(\varepsilon'_m)^2}{\varepsilon''_m}$$

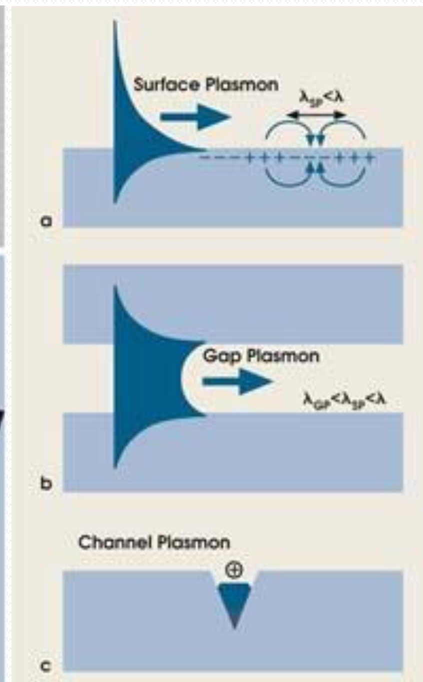
Nanocircuits

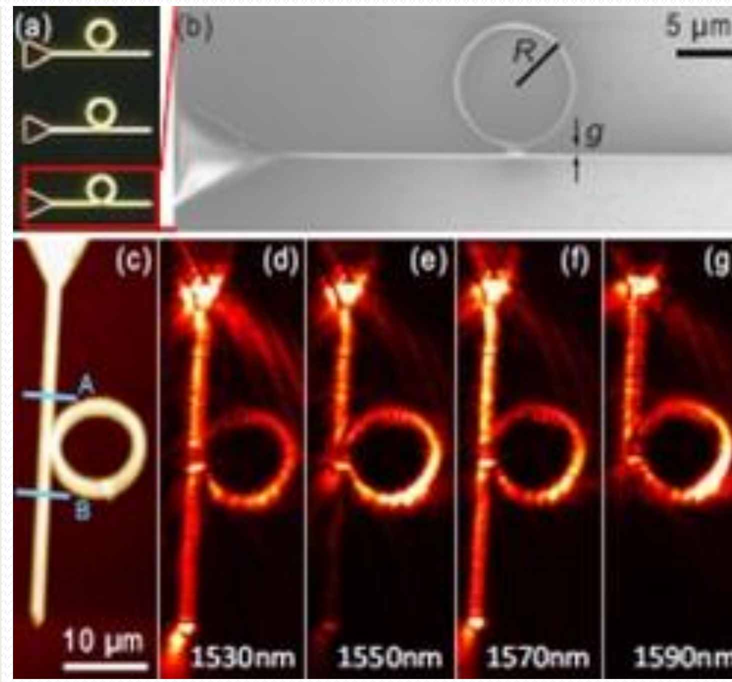


Nanocircuits

Channeling Surface Plasmons





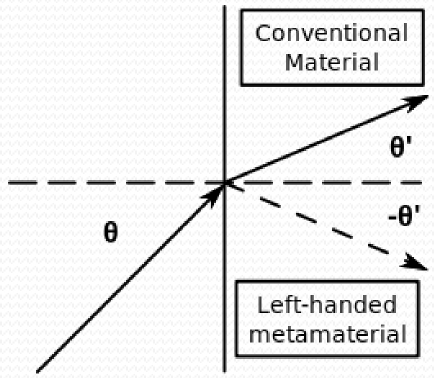


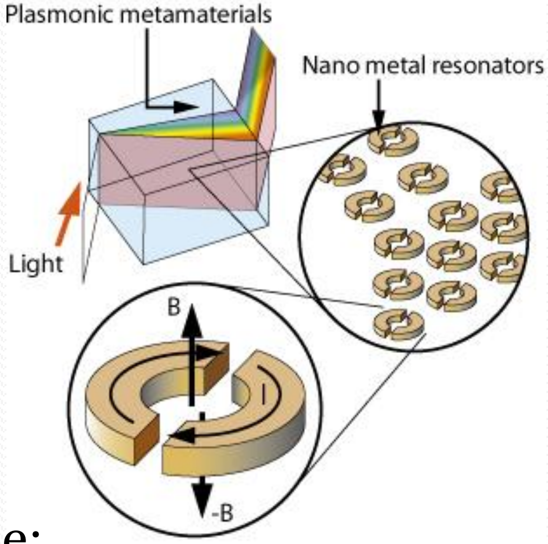
Microscope optique en champ proche (NSOM)

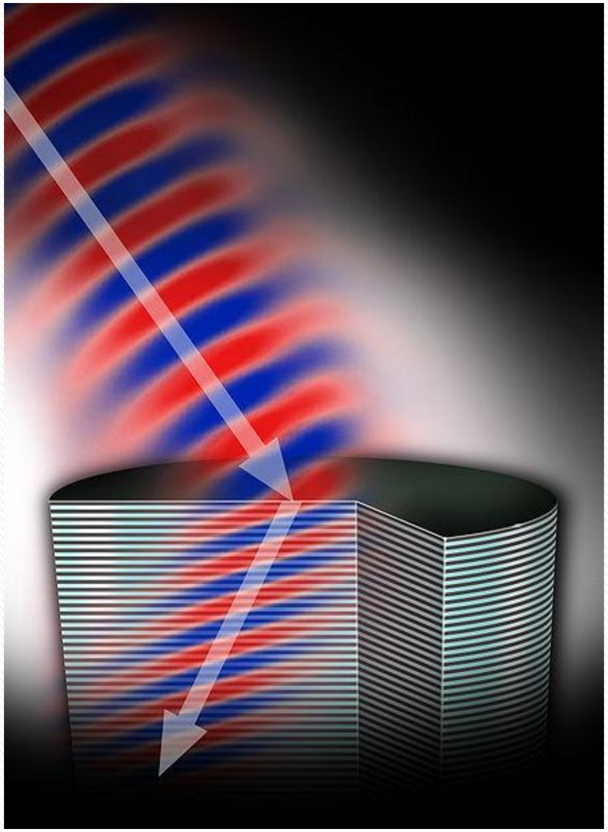
Métamatériaux plasmoniques

Métamatériaux:

matériaux avec propriétés électromagnétiques qui n'existent pas en nature





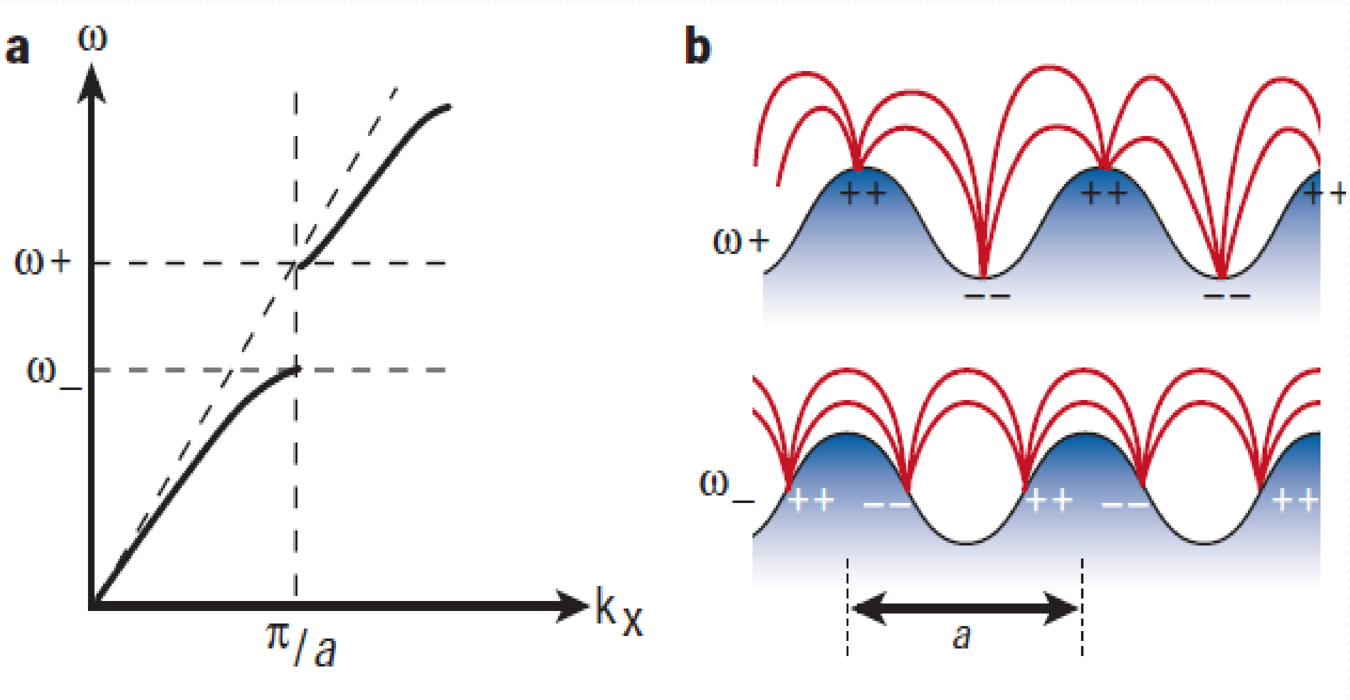


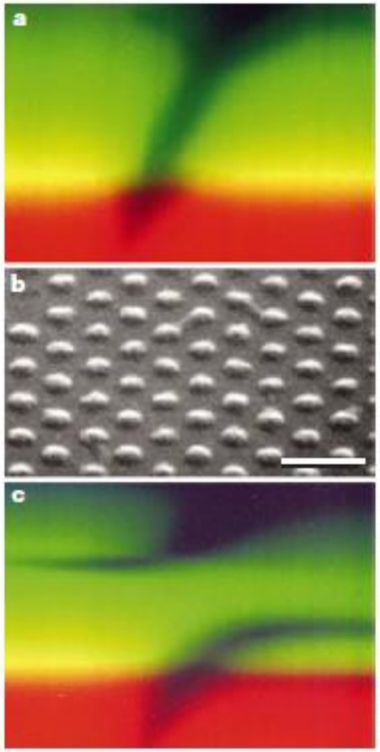
<u>Métamatériaux à main gauche</u>:

- indice de réfraction négatif
- vitesse de phase et groupe opposées
- effet Doppler inversé
- effet Tcherenkov inversé

Métamatériaux plasmoniques

Métamatériaux à bandes photonique (PBG) - à SPs bandes

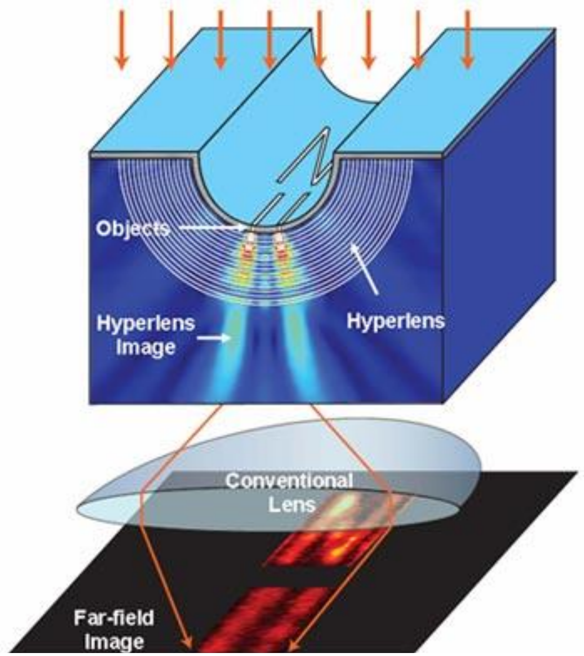


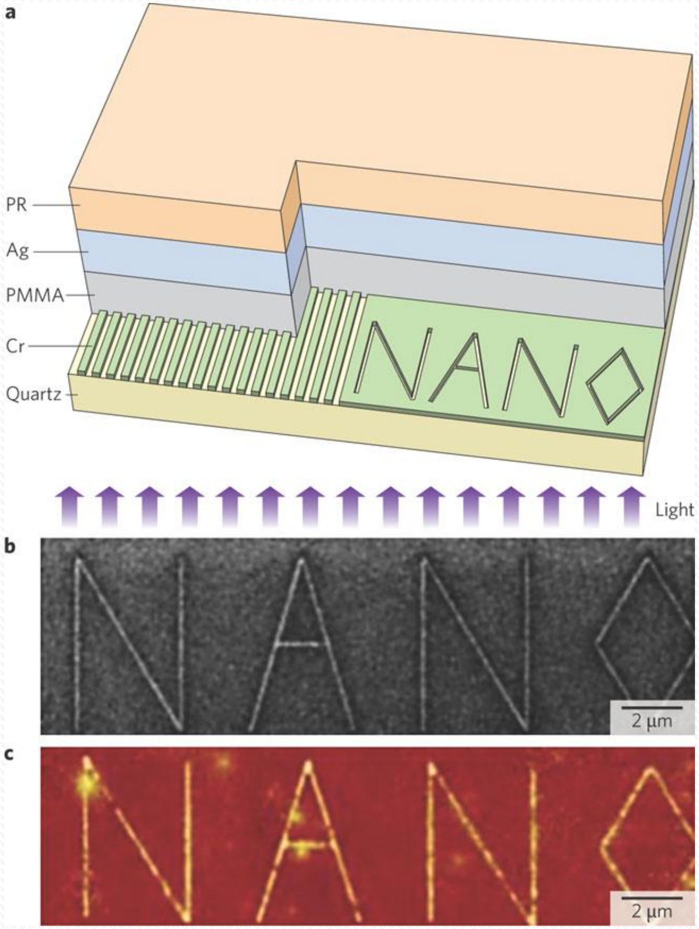


Métamatériaux plasmoniques

Images sous longueur d'onde (subwavelength imaging)

voir structures plus petites de la longueur d'onde de la lumière visible par moyen des images optiques

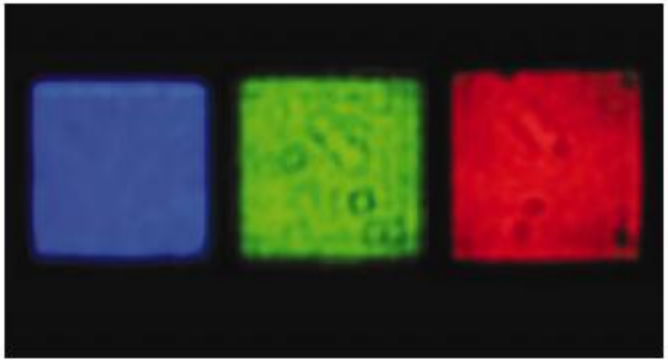




→ Superlentille

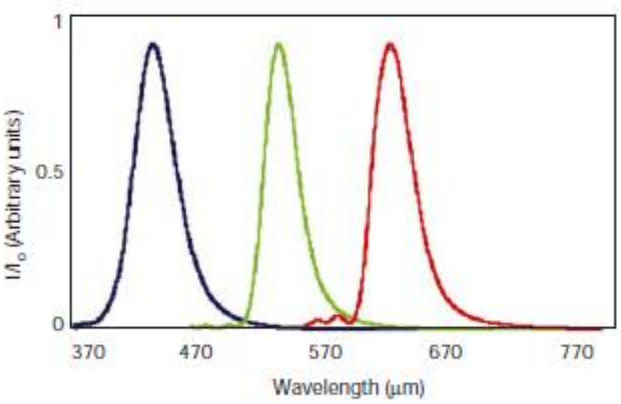
Transmission optique extraordinaire

EOT: amélioration de la transmission de la lumière par moyen d'ouvertures (trous) de dimensions inférieur à la longueur d'onde et périodiques.



Modulation des propriétés :

- dimensions
- distances

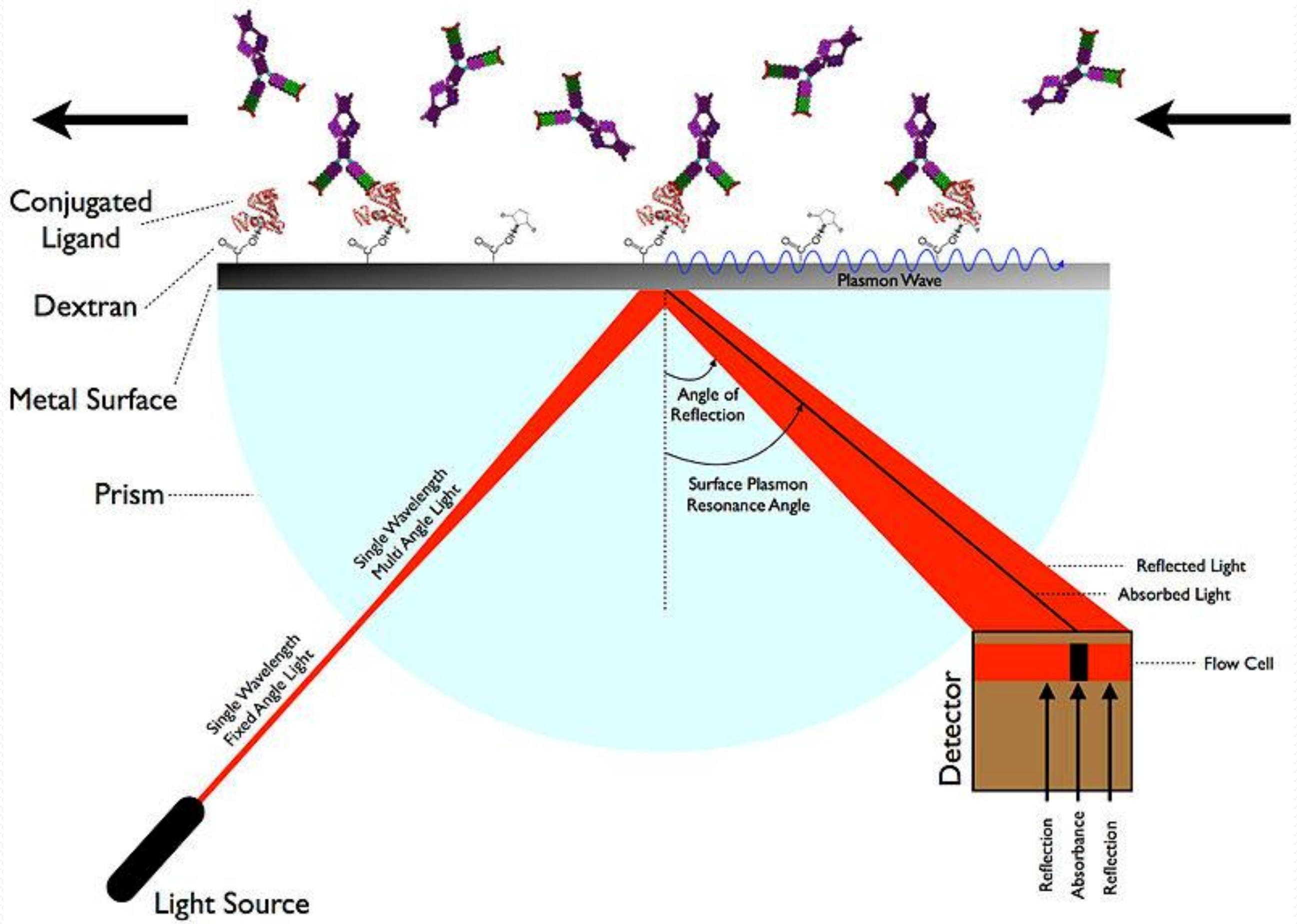


Effets de:

- tunneling
- résonance

Résonance des plasmons de surface

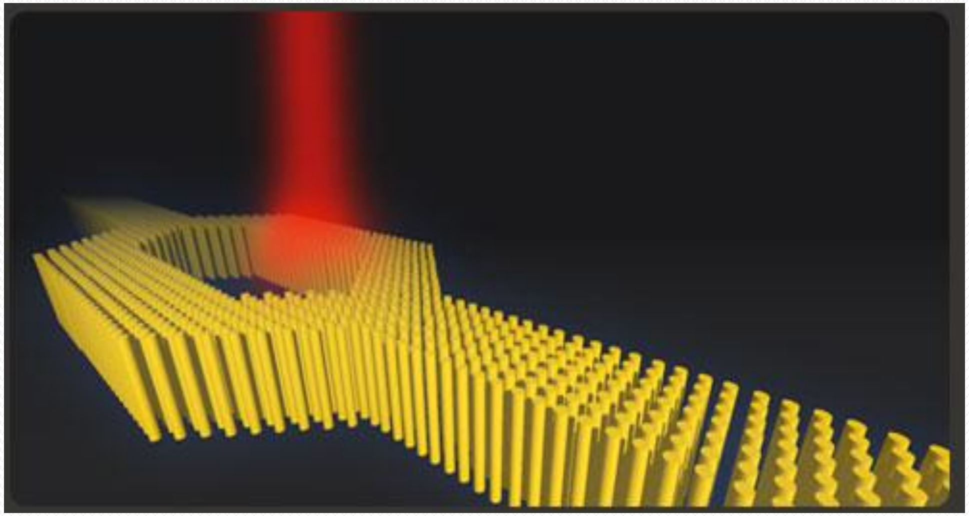
SPR: oscillation collective des électrons de valence d'un solide stimulé par lumière incident avec fréquence correspondent à la fréquence plasma



Conclusions

Développements futurs:

- réutilisation d’une partie de l’énergie des OLED
- composants photoniques non linéaires
- nouvelles technologies dans les domaines sous longueur d’onde
- Spinning-plasmonics



Merci pour votre attention

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