Radiative heat transfer at small scales in complex media (part II)

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SFT Paris 2010

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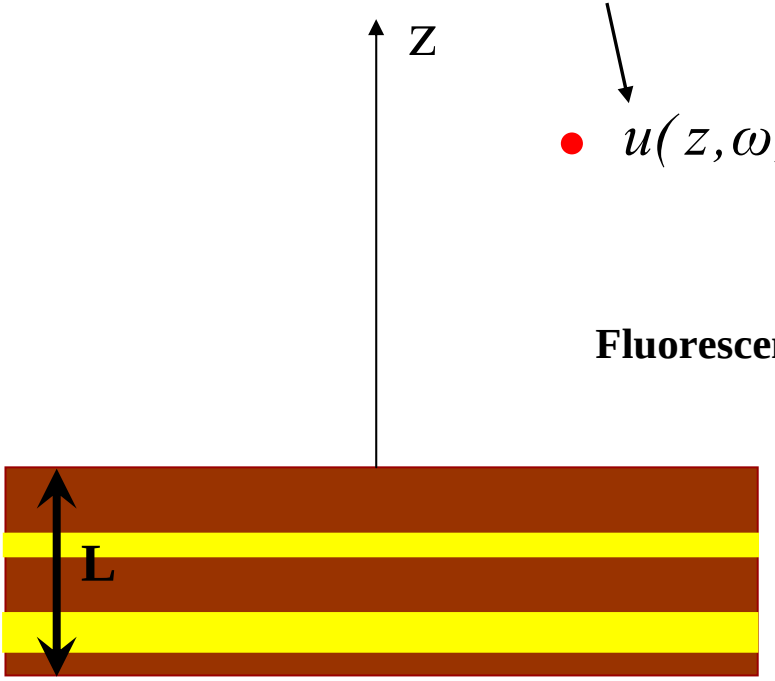
Outline

- Local density of states of electromagnetic field
- Density of states above :
  - a massive Al sample
  - an Al film (hybridization of SPs)
  - two coupled Al films
- Maximizing the LDOS
- Tailoring near field heat exchanges
- Conclusion : applications and prospects

Local density of states of electromagnetic field



LDOE LDOS Energy of 1 photon

$$u(z,\omega,T) = \rho(z,\omega) \times \hbar\omega \frac{1}{exp[\hbar\omega / k_B T] - 1}$$

Nb photons per state (Bose-Einstein)

Fluorescence rate of atoms

$$\Gamma(z,\omega_0) = \frac{4\pi^2\omega}{\hbar} |\mu_{ab}|^2 \rho(z,\omega_0)$$

Transition dipôle moment

$$\rho(\mathbf{r};\omega) = \frac{\omega}{\pi c^2} \mathrm{Im}\mathrm{Tr}[\overline{\overline{\mathbf{G}}}_{\mathbf{EE}}(\mathbf{r},\mathbf{r};\omega) + \overline{\overline{\mathbf{G}}}_{\mathbf{HH}}(\mathbf{r},\mathbf{r};\omega)] \quad \text{(in vacuum)}$$

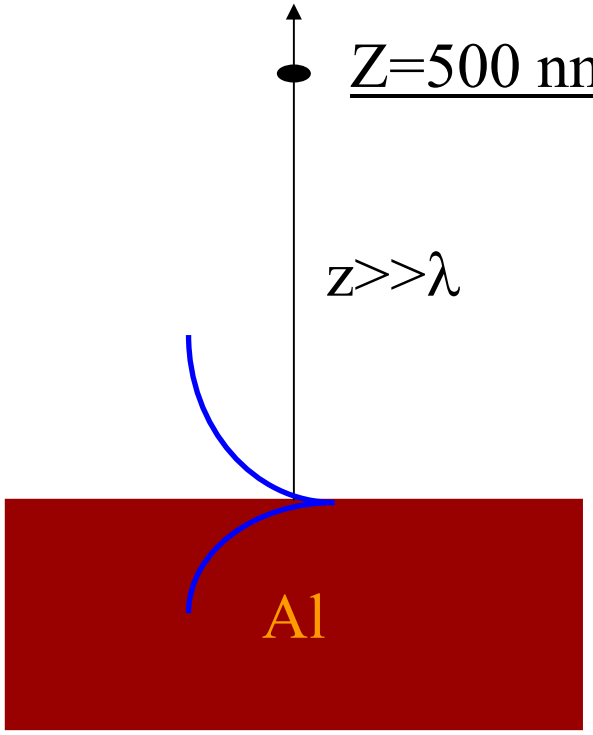
Joulain et al. PRB, 68 (2003)

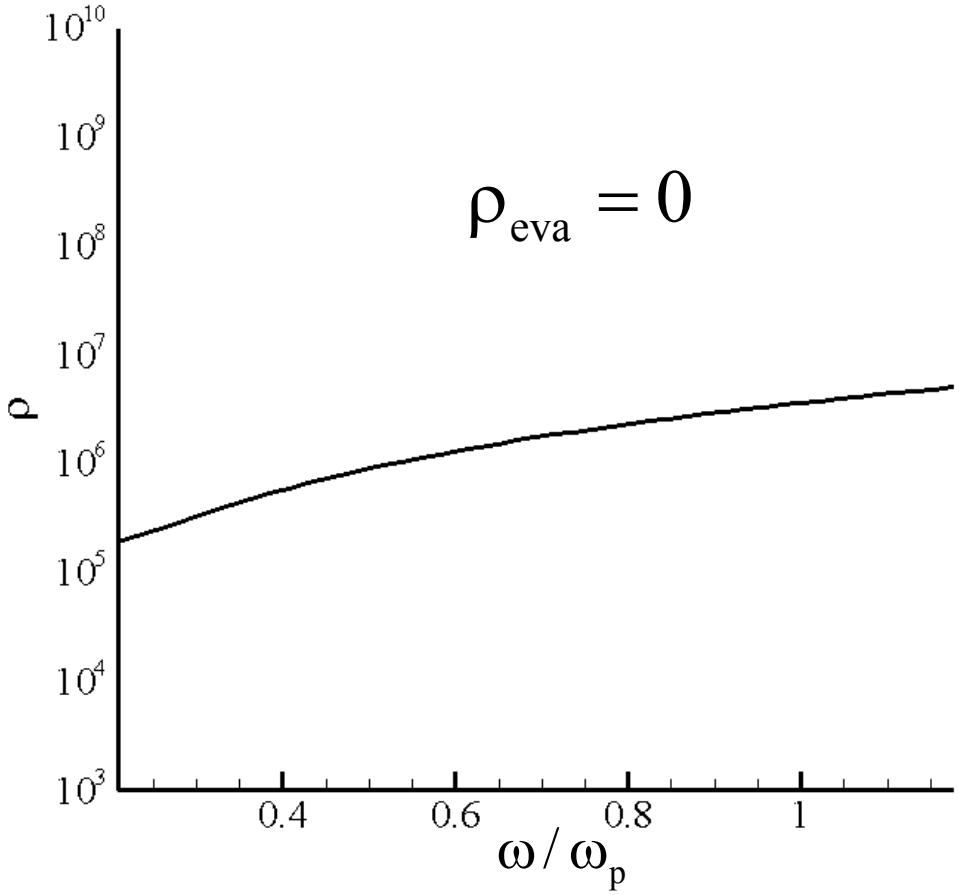
$$\frac{\rho(\mathbf{z},\omega)}{\rho_{vac}} = \int_0^{\omega/c} \frac{k_{//}dk_{//}}{k_0|\gamma|} \frac{2+(k_{//}/k_0)^2 \sum_{j=s,p} Re(r^j exp[2i\gamma(z-L)])}{2} + \int_{\omega/c}^{\infty} \frac{2k_{//}^3 dk_{//}}{k_0^3|\gamma|} \sum_{j=s,p} Im(r^j) exp[2Im(\gamma)(z-L)]$$

Propagative waves → 0 as z>>λ

Evanescent waves

Density of states above a massive Al sample



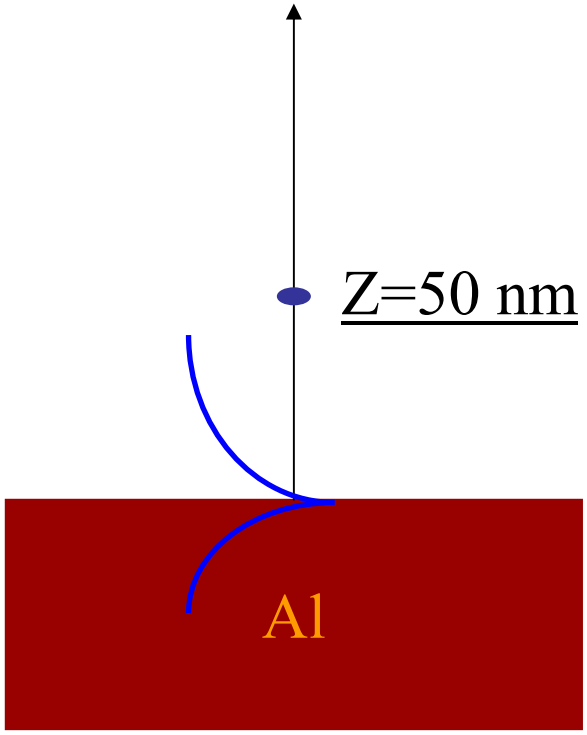


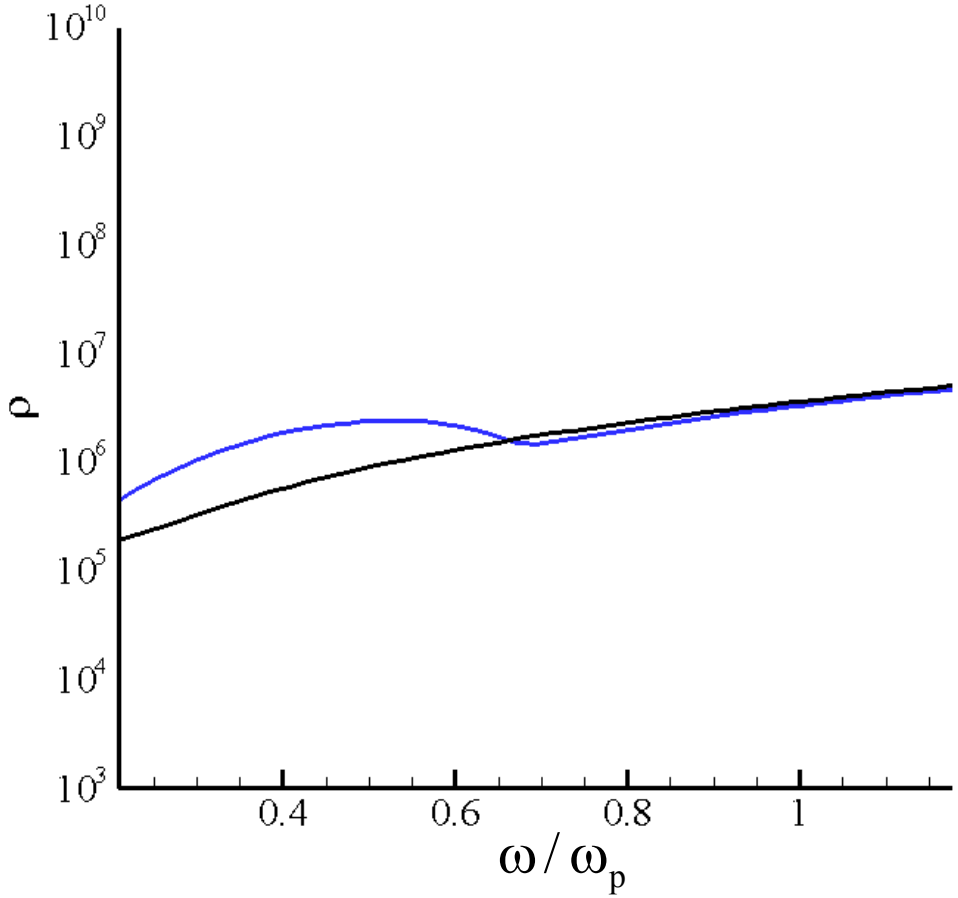
Density of states in the far field

$$\varepsilon_{Al} = 1 - \frac{\omega_p^2}{\omega(\omega - i\omega_c)}$$

Joulain et al. Surface Science Reports, 57 (2005)

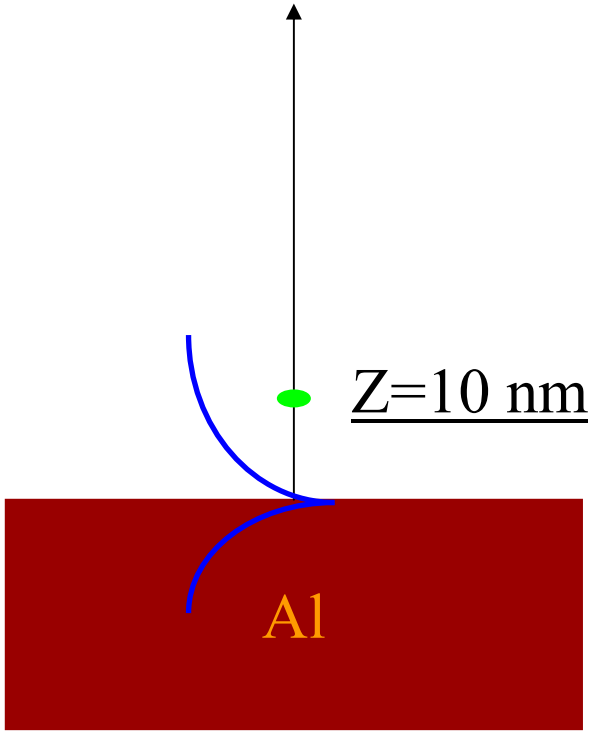
Density of states above a massive Al sample

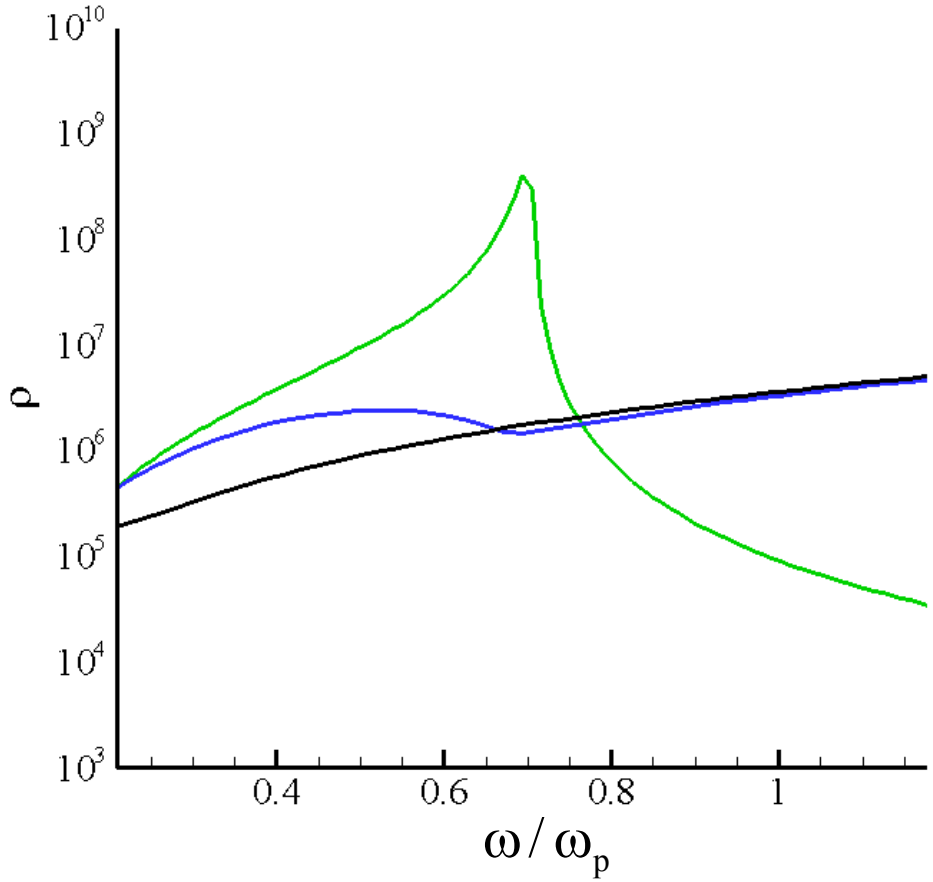




Density of states at the limit near field-far field

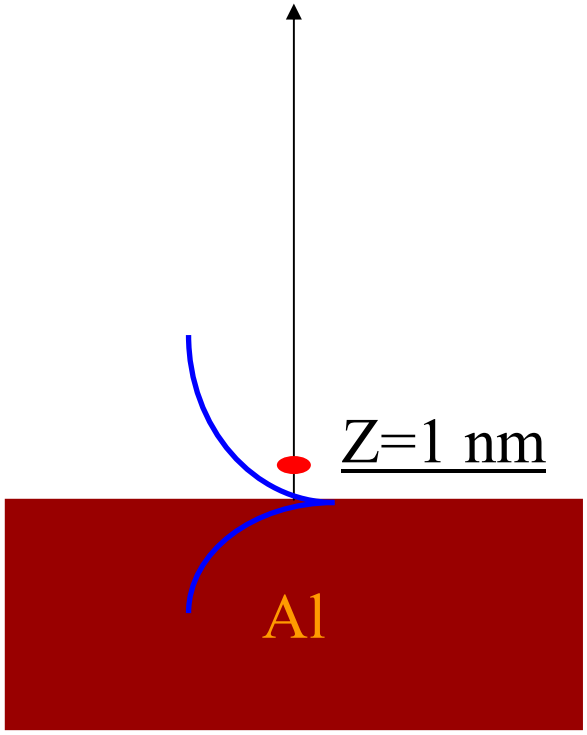
Density of states above a massive Al sample

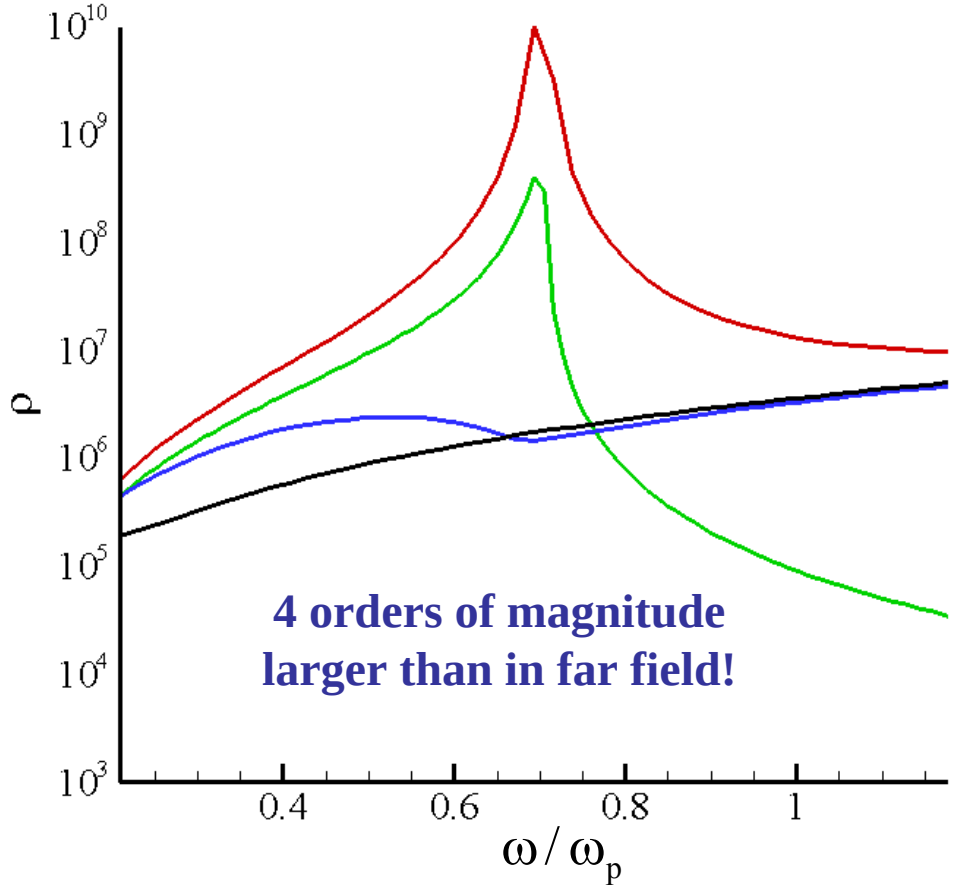




Density of states in the near field

Density of states above a massive Al sample

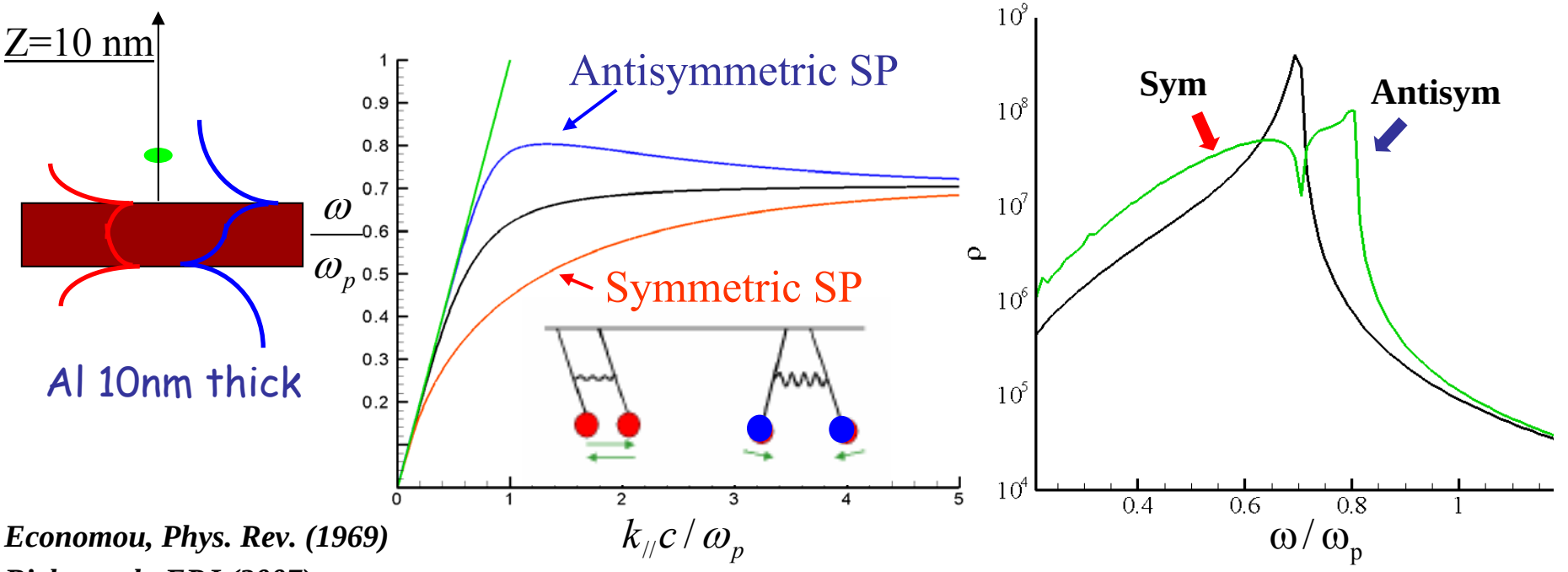




Density of states in the extreme near-field

Density of states is very sensitive to surface plasmon at $\omega = \omega_p/\sqrt{2}$

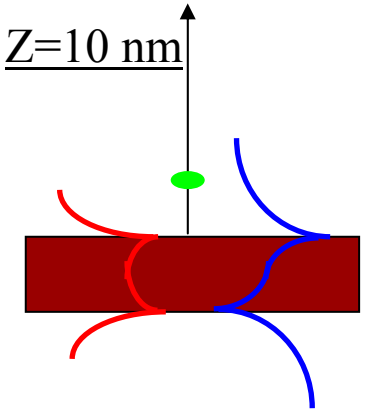
Density of states above an Al film

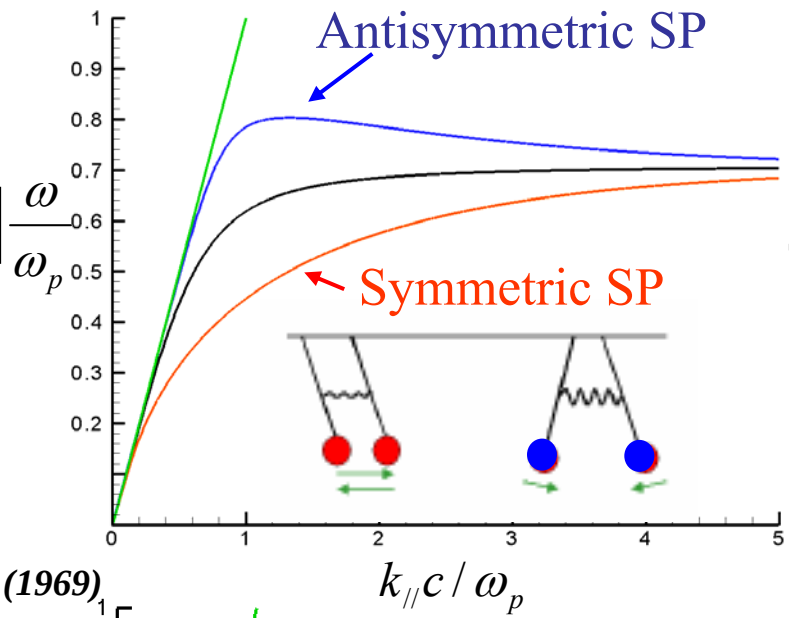


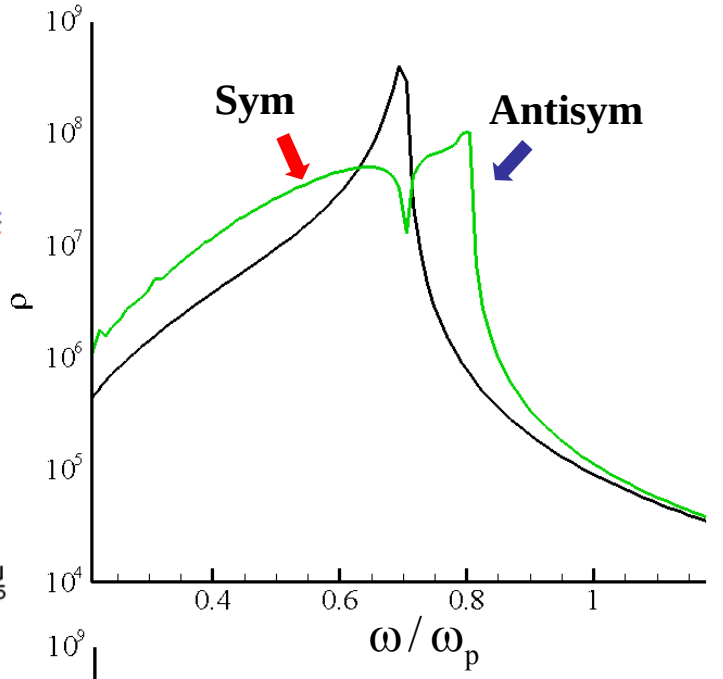
Economou, Phys. Rev. (1969)

Biehs et al., EPJ (2007)

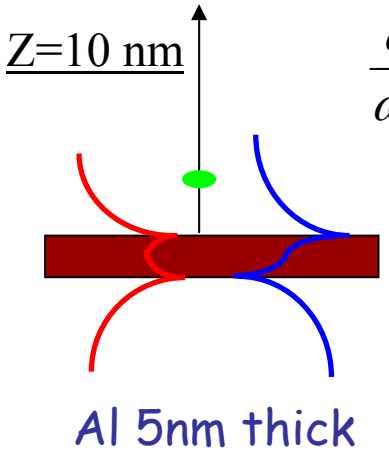
Density of states above an Al film

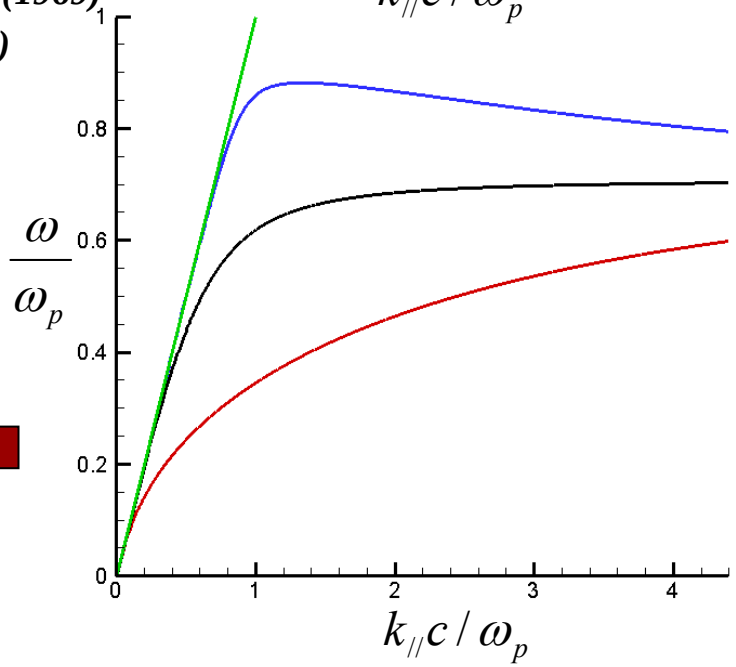


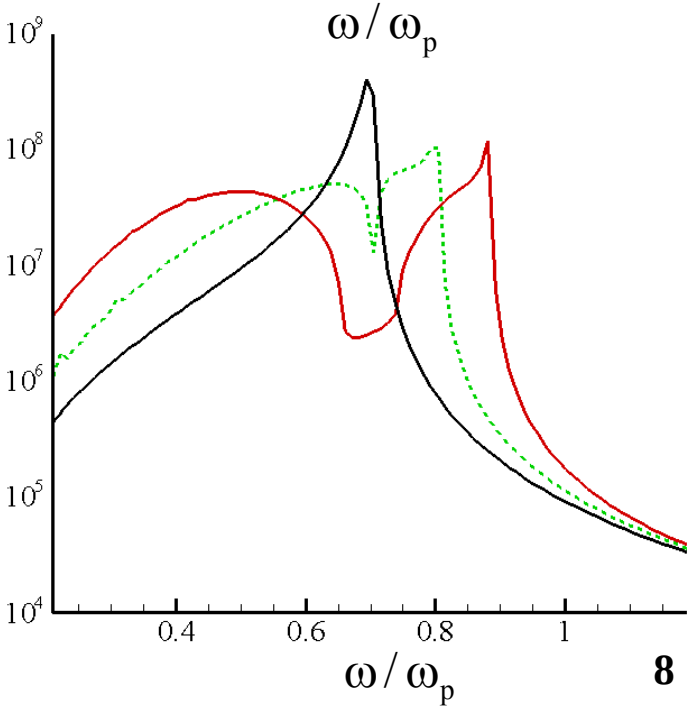




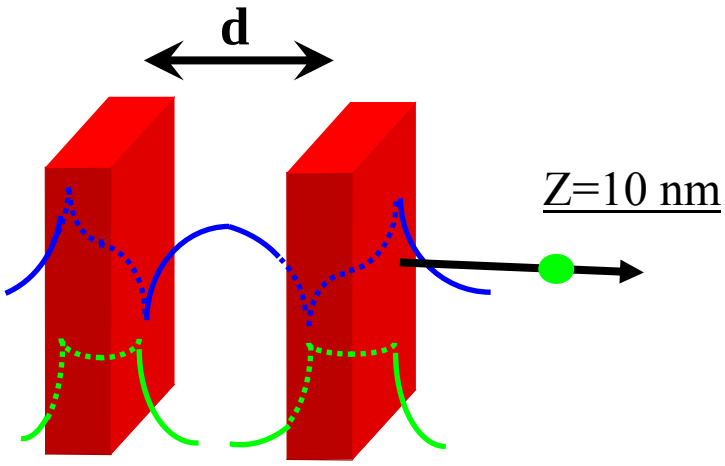
Economou, Phys. Rev. (1969)
Biehs et al., EPJ (2007)

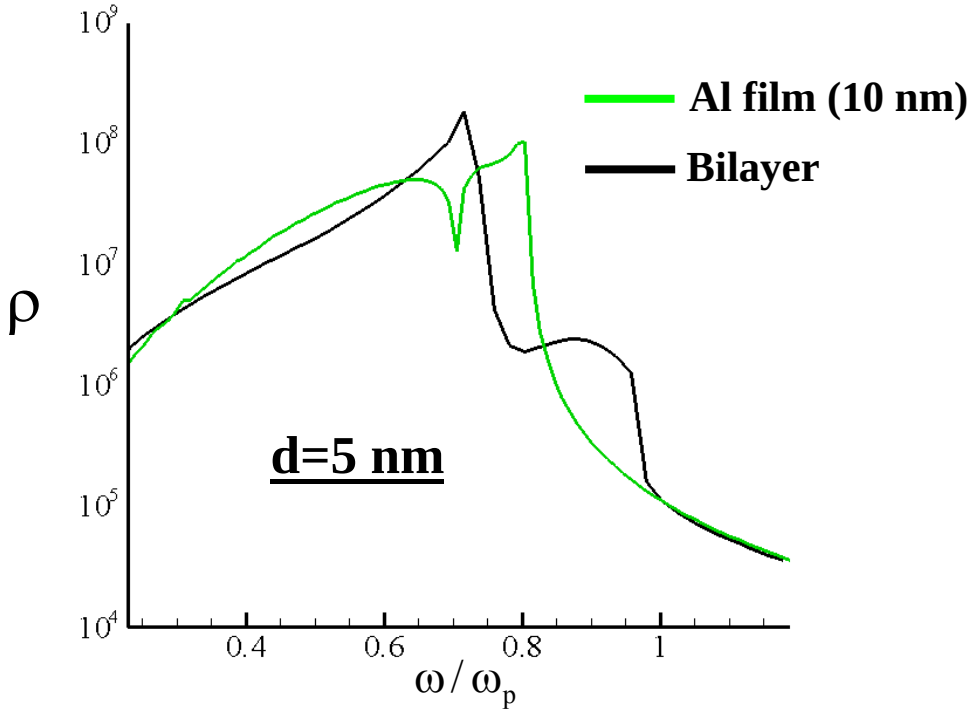




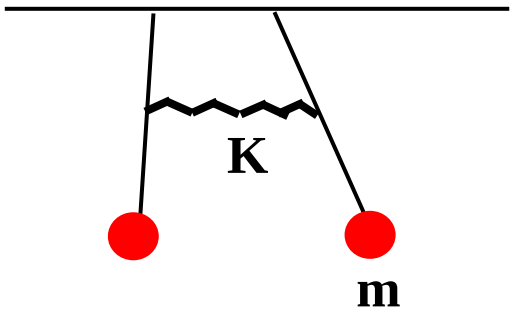


Density of states above two coupled films





Interaction between surfaces plasmons ⟷ **Coupling between oscillators**

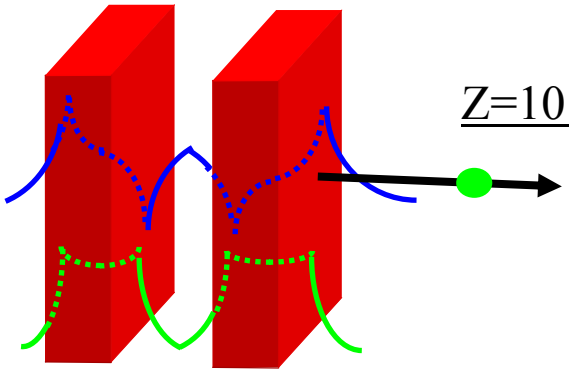


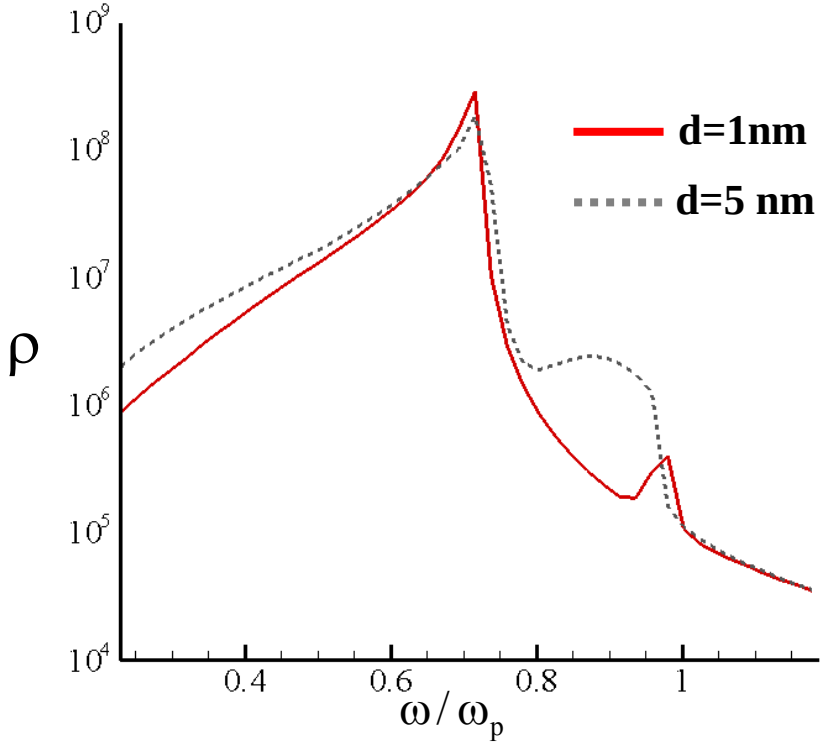
Normal modes :

$$\frac{d^2 q_1}{dt^2} + \omega_0^2 q_1 = 0 \qquad \text{(motion in phase)}$$

$$\frac{d^2 q_2}{dt^2} + (\omega_0^2 + 2\frac{K}{m}) q_2 = 0 \qquad \text{(dephased motion)}$$

Density of states above two coupled films

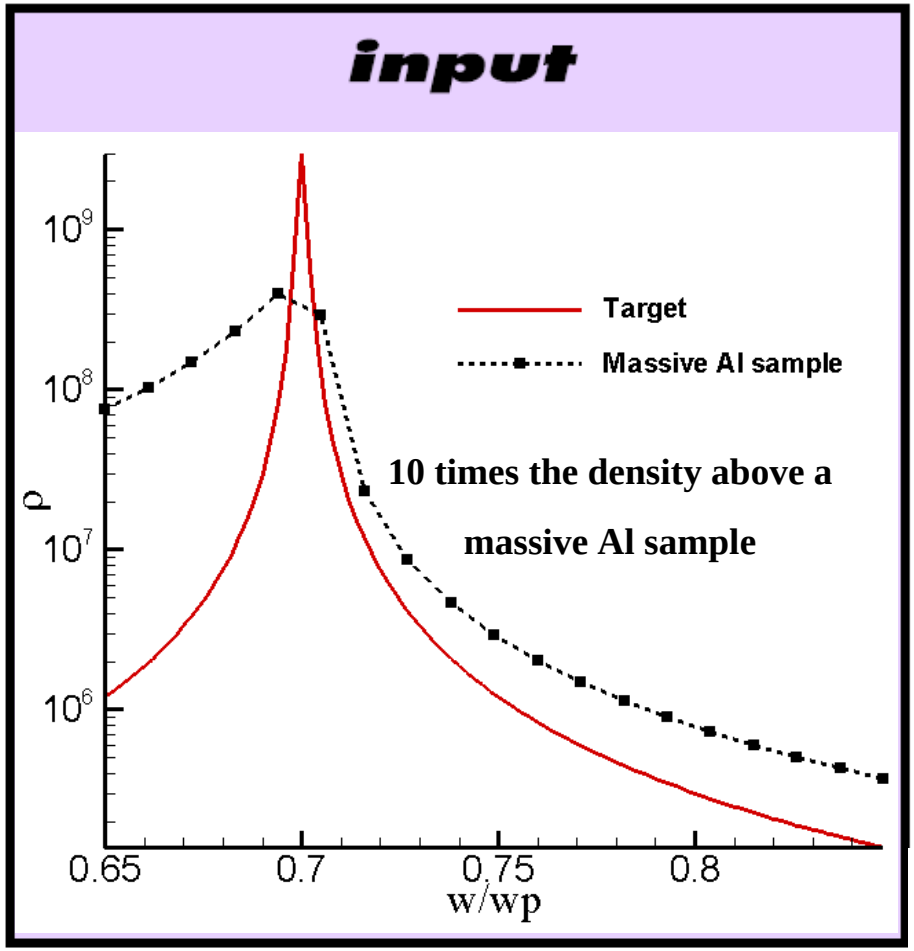




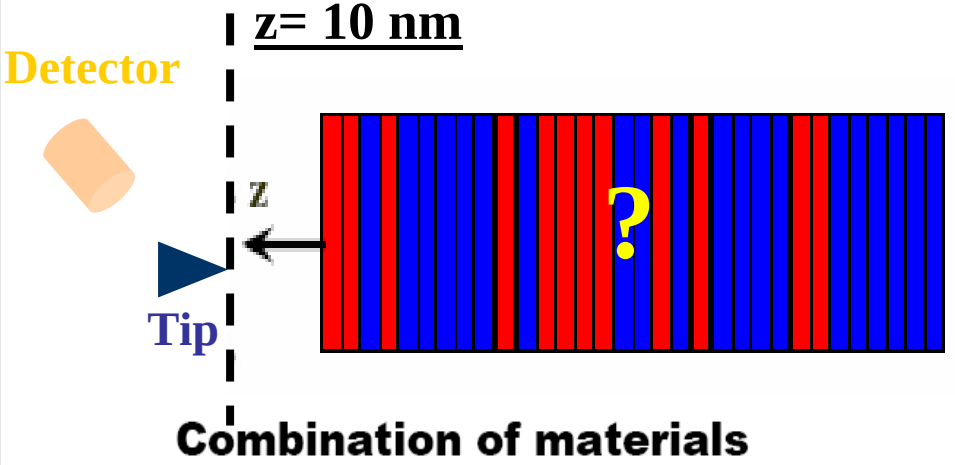
d ↘ ➡ **K** ↗ (strong coupling)

The highest frequency peak shifts toward higher frequencies

Maximizing the LDOS



Point like SNOM



- **Metal : Al**
- **Lossless dielectric ε=2.25**

Parameters of the structure

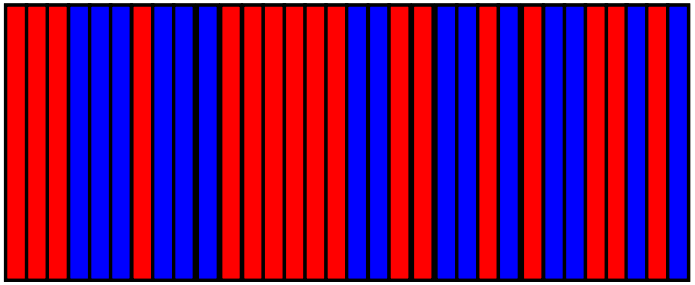
- **32 layers =>~ 4×10^9 possible combinations**
- **5 nm thickness**

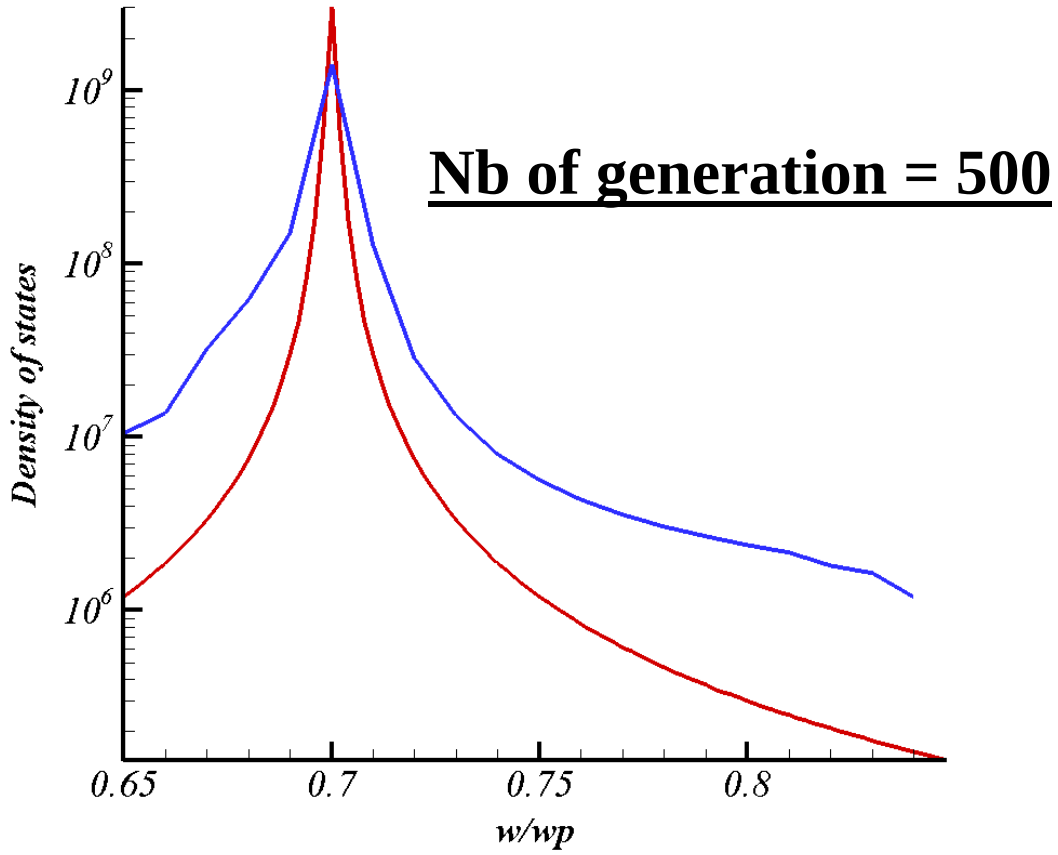
$$\left\| \rho - \rho_{target} \right\| \rightarrow \min$$

Optimization by genetic algorithm

Maximizing the LDOS

output



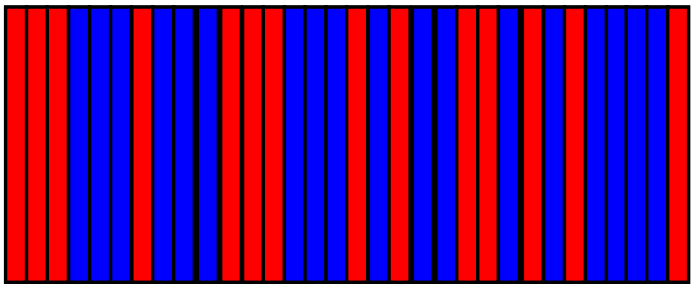


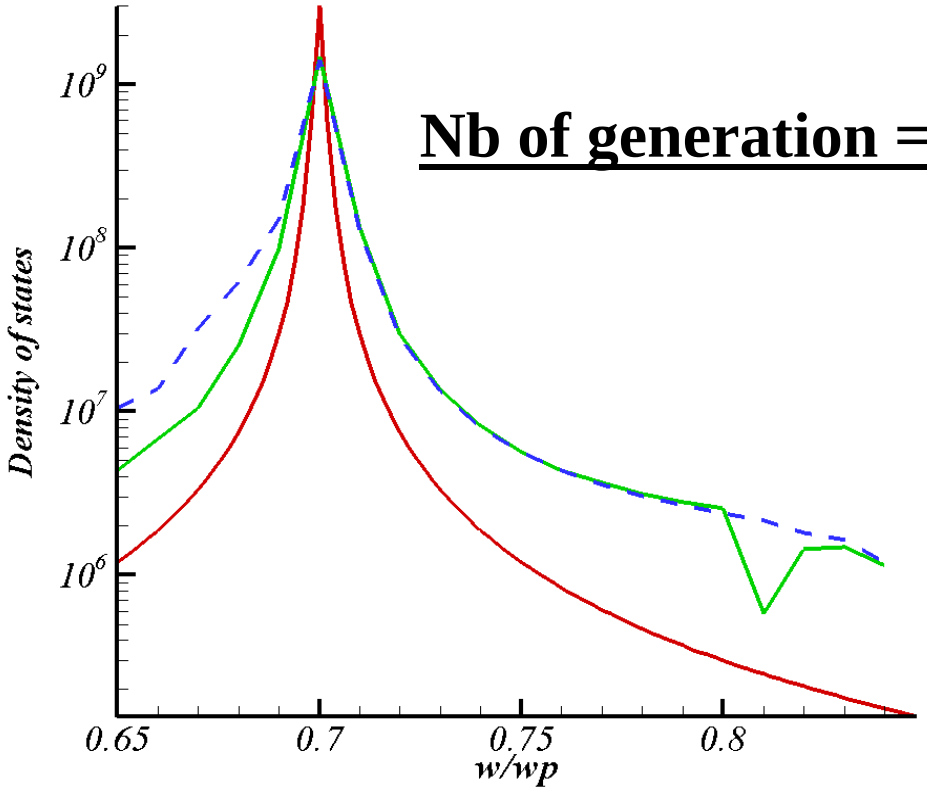
Nb of generation = 500

Ben-Abdallah et al. APL 94 (2009)

Maximizing the LDOS

output

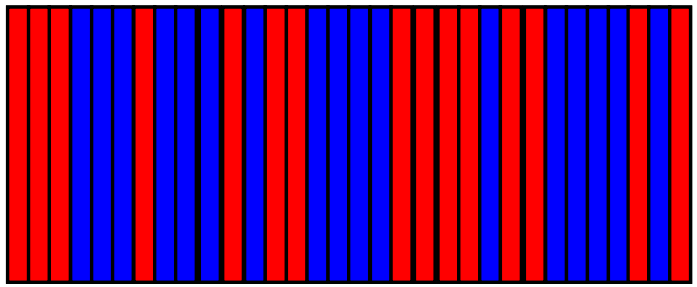


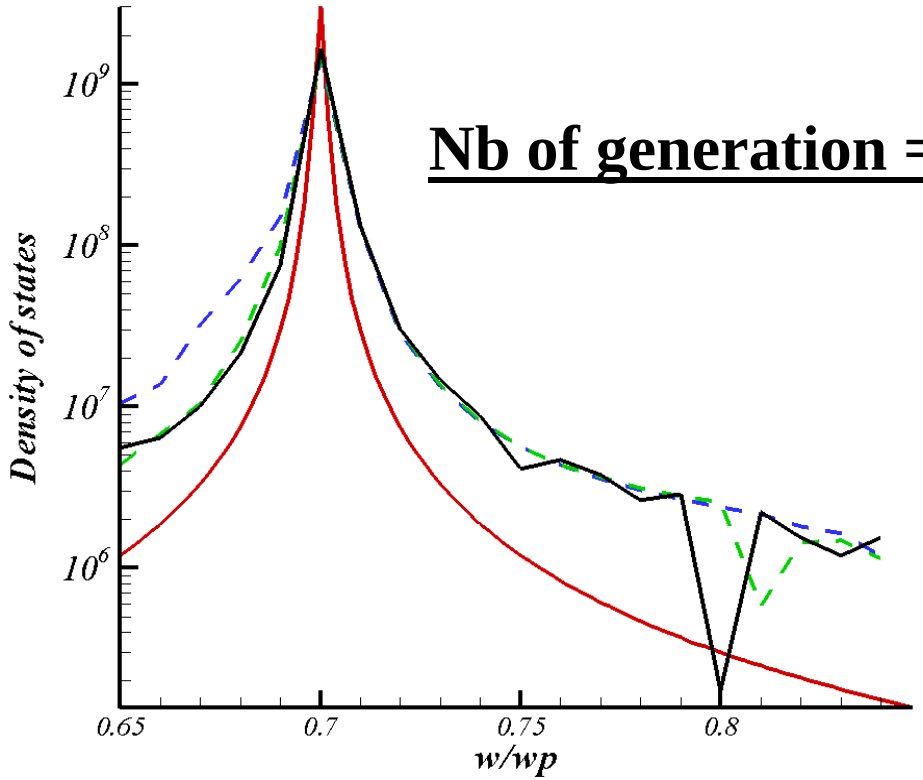


Nb of generation = 5000

Maximizing the LDOS

output

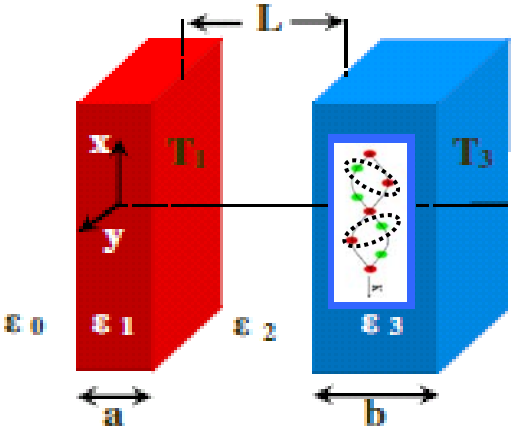




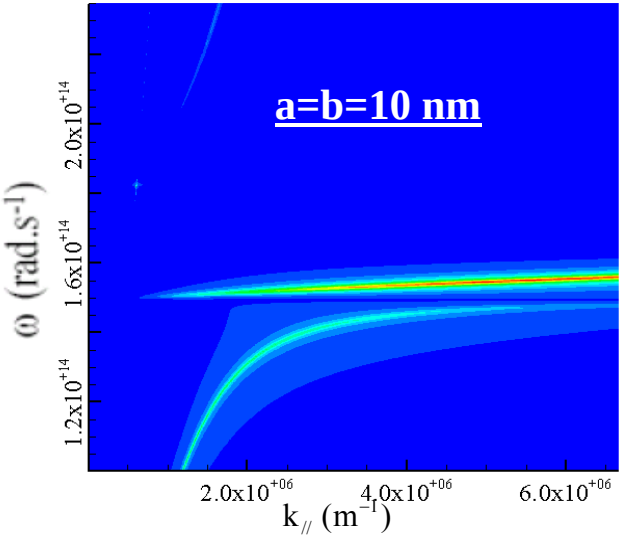
Nb of generation = 50 000

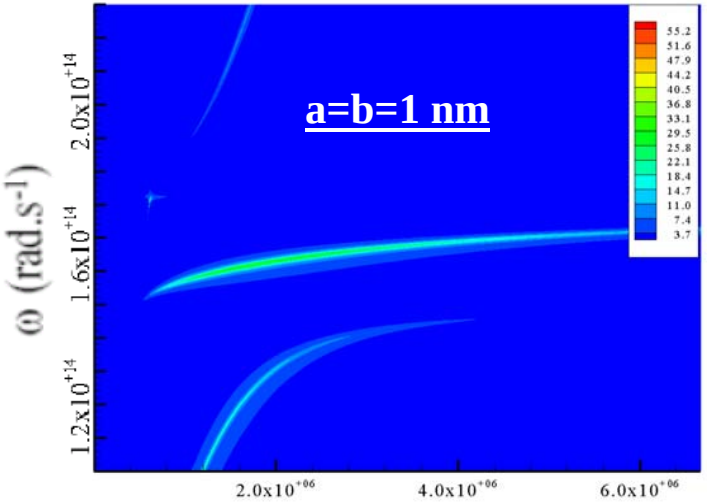
8 times the density above a massive Al sample!

Tailoring near field heat exchanges

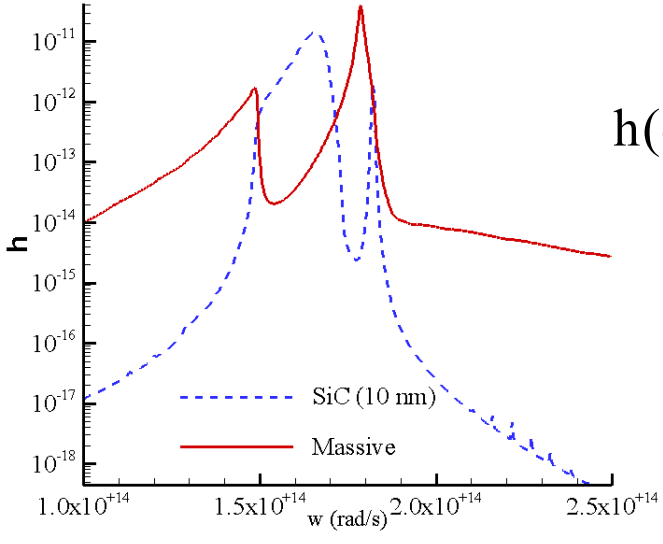


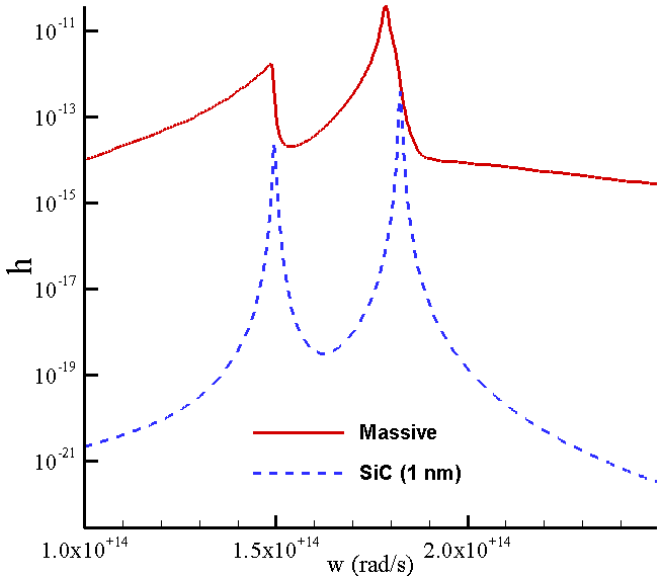
L=100 nm
T=300K





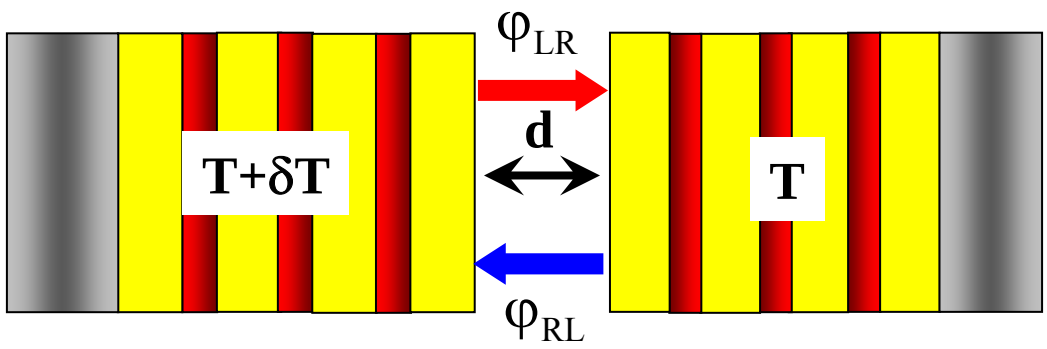
$$h(\omega;T) \equiv \lim_{\delta T \to 0} \left| \frac{\varphi_{LR} - \varphi_{RL}}{\delta T} \right|$$





Ben-Abdallah et al.
JAP 106 (2009)

Tailoring near field heat exchanges

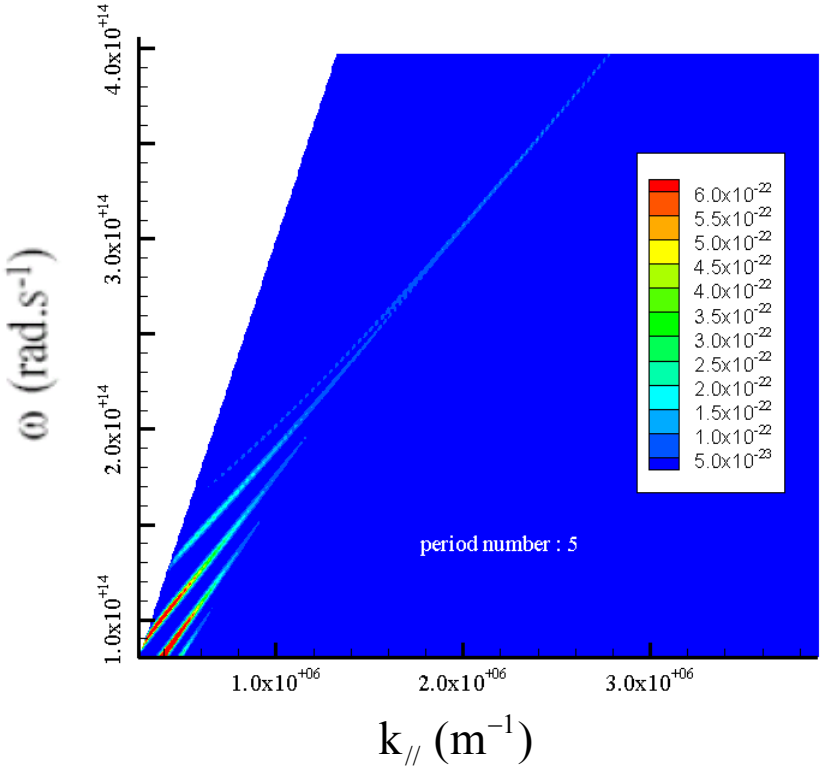


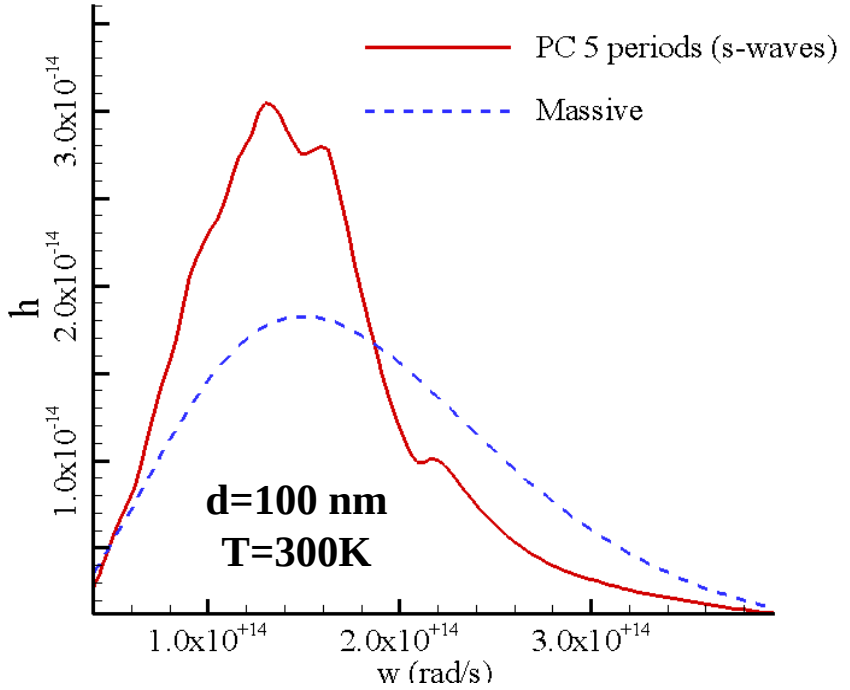
2 quarter-wave PCs with

$\varepsilon_1 = 6.25$

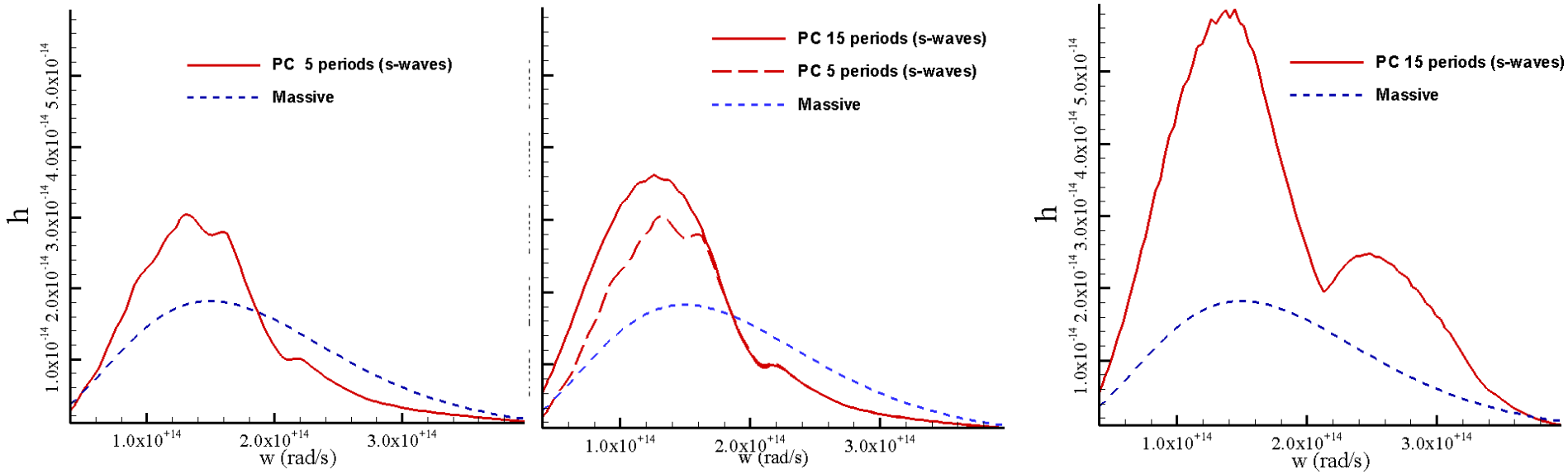
$\varepsilon_2 = 2.25 - 0.3i$

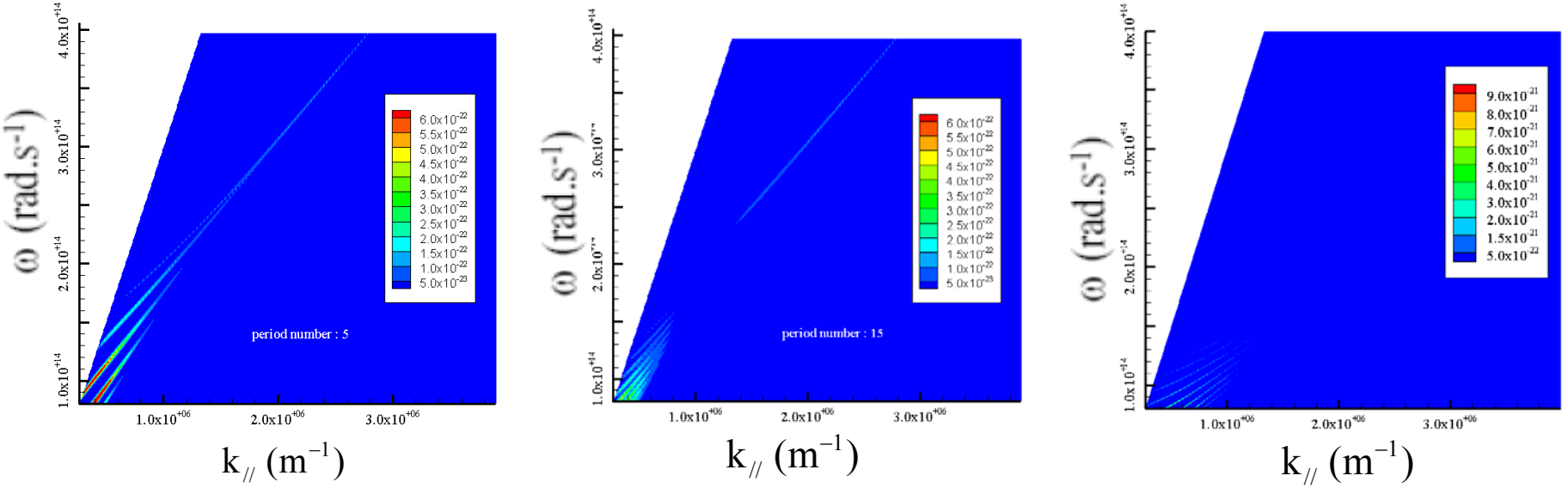
Heat transfer mediated by surface Bloch waves





Tailoring near field heat exchanges

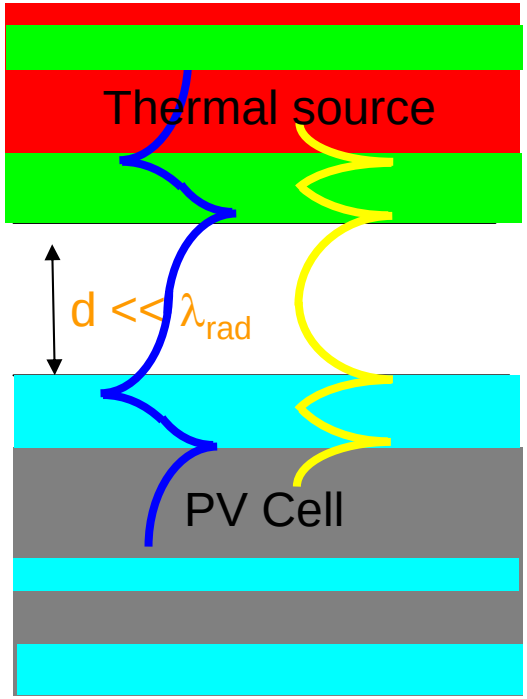




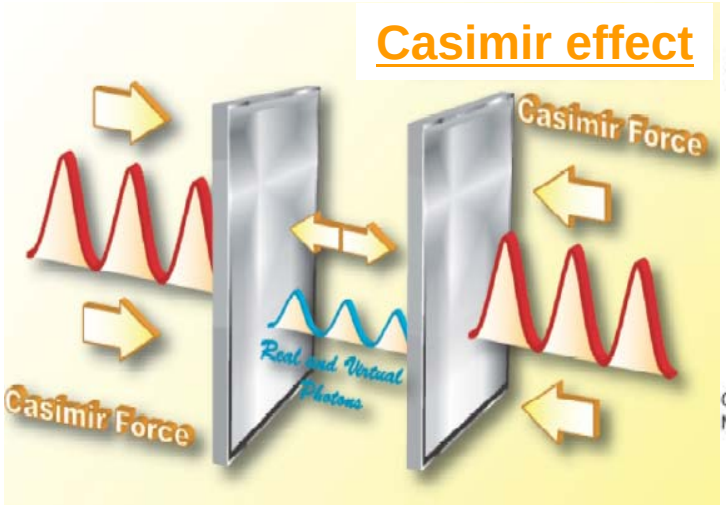
Ben-Abdallah et al. Submitted (2010)

Conclusion : applications and prospects

Near-field TPV

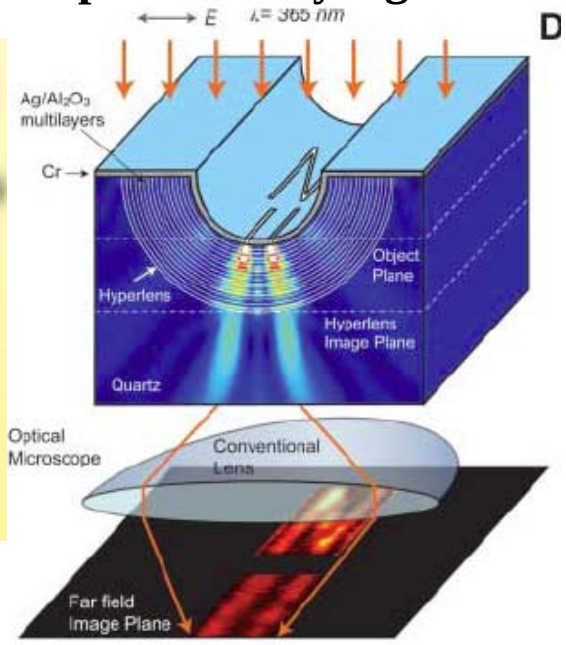


Casimir effect



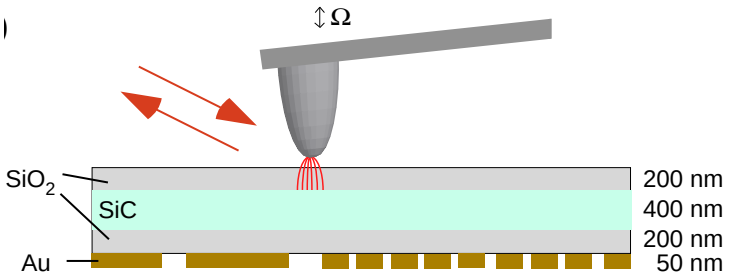
Microscopy (Superlens)

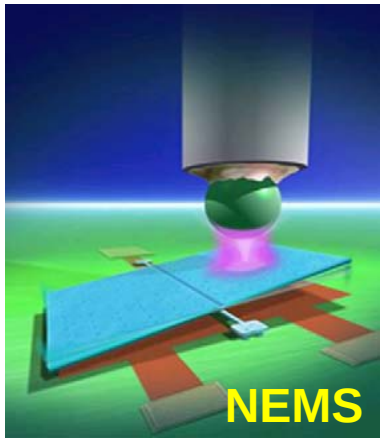
Surpass the Rayleigh limit



Liu et al., 315, Science, 2007

Nano-photolitography





Improve resolution