

Emission thermique de champ
proche diffusée par une pointe.

Transfert à N corps

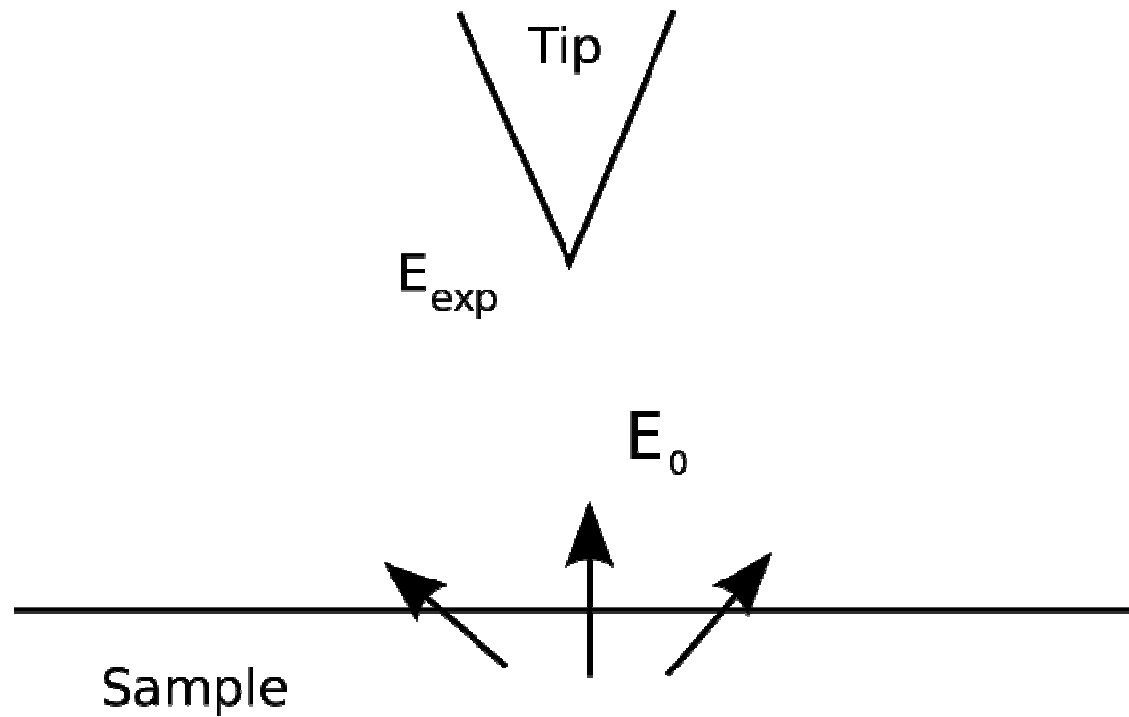
Comment traiter la diffusion de
lumière ou le transfert radiatif en
présence de plusieurs corps?

Transfert à N corps

- En classique : multiréflexions
- En optique : problème de l'interaction pointe surface.
- En transfert radiatif de champ proche : transfert entre nanoparticules

Position du problème

E_{det}
X



$$\langle S(\omega) \rangle = \frac{\epsilon_0 c}{2} |\mathbf{E}^d(\omega)|^2 r^2 d\Omega$$

Champ au dessus de l'interface

- $\mathbf{E}^0, \mathbf{H}^0$: champs sans pointe
- $\mathbf{E}^{exp}, \mathbf{H}^{exp}$: champs avec pointe

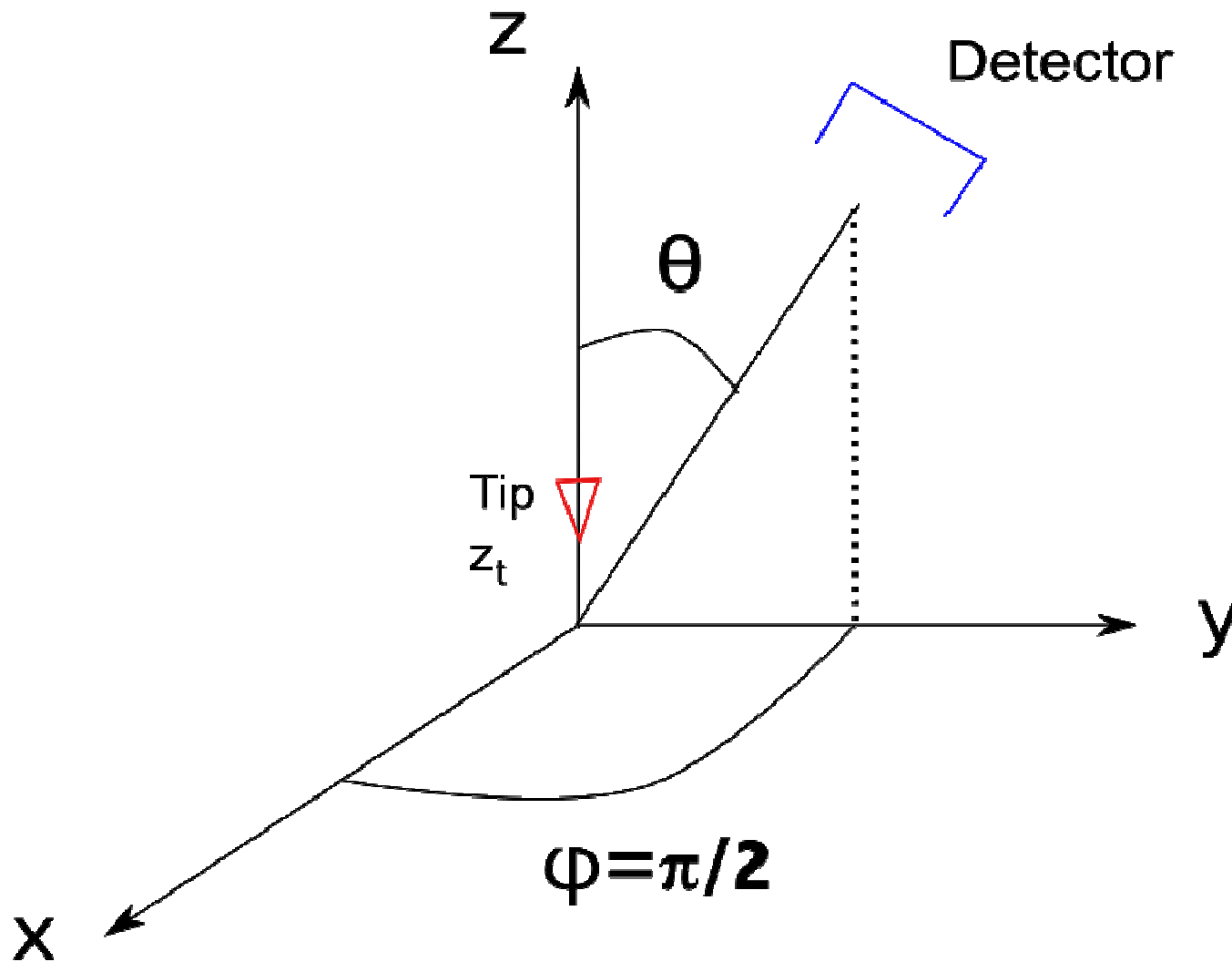
$$\mathbf{E}^{exp}(\mathbf{r}) = \mathbf{E}^0(\mathbf{r}) + \overset{\leftrightarrow}{\mathbf{G}}^{EE}(\mathbf{r}, \mathbf{r}_t) \cdot \alpha^E \mathbf{E}^{exp}(\mathbf{r}_t) + \overset{\leftrightarrow}{\mathbf{G}}^{EH}(\mathbf{r}, \mathbf{r}_t) \cdot \alpha^H \mathbf{H}^{exp}(\mathbf{r}_t)$$

$$\mathbf{H}^{exp}(\mathbf{r}) = \mathbf{H}^0(\mathbf{r}) + \overset{\leftrightarrow}{\mathbf{G}}^{HE}(\mathbf{r}, \mathbf{r}_t) \cdot \alpha^H \mathbf{E}^{exp}(\mathbf{r}_t) + \overset{\leftrightarrow}{\mathbf{G}}^{HH}(\mathbf{r}, \mathbf{r}_t) \cdot \alpha^H \mathbf{H}^{exp}(\mathbf{r}_t)$$

$$\mathbf{E}^{exp}(\mathbf{r}_t) = \left[\overset{\leftrightarrow}{\mathbf{I}} - \alpha^E \overset{\leftrightarrow}{\mathbf{G}}_R^{EE}(\mathbf{r}_t, \mathbf{r}_t) \right]^{-1} \mathbf{E}^0(\mathbf{r}_t)$$

$$\mathbf{H}^{exp}(\mathbf{r}_t) = \left[\overset{\leftrightarrow}{\mathbf{I}} - \alpha^H \overset{\leftrightarrow}{\mathbf{G}}_R^{HH}(\mathbf{r}_t, \mathbf{r}_t) \right]^{-1} \mathbf{H}^0(\mathbf{r}_t)$$

Champ au détecteur



Champ au détecteur : Champ rayonné par un dipole

$$\begin{aligned}
 \mathbf{E}^d = & \frac{\mu_0 \omega^2}{4\pi} \frac{e^{ikR}}{R} \alpha^E \left[\overset{\leftrightarrow}{\mathbf{I}} - \alpha^E \overset{\leftrightarrow}{\mathbf{G}}_R^{EE}(\mathbf{r}_t, \mathbf{r}_t) \right]^{-1} \left[\overset{\leftrightarrow}{\mathbf{h}}(\mathbf{u}_d) + \overset{\leftrightarrow}{\mathbf{h}}^R(\mathbf{u}_d) \right] \mathbf{E}^0(\mathbf{r}_t) \\
 & + \frac{\mu_0 \omega^2}{4\pi c} \frac{e^{ikR}}{R} \alpha^H \left[\overset{\leftrightarrow}{\mathbf{I}} - \alpha^H \overset{\leftrightarrow}{\mathbf{G}}_R^{HH}(\mathbf{r}_t, \mathbf{r}_t) \right]^{-1} \left[\overset{\leftrightarrow}{\mathbf{g}}(\mathbf{u}_d) + \overset{\leftrightarrow}{\mathbf{g}}^R(\mathbf{u}_d) \right] \mathbf{H}^0(\mathbf{r}_t)
 \end{aligned}$$

Polarisabilité effective

$$\overset{\leftrightarrow}{\alpha}^E = \alpha^E \left[\overset{\leftrightarrow}{I} - \alpha^E \overset{\leftrightarrow}{G}_{EE}^R(\mathbf{r}_t, \mathbf{r}_t) \right]^{-1}$$

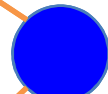
$$\overset{\leftrightarrow}{\alpha}^H = \alpha^H \left[\overset{\leftrightarrow}{I} - \alpha^H \overset{\leftrightarrow}{G}_{HH}^R(\mathbf{r}_t, \mathbf{r}_t) \right]^{-1}$$

Detector

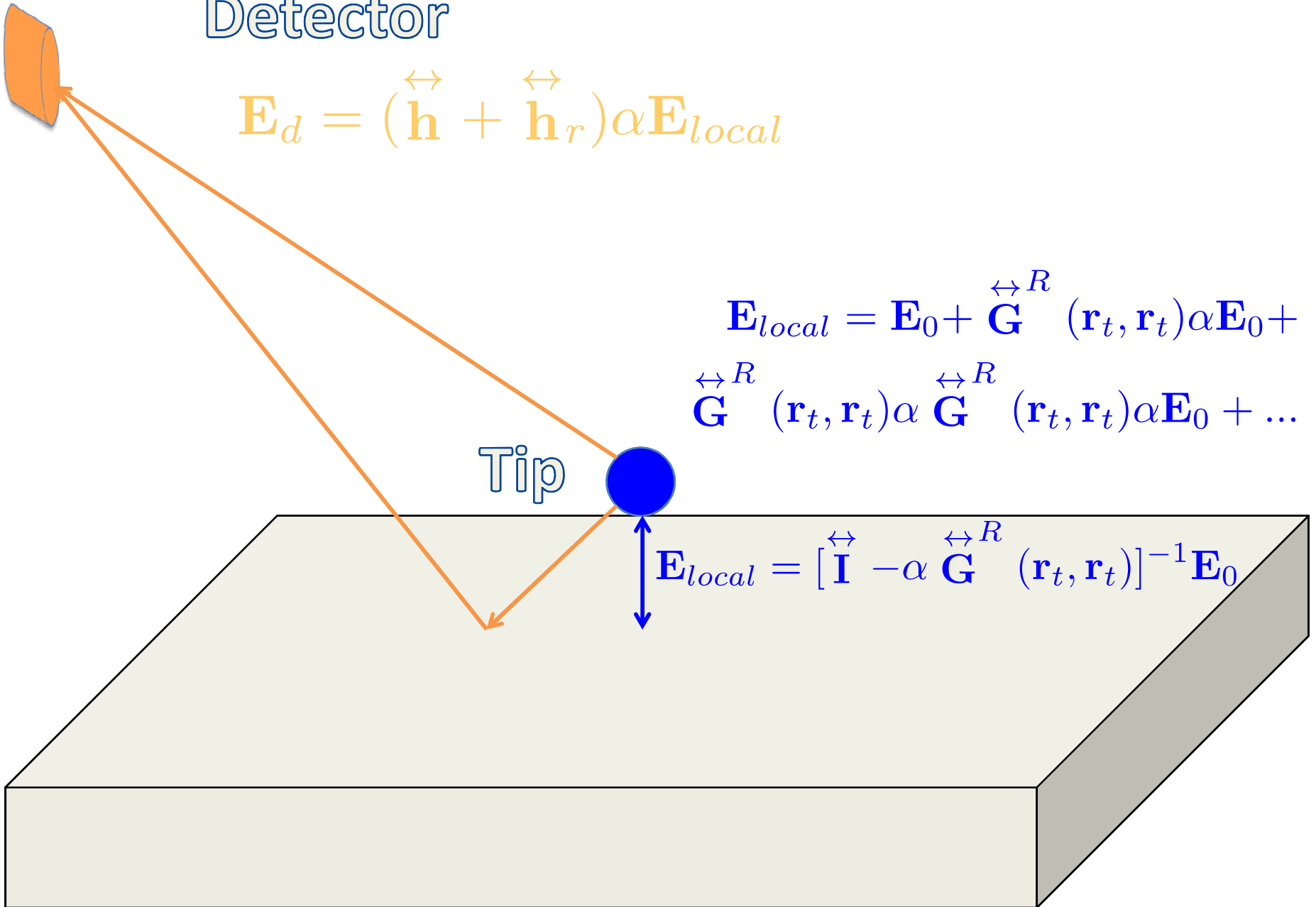
$$\mathbf{E}_d = (\overset{\leftrightarrow}{\mathbf{h}} + \overset{\leftrightarrow}{\mathbf{h}}_r) \alpha \mathbf{E}_{local}$$

$$\mathbf{E}_{local} = \mathbf{E}_0 + \overset{\leftrightarrow R}{\mathbf{G}}(\mathbf{r}_t, \mathbf{r}_t) \alpha \mathbf{E}_0 + \overset{\leftrightarrow R}{\mathbf{G}}(\mathbf{r}_t, \mathbf{r}_t) \alpha \overset{\leftrightarrow R}{\mathbf{G}}(\mathbf{r}_t, \mathbf{r}_t) \alpha \mathbf{E}_0 + \dots$$

Tip



$$\mathbf{E}_{local} = [\overset{\leftrightarrow}{\mathbf{I}} - \alpha \overset{\leftrightarrow R}{\mathbf{G}}(\mathbf{r}_t, \mathbf{r}_t)]^{-1} \mathbf{E}_0$$



Signal reçu au détecteur

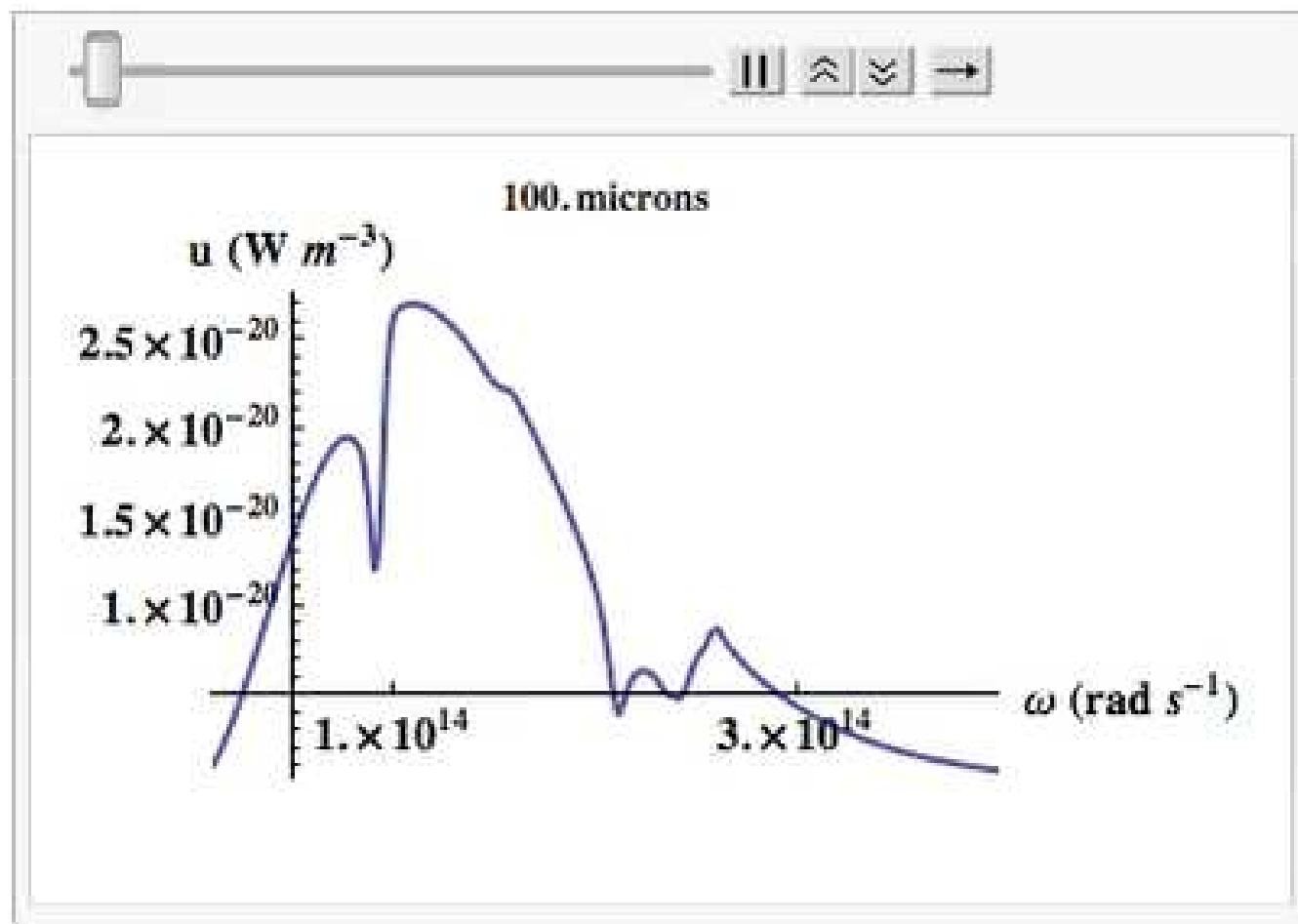
- Emission thermique.

$$\begin{aligned}
 \langle S(\mathbf{r}_d) \rangle = & \frac{\mu_0 \omega^4}{32\pi c} d\Omega \left\{ (\cos^2 \theta |1 - r^p(\theta) e^{2ik_0 z_t \cos \theta}|^2 + |1 + r^s(\theta) e^{2ik_0 z_t \cos \theta}|^2) |\alpha_{xx}^E|^2 |E_x^0(\mathbf{r}_t)|^2 \right. \\
 + & \sin^2 \theta |1 + r^p e^{2ik_0 z_t \cos \theta}|^2 |\alpha_{zz}^E|^2 |E_z^0(\mathbf{r}_t)|^2 + \frac{\sin^2 \theta |1 + r^s e^{2ik_0 z_t \cos \theta}|^2}{c^2} |\alpha_{zz}^E|^2 |H_z^0(\mathbf{r}_t)|^2 \\
 + & \frac{\cos^2 \theta |1 - r^s(\theta) e^{2ik_0 z_t \cos \theta}|^2 + |1 + r^p(\theta) e^{2ik_0 z_t \cos \theta}|^2}{c^2} |\alpha_{xx}^H|^2 |H_x^0(\mathbf{r}_t)|^2 \\
 + & 2 \cos \theta \Re \left[\alpha_{xx}^E \alpha_{xx}^{H*} E_x^0(\mathbf{r}_t) H_y^{0*}(\mathbf{r}_t) \right. \\
 \times & \left. \left(\frac{(1 + r^s e^{2ik_0 z_t \cos \theta})(1 - r^{s*} e^{-2ik_0 z_t \cos \theta}) + (1 - r^p e^{2ik_0 z_t \cos \theta})(1 + r^{p*} e^{-2ik_0 z_t \cos \theta})}{c^2} \right) \right] \left. \right\}
 \end{aligned}$$

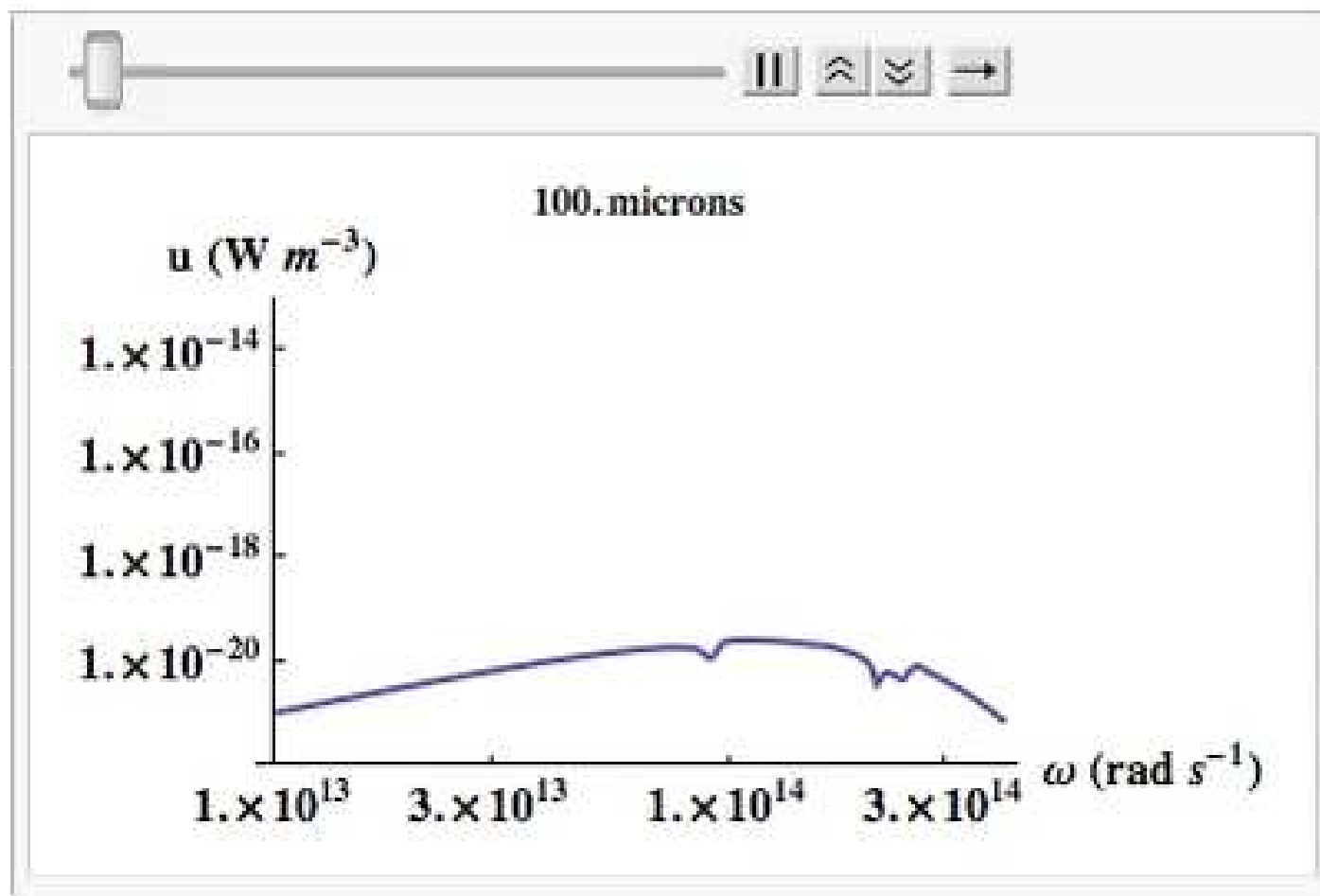
Densité d'énergie au-dessus de SiO₂

T = 300 K

Densité d'énergie SiO2

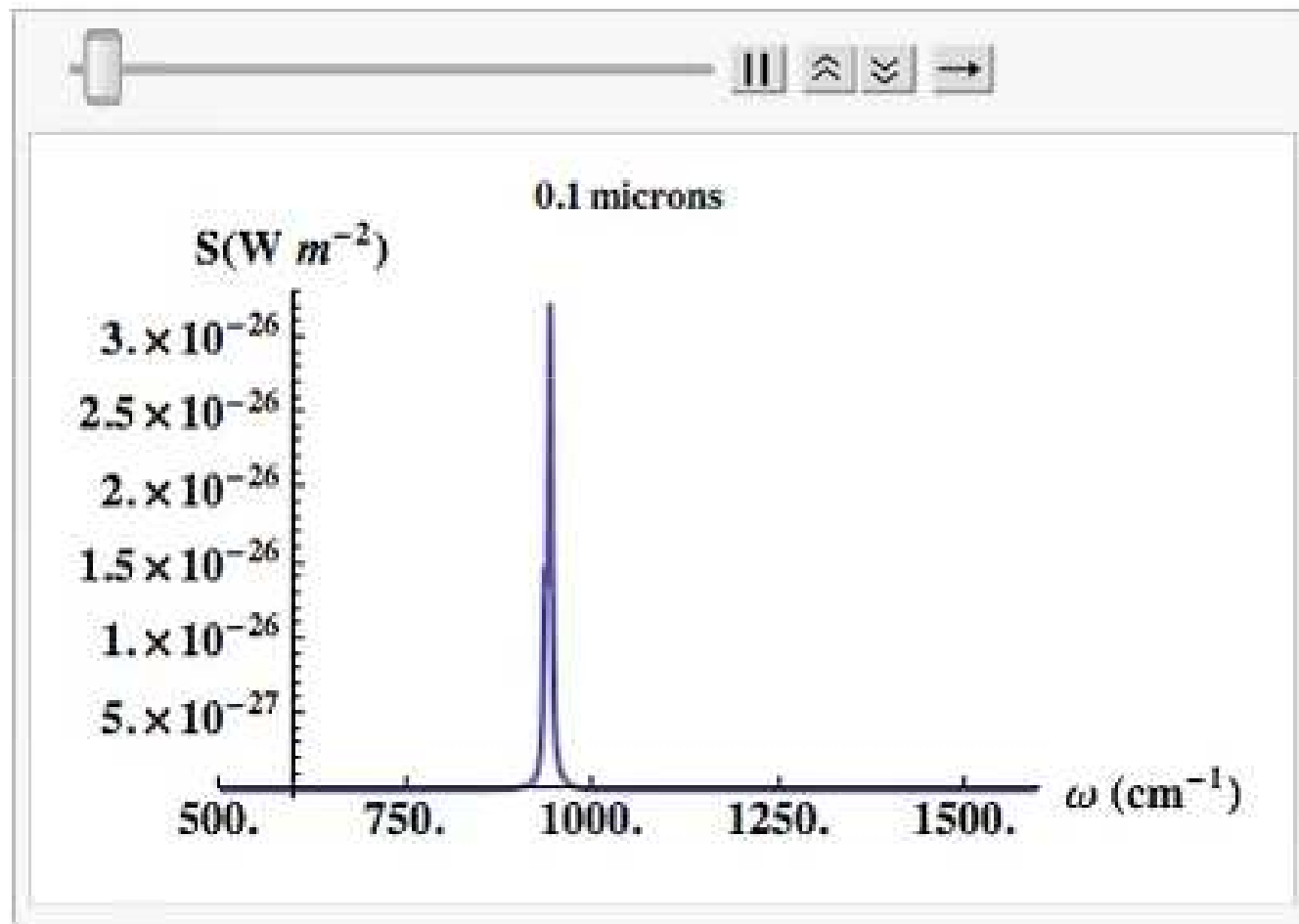


Densité d'énergie SiO₂



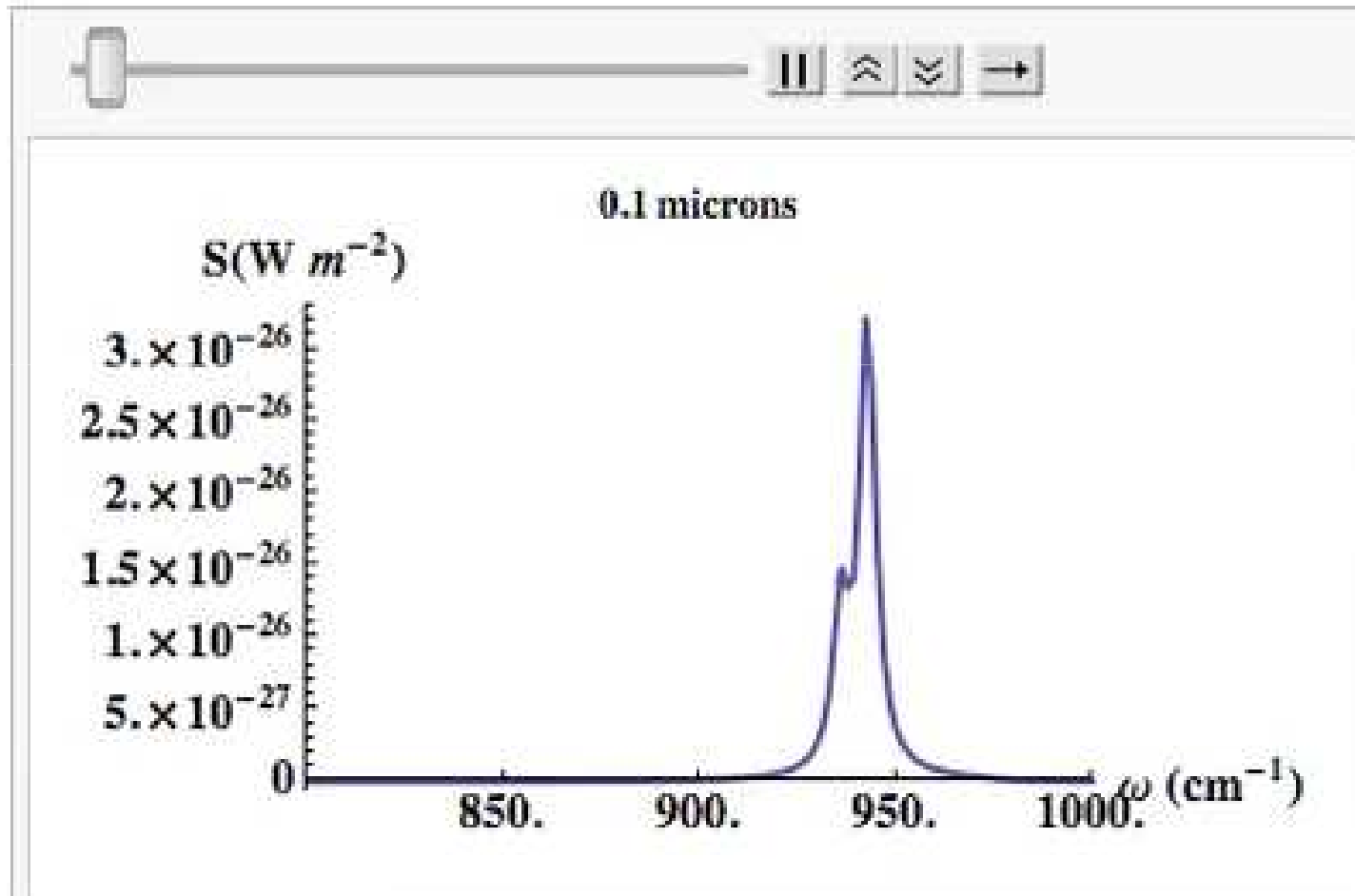
Signal au détecteur

Pointe: W Substrat : SiC



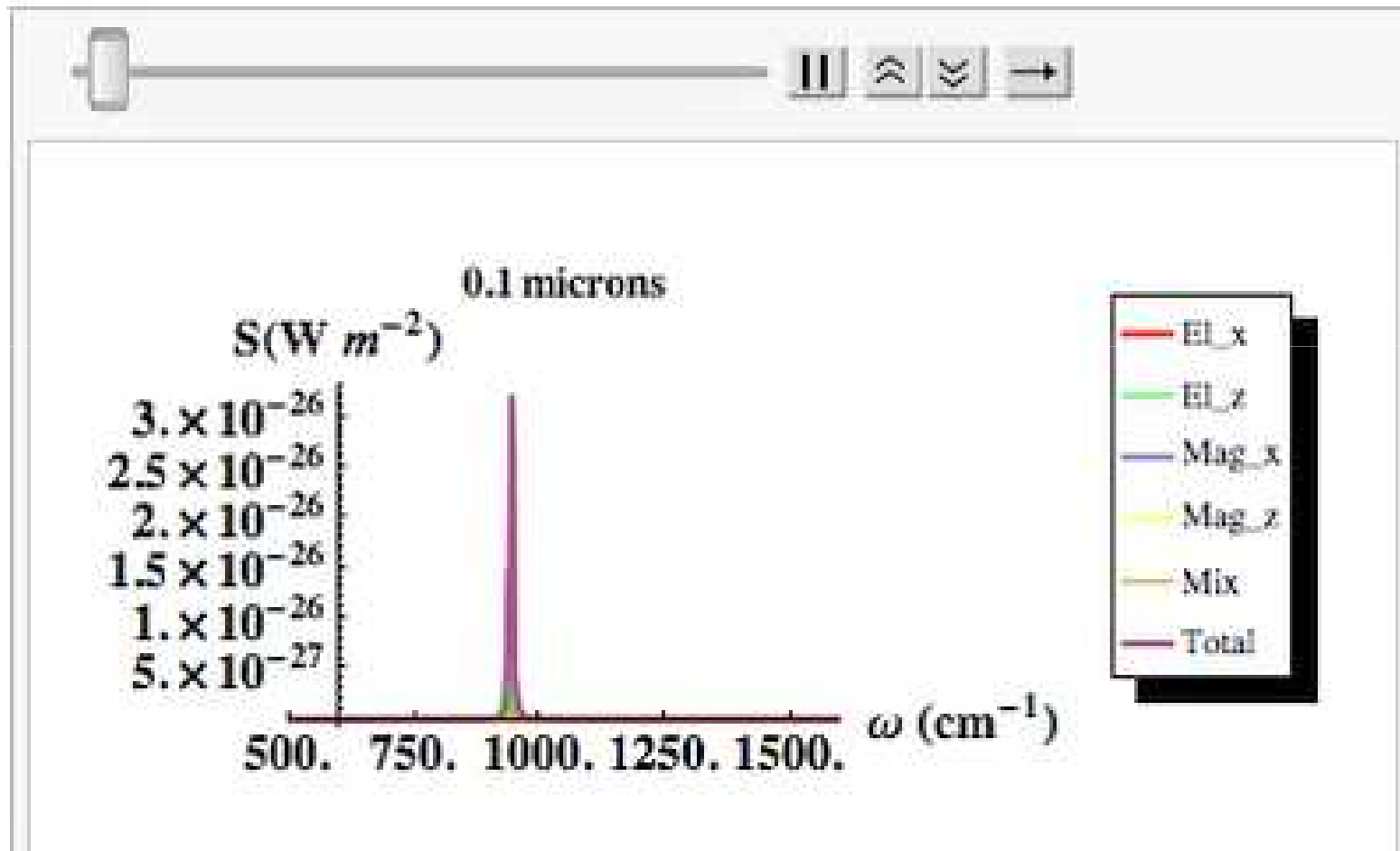
Signal au détecteur (zoom)

Pointe: W Substrat : SiC



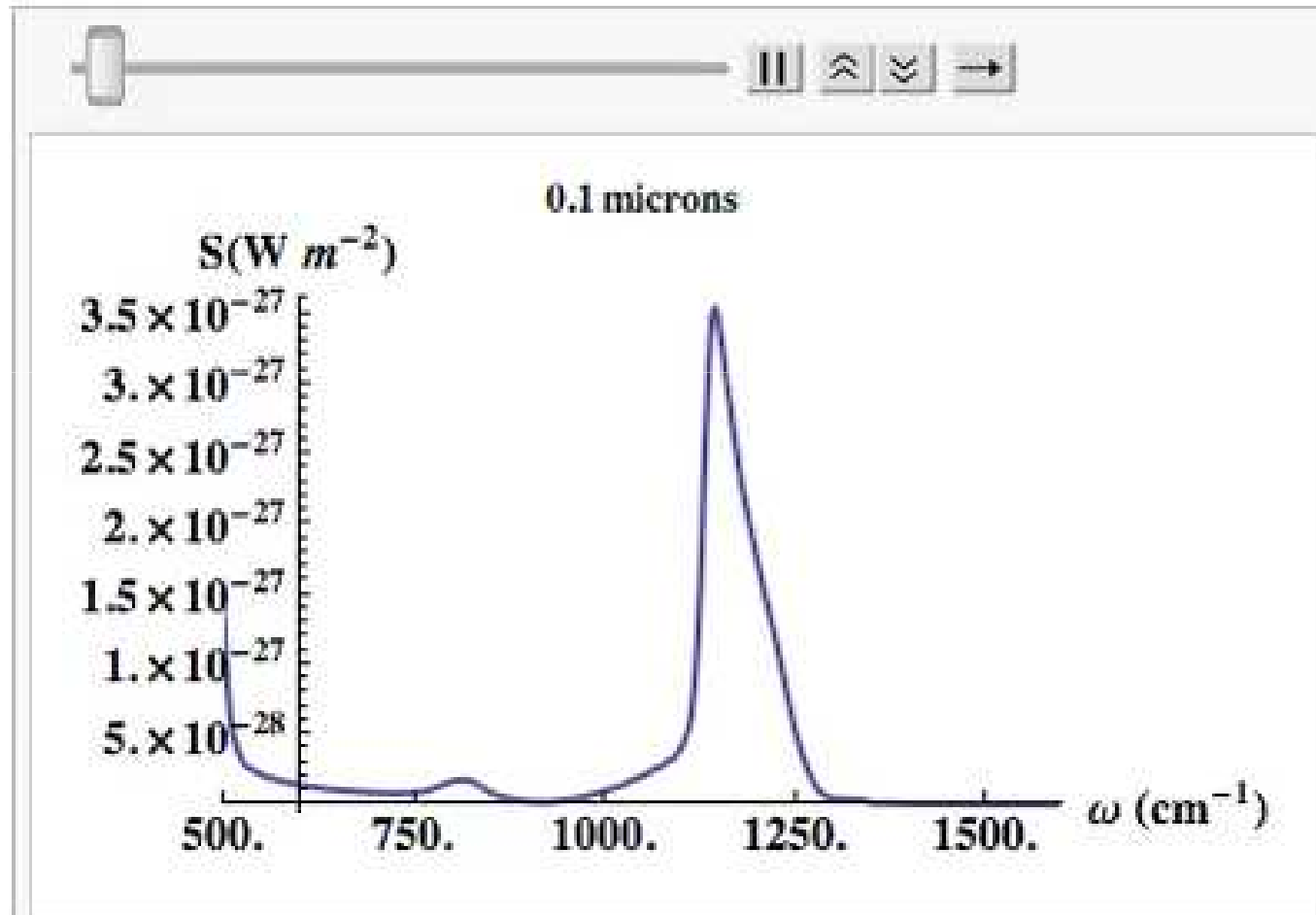
Contributions au signal

Pointe : W Substrat : SiC



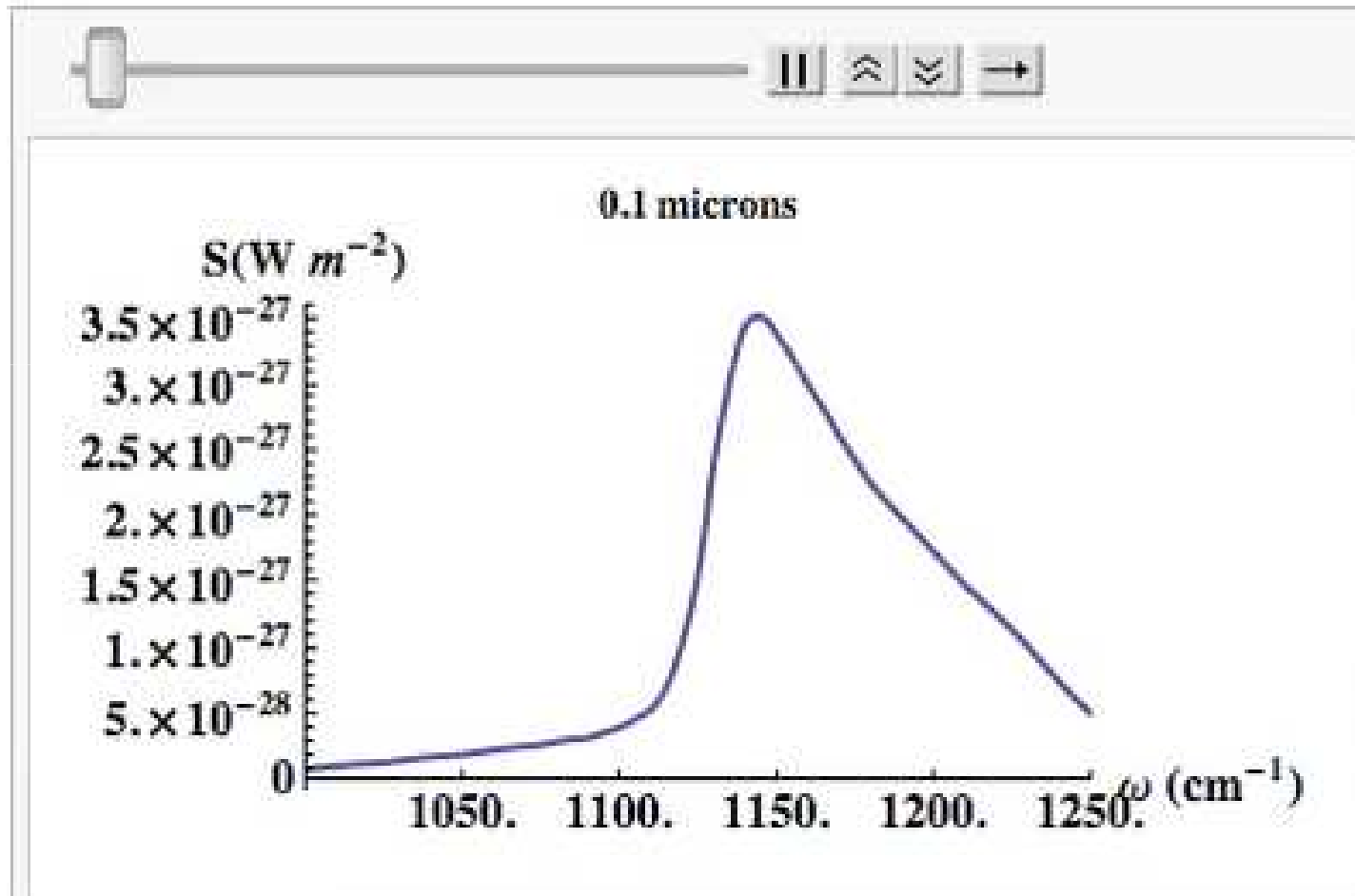
Signal au détecteur

Pointe : W Substrat : SiO2



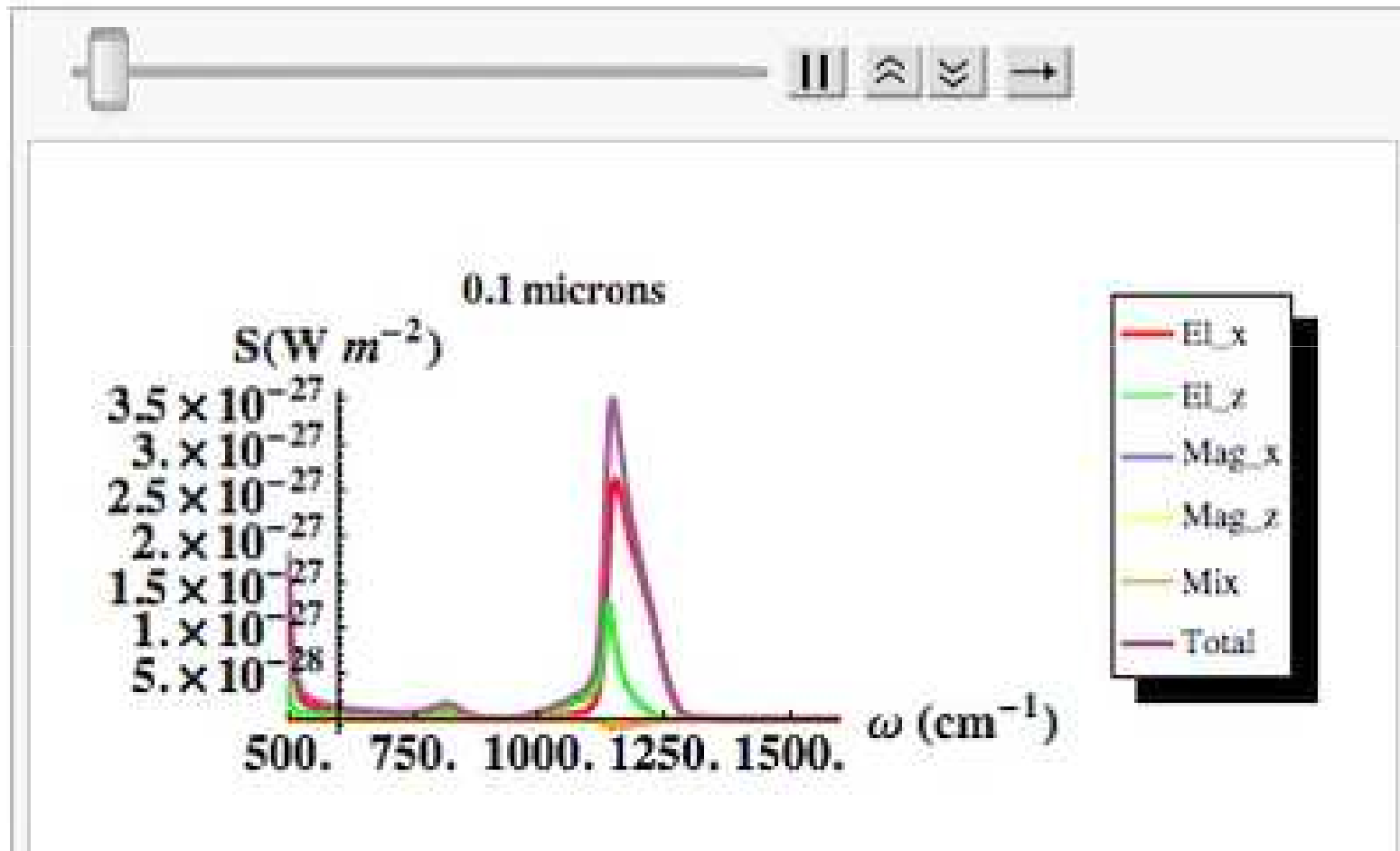
Signal au détecteur (zoom)

Pointe : W Substrat : SiO2

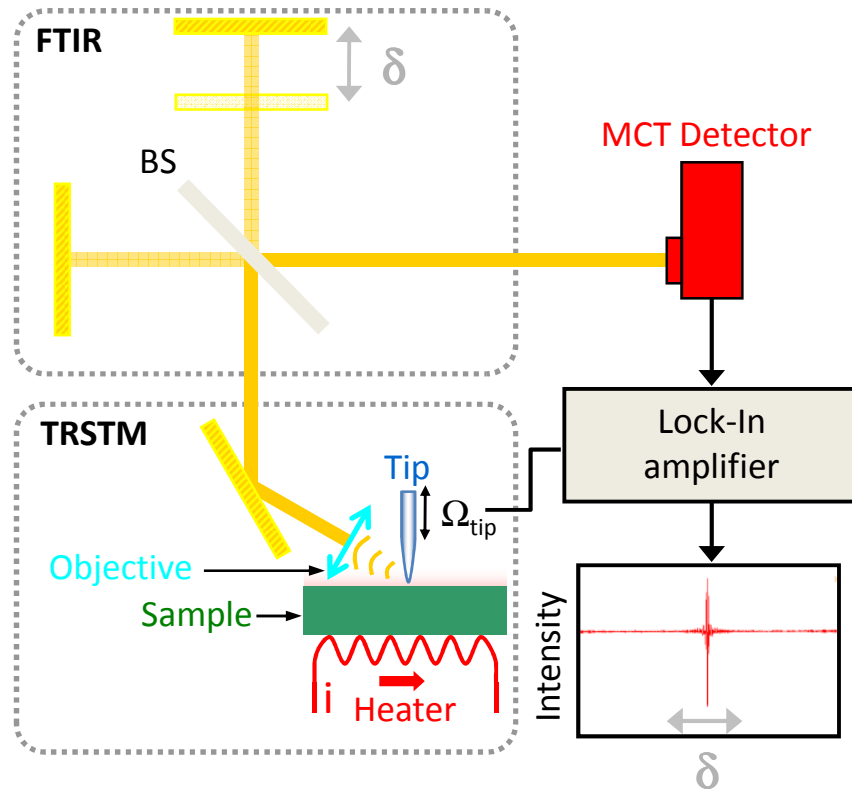


Contributions au signal

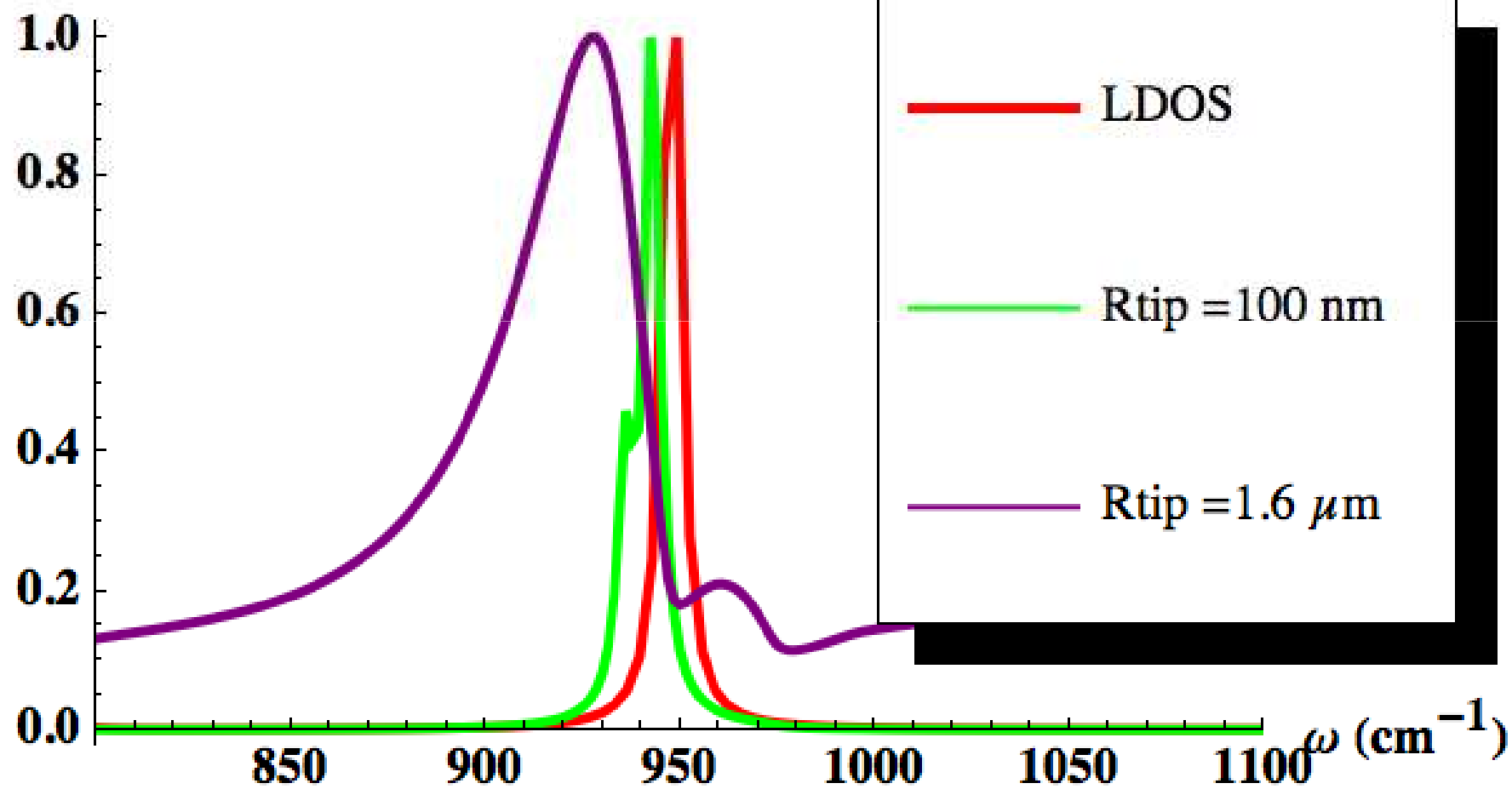
Pointe : W Substrate : SiO2



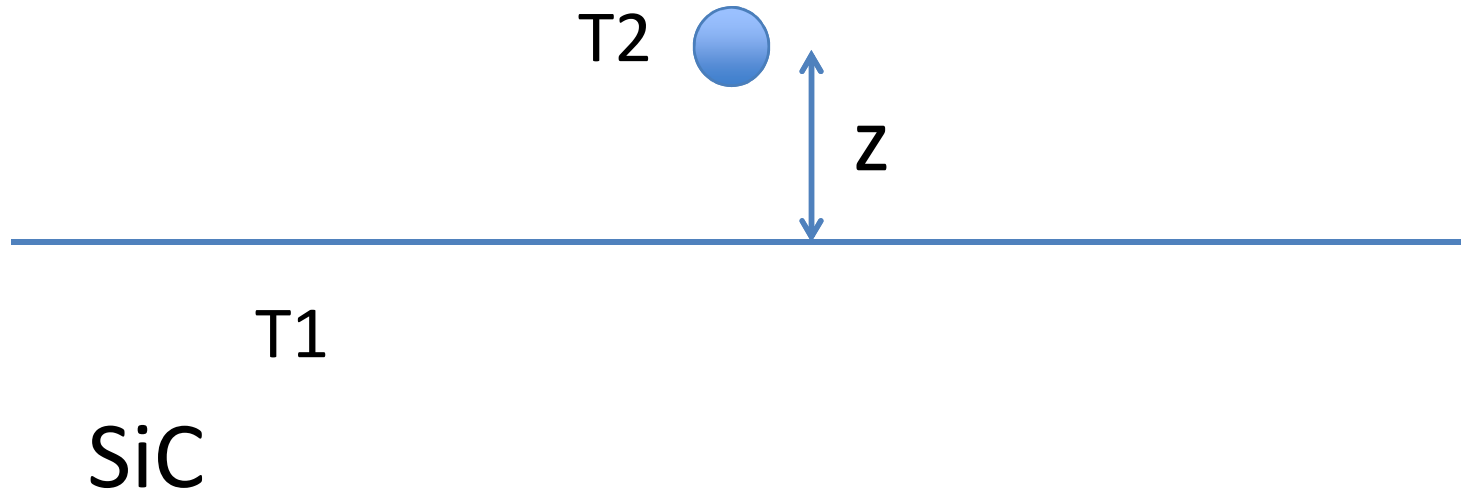
Manip ESPCI (Y. De Wilde, A. Babuty)



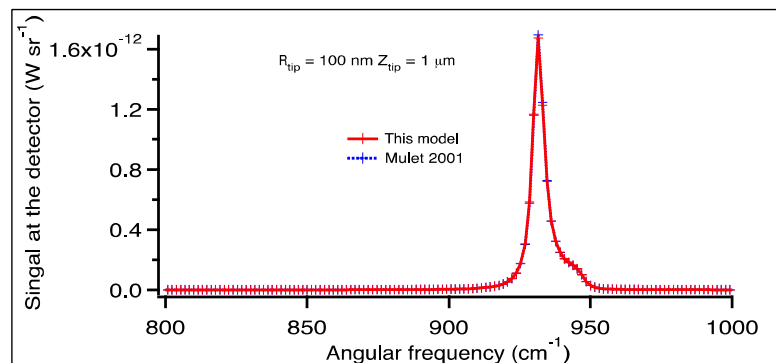
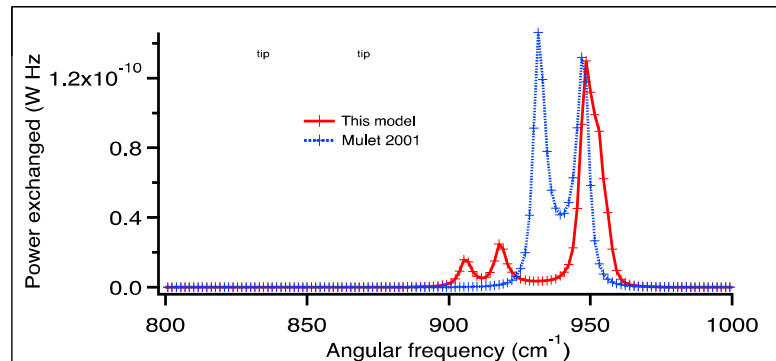
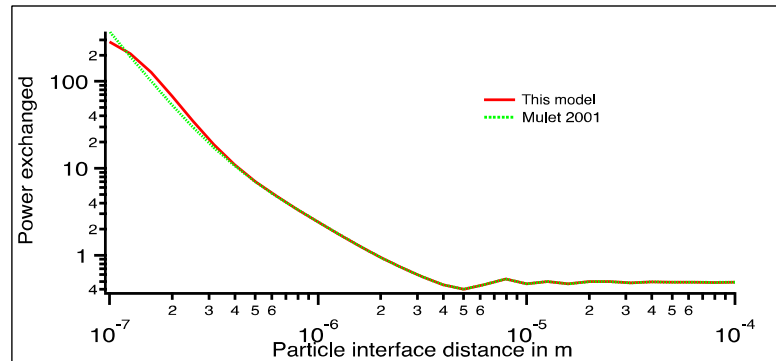
Arbitrary Units



Refroidissement particule près d'une interface

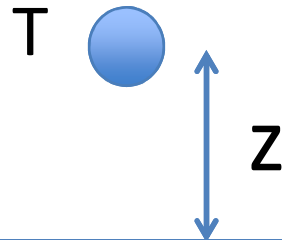


Refroidissement d'une particule près d'une interface



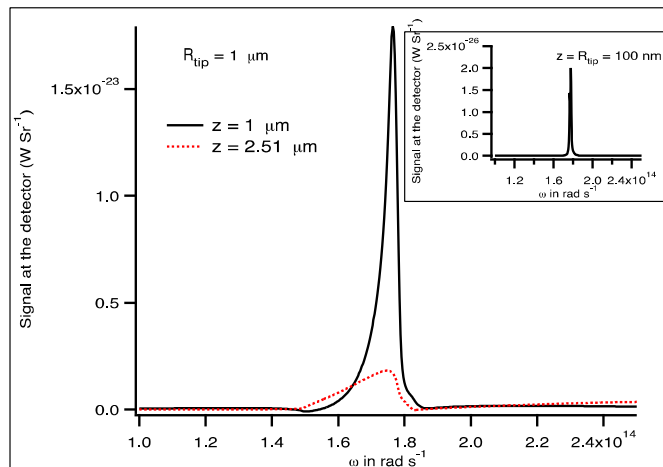
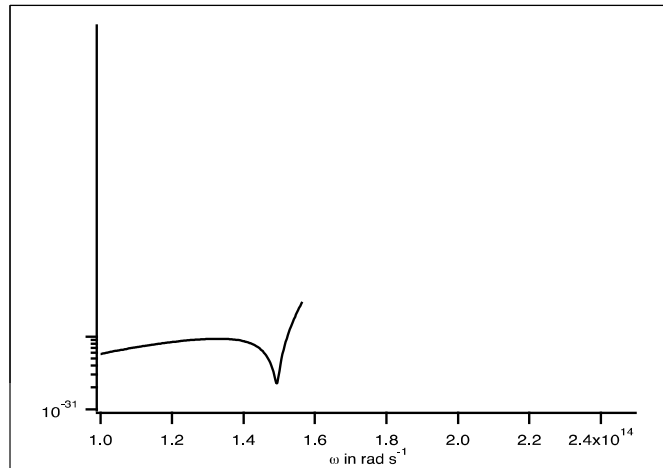
Particule chauffée au-dessus d'une interface

Detecteur

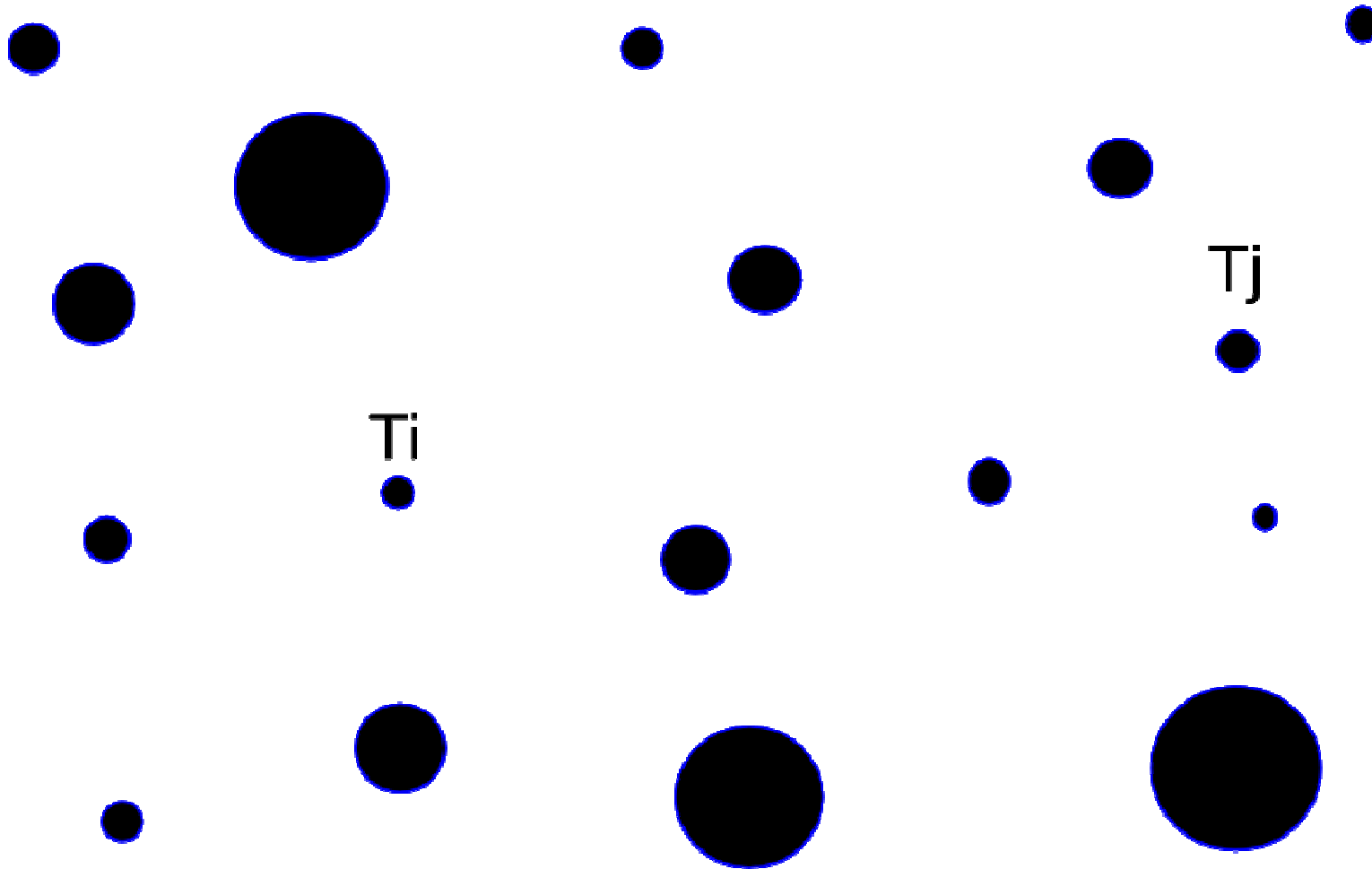


SiC

Particule chauffée au-dessus d'une interface



Transfert à N corps : position du problème



Transfert à N corps

- Equations du problème

$$\mathbf{E}_{ij} = \overset{\leftrightarrow}{\mathbf{G}}_{ij} \mathbf{p}_j$$

$$\mathbf{E}_{ij} = \overset{\leftrightarrow 0}{\mathbf{G}}_{ij} \mathbf{p}_{j \neq i} + \sum_{k \neq i} \overset{\leftrightarrow 0}{\mathbf{G}}_{ik} \alpha_k \mathbf{E}_{kj}$$

Calcul du tenseur de Green

$$\begin{pmatrix} G_{1k} \\ \vdots \\ G_{Nk} \end{pmatrix} = [[1] - A_0]^{-1} \begin{pmatrix} G_{1k}^0 \\ \vdots \\ G_{(k-1)k}^0 \\ 0 \\ G_{(k+1)k}^0 \\ \vdots \\ G_{Nk} \end{pmatrix}$$

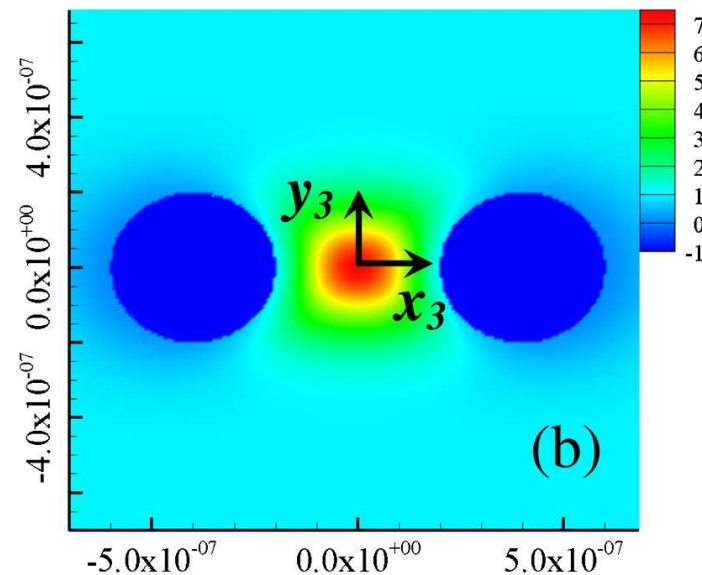
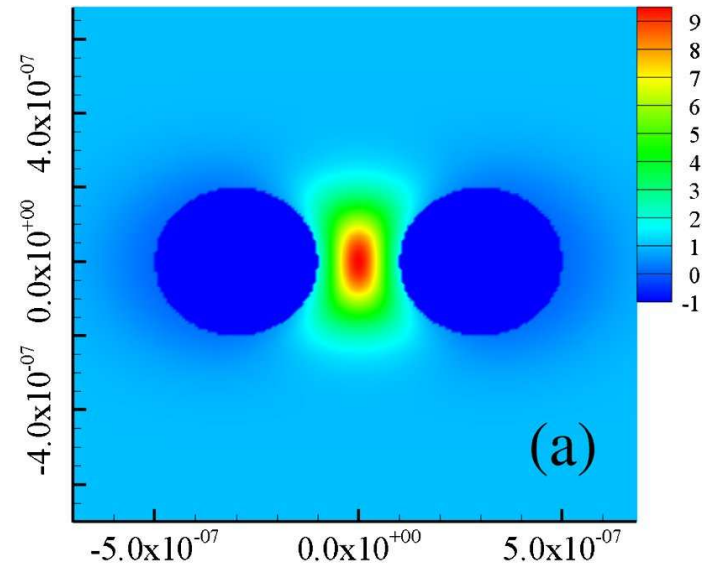
$$A_0 = \begin{pmatrix} 0 & \alpha_2 G_{12}^0 & \cdots & \alpha_N G_{1N}^0 \\ \alpha_1 G_{21}^0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \alpha_N G_{(N-1)N}^0 \\ \alpha_1 G_{N1}^0 & \cdots & \alpha_{N-1} G_{N(N-1)}^0 & 0 \end{pmatrix}$$

Calcul du flux échangé

$$P_{j \rightarrow i} = 3 \int_0^\infty \frac{d\omega}{2\pi} \Theta(\omega, T_j) \tau_{i,j}(\omega)$$

$$\tau_{i,j}(\omega) = \frac{4}{3} \mathfrak{I}(\alpha_i) \mathfrak{I}(\alpha_j) \text{Tr}[\overset{\leftrightarrow}{\mathbf{G}}_{ij} \overset{\leftrightarrow+}{\mathbf{G}}_{ij}]$$

Transfert entre trois corps (SiC)



PRL, 107, 114301 (2011)

Perspectives

- Résoudre le problème thermique couplé avec la conduction
- Trouver les conditions pour lesquelles le radiatif thermique approche le transfert conductif. Temps de désexcitation radiative sans doute très rapide
- Faire la manip...