Transport d'Énergie Thermique par Phonons-Polaritons de Surface dans un Crystal de Nanoparticules Polaires

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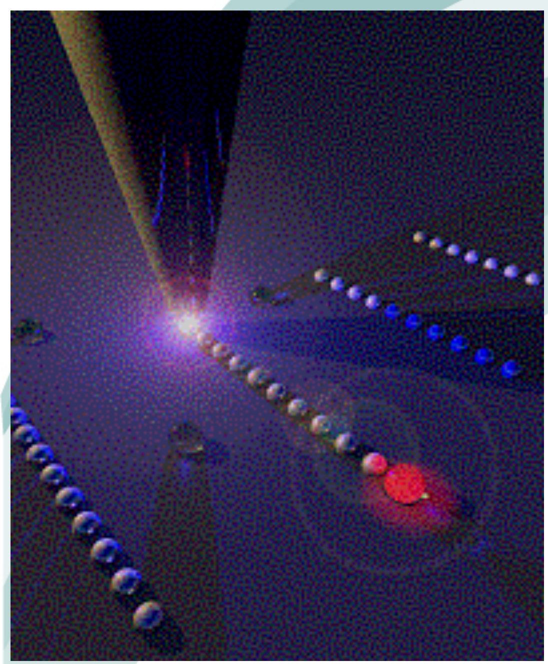

Groupes de Thermique aux Nanoéchelles et Rayonnement:

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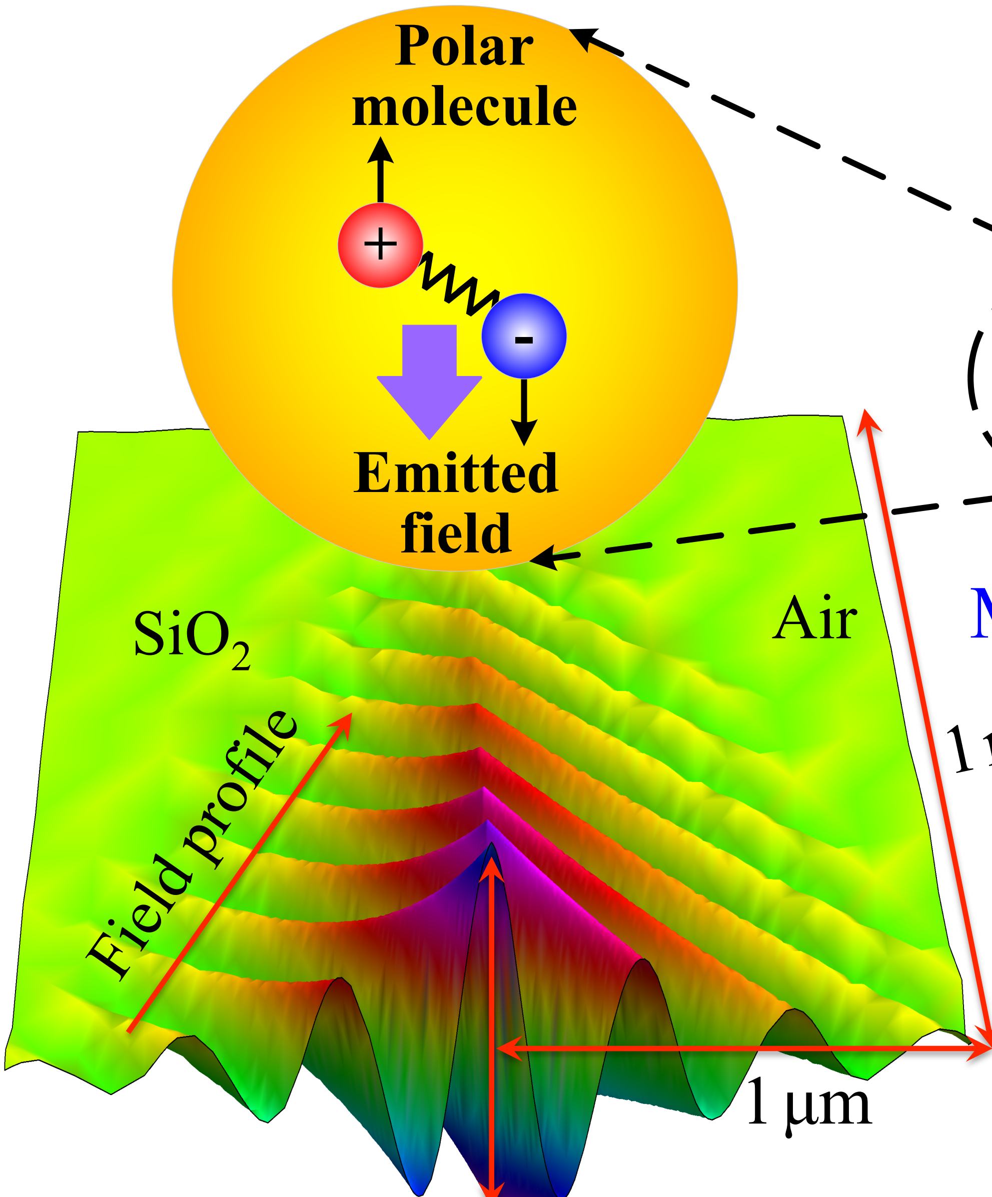
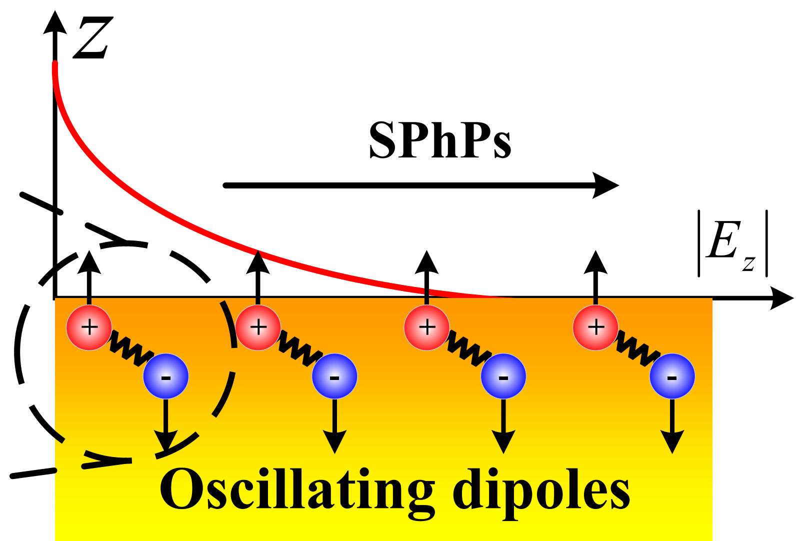
JERT 2015

Futuroscope, 26 Novembre, 2015

Phonon-Polaritons de Surface (SPhPs)

Ondes électromagnétiques de surface résultant du couplage phonon-photon.



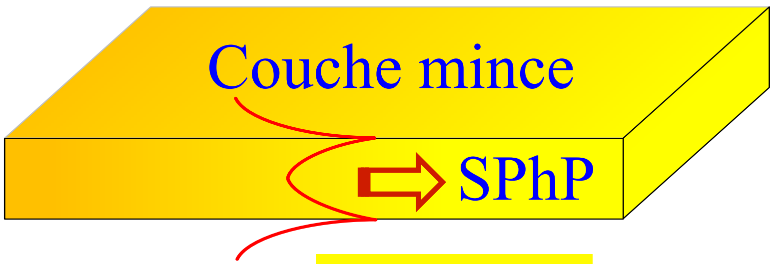


Matériau polaire (SiO_2, SiC)

SPhPs:

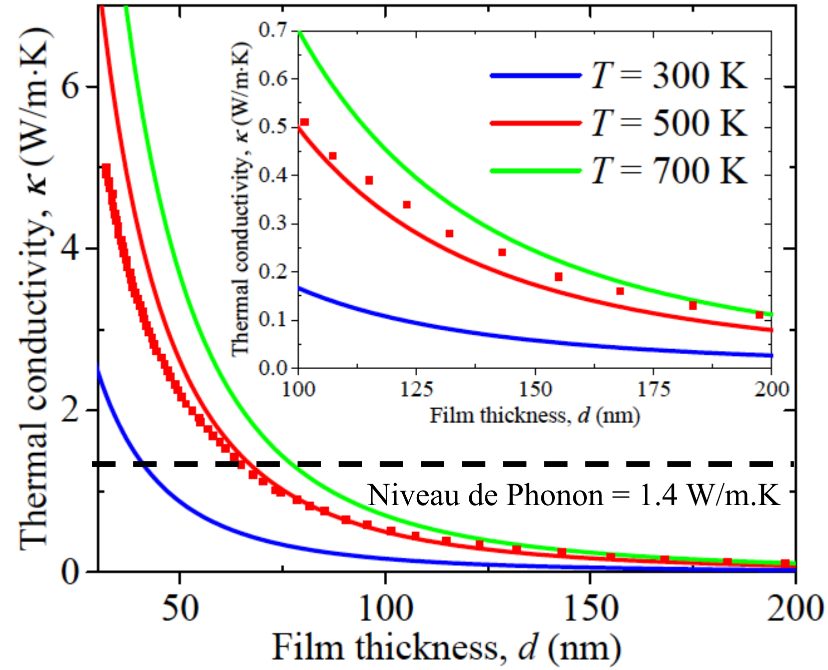
- Echauffent les matériaux.
- Porteurs d'énergie.
- Fortes effets en nanomatériaux.

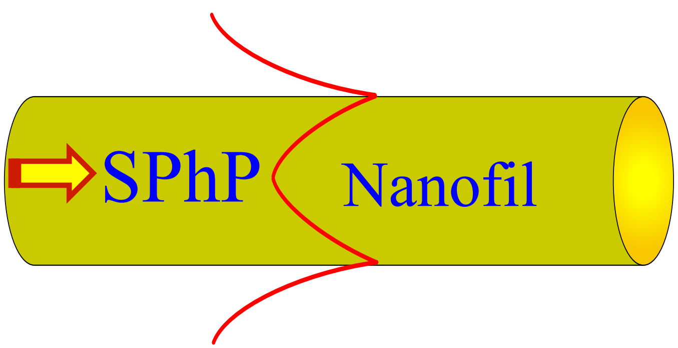
Transport d'Énergie des SPhPs



$$\kappa = \frac{A}{d^3} + \frac{B}{d}$$

JAP **113**, 084311 (2013).

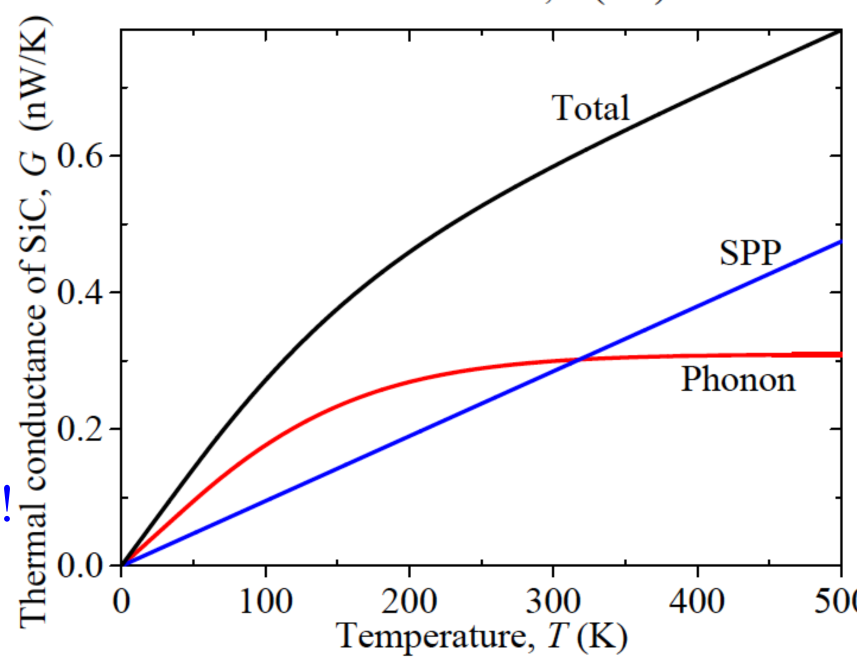




$$G_0 = \frac{\pi^2 k_B^2 T}{3h} = 0.95x10^{-12} T \ \text{(W/K)}$$

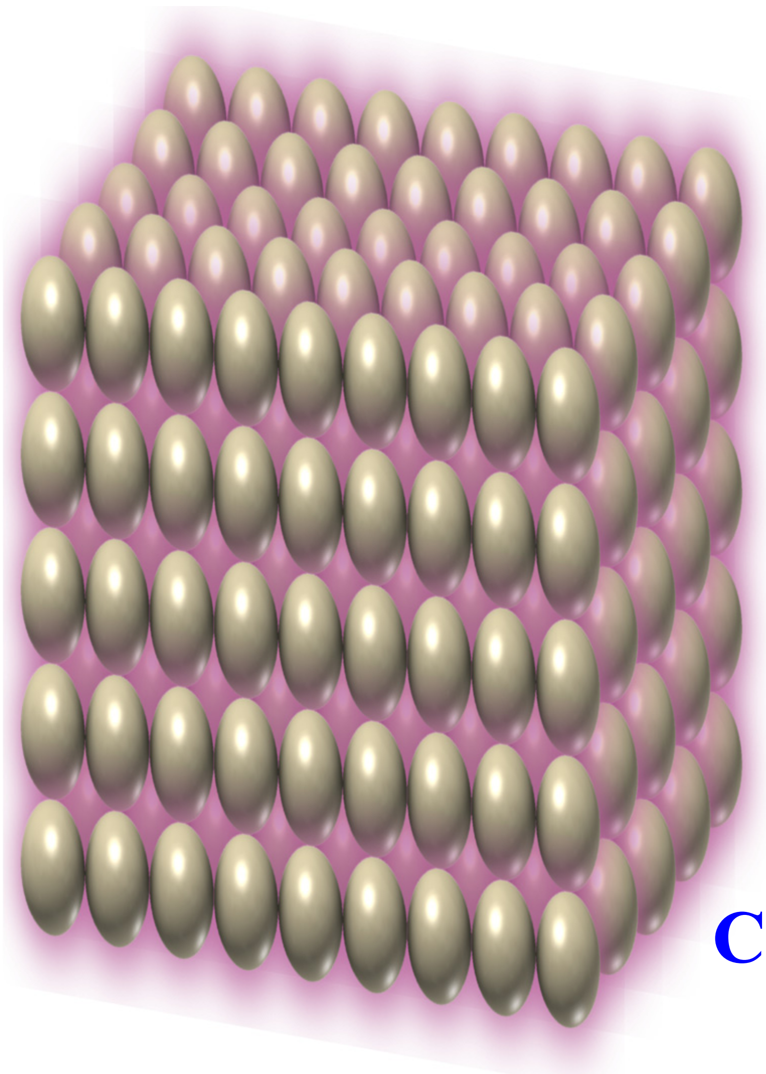
Valeur universelle!

PRL **112**, 055901 (2014).



But du présent travail

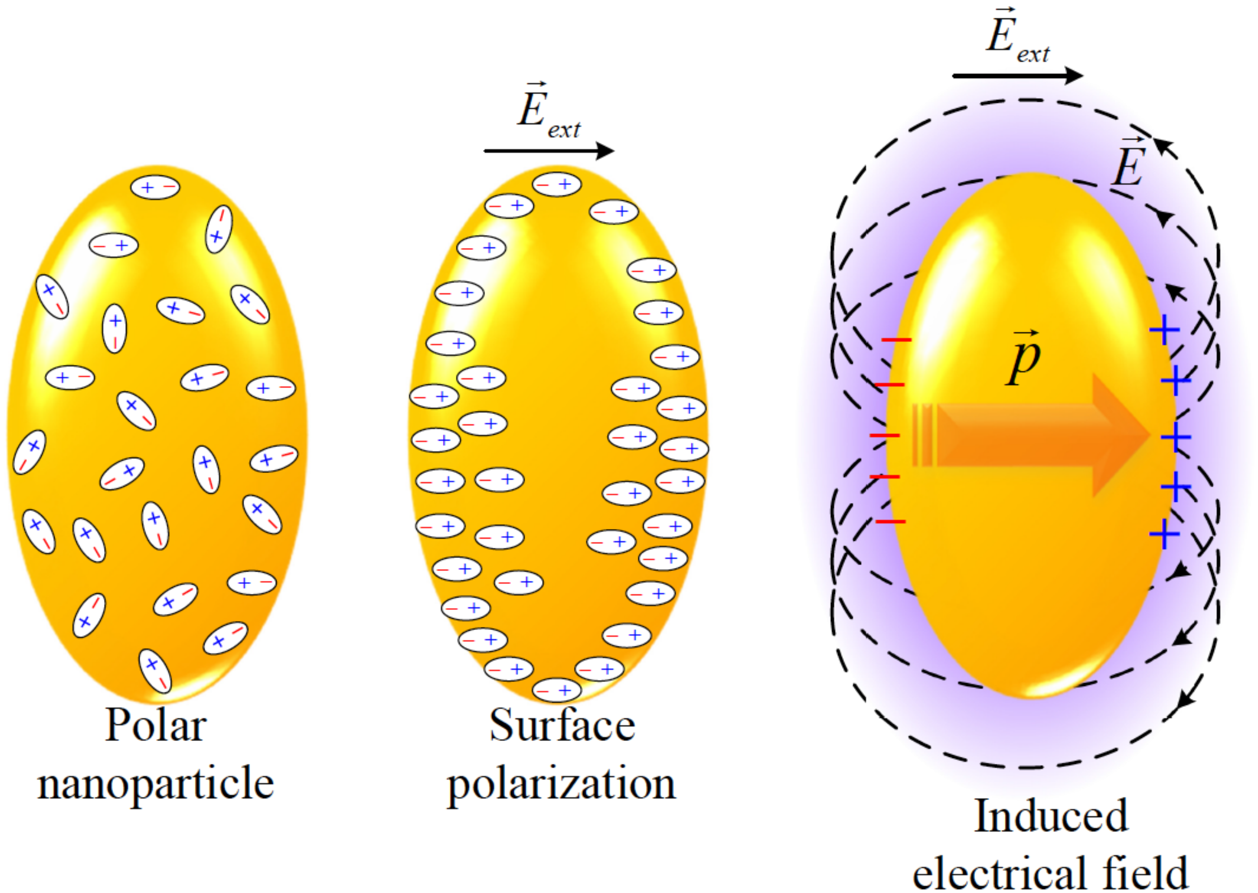
Transport d'énergie de SPhPs en propageant au long de la surface d'un ensemble 3D de nanoparticules sphéroïdals

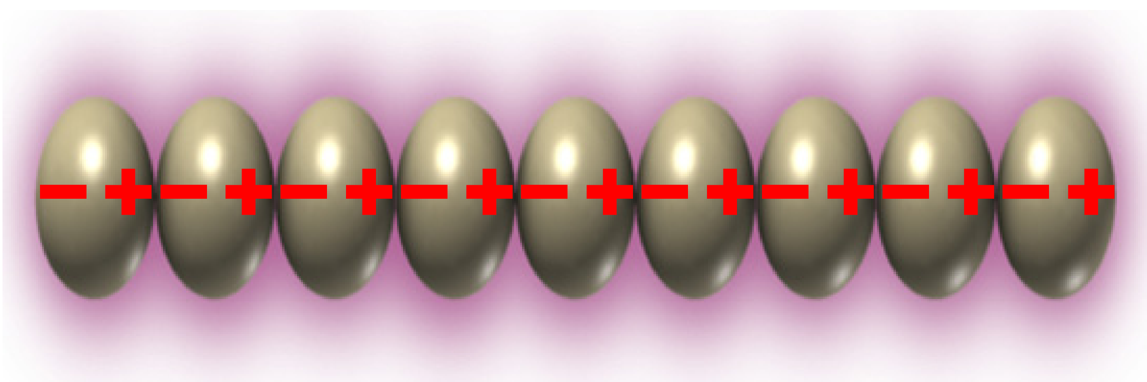


- Très basse énergie phononique.
- Haute raison surface/volume.

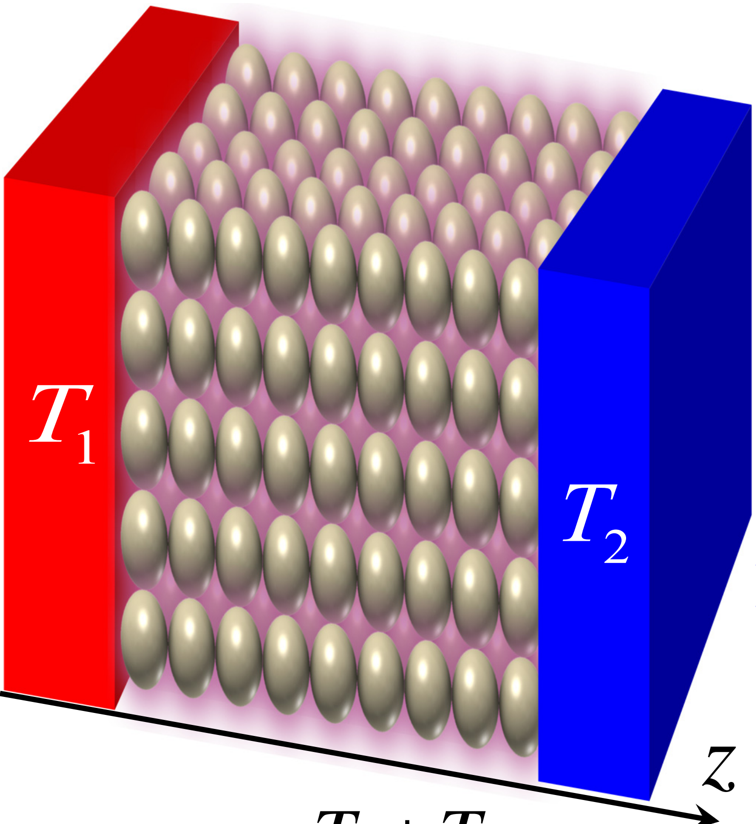
Crystal de Nanoparticules

SPhPs: Polarisation Longitudinal





Modelisation de la Conductance Thermique (G)



Flux de la Chaleur

$$\vec{q} = \frac{1}{4\pi}\int \hbar\omega\vec{V}\left[f(T_1) - f(T_2)\right]D(\omega)\,d\omega\,d\Omega$$

$$f(T) = \frac{1}{e^{\hbar\omega/k_B T} - 1} \qquad d\Omega = \sin(\theta)d\theta d\phi$$

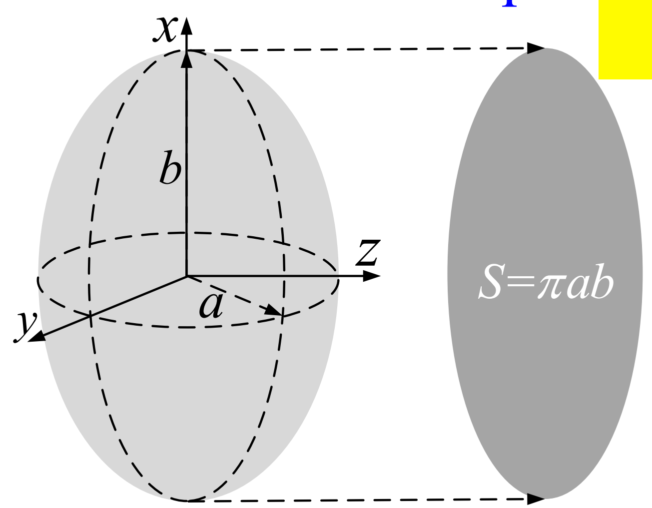
Densité d'états en 3D: $D(\omega) = \dfrac{\beta_R^2(\omega)}{2\pi^2 V}$

Conductance thermique: $G = \dfrac{qS}{T_1 - T_2}$

Pour: $T = \dfrac{T_1 + T_2}{2} \gg T_1 - T_2$

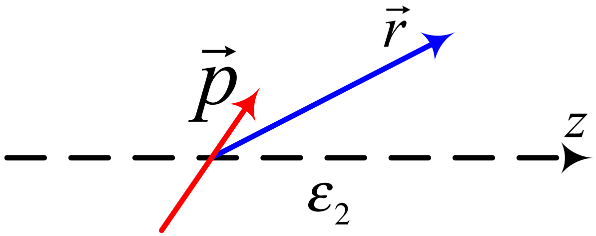
$$G = \frac{S}{8\pi^2}\int_{\omega_{\min}}^{\omega_{\max}} \hbar\omega\beta_R^2 \frac{\partial f}{\partial T} d\omega$$

Effet 3D: $S\beta_R^2/4\pi$

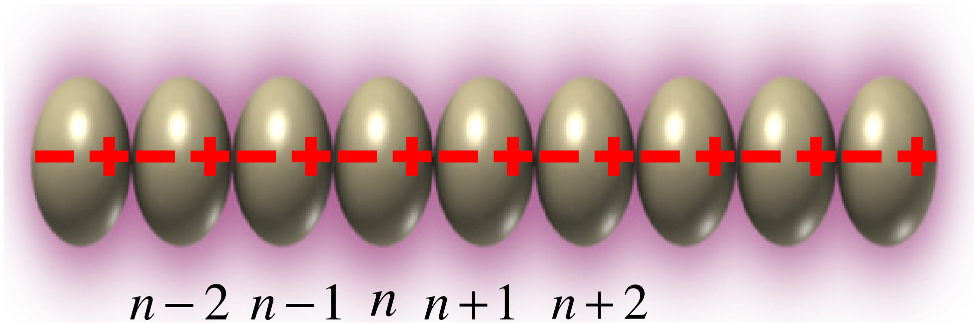


$\beta_R = \mathrm{Re}(\beta) = ?$

Relation de Dispersion



$$\vec{E}(\vec{r},t)=\frac{1}{4\pi\varepsilon_2}\left(\frac{\vec{A}}{r^3}-\frac{ik\vec{A}}{r^2}+\frac{k^2\vec{B}}{r}\right)e^{i(kr-\omega t)}$$



$$\vec{E}_n=\sum_{m\neq n}\vec{E}_m(|m-n|d,t)$$

$$\vec{p}_n=\vec{p}_0e^{i(\beta nd-\omega t)} \qquad \vec{p}_n=\alpha\vec{E}_n$$

$$-i+\alpha_e^{-1}=\frac{3}{x^3}\left[f_3(\beta,k_2)-ik_2f_2(\beta,k_2)\right] \qquad k_2=\frac{\omega}{c}\sqrt{\varepsilon_2}$$

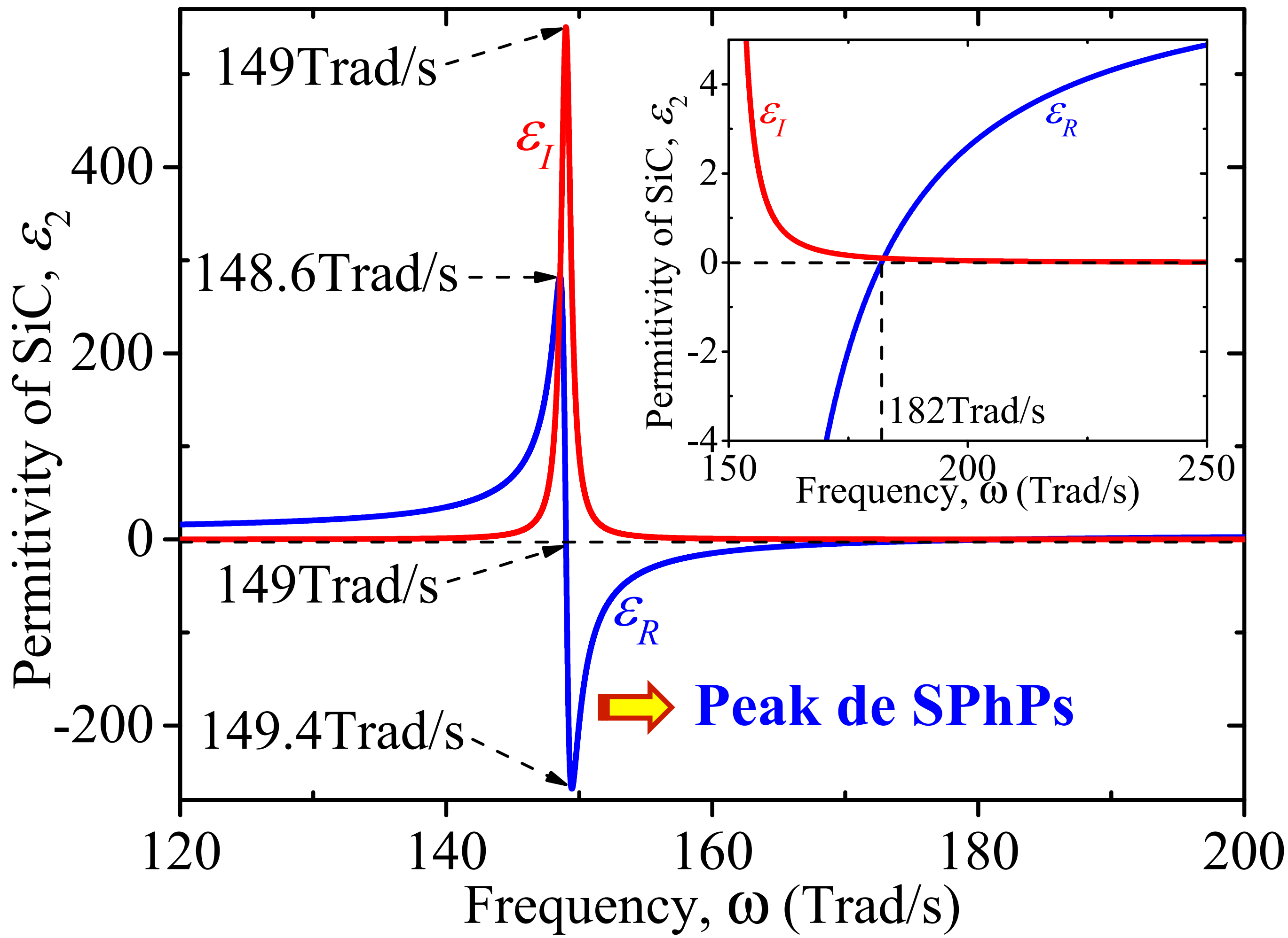
Relation de dispersion: $\beta=\beta_R+i\beta_I=?$

(PRB **92**, 115409 (2014))

$$\alpha_e=\frac{2}{9k_2^3a^2b}\left[\frac{\varepsilon_1-\varepsilon_2}{\varepsilon_2+L(\varepsilon_1-\varepsilon_2)}\right] \qquad \beta_I=\mathrm{Im}(\alpha_e^{-1})\frac{\partial\beta_R}{\partial\mathrm{Re}(\alpha_e^{-1})}$$

Polarisabilité

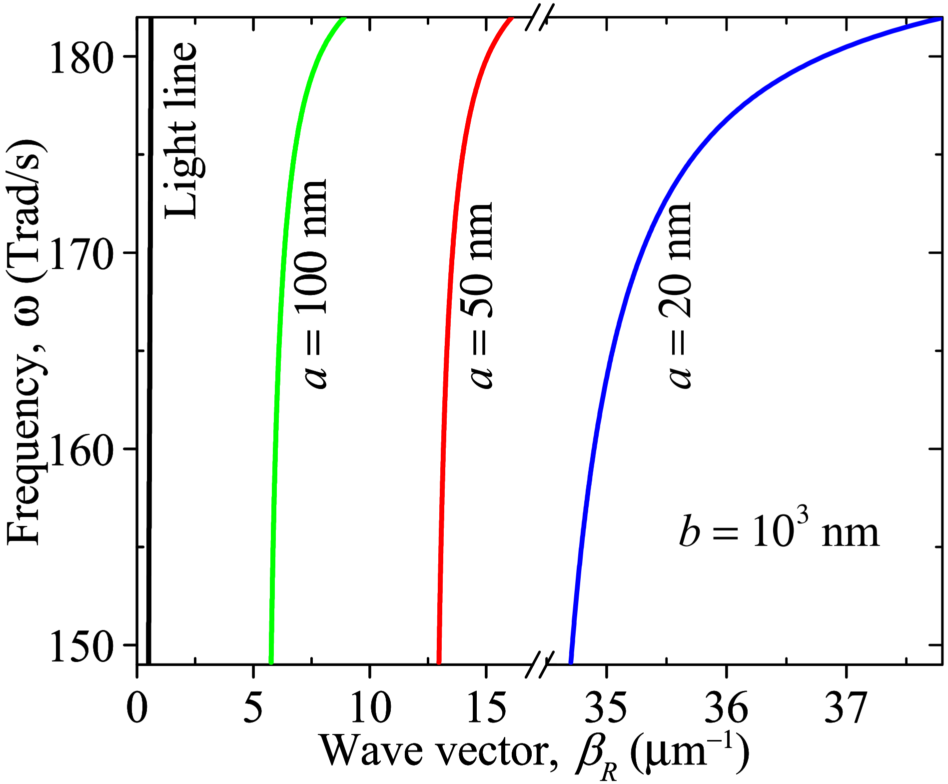
Permittivité de SiC

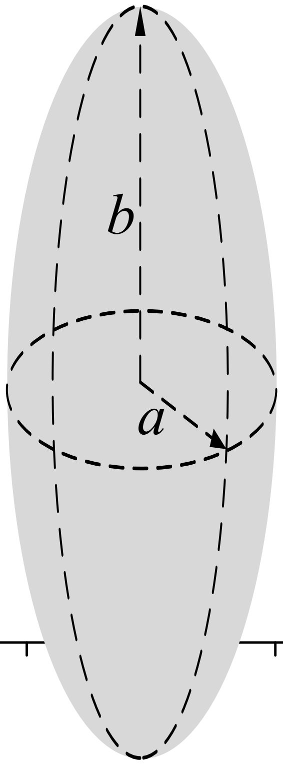


$$\varepsilon_2 < 0$$

$$149\ \text{Trad/s} < \omega < 182\ \text{Trad/s}$$

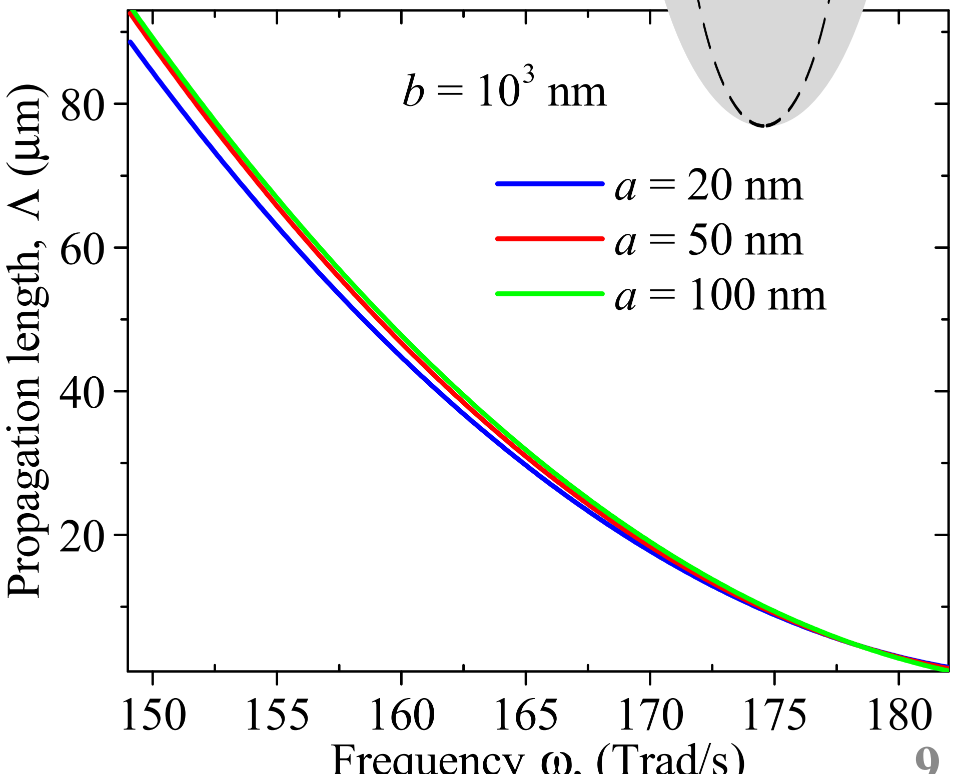
Parametres de Propagation





$b = 10^3$ nm

$b >> a$

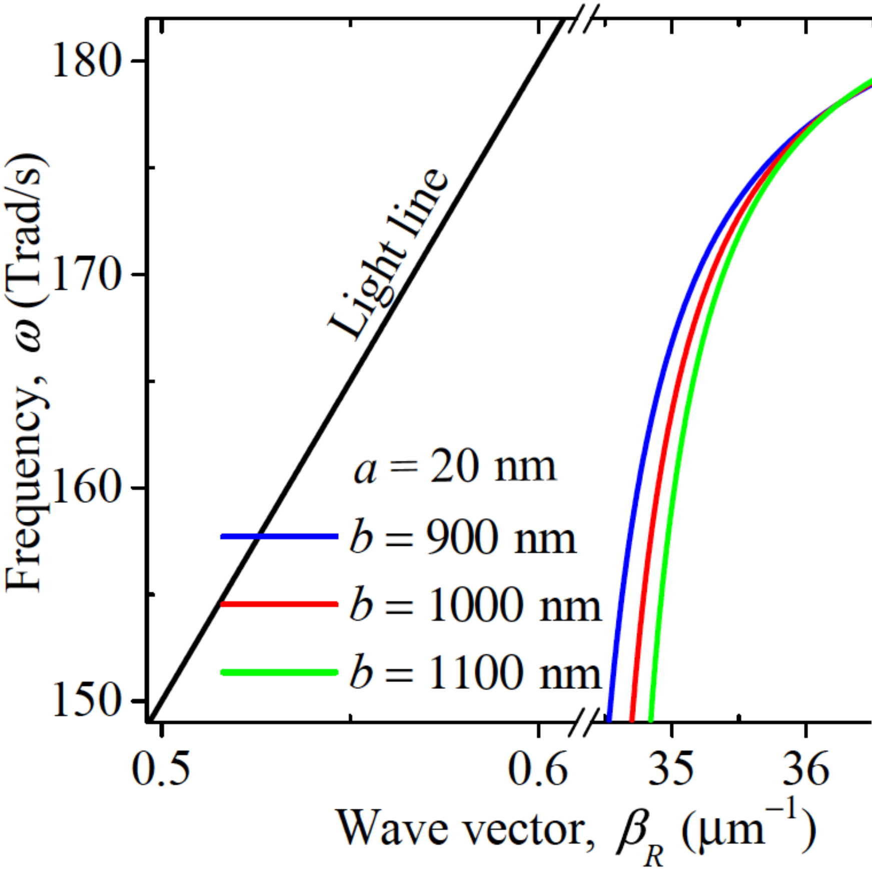


Confinement ⇧⇩ a

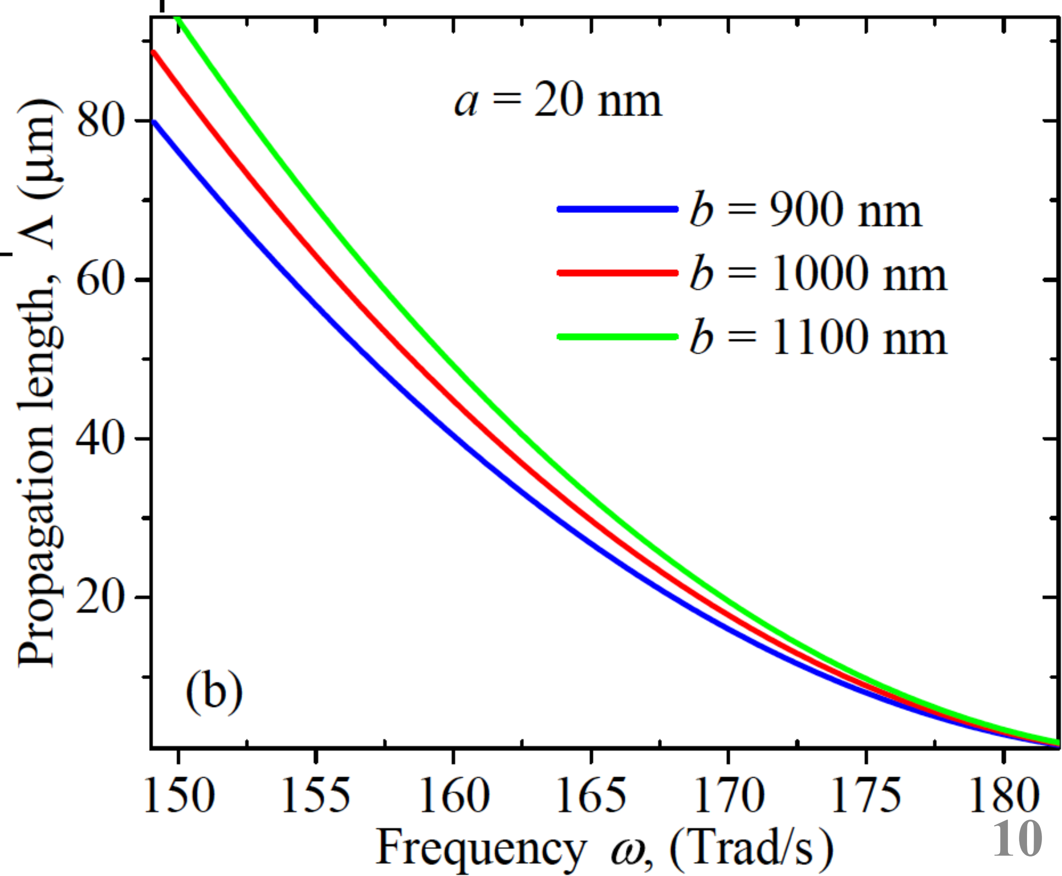
Longeur de propagation ≠ $\Lambda(a)$

$\Lambda > 100$ nanoparticules

Parametres de Propagation 2

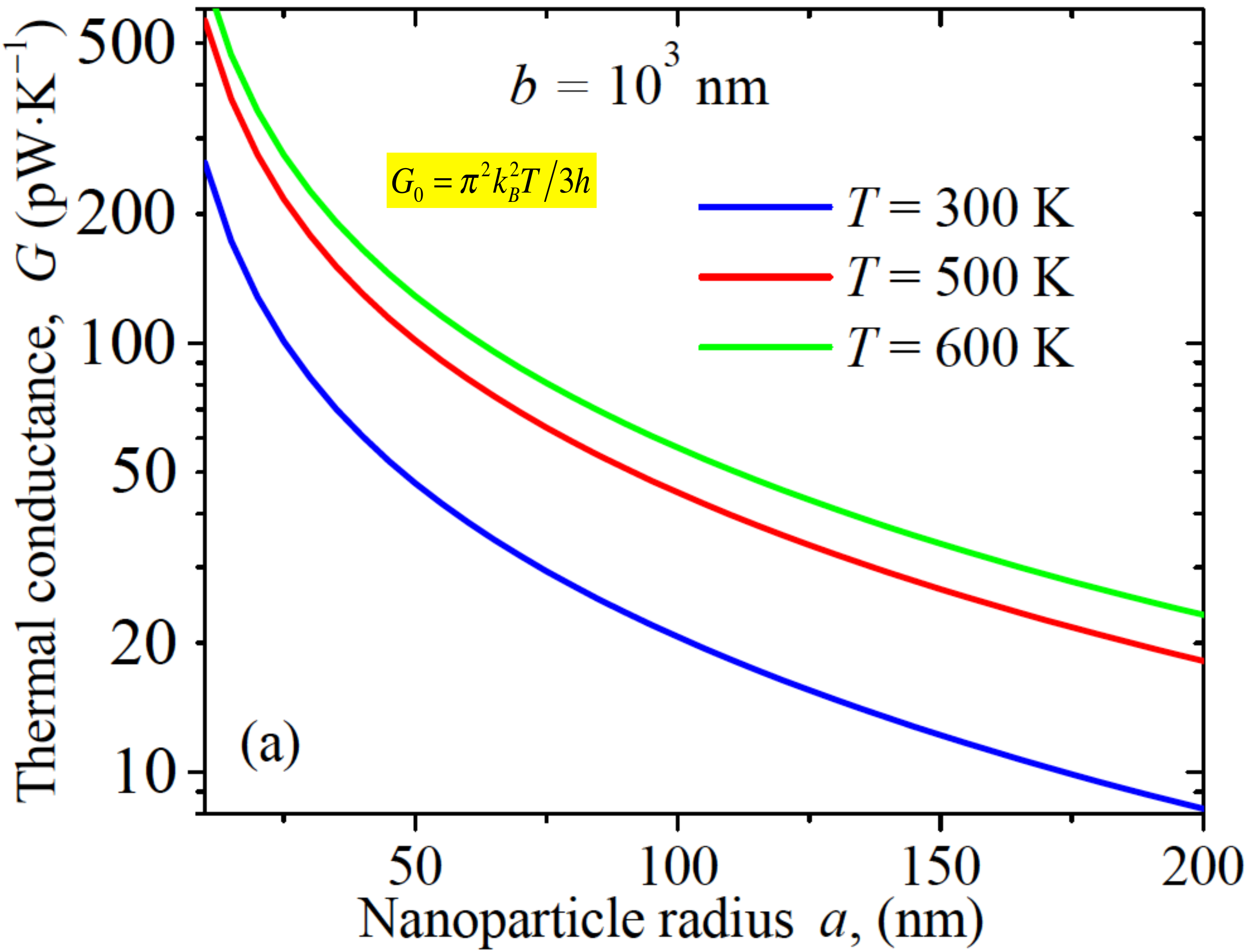


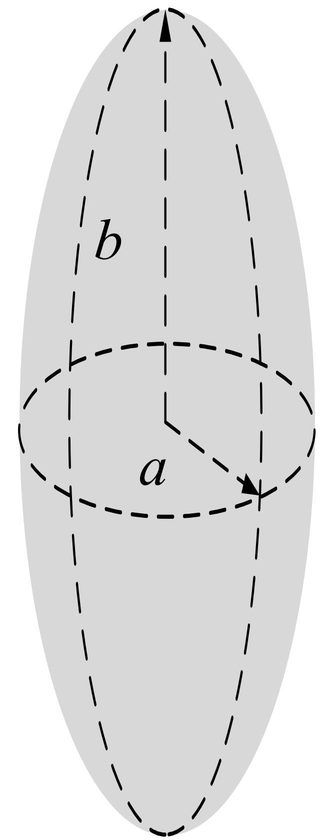
Un changement de taille de 200 nm n'affect pas beaucoup ni la relation de dispersion ni la longueur de propagation.



L'énergie de SPhPs n'est pas modifié significativement pour la dispersion de taille des nanoparticules, si $b >> a$.

Conductance Thermique (G)

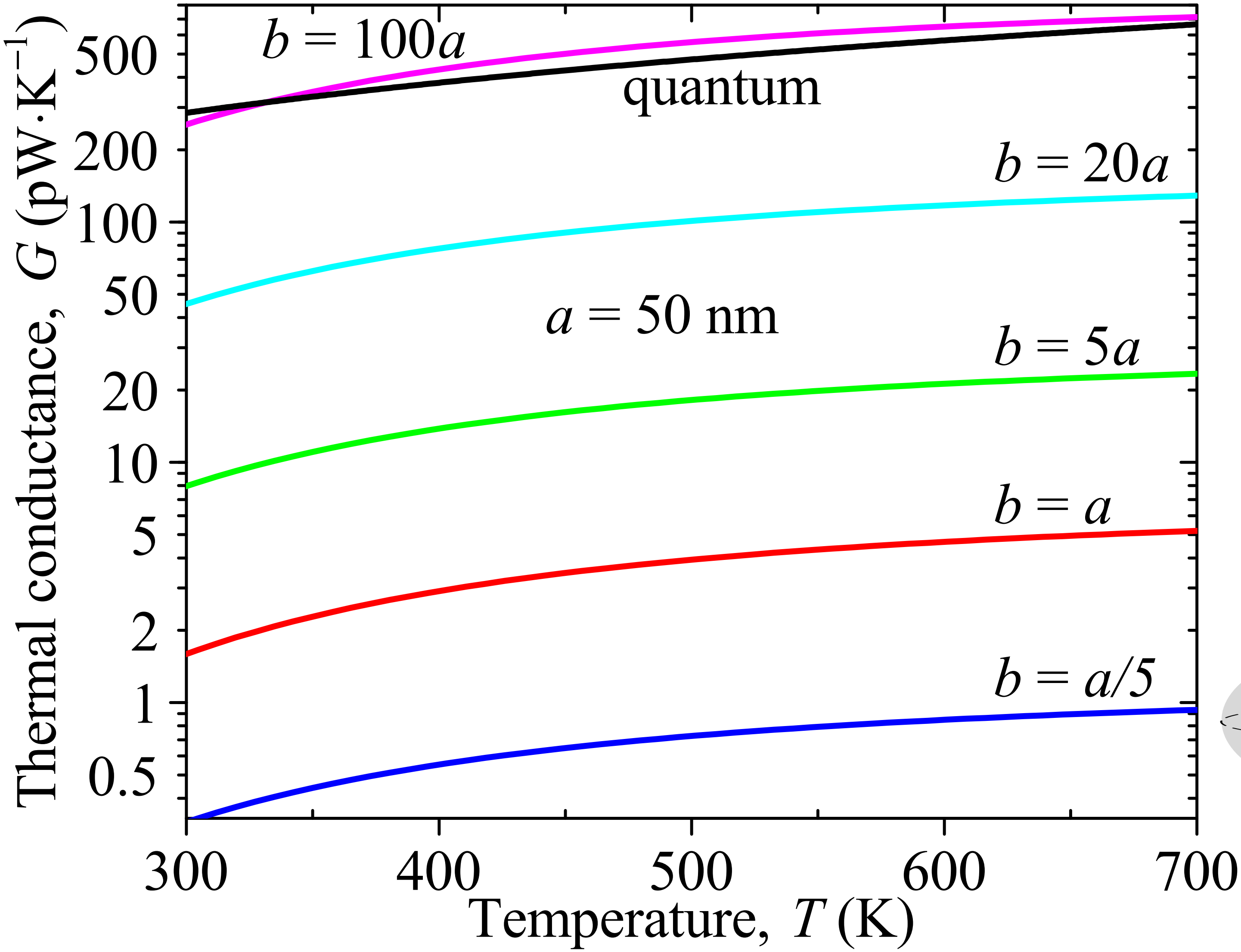


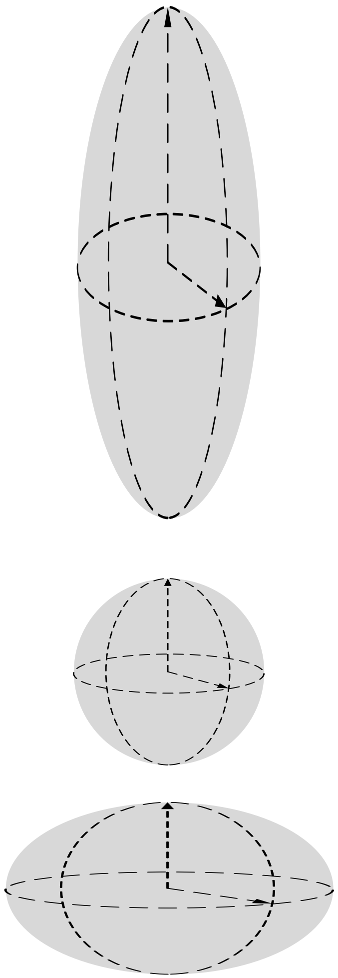


$b >> a$

G ⇑ ⇓ a

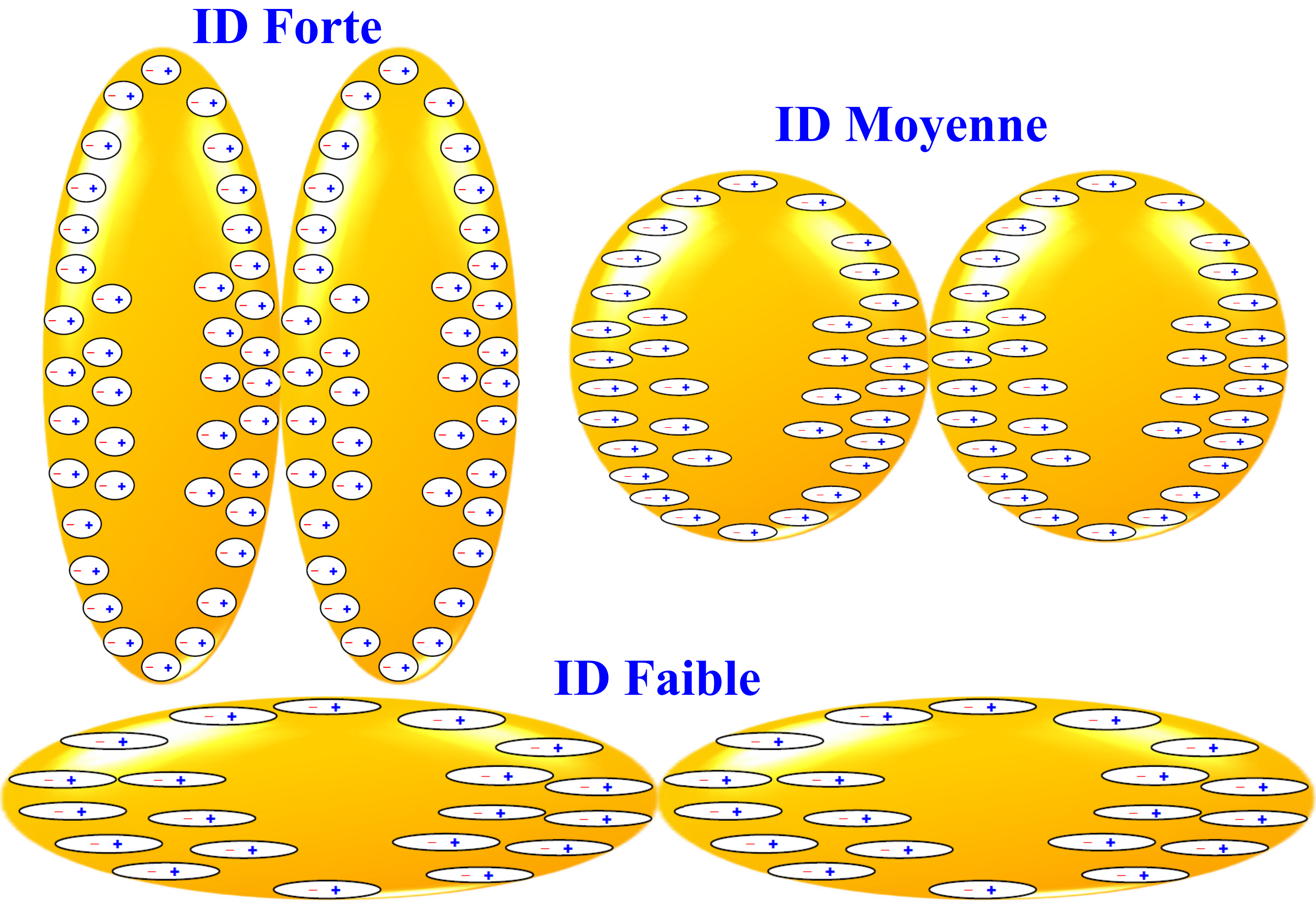
Conductance Thermique 2



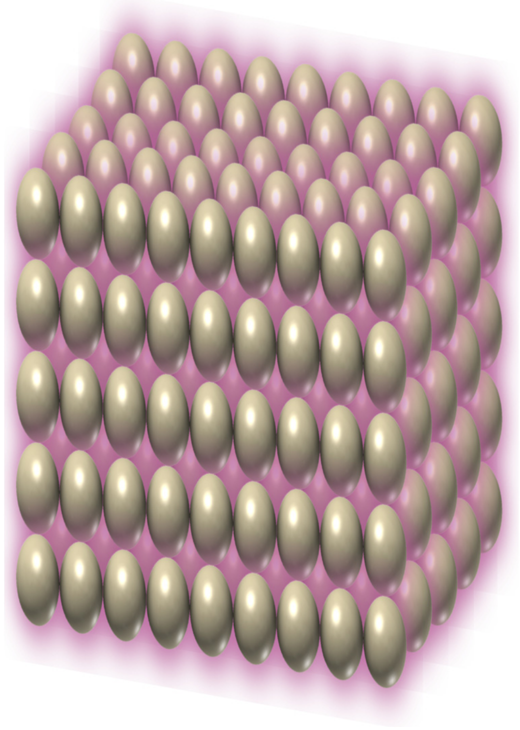


G ⇧⇧ b/a

Interaction Dipolaire (ID)



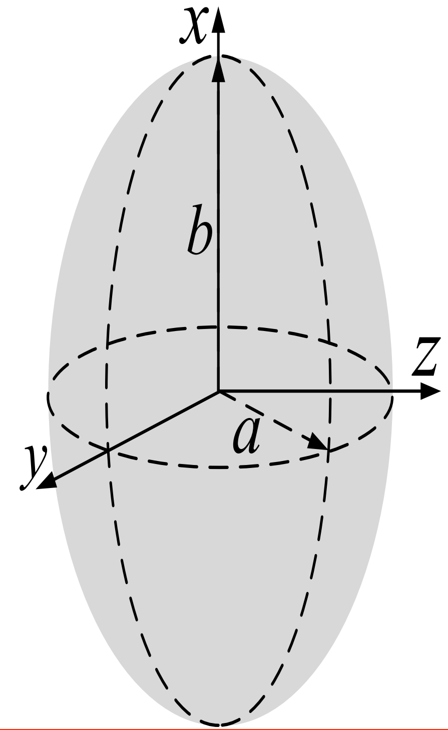
Conclusions



Conductance thermique de SPhPs

G ⇧⇧ b/a

Nanoparticules cylindriques sont bien mieux que les sphériques.



$a = 50$ nm
$b = 5\ \mu$m

$$G \sim \frac{\pi^2 k_B^2 T}{3h}$$

Quantum de conductance thermique

Énergie de SPhPs >> Énergie phononique

SPhPs, Porteurs d'énergie dominants dans le Crystal de Nanoparticules!

Merci!

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Papiers and preprints

www.researchgate.net/profile/Jose_Ordonez-Miranda