Thermal Casimir effect in nanostructured surfaces

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Outline

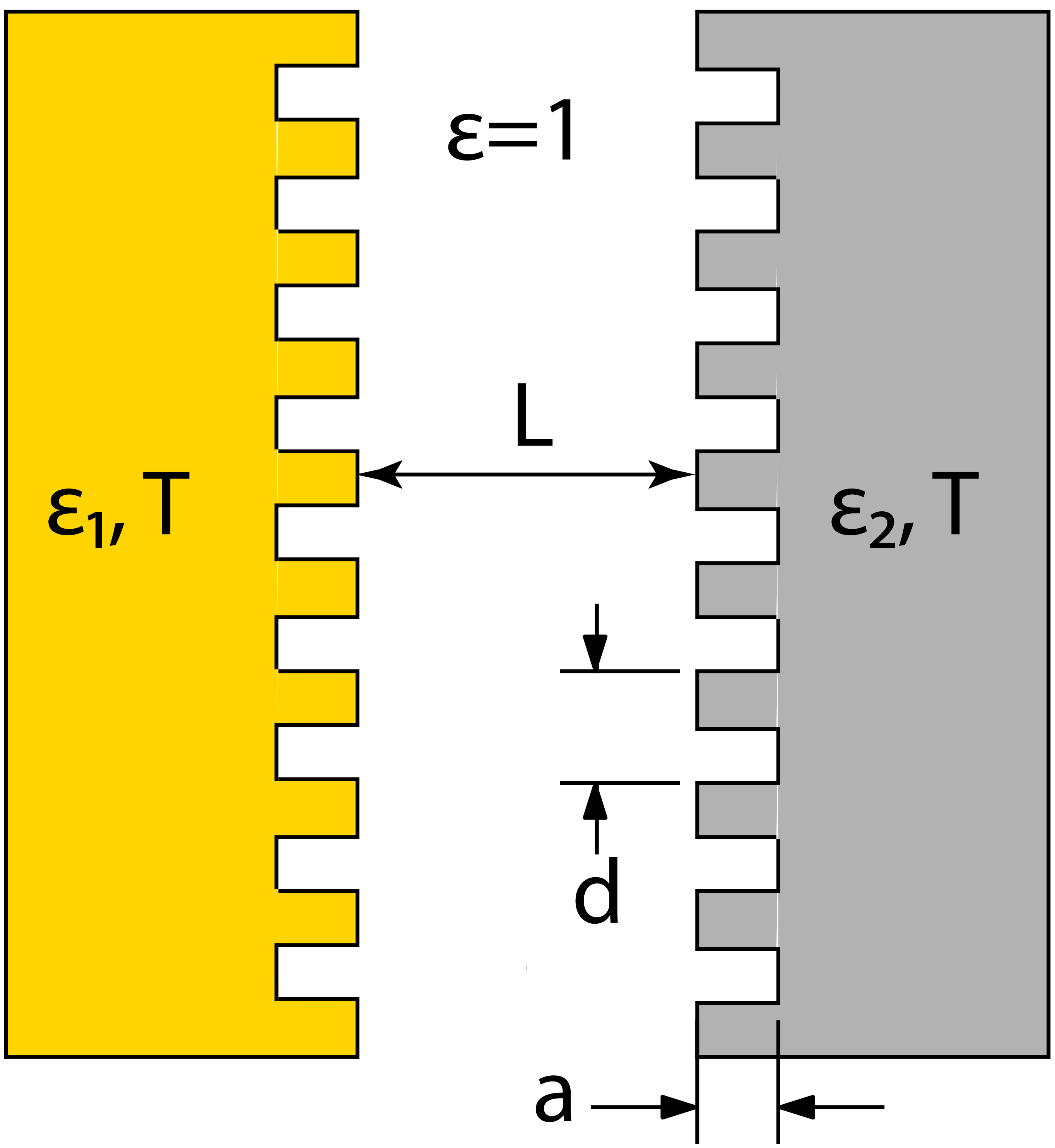
- Study the effect of the temperature on the Casimir force between nanostructured surfaces

- The differences with respect to the plane-plane geometry

- Effect of the materials used

- Effect of the geometry of the corrugations

Overview of the problem



- Two 1D lamellar gratings at temperature T, materials ε_1 and ε_2, separated by a distance L of vacuum.

- 1D lamellar gratings: period d, corrugation height a.

Calculations

- Two 1D lamellar gratings at temperature T, materials ε_1 and ε_2, separated by a distance L of vacuum.

$$F(L) = 2\pi k_B T \sum_{n=0}^{\infty}{}' \iint \mathrm{tr}\left[(\mathbf{1} - \boldsymbol{\mathcal{M}}_n)^{-1}\, \partial_L \boldsymbol{\mathcal{M}}_n\right] \mathrm{d}^2\mathbf{k}_\perp^{(0)}$$

Sum over Matsubara frequencies.

FBZ-restricted 0-order transverse wavevector.

$$\boldsymbol{\mathcal{M}}_n = \mathbf{R}_1(\xi_n) e^{-\boldsymbol{k}_\parallel L} \mathbf{R}_2(\xi_n) e^{-\boldsymbol{k}_\parallel L}$$

Wick-rotated Matsubara frequencies.

Reflection operators. Dimension 2(2N+1).

Polarizations Diffraction

Materials considered and conductivity models

- Gold: optical data + Drude model

$$\epsilon_{\rm gold}(\imath\xi) = 1 + \frac{\xi_p^2}{\xi(\xi+\gamma)} \qquad \text{for } \omega < 0.1 \text{ meV}$$

$\xi_p = 9$ eV $\quad \gamma = 35$ meV

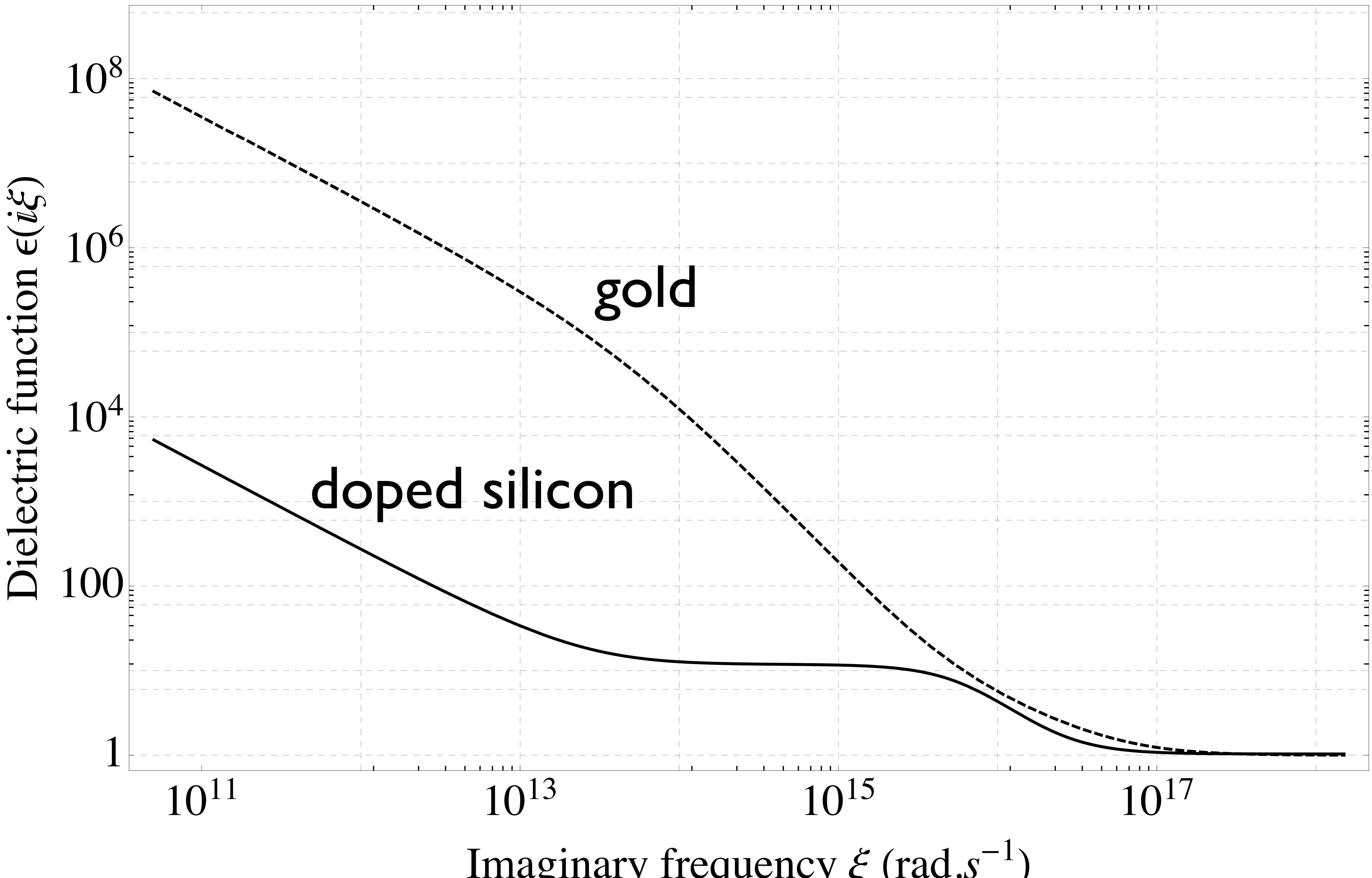
- Doped silicon: Drude-Lorentz

$$\epsilon_{\rm silicon}(\imath\xi) = \epsilon_\infty + \frac{(\epsilon_0 - \epsilon_\infty)\xi_0^2}{\xi^2 + \xi_0^2} + \frac{\xi_p^2}{\xi(\xi+\gamma)}$$

$\varepsilon_\infty = 1.035$ $\varepsilon_0 = 11.87$ Intrinsic Doping ($n=2.10^{18}$ cm^{-3})

$\xi_0 = 4.3$ eV $\xi_p = 74$ meV $\gamma = 31$ meV

Materials considered and conductivity models



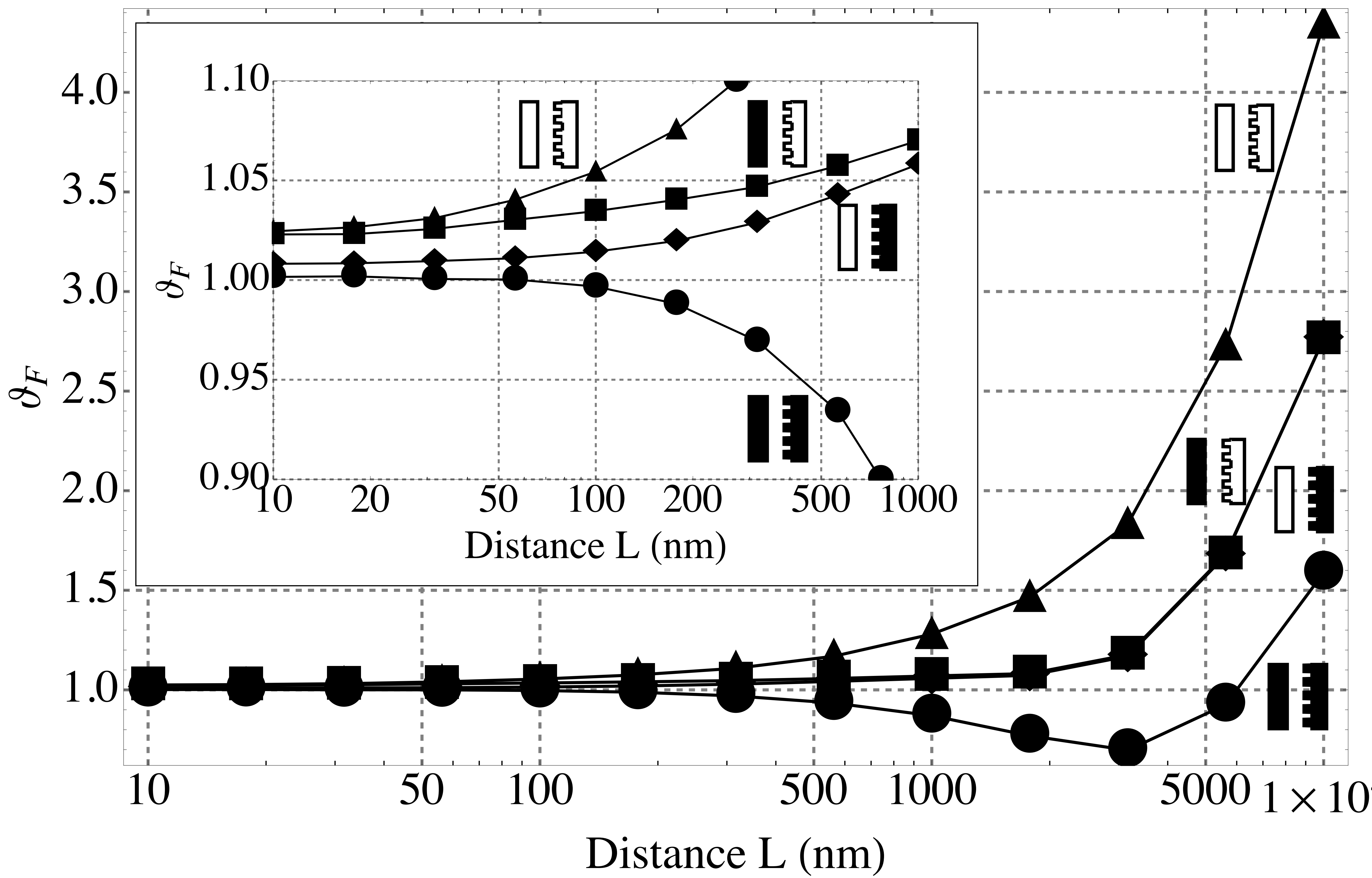
Results: Effects of the materials' conductivity

- Calculations of $\theta_F = F(T=300K)/F(T=0K)$ as a function of the distance L

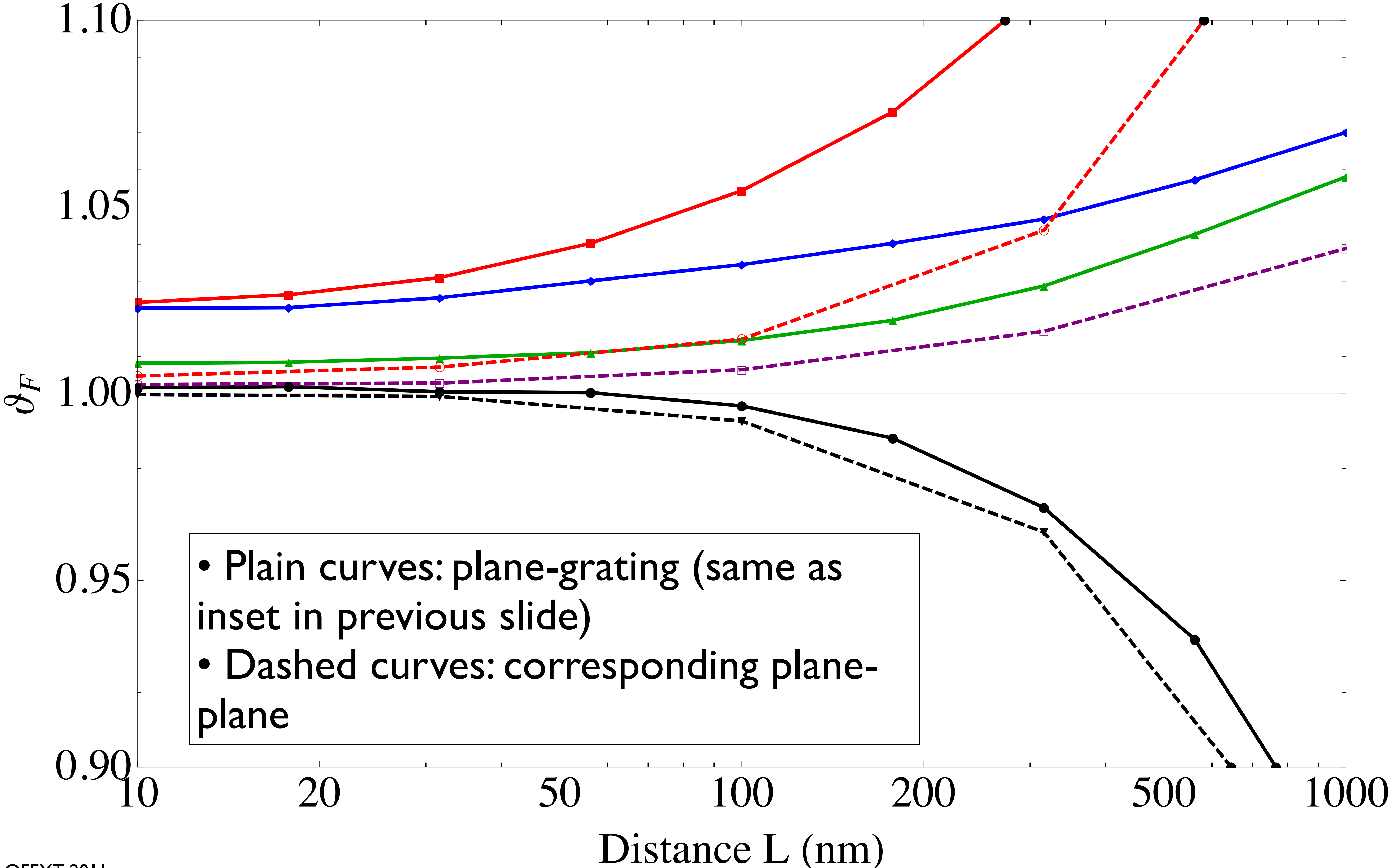
- Calculations for plane-grating geometry. "Shallow" gratings: d=400nm, a=100nm

- Calculations for
  - gold plane/gold grating
  - gold plane/silicon grating
  - silicon plane/gold grating
  - silicon plane/silicon grating

Results: Effects of the materials' conductivity



Results: Comparison with plane-plane



Results: Effects of the materials' conductivity

- gold-gold: thermal photons **reduce** the force for L≈3 μm

- silicon-silicon: highest and "earliest" temperature effect

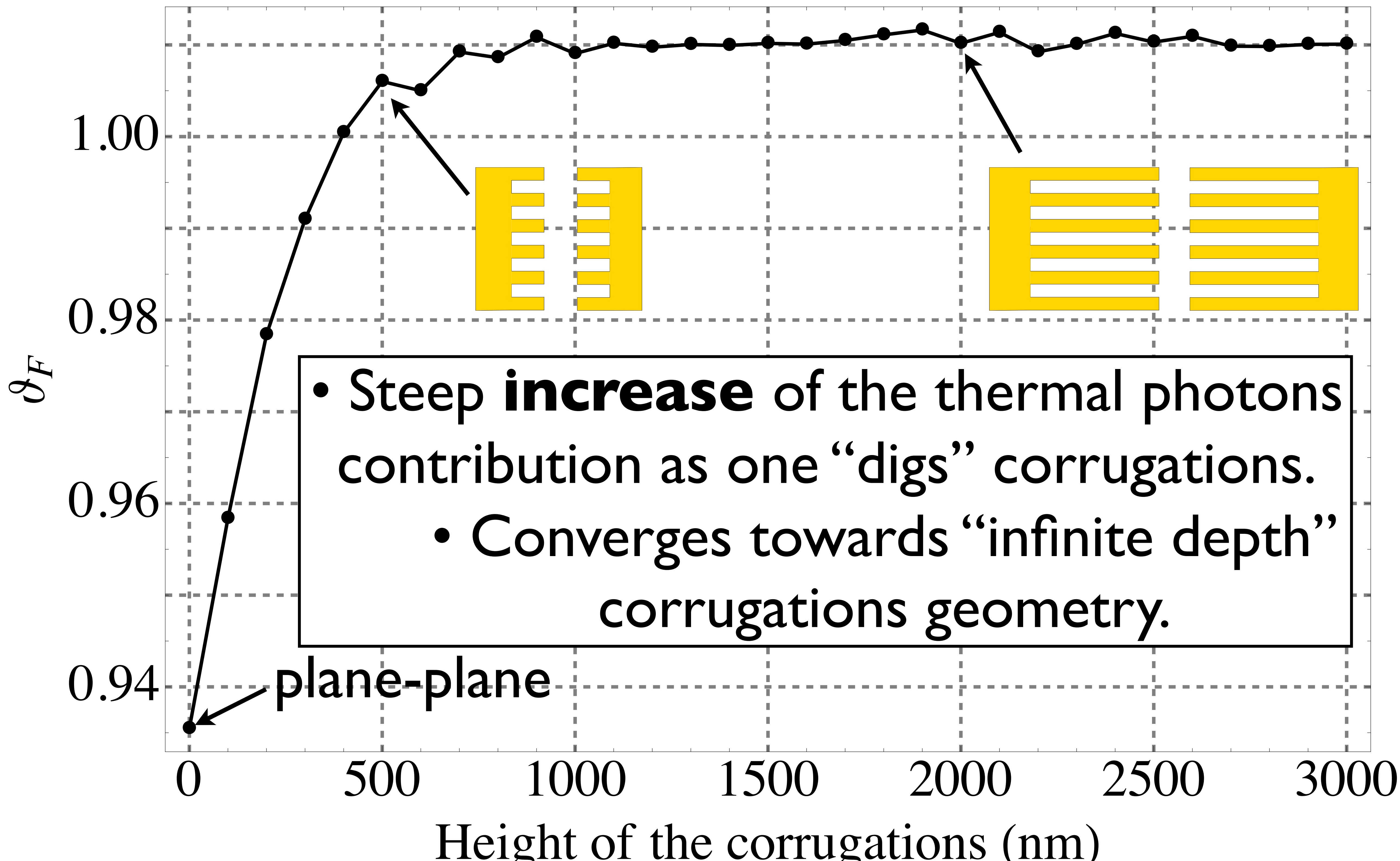
- gratings: non-zero temperature effect as L –› 0

Results: Effects of the corrugations' geometry

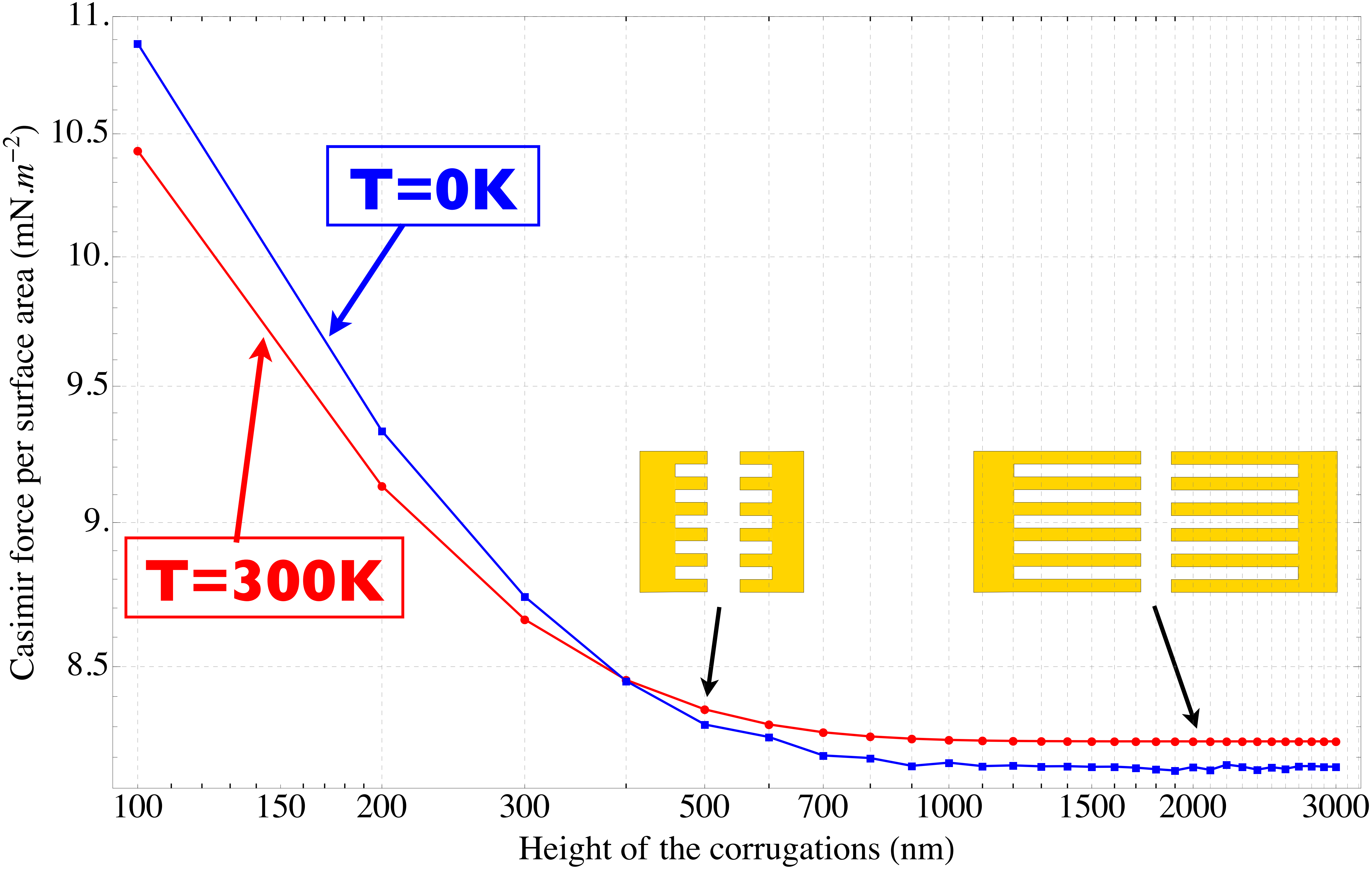
- Calculations of θ_F=F(T=300K)/F(T=0K) as a function of the corrugations height a, for a fixed distance L

- Calculations for two gold gratings.
  Period d=400nm, L=500nm

Results: Effects of the corrugations' geometry



Results: Effects of the corrugations' geometry

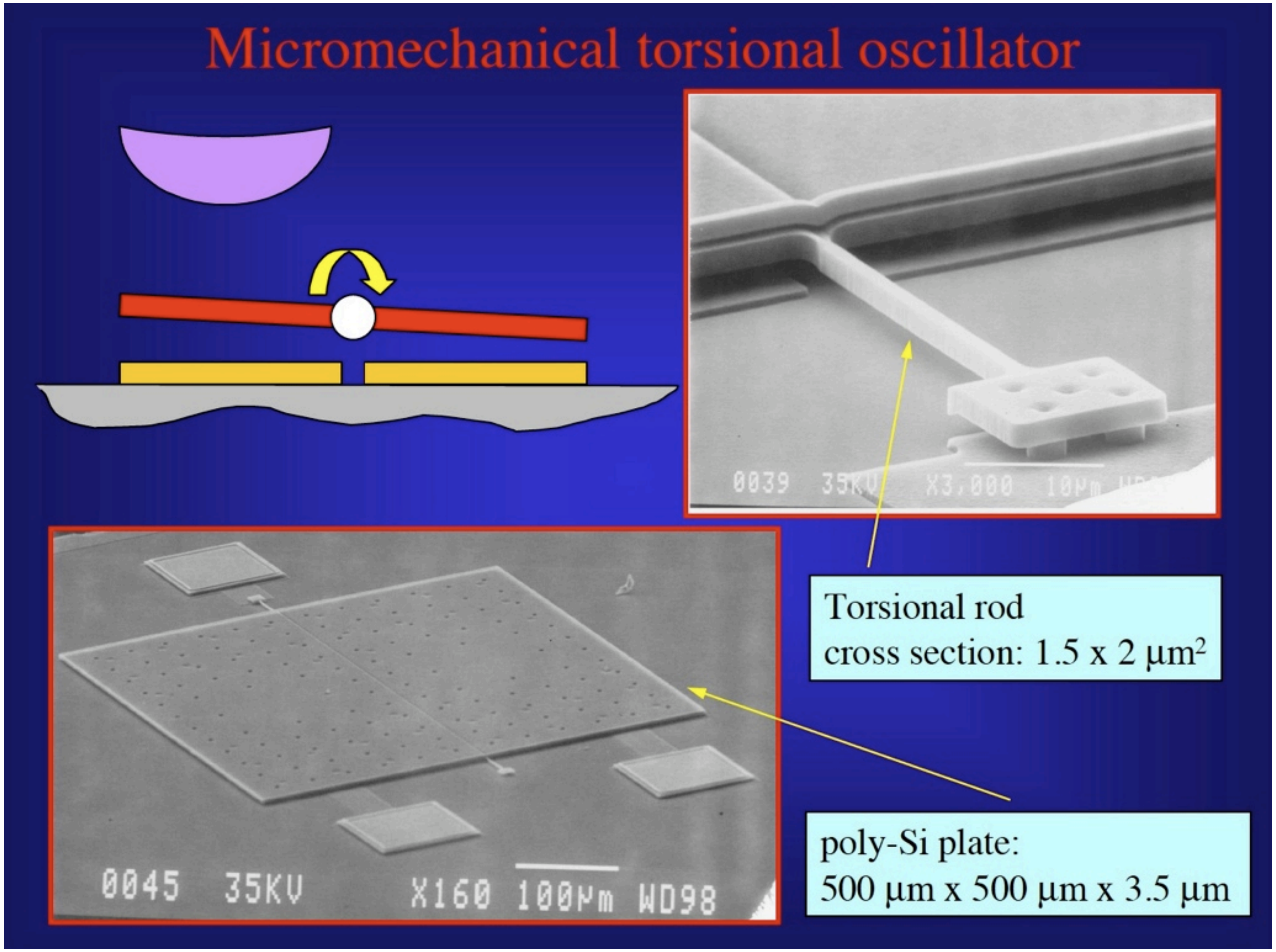


Results: Effects of the corrugations' geometry

Corrugations add thermal modes which **increase** the force

a=0 (L=500nm)	a=∞ (L=500nm)
• gold-gold	
$\theta_F \approx 0.94$ Th. ph. **decrease** the force by 6%	$\theta_F \approx 1.01$ Th. ph. **increase** the force by 1%
• silicon-silicon	
$\theta_F \approx 1.17$ Th. ph. **increase** the force by 17%	$\theta_F \approx 1.31$ Th. ph. **increase** the force by 31%!

Results: Comparison with experimental data

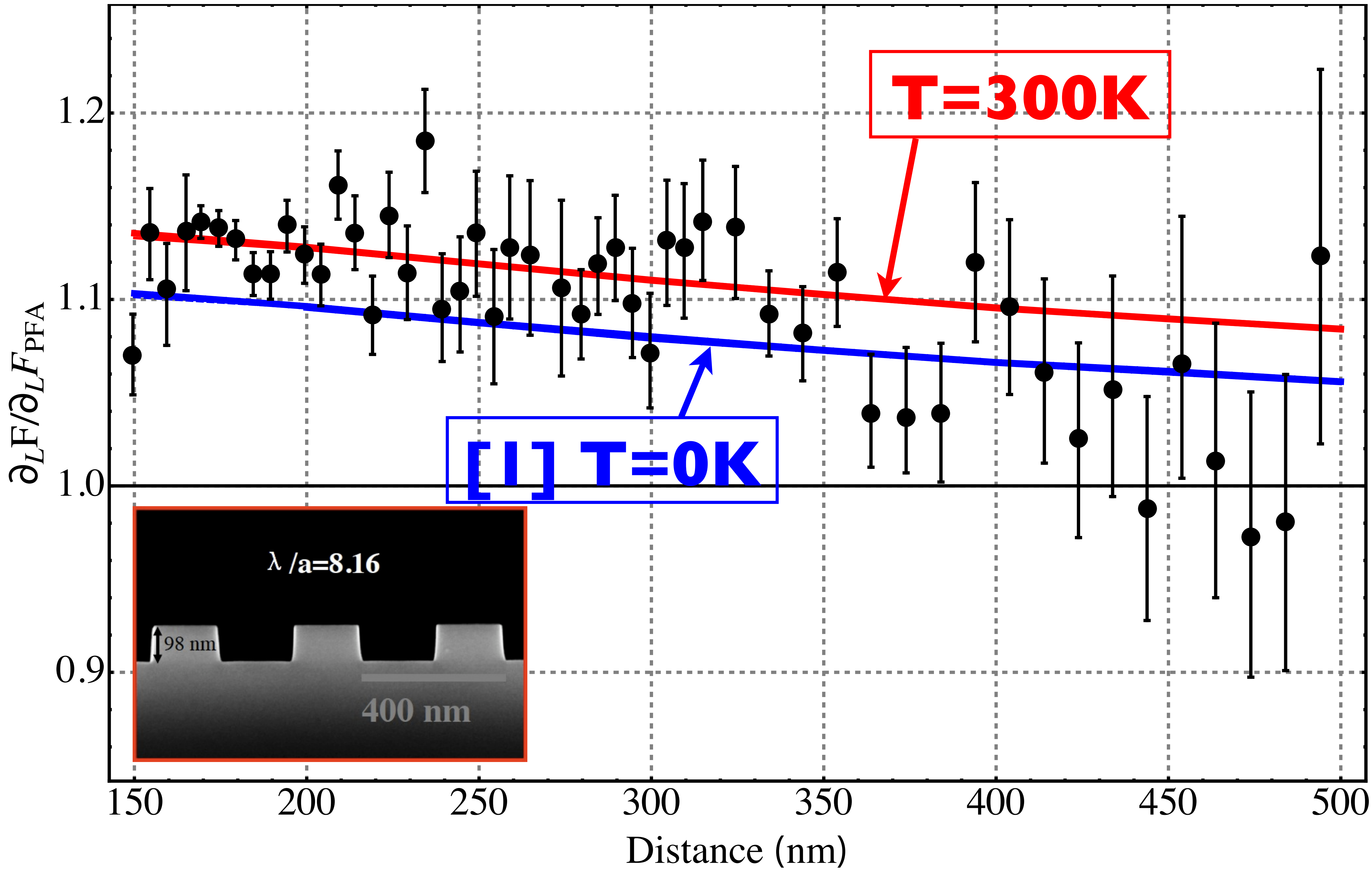


Courtesy H B Chan (Hong Kong)

gold sphere–silicon grating → PFA → gold plane–silicon grating

Results: Comparison with experimental data

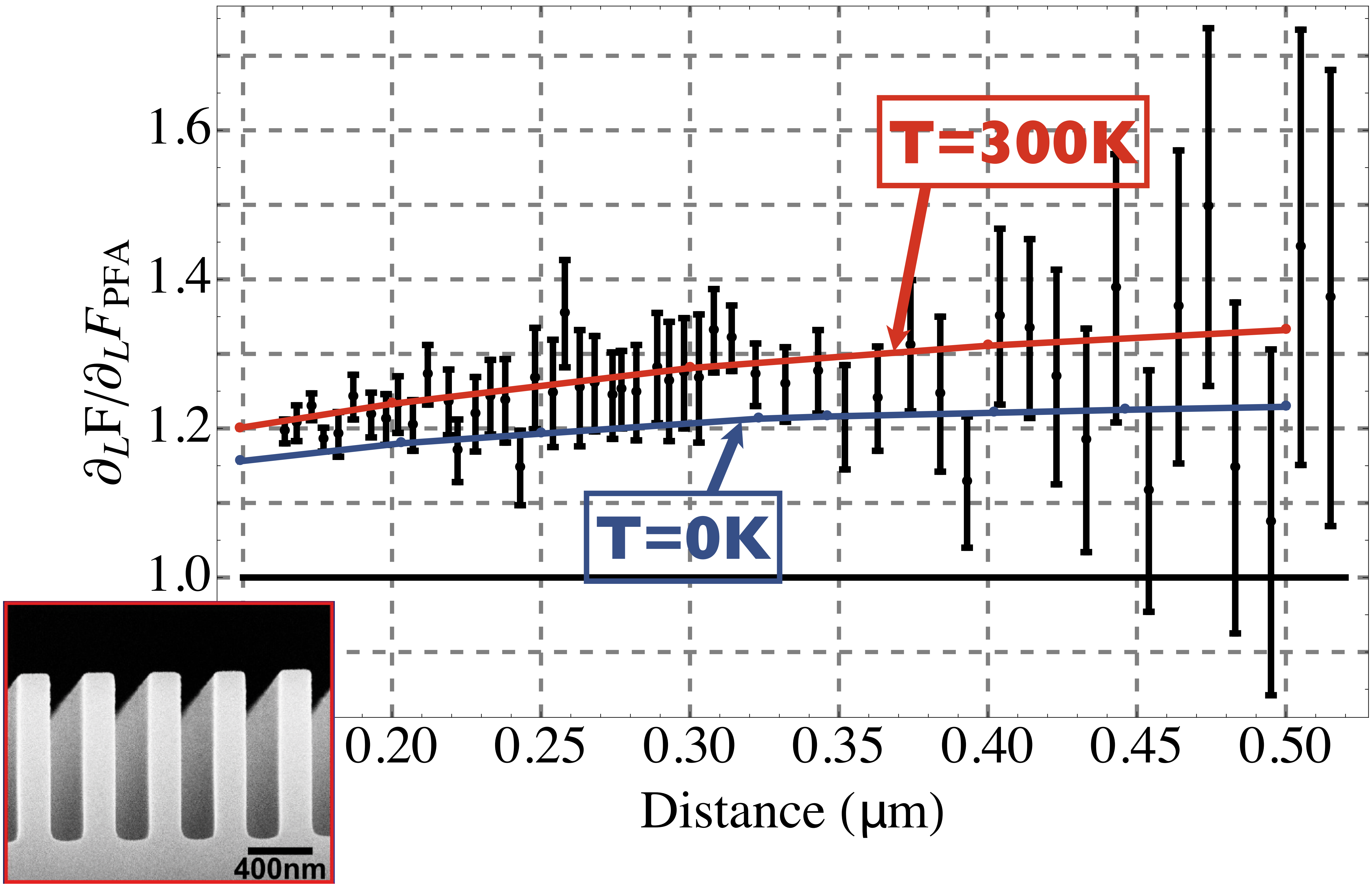
"shallow", slightly trapezoidal profile



[1]: Phys. Rev. Lett. **105**, 250402 (2010)

Results: Comparison with experimental data

“deep” profile



Take-home messages

- Material conductivity is important: very different behaviour between gold and silicon

- Gratings: temperature effects **do not** vanish at small distances contrary to plane-plane geometry

- Gratings: higher sensitivity to thermal effects at small distances

Thank you for your attention