REDUCING THERMAL RADIATION HEAT TRANSFER WITH INTERFERENCES?

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Introduction

Thermal insulation

Thermal insulation is important in terms of social need and fundamental science

Need
- Lower energy consumption
- Apparatuses used in extreme conditions work properly

Requirement
- High insulation performance
- Thinness

Insulation materials

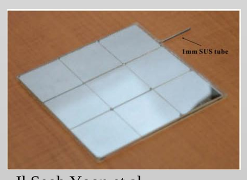
Insulation performance

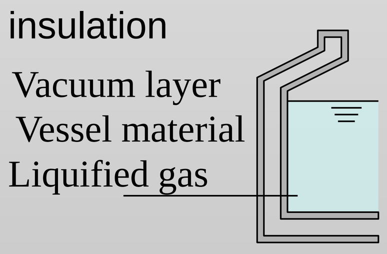
Low → High

Glass wool

Styrofoam

Vacuum insulation





?

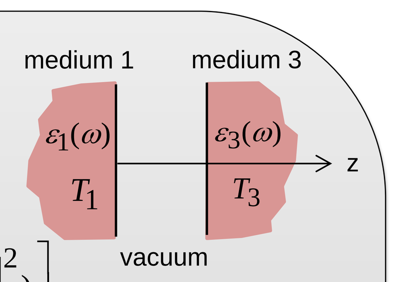
15– 25 | 15 – 20 | 0.5 at 0.24Pa

overall heat transfer coefficient $K[\mathrm{Wm^{-2}K^{-1}}]$ (Data with thickness of 1.8mm)

Can we improve the performance of vacuum insulation with interferences of thermal radiation?

Physical Background

Configuration : Two semi-infinite parallel plates



Equations

$$q''^{prop} = \int_0^\infty d\omega \frac{\Theta(\omega,T_1)-\Theta(\omega,T_3)}{4\pi^2}\int_0^{k_0} k_\rho dk_\rho \left[\frac{(1-|r_{12}^{TE}|^2)(1-|r_{23}^{TE}|^2)}{|1-r_{12}^{TE}r_{23}^{TE}e^{2ik'_{z2}d}|^2}+\frac{(1-|r_{12}^{TM}|^2)(1-|r_{23}^{TM}|^2)}{|1-r_{12}^{TM}r_{23}^{TM}e^{2ik'_{z2}d}|^2}\right]$$

Interference

$$q''^{evan} = \int_0^\infty d\omega \frac{\Theta(\omega,T_1)-\Theta(\omega,T_3)}{\pi^2}\int_{k_0}^{\infty} k_\rho dk_\rho e^{-2k''_{z2}d} \left[\frac{\mathrm{Im}(r_{12}^{TE})\mathrm{Im}(r_{23}^{TE})}{|1-r_{12}^{TE}r_{23}^{TE}e^{-2k''_{z2}d}|^2}+\frac{\mathrm{Im}(r_{12}^{TM})\mathrm{Im}(r_{23}^{TM})}{|1-r_{12}^{TM}r_{23}^{TM}e^{-2k''_{z2}d}|^2}\right]$$

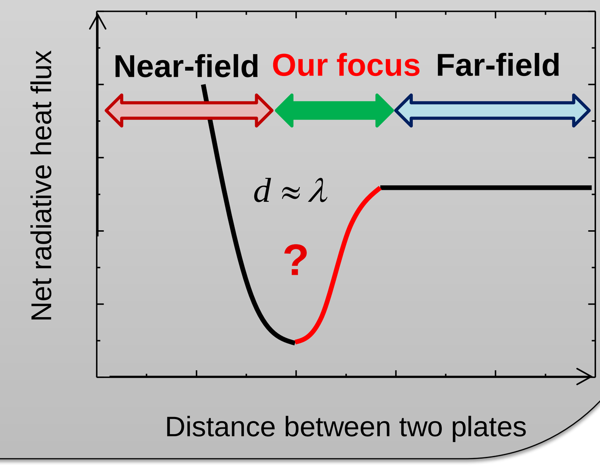
Interference of thermal radiation

- Constructive components
- Destructive components

→ Control of DOS

→ **Decrease of radiative heat flux**

But! Evanescent waves appear in this scale



Our approach

Numerical simulation for several materials

- Metal – Metal (Al – Al, Au – Au)
- Metal – Dielectric material (Al – cBN)
- Dielectric material – Dielectric material (cBN – cBN, SiC – SiC)
- Model material – Model material (ε = 20 + i0.0001)

Dielectric constants

Drude model

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

Lorentz model

$$\varepsilon = \varepsilon_\infty\left[\frac{\omega^2-\omega_{LO}^2+i\gamma\omega}{\omega^2-\omega_{TO}^2+i\gamma\omega}\right]$$

Approach to the problem

→ **Find the optimized conditions of each component respectively**
(materials, distances, temperatures)

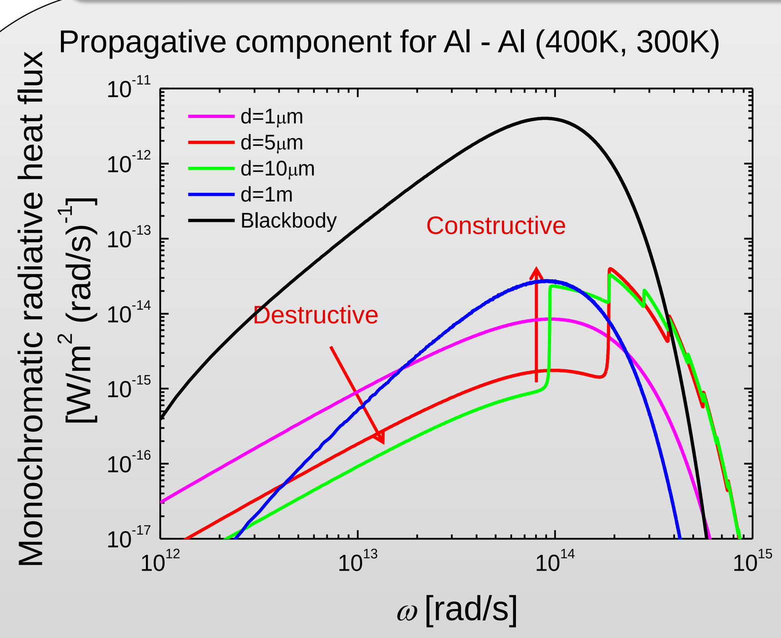
Radiative heat flux q^{total}

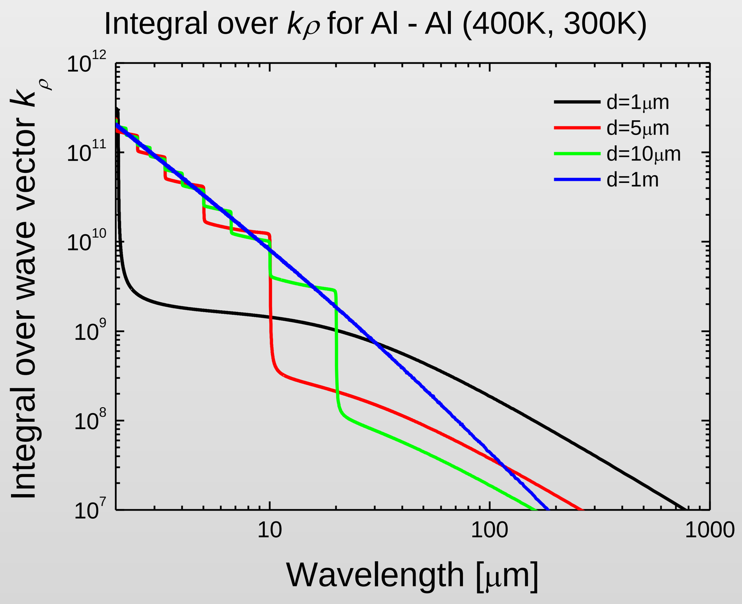
→ Propagative component $R^{prop} = \frac{q^{prop}}{q^{total}}$ → **Minimum**

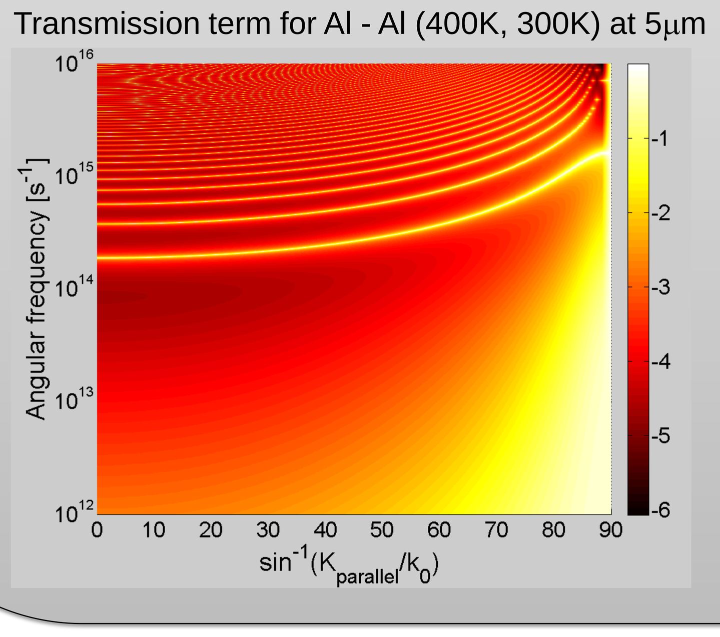
→ Evanescent component **Push it towards lower distances**

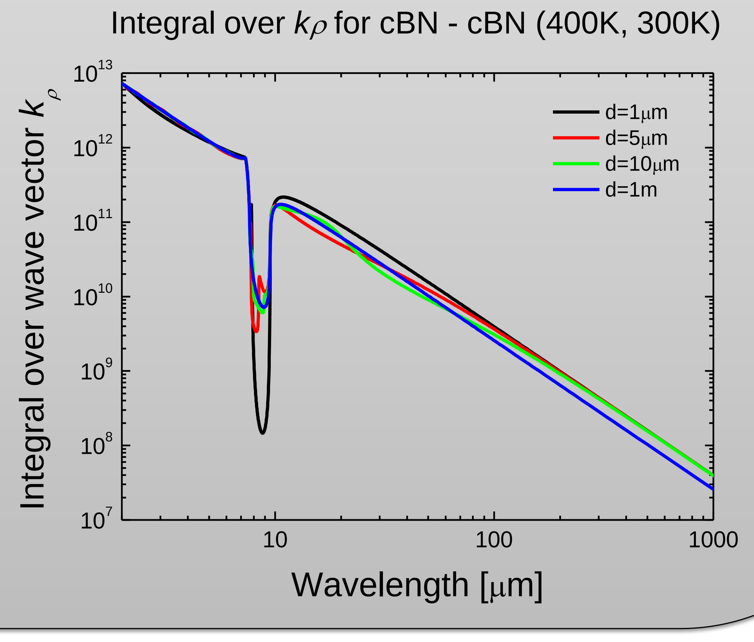
→ **Desired dielectric constants** **Is it possible to realize it?**

Spectral and directional analysis



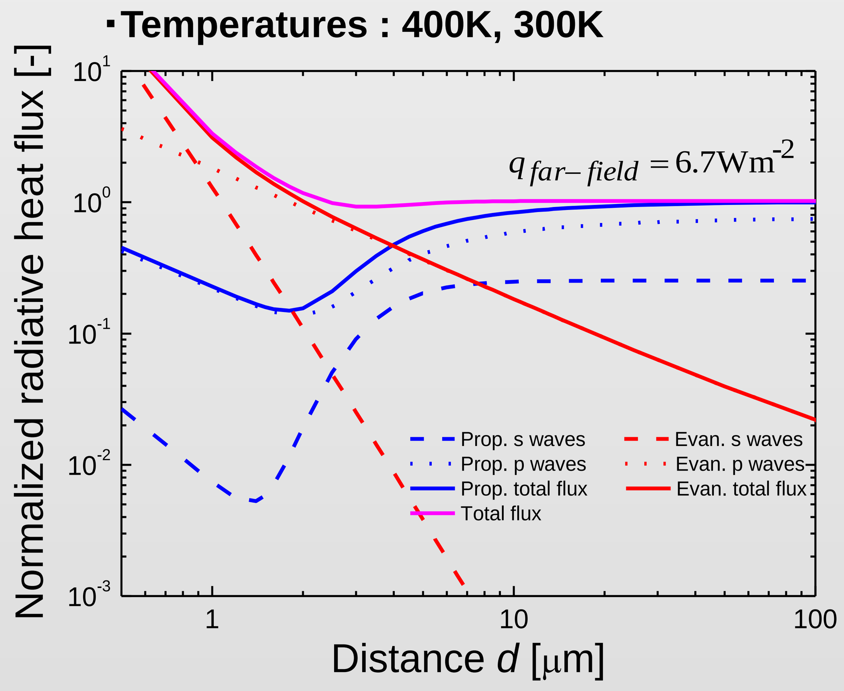




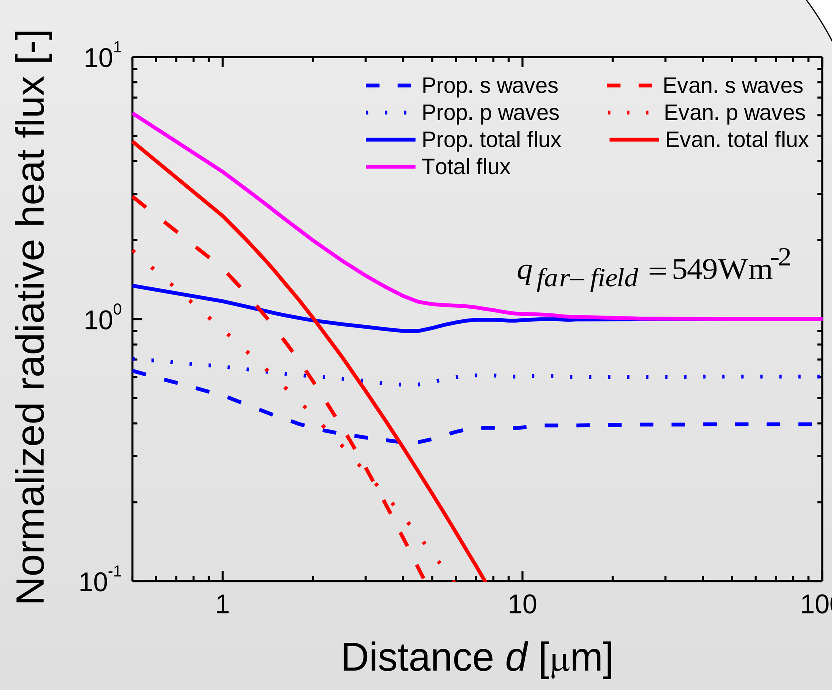


Fluxes in the transition regime

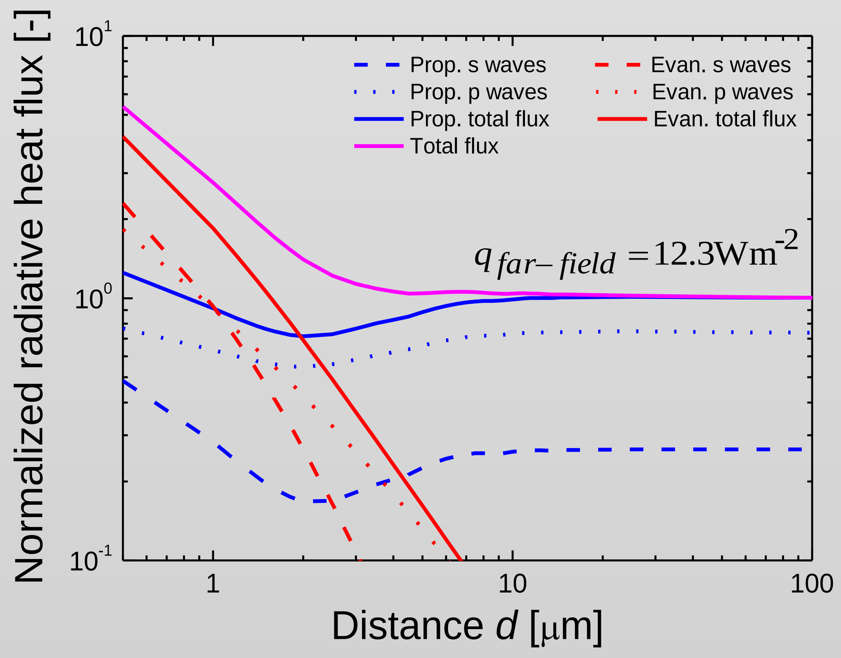
- **Temperatures : 400K, 300K**



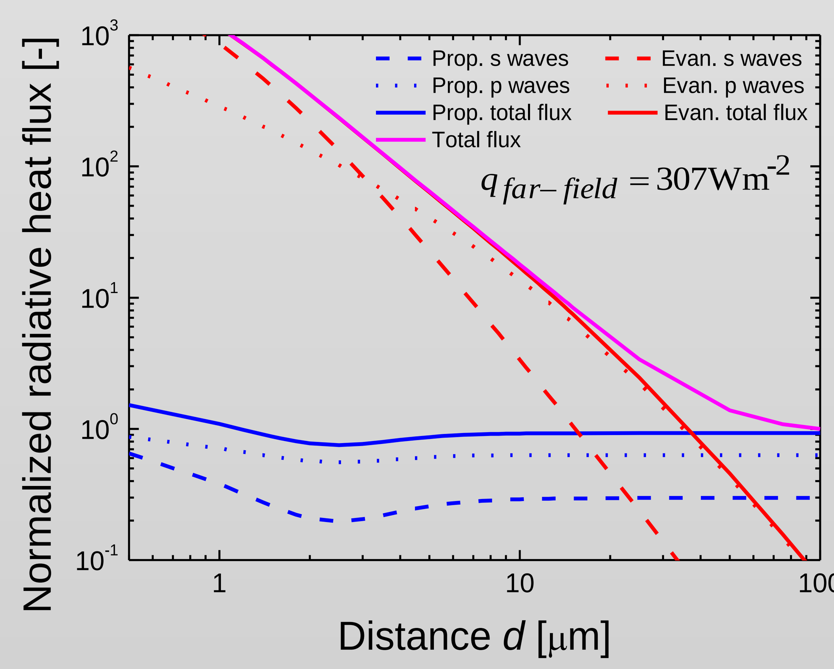
Al - Al



cBN - cBN



Al - cBN



ε = 20+i0.0001

Propagative components

	Al – Al	Al – cBN	cBN – cBN	ε =20+i0.0001
$R^s_{prop} = \frac{q^s_{min}}{q^s_{far-field}}$	0.021 (1.4μm)	0.633 (2μm)	0.856 (4μm)	0.66 (2.5μm)
$R^p_{prop} = \frac{q^p_{min}}{q^p_{far-field}}$	0.182 (2μm)	0.744 (2μm)	0.930 (4μm)	0.881 (2.5μm)
$R^{total}_{prop} = \frac{q^{total}_{min}}{q^{total}_{far-field}}$	0.149 (1.8μm)	0.715 (2μm)	0.900 (4μm)	0.811 (2.5μm)
$R^{total} = \frac{q^{total}_{min}}{q^{total}_{far-field}}$	0.925 (3μm)	1	1	1

Evanescent components

$d\vert_{q^{prop}=q^{evan}}$	3.8μm	1.9μm	2μm	38μm

Conclusion & Prospects

- We observe a 7.5% decrease of the total flux in the case of Al – Al
- Otherwise, the increase due to the evanescent waves hides the decrease of the propagative component
- A reduction of 85% is observed for the propagative component of the radiative heat flux in the case of Al - Al
- The contribution of evanescent waves seems to become predominant at smaller distances for dielectric materials than for metals
- Can we engineer dielectric constants to get the desired effect?

Acknowledgement

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