Near-Field Radiative Heat Transfer Between Hexagonal Boron Nitride Nanotubes

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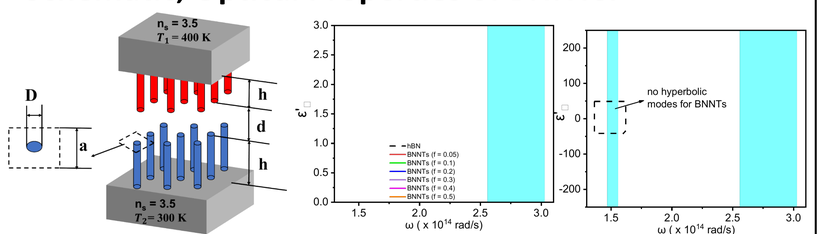
Research Question

Radiative heat transfer can exceed blackbody limits if the separation distance is less than the characteristic wavelength. Hyperbolic materials has shown the potential to enhance near-field radiative heat transfer making use of its non-resonant propagating modes [1,2]. This research will address the question "Can boron nitride nanotubes (BNNTs) control hyperbolic bands?"

References:
[1] X. Wu, C. Fu, and Z. Zhang, Journal of Photonics for Energy **9**, 1 (2018).
[2] H. Salihoglu and X. Xu, Journal of Quantitative Spectroscopy and Radiative Transfer **222–223**, 115 (2019).

Schematic, Optical Properties of BNNTs:



Maxwell-Garnet Effective medium theory: $\varepsilon_{e,\parallel} = \dfrac{\varepsilon_\perp(1+f) + \sqrt{\varepsilon_\perp/\varepsilon_\parallel}(1-f)}{\varepsilon_\perp(1-f) + \sqrt{\varepsilon_\perp/\varepsilon_\parallel}(1+f)}$ $\quad \varepsilon_{e,\perp} = f\varepsilon_\parallel + (1-f)$

$\varepsilon_\parallel$- parallel dielectric function component of hBN

$\varepsilon_\perp$ - perpendicular dielectric function component of hBN

Near-field Radiative Heat Flux

$$q = \int_0^\infty [(\omega, T_1) - (\omega, T_2)] \int_0^\infty \beta \sum_{\alpha=s,p} \xi_\alpha(\omega,\beta)\, d\beta$$

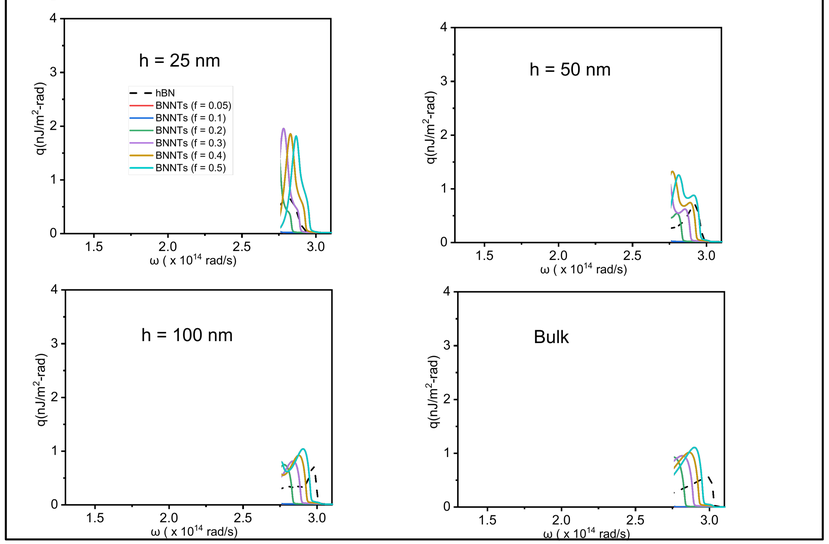
$$\xi_\alpha(\omega,\beta) = \begin{cases} \dfrac{\left(1 - |R_1^{\alpha 2}| - |T_1^{\alpha 2}|\right)^2}{\left|1 - R_1^{\alpha 2} e^{i2k_{z0}d}\right|^2}, \\ \dfrac{4[Im(R_1^\alpha)]^2 e^{-2Im(k_{z0})d}}{\left|1 - R_1^{\alpha 2} e^{i2k_{z0}d}\right|^2}, \end{cases}$$

where $\Theta(\omega, T) = \dfrac{\hbar\omega}{e^{\frac{\hbar\omega}{k_b T}} - 1}$, $\alpha = s \text{ or } p$

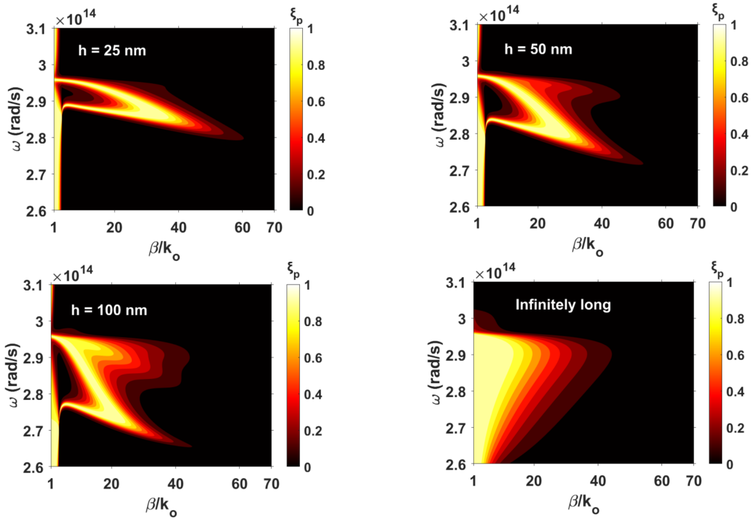
$\beta < k_0 = \dfrac{\omega}{c}$

$\beta > k_0 = \dfrac{\omega}{c}$

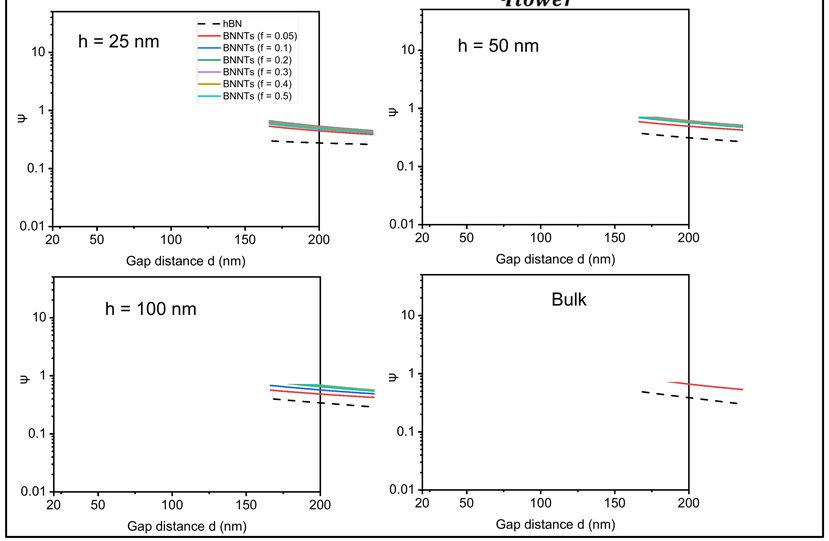
Spectral Heat Flux:



Energy Transmission Coefficient: $\xi_\alpha(\omega, \beta)$



Spectral Allocation Ratio: $\psi = \dfrac{q_{higher}}{q_{lower}}$



Conclusions

- BNNTs has type I hyperbolic band at higher frequencies and no hyperbolic bands at lower frequencies.
- Peak in spectral flux is larger for a thin film than the infinitely long tubes
- For thin films, higher β values are occupied resulting in higher peak in spectral heat flux
- Higher frequency hyperbolic band contributes highly to total heat flux
- Preliminary results done in this MORE project will be used to perform experiments in the future.

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