Near-Field Radiative Heat Transfer Between Two $\alpha - MoO_3$ Biaxial Crystals

GROUP - 9
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PH202: Waves, Oscillations and Optics

Overview

Introduction

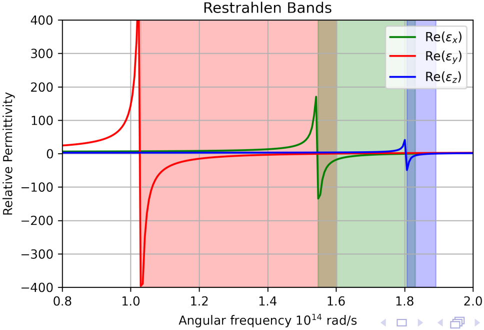
- What is Near Field Heat Transfer?
- What are *HPPs* and *HSPhPs*?
- Anisotropy and How it affects the system?

Material Characteristics

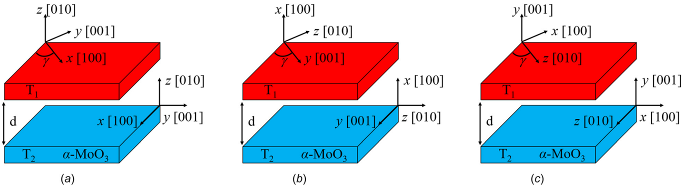
- Principal Relative Permittivity Components (Lorentz Model)

$$\epsilon_m = \epsilon_{\infty,m}\left(1 + \frac{\omega_{LO,m}^2 - \omega_{TO,m}^2}{\omega_{TO,m}^2 - \omega^2 - j\omega\Gamma_m}\right),\ \ m = x, y, z$$

- Restrahlen Bands



Experimental Setup



- Rotated Permittivity Tensor

$$\begin{pmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{pmatrix} \epsilon \begin{pmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\xi(\omega, \beta, \phi)$: Phonon Tunelling Probability

- ξ is the Energy Transmission Coefficient/ Phonon tunneling Probability
- If $\beta < k_0$ (Propagating waves):

$$\xi(\omega, \beta, \phi) = Tr[(I - R_2^\dagger R_2)D(I - R_1^\dagger R_1)D^\dagger]$$

- If $\beta > k_0$ (Evanescent waves):

$$\xi(\omega, \beta, \phi) = Tr[(R_2^\dagger - R_2)D(R_1 - R_1^\dagger)D^\dagger]e^{-2|k|d}$$

Reflection Matrix

- The Fresnel Coefficient Matrix

$$R_{1,2} = \begin{pmatrix} r_{ss}^{1,2} & r_{sp}^{1,2} \\ r_{ps}^{1,2} & r_{pp}^{1,2} \end{pmatrix}$$

- Coefficients obtained using the Modified 4×4 transfer matrix method.
- $\mathrm{D} = (I - R_1 R_2 e^{2jkd})^{-1}$

Heatmaps

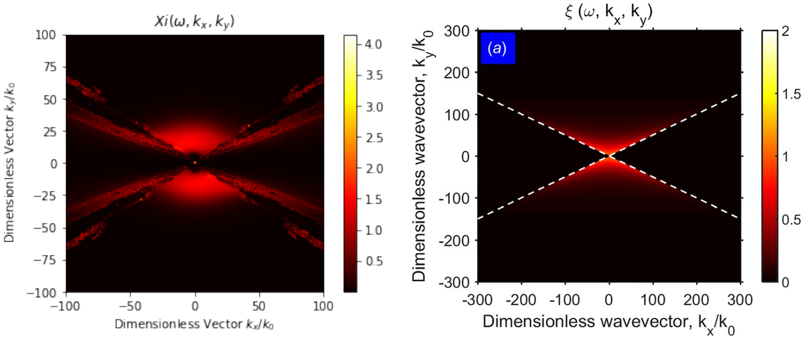
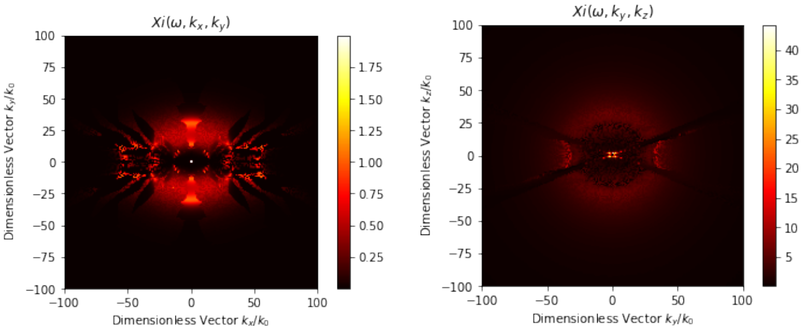


Figure: Result Comparison

More Heatmaps



Near-Field Radiative Heat Flux

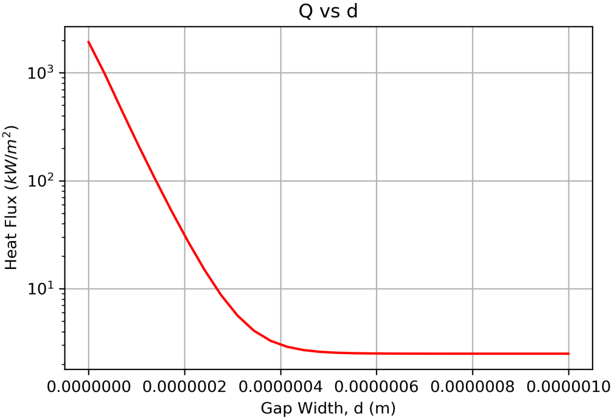
- Radiative Heat Flux:

$$Q = \frac{1}{8\pi^3} \int_0^\infty [\Theta(\omega, T_1) - \Theta(\omega, T_2)]\, d\omega \int_0^{2\pi} \int_0^\infty \xi(\omega, \beta, \phi) \beta \, d\beta \, d\phi$$

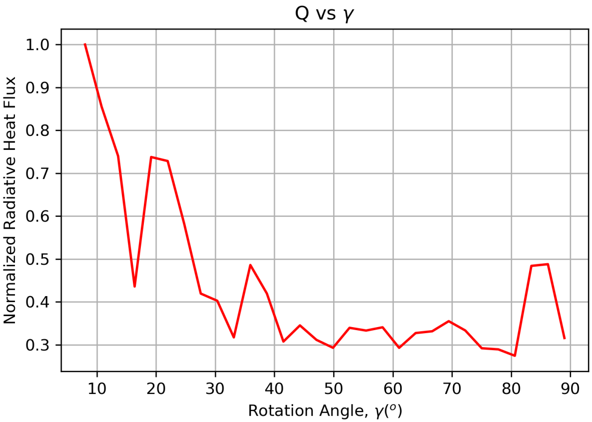
- Mean Energy of Planck Oscillator:

$$\Theta(\omega, T) = \frac{\hbar\omega}{e^{\frac{\hbar\omega}{kT}} - 1}$$

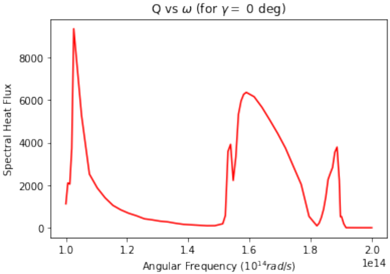
Variation of NFRHF with Gap Width, d

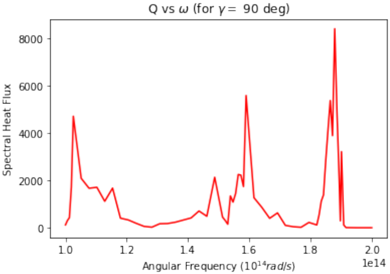


Variation of NFRHF with Relative Rotation Angle, γ



Variation of NFRHF with Angular Frequency, ω





Conclusion

- Enhanced Heat Flux in the near field regime
- NFRHF modulation by changing the relative rotation angle
- Ways to manipulate near-field radiative transfer between anisotropic materials

Contributions

- Restrahlen Bands plot done by Vinit
- Figuring out the methodology and math of 4×4 matrix and studying theory of HPPs and HSPhPs was done by Kaushik and Parth
- Implementation of ξ function and plotting of heat maps done by Kaushik, Parth and Vinit
- Implementation of Heat Flux function done by Shourish and Vinit
- Plotting of Variation of Heat flux with γ, d, ω done by Shourish