Thermal Resistance-Based Bounds for the Effective Conductivity of Composite Thermal Interface Materials

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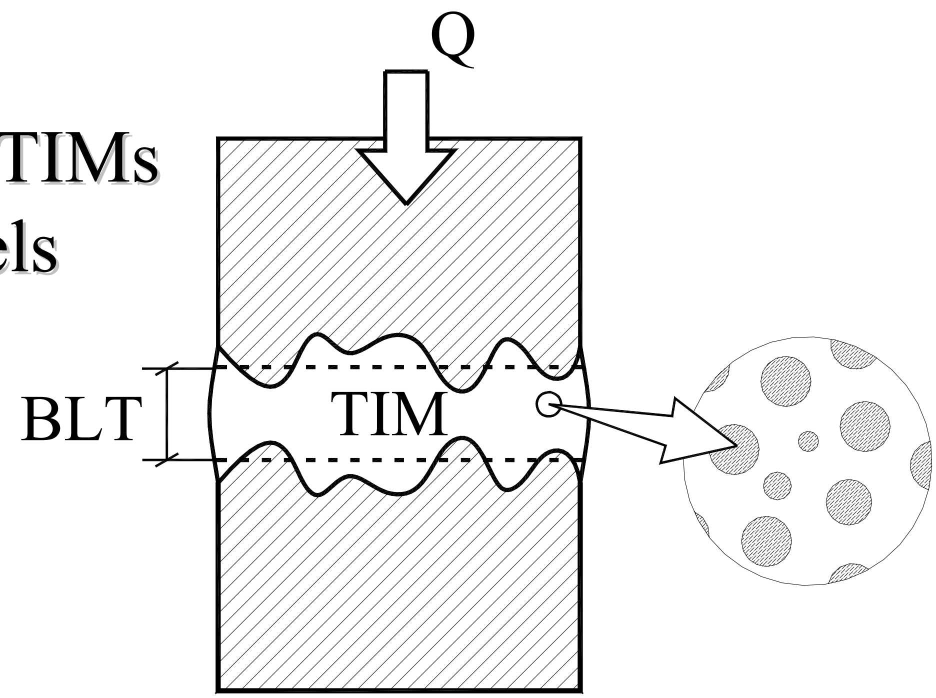
Outline

- Motivation
- Problem statement
- Model development
- Numerical and experimental validation
- Conclusions
- Future work

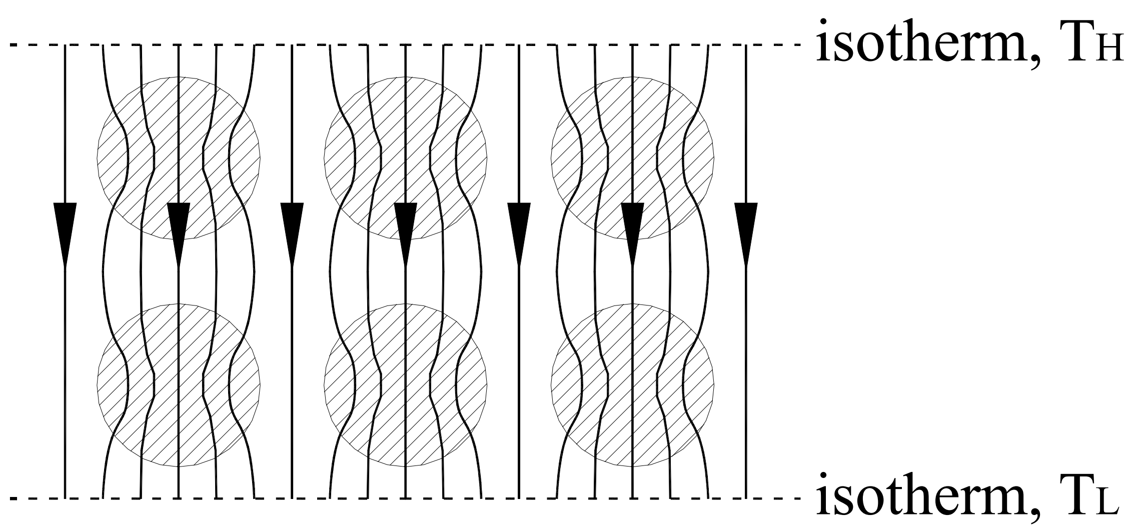
Motivation

- Thermally enhanced greases used as thermal interface materials (TIMs) in microelectronics cooling applications
- Thermal resistance, R, of TIMs required for thermal models
- $R = R(k_e, BLT, R_{contact})$



Problem Statement

- To develop analytical models for effective thermal conductivity of fluidic composite materials
- Account for particle-particle interactions → good agreement for high and low particle volume fractions (Φ)

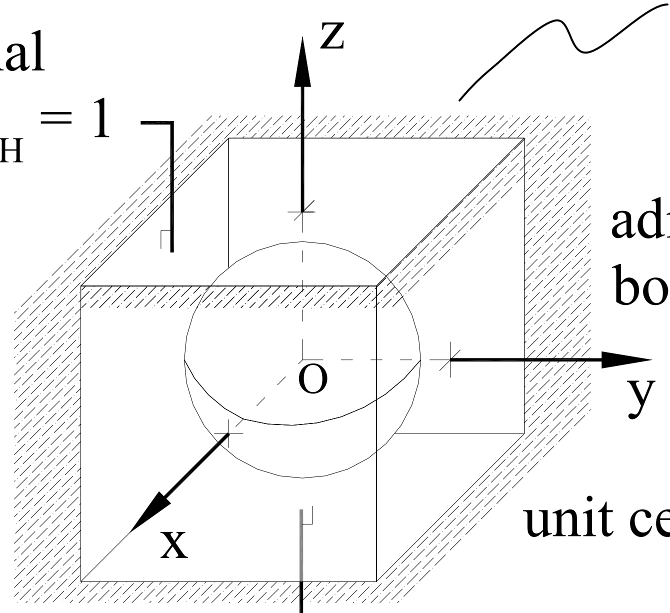


Model: Assumptions

1. N uniform spherical particles, N >> 1
2. arranged in cubic lattice with
3. perfect thermal contact between phases and
4. isotropic and constant thermal conductivities

Model: Characteristic Cell

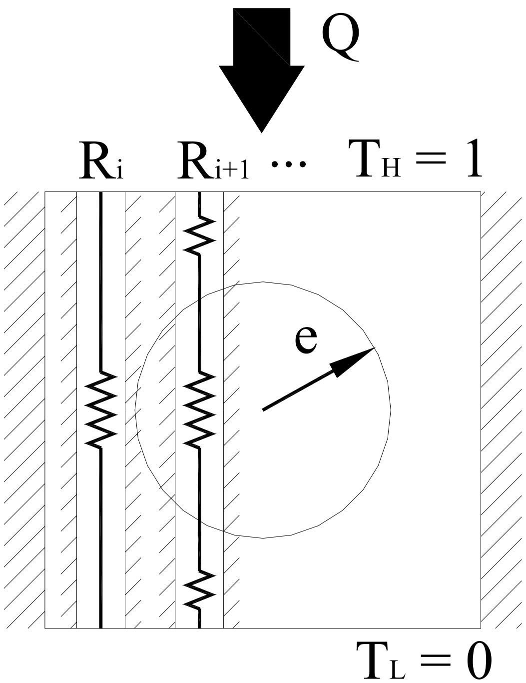
- The assumptions allow one to consider a *characteristic cell*

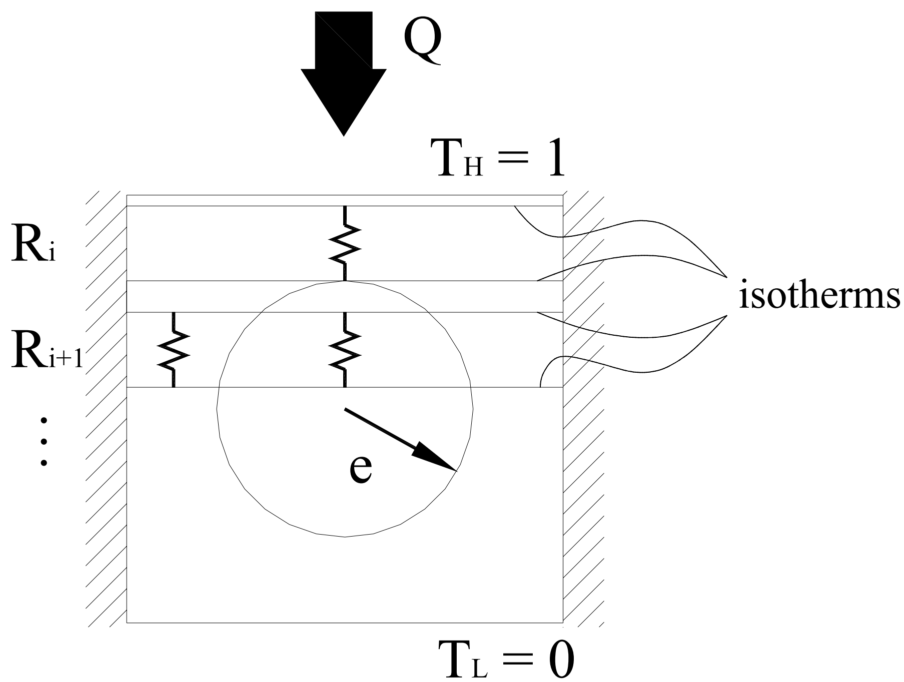


No simple analytical solution → <u>develop bounds</u>

Model: Bounds

- Lower bound on k_e: Parallel adiabats
- Upper bound on k_e: Perpendicular isotherms



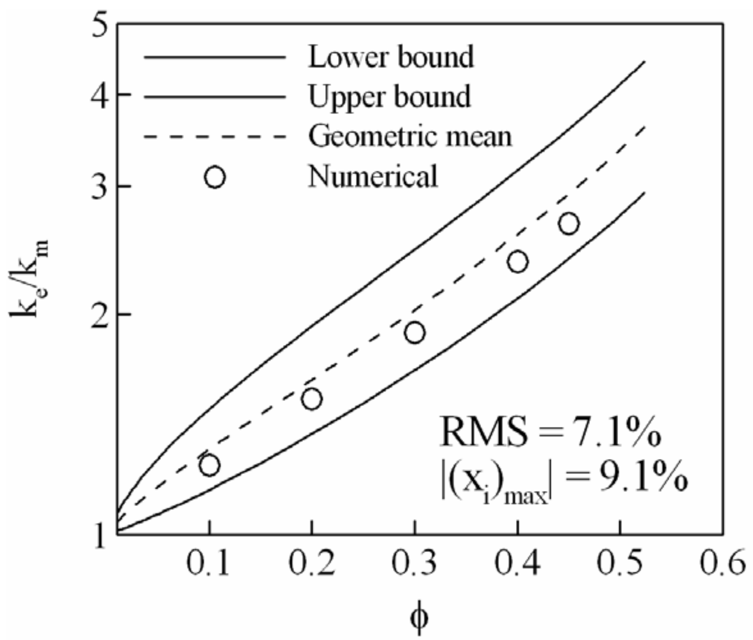


Numerical Results

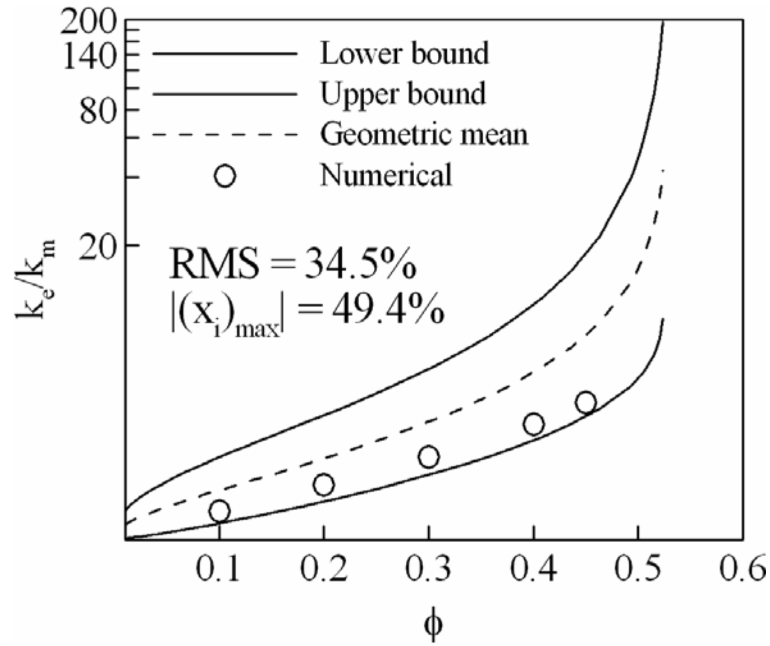
- Model validated for

  Volume fractions, $\Phi = 0.1, 0.2, 0.3, 0.4, 0.45$

  Conductivity ratios, $\kappa = 10, 100, 1000$



$\kappa = 10$



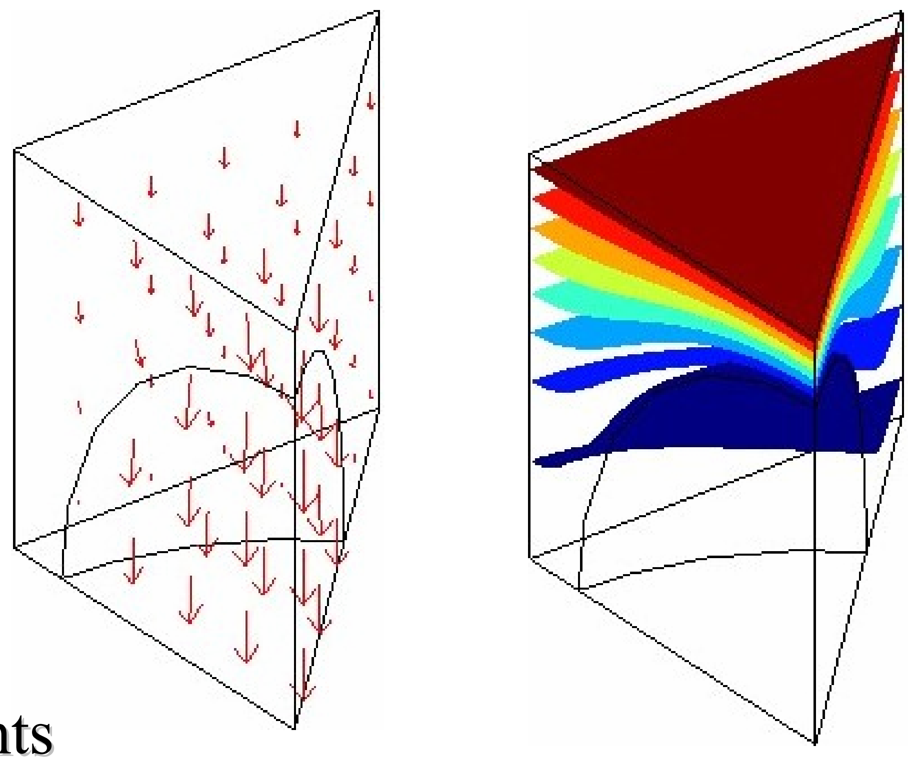
$\kappa = 1000$

Numerical Results (cont'd)

- Geometric mean of bounds gives good agreement
- Physically, adiabats are neither parallel nor isotherms perpendicular, though numerical results indicate parallel adiabats more realistic

$\Phi = 0.3$

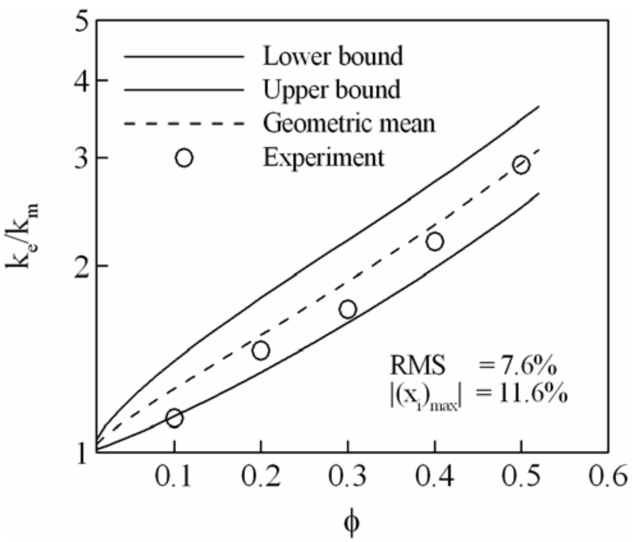
$\kappa = 100$



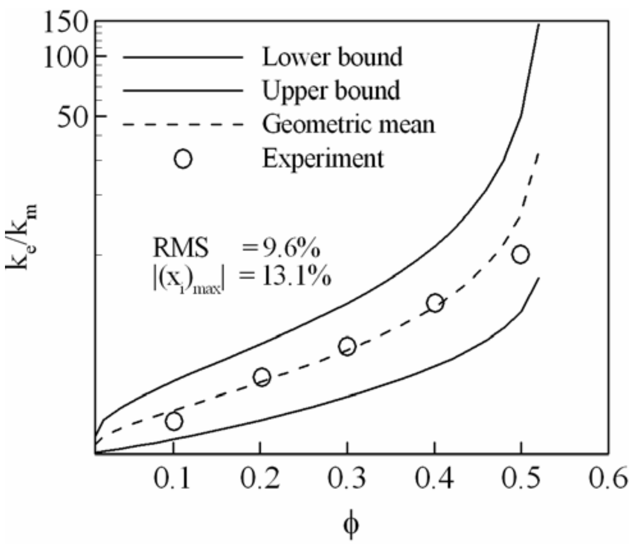
1/16th cell, ~ 50K elements

Experimental Results

- Model validated with experimental data in literature
- Geometric mean gives very good agreement, even when particles are irregular (non-spherical)



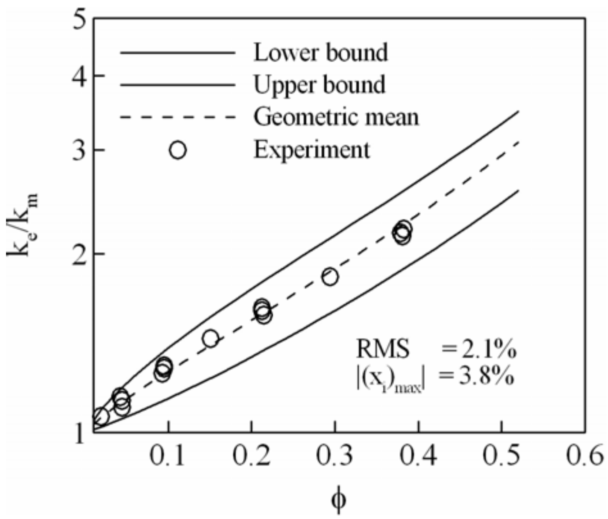
$\kappa = 7.7$
silica, epoxy
spherical



$\kappa = 1128$
silica-coated Al nitride, epoxy
highly irregular

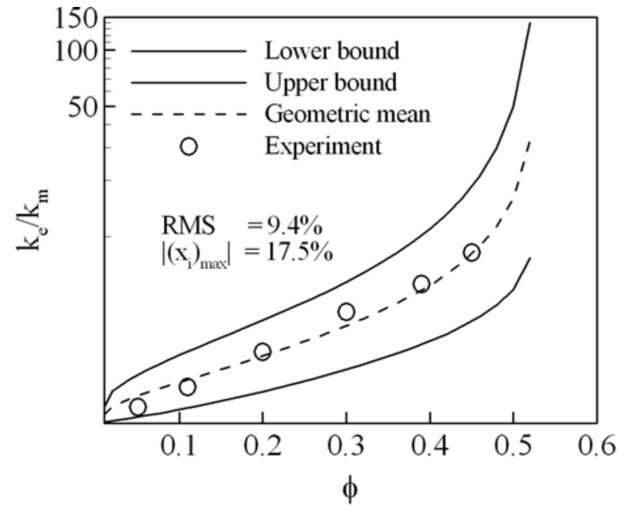
(Wong and Bollampaly, 1999)

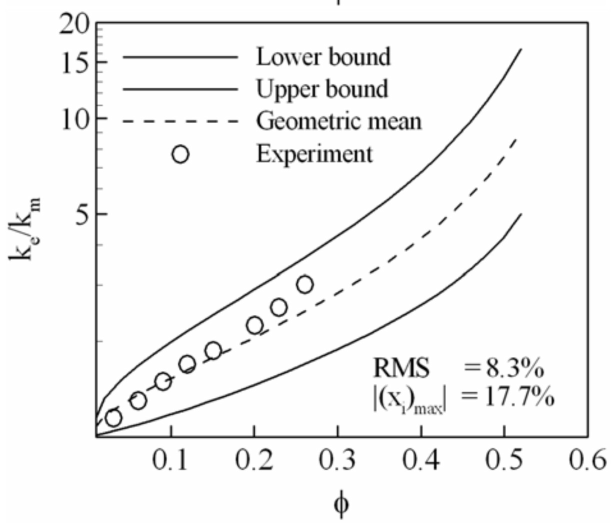
Experimental Results (cont'd)



(a)

(b)





(c)

(a) $\kappa = 7.7$; silica, epoxy; spherical[1]

(b) $\kappa = 41.7$; Al_2O_3, epoxy; irregular[2]

(c) $\kappa = 51.7$; Al_2O_3, epoxy; irregular[3]

[1](Sundstrom and Chen, 1970)
[2](Lin, Bhatia, and Ford, 1993)
[3](Tavman, 2000)

Summary and Conclusions

Model gives very good agreement with

(i) Numerical results

- Model consistently overpredicts numerical results
- Parallel adiabats more realistic model

(ii) Experimental results

- Even when particles are irregular

$$0.1 \leq \Phi \leq 0.45$$
$$10 \leq \kappa \leq 1000$$

Future Work

Extend the present analysis to

1. a general rectangular lattice arrangement → particle distribution,
2. various particle geometries (e.g. ellipsoids, prismoids, right circular cylinders, etc.) → particle alignment, and
3. imperfect thermal contact between particle and matrix (e.g. oxides)

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