Development of Conduction, Convection, Spreading and Contact Resistance Models for Microelectronics Applications

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Outline

- Project Overview
- Objectives
- Year 1 Deliverables
- Design & Analysis Tools
- Personnel
- What Lies Ahead
- Concluding Comments
Project Strategy

Heat sink conduction and convection
joint resistance at heat sink attach
spreading resistance at heat sink attach
spreading / constriction resistance in package substrate and interconnects
spreading resistance in board
board conduction and convection

$T_\infty$  $R_{hs}$  $R_j$  $R_s$  $Q$  $T_j$  $R_s$  $R_s$  $R_b$  $T_\infty$

Section 1  Section 2  Section 3  Section 4
Objectives

- Thermal model development: chip level → cooling medium
  - heat sink optimization
  - modeling & characterization of thermal interfaces
  - modeling of spreading & constriction resistance
  - modeling of conduction & convection in PWBs
Year 1 Deliverables

- Heat sink optimization model
  - shrouded, air-cooled, plate fin heat sink
  - interactive web-based modeling tool

- Thermal resistance models
  - non-conforming, smooth surfaces
  - conforming rough surfaces
  - Excel spreadsheet models
Year 1 Deliverables

- Spreading resistance model for
  - multiple discrete sources
  - isotropic or multi-layered substrate
  - interactive web-based modeling tool

- Thermal Interface Test Rig
  - design, build and commission test apparatus
Heat Sink Optimization

**Analysis Tool** vs. **Design Tool**

- design is known a priori
- used to calculate the performance of a given design, i.e. Nu or R vs. Re
- cannot guarantee an optimized design

- used to obtain an optimized design for a set of known constraints i.e. given:
  - maximum temperature
  - heat input
  - maximum outside dimensions

**find:** the most efficient design
Why use Entropy Generation Minimization?

- entropy production $\propto$ amount of energy degraded to a form unavailable for work
- lost work is an additional amount of heat that could have been extracted
- degradation process is a function of thermodynamic irreversibilities e.g. friction, heat transfer etc.
- minimizing the production of entropy, provides a simultaneous optimization of all design variables
**Value:** provide specific values for constrained parameters

**Optimize:** indicate parameters to be optimized

**Calculate:** run optimization code to calculate design parameters for maximum thermal-fluid performance

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Web URL: [http://mhtlab.uwaterloo.ca/onlinetools/optimize/index.html](http://mhtlab.uwaterloo.ca/onlinetools/optimize/index.html)
Contact Resistance Models

- Non-conforming, smooth surfaces:
  - assume material waviness (out-of-flatness) predominates
  - microscopic roughness is negligible
  - example: heat sink on a silicon chip
  - determine contact, gap and joint resistance

- Conforming rough surfaces:
  - assume microscopic roughness predominates
  - out-of-flatness is negligible
  - example: two machined (lapped or ground) surfaces
  - determine contact, gap and joint resistance
Non-Conforming Smooth Surfaces
Spreading Resistance Model

- Analytical solution for heat sources on a rectangular flux channel
  - isotropic or laminated substrates
  - multiple discrete sources

- Model details in:

Spreading Resistance of Multiple Sources on Rectangular Substrate

Instructions: user’s guide & sample problem
Background: governing eqns. & model development
Input/Output: data entry & units
References: publications & sample pdf files

Properties: set substrate & source properties
Add/move, Edit, Delete, New, Copy: on screen package placement

Note: Java source requires Netscape (IE will not work)

Web URL: http://mhtlab.uwaterloo.ca/onlinetools/multisource/index.html

October 17, 2001
Add a new source: a pop-up window will appear for entering heat source inputs - click on substrate to place current heat source.
Mean source temperature rise - \( ^\circ\text{C} \)

**Calculate:** click calculate to obtain mean heat source temperature rise for each source
- Java-based code will be executed on local CPU
- typical run times are approximately 10 seconds per source
Thermal Interface Materials

- Design, build & commission test apparatus & data acquisition interface for testing interface materials:
  - Measure joint resistance and thermal conductivity as function of:
    - interface temperature
    - contact pressure
    - material properties
    - surface characteristics
  - in-situ thickness measurement: sub micron precision
Testing Capabilities

- 4 categories of materials can be tested
  - materials requiring stops & minimal clamping force
    - grease, liquids, phase change
  - materials deforming more than 10% under clamping force - compliant materials
  - materials deforming less than 10%, no stops required - hard rubber
  - thermally conductive materials requiring high clamping force - ceramics & plastics
Apparatus

- **Load cell**
  - 100 or 1000 lbs

- **Spring**
  - To compensate for thermal expansion

- **Thrust bearing**
  - To remove torque loads

- **Electric cylinder**
  - Digitally controlled stepper motor
  - 400 steps / rev 0.1” per revolution
Thermal Interface Test Apparatus
Thermal Interface Test Apparatus
Thickness and Deflection

- Detector, Lower Block
- Detector, Upper Block
- Laser, Lower Block
- Laser, Upper Block
- Translation Stage

October 17, 2001

CMAP 1st Annual Project Review
University of Waterloo
HQP’s

- Graduate Students
  - Mr. Majid Bahrami
    - Ph.D candidate - *topic*: contact resistance in non-conforming rough surfaces
  - Ms. Irena Savija
    - M.A.Sc. Candidate - *topic*: modeling and characterization of thermal interface materials

- Summer Students
  - Mr. Joel Reardon and Mr. Chris Hurley
    - Web tool model development: Java, C, Javascript, CGI

- Senior Undergraduate Projects
  - Dana Frigula and Matthew Morrissey
    - Laser measurement system
What Lies Ahead

- Heat sink models for base plate enhancements such as copper inserts, laminates and heat pipes
- Heat sink flow by-pass models
- Joint resistance models for non-conforming rough surfaces
- Thermal interface models: grease, phase change materials and compliant polymers
- Board level modeling
Concluding Comments

- Thank you to sponsoring companies:
  - Alcatel
  - Celestica
  - Dy4
  - Coretec

- Cross our fingers for a successful CFI bid in the new year