Overview of Research
Experience and Capabilities

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March 13, 2003 CMAP Workshop on Thermal Issues
Outline

- Background
- Capabilities
- Facilities
- Research Projects
- Modeling Tools
Microelectronics Heat Transfer Laboratory

- established in 1984 within the Department of Mechanical Engineering at the University of Waterloo
- research and development related to heat transfer and other thermodynamic phenomena
- fully funded through industrial and governmental grants and contracts
- staff includes:
  - 1 faculty member + 1 retired faculty member
  - 2 research engineers
  - 4 graduate students
  - 1 post doctoral fellow
  - 1 technician
Modeling Capabilities

- conjugate heat transfer for microelectronics
- convection and conduction from bodies of arbitrary shape
- thermal contact resistance
- thermal spreading resistance
- fluid flow and heat transfer for heat exchangers and cold plates
Experimental Capabilities

- conjugate heat transfer for packages & boards
- air and liquid cooled heat sink performance
- thermal contact & spreading resistance
- thermal conductivity measurements
- testing of thermal interface materials
- surface characterization
- radiation heat transfer
Facilities

- wind tunnel
- heat exchanger test rig
- contact resistance test rig
- thermal interface material test rig
- surface analysis
- computing equipment
Wind Tunnel

- 18” open circuit wind tunnel
- adaptable test section
- airflow up to 15 m/s
Heat Exchanger Test Rig

- flow rates up to 3 gpm
- power input up to 3 kW
- water, glycol, other fluids
Contact Resistance Rig

Working Ranges

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface Temperature</td>
<td>-20 °C</td>
<td>400 °C</td>
</tr>
<tr>
<td>Environment Pressure</td>
<td>$10^{-10}$ atm</td>
<td>1 atm</td>
</tr>
<tr>
<td>Load</td>
<td>50 N</td>
<td>5000 N</td>
</tr>
<tr>
<td>Interface Pressure</td>
<td>0.4 MPa</td>
<td>10 MPa</td>
</tr>
<tr>
<td>Working Fluids</td>
<td>Air</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Argon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Helium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nitrogen</td>
<td></td>
</tr>
</tbody>
</table>
Thermal Interface Materials

- load cell
  - 100 or 1000 lbs
- linear actuator
  - digitally controlled stepper motor
  - 400 steps / rev
  - 0.1 inch per revolution
- laser-based thickness measurement:
  - 1 micron precision
Surface Characterization

➢ Leitz Durimet Microhardness Tester
  • indenter loads: 15 - 2000 g
  • sample temperatures: up to 200 °C

➢ Talysurf 5 surface profilometer
  • surface roughness, wavines and profile for flat or circular surfaces
  • calculates RMS roughness & RMS surface slope

➢ Taylor Hobson Surtronic 3+
  • portable surface profilometer
  • resolution $0.01 \mu m \rightarrow 300 \mu m$

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Computing Facilities

- **Hardware:**
  - SUN SunBlade 1000 dual processor UltraSparc
  - SGI Octane dual processor R10000 workstation
  - 14 networked PC’s

- **Software:**
  - Numerical CFD Simulation: Flotherm, Ideas, Icepack
  - Symbolic Mathematics: Mathematica, Maple, Matlab
  - Code Development: Visual Basic, C++, CGI, Java, Javascript
Research Projects

- natural convection in microelectronic enclosures
- analytical modeling of heat sinks
  - flow by-pass
  - design optimization
- modeling of liquid cooled cold plates
- contact & spreading resistance models
  - non-conforming, rough surfaces
  - sources on compound disks and flux channels
- characterization of thermal interface materials
- virtual reality modeling of heating/ventilation in car seats

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Natural Convection in Enclosures

Objectives
- develop analytical models for steady-state natural convection from a heated body to its surrounding, cooled enclosure

Overview
- combine conduction and laminar natural convection limiting cases using composite solution technique
- simple model formulation can include radiation and conduction effects

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Heat Sinks: Optimization Routines

Objectives

- develop thermal simulation tools that optimize heat sink design variables based on the minimization of entropy generation
- establish a thermodynamic balance between heat transfer, viscous dissipation and mass transport

Overview

- 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
- minimizing the production of entropy provides a concurrent optimization of all design variables
Modelling of Heat Exchangers & Cold Plates

**Objectives**

- develop analytical models for predicting the heat transfer and fluid friction characteristics of heat exchangers and cold plates

**Overview**

- general models for predicting friction factors and Nusselt numbers for fully developed, thermally developing, and simultaneously developing flow in non-circular ducts.
- models are developed by combining the asymptotic behavior for various flow regions.

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Thermal Contact Resistance: Non-Conforming, Rough Surfaces

**Objectives**

- develop thermo-mechanical models for predicting contact resistance in real surfaces with microscopic roughness and waviness

**Overview**

- mechanical models combine the effects of plastic deformation at the microscopic level with elastic deformation at the macroscopic level
**Objectives**

- develop a simple model for determining thermal joint resistance with grease filled interstitial gaps

**Overview**

- combine joint conductance models with a bulk resistance model for grease, based on an equivalent layer thickness
Objectives

- develop thermofluid models for simulating heating and cooling of car seats
- develop a human interaction model to assess the ergonomic response between the human and the seat

Overview

- a 21 segment model of a human is developed to determine the response to rapid changes in temperature
- models must be fast and accurate in order to provide near real time simulation as part of a virtual reality model
Design Tools

- URL for the MHTL Web page
  
  http://www.mhtlab.uwaterloo.ca

- tool set includes:

  ➢ natural convection in heat sinks: radial fins, plate fins

  ➢ spreading resistance:
    • circular source on a compound disk, flux tube or half space
    • rectangular source on a rectangular disk, flux tube or half space

  ➢ PCB thermal simulation

  ➢ thermophysical property calculator

  ➢ special function calculator
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
Contact Information

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