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

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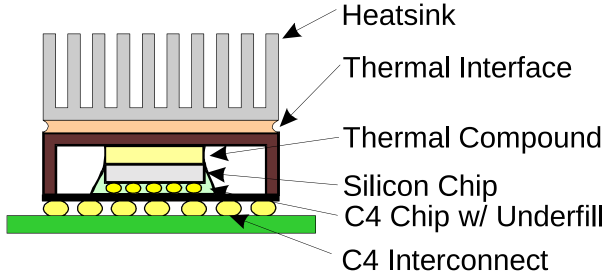
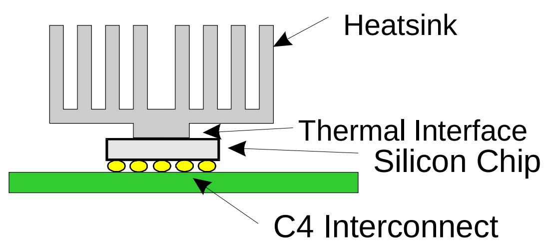
Outline

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

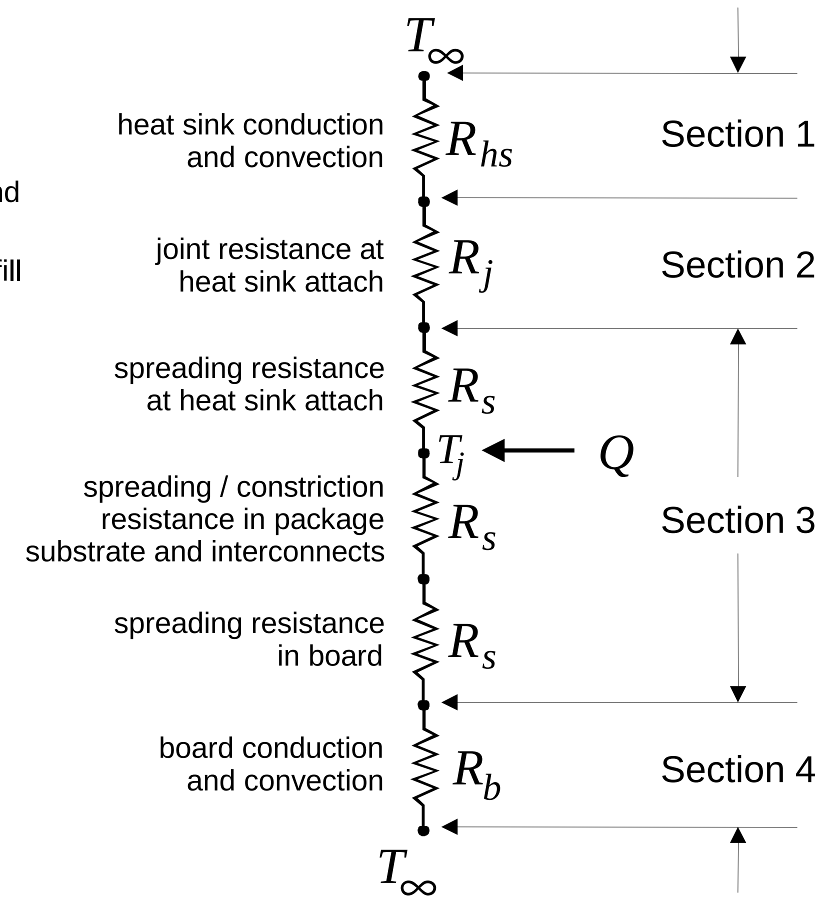
Project Strategy



BGA with Heatsink



Flip Chip with Heatsink



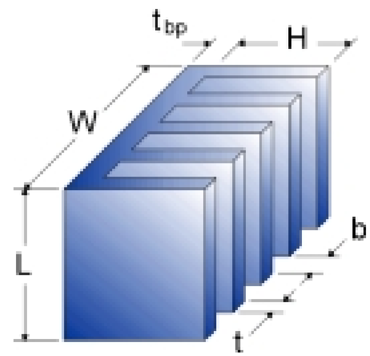
Objectives

- Thermal model development:
  chip level → cooling medium

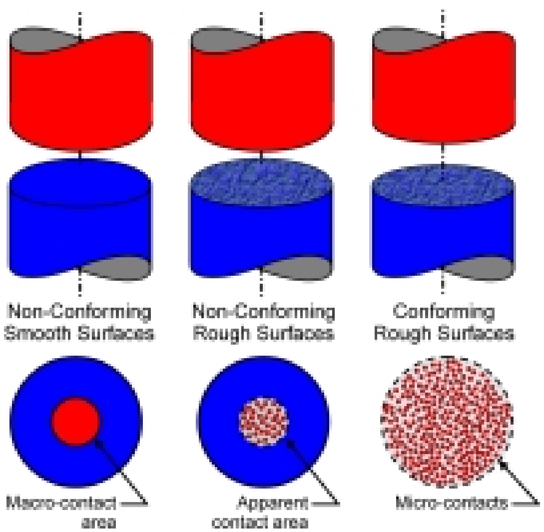
  - ✓ heat sink optimization
  - ✓ modeling & characterization of thermal interfaces
  - ✓ modeling of spreading & constriction resistance
  - ✓ modeling of conduction & convection in PWBs

Year 1 Deliverables

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

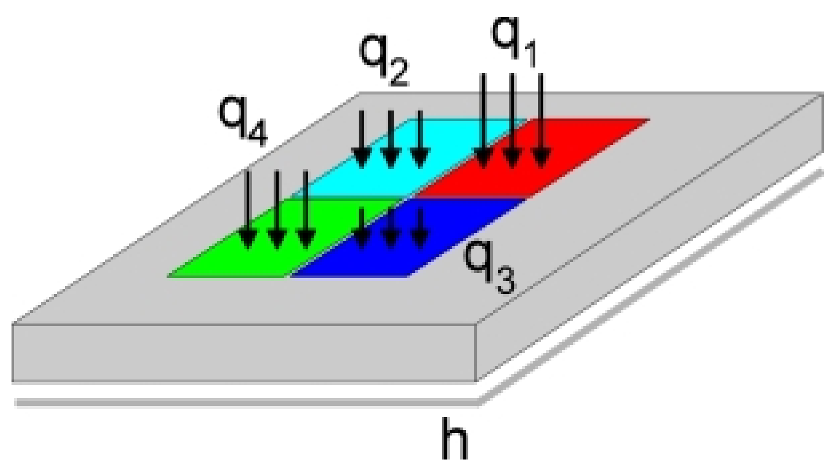


- Thermal resistance models
  - ✓ non-conforming, smooth surfaces
  - ✓ conforming rough surfaces
  - ✓ Excel spreadsheet models



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

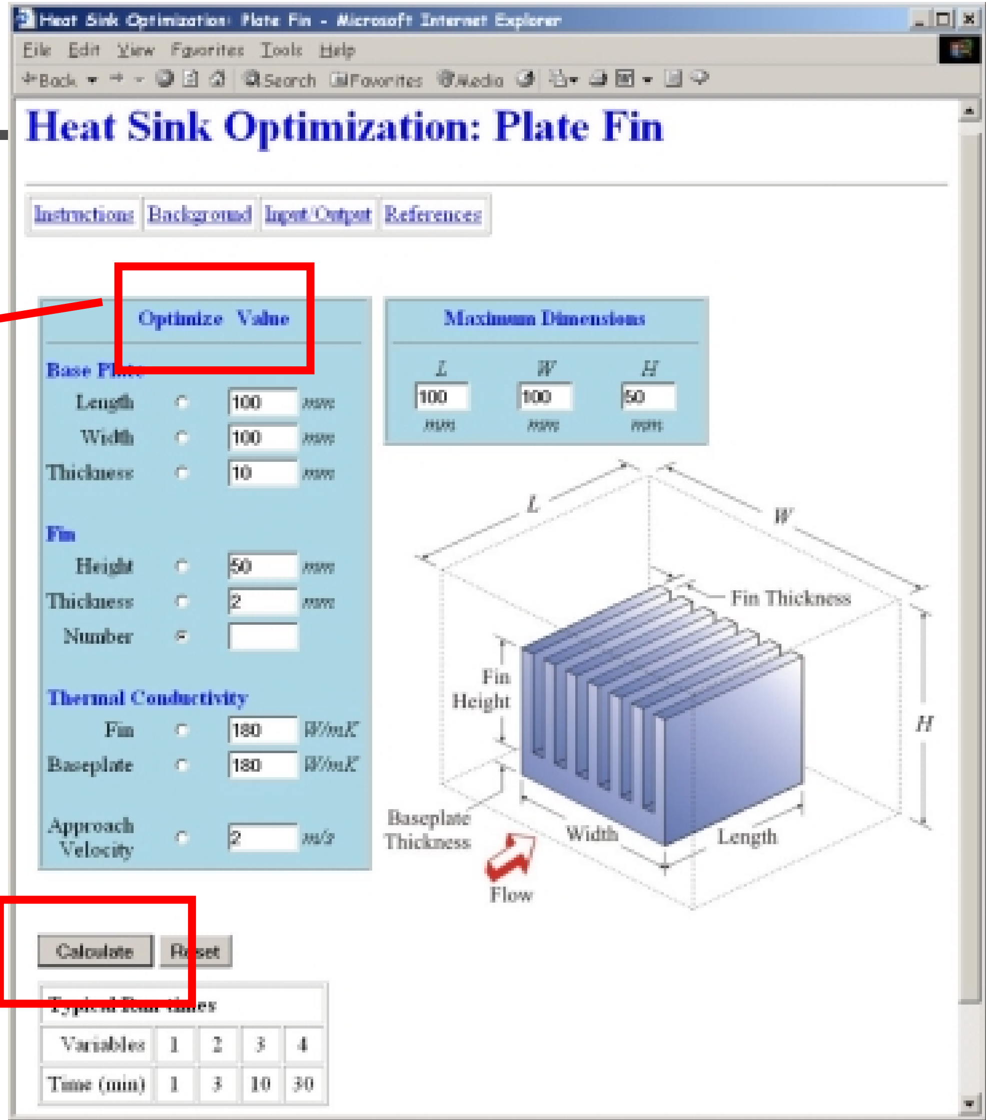
- used to obtain an optimized design for a set of known constraints i.e.
  given:
  - ✓ maximum temperature
  - ✓ heat input
  - ✓ maximum outside dimensions

find: the most efficient design

Optimization Using EGM

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

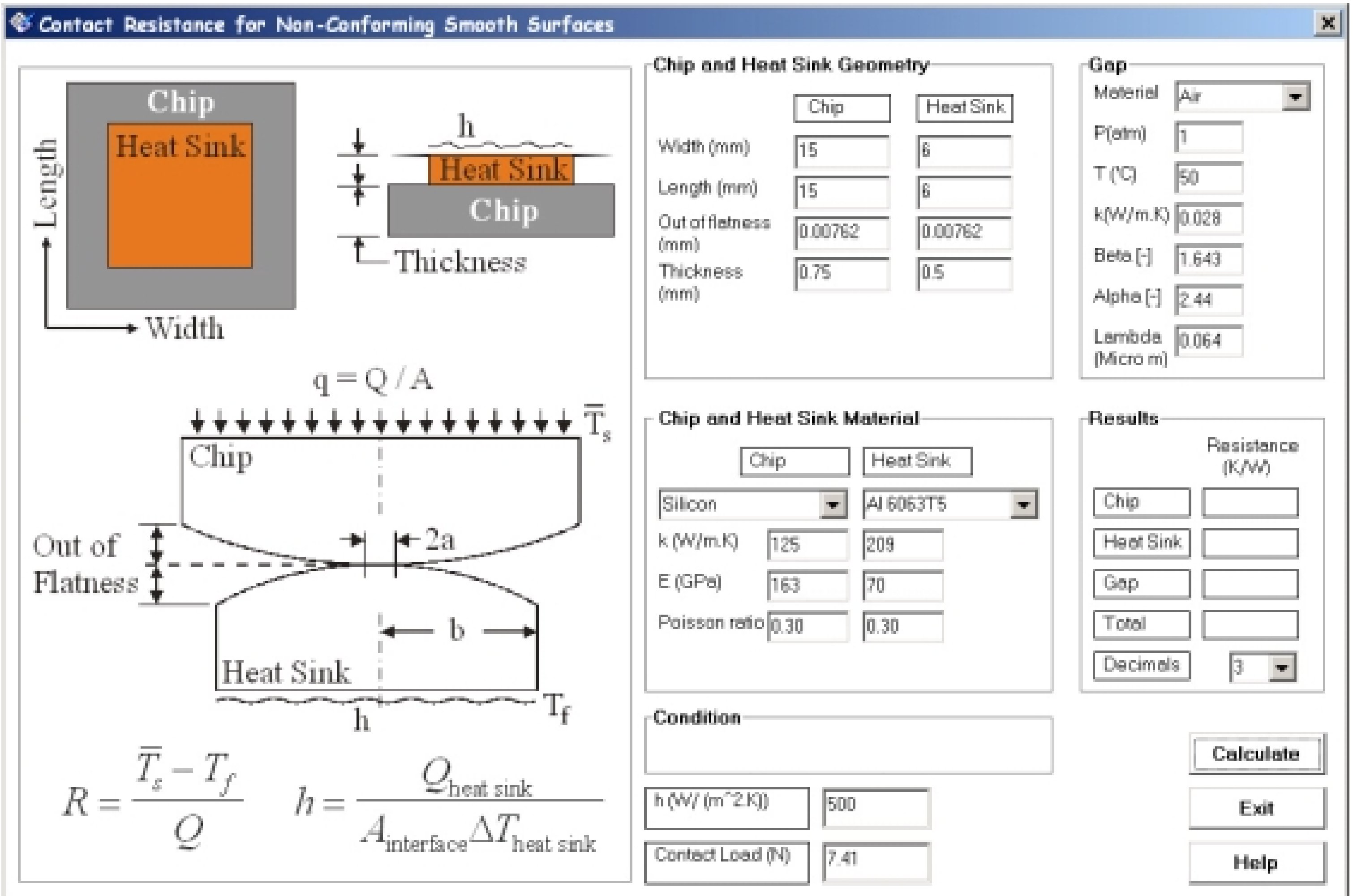
Calculate: run optimization code to calculate design parameters for maximum thermal-fluid performance

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

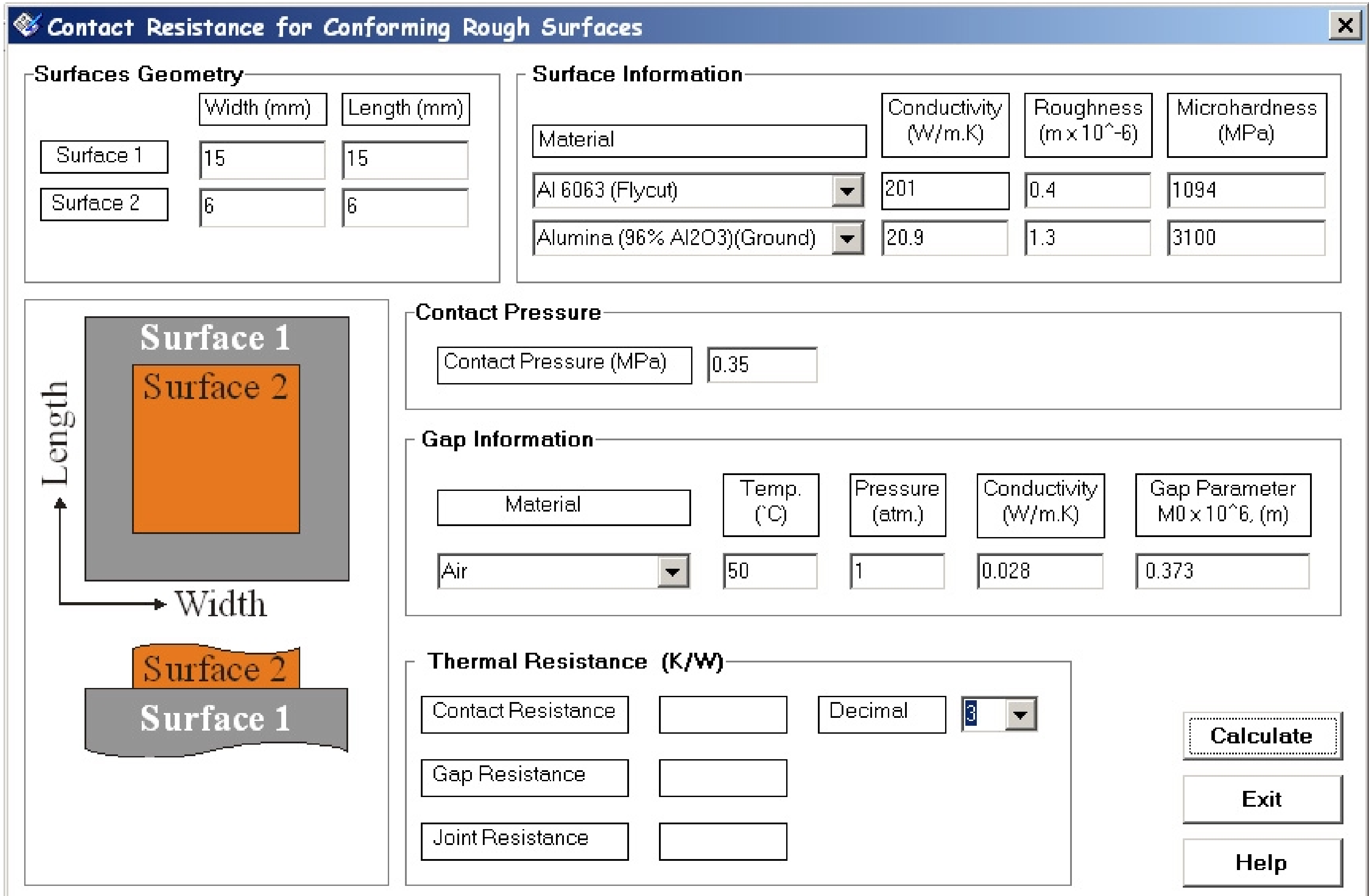
Contact Resistance Models

- 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



Conforming Rough Surfaces



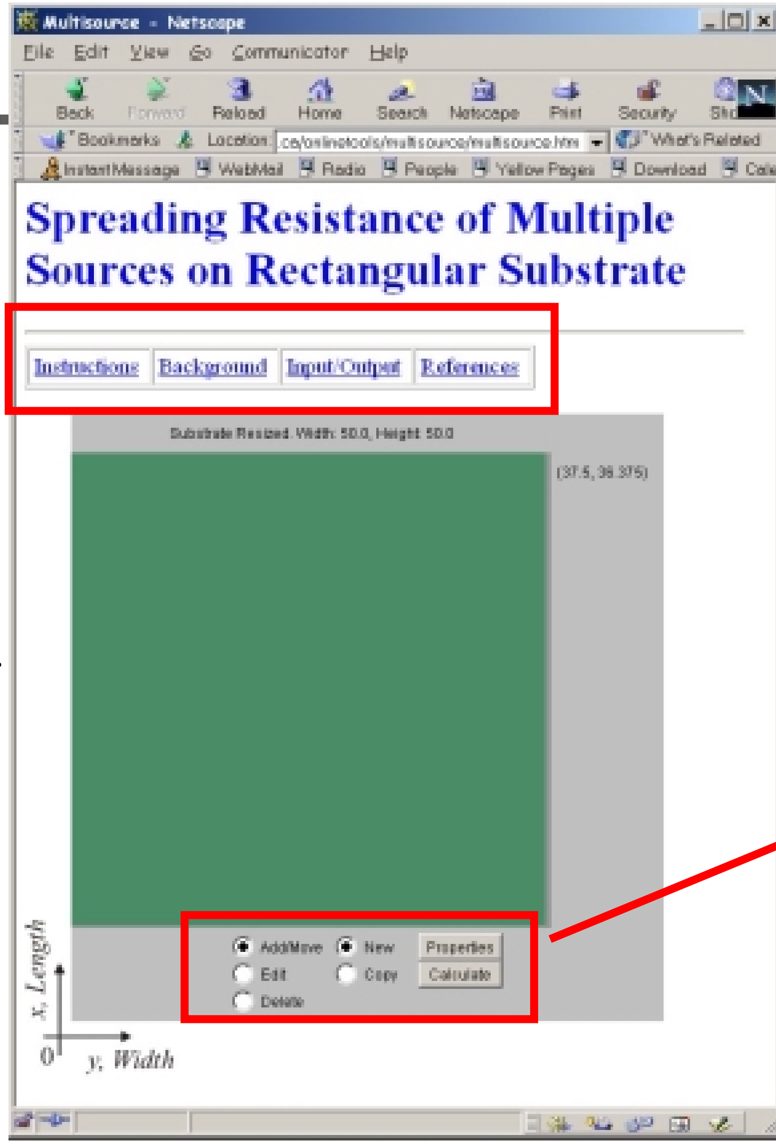
Spreading Resistance Model

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

- Model details in:

“Muzychka, Y.S., Culham, J.R. and Yovanovich, M.M., 2000, "*Thermal Spreading Resistance of Eccentric Heat Sources on Rectangular Flux Channels*," ASME IMECE, Orlando, FL, November 5-10.

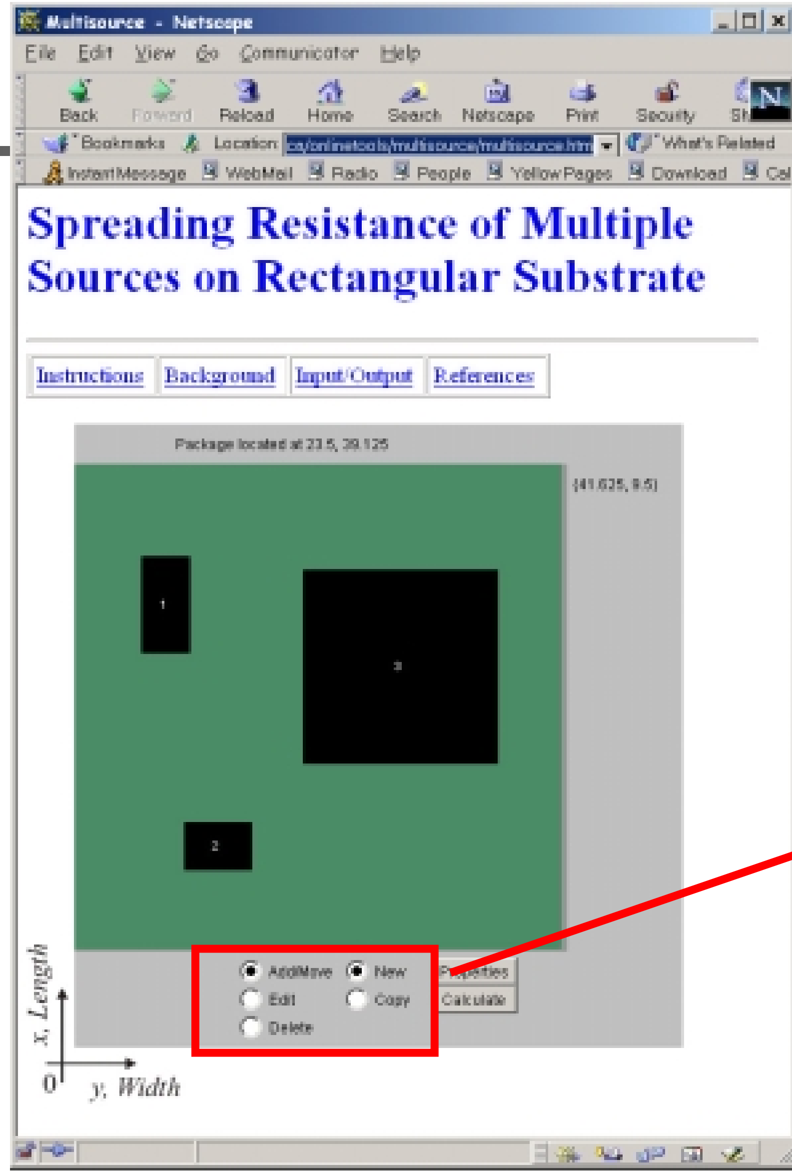
Instructions: user’s guide & sample problem
Background: governing eqns. & model development
Input/Output: data entry & units
References: publications & sample pdf files



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

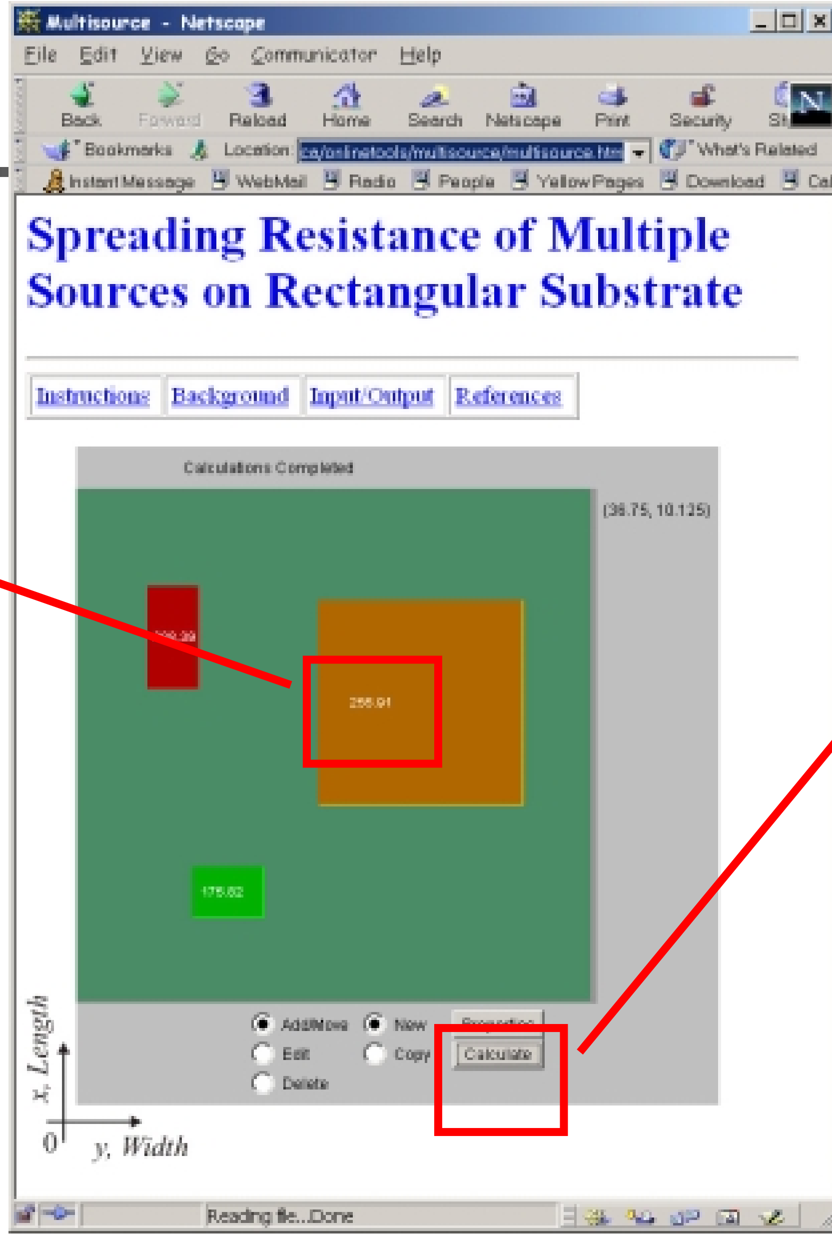
Note: Java source requires Netscape (IE will not work)

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



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 - ^{o}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

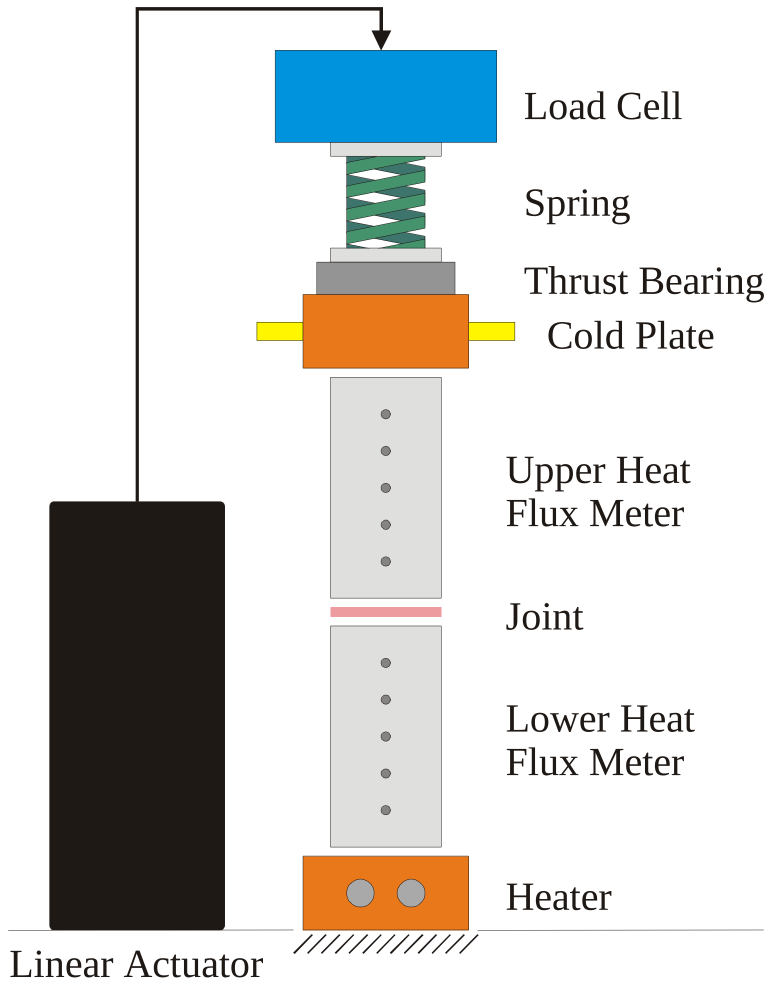
Thermal Interface Materials

- 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

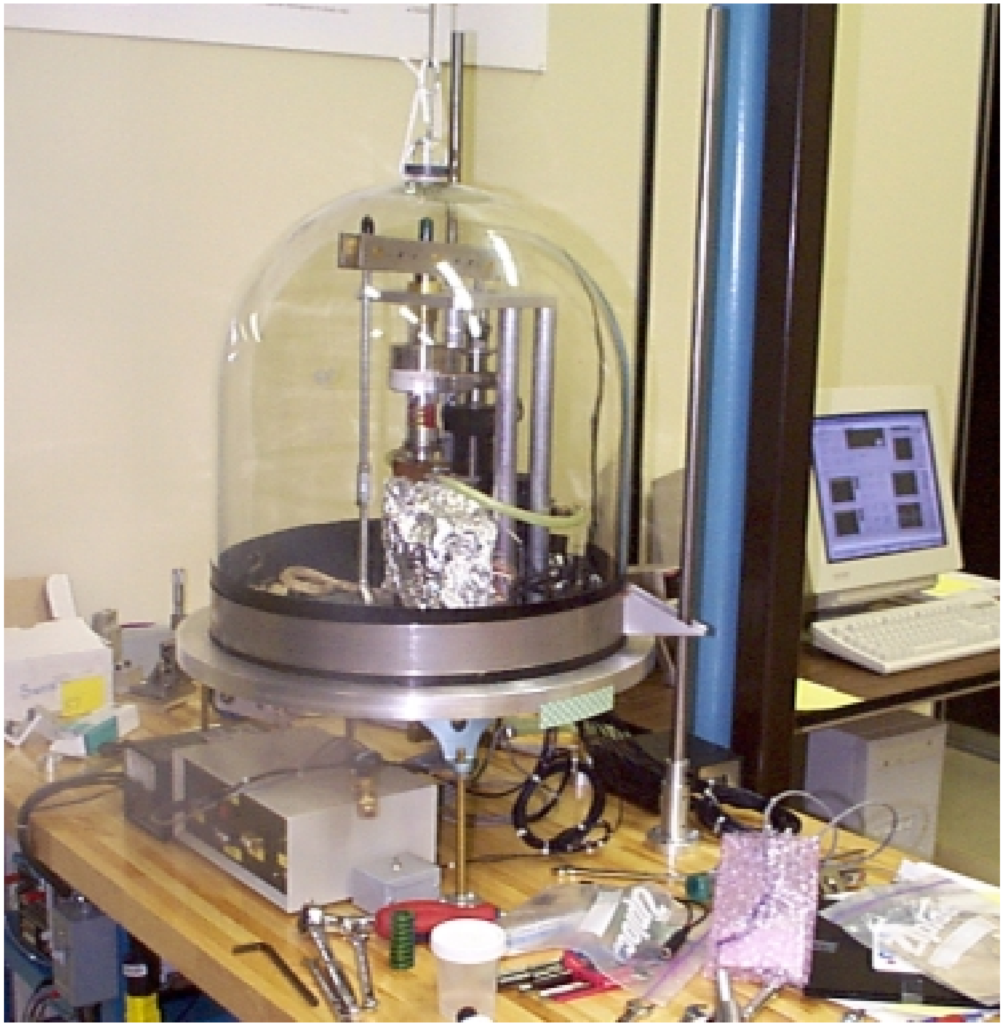
- 4 categories of materials can be tested
  - ✓ materials requiring stops & minimal clamping force
    - grease, liquids, phase change
  - ✓ materials deforming more than 10% under clamping force - compliant materials
  - ✓ materials deforming less than 10%, no stops required - hard rubber
  - ✓ thermally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

Apparatus

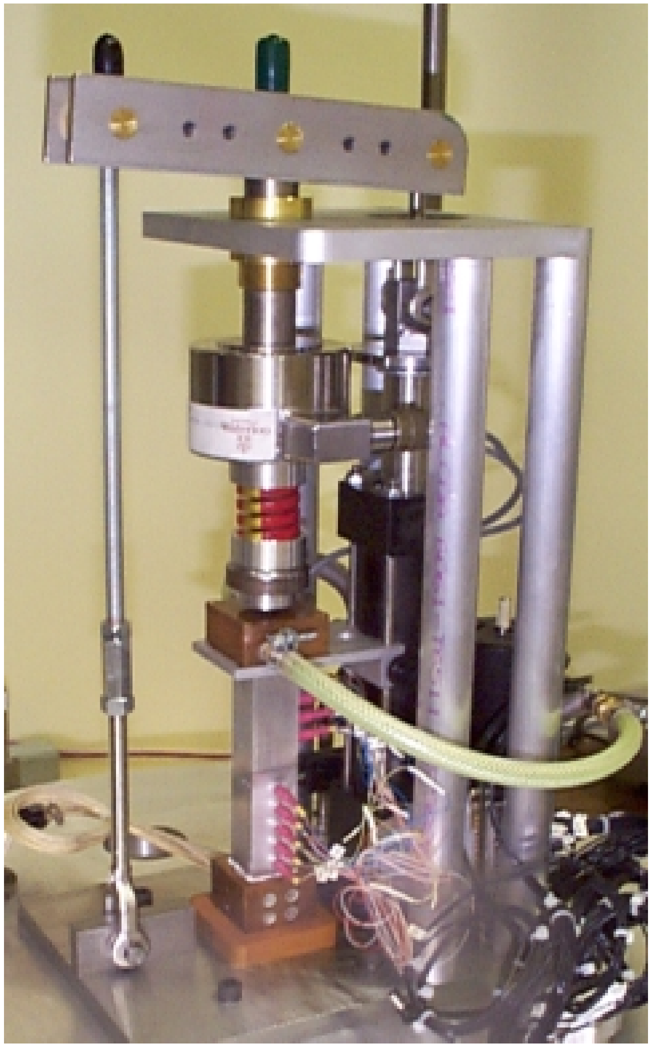


- Load cell
  - ✓ 100 or 1000 lbs
- Spring to compensate for thermal expansion
- Thrust bearing to remove torque loads
- Linear actuator
  - ✓ digitally controlled stepper motor
  - ✓ 400 steps / rev
    0.1 inch per revolution

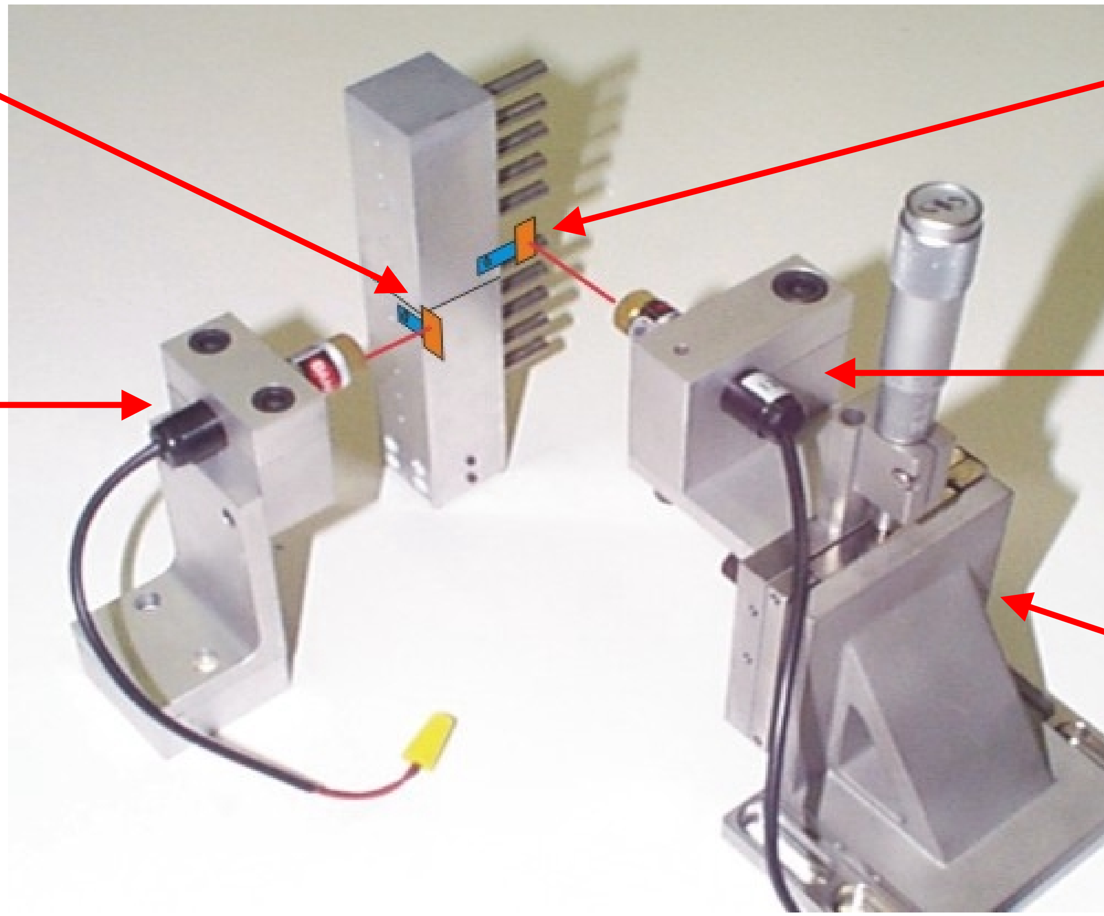
Thermal Interface Test Apparatus



Thermal Interface Test Apparatus



Thickness and Deflection



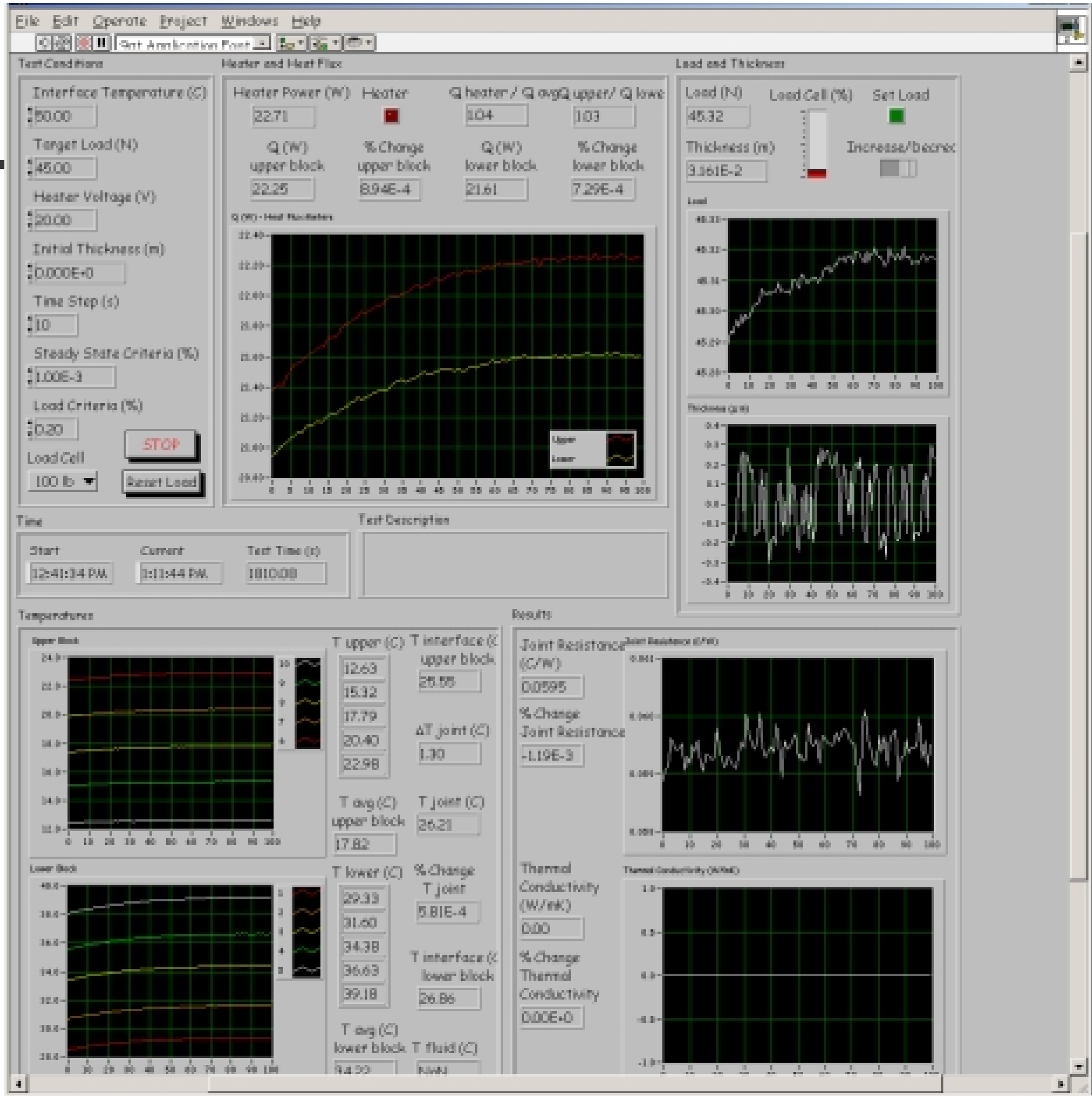
Detector, Lower Block

Detector, Upper Block

Laser, Lower Block

Laser, Upper Block

Translation Stage


File Edit Operate Project Windows Help
Test Conditions
Interface Temperature (C)
50.00
Target Load (N)
45.00
Heater Voltage (V)
20.00
Initial Thickness (m)
0.000E+0
Time Step (s)
10
Steady State Criteria (%)
1.00E-3
Load Criteria (%)
0.20
STOP
Load Cell
100 lb
Reset Load
Heater and Heat Flux
Heater Power (W)
22.71
Heater
Q heater / Q avg
1.04
Q upper/ Q lowe
1.03
Q (W) upper block
22.25
% Change upper block
8.94E-4
Q (W) lower block
21.61
% Change lower block
7.29E-4
Upper
Lower
Load and Thickness
Load (N)
45.32
Load Cell (%)
Set Load
Thickness (m)
3.361E-2
Increase/Decrea
Load
Time
Start
12:41:34 PM
Current
1:11:44 PM
Test Time (s)
1810.08
Test Description
Temperatures
Upper Block
T upper (C)
12.63
15.32
17.79
20.40
22.98
T interface (C upper block
25.55
ΔT joint (C)
1.30
T avg (C) upper block
17.82
T joint (C)
26.21
Lower Block
T lower (C)
29.33
31.60
34.38
36.63
39.18
% Change T joint
5.81E-4
T interface (C lower block
26.86
T avg (C) lower block
34.22
T fluid (C)
NaN
Results
Joint Resistance (C/W)
0.0595
% Change Joint Resistance
-1.19E-3
Thermal Conductivity (W/mK)
0.00
% Change Thermal Conductivity
0.00E+0

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