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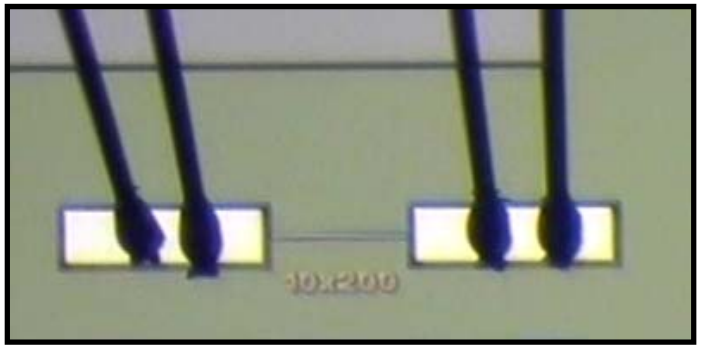
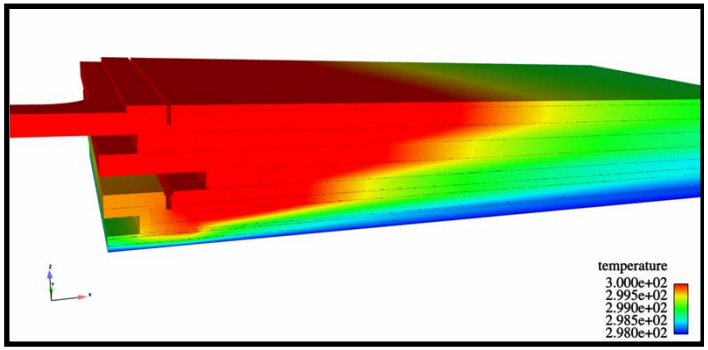
$$q = -k\frac{\partial T}{\partial x}$$





Thermal Conductivity Measurement Techniques and Capabilities

Leslie Phinney

November 12, 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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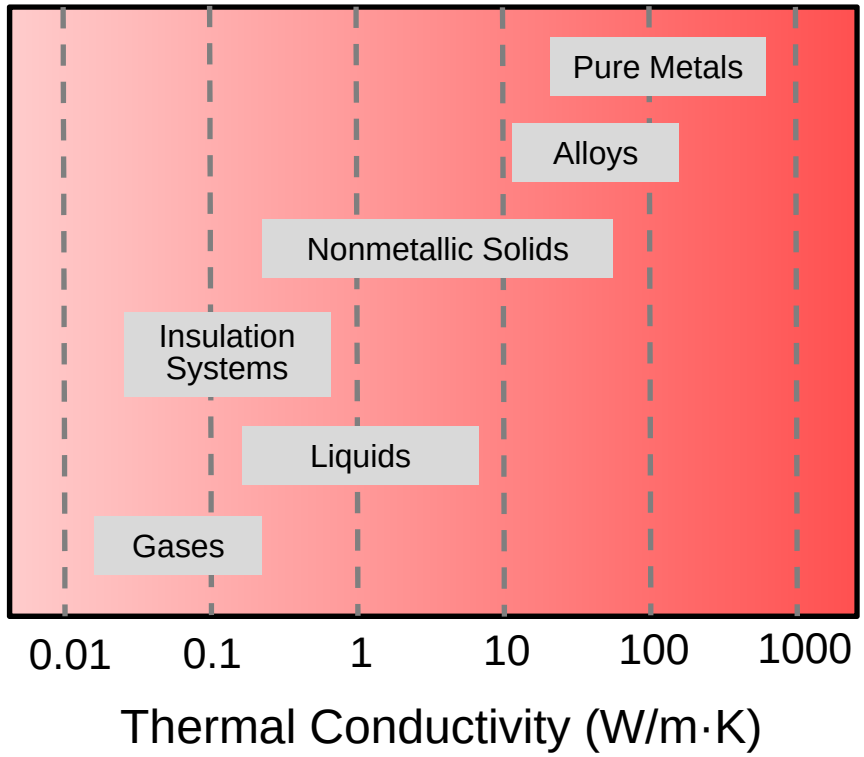
SNL Engineers and Scientists Utilize a Wide Variety of Materials

- Metals
  - Aluminum
  - Stainless Steel
  - Copper
  - Etc.
- Semiconductors
  - Silicon, polycrystalline silicon
  - GaN
- Insulators
  - Epoxies
  - Concrete
- Other
  - Liquids, pressed polytechnic powders, etc.



A Suite of Measurement Techniques Are Required to Obtain Thermal Conductivities

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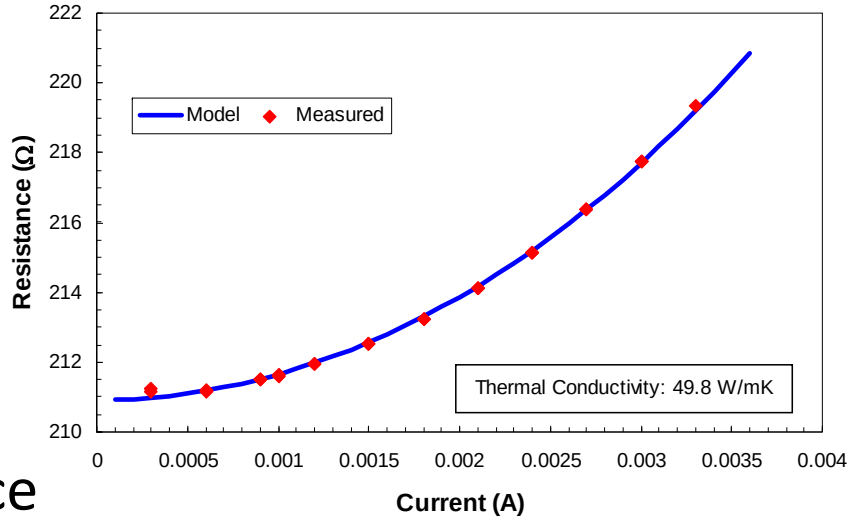
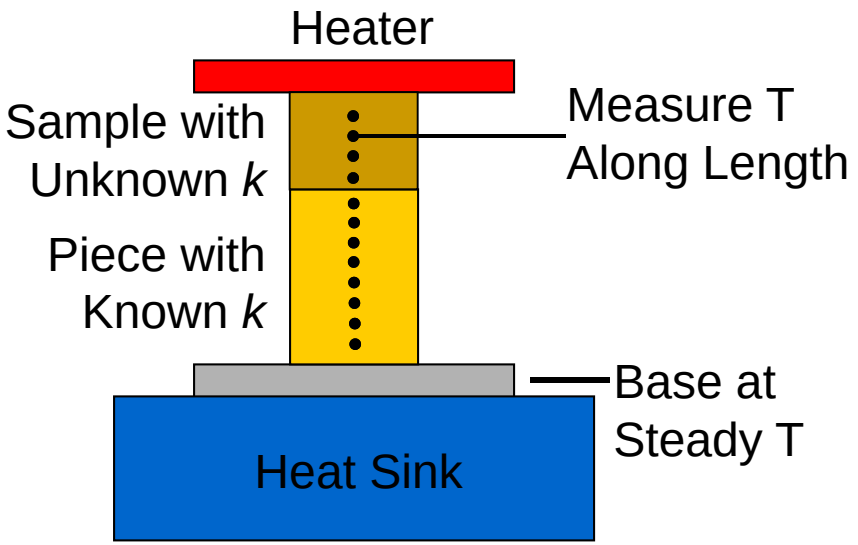
- Calorimetric
- Electrical
  - Resistance
    - Steady State
    - Three-Omega
  - Modified Transient Plane Source
  - Hot wire probe
- Optical
  - Laser Flash
  - Time Domain Thermal Reflectance
  - Frequency Domain Thermal Reflectance
- Mix of Commercial and Custom Systems



Calorimetric Techniques Measure Temperature and Heat Transfer Rate

- Materials: Insulating materials like concrete to alloys and metals
- Thermal Conductivity Range: 0.5 – 200 W/(mK)
- Sample Requirements: Samples must be machinable or moldable, want 8 mm diam. cylinders, 8-15 mm thick with thermocouple holes
- Temperature: Room temperature
- POCs: Bob Sayer and Walt Gill



$q, \Delta T, L$

$$q = -k\frac{\partial T}{\partial x}$$

3-Omega Measures the Change in the Third Harmonic of the Voltage After AC Heating

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- Materials: dielectrics with low thermal conductivities, electrically conducting samples require more care
- Thermal Conductivity Range: 0.1 – 1000 W/mK (bulk samples) 0.1 - 20 W/mK (thin film samples)
- Sample Requirements: Samples compatible with deposition of a metal sensor with four electrical contacts and packaging
- Temperature: Room temperature, -190˚C to 77˚C or -190˚C to 300˚C, depending on cryostat
- POC: Leslie Phinney – being reconstituted in FY15

$$V_{3\omega} \approx \frac{4V^3 L}{\pi^4 kAR^2}\frac{dR}{dT}$$

*Lu *et al*, Review of Scientific Instruments, 72, 2996 (2001).

Modified Transient Plane Source Electrically Heats the Material and Relates Decay in the Resistance to the Thermal Properties

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- Materials: Low conductivity fluids, powders, and pastes
- Thermal Conductivity Range: 0 - 0.6 W/(mK) with current sensor
- Sample Requirements: Sensor is ~1.5 cm in diameter, need specific heat
- Temperature: Room temperature, -73˚C to 200˚C
- POCs: Leslie Phinney and Walt Gill

Hot Wire

- Hot Wire Technique measures the change in electrical resistance of the probe and relates it to the thermal properties of the surrounding material
- Materials: Liquids and Pastes, need specific heat
- Thermal Conductivity Range: 0.01 to 2 W/mK
- Sample Requirements: 50 ml volume
- Temperature: -30˚C to 400˚C (customized so that can go up to 35 bar)
- POC: Martin Nemer

FDTR and TDTR Are Based on the Change in Surface Reflectance with Temperature

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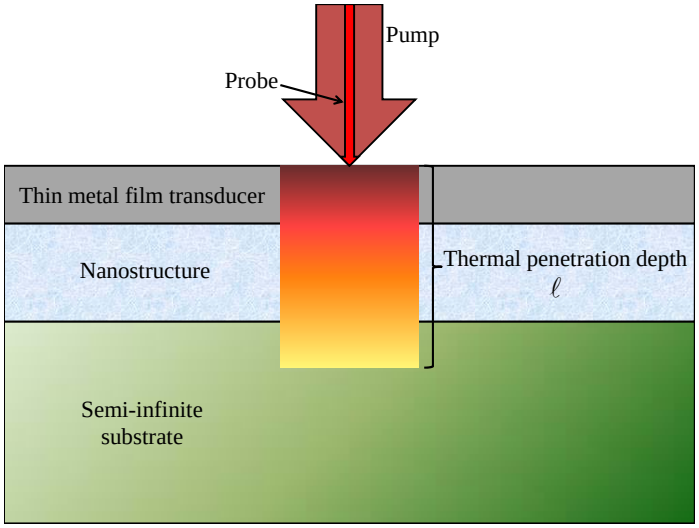
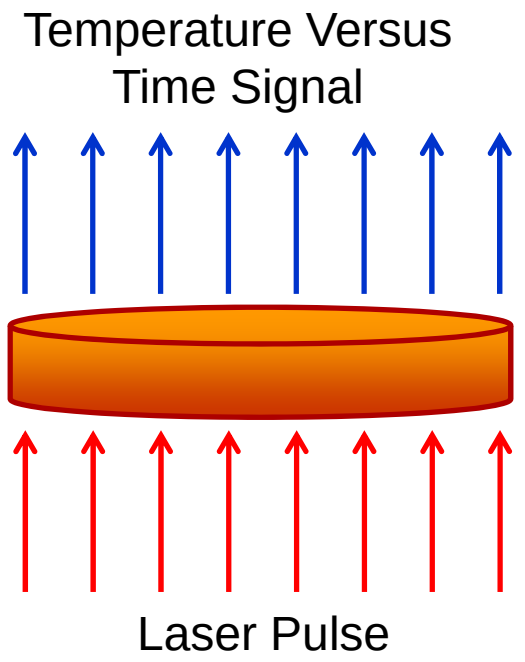
- Materials: Thin film insulating, semiconducting, and metal films
- Thermal Conductivity Range: TDTR - 0.5 to 2000 W/mK
  FDTR - 1.5 to 300 W/(mK)
- Sample Requirements: ~3 µm thick, 1 cm^2 sample with smooth surface suitable for metal transducer deposition, FDTR can tolerate slightly rougher surface than TDTR, need specific heat
- Temperature:
  Room temperature
  TDTR - cryostat from 77K to 500K
- POCs: Thomas Beechem, Colin Landon, Leslie Phinney, Justin Serrano



Laser Flash Heats a Sample and Measures the Change in Temperature at the Back of the Sample

- Materials: Insulating materials like epoxies to alloys and metals
- Thermal Conductivity Range: 0.1 W/(mK) - 2000 W/(mK)
- Sample Requirements: 8 mm or 12.7 mm disks, 1-3 mm thick, need specific heat
- Temperature: Room temperature to 275˚C
- POCs: Paul Specht, Marcia Cooper – Netzsch, Walt Gill – Anter



Other Capabilities Exist

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- Dynamic Heating of a Hot Disk – Kevin Dowding analysis, POC: Walt Gill
- Steady State Electrical Resistance – POC: Leslie Phinney
- Geology Laboratory
- TPRL – Thermophysical Properties Research Laboratory, Inc. – at Purdue

A Few Take Away Messages

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- Since a one size fits all thermal conductivity measurement technique does not exist, a suite of methods is necessary to encompass the range of materials of interest to SNL engineers and scientists. Each technique has a range of applicability and sample preparation requirements.
- Many techniques measure thermal diffusivity/effusivity and require the specific heat to obtain the thermal conductivity.
- SNL has extensive thermal characterization capabilities including calorimetric, electrical, and optical techniques.
- Some of the techniques can also be used to measure thermal contact conductance – calorimetric and TDTR.