Thermoelectric Material Characterization

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U.S. NAVAL RESEARCH LABORATORY

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NAVAL RESEARCH ENTERPRISE INTERNSHIP PROGRAM

Project Objectives:

1. Characterize thermoelectric samples using laser flash analysis (LFA) and Seebeck analysis to measure **thermal conductivity κ**, and **Seebeck coefficient** $S = \frac{\Delta V}{\Delta T}$, where S indicates voltage generated per temperature difference.
2. Design automated liquid nitrogen (LN2) dispenser to automatically cool LFA instrument.

Contributions:

1. Developed automated LN2 dispenser using an Arduino-controlled embedded system comprising two thermocouples and a relay-controlled solenoid valve to automatically deliver LN2 through a vacuum-sealed pipe system I constructed.
2. Used Python to create a graphical-user-interface and data-logging system that uses serial communication to interface between the LN2 dispenser and lab computer.
3. Cut, coated, and prepared thermoelectric and semiconductor samples for Seebeck and LFA analysis.
4. Facilitated LFA measurements to measure thermal diffusivity α and specific heat C_p, which we used with sample density ρ to determine thermoelectrics' thermal conductivity $\kappa = \alpha \cdot C_p \cdot \rho$.
5. Measured Seebeck coefficients of thermoelectrics using Seebeck instrument.
6. Created Python script to organize LFA output data.
7. Presented research updates to NRL scientists and engineers and maintained thorough research notes.

Thermoelectric schematic

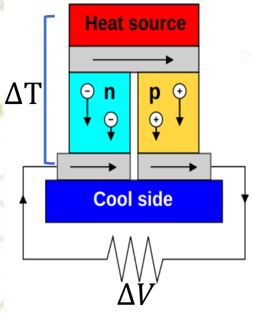
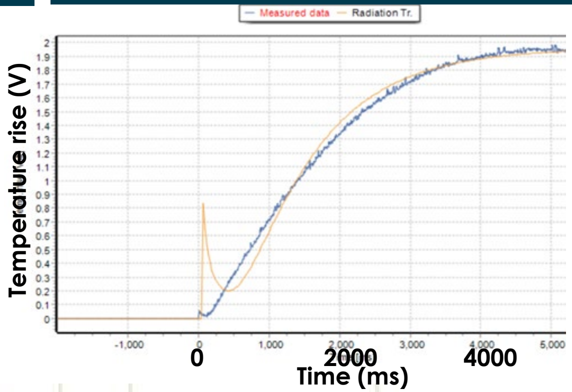


Image: Wikipedia

LFA temperature/time curve used to determine thermal diffusivity



Most significant contribution: using the automated LN2 dispenser I developed to cool the LFA instrument, I ran long thermal diffusivity measurements of thermoelectrics, obtaining high-quality data that I organized and analyzed using a Python script I developed.

Internship value:

- Improved my ability to develop embedded systems, collaborate with scientists and engineers, code microcontrollers in C, prepare samples for measurements, and carefully operate advanced instruments.
- Taught me fundamentals of nanomaterial science and improved my chemistry knowledge, especially regarding crystal growth, chemical bonding properties, and electron physics.
- Introduced me to semiconductor and solid-state physics, including topics such as n and p-type doping, electron bands, p/n junctions, diodes, transistors, and thermoelectrics.

Advice for future cohorts: meet as many people as possible to learn about potential projects and careers.

Achievements:

- Improved LFA method for measuring difficult transparent samples, achieving high-quality data.
- Obtained thermal diffusivity and conductivity data for thermoelectric and semiconductor samples.
- Developed and documented standard operating procedures for LFA to ensure measurement consistency.

Next steps:

- Analyze effect of high doping on Seebeck coefficients of wide band-gap semiconductors.
- Measure infrared (IR) transparent samples in LFA, which is difficult due to the laser's IR wavelength.

Future utility:

- Thermoelectrics will be used to harvest electricity from waste heat in vehicles and other systems, and to cool systems without requiring refrigerant or moving parts.

LN2 dispenser mounted to the LFA

LN2 dispenser housing and circuitry