Characterization of Thermoelectric Materials

Dylan Jacobs, Dr. Benjamin Greenberg

Semiconductors and Thermoelectrics

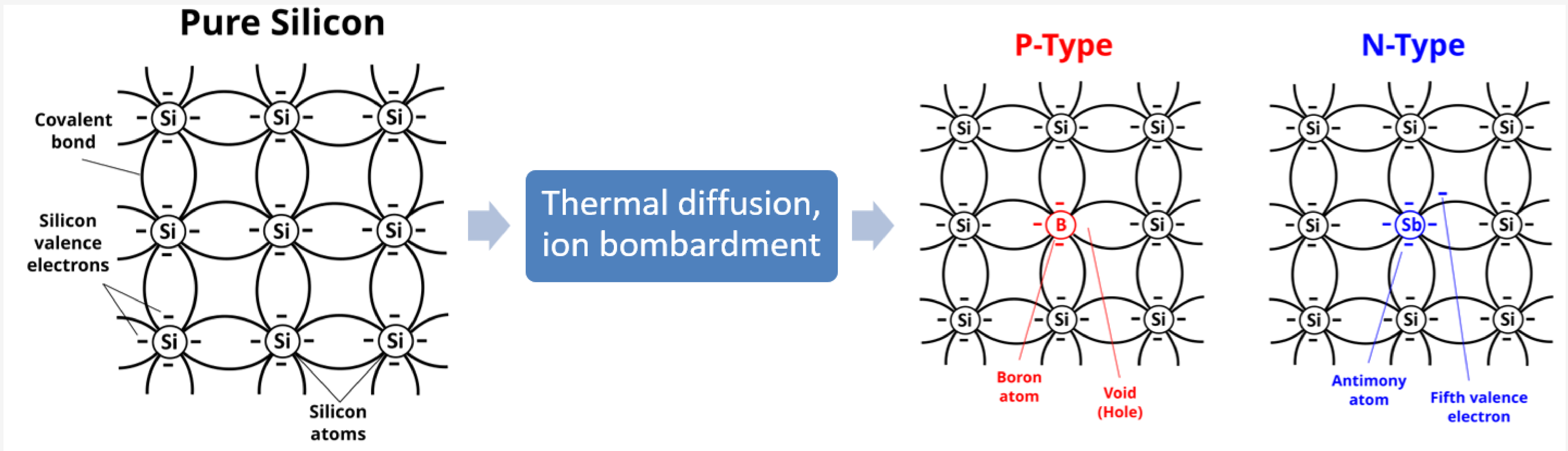


Image source: [1]

n/p-doped semiconductors → thermoelectrics

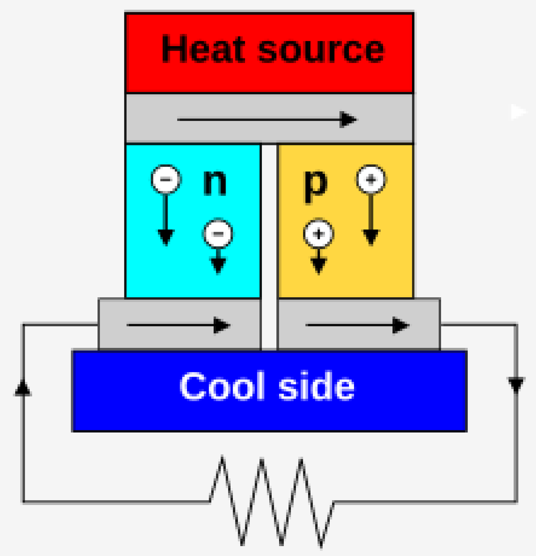


Image source: [2]

- **Bi_2Te_3**: narrow band-gap semiconductor, topological insulator
- **SiGe:** combines silicon's thermal stability with high electron mobility of germanium, tunable band-gap

Charge-carrier diffusion induces electrical current

$$\mathbf{J} = \sigma(-\nabla \mathbf{V} + \mathbf{E}_{\mathbf{emf}}), \quad \mathbf{E}_{\mathbf{emf}} = -S\nabla \mathbf{T}$$

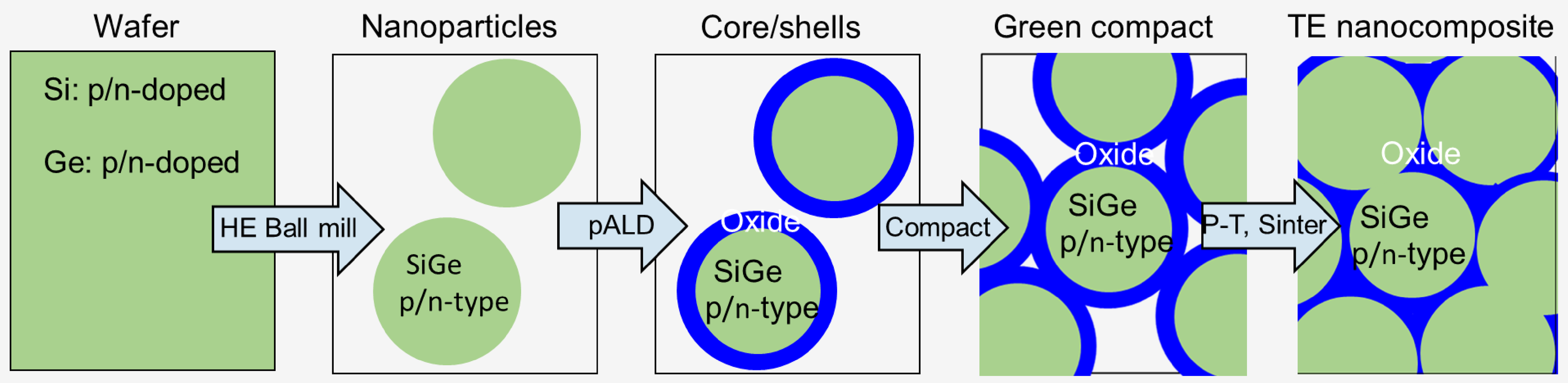
Application: power generation from waste heat

- SiGe thermoelectrics used in Voyager I, II spacecrafts

Thermoelectric design goals:

$$\left.\begin{array}{l}\text{High electrical conductivity } \sigma \\ \text{Low thermal conductivity } \kappa \\ \text{High Seebeck coefficient } S = \frac{\Delta V}{\Delta T}\end{array}\right\} \quad \text{figure of merit } zT = \frac{S^2 \alpha T}{\kappa}$$

Solution: core/shell nanomaterial compacts



Laser Flash Analysis (LFA) Characterization

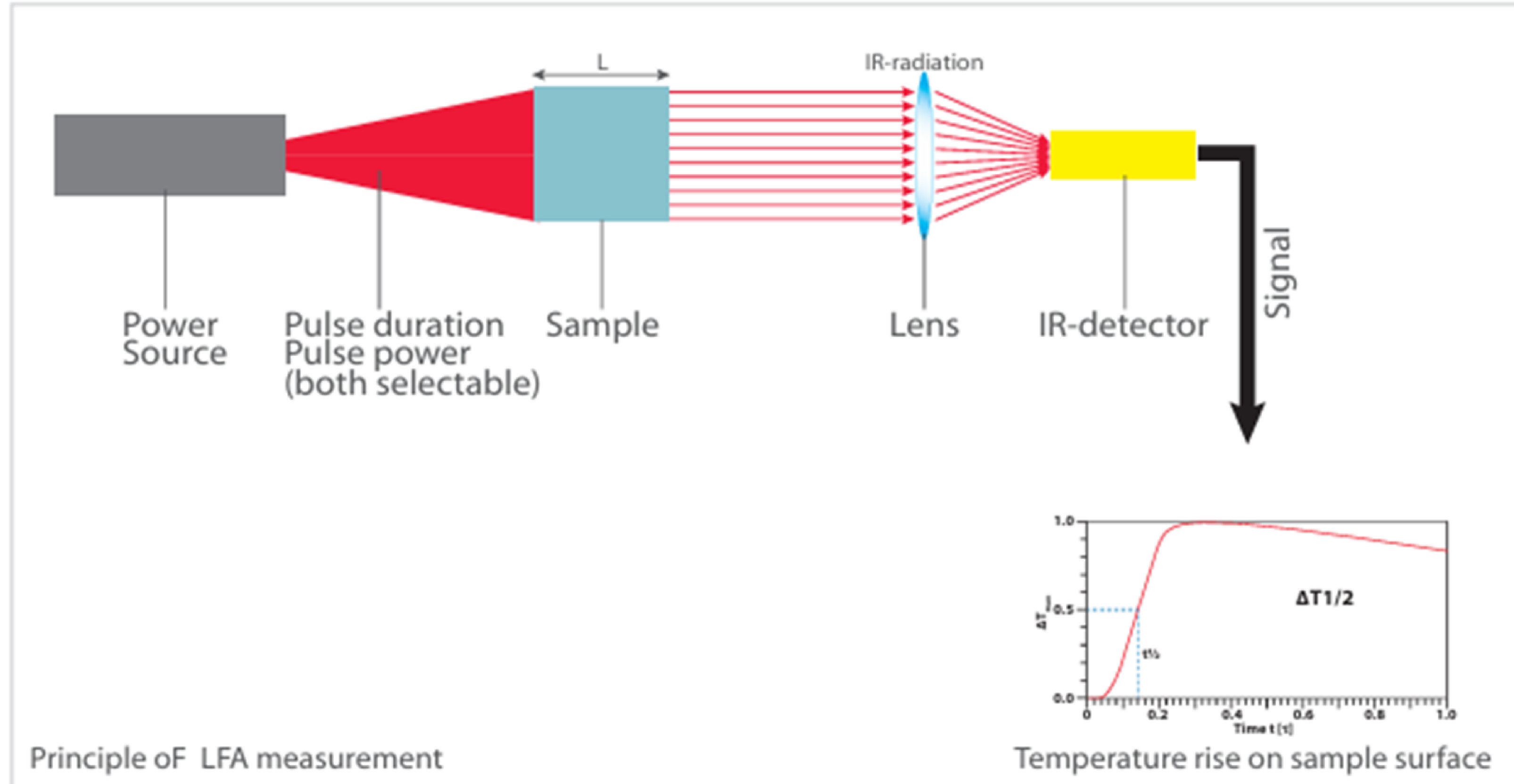


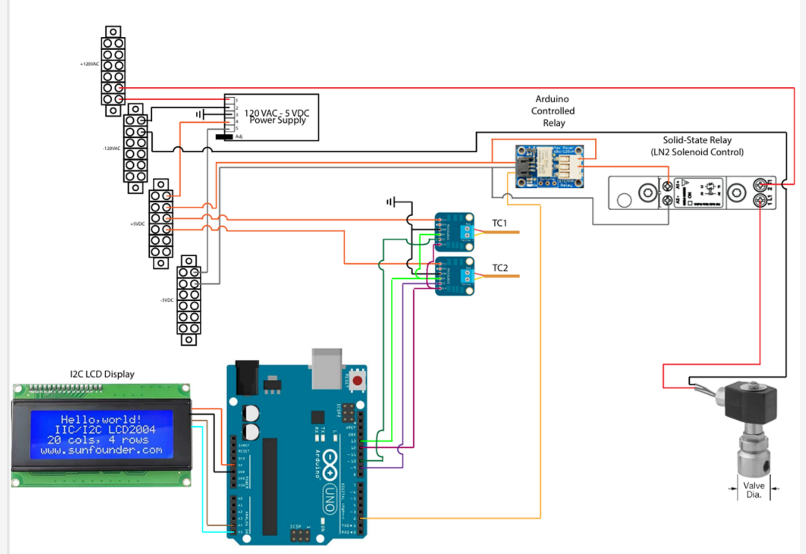
Image source: [3]

Thermal conductivity $\kappa(T) = \alpha(T) \cdot C_p(T) \cdot \rho(T)$

Thermal diffusivity $\alpha(T) = \frac{0.13879 L^2}{t_{1/2}}$, $\rho(T)$=density, $C_p(T)$=specific heat, $t_{1/2}$=half rise time, L=sample thickness

Challenge: high signal/noise ratio → liquid nitrogen (LN2)

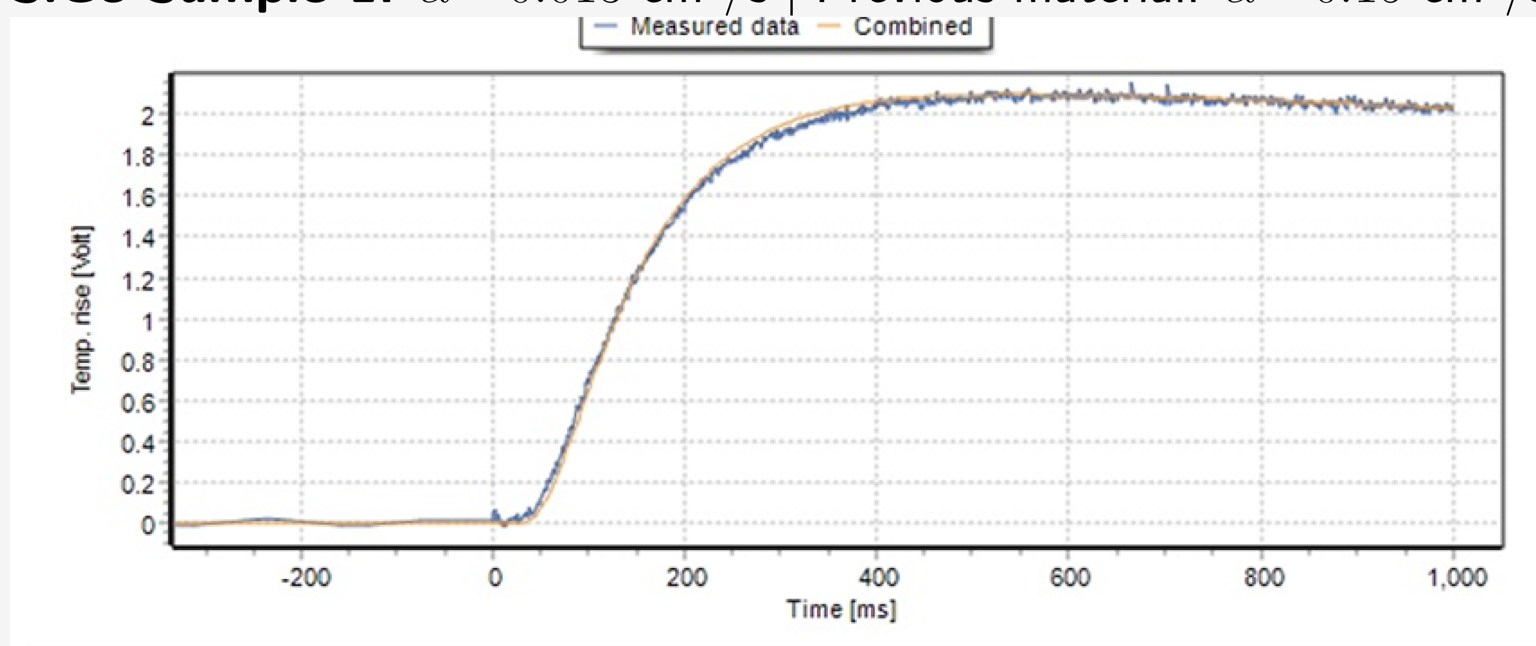
Automated LN2 dispenser for LFA



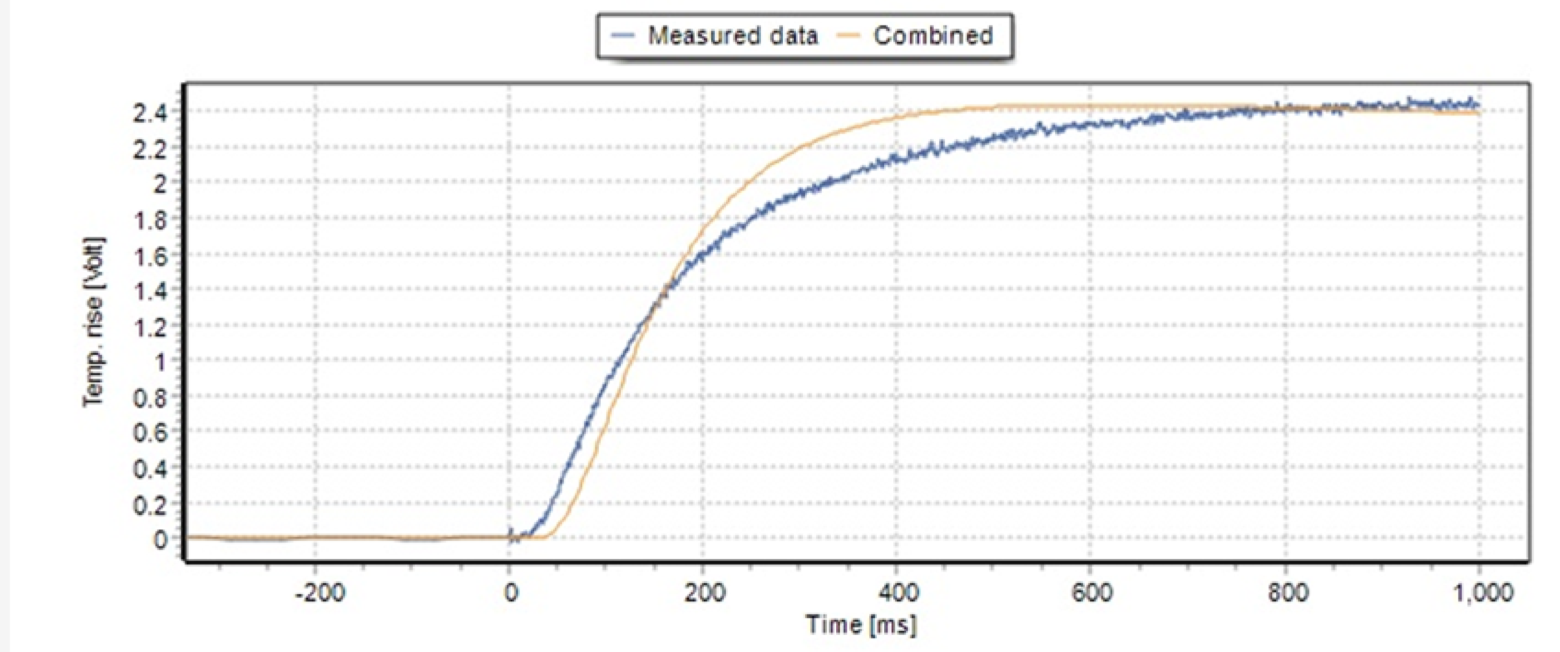
- Developed Arduino-controlled embedded system to automate LN2 delivery.
- Used Python to create a graphical user interface and data logger to interface between the LN2 dispenser and lab computer.
- Obtained thermal diffusivity and conductivity data for thermoelectric and semiconductor samples.

LFA Characterization Results

SiGe Sample 1: α = 0.013 cm^2/s | Previous material: α = 0.15 cm^2/s



SiGe Sample 2: α = 0.007 cm^2/s | Previous material: α = 0.15 cm^2/s



Ongoing work:

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

References

Special thanks to Dr. Benjamin Greenberg, Dr. Boris Feigelson, and Dr. AJ Cendejas for their mentorship and guidance throughout this project.

[1] Image credit: Wikipedia, VectorVoyager - Own work, This file was derived from: Silicon doping - Type N.svg: Silicon doping - Type P.svg:
[2] Image credit: Wikipedia, Ken Brazier - self-made, based on w:Image:ThermoelectricPowerGen.jpg by CM Cullen (which is GFDL 1.2 and CC-by 2.5 licensed)
[3] Image credit: Linseis