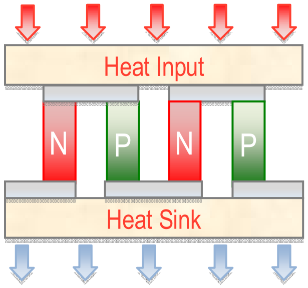
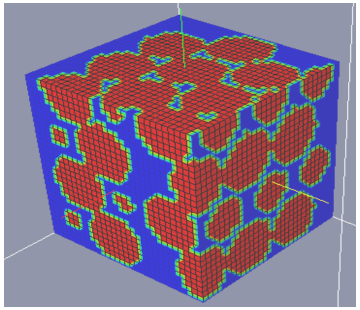
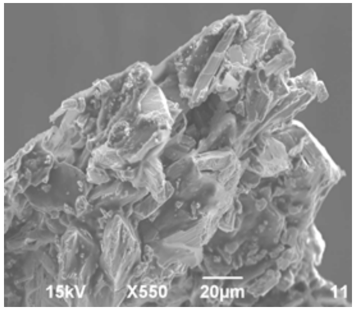
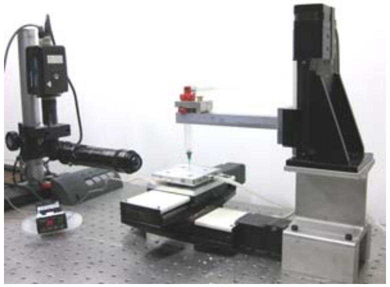








Meso-Energy Harvesting with Waste Heat

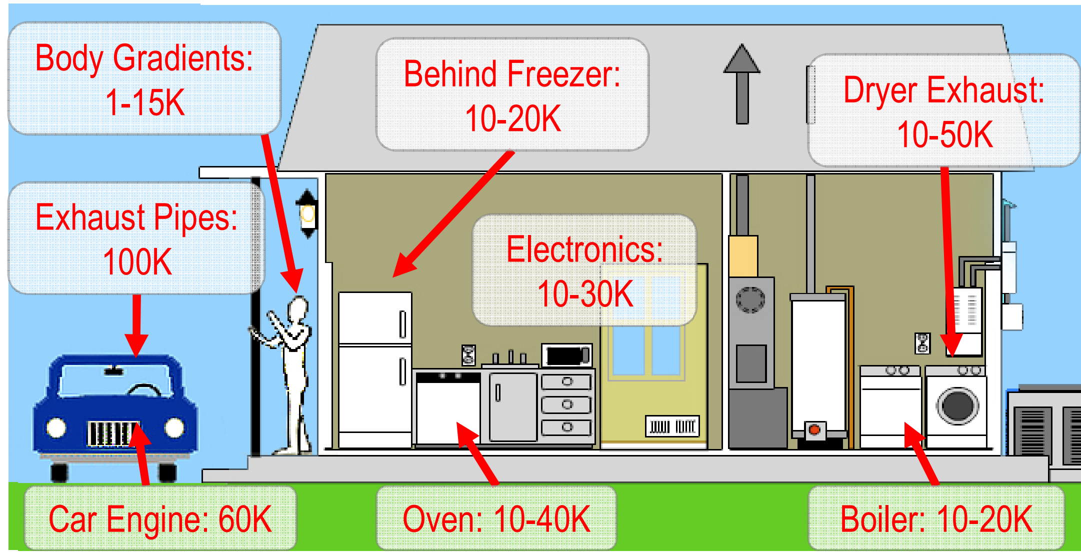
Alic Chen
Mike Koplow
Deepa Madan

Available Power from Waste Heat

Alternate applications

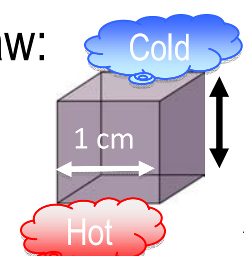
Location	Source	Gradient
Factories	Exhaust pipes, Boilers, condensers	10-80K
Vehicles	Engine Exhaust pipes	60K >100K
Airplanes	Cabin to External	10-50K

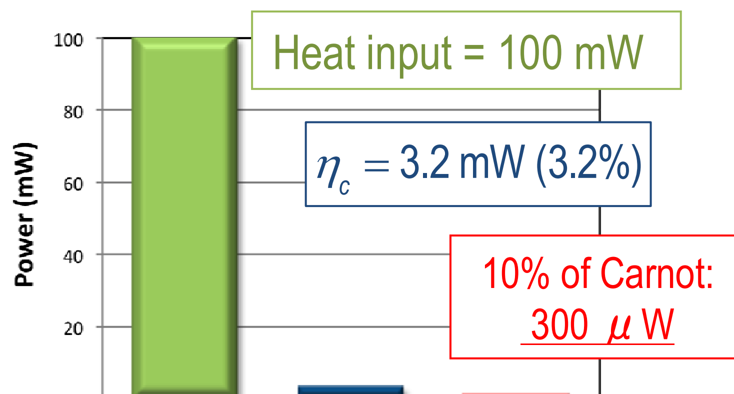
Residential temperature gradients



Total available power

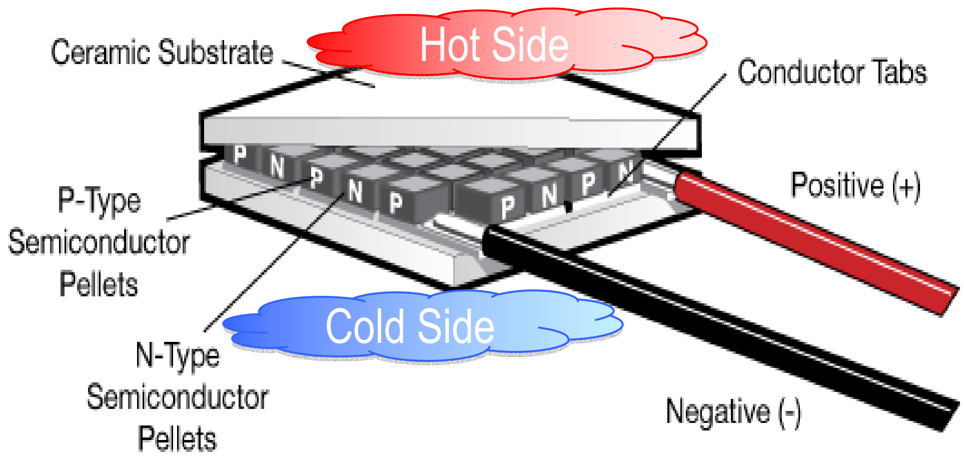
- Fourier's Law:





Thermoelectric Basics

Bulk Thermoelectric Device



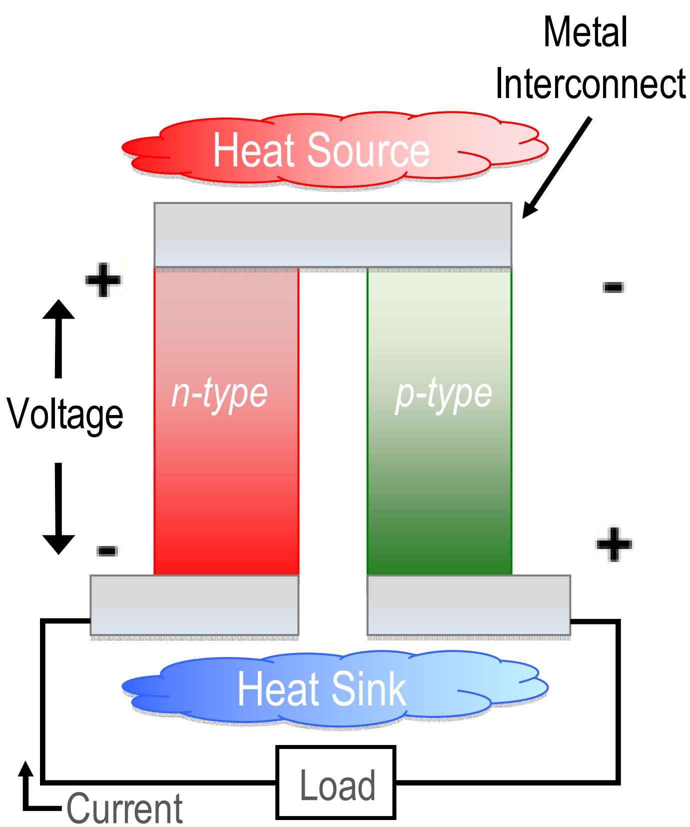


Figure of Merit

$$ZT = \frac{\alpha^2 \sigma T}{k}$$

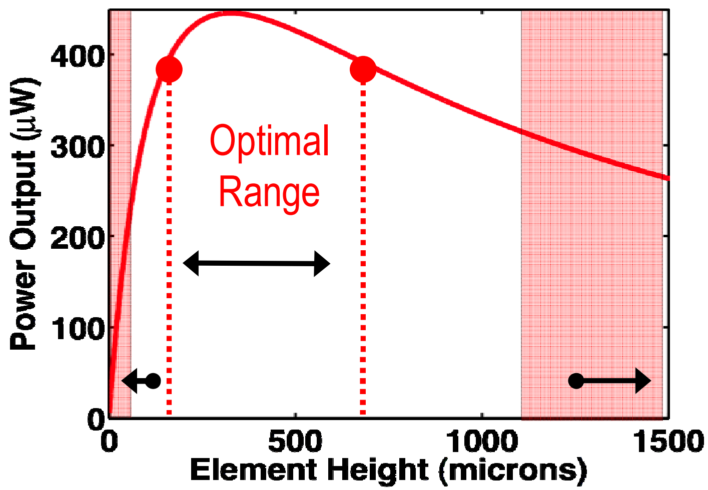
Seebeck coefficient (α)

Electrical conductivity (σ)

Thermal conductivity (k)

Design of Thermoelectric Devices

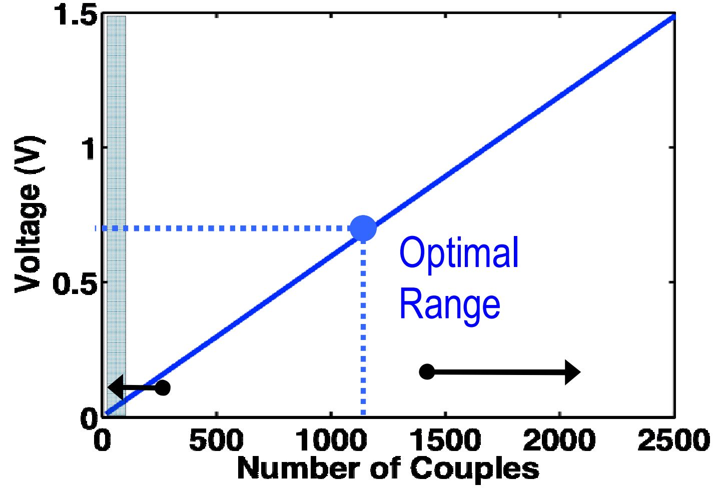
Power Dependence



Thin film elements

Bulk elements

Voltage Dependence

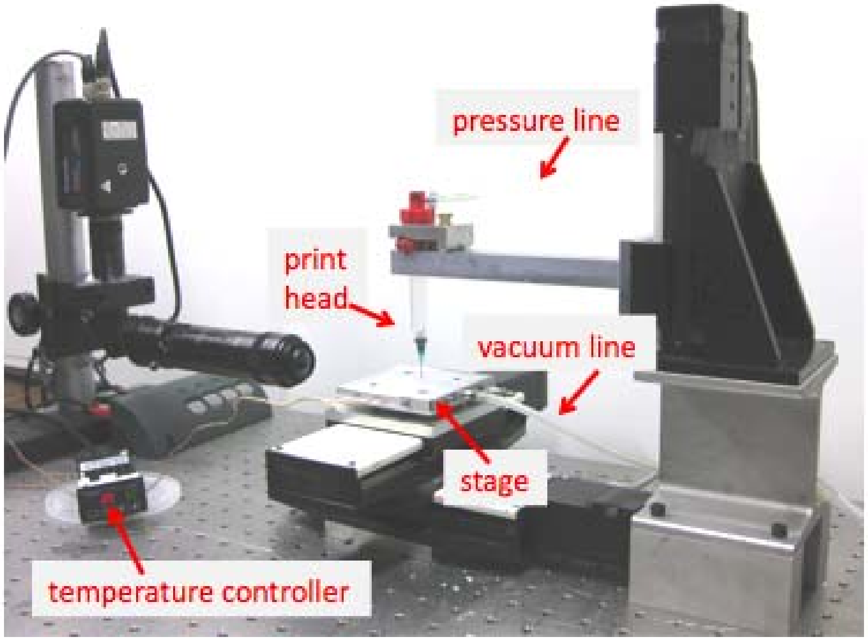


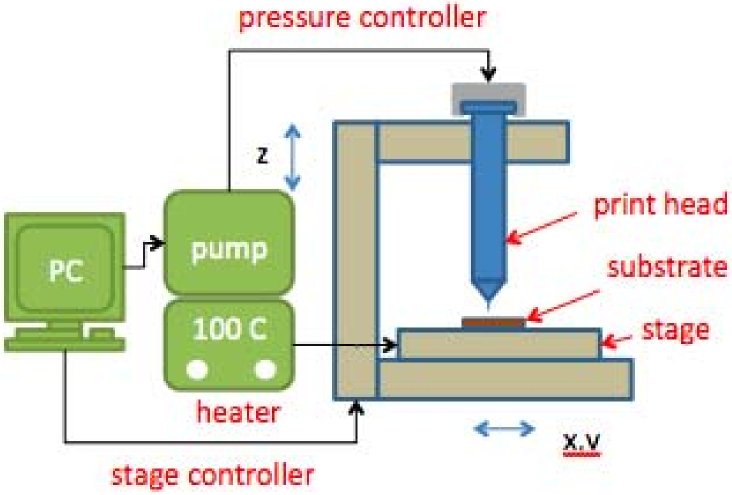
Bulk elements

Design Choice:

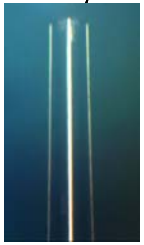
- Traditional technologies don't optimize for power output
- For waste heat sources, it is best to optimize for maximum power
  - Requires 100-500 μ m element sizes

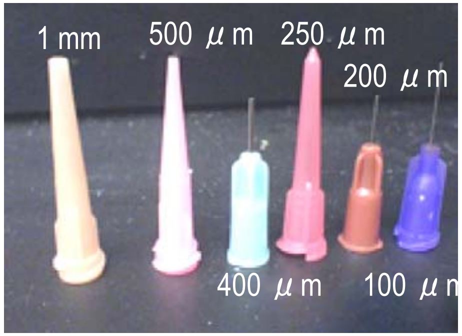
Direct-Write Dispenser Printing





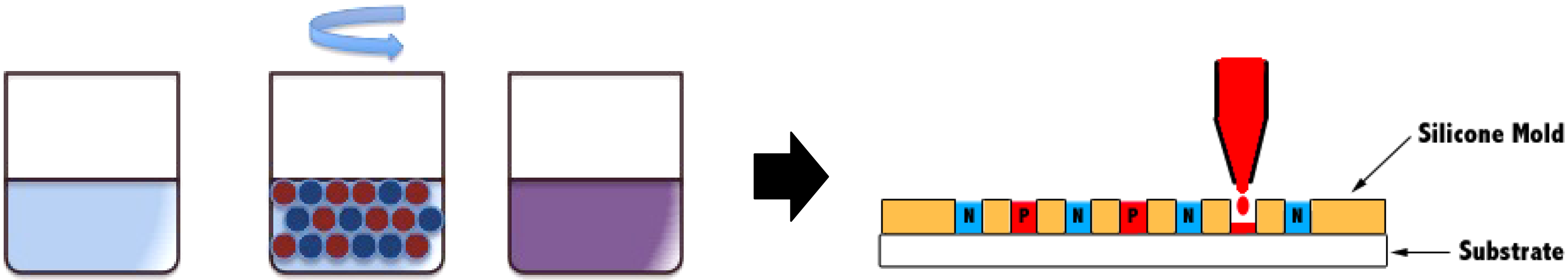
50 µm



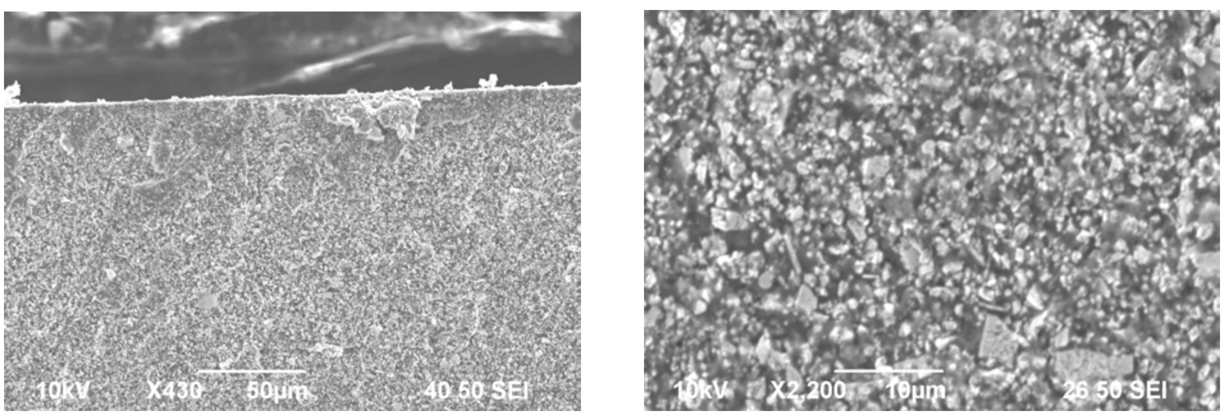


- 3 axis (X, Y, Z) Dispenser Printer
- 5 µm resolution stage
- Feature size limited by syringe tip size

Dispenser Printed Thermoeletrics



Polymer Resin | Add Active Particles | Ink | Print

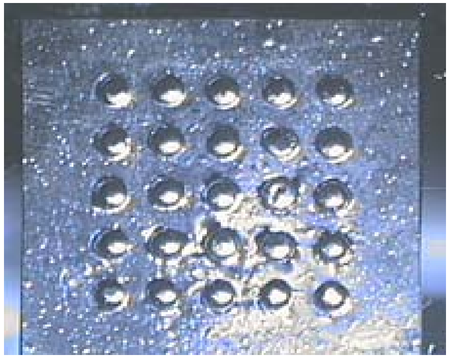


SEM Images of Printed Thermoelectric Materials

Preliminary Findings

- Existing bulk devices cannot meet the requirements for low waste heat sources to power
- Dispenser printing is a viable technique for creating the optimal size factors
- Initial materials show promising behavior
- Further work is being performed on materials optimization & device fabrication

Printed Thermoelectric Film



Device PDMS Mold

Predicted Performance (10K gradient)

Picocube Demand	Predicted
Power : 10 μW avg. Voltage : **0.7 V (DC conv)**	Power : 50 μW. Voltage : **1.3 V**