Concentrated Solar Thermoelectric Power

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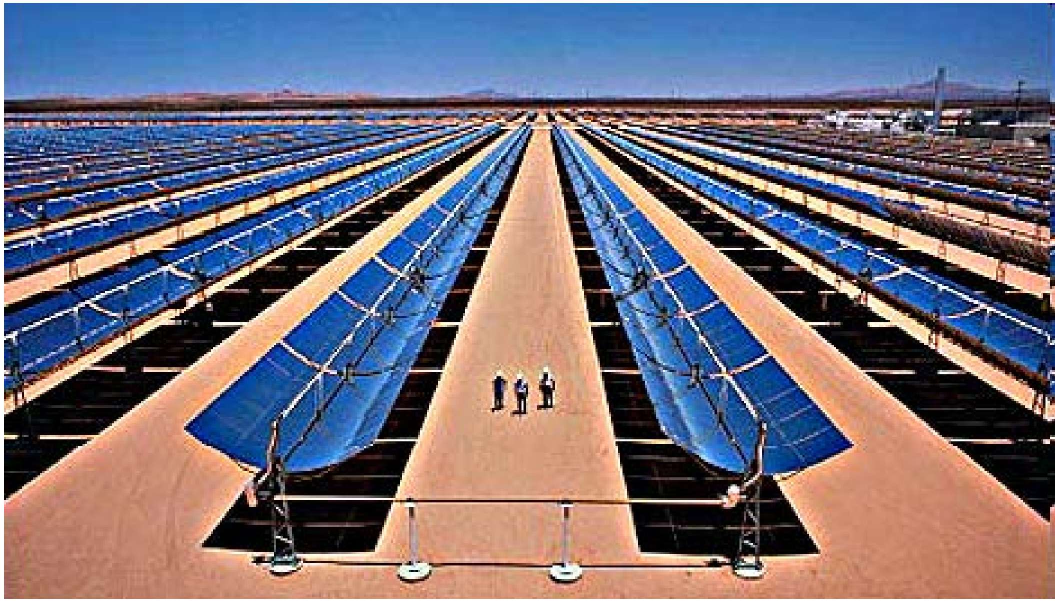
DOE EERE CSP Program: Funding Category: Seed Concept

Solar to Electricity Conversion

Solar Electricity: PV

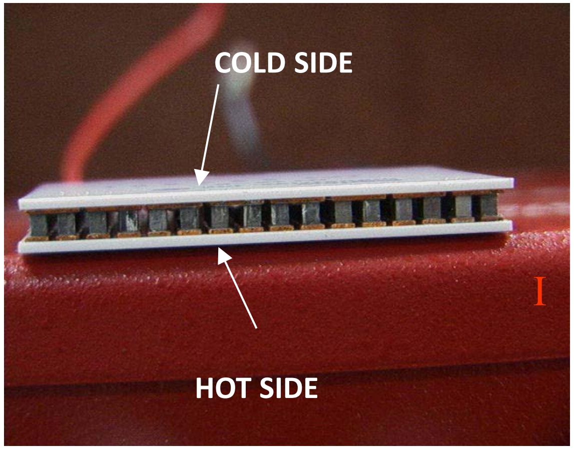
http://www.homesolarpvpanels.com

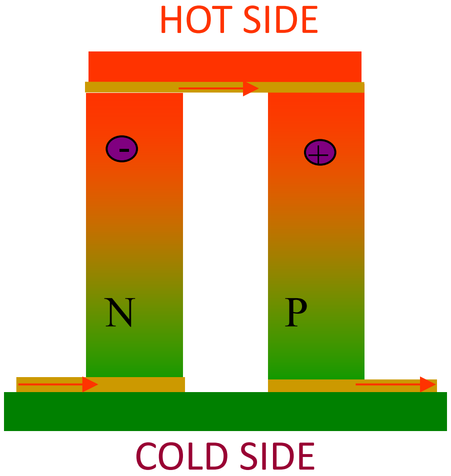
Solar Electricity: Thermal-Mechanical



http://www.treehugger.com/Solar-Thermal-Plant-photo.jpg

Thermoelectric Devices and Effects





Nondimensional Figure of Merit

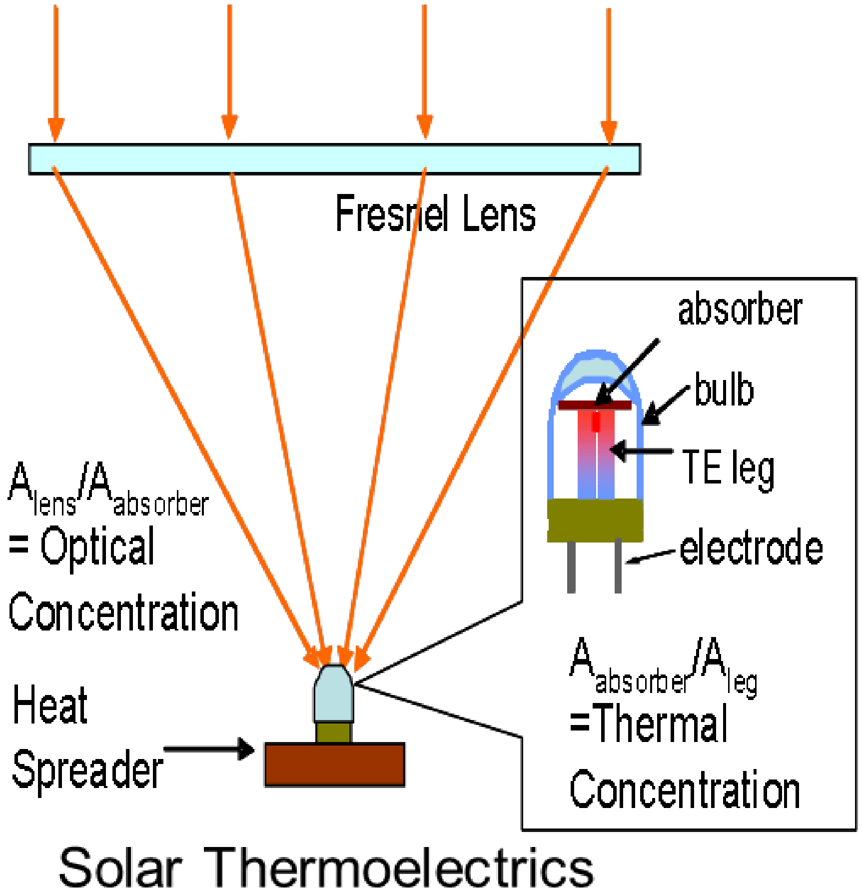
Joule Heating → σ

Seebeck Coefficient Electron Cooling → S^2

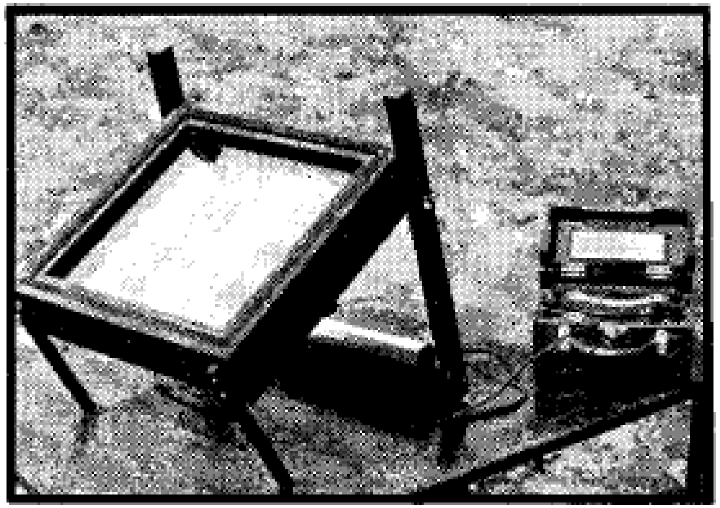
$$ZT = \frac{\sigma S^2 T}{k}$$

Reverse Heat Leakage Through Heat Conduction → k

Solar Thermoelectric Energy Conversion



- US Patent No. 389124: E. Weston in 1888
- M. Telkes, JAP, 765, 1954



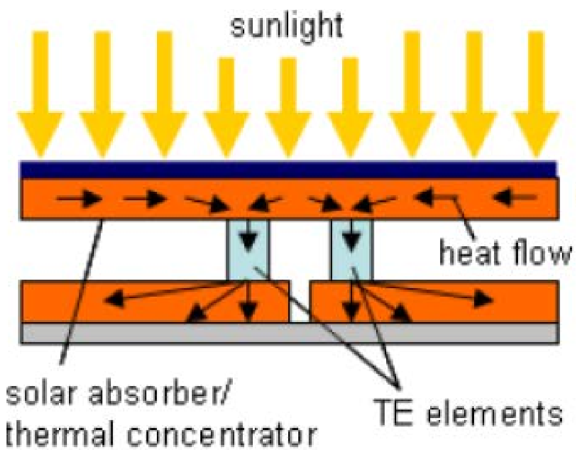
Efficiency: 0.63%

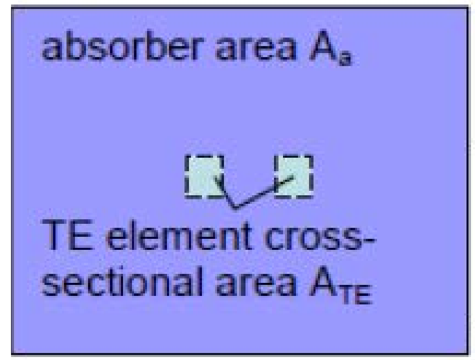
Heat Flux Considerations

$$q = k\frac{\Delta T}{L} \approx 1\frac{\mathrm{W}}{\mathrm{m}*\mathrm{K}}\frac{100\,\mathrm{K}}{L}$$

***q*=1000 W/m^2 (1 Sun); *L*=100 mm**
***q*=100,000 W/m^2 (100 Sun); *L*=1 mm**

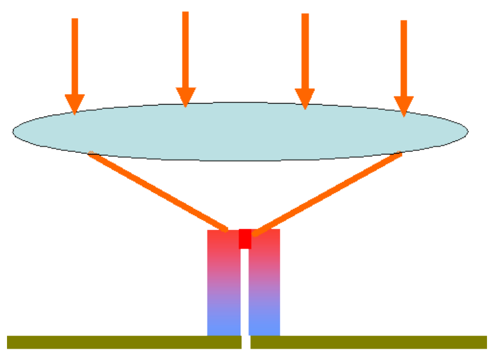
Optical vs. Thermal Concentration



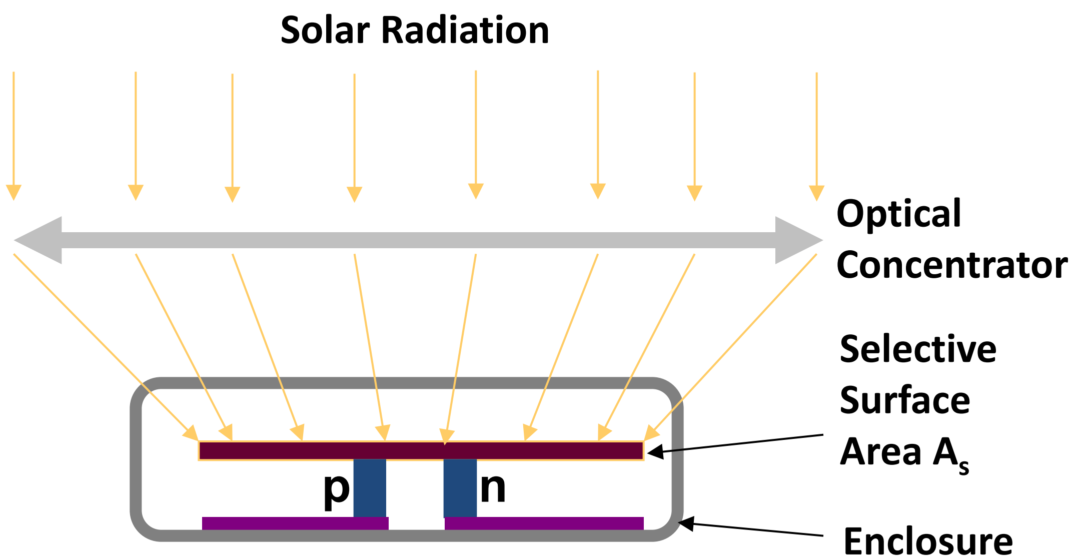


thermal concentration

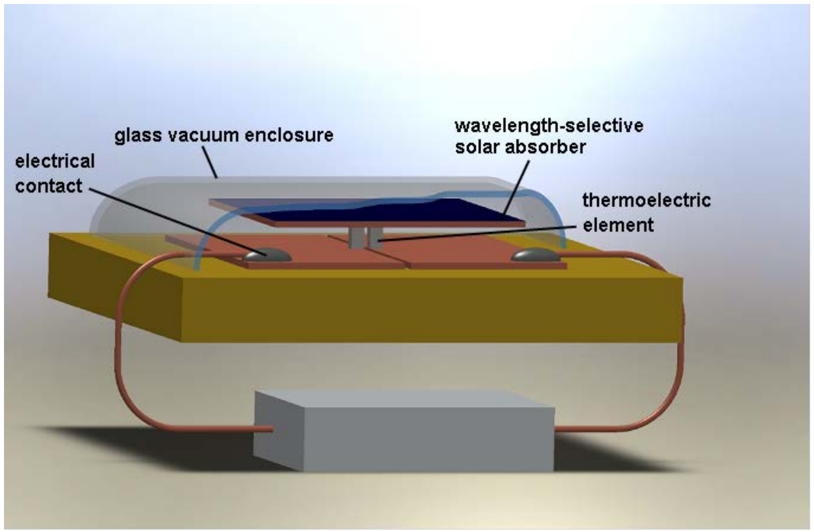
$$C_{th} = \frac{A_a}{A_{TE}}$$

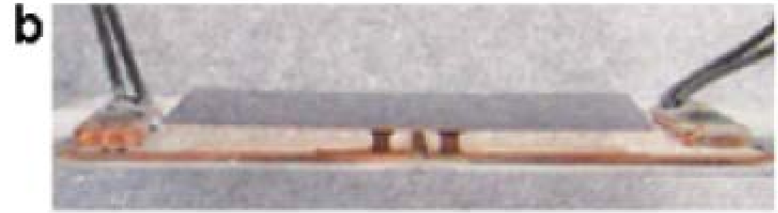


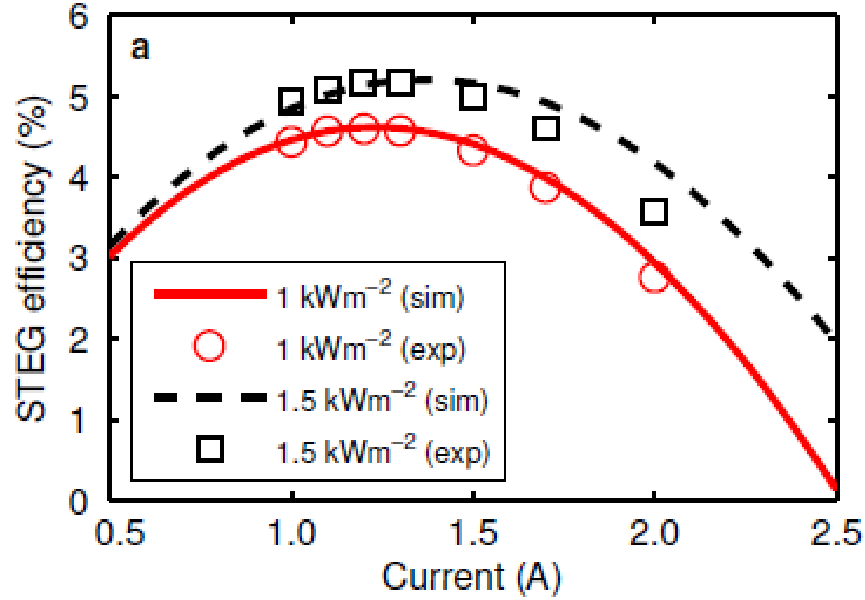
Optical Concentration



Flat Panel Solar Thermoelectric Generators (STEGs)

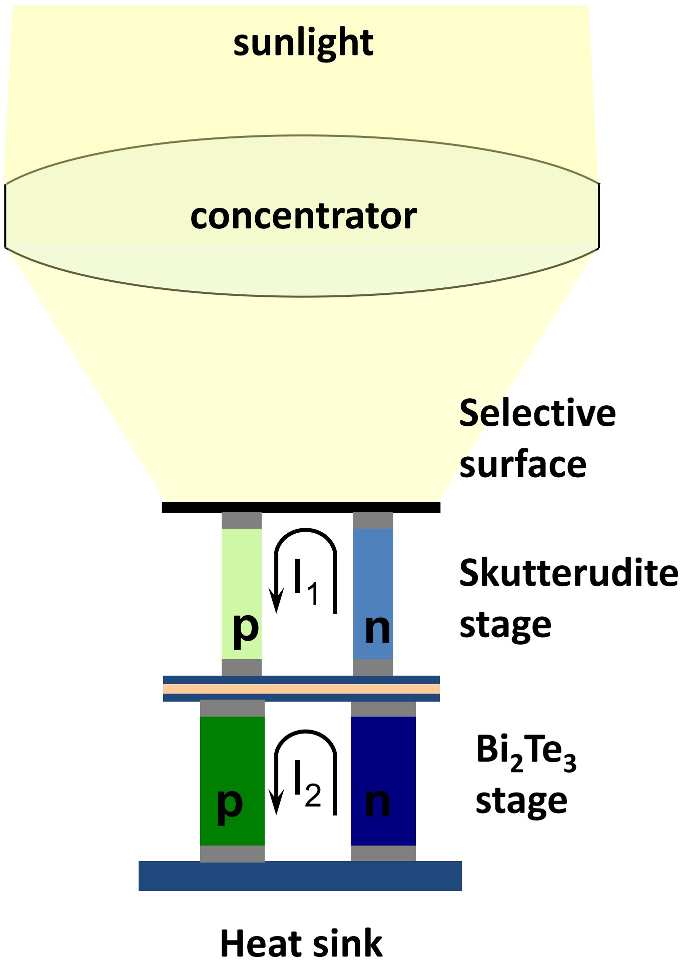


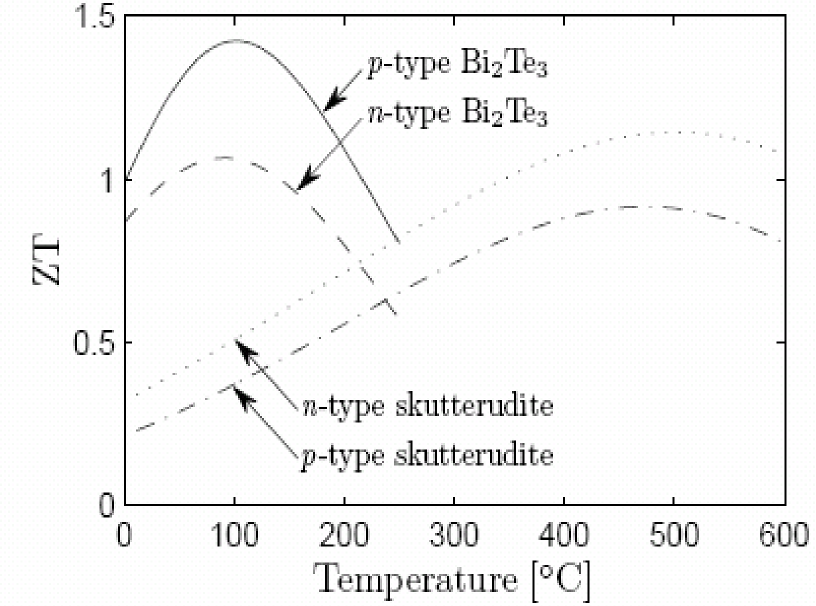


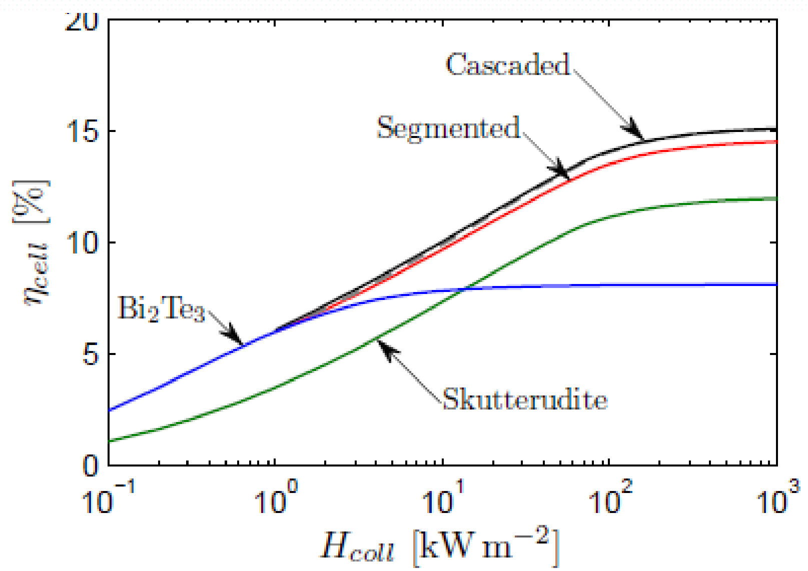


Kraemer et al., Nature Materials, May, 2011

Two-Stage Concentrated STEGs





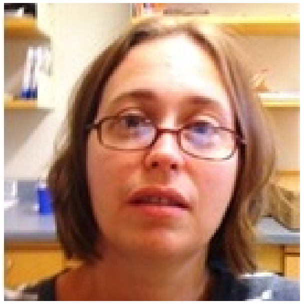


Program Goals

- Demonstrate 10% solar-to-electric energy conversion by using optical concentration and a multi-stage TEG
- Limit required optical concentration to less than 10X, ideally less than 4X
- Demonstrate the potential for 24-hour operation by incorporating phase change materials into design

Core Team

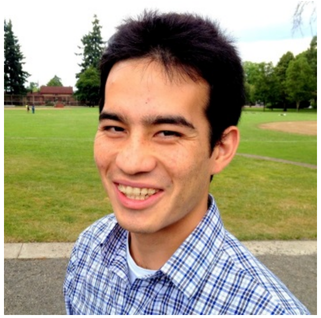
Professor Gang Chen, Principal investigator



Dr. Sveta Boriskina
Optical Engineer

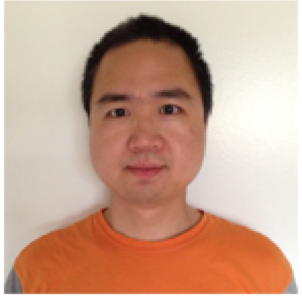
Ken McEnaney
Device Engineer

Daniel Kraemer
System Engineer



Lee Weinstein
System Engineer

Professor Zhifeng Ren
Co-Principal Investigator



Dr. Qing Jie
Materials Scientist

Dr. Feng Cao
Materials Scientist

Dr. Weishu Liu
Materials Scientist

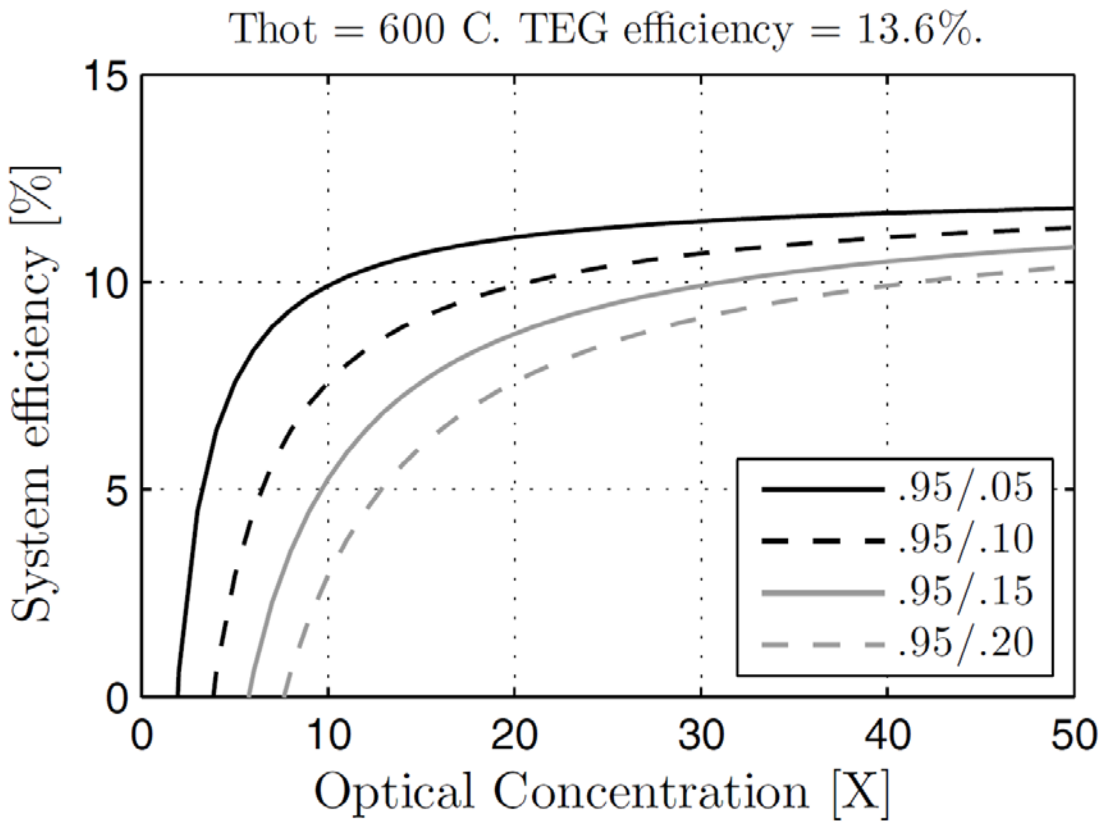
Major Tasks and Challenges

- Devices
  - Electrodes
  - Device joining
- Emittance
  - Selective surfaces
  - Optical design
- Systems
  - Modeling
  - Integration
  - Testing

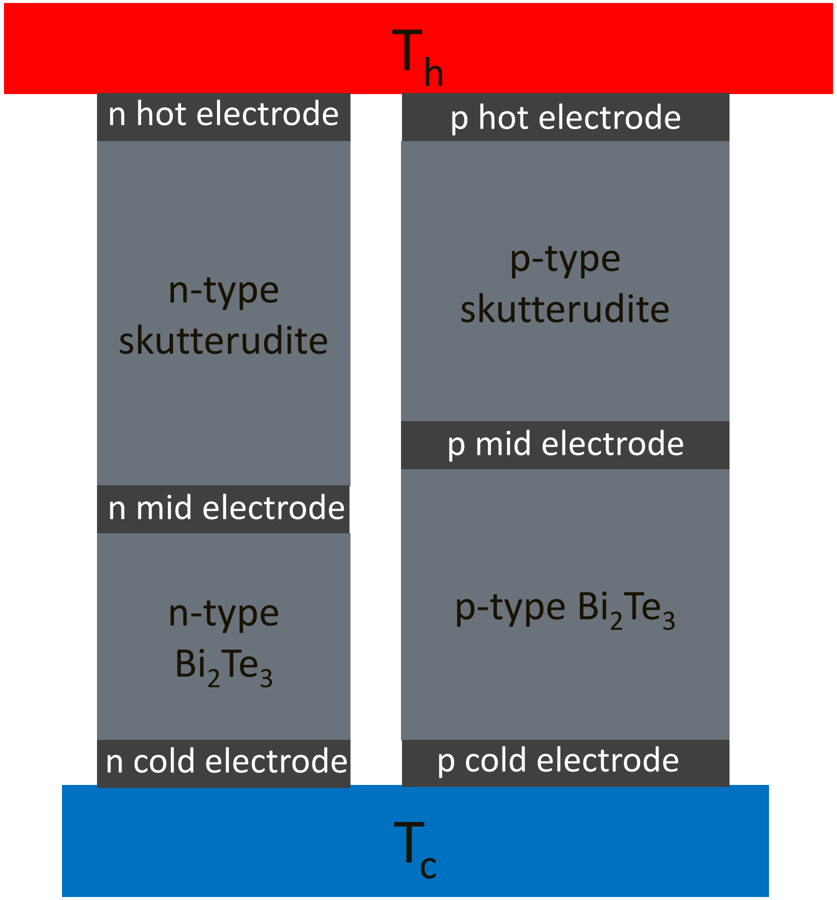
Effect of electrodes and contacts:

- Parasitic losses have a linear negative effect on system performance

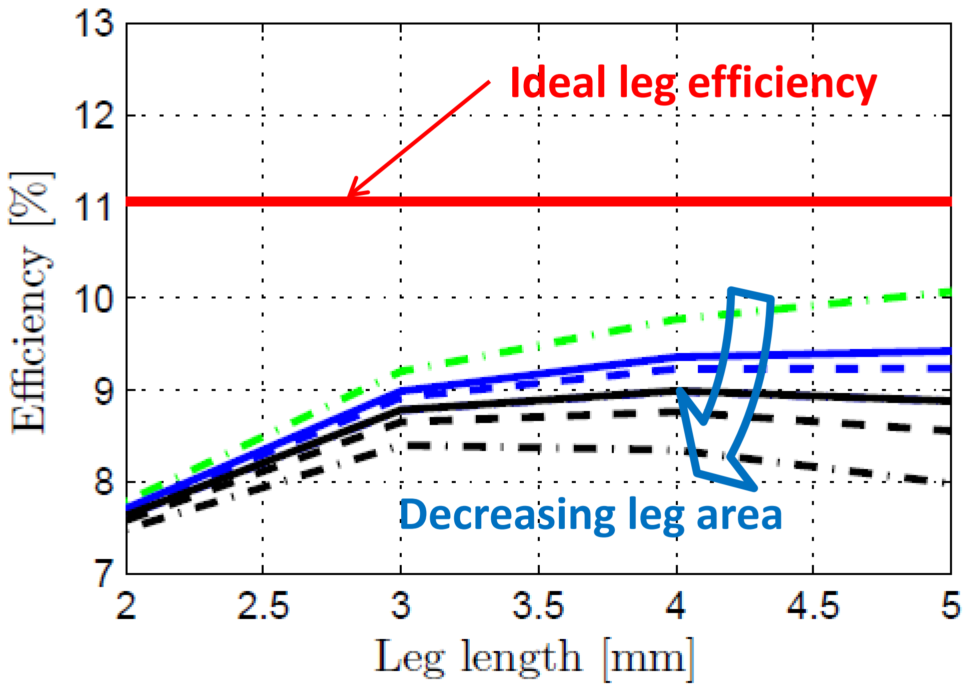
Effect of absorptance/emittance:



TEG Optimization: Critical Parameters

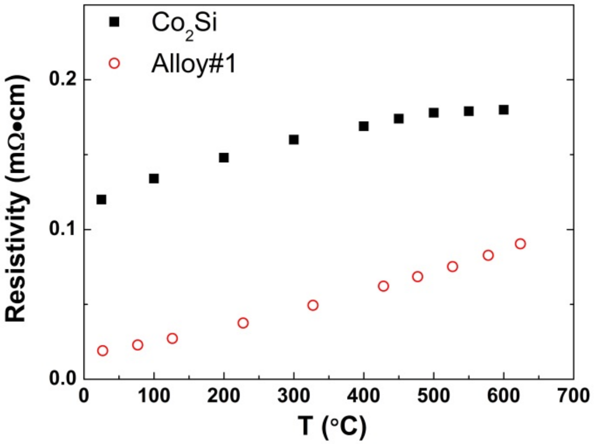


- Geometry must be optimized to
  - Reduce parasitic effects of electrode and contact resistance
  - Reduce effect of radiative losses from sidewalls
- For each thermoelectric leg:

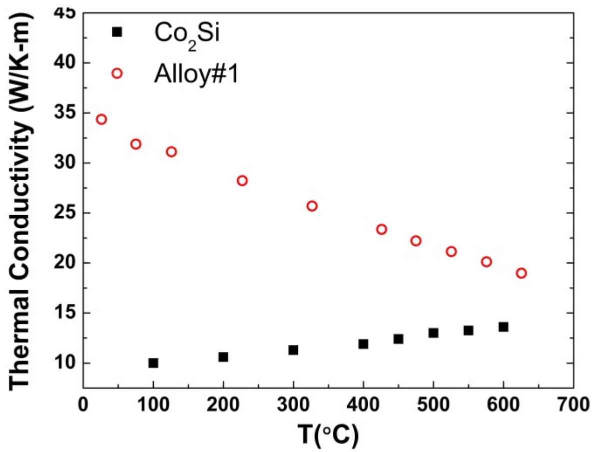


Electrodes: Material Properties

- Bi_2Te_3 electrodes: <1% of system resistance
- New p-type skutterudite electrode alloy:



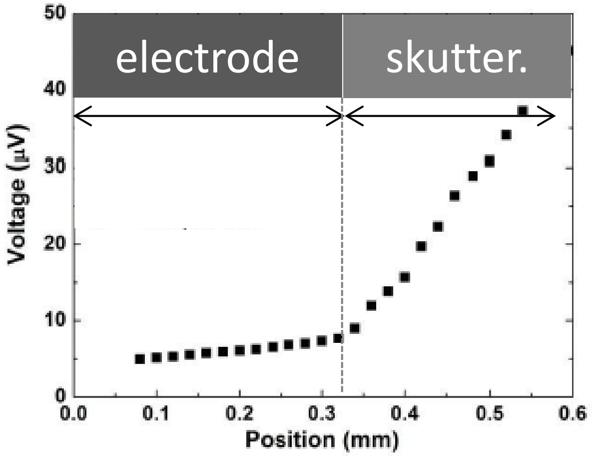
Electrical resistivity reduced by a factor of 3+



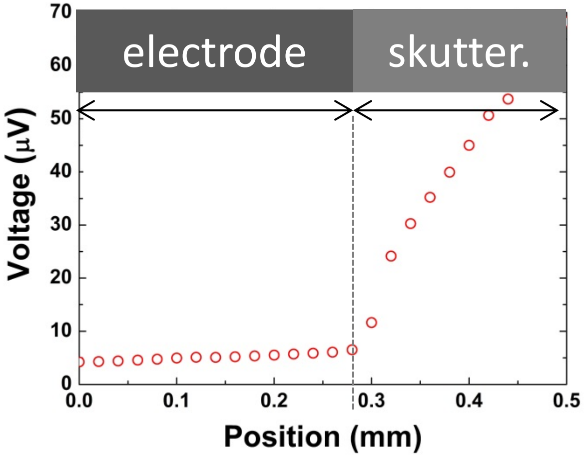
Thermal conductivity increased 50% – 200%

Electrodes: Contact Resistance

- Bi_2Te_3/copper contact resistance < 1 μΩ•cm^2
- Skutterudite/electrode contact resistance:



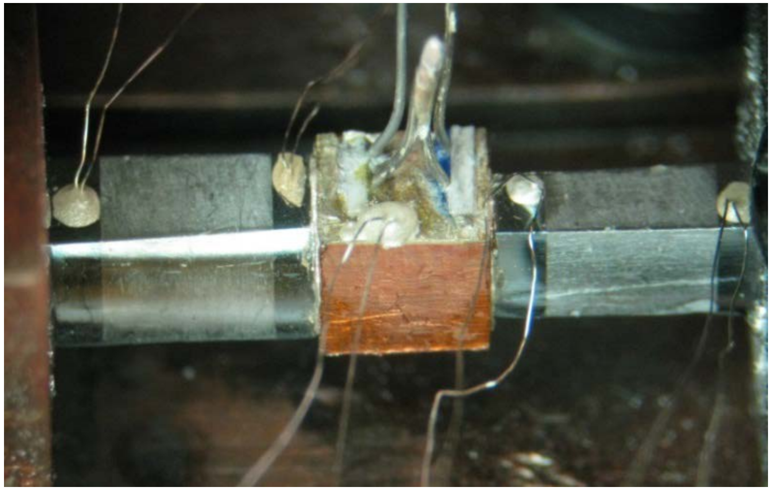
n-type: <1 μΩ•cm^2

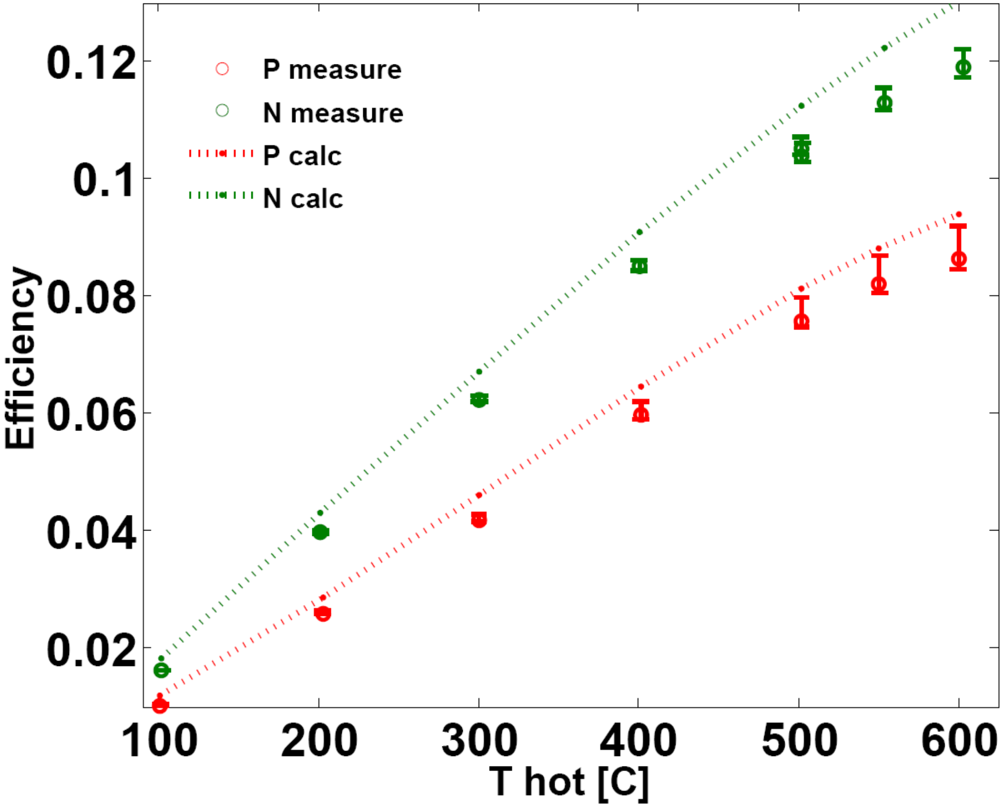


p-type: 6 μΩ•cm^2

TEG Device Testing

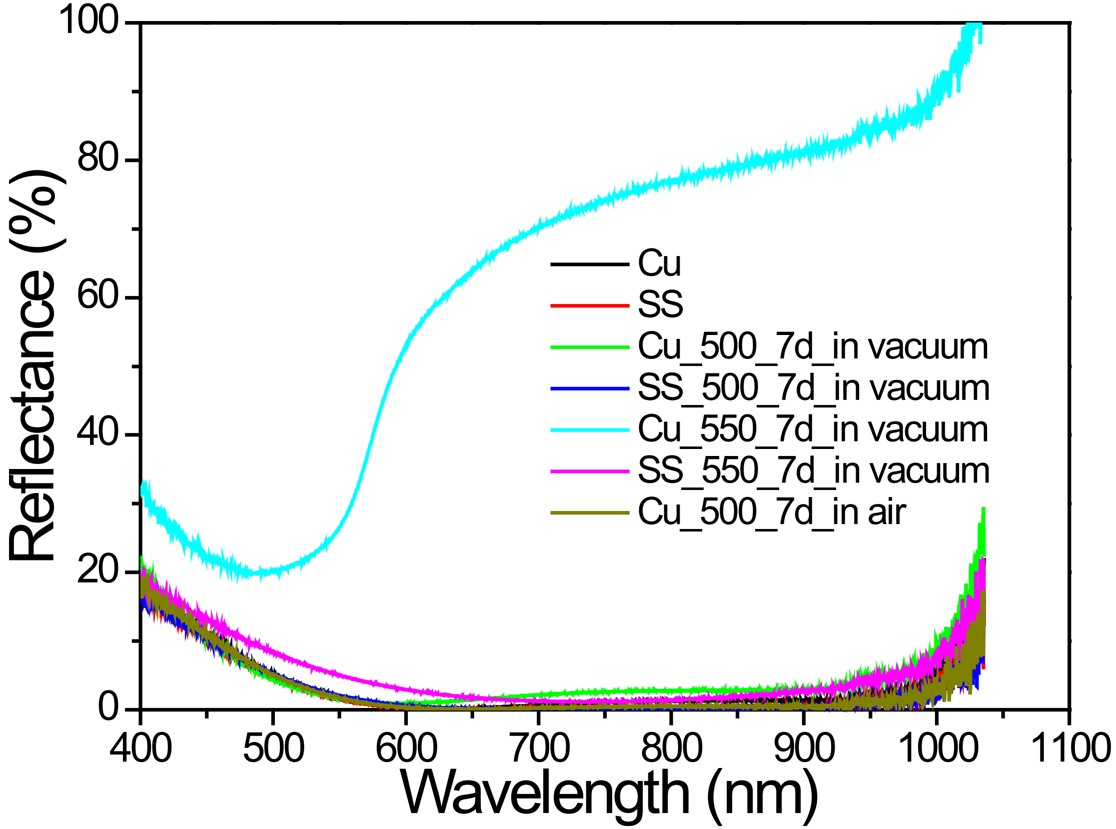
- Currently testing single-stage devices; 9% efficiency recorded.
- Multi-stage devices should boost efficiency to ~13%

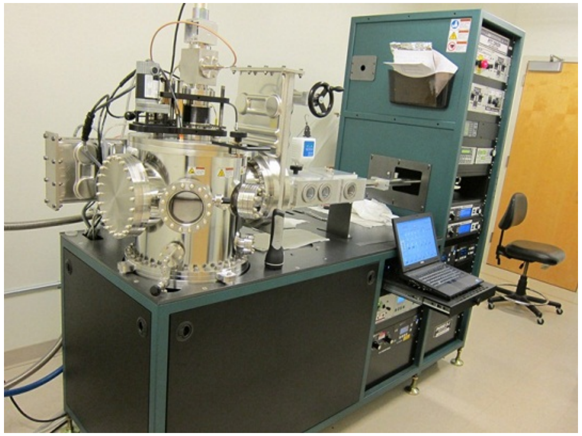




Selective Surfaces

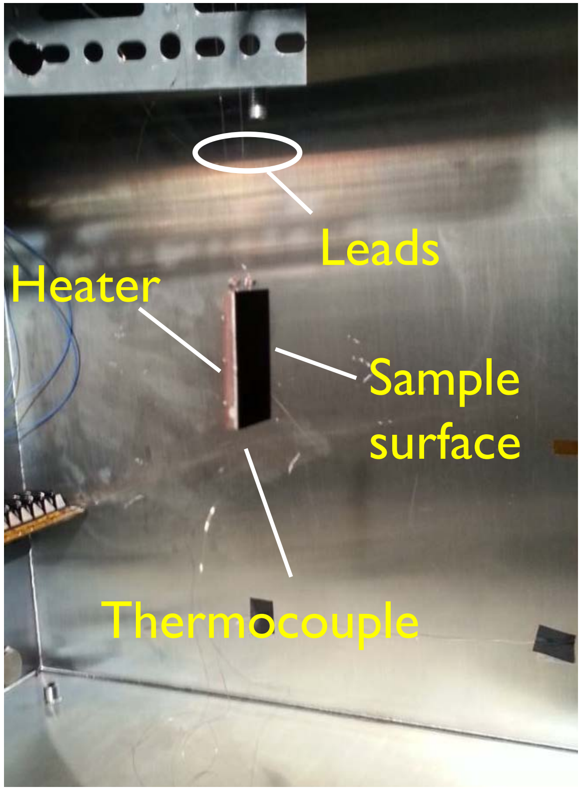
- Optimized for operating temperature (500 – 600 °C)
- Manufactured via sputtering
- Surfaces with copper substrates not stable at high T

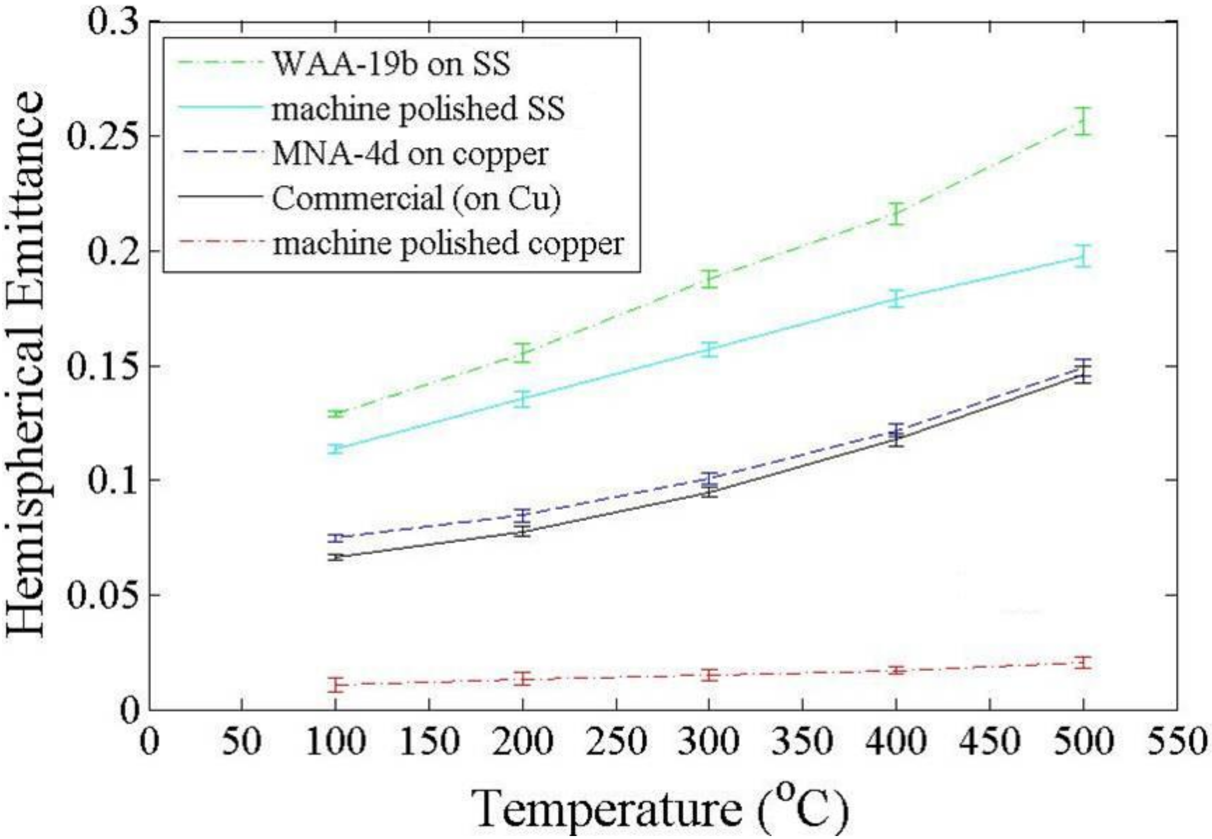




Emittance Testing

- Direct measurement of total hemispherical emittance at high T:

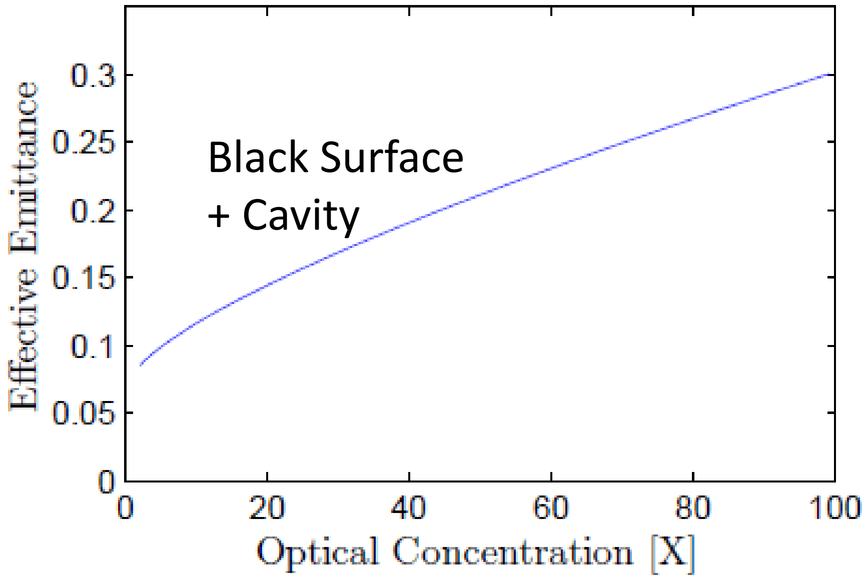




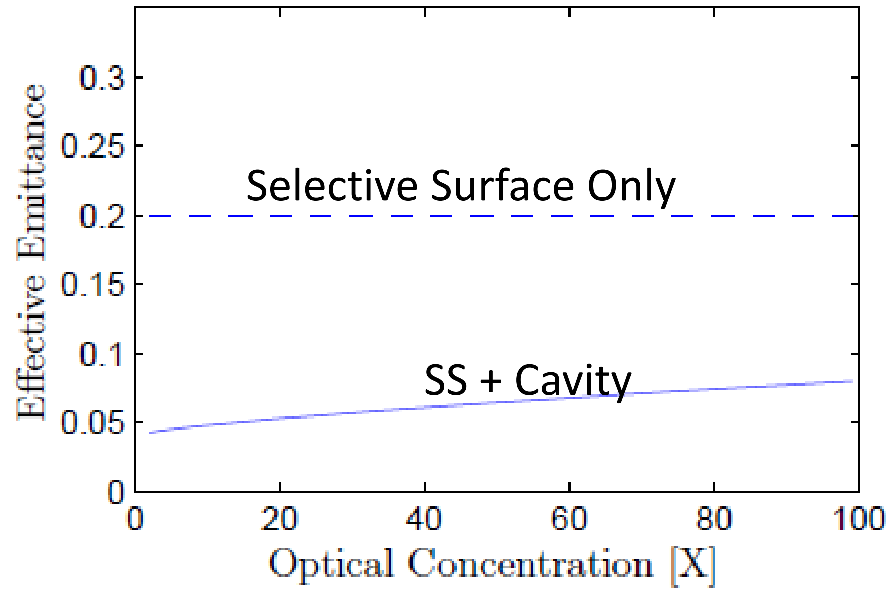
Receiver Cavity

- Receiver cavity can reduce heat loss from black surface or selective surface

With blackbody absorber:

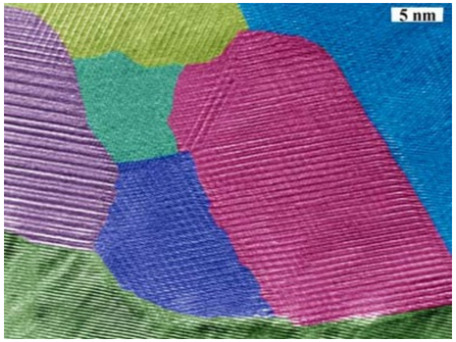


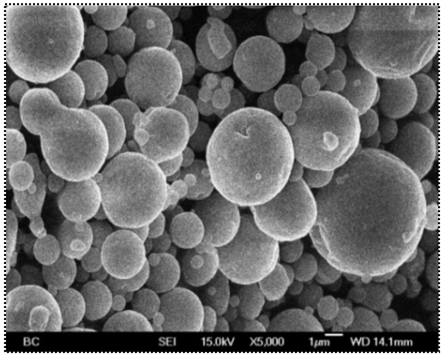
With 20% selective surface:

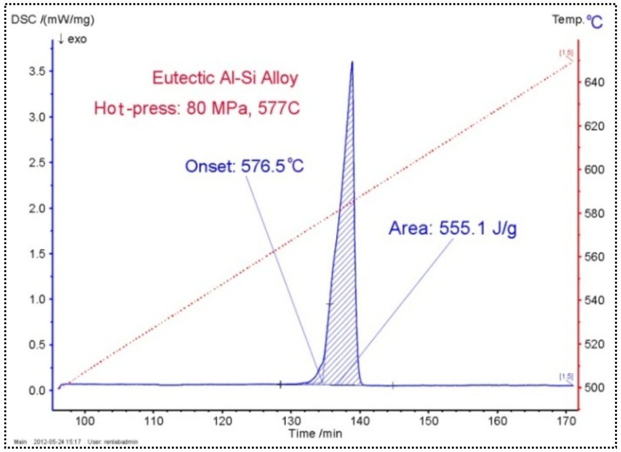


Additional Leverage

- Experience:
  - Materials
  - Devices
  - Heat Transfer
  - Multiple Start-ups
- Other Programs:
  - EFRC S^3TEC: thermoelectric materials
  - ARPA-E HEATS: Storage







Transformative Potential

- Third way: sunlight into electricity
- Low cost due to:
  - Solid state power block
  - Low optical concentration
  - Small amount of materials
  - Thermal storage
- Large market
  - Rooftops
  - Small communities
  - Power plants