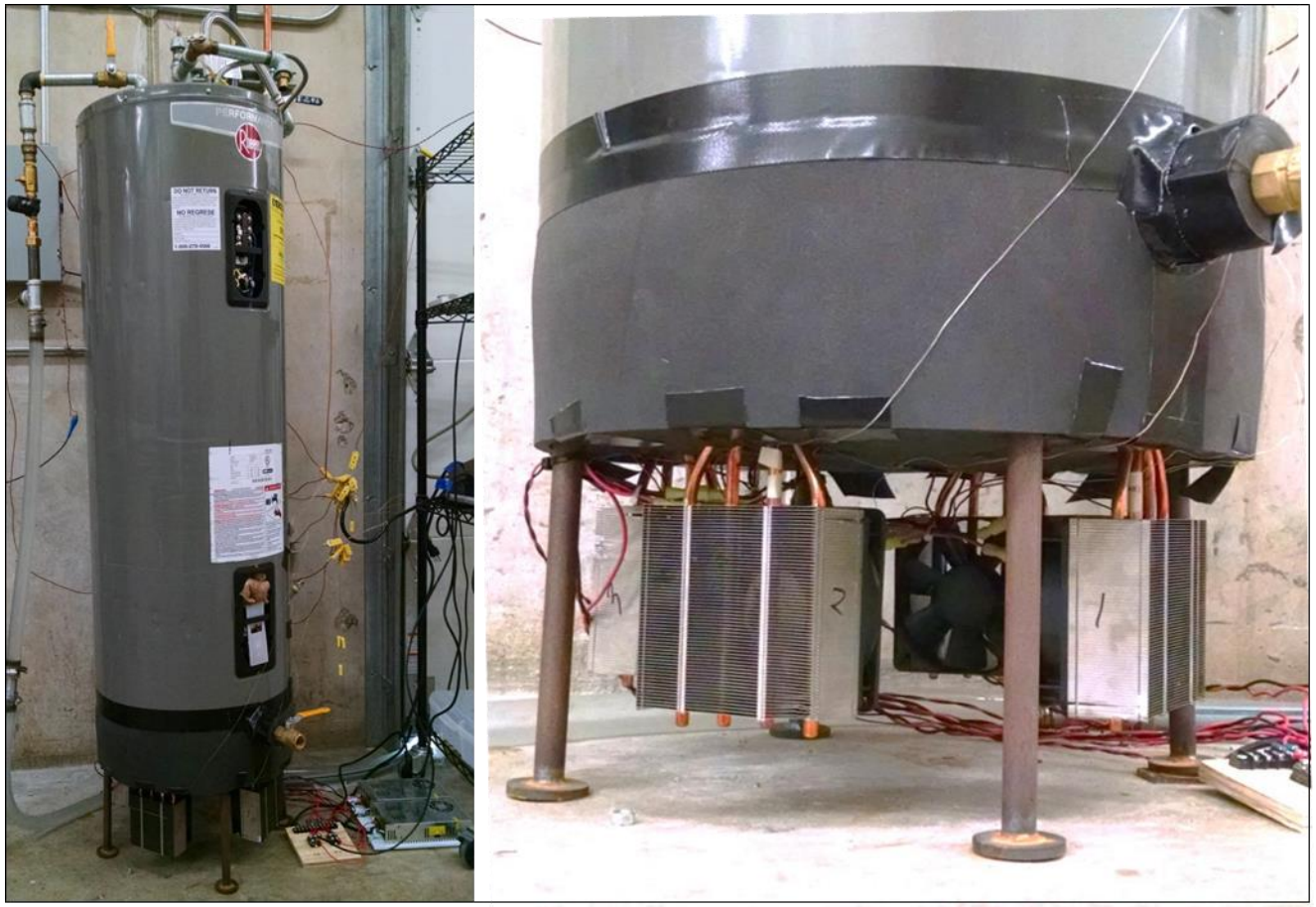
Heat Pump Water Heater Using Solid-State Energy Converters

2015 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: 11/15/2012

Planned end date: 5/14/2016

Key Milestones:

1. Development of Bottom Mount 4-Engine Thermoelectric Heat Pump; 5/14/2014
2. Development of High Cooling Power Thermoelectric Modules for Heat Pumps; 5/14/2015
3. Performance (COP > 1.1) and Reliability of 4- and 8-Engine Thermoelectric Heat Pumps ; 6/14/2016

Budget:

Total DOE $ to date: $1149900.00

Total future DOE $: $499975.00

Target Market/Audience:

Home Water Heaters with Affordable, Reliable Solid-State Heat Pumps

Key Partners:

Whirlpool Appliance (Consultation for Specs)

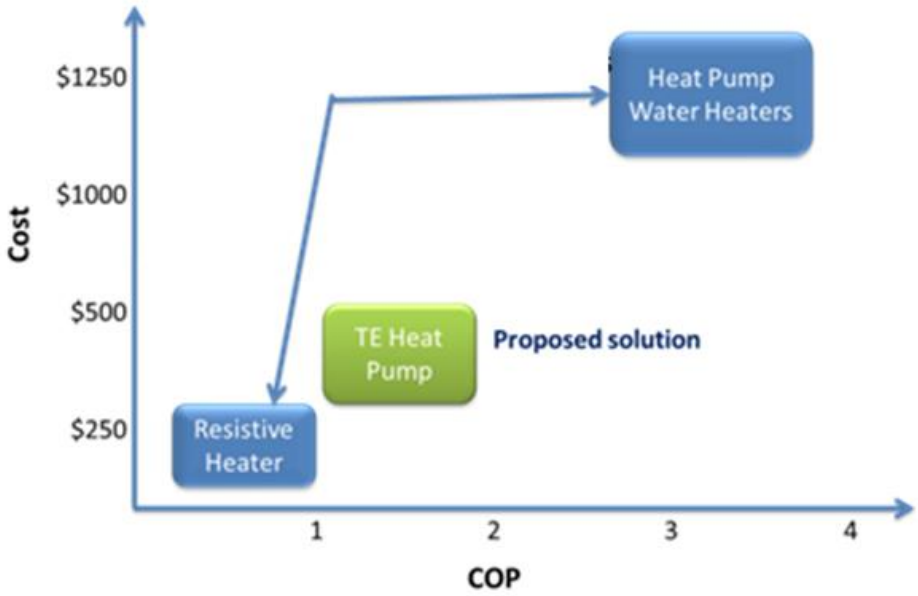
Project Goal:

Demonstrate a home water heater product with affordable and reliable solid-state heat pumps with COP > 1.1 The project includes development of high cooling power thermoelectric modules as well as development of bottom-mount 4-engine and 8-engine heat pumps.

Purpose and Objectives

Residential Water Heaters

- 15% of energy consumption
- 45% are electric heaters: ~ 1.34 Quads of primary energy
- $300- $700 per year energy cost
- Vapor compression based heat pump water heater are very expensive



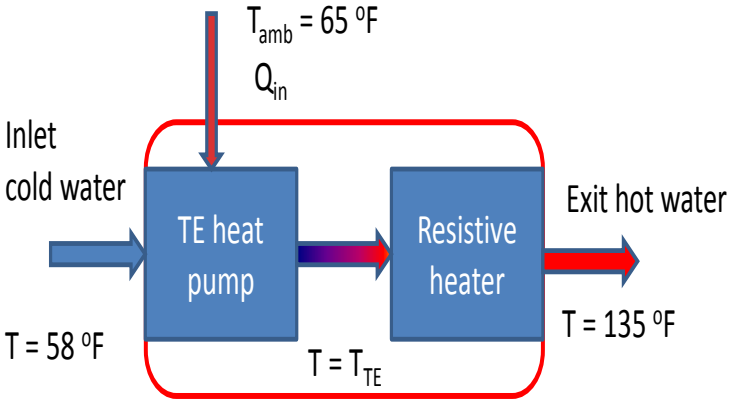
Sheetak's Solution

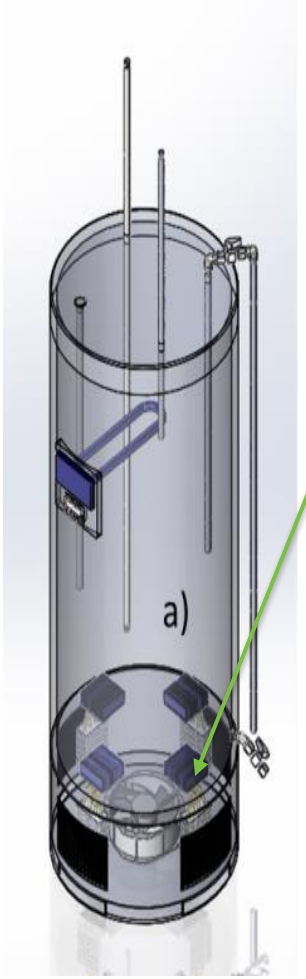
Low-Cost Thermoelectric (TE) Heat Pump Water Heater

Impact of the Project

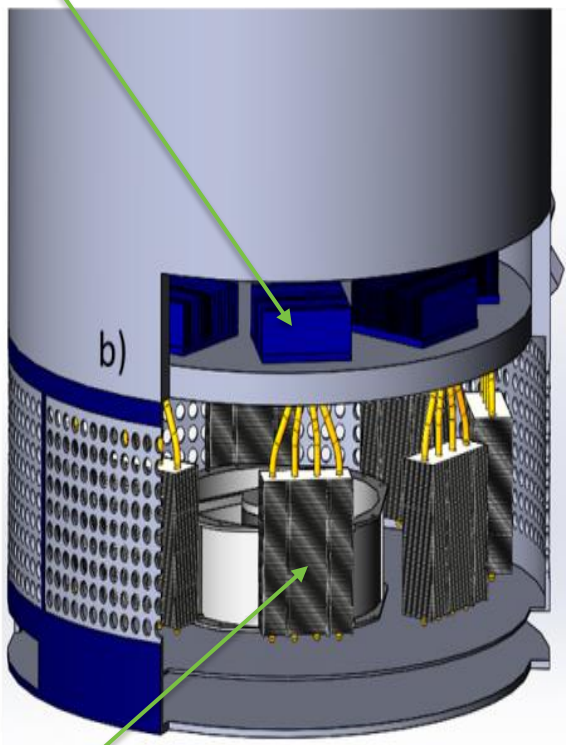
- Demonstration of first TE-based 50 gallon heat pump water heater
- COP > 1.1 (goal of the SBIR)
- Development of novel thermoelectric modules and substrates
- Development of novel system-level hardware
- Cost-effective heat pump water heater
- Achievements
  - Near term: COP > 1 with 4 TE cooling engines
  - Intermediate term: COP > 1.2 with 8 TE cooling engines, teaming with a water heater manufacturer
  - Long term: Launch of TE based water heater in the market

Thermoelectric Heat Pump Water Heater



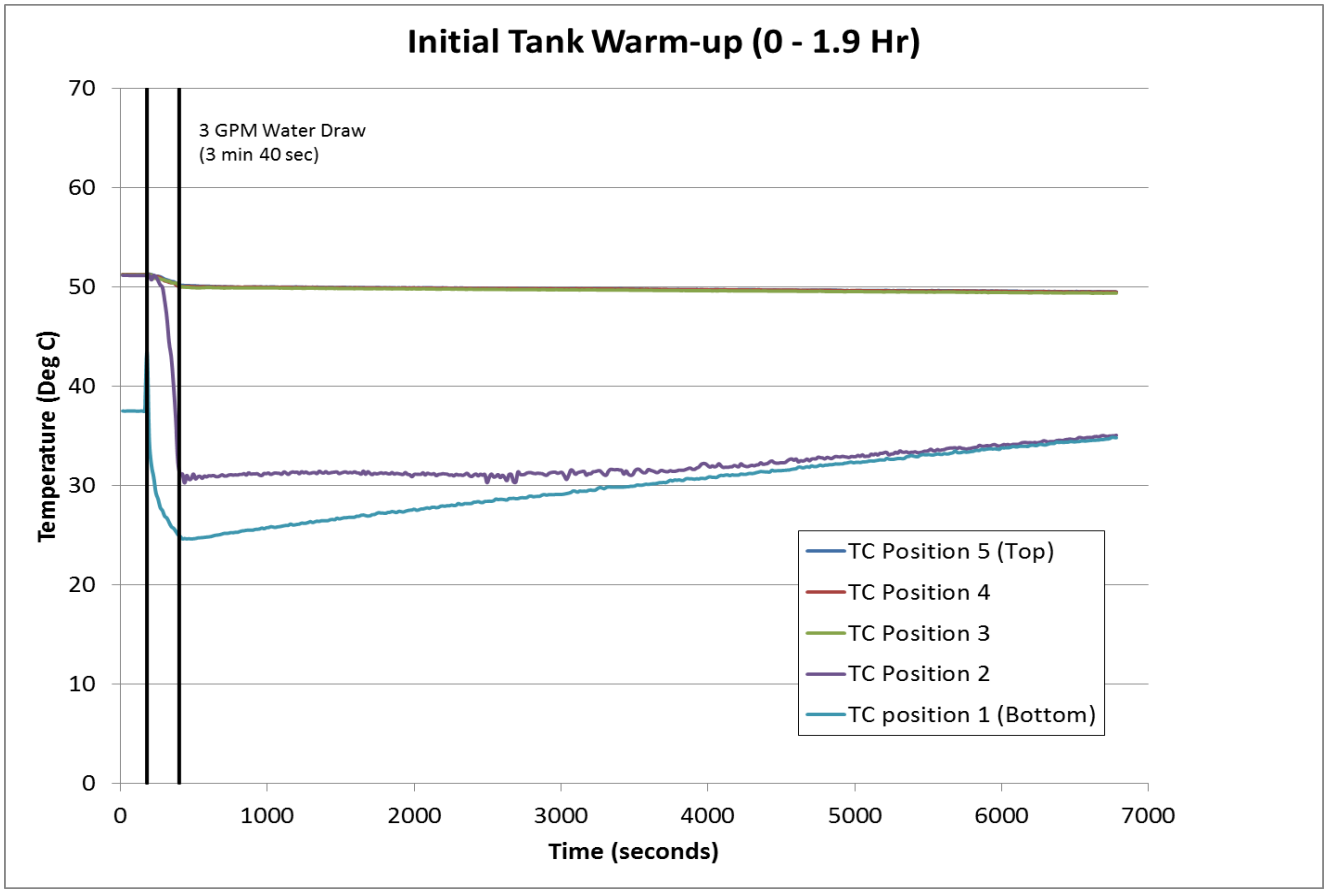


Thermoelectric Hot Side



Thermoelectric Cold Side (Heat-Pipe Heat Sink)

Preliminary Results: 4 TE Engine Water Heater



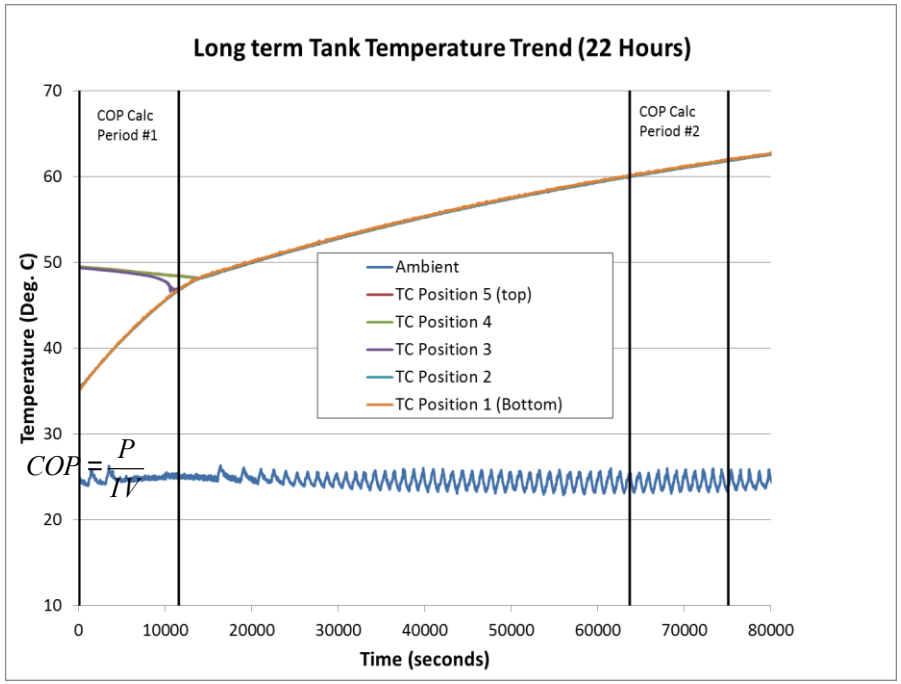
- 3GPM water withdrawal in 3 minutes 40 sec (as per testing standards)
- Only TE used for heating after the withdrawal
- Issues: Slow heating observed by TE

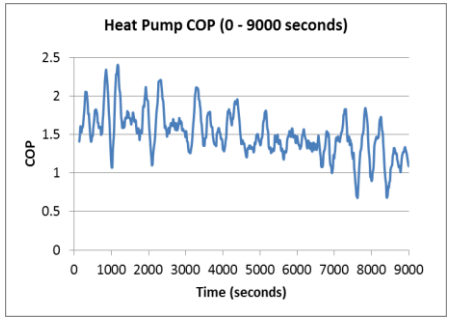
Preliminary Results: 4 TE Engine Water Heater

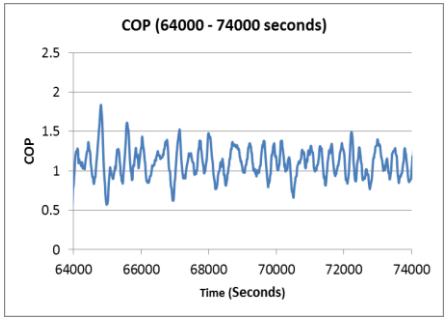
$$P = mC_p \frac{dT}{dt} + K(T - T_a)$$

$$COP = \frac{P}{IV}$$

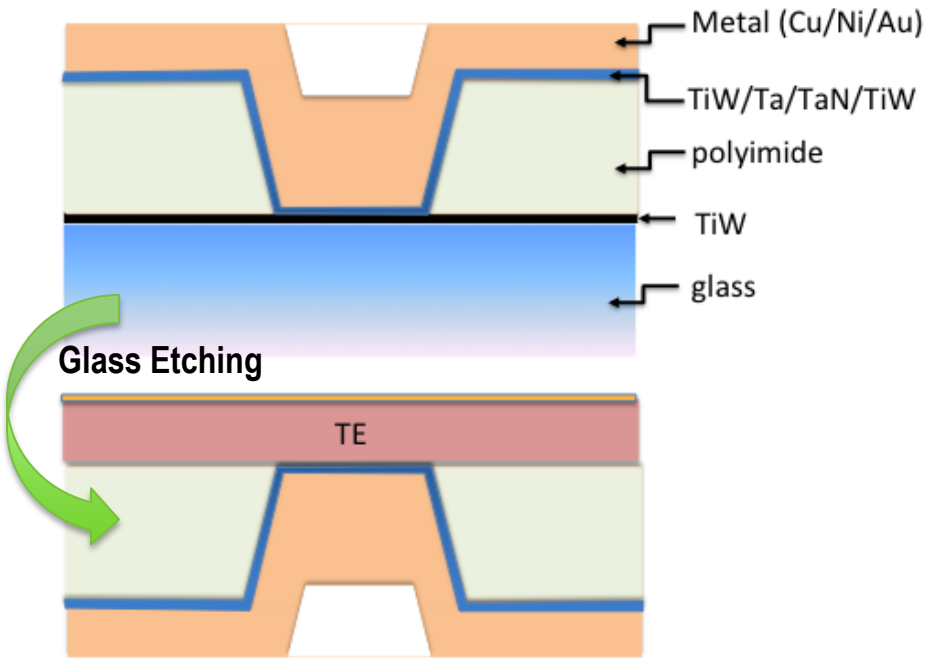
- P = heating rate, estimated using the above equation
- Due to discrete measurements and fluctuations in ambient temperature, there are some uncertainties
- COP is high in the beginning due to low temperature difference
- COP decreases with time due to increase in temperature difference
- After a certain temperature rise, resistive heater will be switched on (work on controls, in progress)







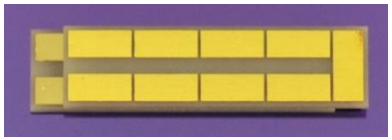
High Performance TE Modules – Thin Film Devices

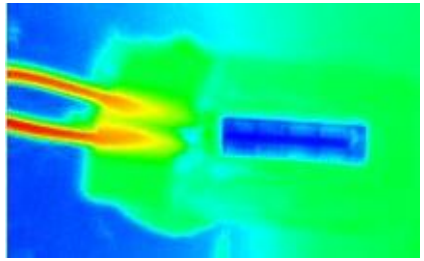


Thin Film $Bi_{0.5}Sb_{1.5}Te_{3.0}$ and $Bi_2Te_{2.8}Se_{0.2}$ Devices

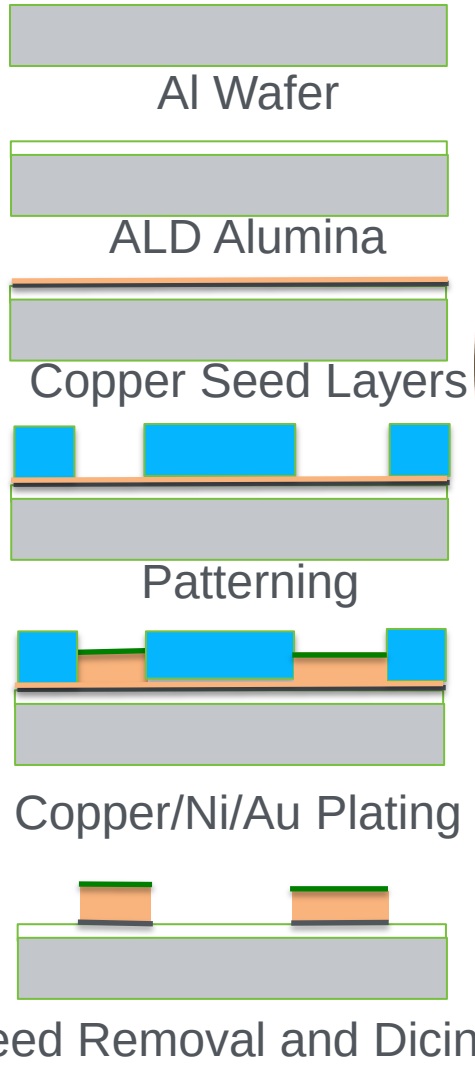
- Very high heat flux > 100 W/cm^2
- ΔT ~ 50°C for AlN substrates, COP ~0.6 for ΔT (external) = 30°C
- Requires metal-core substrates and high performance solders
- Packaging cost may be high

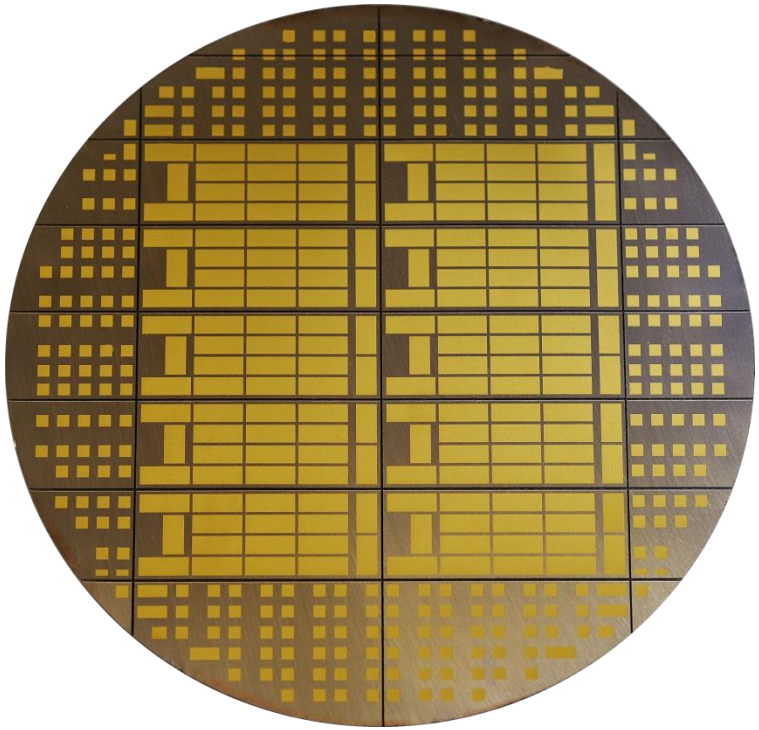
8-Couple Q&T



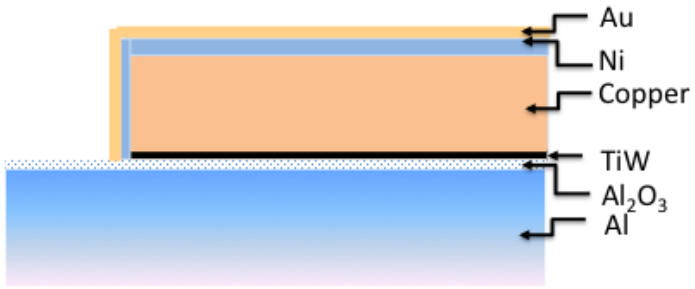


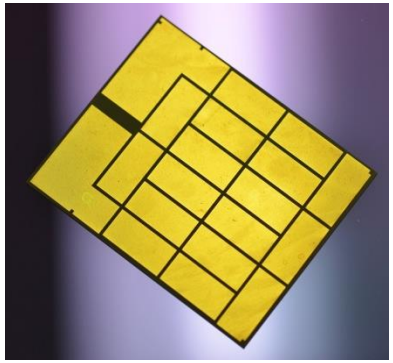
High Performance TE Modules – Substrates



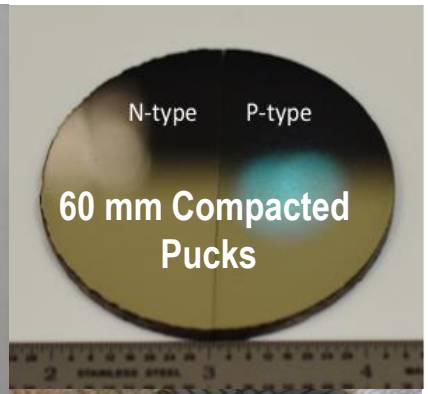


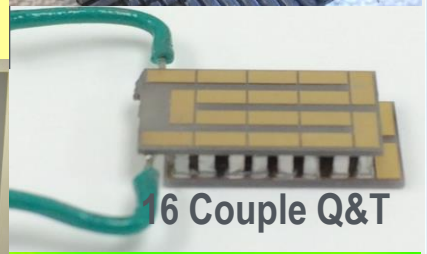
- 150-200 mm Al wafers
- ΔT (substrate) < 1°C for flux ~ 100W/cm^2
- Lower cost than AlN ceramics
- CTE-compatible with heat exchangers

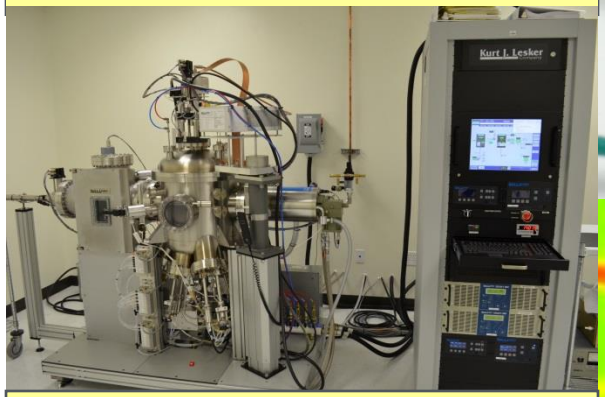




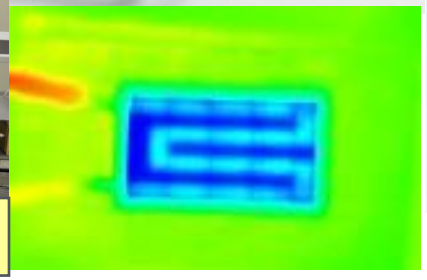
High Performance TE Modules – Thick Film Devices



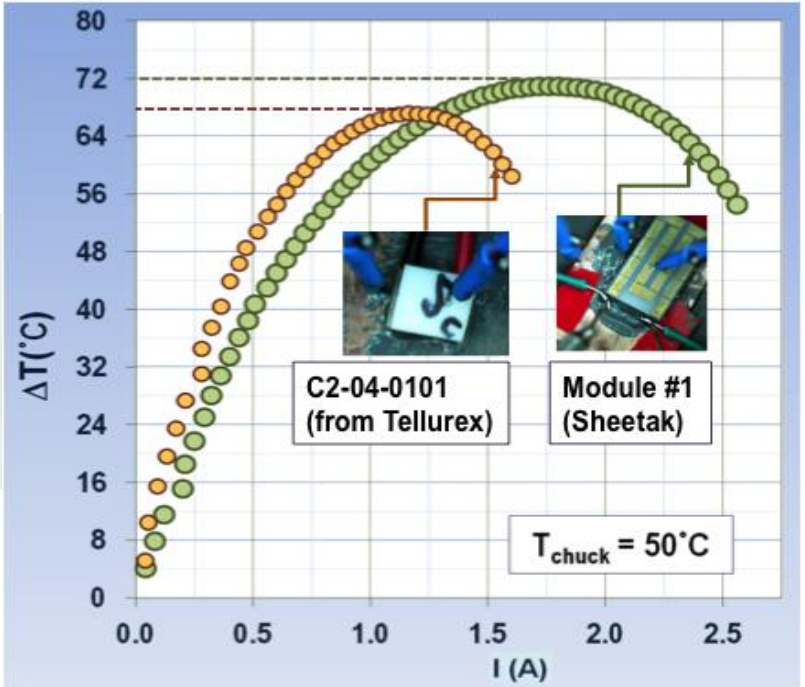




Barrier Sputtering



- ΔT ~ 80°C for Al-core substrates
- Significant performance improvements with proprietary nanostructured materials
- Packaging cost is small for ~1kW heat pumps



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Progress and Accomplishments

Accomplishments

- Bottom-mount TE heat pump water heater fabricated and preliminary testing data obtained
- Thin film and new thick film TE fabrication process
- Novel metal-core TE substrate developed (superior to state-of-the-art are ceramic substrate)

Challenges

- Slow heating observed by TE heat pump. Risk mitigation involves use of TE heater in conjunction with the resistive heater and better heat sink design
- Significant parasitic temperature losses due to high heat flux in thin film TE. Novel thick film process developed to reduce the parasitic losses

Commercialization Strategy

- Established contacts with Whirlpool and AO Smith in the US and Godrej and Boyce in India
  - AO Smith: World leader in water heaters
  - Whirlpool: Makes store branded heaters
  - Godrej and Boyce: Appliance maker with focus on developing world markets (e.g. India)
  - A.O. Smith is quite cost conscious but Whirlpool and Godrej have stronger interest

- Commercialization focus for the first year:
  - Establish contacts and have introductory discussions

- Commercialization focus for second year:
  - Demonstrate performance of the final prototype with Sheetak TECs (available in the middle of 2nd year)
  - Get into commercial discussions for licensing our system technology and supplying Sheetak TECs

Next Steps and Future Plans

- 8-Engine TE heat pump integration to the water tank
- Development of control algorithm to control TE heat pump and resistive heater operation
- Fabrication of large TE modules on metal-core substrates using Sheetak's thick film process
- Integrated heat pump modules with Sheetak TE and heat sinks
- Demonstration products for engaging potential electric water heater manufacturers (AO Smith, Godrej and Whirlpool)

REFERENCE SLIDES

Project Budget

Project Budget: $1,149,900.00
Variances: None
Cost to Date: $1,149,900.00
Additional Funding: N/A

Budget History					
11/15/2012– FY2014 (past)		FY2015 (current)		FY2016 – 5/14/2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$149,950.00	0	$499,974.57	0	$499,975.00	0

Project Plan and Schedule