ENERGY HARVESTING:

MEMS Piezoelectric Vibration Harvesting 

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Thermoelectric Harvesting 

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BMI

pier PUBLIC INTEREST ENERGY RESEARCH

DR ETD DEMAND RESPONSE enabling technology development

iTRIS Center for Information Technology Research in the Interest of Society

BWRC

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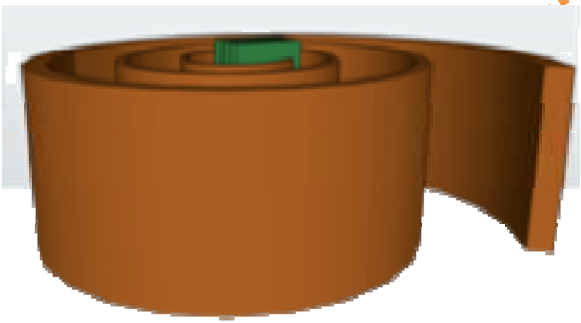
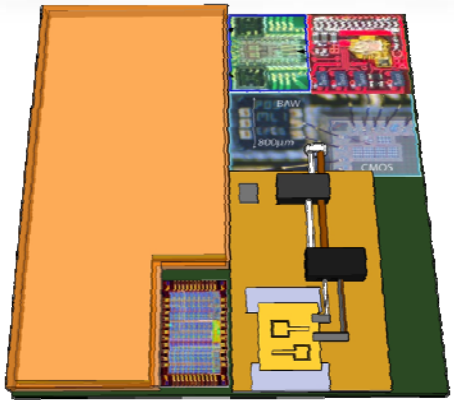
Multi-source Energy Harvesting

Industrial Pump



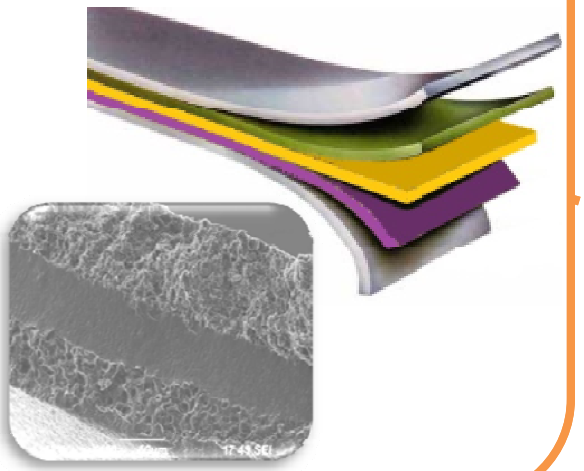
"Smart Roll"
Thermoelectric Wireless
Sensor Node

"Smart Stamp"
Piezoelectric Wireless
Sensor Node

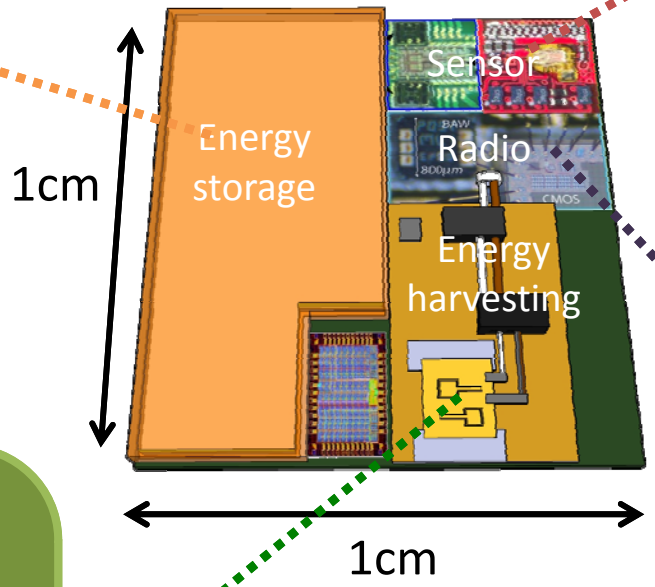


“Smart Stamp”

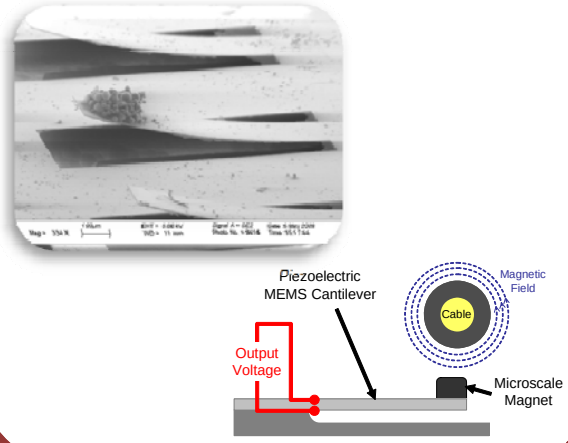
Energy Storage



Wireless Sensor Micro-device

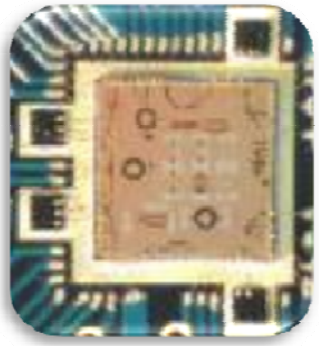


MEMS Sensor



Piezoelectric Energy Harvesting

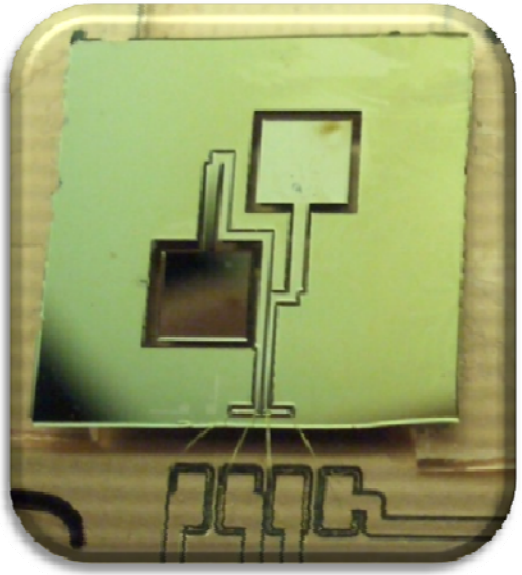
Radio



Progress made in past 6 months:

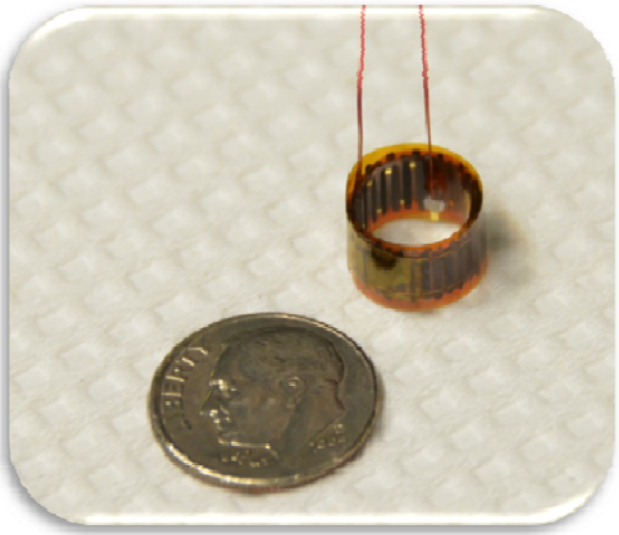
PIEZOELECTRIC

- Modeling completed
- Device optimization completed – P > 1 µW at matched frequency
- Investigating methods for frequency tuning



THERMOELECTRIC

- 1st printed 50 couple prototype with 75µW/cm^2 @ ΔT = 20K
- Future work on materials processing can improve device performance
- Exploring alternative geometries

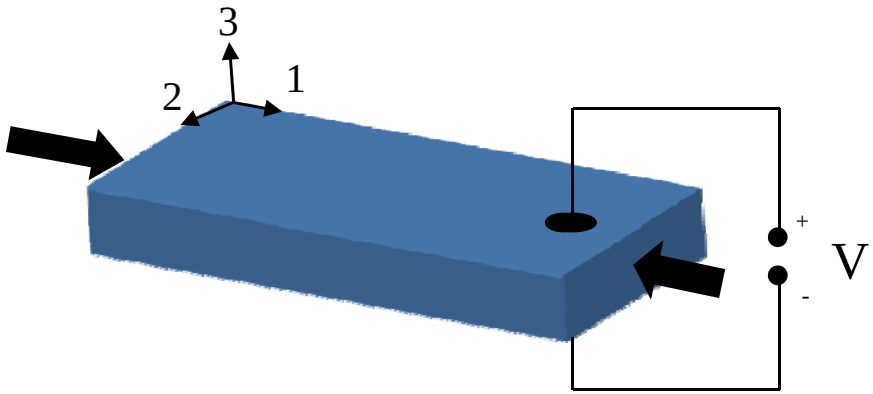


Piezoelectric operating principle

DEFORMATION
(mechanical energy)

VOLTAGE
(electrical energy)

PIEZOELECTRIC MATERIAL



S. Roundy, PhD Thesis UC Berkeley 2003

CANTILEVER BEAM

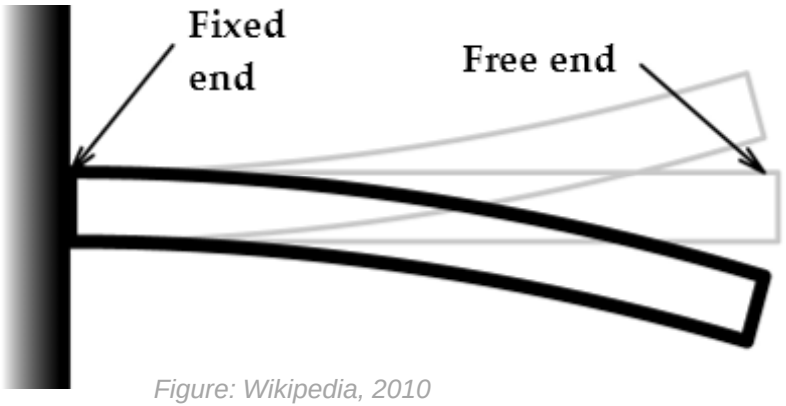


Figure: Wikipedia, 2010

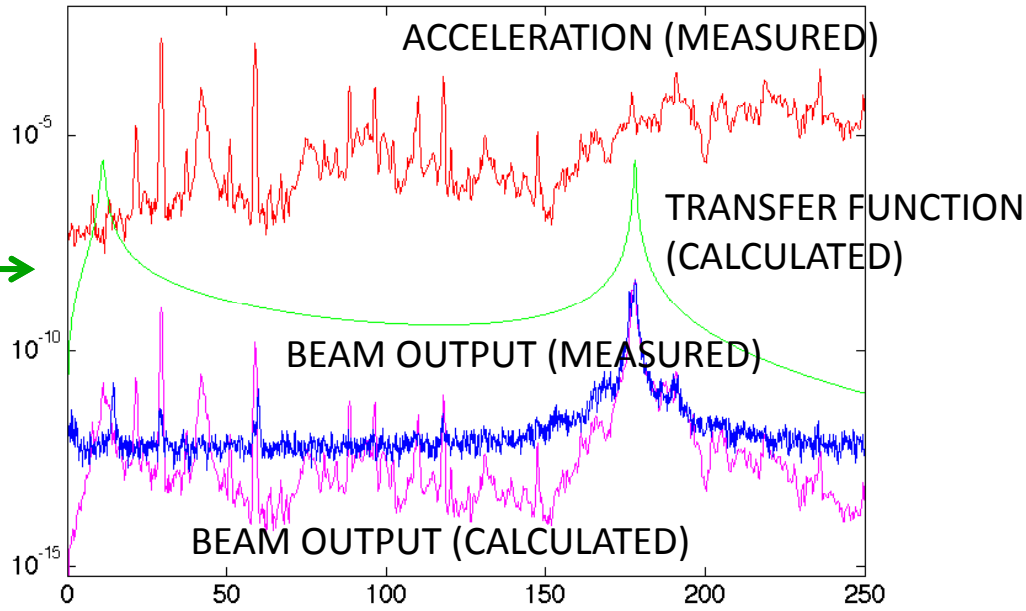


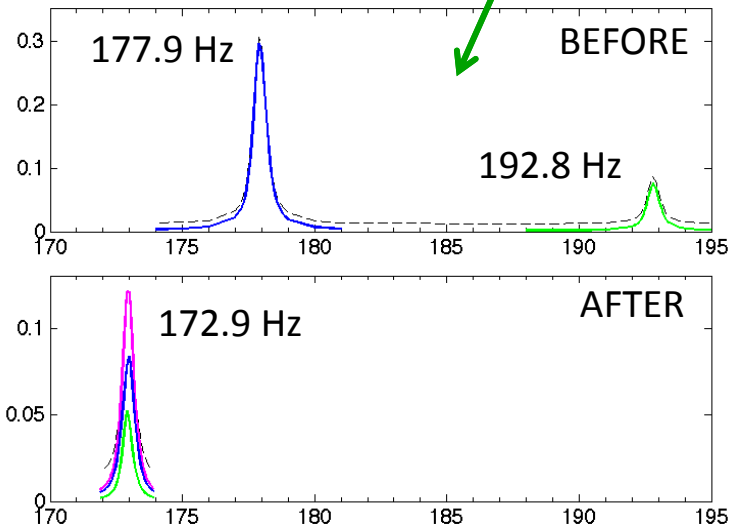


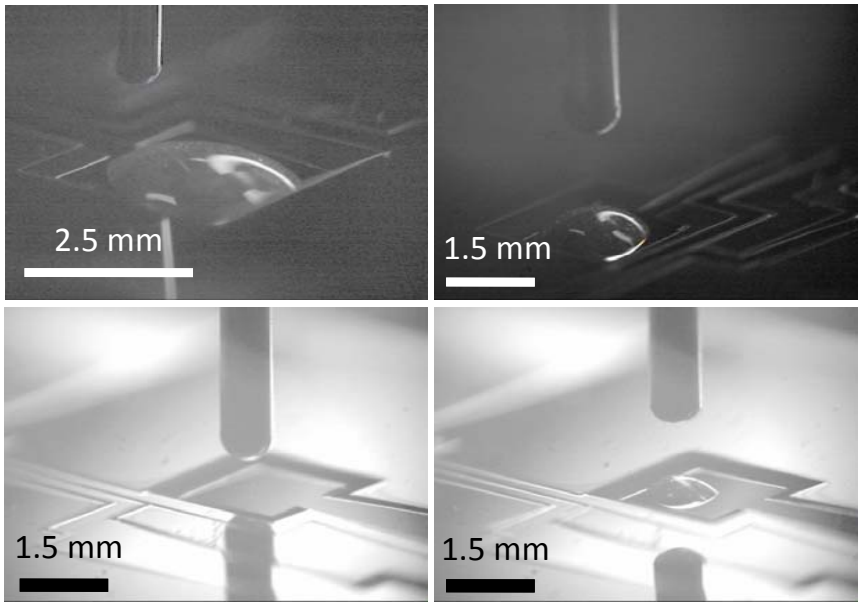
Where we left you 6 months ago:

PIEZOELECTRIC VIBRATION

- Tested 8 beams on 8 ambient sources – reliably produce low power
- Successfully printed proof mass on harvesters to modify resonance frequency

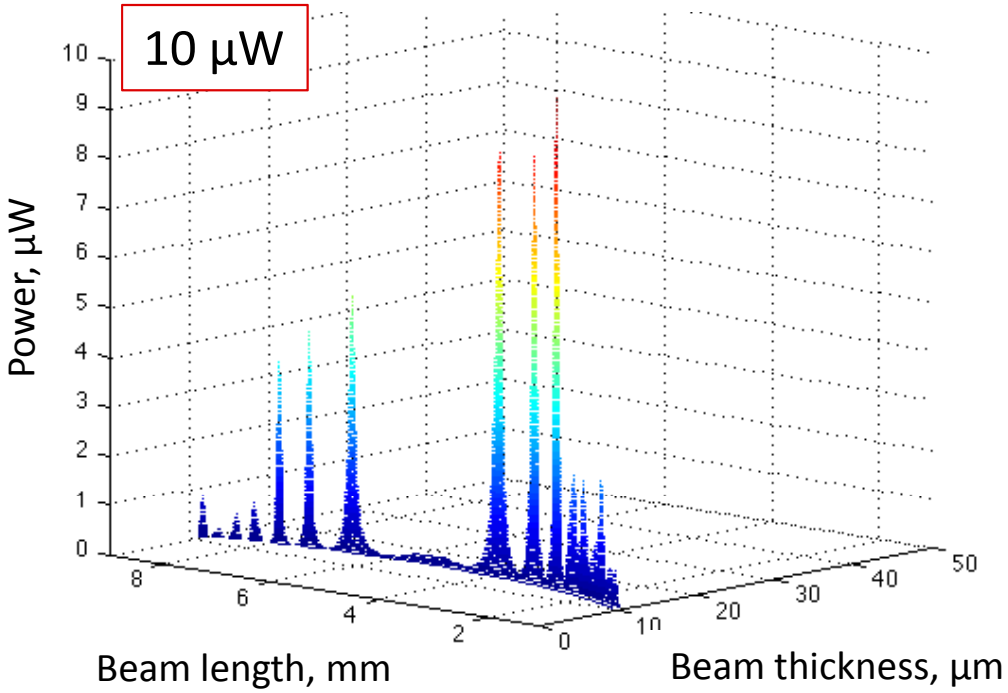




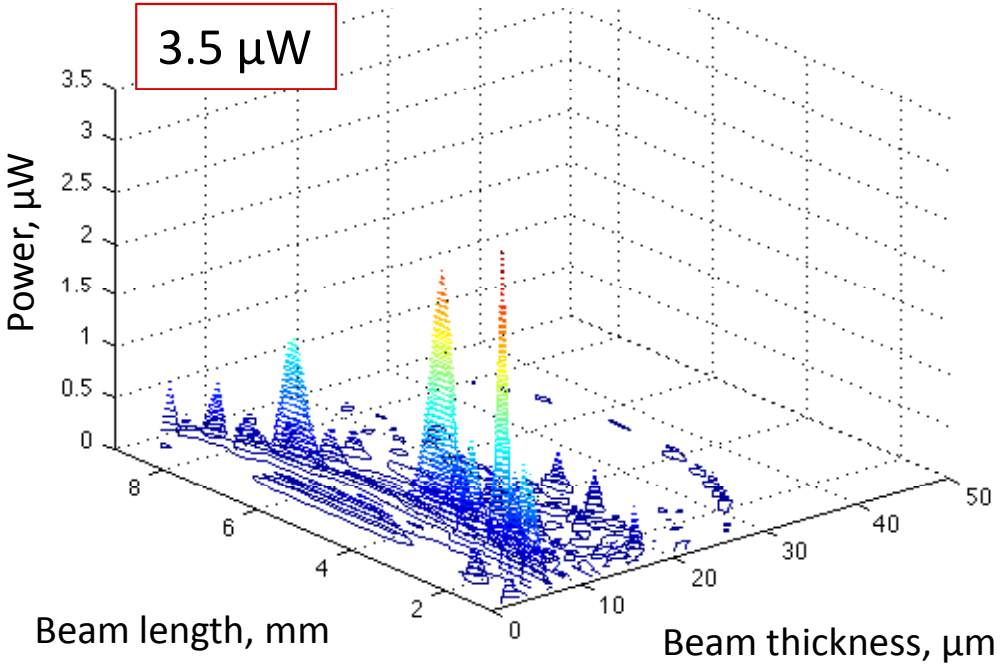


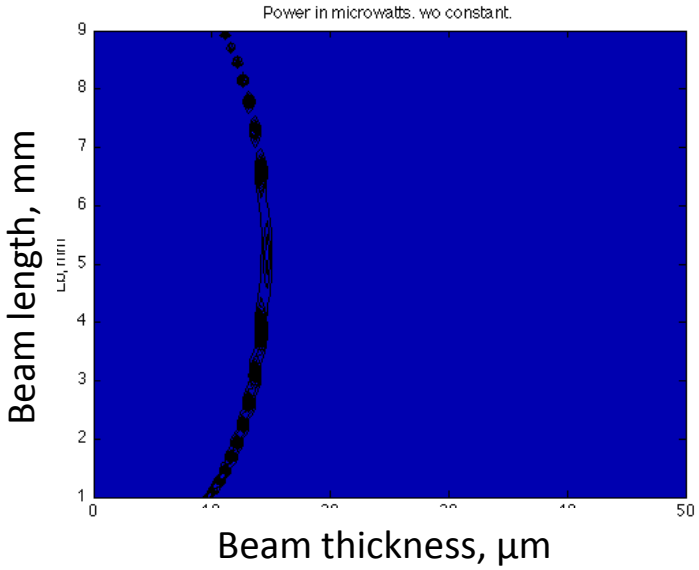
Progress: Optimization & redesign

Power out for 30 Hz sinusoidal accel input:

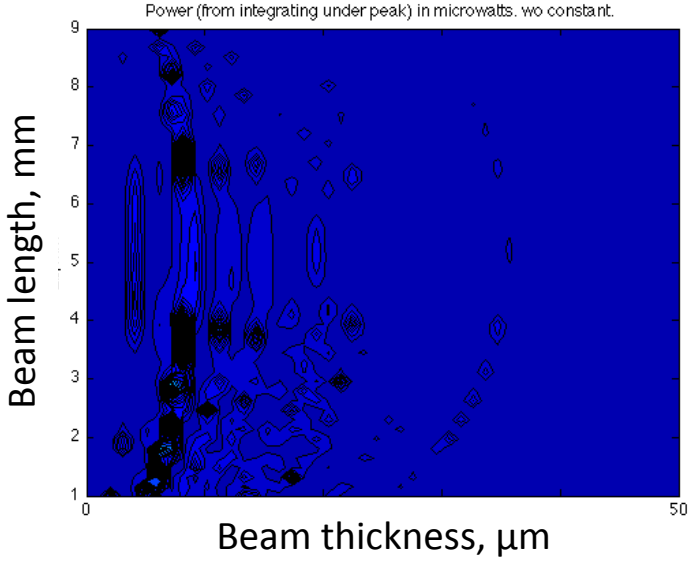


Power out for ambient accel input:





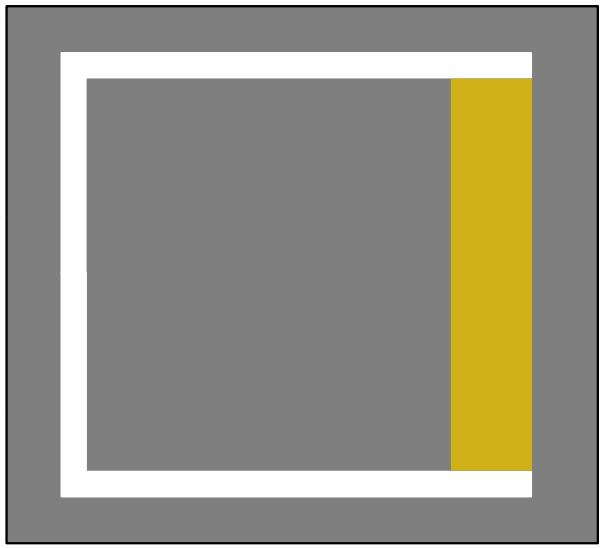
Constrained area = 1 cm^2.



Progress: Optimization conclusions

1. P > 1 μW is attainable if optimize for specific vibration source
2. If optimized harvester is moved to different source, power drops off
3. A broadband or tunable device is needed

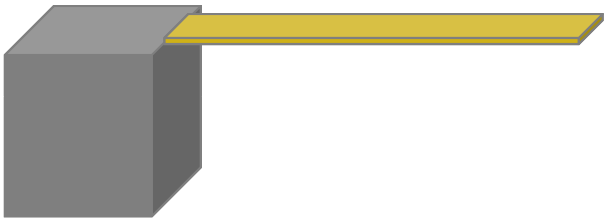
Optimized geometry

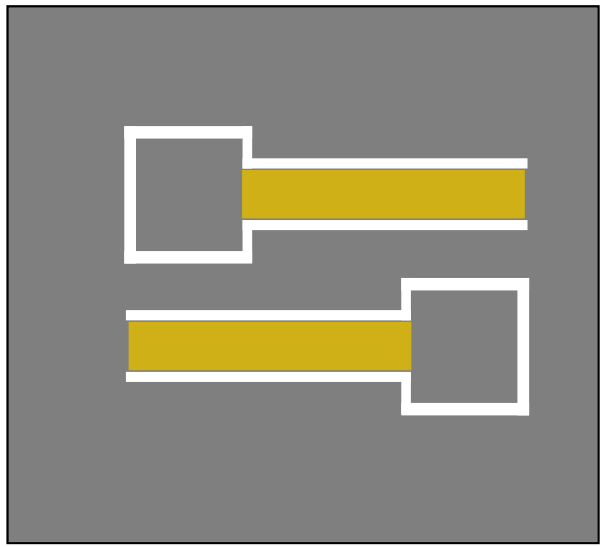


Top view of MEMS chip

Old geometry

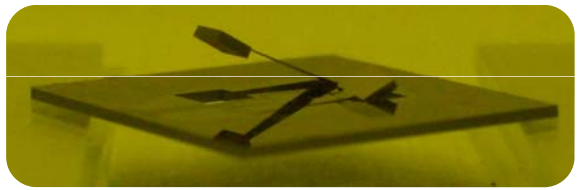
Schematic

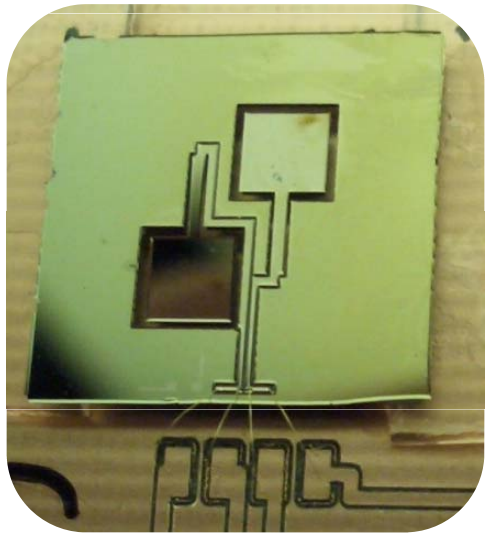




Top view of MEMS chip

Photograph



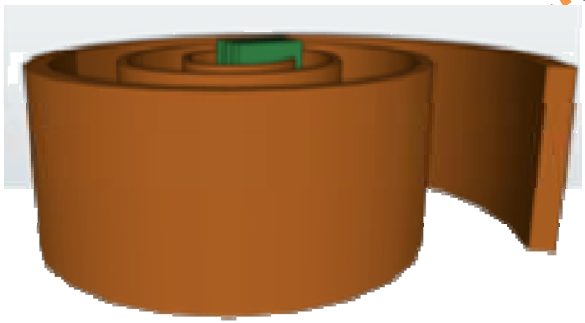


Progress: How to deal with the need to match harvester and source frequencies

1. Measure vibration source a priority, customize harvester
2. Make an array with harvesters of different resonances
3. Design broadband device
4. Active tuning
   - External applied force – magnetic, electrostatic
   - Stiffness modification
   - Axial mechanical preload
5. Passive tuning
   - Mechanical stoppers
   - Nonlinear spring stiffness
   - Bi-stable oscillator

Multi-source Energy Harvesting

Industrial Pump



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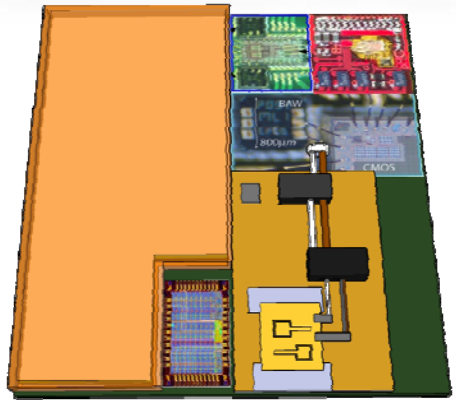
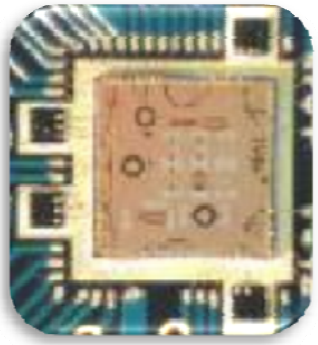
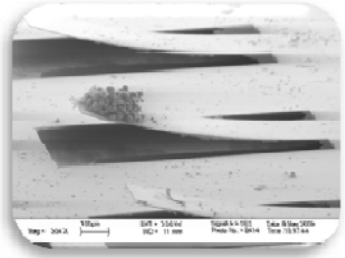


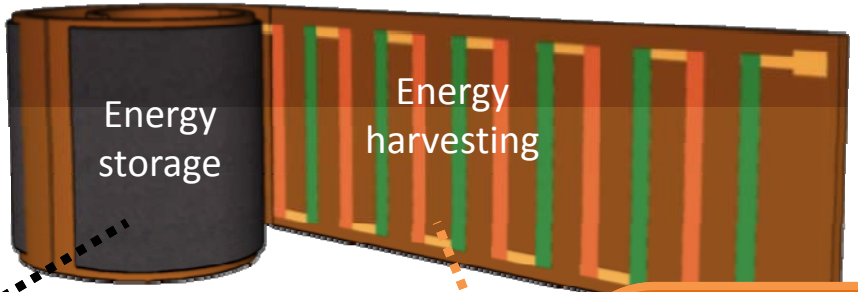
“Smart Roll”

Radio



MEMS Sensor

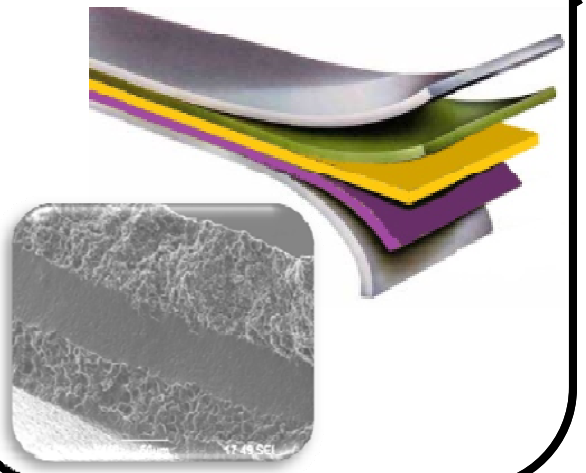




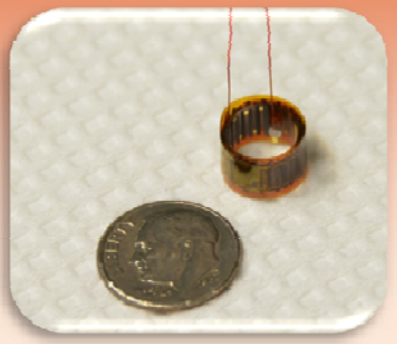
1cm

Wireless Sensor Micro-device

Energy Storage

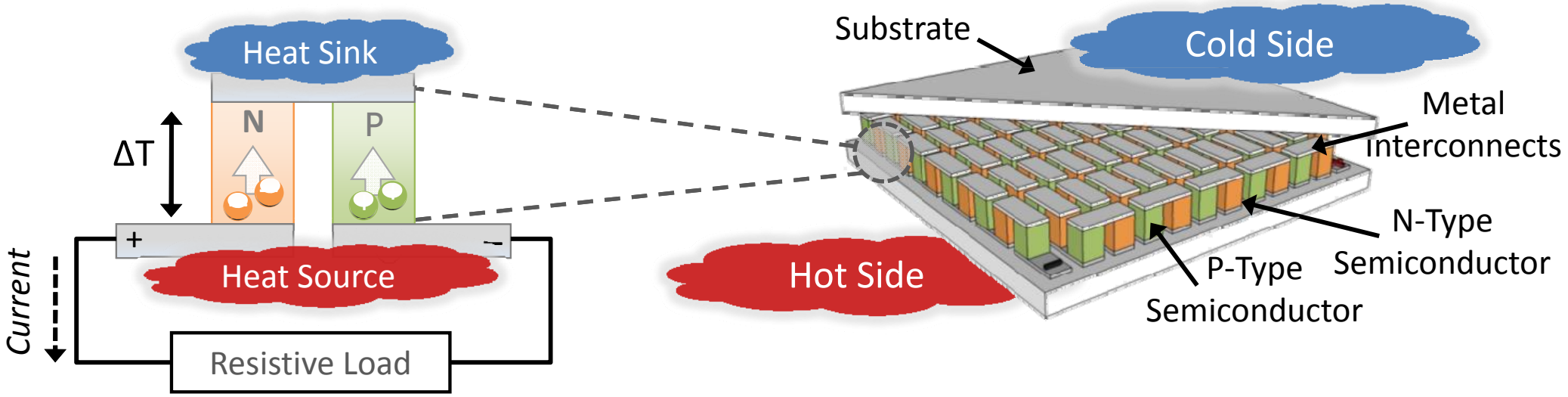


Thermoelectric Energy Harvesting



Thermoelectric (TE) Operating Principles

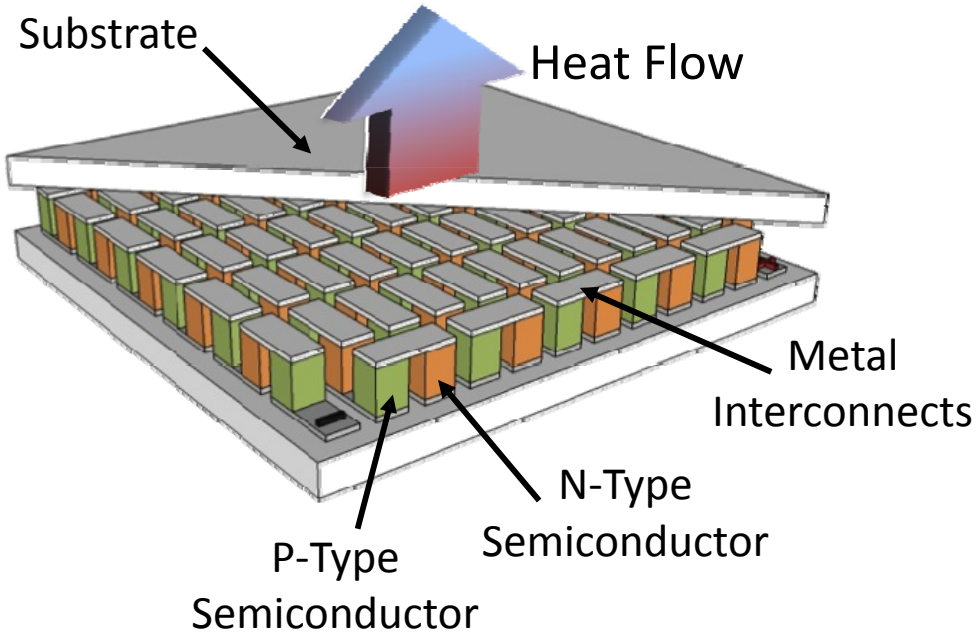
Thermoelectric (TE) Energy Harvesting



Sources of Waste Heat

Location	Source	Temp. Gradient
Residential	Boilers, Dryers, Freezers, Oven	10-30K
Factories	Exhaust pipes, Boilers, Condensers	10-80K
Vehicles	Engine, Exhaust pipes	60K >100K
Airplanes	Cabin to External	10-50K

Thermoelectric Device Design

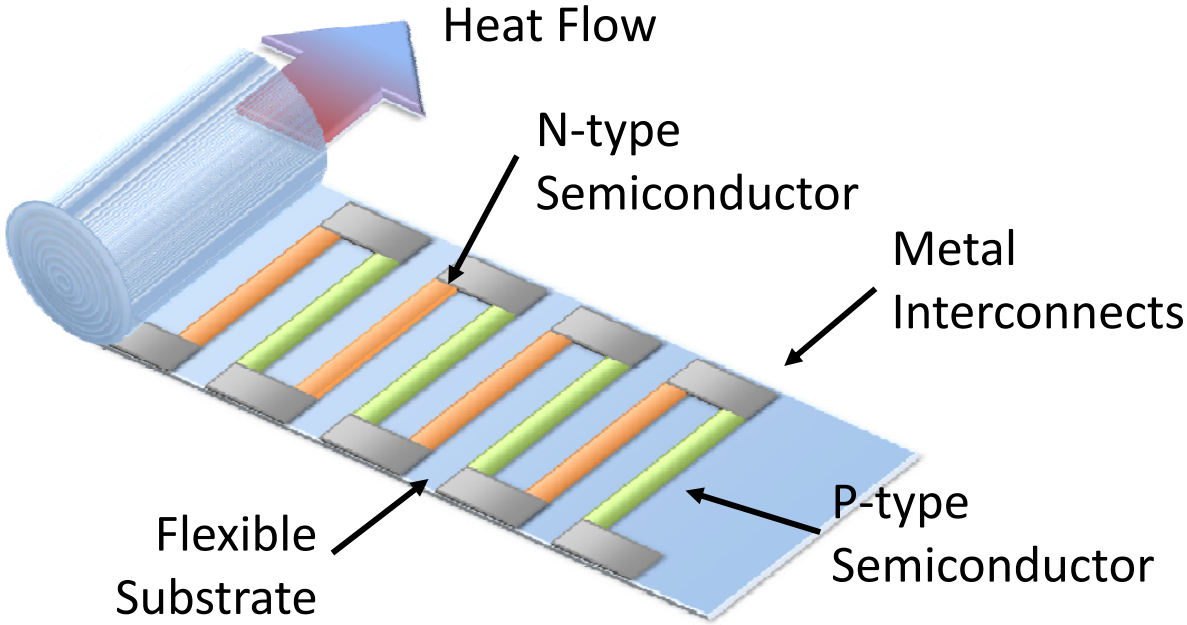


Traditional Design

- Low Aspect Ratios
- Requires structural support
- Labor intensive assembly

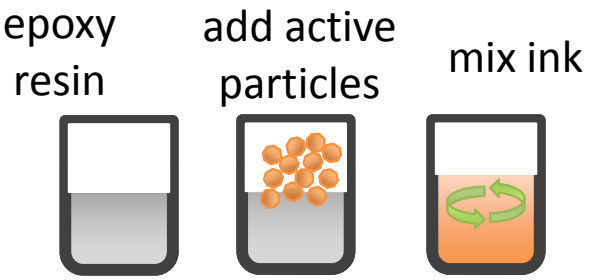
Planar Design

- High aspect ratio pillars
- High density arrays
  - 900+ couples for D = 1cm
- Takes advantage of printing process

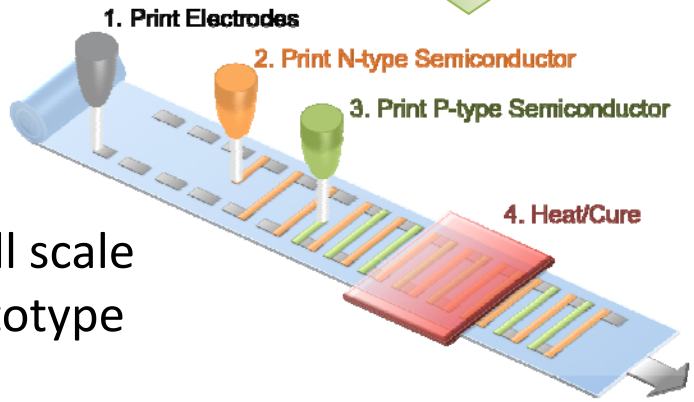


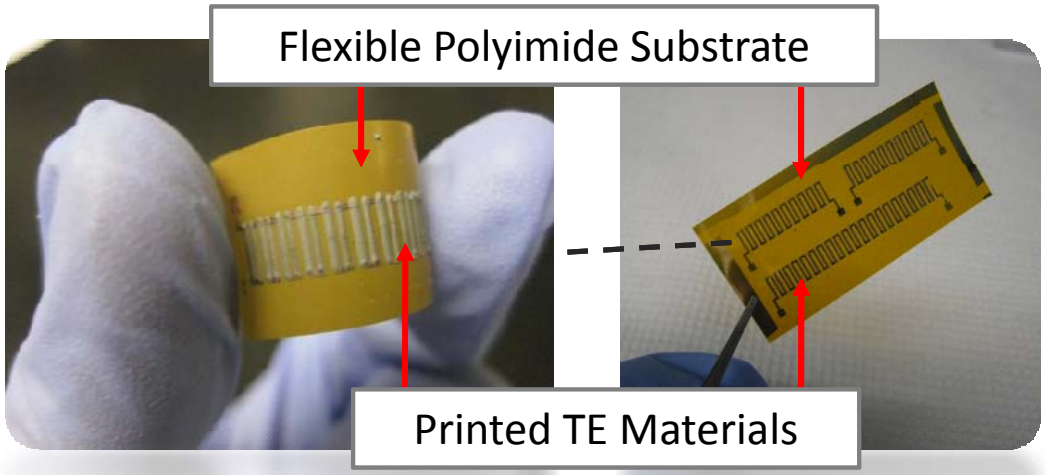
Where we left you 6 months ago:

Printable TE Materials



Small scale prototype



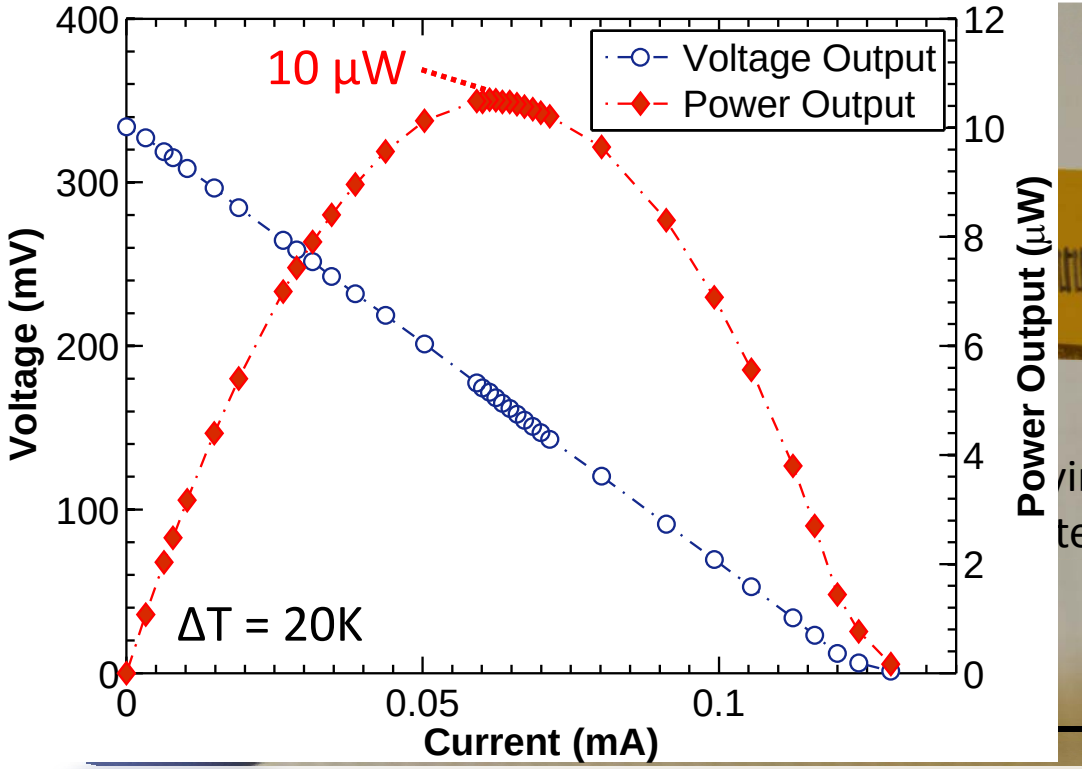


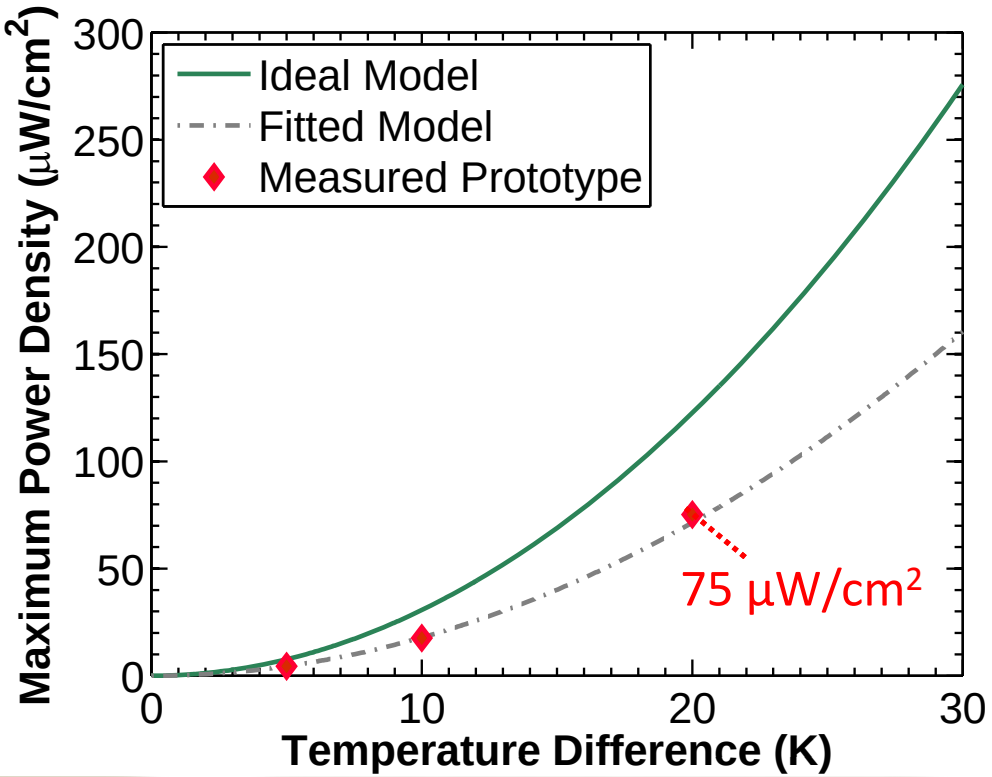
Leg Dim.: 5 mm Length, 500 µm width, 200 µm thick

THERMOELECTRIC

- Printable semiconductor/epoxy thermoelectric materials synthesized
- Printed 10-couple prototype which produced 0.85µW for 20K temperature difference

Progress: Device Scaling & Fabrication

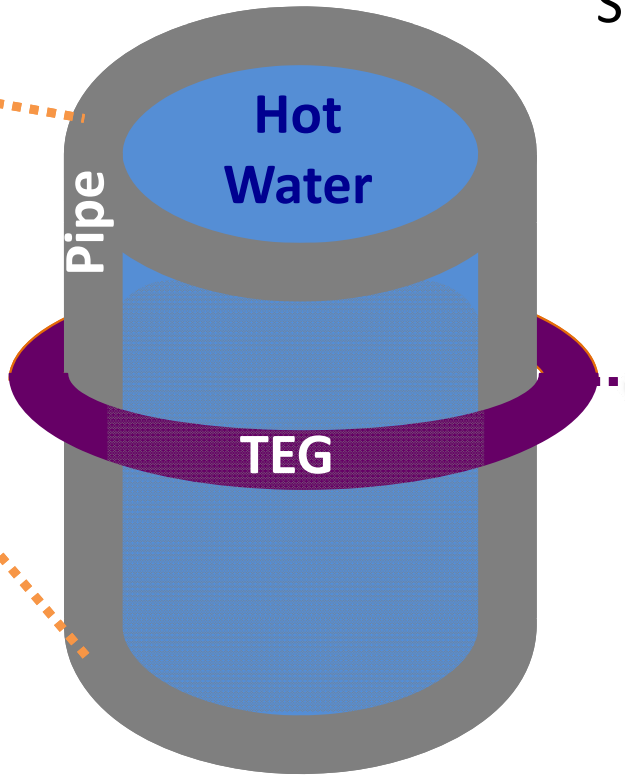


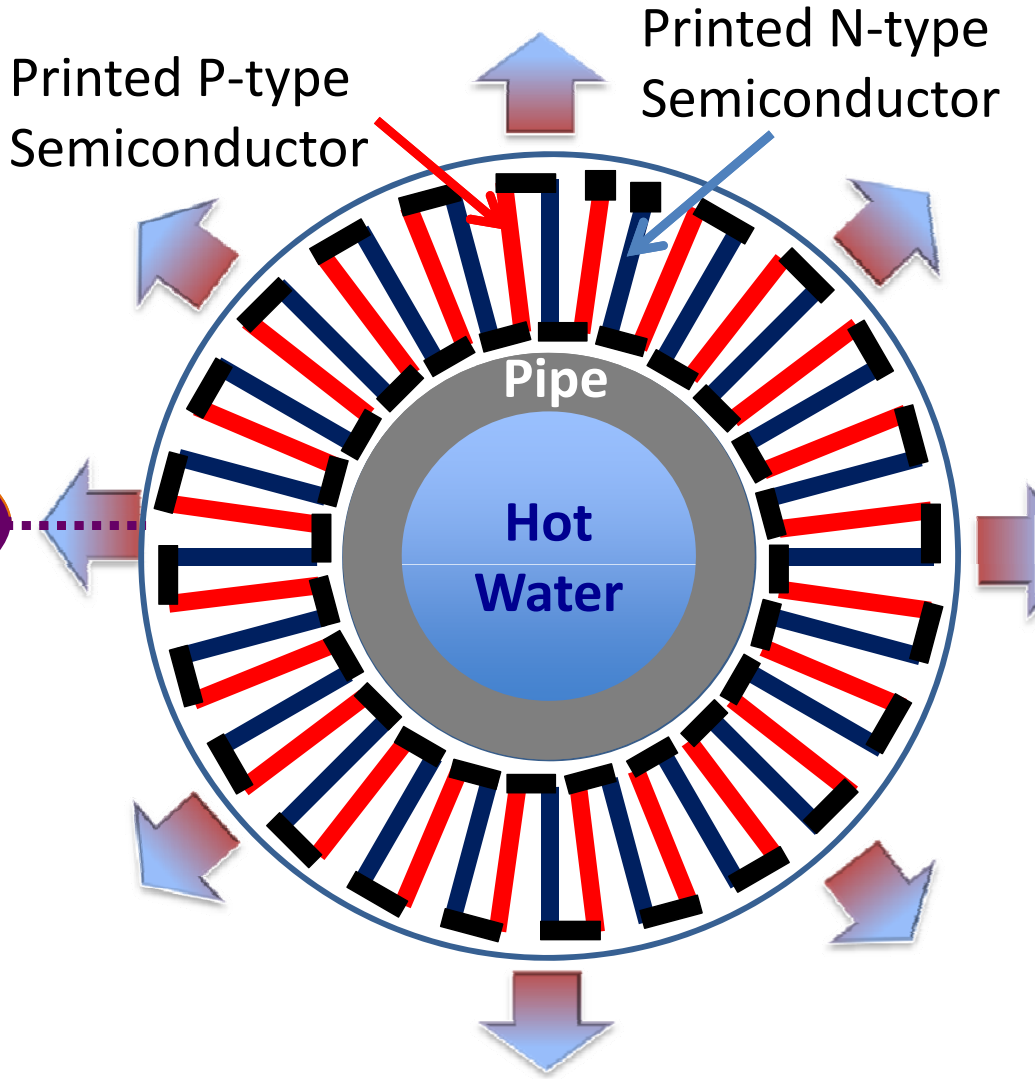


- **Device Prototype:**
  - 50 Couple Device (100 elements)
  - ΔT = 5, 10, 20 Kelvin
- Element Dim.: 5mm x 640µm x 90µm
- Device Resistance ~ 2.5 kΩ
- Power Density ~75µW/cm² @ ΔT = 20K

Progress: Harvesting from Hot Pipes

Central heating unit





Cross- Sectional view of pipe and device

- High aspect ratio pillars
- High density arrays
  - 100+ couples for D = 10cm
- Takes advantage of printing process
- “Rings” can be stacked

Progress made in past 6 months:

PIEZOELECTRIC

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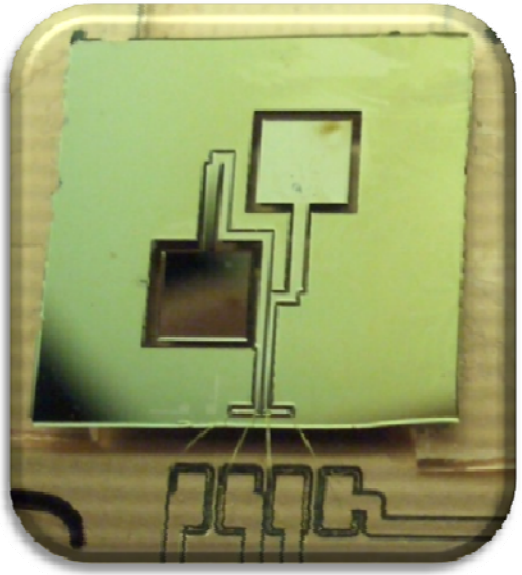
- Device optimization completed – P > 1 µW at matched frequency
- Investigating methods for frequency tuning



THERMOELECTRIC

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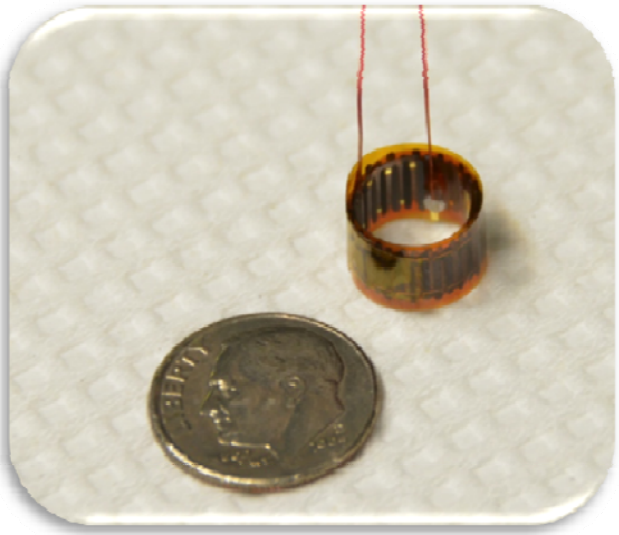
- Future work on materials processing can improve device performance
- Exploring alternative geometries



Thank you! Any questions?

THERMOELECTRIC

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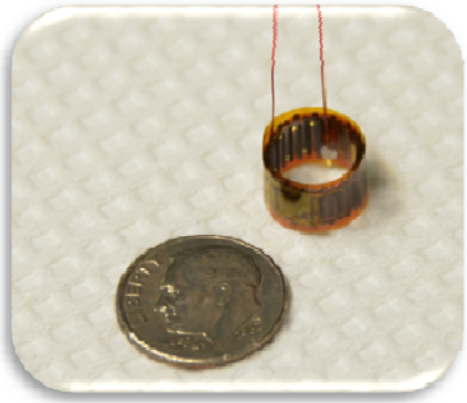

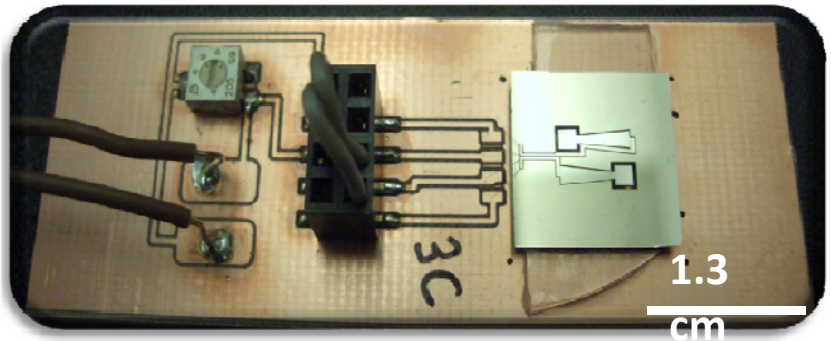

PIEZOELECTRIC

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Acknowledgements: California Energy Commission, CITRIS, Berkeley Manufacturing Institute, Berkeley Wireless Research Center