ENERGY HARVESTING FROM VIBRATIONS, AIR FLOW, & TEMPERATURE CHANGE

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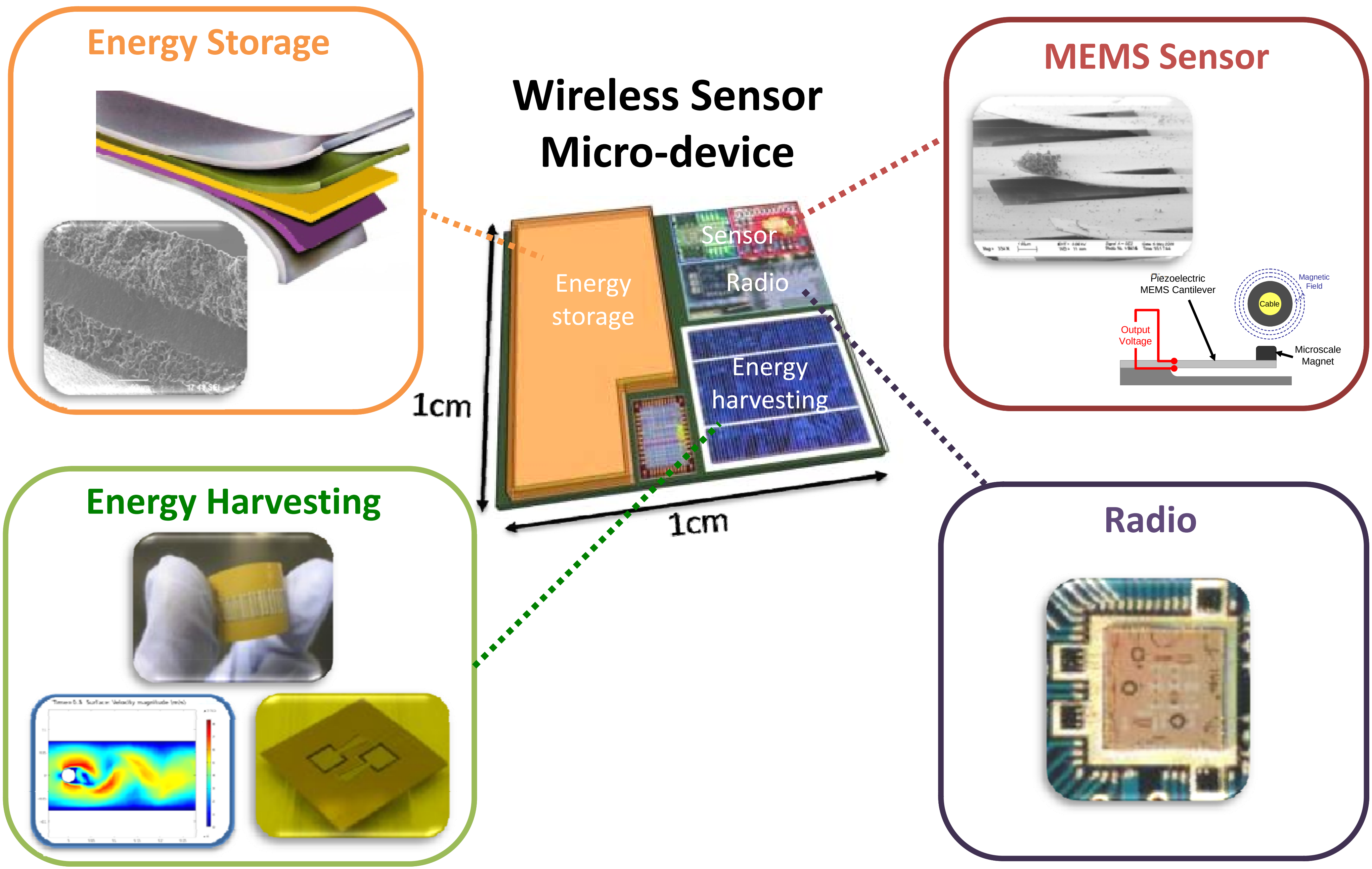
Dr. Elizabeth Reilly, Dr. Yiping Zhu,
Prof. Paul Wright, Prof. Jim Evans

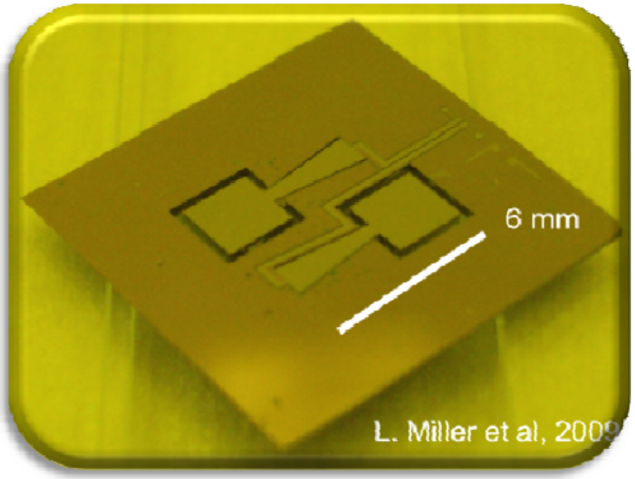
System on a Chip



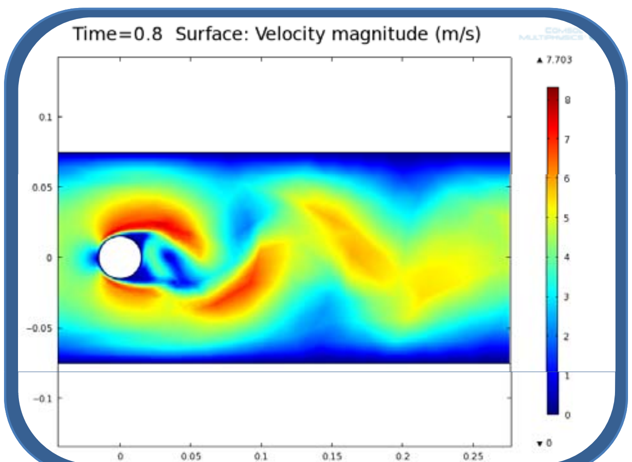
Multi-source energy harvesting

PIEZOELECTRIC

VIBRATIONS

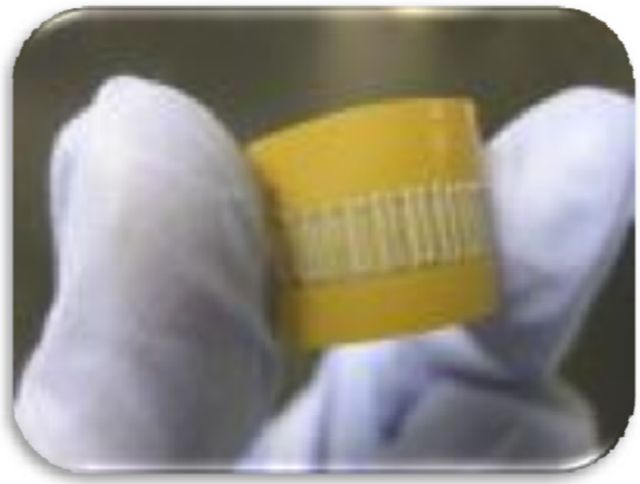


AIR FLOW



THERMOELECTRIC

TEMPERATURE DIFFERENCE



Progress made in past 6 months:

PIEZOELECTRIC

VIBRATIONS

- P_{rms} = 1.1 nW/beam,
  micro device on ambient source
- Developed process to modify frequency with printed mass

AIR FLOW

- Meso-scale prototype developed
- P_{rms} = 1.1 mW, optimal conditions

THERMOELECTRIC

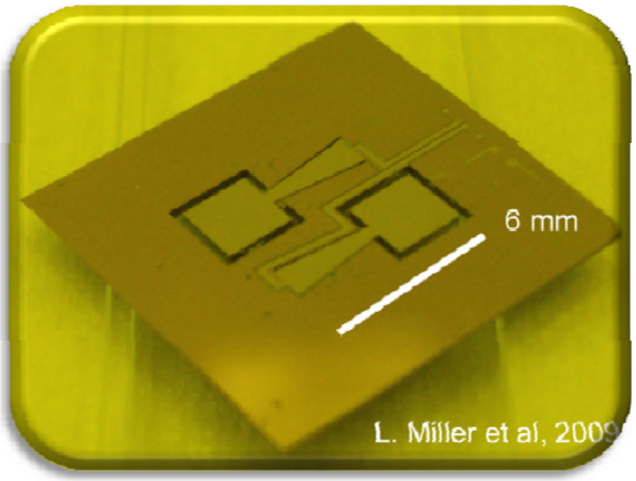
TEMPERATURE DIFFERENCE

- Composite materials improved
- Developed scalable fabrication process for meso-scale devices
- P = 0.58 µW
  (ΔT = 10 K, 10-couple device)

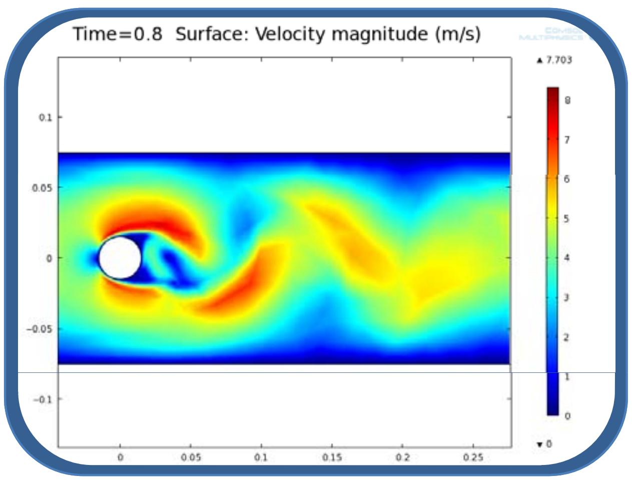
Multi-source energy harvesting

PIEZOELECTRIC

VIBRATIONS



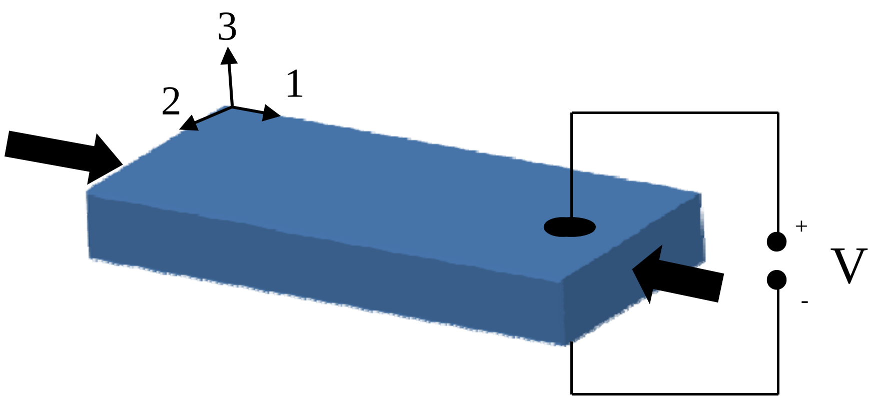
AIR FLOW



Piezoelectric operating principle

DEFORMATION
(mechanical energy) ⟷ VOLTAGE
(electrical energy)

PIEZOELECTRIC MATERIAL



S. Roundy, PhD Thesis UC Berkeley 2003

CANTILEVER BEAM

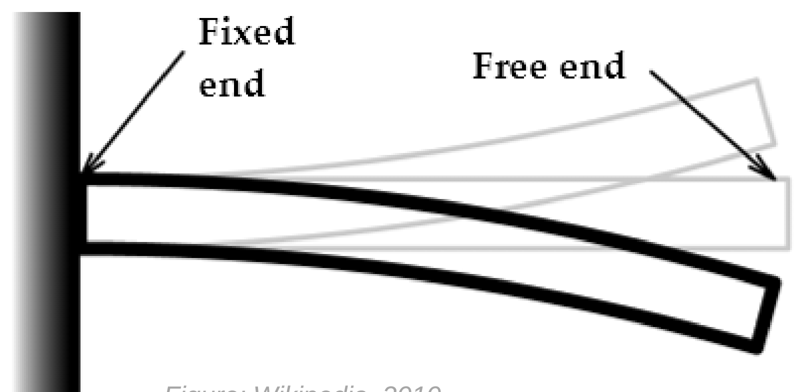


Figure: Wikipedia, 2010





Where we left you 6 months ago:

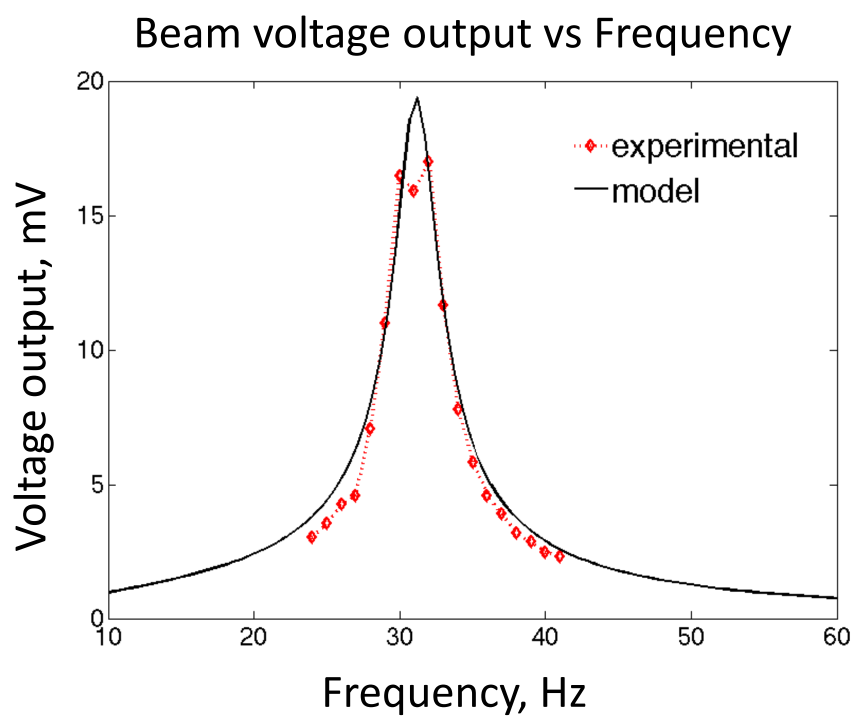
PIEZOELECTRIC

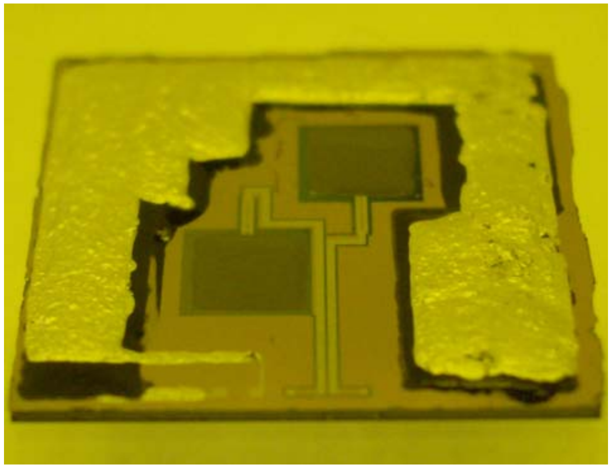
VIBRATIONS

- MEMS harvester fabricated
- Low resonance frequency achieved
- P_{rms} = 1 nW on shaker table
- 1 beam tested on 1 ambient source
- Printed capacitor on harvester die

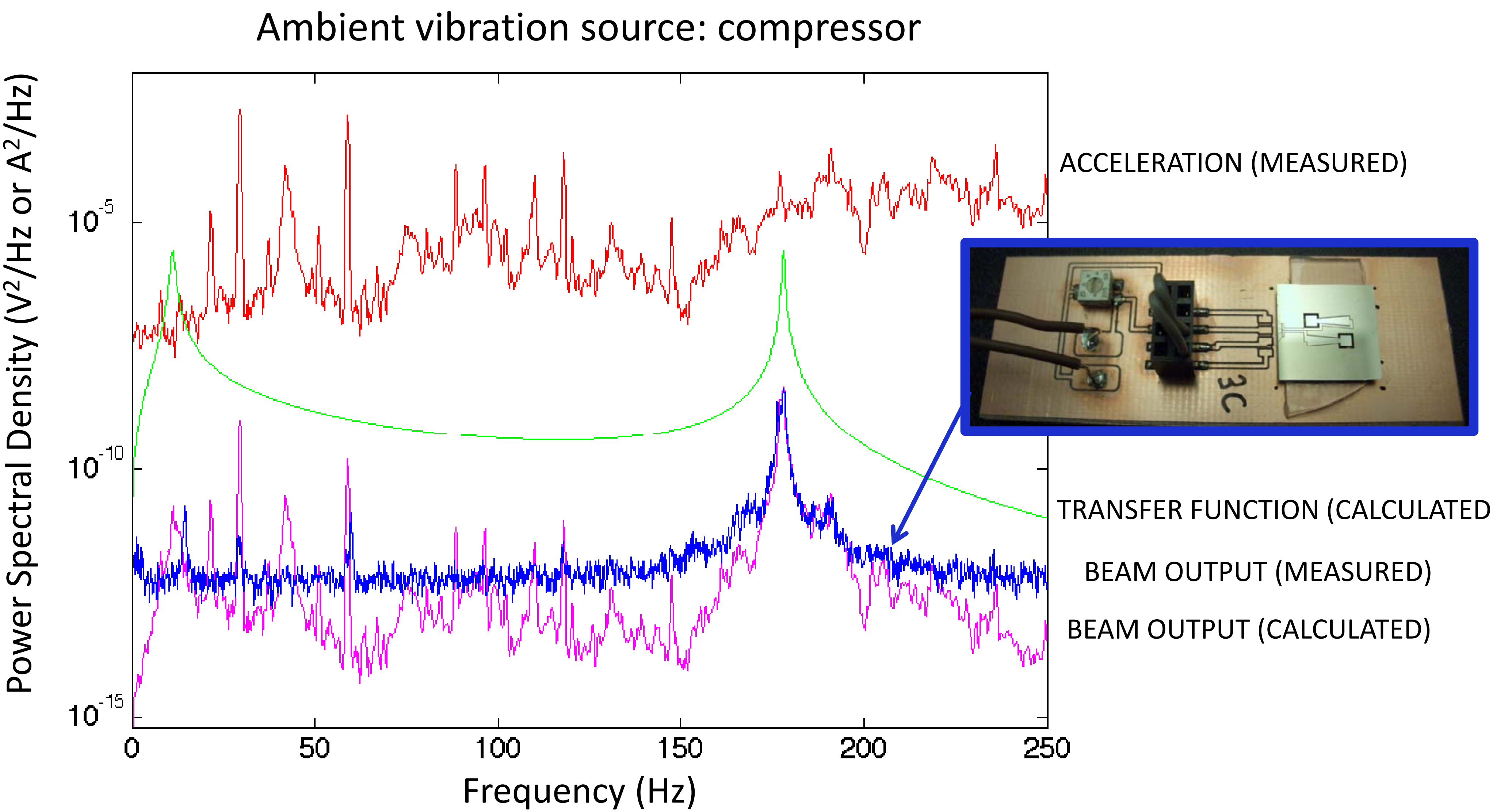
AIR FLOW

- Project was just starting





Progress: ambient vibration harvesting

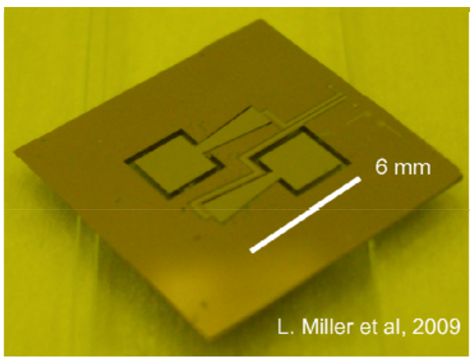


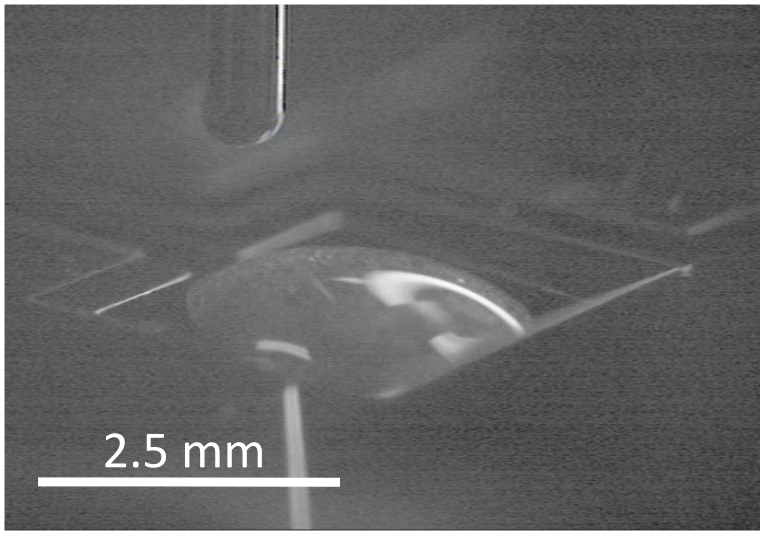
- Tested 9 beams on 7 ambient sources – reliably produce low power
- Almost finished with model – measured accel. input ➔ predicted beam output

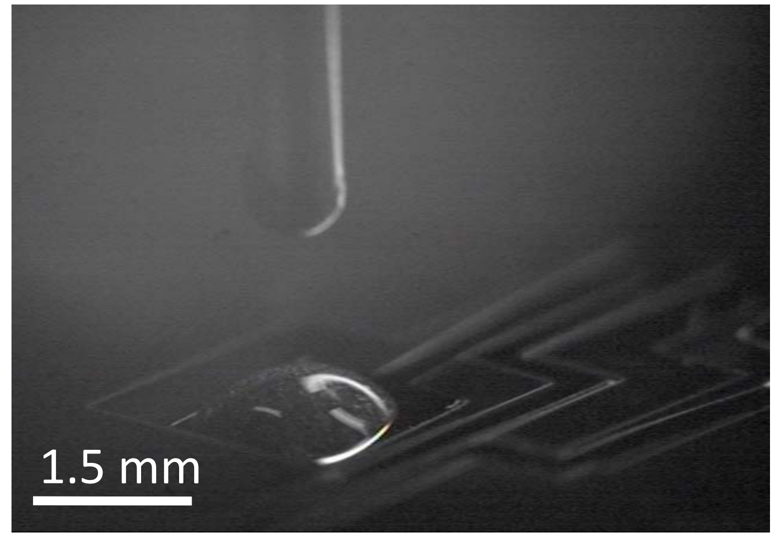
Progress: print mass → modify frequency

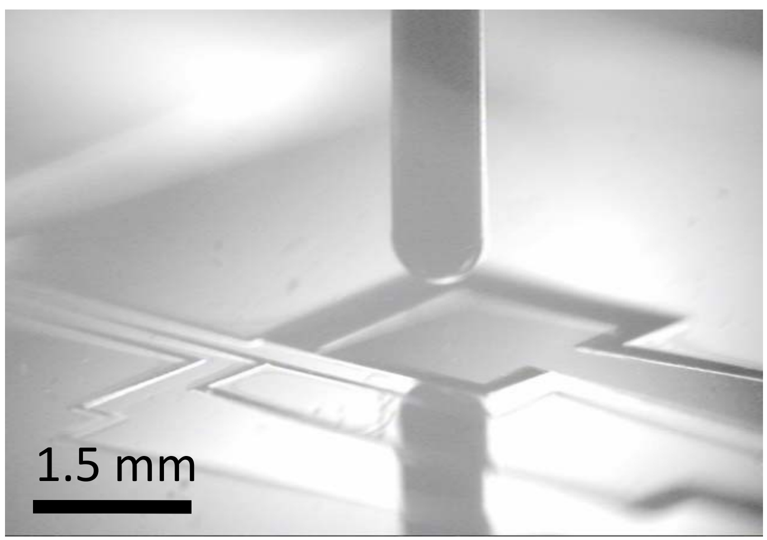
$\omega^2 = k/m$

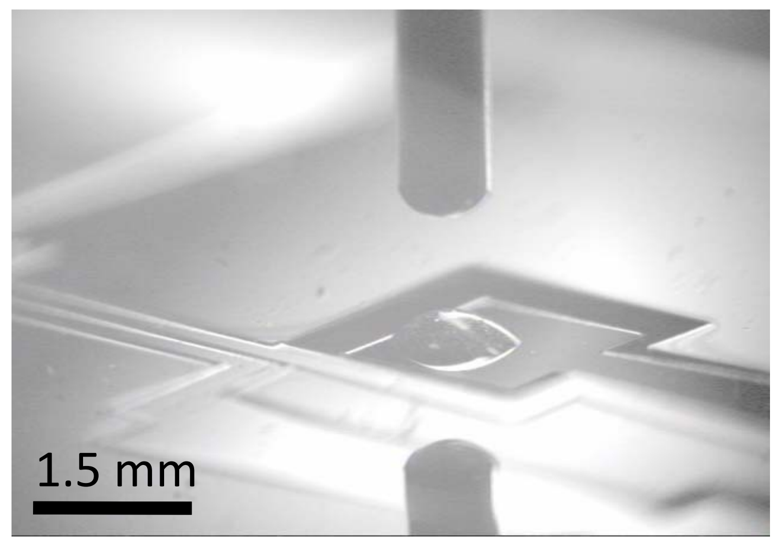
Successfully printed on 6 released beams with no "casualties"





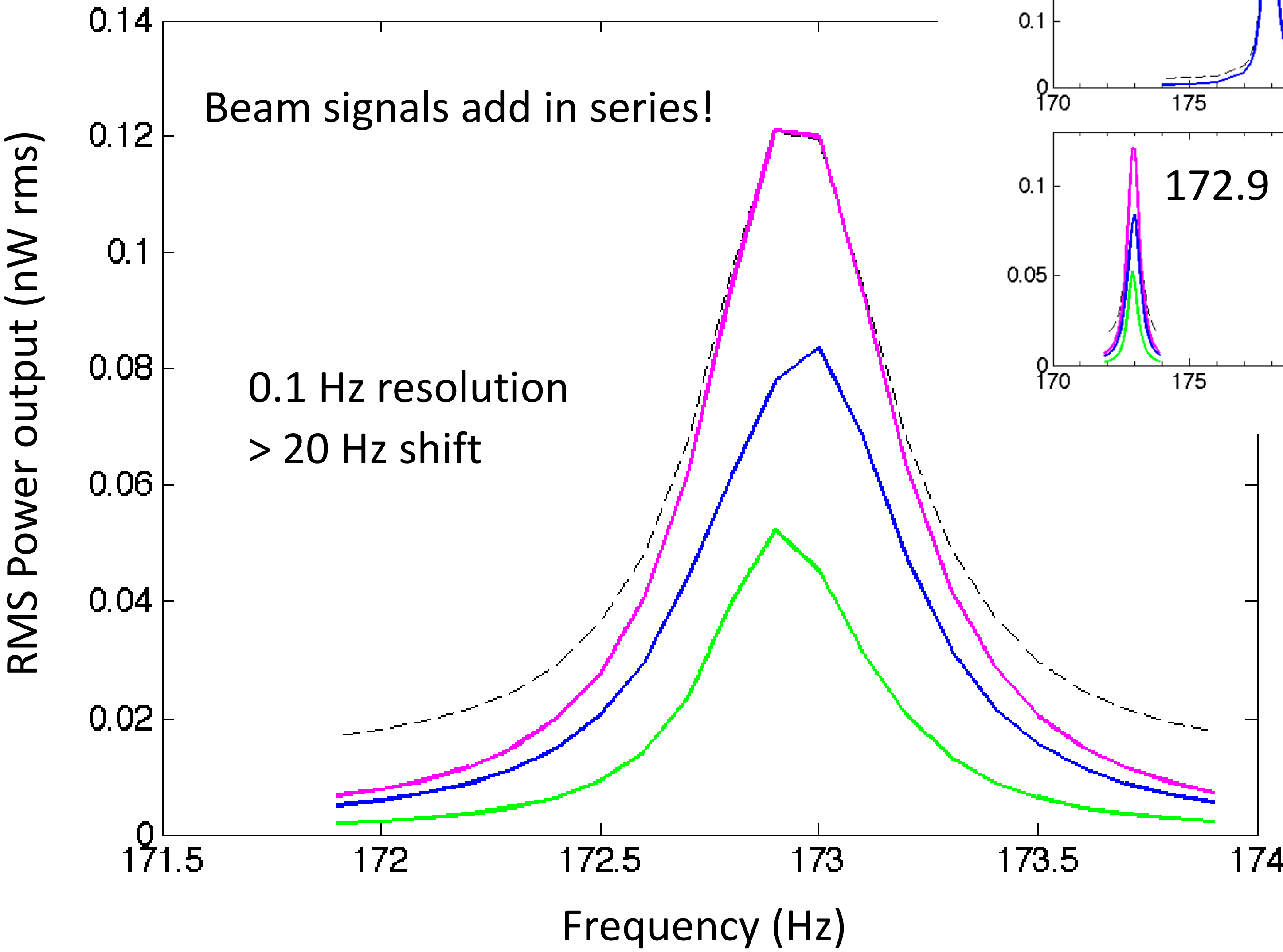




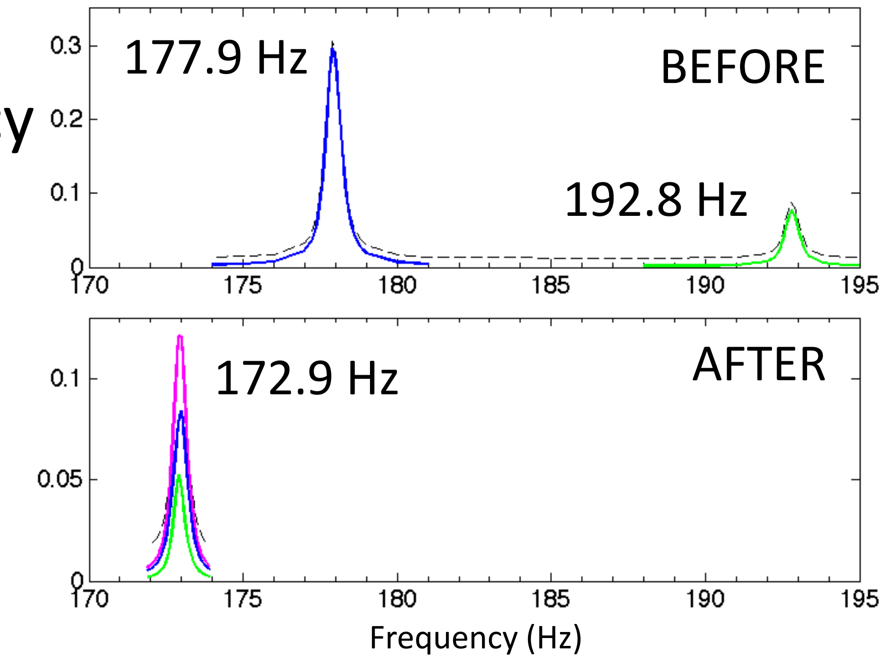


Progress: print mass → modify frequency

Beam power output vs frequency

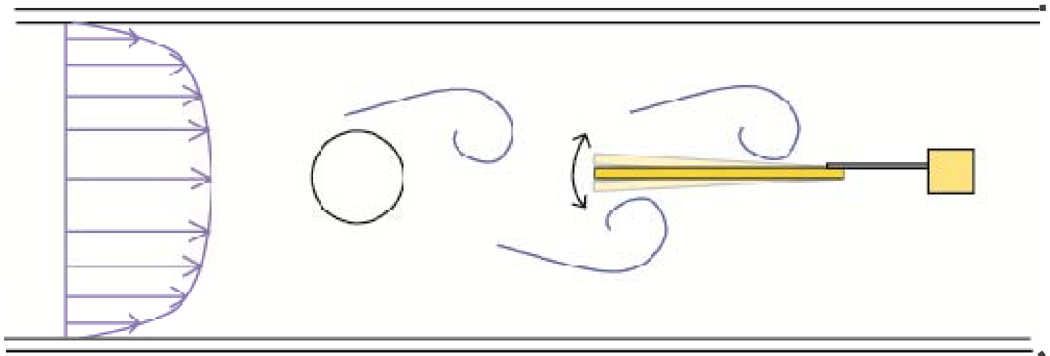


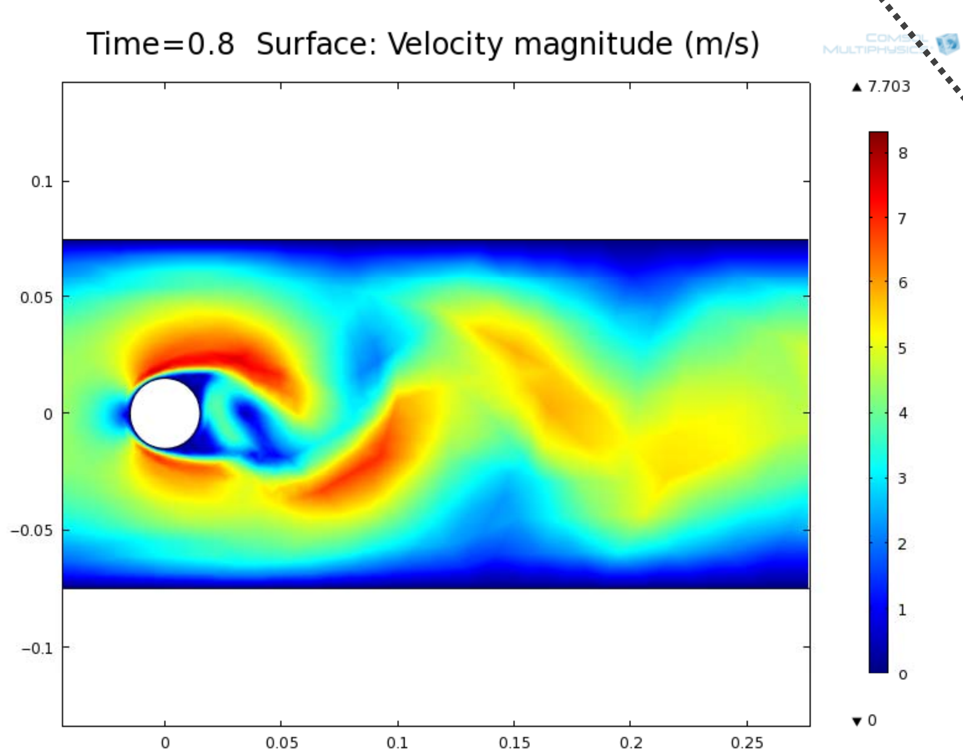
Shift in frequency with addition of printed mass



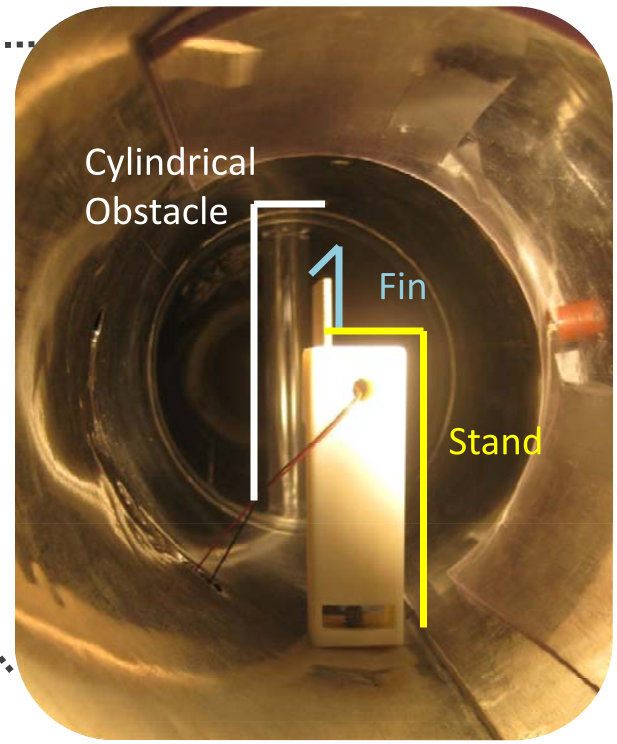
Progress: air flow harvester design

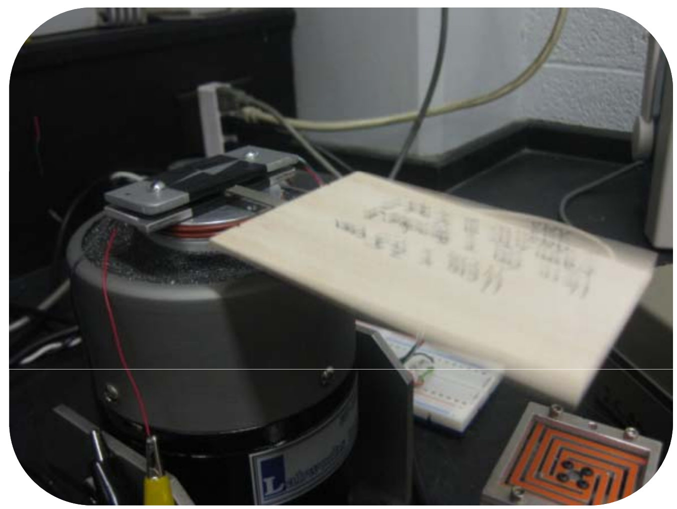
Top View



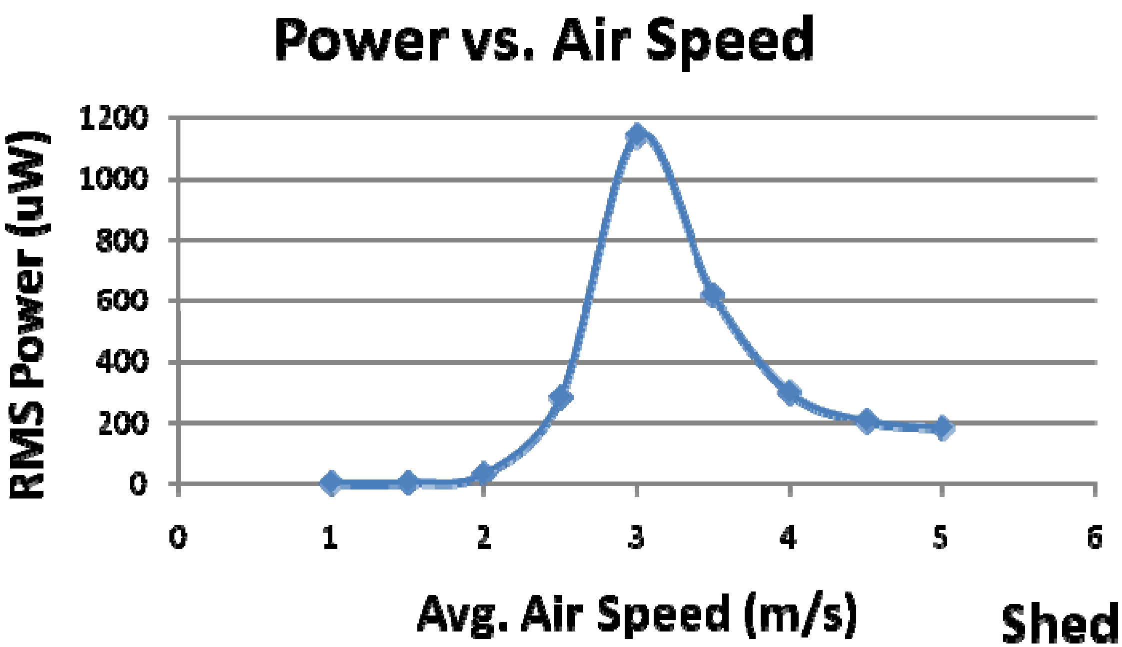


Back View





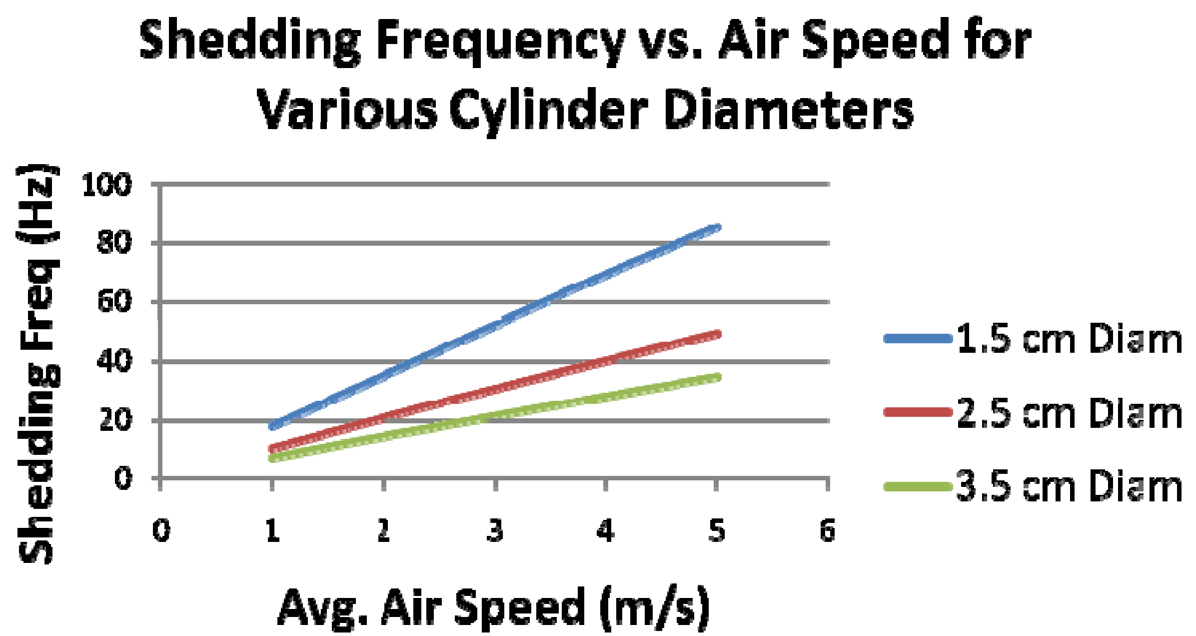
Progress: air flow harvester performance



Power output > 1 mW at optimal conditions

For results shown:

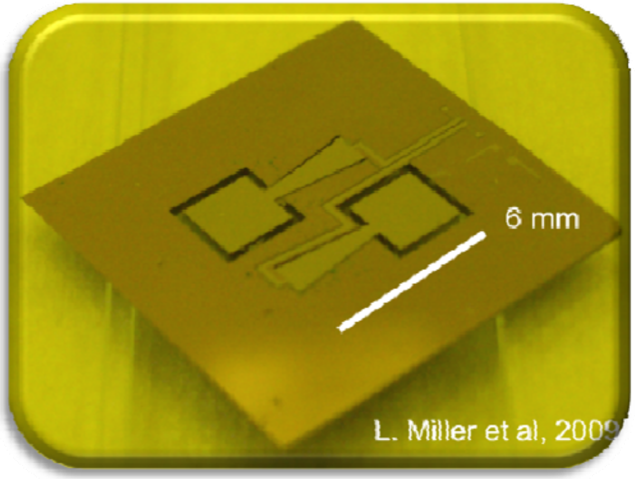
Fin: 7.5 cm wide x 7 cm long
Fin material: balsa wood
Cylinder Diameter: 2.5 cm
Optimum Load R: 194 kOhm



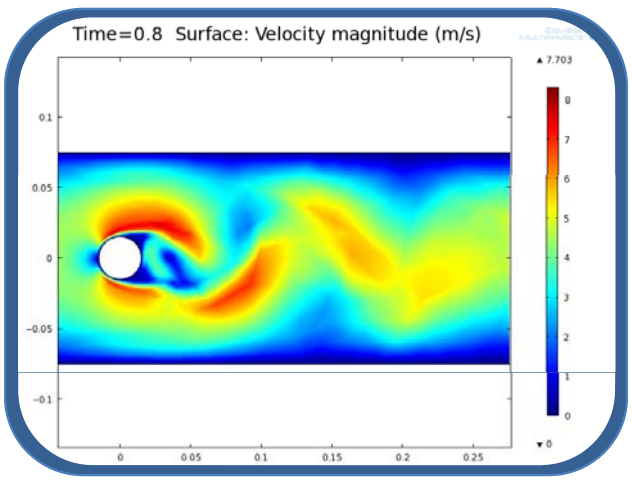
Multi-source energy harvesting

PIEZOELECTRIC

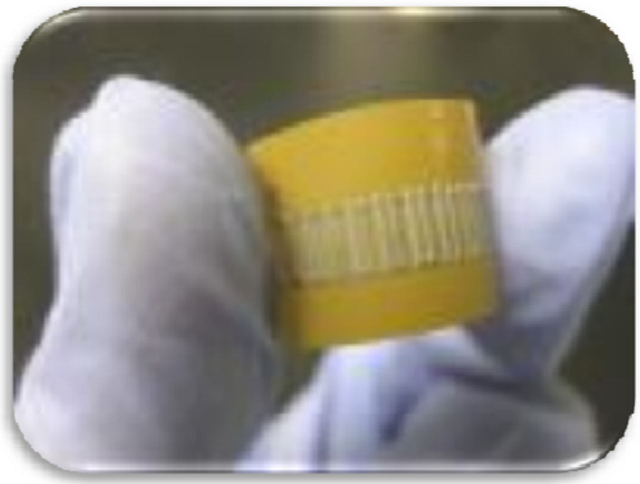
VIBRATIONS



AIR FLOW

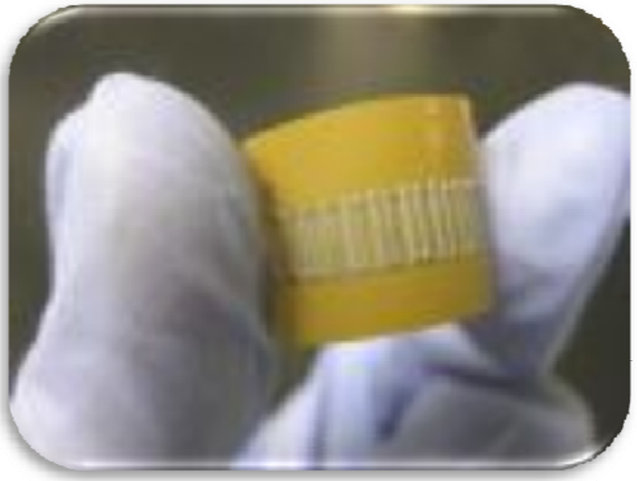


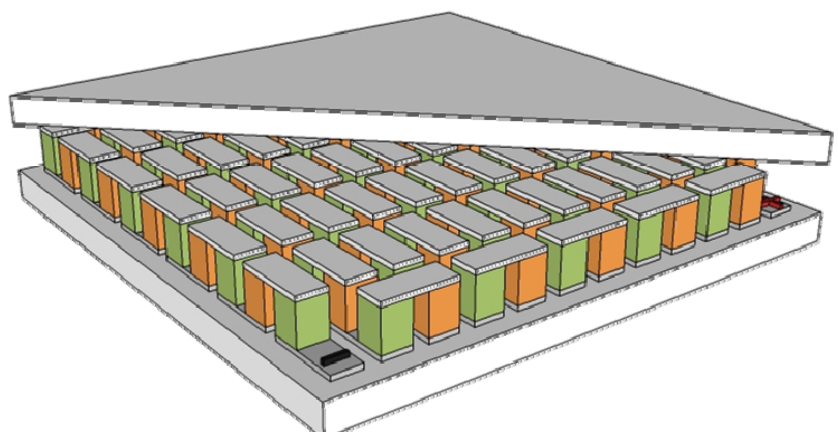
THERMOELECTRIC



Multi-source energy harvesting

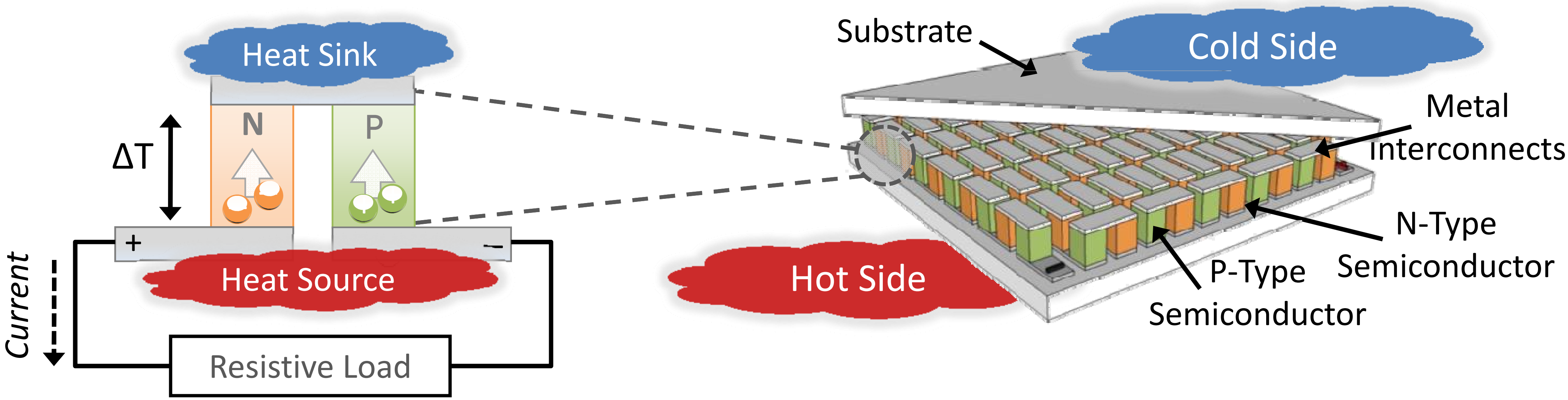
THERMOELECTRIC





Thermoelectric (TE) Operating Principles

Thermoelectric (TE) Energy Harvesting

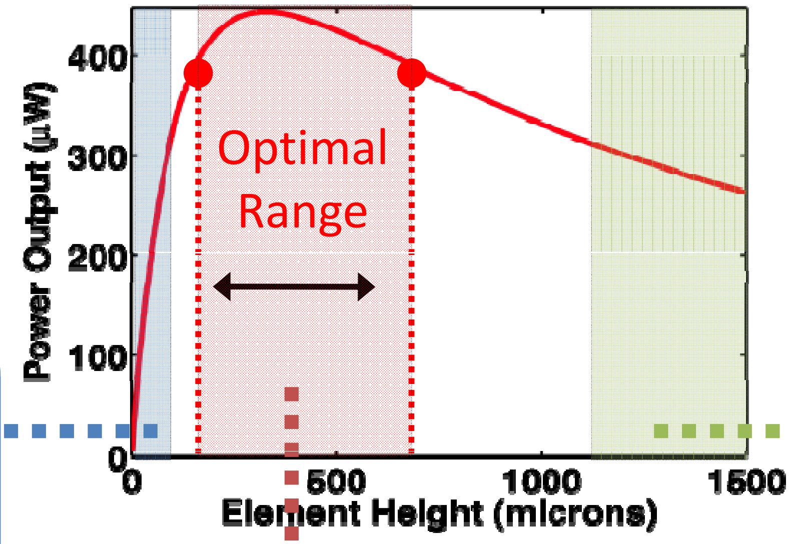


Sources of Waste Heat

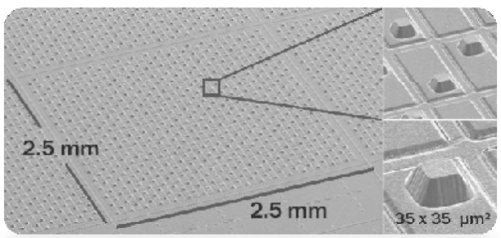
Location	Source	Temp. Gradient
Residential	Boilers, Dryers, Freezers, Oven	10-30K
Factories	Exhaust pipes, Boilers, Condensers	10-80K
Vehicles	Engine, Exhaust pipes	60K >100K
Airplanes	Cabin to External	10-50K

Thermoelectric Design

TE Power Output Optimization



Thin film elements

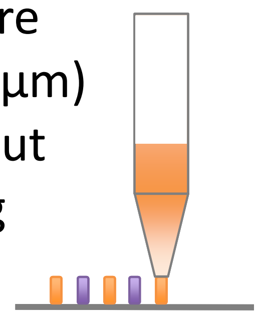


- Microfabrication processes
  - 60μm max. height
- *Materials intensive*

Micropelt, Inc

Dispenser Printing

- Optimal Feature Sizes (100-500μm)
- High throughput manufacturing

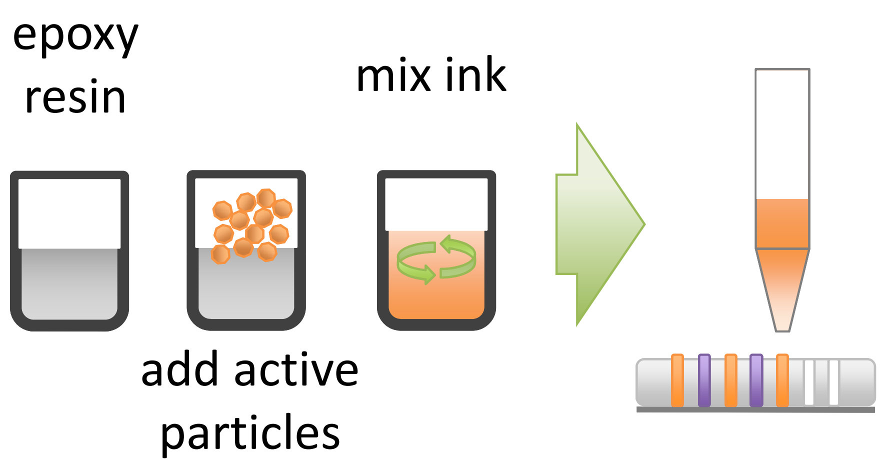


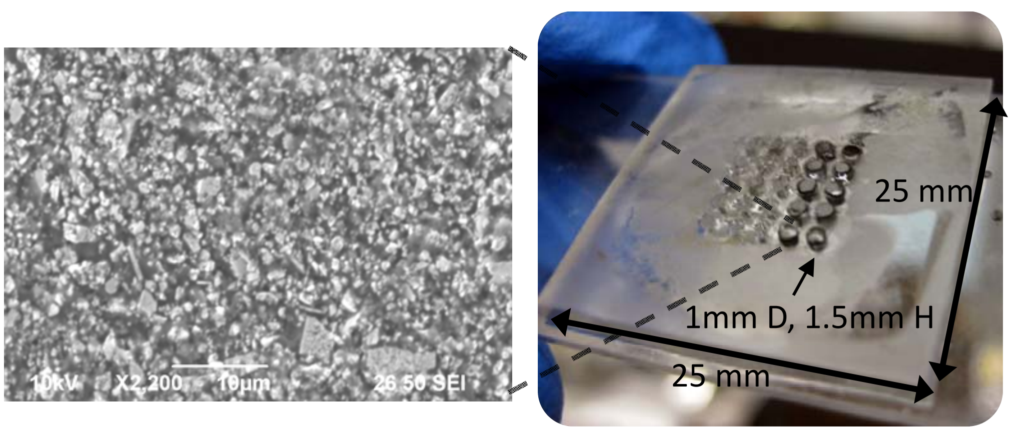
Bulk elements

- Diced elements from ingots
  - 1mm height min.
- *Labor intensive*
  - Manual pick & place

Ferrotec, Inc.

Where we left you 6 months ago:

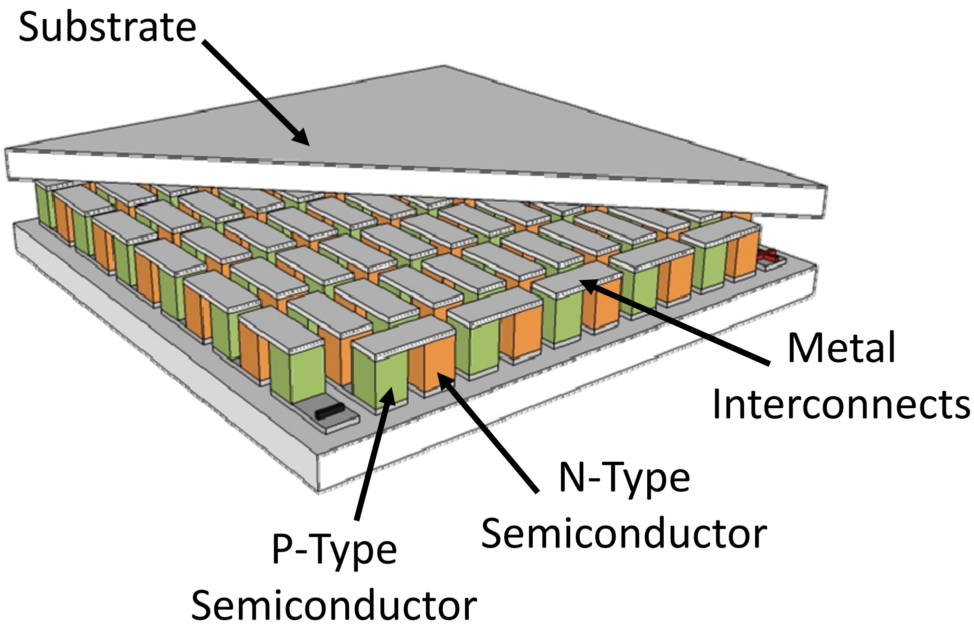




THERMOELECTRIC

- Meso-scale prototype fabricated using dispenser printing technique
- Printable semiconductor/epoxy thermoelectric materials synthesized

Progress: innovative design of TE harvester

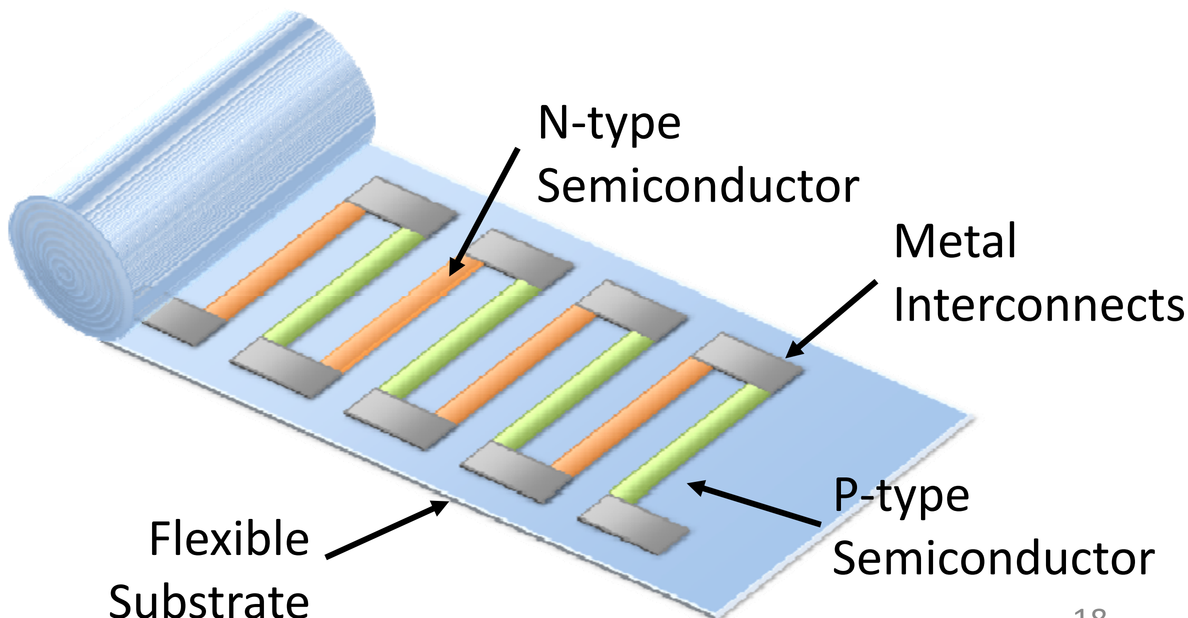


Traditional Design

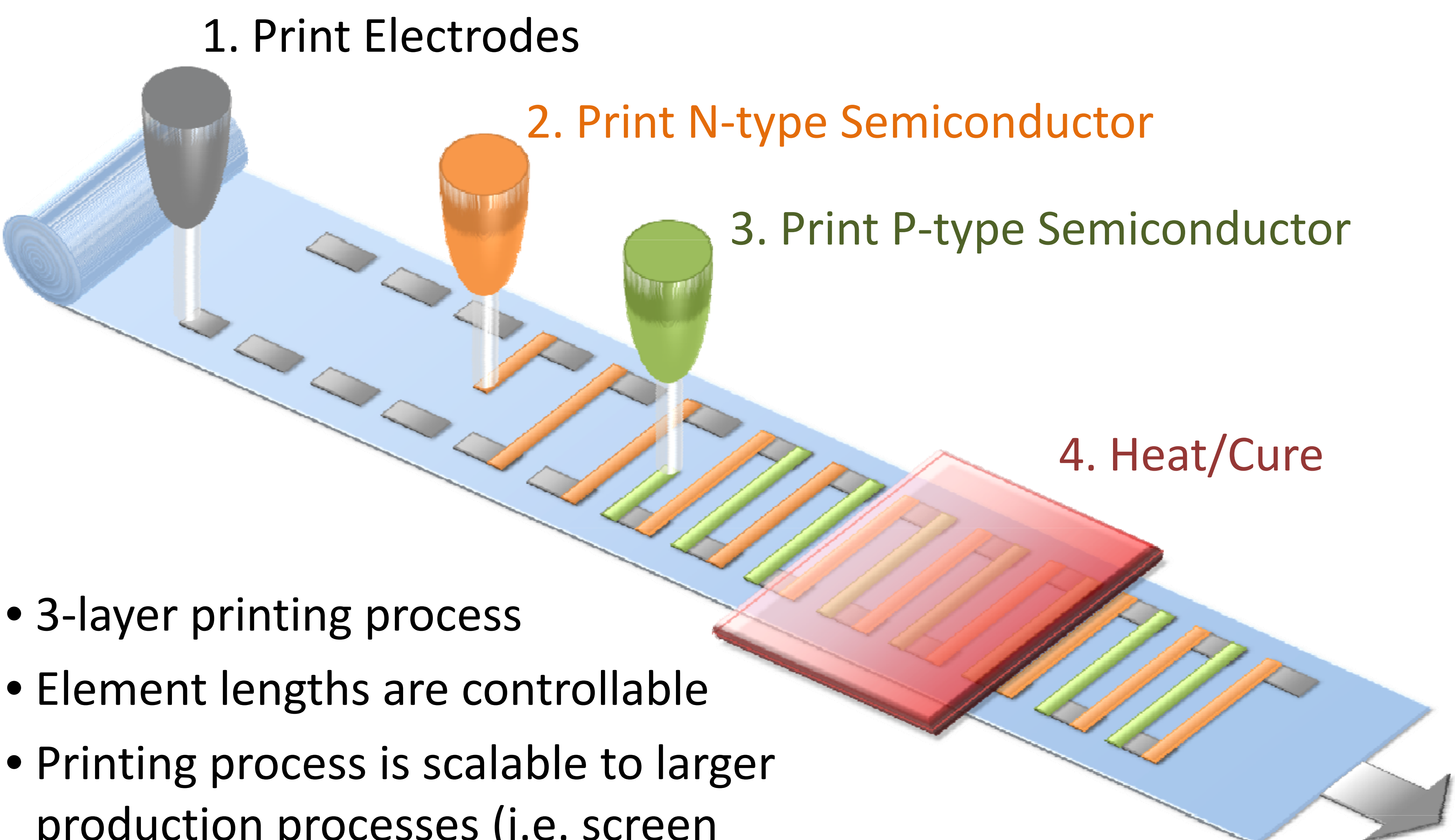
- Aspect ratios from 1.5 to 2
- Commercially available
- Labor intensive assembly

Planar Design

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



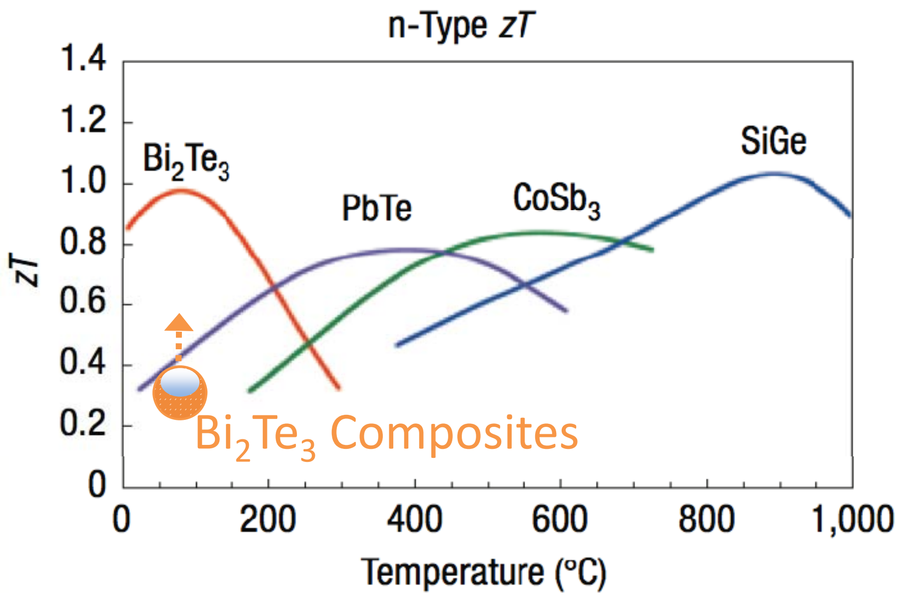
Progress: new design is easily scalable

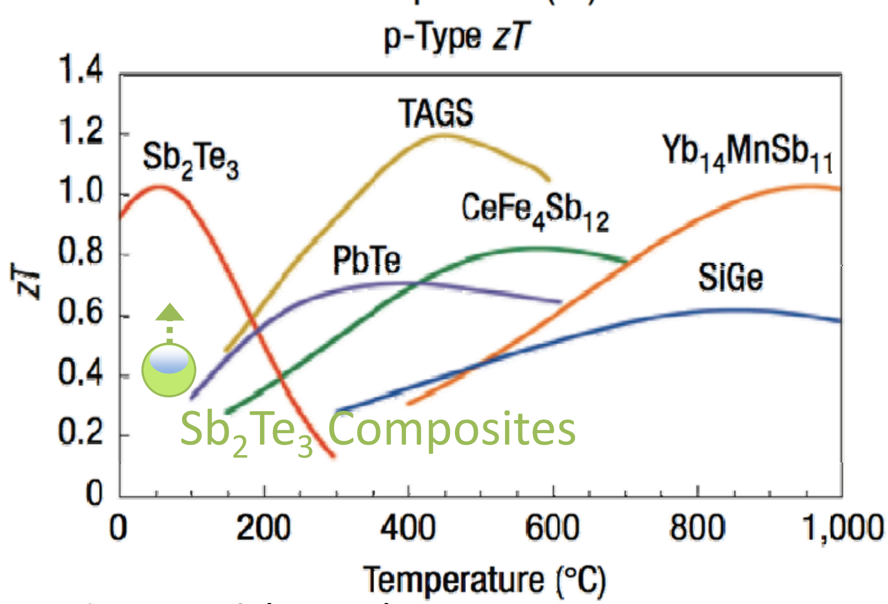


- 3-layer printing process
- Element lengths are controllable
- Printing process is scalable to larger production processes (i.e. screen printing, flexography)

Progress: performance of TE prototype

Thermoelectric Materials

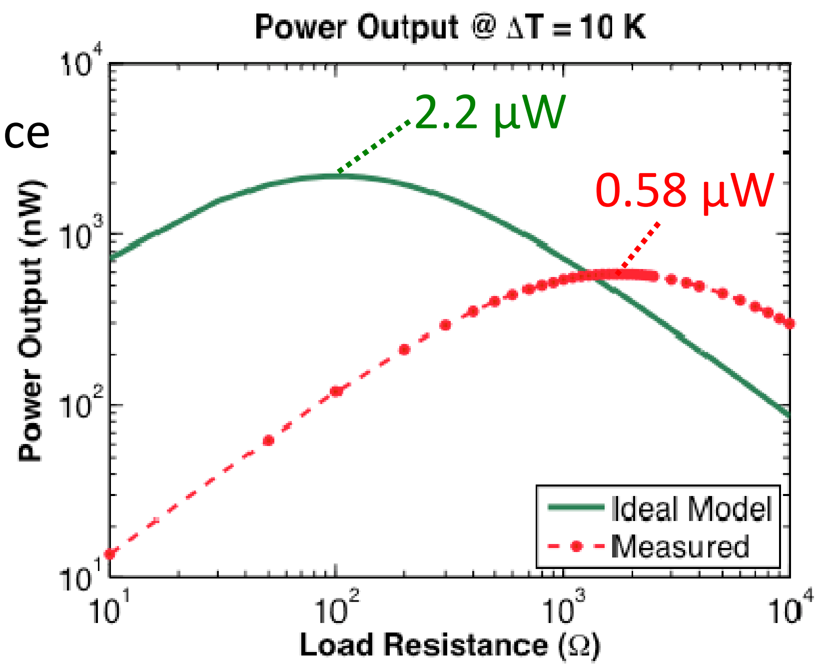


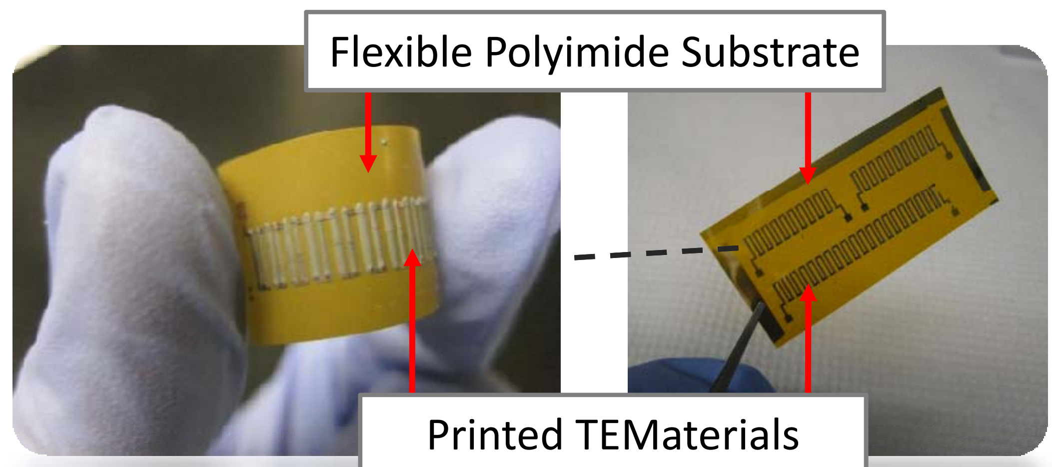


Snyder et al (2008)

Flexible TE Devices

- 10 Couple Device
- ΔT = 10 Kelvin
- Losses from contact resistance





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

Progress summary

PIEZOELECTRIC

VIBRATIONS

- P_{rms} = 1.1 nW/beam,
  micro device on ambient source
- Modified frequency by 20 Hz with printed mass
- Beam signals add when in series

AIR FLOW

- Meso-scale prototype designed, built, & characterized in duct
- P_{rms} = 1.1 mW, optimal conditions

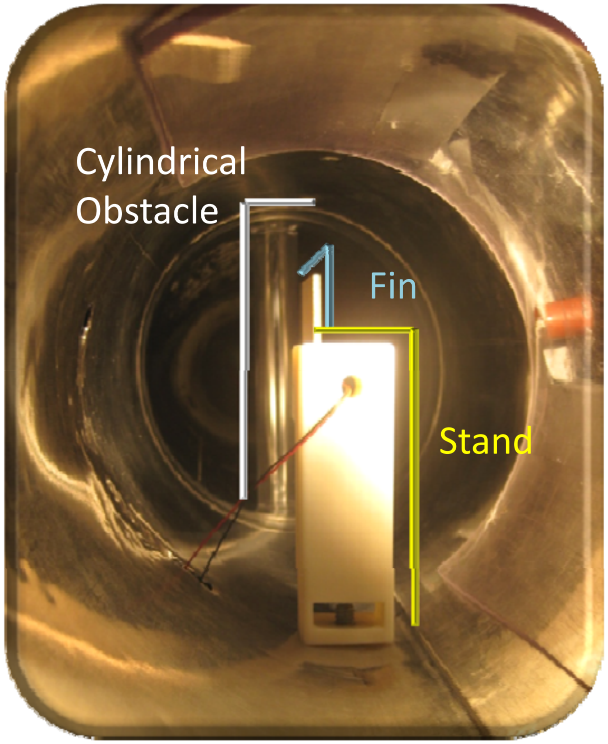
THERMOELECTRIC

TEMPERATURE DIFFERENCE

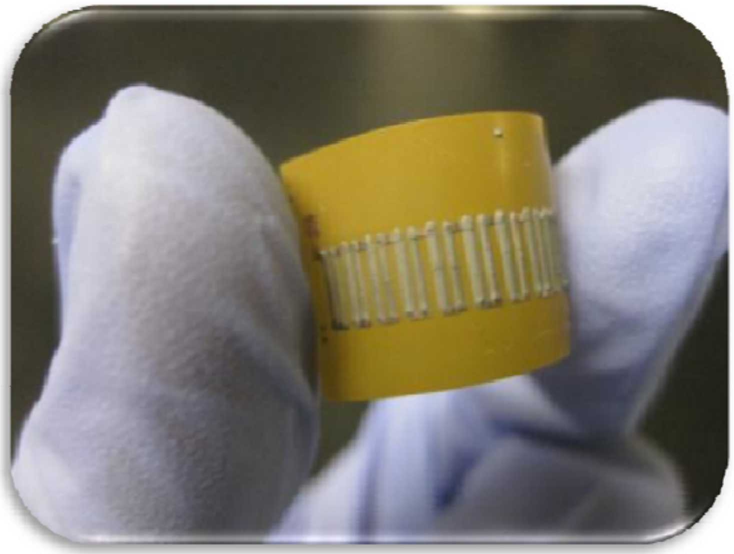
- Synthesized efficient, printable composite TE materials (ZT ~ 0.4)
- Developed scalable fabrication process for meso-scale devices
- P = 0.58 μW
  (ΔT = 10 K, 10-couple device)

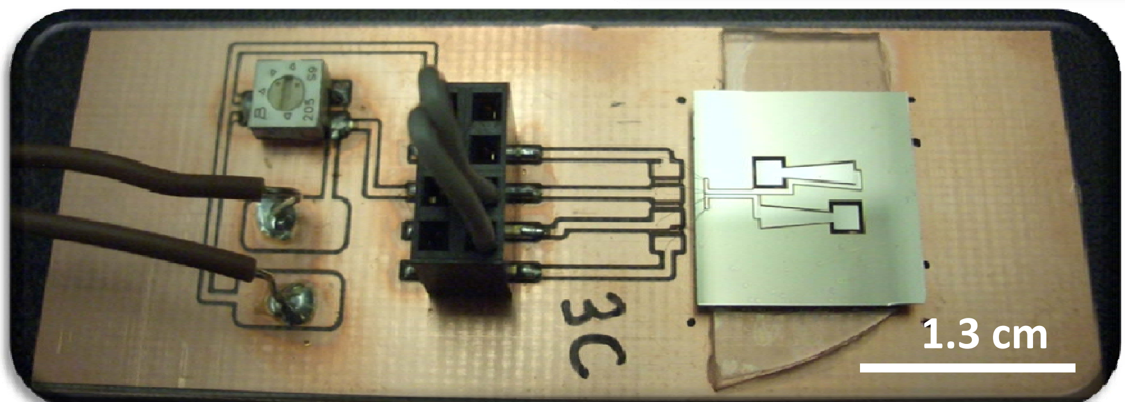
Thank you! Any questions?

AIR FLOW



THERMOELECTRIC





VIBRATION

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