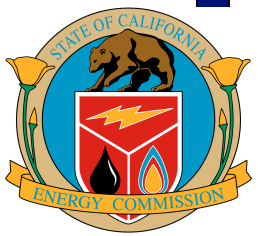
Micro scale energy harvesting from ambient vibrations

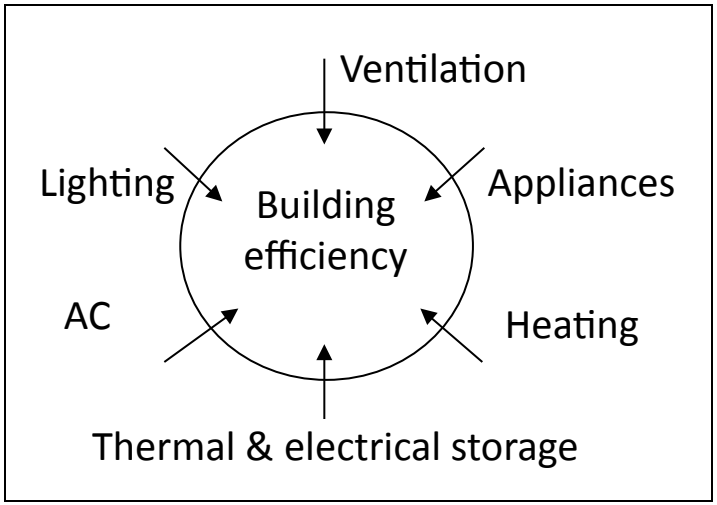
Lindsay Miller & Professor Paul Wright



Wireless sensor networks are very useful!

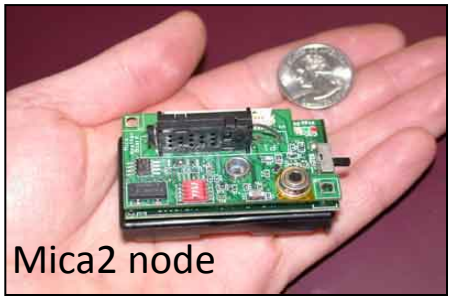
From serious…

- Energy efficiency in buildings
- Health care info management



…to frivolous…

- Meeting up with friends in a crowd



Sensor nodes limited by high maintenance cost to replace batteries.

Can't use wires, don't want to use batteries,
how else can we power the sensor nodes?

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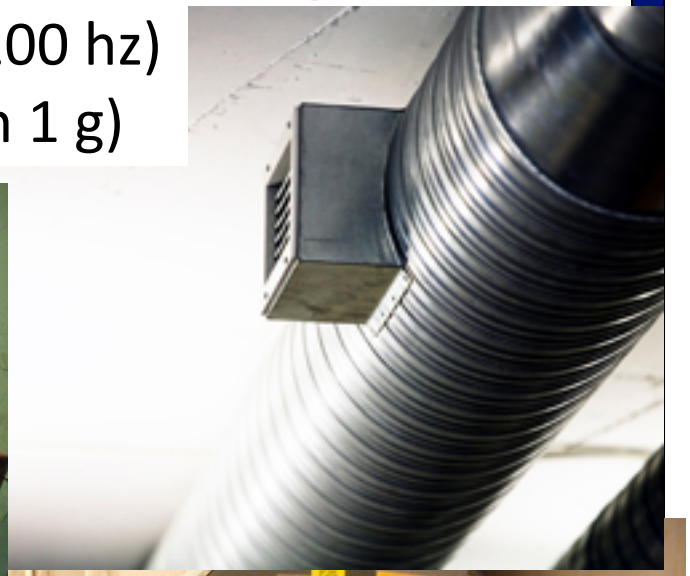
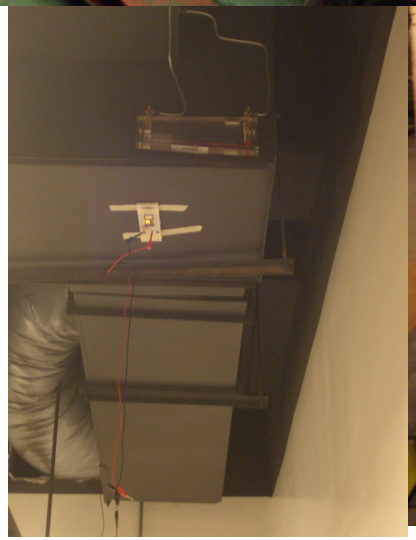
Ambient vibrations in buildings

low frequency (less than 200 hz)
low acceleration (less than 1 g)





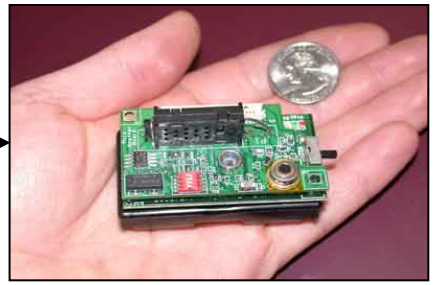
What if we could use those ambient vibrations to provide useful energy!?

My research goal:

?

Mechanical energy (vibrations)

Electrical energy



What to remember:

- Wireless sensor networks benefit society; need a better power supply
- We have successfully fabricated prototype vibration energy harvesters
- Prototype harvesters produced 1-38 nW from ambient vibration sources

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How much energy is available from ambient vibrations?

Characteristics of several vibration sources in buildings

	acceleration (g's)	frequency (hz)	ideal average power (uW/cm^3)
Washing machine	0.31	85	58
Clothes dryer	0.36	121	55
Small microwave oven	0.23	121	23
External windows by street	0.07	100	2.8
HVAC Etcheverry roof	0.25	185	18
HVAC duct Etcheverry 5th floor	0.2	29	66
Refrigerator	0.02	59	0.35

S. Roundy, PhD Thesis UC Berkeley 2003, Romy Fain, UC Berkeley undergrad

$$P = \frac{m\zeta_e A^2}{4\omega\zeta_t^2}$$

P = power
m = mass
A = acceleration
ω = freq
ζ =damping coeff

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How much power does a next-generation wireless sensor node need?

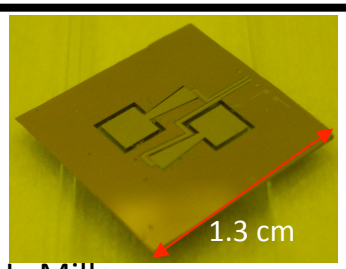
Energy harvesting: vibrations, thermal gradients

Power conditioning

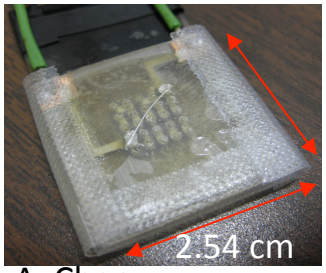
Energy storage: printed micro battery & micro capacitor

Load: radio & sensor

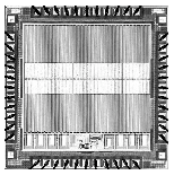
Sensor node boundary

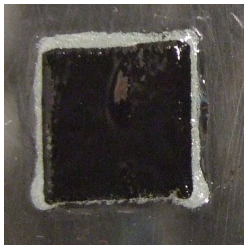


L. Miller

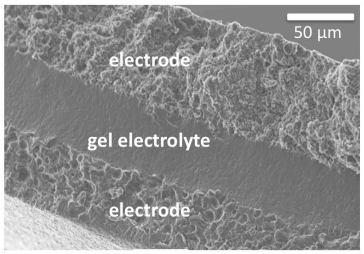


A. Chen

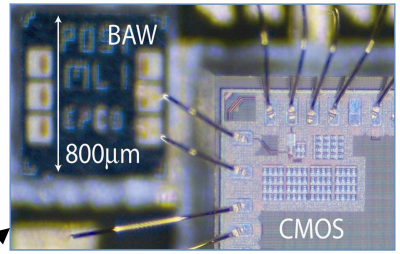




C. Ho



C. Ho



N. Pletcher

> ~0.5 V_{rms}
> ~1 µW

5 mW peak
5 µW average

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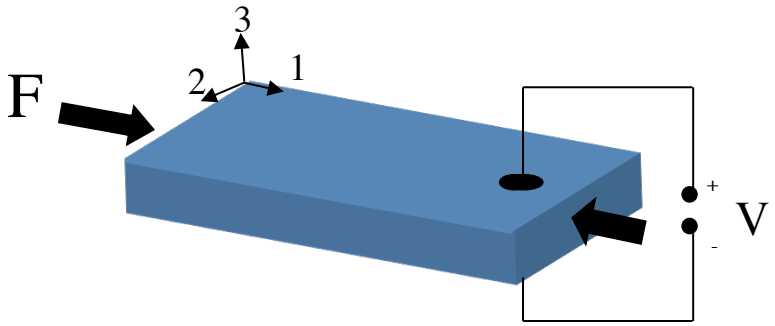
How to convert vibrations into electricity?

- Piezoelectric materials: mechanical to electrical energy conversion.
- Deform when a voltage is applied, produce voltage when deformed.

$$S_1 = s_{11}^E T_1 + d_{31} E_3$$

$$D_3 = d_{31} T_1 + \varepsilon_{33}^T E_3$$

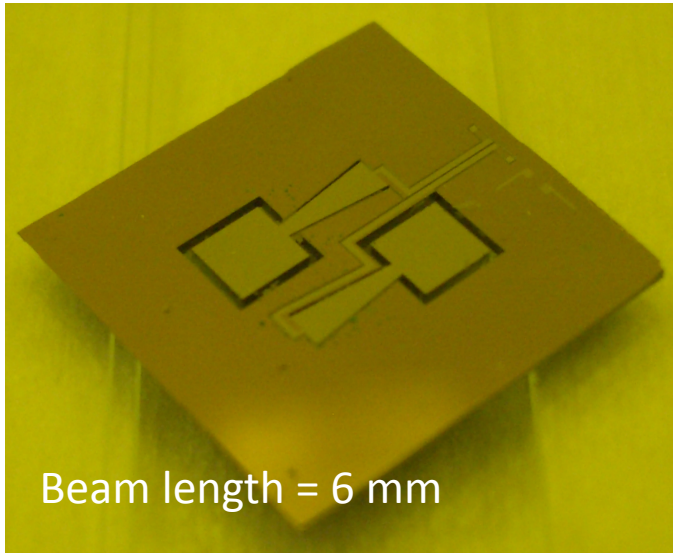


D_i = electric displacement
S_i = strain
T_i = stress
E_i = electric field
d_{31} = piezoelectric constant
ε_{33} = permittivity (at constant stress)
s_{11} = elastic compliance
(at constant electric field)

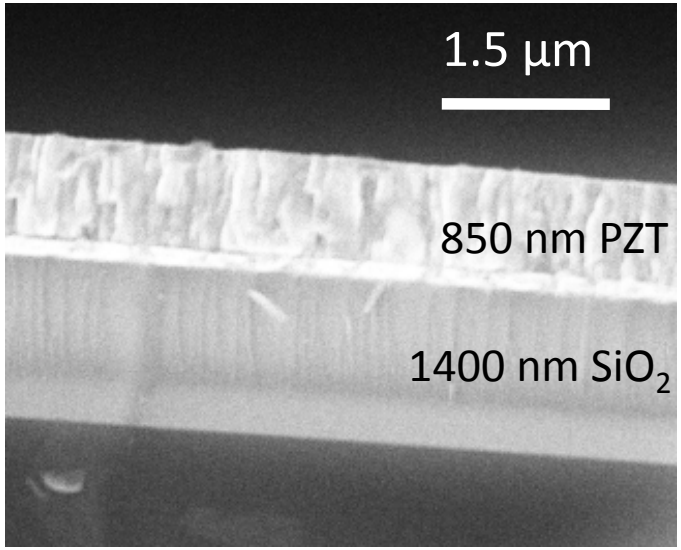
Examples of piezoelectric materials:
Quartz,
Lead Zirconate Titanate (PZT),
Aluminum Nitride (AlN),
Zinc Oxide (ZnO),
Bismuth Ferrite (BFO)

Meet the energy harvester.

Fabricated using MEMS (micro electro mechanical systems) processes.

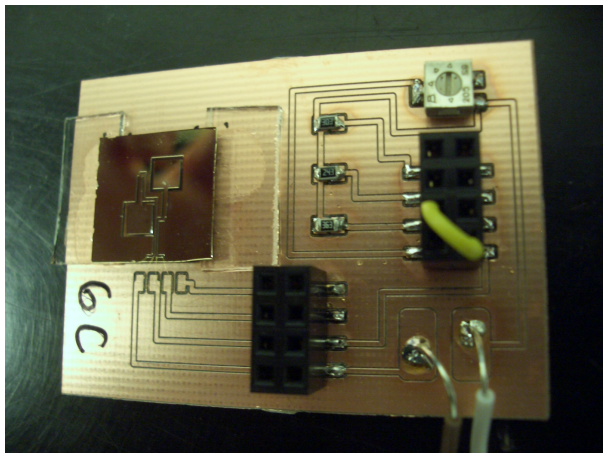


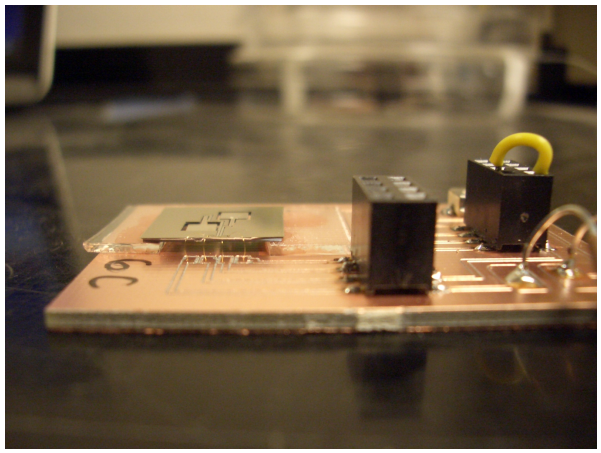
L. Miller et al, 2009

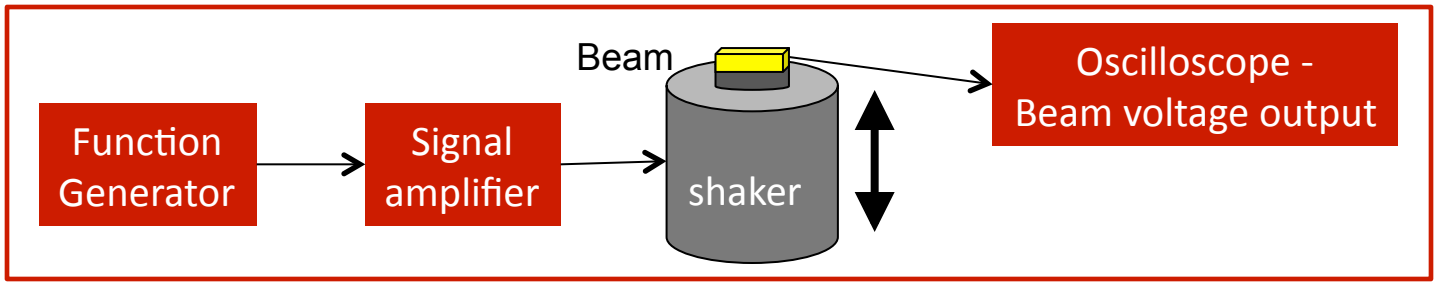


Micrograph of beam cross section: PZT is sandwiched by two 150 nm electrodes.

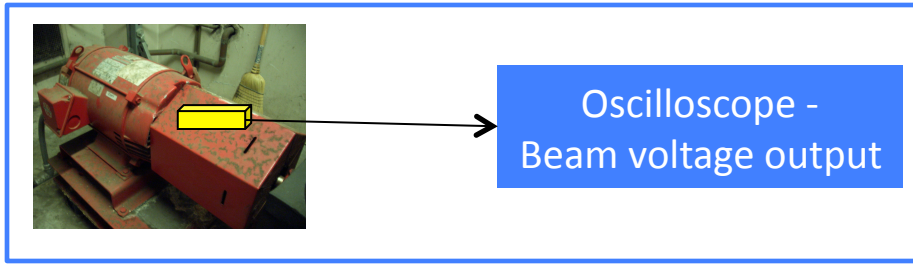
Energy harvester mounted for testing







Testing on shaker table



Testing on ambient source

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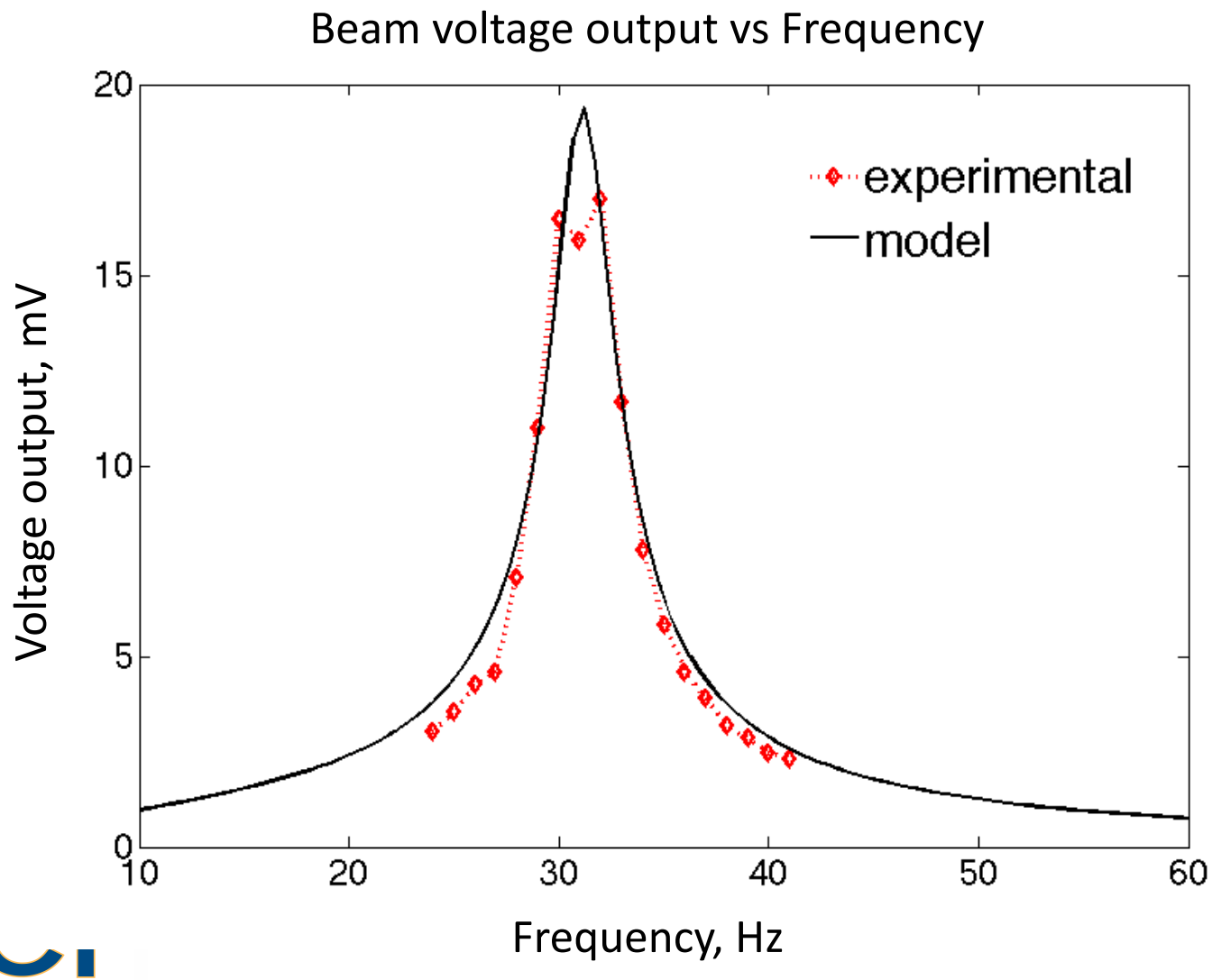
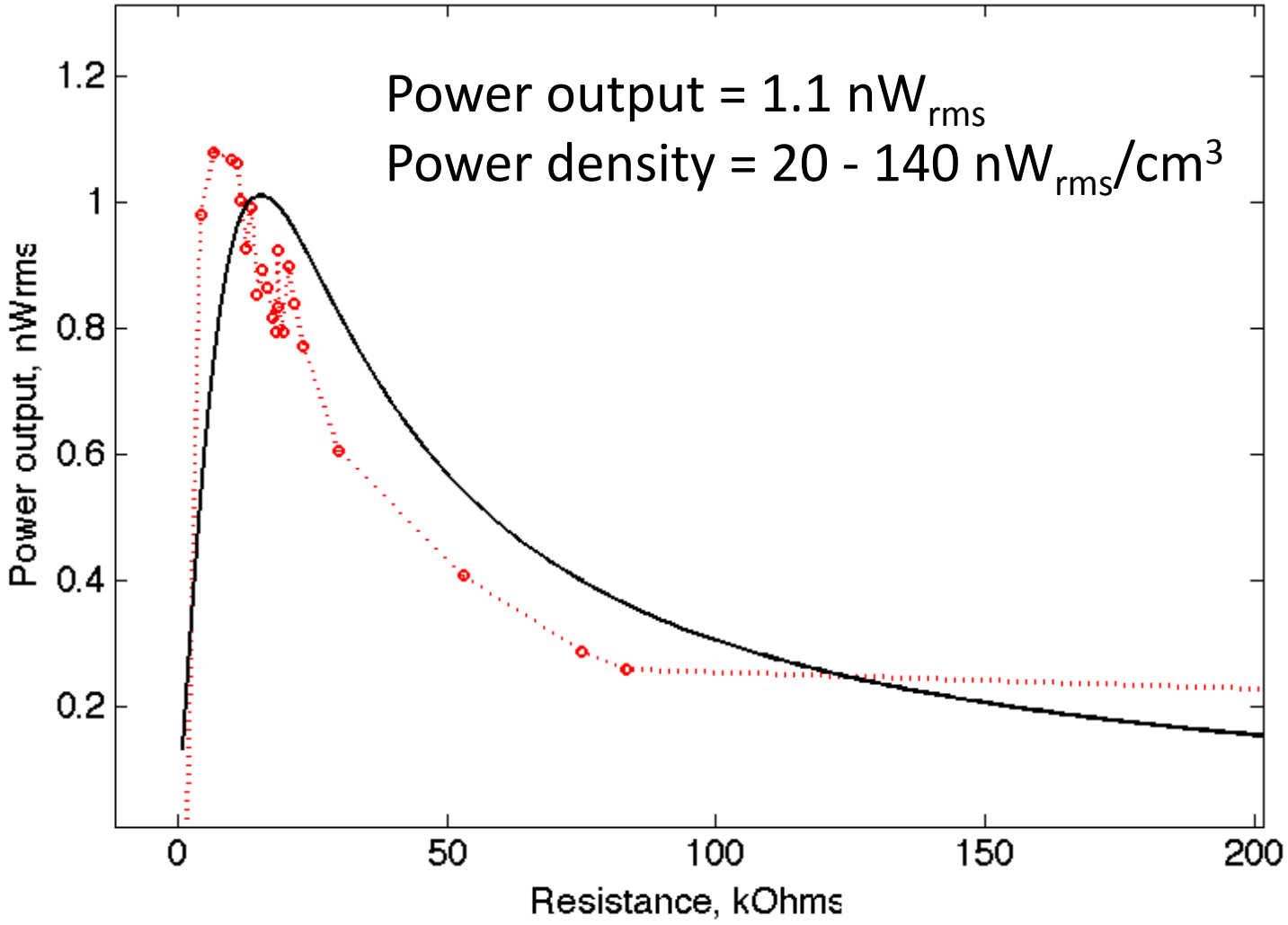
Results: beam has low resonance freq

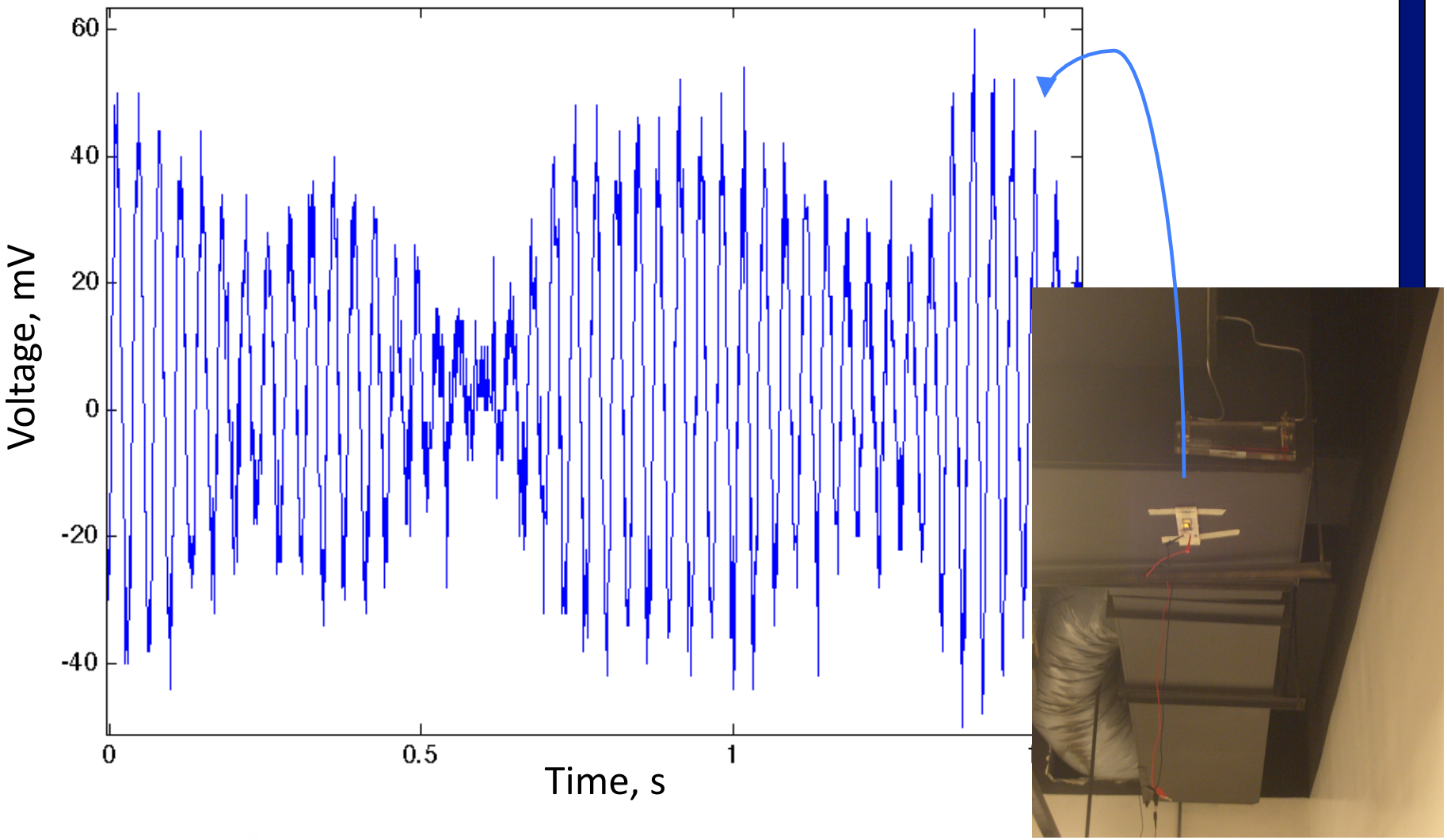


Results: output power is ~ 1-38 nW



Harvested energy from ambient sources

Voltage output from harvester on HVAC duct vs time (V_{rms}=22 mV)

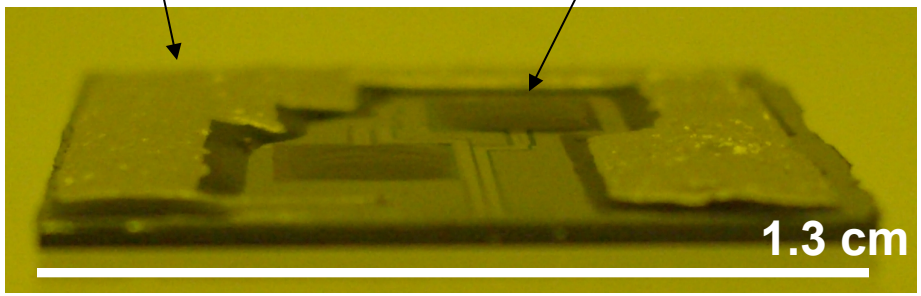


Next steps: printing mass & capacitor

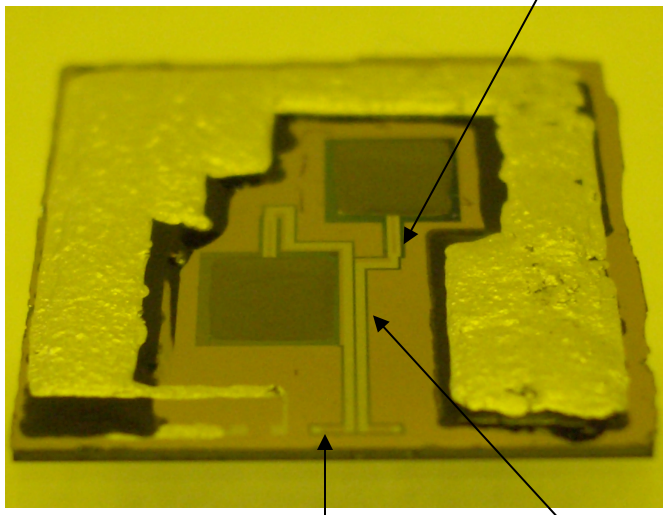
This is the first phase of work to integrate energy harvester with energy storage

Dispenser-printed capacitor sandwiched between current-collectors

Dispenser-printed proof mass



Beam structure



Electrode bond pads

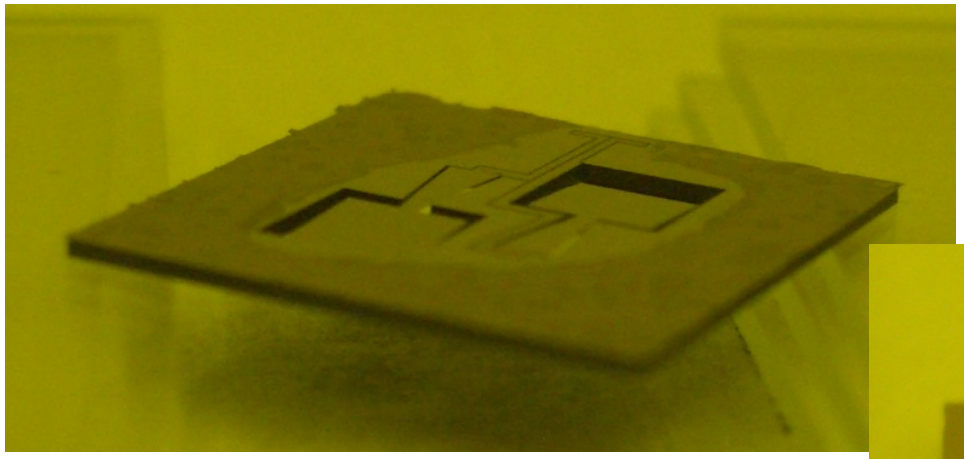
Electrode leads

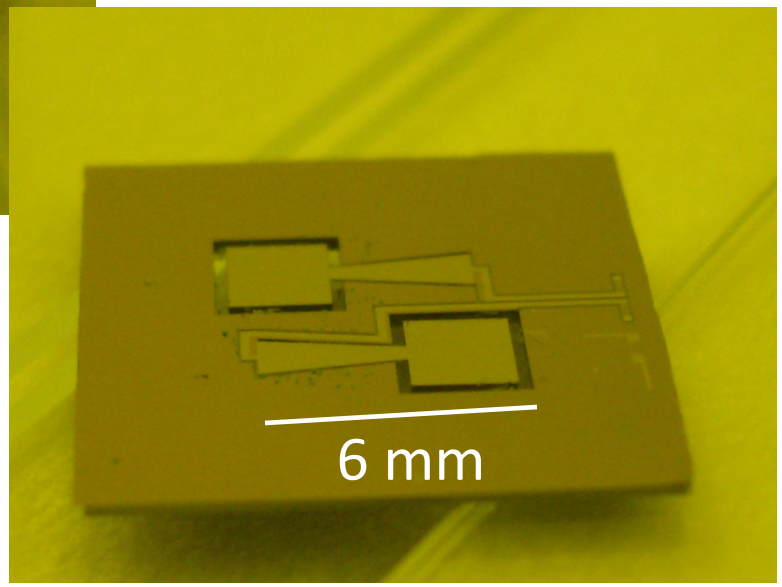
Remember these things:

- Wireless sensor networks benefit society; need a better power supply
- Successfully fabricated prototype energy harvesters with MEMS processes
- Prototype harvesters produced 1 - 38 nW from ambient vibration sources

- Future work
  - Printing capacitor/battery onto energy harvester chip
  - Printing mass to customize resonance frequency
  - Assess fatigue/failure mechanisms

Thank you! Questions?





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First generation prototypes