PennState

SSIST

# Energy Harvesting
# Power from the People!

Christopher D. Rahn
The Pennsylvania State University

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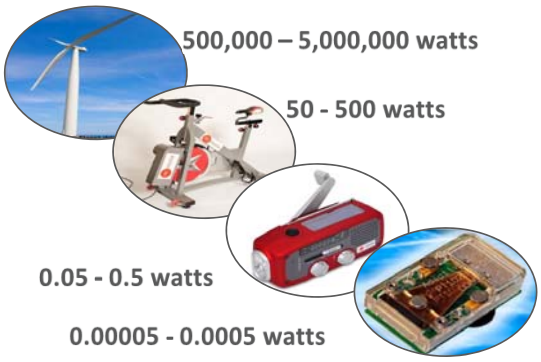
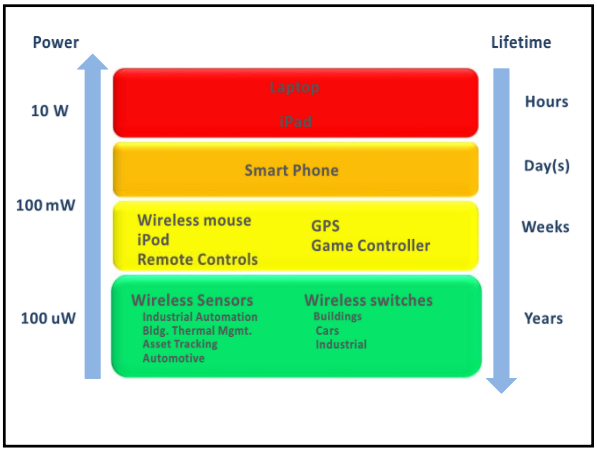


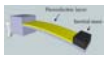
**Standard Quartz Watch**
< 10 uW

**Jawbone UB4**
- Battery: 38 mAh, 3.6 v = 137 J
- Lasts "up to 7 days".
- 225 – 500 uW average power draw

**Apple Watch** (38 mm version)
- Battery: 205 mAh, 3.6 V = 738 J
- Lifetime: 5 – 18 hrs → 14 - 41 mW
- 14 – 41 mW average power draw

Thermal

Solar



Vibration

Human Power

## Energy harvesting technologies

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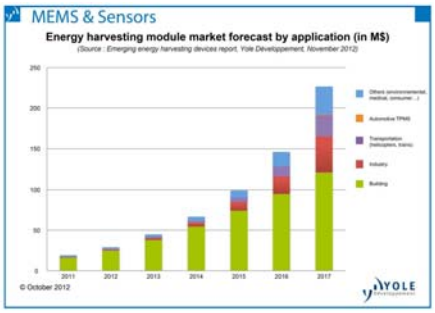
## Energy Harvesting Market




http://www.yole.fr/iso_upload/News/2012/PR_EmergingEnergyHarvestingDevices_YoleD%E9veloppement_Oct2012.pdf

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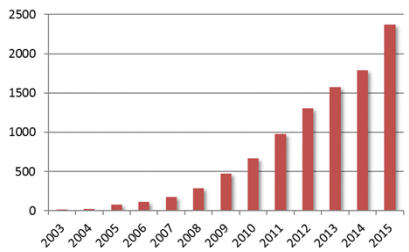
## Energy Harvesting Publications by Year




From Google Scholar
"Energy Harv*" or "Energy Scav*" in title

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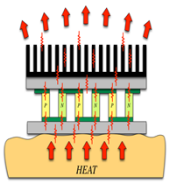
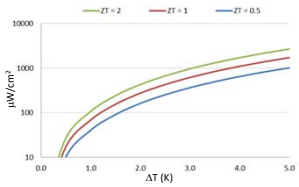
## Thermal Energy Harvesting




Courtesy of Prof. Mehmet Ozturk, NC State

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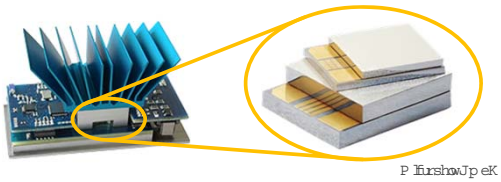
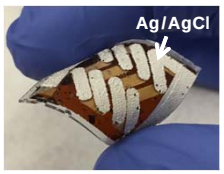
## Thermal Energy Harvesting



- Example using http://www.micropelt.com/products/mypelt.php
  - ΔT = 5 °C, 25 rows in series
  - Output
    - 88 mA, 0.75 V
    - 33 mW with matched load

## Flexible thermoelectrics




Courtesy of Prof. Mehmet Ozturk, NC State

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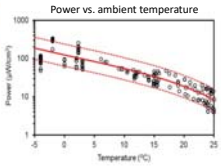
## Wearable devices




- Thermoelectric energy harvesters from the Holste Center (IMEC)
- Able to achieve about about 50 uW/cm$^2$ on wearable devices
- http://www.holstcentre.com/PartneringinResearch/SharedPrograms/WAST/MicroPowerGeneration.aspx

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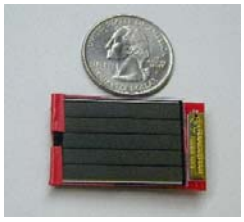
## Photovoltaic

- ~ 15 mW/cm$^2$ outside in direct sunlight
  - 15% efficiency, 100 mW/cm$^2$

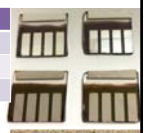


Power Measured At Increasing Distances from a 60 watt Bulb

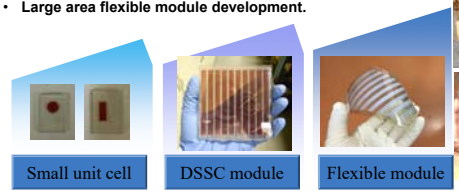
| Distance | Power ($\mu$W/cm$^2$) |
|---|---|
| 20 cm | 503 |
| 30 cm | 236 |
| 45 cm | 111 |
| Office Light | 7.2 |

## DSSC / Perovskite Solar Cells and Modules

| Samples | Voc (V) | Jsc (mA cm$^{-2}$) | FF(%) | η (%) |
|---|---|---|---|---|
| One-step deposition | 0.84 | 18.48 | 48.45 | 7.52 |
| Two-step deposition | 0.88 | 19.86 | 63.12 | 11.01 |
| Solvent engineering | 1.06 | 20.4 | 73.91 | 15.99 |



- **Close to highest efficiency reported in literature.**
- **One of the first demonstrations of the ferroelectric nature.**
- **Large area flexible module development.**

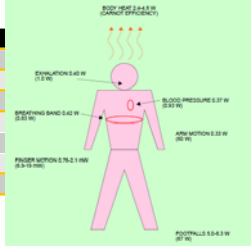




**Shashank Priya et al.**

## Power Potential from Human Motion

| Joint/Motion | Power [W] |
|---|---|
| Heel Strike | 2 |
| Ankle | 70 |
| Knee | 50 |
| Hip | 39 |
| Elbow | 2 |
| Shoulder | 2 |
| Center of Mass | 1 |

Niu et. al. 2004. IEEE Power Electronics Specialists Conference.



Power from body-driven sources
(Starner, 1996, *IBM Systems Journal*)

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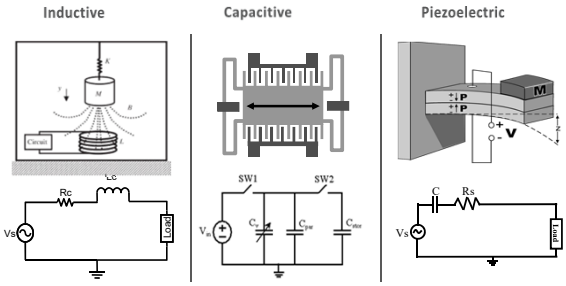
## Electromechanical Energy Harvesting

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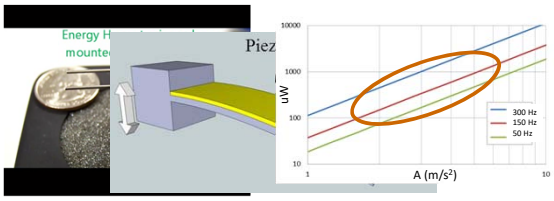
## Vibrations




Microgen Systems Inc.

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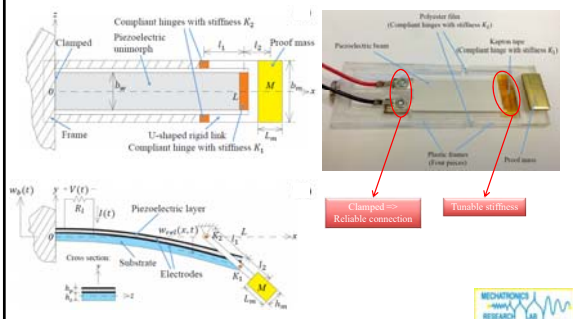
## State of the art mechanical harvester







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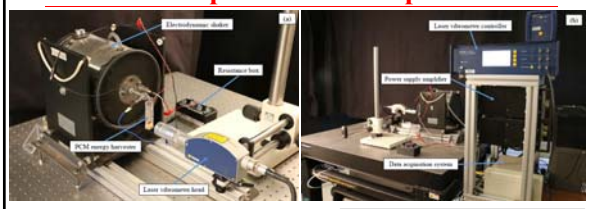
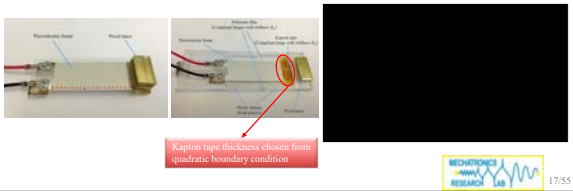
## Experimental Setup





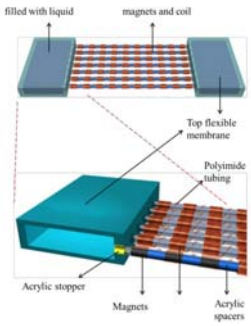
## Heel Strike - Shoes


Krupenkin and Taylor. 2011 Nature Communications

"few mW"

See also http://www.instepnanopower.com/

## Heel Strike - Shoes

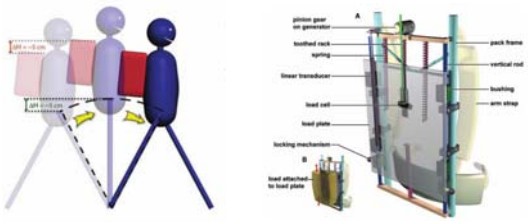



Bramhanand et. al., 2012. Hilton Head

7.3 mW

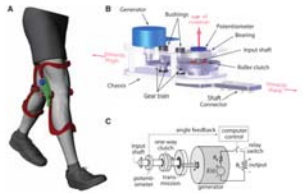
Prof. Hanseup Kim's group.

## Energy harvesting backpacks



Rome et. al., 2005 Science.
7.4 watts
80 lb backpack

## Energy harvesting from knee rotation



http://www.bionic-power.com/

Donelan et. al. 2008, Science.
~ 3.5 watts / leg
~ 2.4 watts / leg – regenerative braking mode

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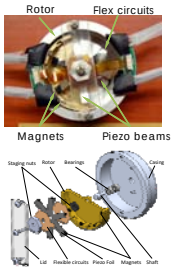
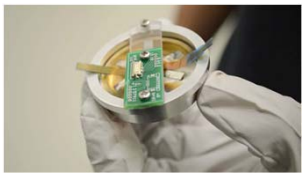
## Wrist worn piezoelectric energy harvester



Piezo by Susan Trolier-McKinstry group, Penn State
Flex circuits by Tom Jackson group, Penn State,
Device design/integration by Shad Roundy group,
U. Utah

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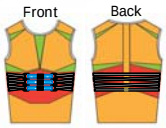
## Energy harvesting from breathing

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Thermal

Solar

Vibration

Human Power

## Energy harvesting technologies

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PennState

- Susan Trolier-McKinstry, Tom Jackson, Zoubeida Ounaies

NC STATE UNIVERSITY

- Mehmet Ozturk

Imperial College London

- Paul Mitcheson

Virginia Tech

- Shashank Priya

THE UNIVERSITY OF UTAH

- Shad Roundy, Jiyoung Chang

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# Thank You

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