LATEST ADVANCEMENTS IN ENERGY HARVESTING TRANSDUCERS

Applied Power Electronics Conference and Exposition 2014

Henrik Zessin, Fraunhofer IIS
Fort Worth, March 18, 2014

© Fraunhofer IIS

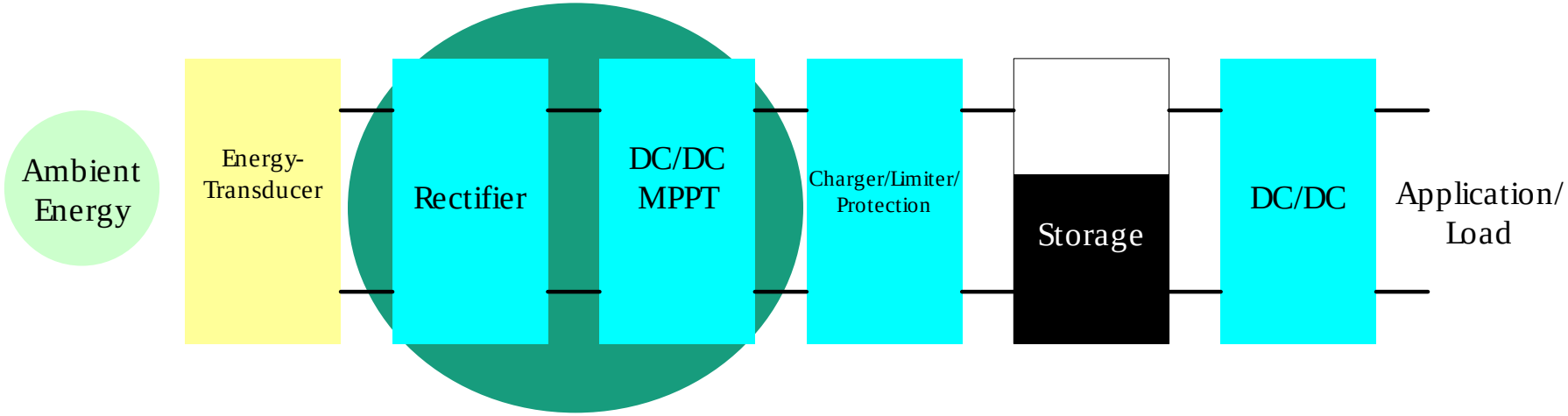
LATEST ADVANCEMENTS IN ENERGY HARVESTING TRANSDUCERS

- Introduction
- Energy Sources
  - Light
  - Vibrations
  - Temperature
- Something new

© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers

Introduction



- Photovoltaic
- Electro-Mechanical
- Piezo-Electric
- Thermo-Electric
- Radio Frequency

- Energy Conversion
- Manage Energy Storage
- Powers Application

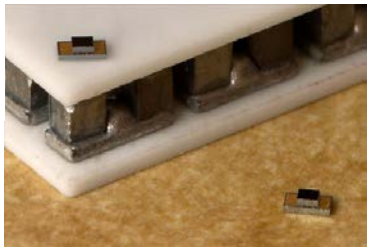
- Thin Film Battery
- Capacitor
- Traditional Battery
- Etc.

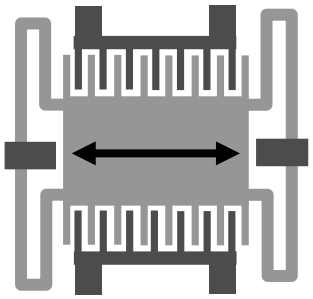
- Wireless Sensor
- Powered Card
- Implantable Medical
- Many, many more…

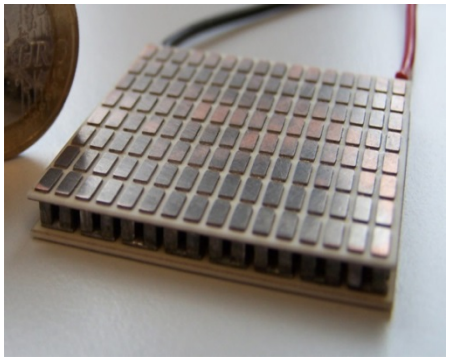
© Fraunhofer IIS

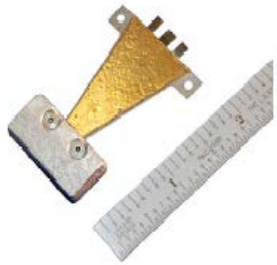
Latest Advancements in Energy Harvesting Transducers

Introduction



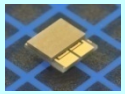






© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Introduction

Energy Source	Challenge	Typical Impedance	Typical Voltage	Typical Power Output	Cost
Light	Conform to small surface area; wide input voltage range	*Varies with light input* *Low kΩ to 10s of kΩ*	*DC: 0.5V to 5V [Depends on number of cells in array]*	10µW-15mW (Outdoors: 0.15mW-15mW) (Indoors: <500µW)	$0.50 to $10.00
Vibrational	Variability of vibrational frequency	*Constant impedance* *10s of kΩ to 100kΩ*	*AC: 10s of volts*	1µW-20mW	$2.50 to $50.00
Thermal 	Small thermal gradients; efficient heat sinking	*Constant impedance* *1Ω to 100s of Ω*	*DC: 10s of mV to 10V*	0.5mW-10mW (20°C gradient)	$1.00 to $30.00
RF & Inductive	Coupling & rectification	*Constant impedance* *Low kΩs*	*AC: Varies with distance and power* *0.5V to 5V*	Wide range	$0.50 to $25.00

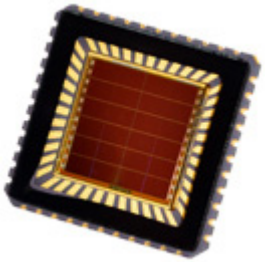
© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers

- Introduction
- **Energy Sources**
  - *Light*
  - Vibrations
  - Temperature
- Something new

© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Light



Voc [Volts]	Isc [mAmp]	Max Power [mWatt]	Anode pin (+)	Cathode pin (-)	Required connections
9	0.6 (1)	3 (1) 0.018 (2)	6	19	1-48, 2-3, 4-5, 20-21, 22-23, 24-25, 26-27, 28-29, 30-43, 44-45, 46-47
4.5	1.2 (1)	3 (1) 0.018 (2)	6	19	1-48, 2-3, 4-5, 6-30, 19-43, 20-21, 22-23, 24-25, 26-27, 28-29, 44-45, 46-47
3	1.7 (1)	3 (1) 0.018 (2)	6	19	1-48, 2-3, 4-5, 6-26-46, 19-27-47, 20-21, 22-23, 24-25, 28-29, 30-43, 44-45
2.25	2.4 (1)	3 (1) 0.018 (2)	6	19	1-19-25-43, 2-3, 4-5, 6-24-30-48, 20-21, 22-23, 26-27, 28-29,44-45, 46-47
1.5	3.5 (1)	3 (1) 0.018 (2)	6	19	1-48, 2-6-22-26-30-46, 3-19-23-27-43-47, 4-5, 20-21, 24-25, 28-29, 44-45
0.75	7 (1)	3 (1) 0.018 (2)	6	19	1-3-5-19-21-23-25-27-29-43-45-47, 2-4-6-20-22-24-26-28-30-44-46-48

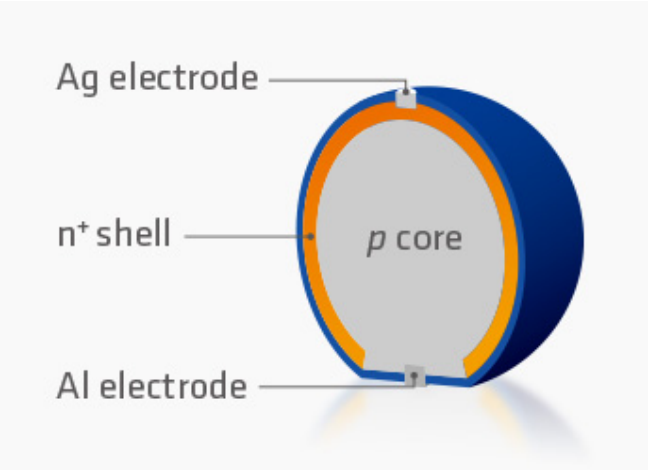
- Sol Chip
  - Selectable output voltages
  - Full daylight: 3,3mW
  - Office light: ~20µW
  - Automatic assembly

© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Light

- Sphelar
  - One: 0,6mW
  - Array: 13,5mW
  - Dome: 230mW

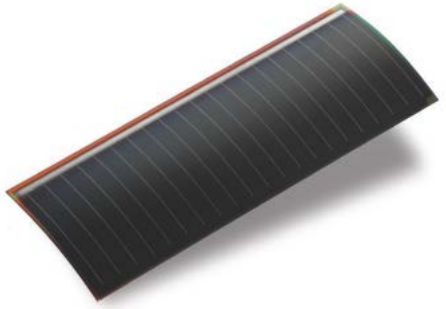
- Spherical light receiving surface
- Advantages in unfavorable lighting situations like
  - Cloudy days
  - Low light



© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Light

- Alta Devices
  - GaAs-based
  - Conversion efficiency at 28,8%



Electrical Specifications

Performance Outdoors at STC

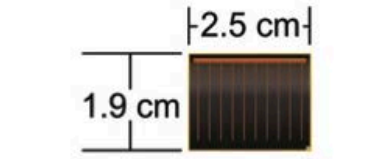
		Sensor Cell	Standard Cell	1W String
P_{mp}	[W]	0.110	0.220	1.10
V_{mp}	[V]	0.960	0.960	4.80
I_{mp}	[A]	0.115	0.230	0.23
V_{oc}	[V]	1.090	1.090	5.45
I_{sc}	[A]	0.120	0.239	0.24

Standard test conditions [STC]: AM1.5, 1000 W•m-2 at 25°C.

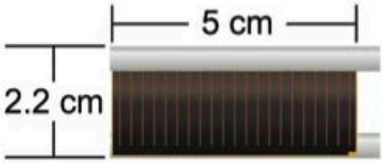
Performance Indoors at ITC

		Sensor Cell	Standard Cell	1W String
Dim (200 Lux)	[µW]	75	150	750
Bright (500 Lux)	[µW]	195	390	1950
Industrial (1000 Lux)	[µW]	400	800	4000

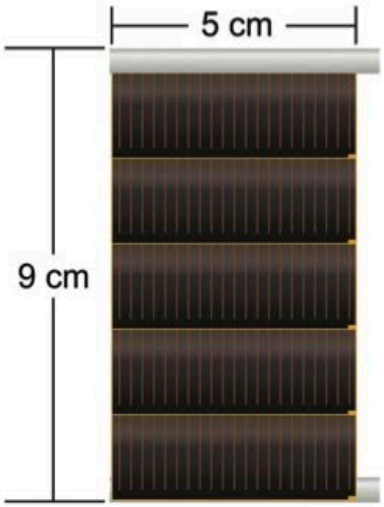
Indoor test conditions [ITC]: 2700K LED at 25°C.



Sensor cell* without ribbons



Standard cell with ribbons



1 W string with ribbons

© Fraunhofer IIS

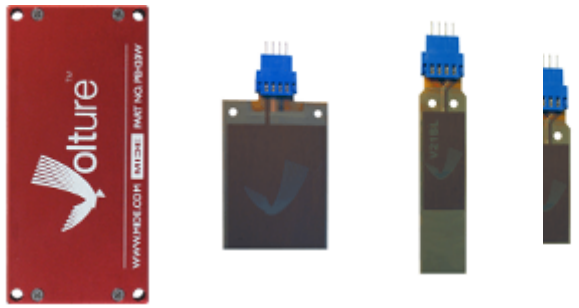
Latest Advancements in Energy Harvesting Transducers

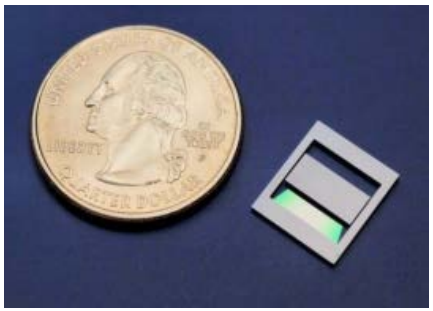
- Introduction
- **Energy Sources**
  - Light
  - *Vibrations*
  - Temperature
- Something new

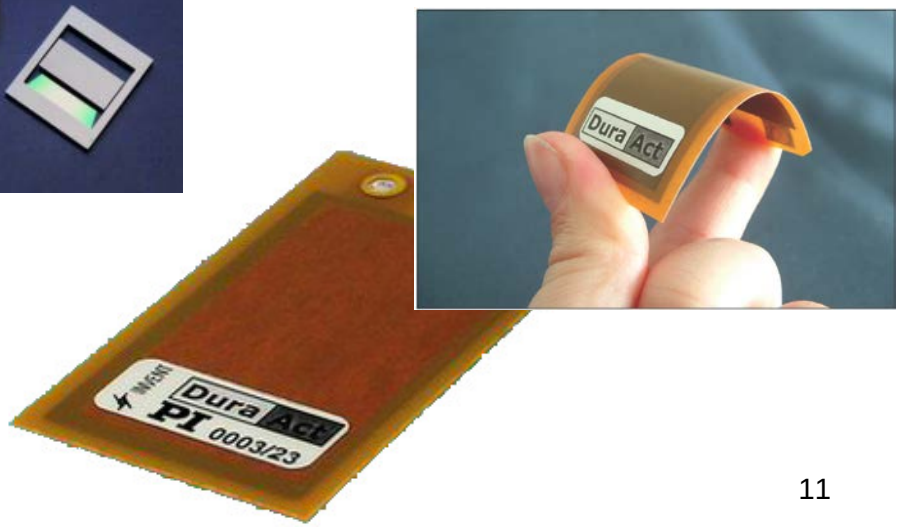
© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Vibrations

- **Piezoelectric**
  - Hundreds of kΩ
  - Relatively **high** Voltages
- **Midé**
  - Up to 10mW
- **microGen** BOLT
  - 25 – 100µW
- **PI Ceramic**
  - DuraAct
  - Robust and **flexible**





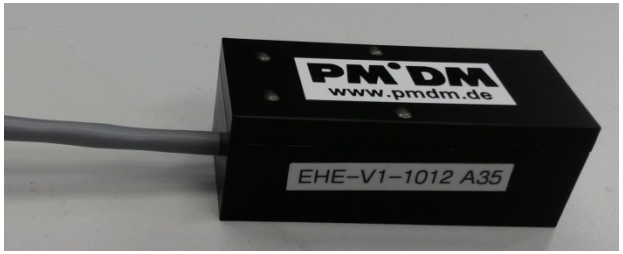


© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Vibrations

- **Electrodynamic**
  - Hundreds of Ω
  - **Medium** Voltage range

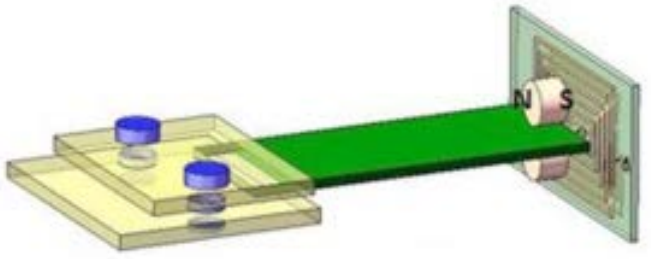
- Perpetuum
  - 10mW @100mg
- Ferro Solutions
  - 5mW @100mg
- PMDM
  - 0,8mW @100mg



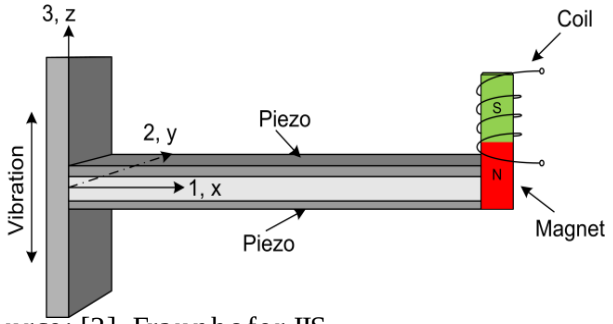
© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Vibrations

- **Hybrid** Generator
- Can achieve higher **power density** than single transducer [4]
- **Easy to add** coil and magnet to piezoelectric generator



Source: [1] National University of Singapore

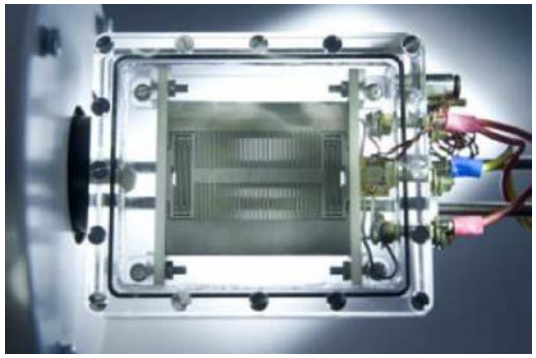


Source: [2] Fraunhofer IIS

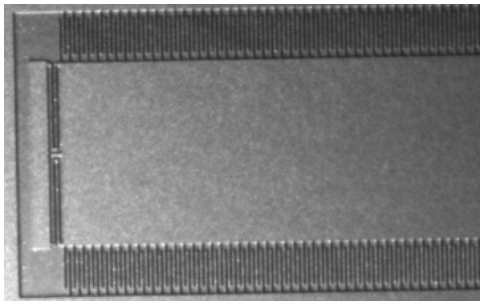
© Fraunhofer IIS

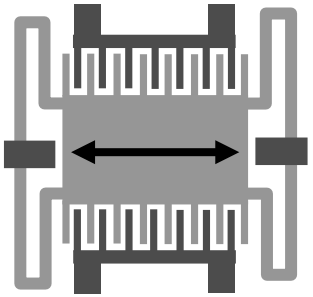
Latest Advancements in Energy Harvesting Transducers
Vibrations

- **Electrostatic** Generators
- Size reduction through **MEMS** fabrication
- Possibly **low cost** generators
- Here: 50Hz, 90µm amplitude:
- **~1,1mW** harvested power



Source: [5] High Damping Electrostatic System For Vibration Energy Scavenging





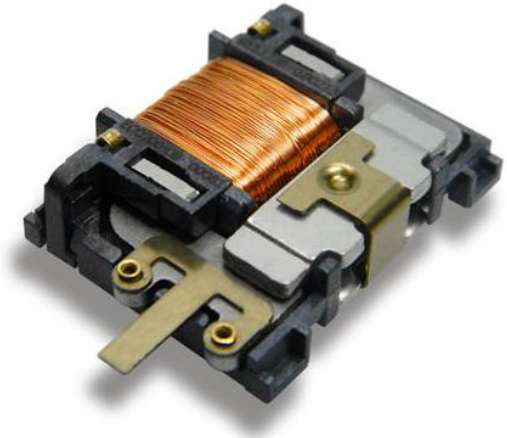
© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Vibrations

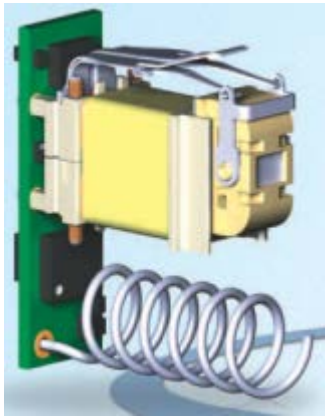
- Switches

- EnOcean
  - Force 2,7 – 3,9N
  - Energy: **0,12 – 0,21mWs** after DC/DC

- Cherry
  - Force ~3N
  - Energy: **0,33mWs**



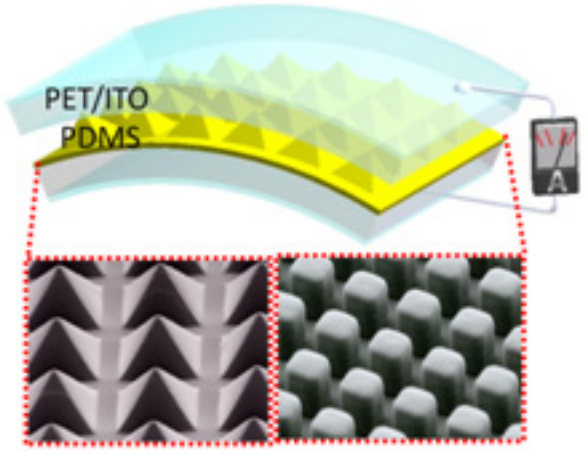
Source: [7] EnOcean, Cherry



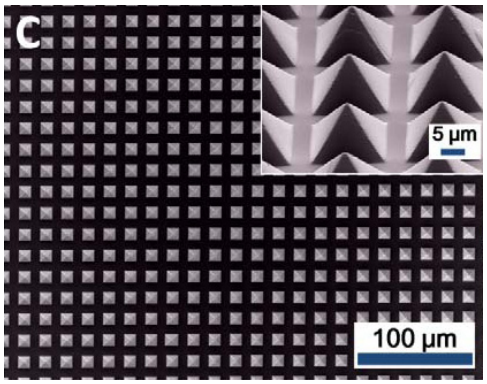
© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Vibrations

- Newnagy **Triboelectric** Generator
- Triboelectric Effect:
  - Materials become **electrically charged** after contact with different material through **friction**
  - PET **donates** electrons
  - PDMS **accepts** electrons
- Can be **nearly transparent**
- 18 V * 130nA = **2,3 µW** per cm²



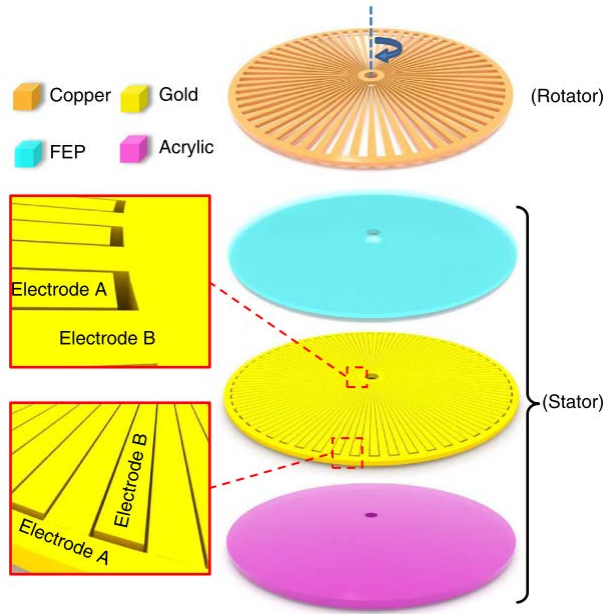
Source: [6] Georgia Tech, Newnagy

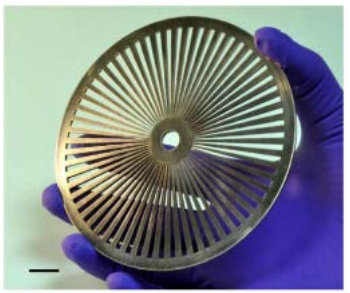


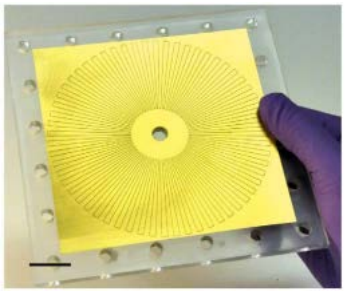
© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Vibrations

- Rotary **Triboelectric** Generator
- Area power density **19mW/cm²**
- Conversion efficiency **24%**
- Produced **1,5W** at 3000rpm







[10] Chinese Academy of Sciences, Georgia Institute of Technology

© Fraunhofer IIS

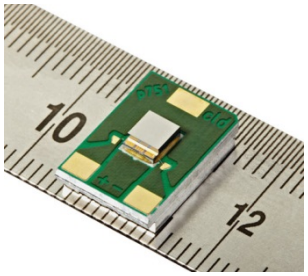
Latest Advancements in Energy Harvesting Transducers

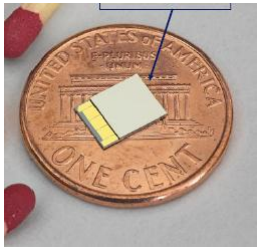
- Introduction
- **Energy Sources**
  - Light
  - Vibrations
  - ***Temperature***
- Something new

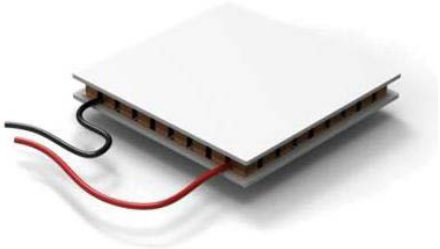
© Fraunhofer IIS

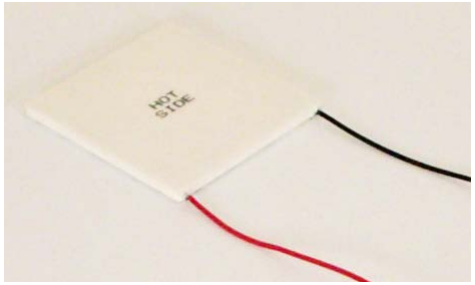
Latest Advancements in Energy Harvesting Transducers
Temperature

- **Micropelt**
  - hundreds of Ω, ~100mV/K
- "Classic" **TEGs**
  - tens of Ω, ~30mV/K

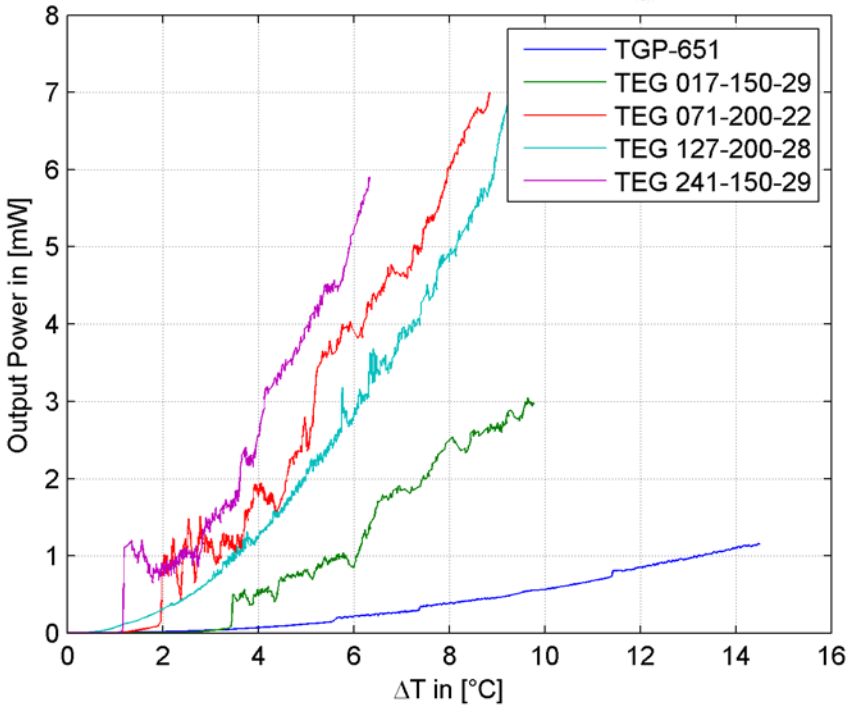








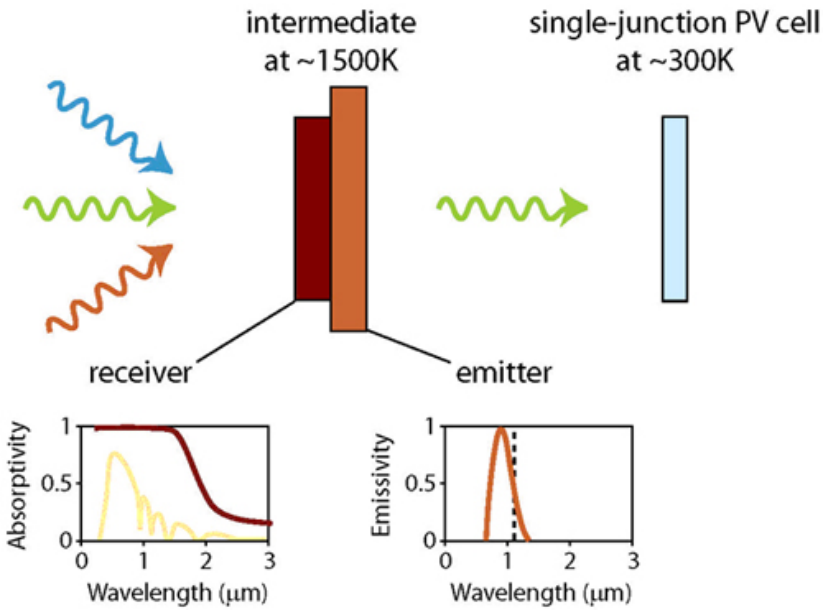
Source: Thermalforce



© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Temperature

- Solar **Thermophotovoltaic** (STPV)
  - Turn **sunlight** into **heat** first
  - Then use PV optimized for **infrared radiation**
  - Classic Solar: Shockley-Queisser **limit** at 33,7% (single p-n junction layer)
  - **Efficiency** of TPV could be significantly **higher**



Source: [9] Stanford

© Fraunhofer IIS

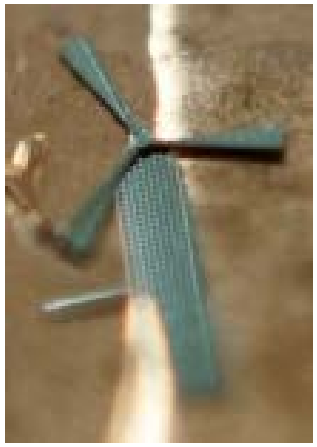
Latest Advancements in Energy Harvesting Transducers

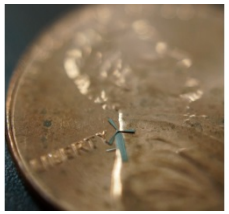
- Introduction
- **Energy Sources**
  - Light
  - Vibrations
  - Temperature
- ***Something new***

© Fraunhofer IIS

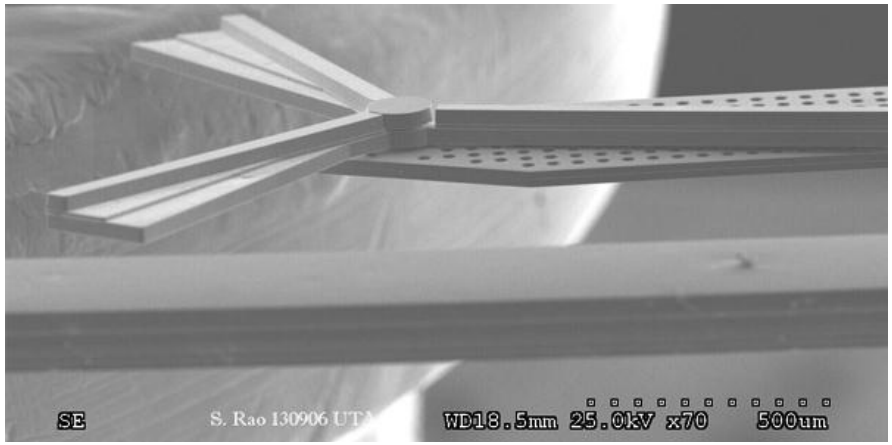
Latest Advancements in Energy Harvesting Transducers
Something new

- **Micro Windmills**, *UT Arlington*
- About **1,8mm** wide
- **Mass-producable** on single wafer





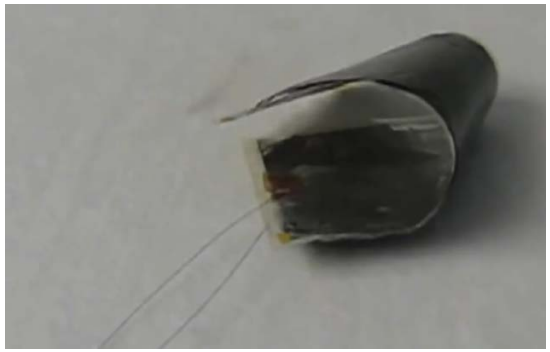
Source: [3] UT Arlington



© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Something new

- **Water vapor** generator, MIT
- Material changes shape after **absorbing evaporated water**
- Generate electricity by
  - Humidity gradient cause polymer to cyclically
  - **Roll** up
  - **Flip** over
  - **Roll** in other direction
- Were able to generate **5,6 nW**



Source: [8] MIT

© Fraunhofer IIS

Latest Advancements in Energy Harvesting Transducers
Summary

- **Different** kinds of **generators** for **different** kinds of ambient **energy**:
- Light, Vibrations, Temperature and Wind
- **Ongoing research** for all generators
  - **Material** development
  - **Structural** development
- Higher **power densities**
- Reduction of **production costs**

© Fraunhofer IIS

Thank you for listening!

Any questions.....?

- Contact: Henrik Zessin
  Fraunhofer-Institute for Integrated Circuits
  Nordostpark 93
  90411 Nuremberg
  Tel. 0911 / 58061 6425
  henrik.zessin@iis.fraunhofer.de

- www.iis.fraunhofer.de/ec/power
- www.smart-power.fraunhofer.de

© Fraunhofer IIS

References

- [1] Hybrid energy harvester based on piezoelectric and electromagnetic mechanisms, *Bin Yang Changkuo Lee and Wei Loon Kee Siak Piang Lim*, National University of Singapore
- [2] Modeling of Hybrid Piezoelectrodynamic Generators, *Henrik Zessin, Loreto Mateu and Peter Spies*, 8th Energy Harvesting Worshop 2013 at Leibnitz Universität Hannover, http://www.iis.fraunhofer.de/content/dam/iis/de/dokumente/em/Power-und_Batteriemanagement/Modeling%20of%20Hybrid%20Piezoelectrodynamic%20Generators.pdf
- [3] Micro Windmills, *UT Arlington*, http://www.uta.edu/news/releases/2014/01/microwindmill-rao-chiao.php
- [4] A coupled piezoelectric-electromagnetic energy harvesting technique for achieving increased power output through damping matching, *V. R. Challa, M. G. Prasad, F. T. Fisher*, Smart Materials and Structures (2009)
- [5] High Damping Electrostatic System For Vibration Energy Scavenging, *G. Despesse, J.J. Chaillout, T. Jager, J.M. Léger, A. Vassilev, S. Basrour and B.Charlot*, Joint sOc-EUSAI conference
- [6] Georgia Tech: http://www.gtresearchnews.gatech.edu/triboelectric-generator-produces-electricity-from-friction/
  Newnagy: http://www.newnagy.com/en/newsc_hyxw_20121120.html
- [7] http://www.enocean.com, http://www.cherrycorp.com/english/switches/energy%20harvesting/index.htm
- [8] http://web.mit.edu/newsoffice/2013/new-material-harvests-energy-from-water-vapor-0110.html
- [9] http://www.stanford.edu/group/gcep/cgi-bin/gcep-research/all/ultra-high-efficiency-thermophotovoltaic-solar-cells-using-metallic-photonic-crystals-as-intermediate-absorber-and-emitter/
- [10] Radial-arrayed rotary electrification for high performance triboelectric generator, *Guang Zhu, Jun Chen, Tiejun Zhang, Qingshen Jing, Zhong Lin Wang*, Nature Communications (2014), http://www.nanoscience.gatech.edu/paper/2014/13_NC_01.pdf

© Fraunhofer IIS