UNIVERSITÀ DEGLI STUDI
DI PERUGIA

Energy Harvesting

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Dipartimento di Fisica e Geologia
Università di Perugia

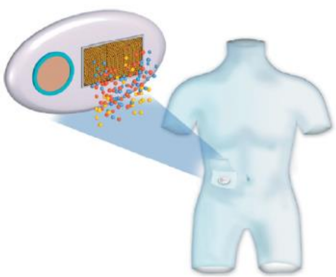
Workshop di orientamento alla
Laurea Magistrale in Fisica
12 Marzo 2021

Summary

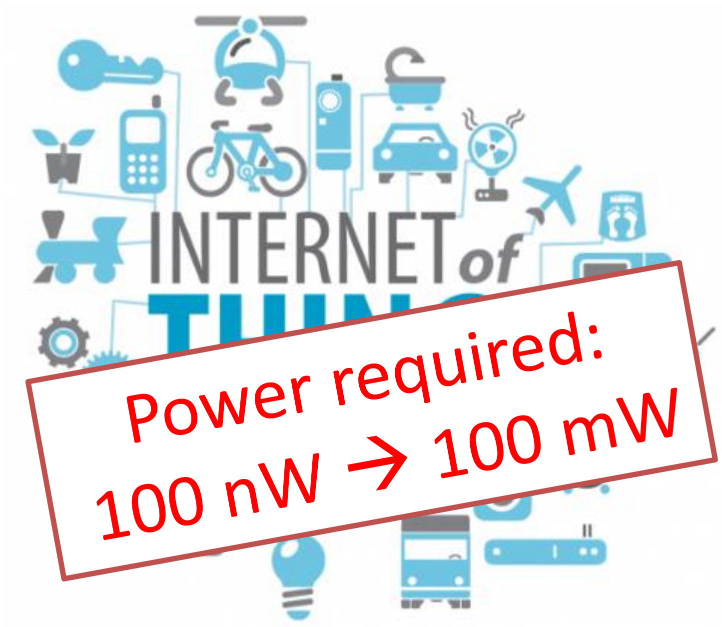
- Introduction
- Research activity @ UNIPG
  - **Energy harvesting systems**
  - **Self-powering sensors** and IoT
  - **Micro**- and **nano-generators**
  - **Electroactive materials** for energy conversion
  - **Energy harvesting** from **biological cells**
- Thesis titles

Energy Harvesting and IoT

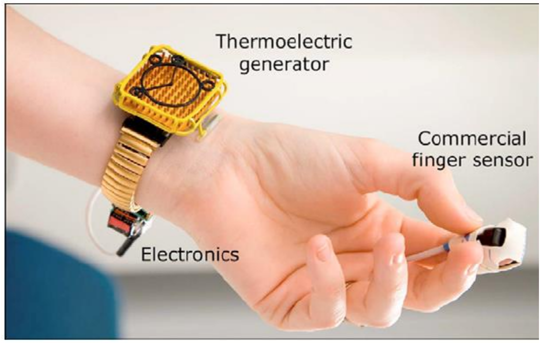
MEMS-based drug delivery systems



Bohm S. et al. 2000

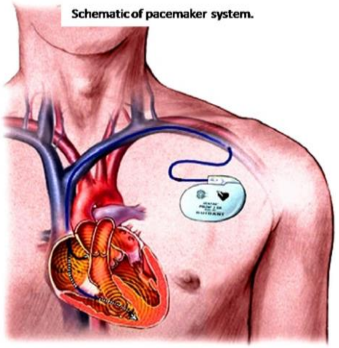


Body-powered oximeter



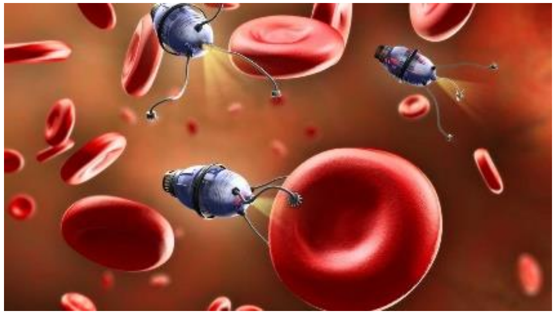
Leonov, V., & Vullers, R. J. (2009).

Heart powered pacemaker



D. Tran, Stanford Univ. 2007

Micro-robot for surgery

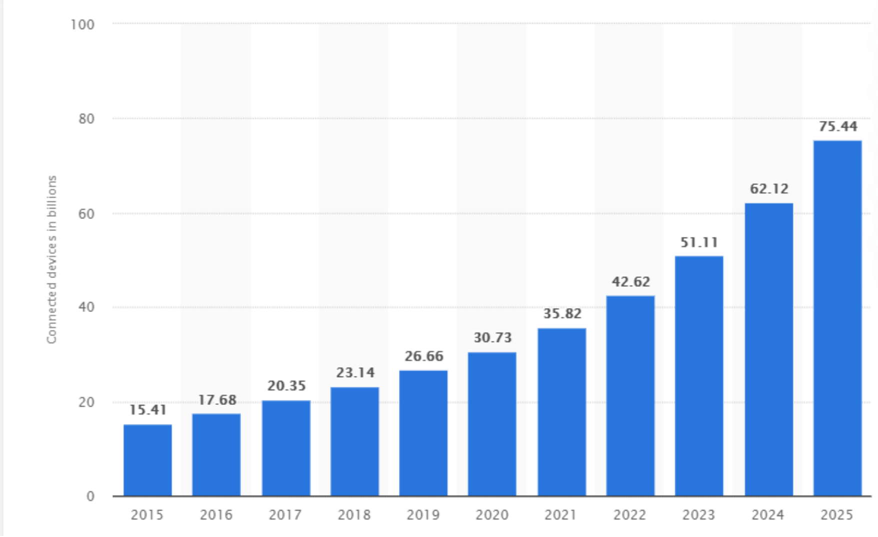


Remote monitoring

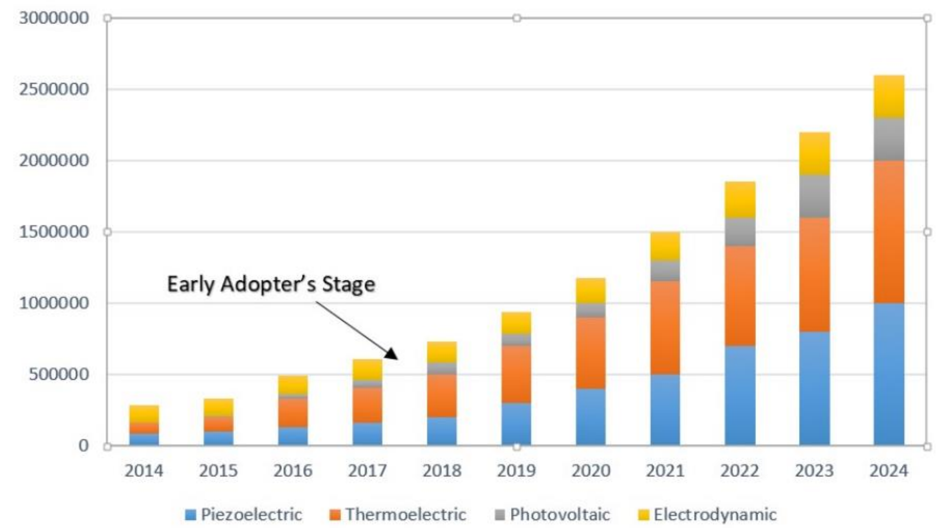
A. Freitas Jr., Nanomedicine, Landes Bioscience, 1999

Energy Harvesting and IoT

Internet of Things (IoT) connected devices installed base worldwide from 2015 to 2025 (in billions) – (Statista 2019)



Global **energy harvesting** market (IDTechEx 2019)



75 Billions of IoT devices in 2025 need tech for energy autonomy

Vibration powered wireless sensor node

Power density objective for EH:
> 100 μW/cm^3

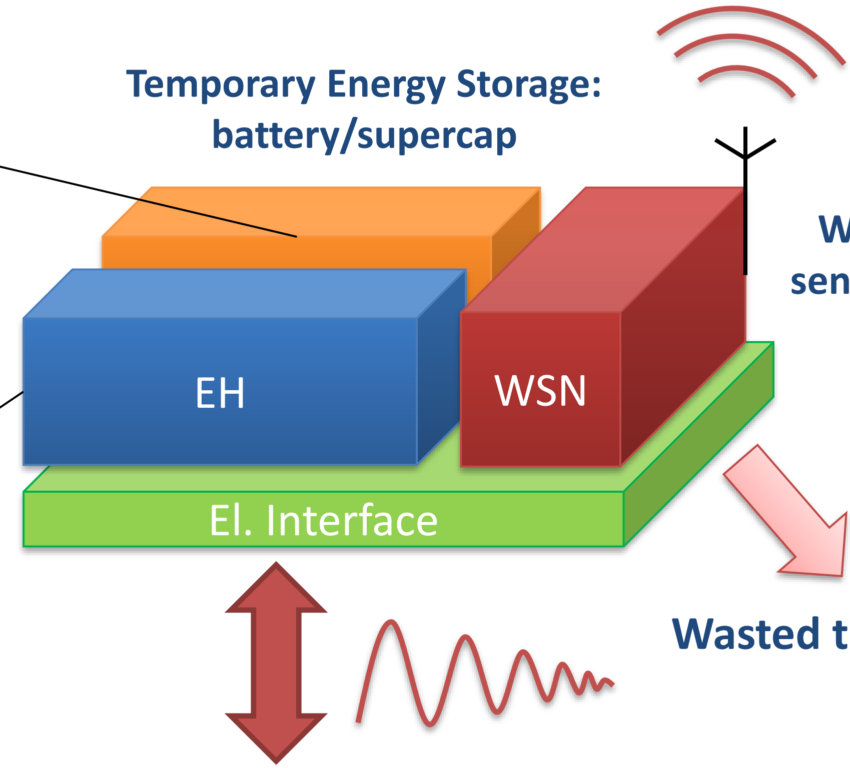
Transmitted EM energy

Temporary storage and conditioning electrinics:

- *Ultra capacitors*
- *Rechargeable Batteries*

Temporary Energy Storage: battery/supercap

Wireless sensor node



Vibration energy harvester:

- *piezoelectric,*
- *electromagentic,*
- *electrostatic,*
- *magnetostrictive*

Mechanical vibrations

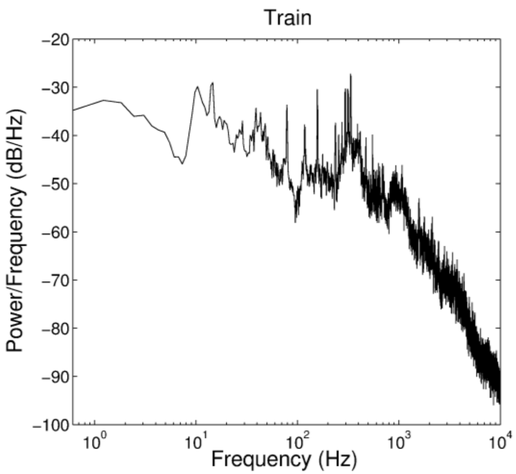
Wasted thermal energy

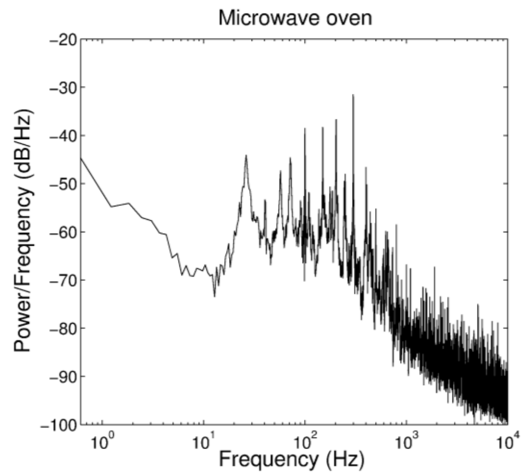
Vibration sources

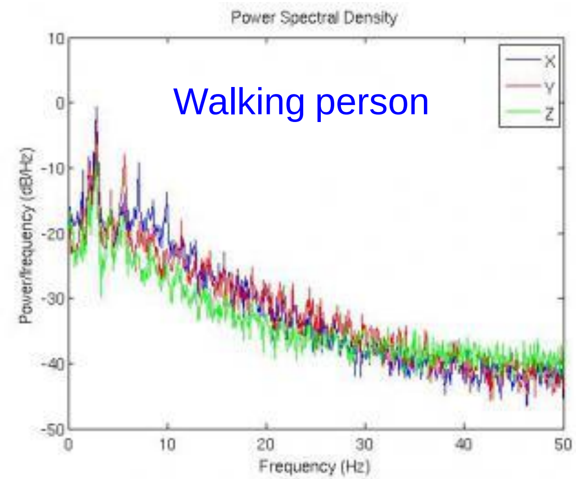
Energy Source	Characteristics	Efficiency	Harvested Power
Light	Outdoor Indoor	10~24%	100 mW/cm^2 100 µW/cm^2
Thermal	Human Industrial	~0.1% ~3%	60 µW/cm^2 ~1-10 mW/cm^2
Vibration	~Hz–human ~kHz–machines	25~50%	~4 µW/cm^3 ~800 µW/cm^3
RF	GSM 900 MHz WiFi	~50%	0.1 µW/cm^2 0.001 µW/cm^2

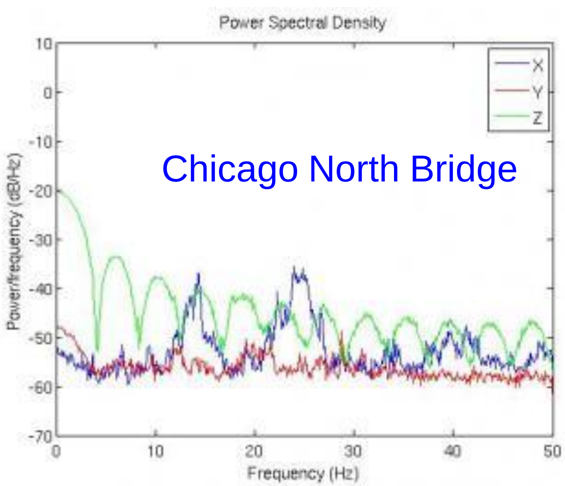
Source: Texas Instruments 2009

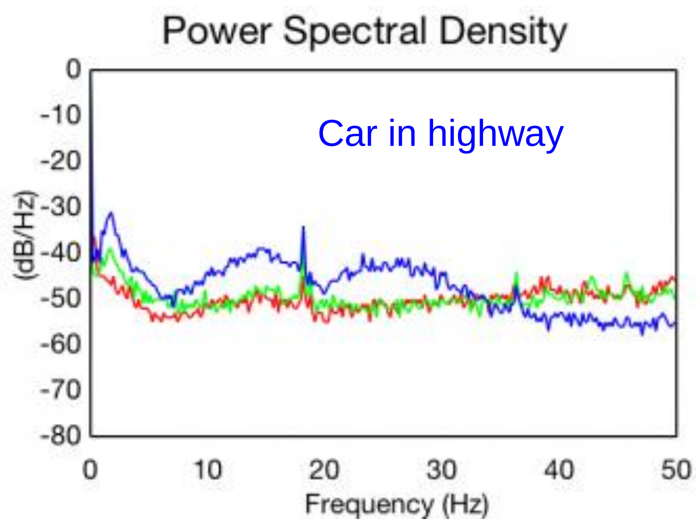
Vibration sources









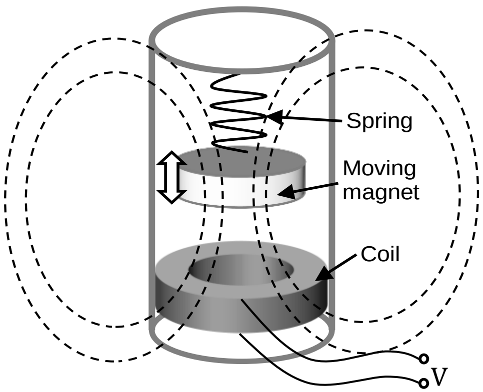


http://www.enables-project.eu/offer/virtual-access/ https://realvibrations.nipslab.org/

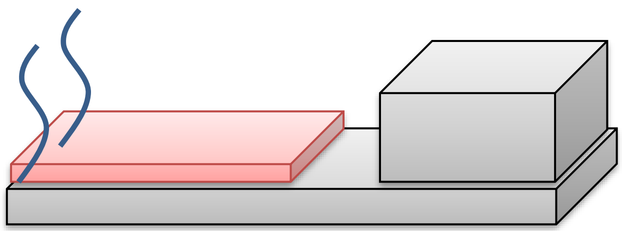
Vibration energy harvesters

Main Transduction Techniques

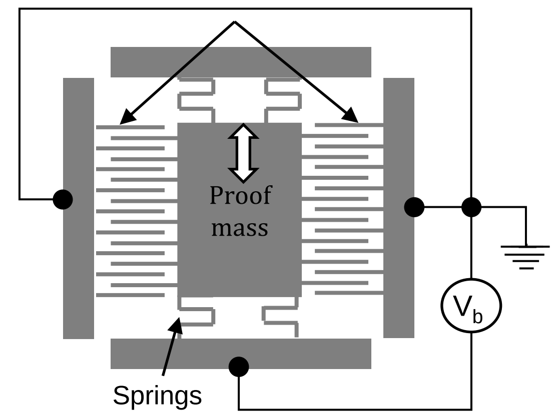
Electromagnetic/Inductive

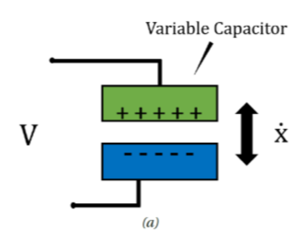


Piezoelectric, Magneto-strictive



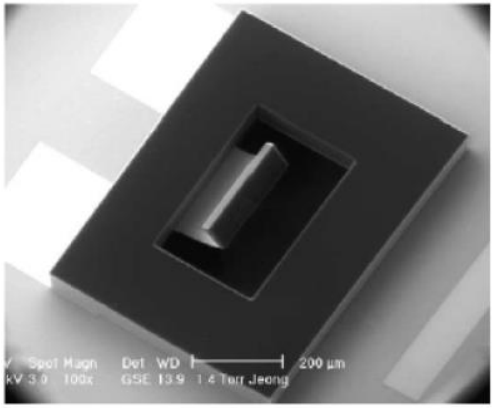
Electrostatic/Capacitive



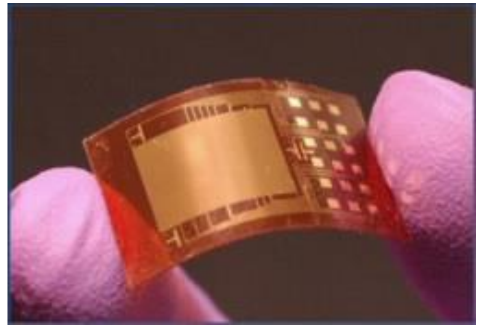


Microscale vibration energy harvesters

Piezoelectric

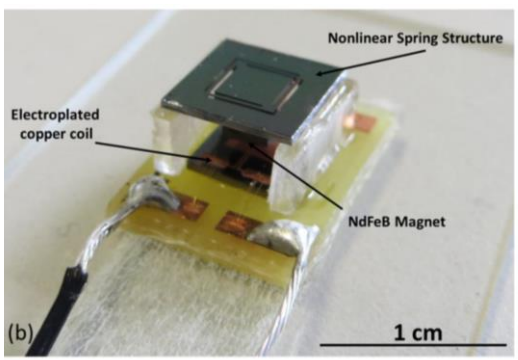


Jeon et al. 2005

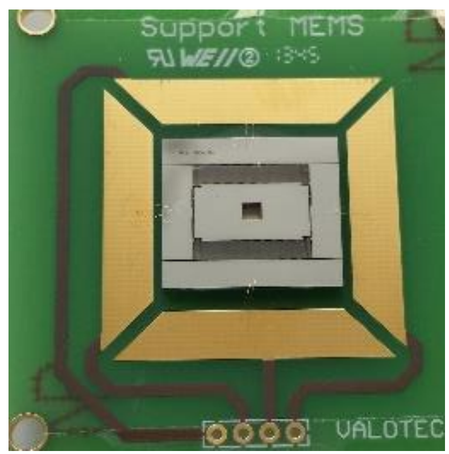


ZnO nanowires
Wang, Georgia Tech (2005)

Chang. MIT 2013



Mallick D. and Roy S., 2015

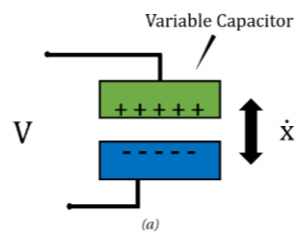


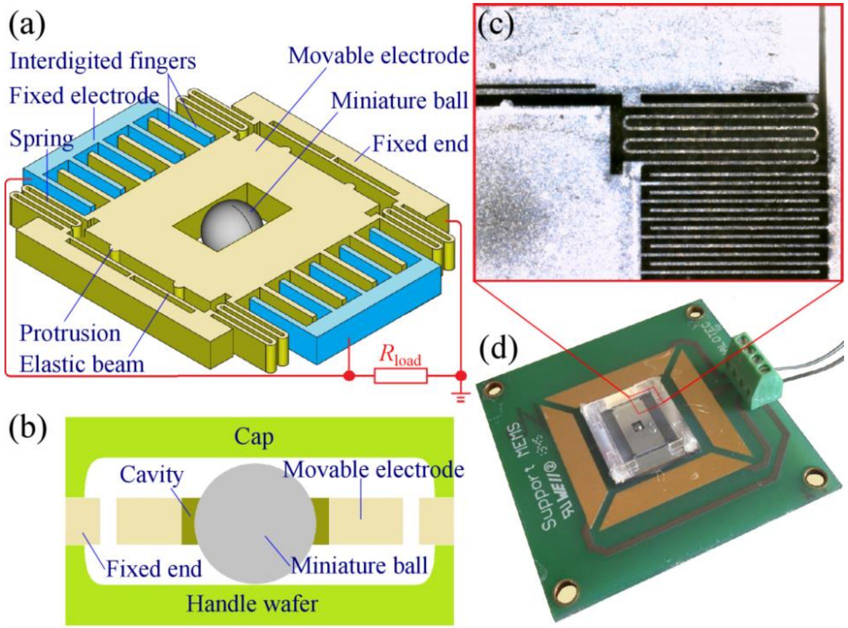
Cottone F., Basset P. ESIEE Paris 2013

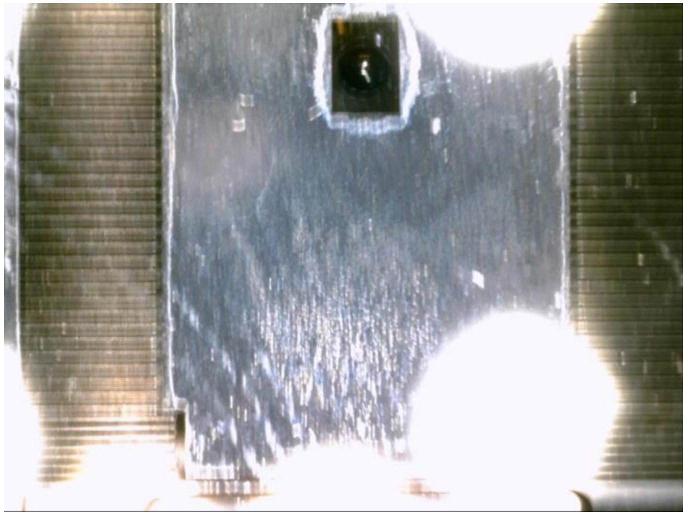
Ultrathin 3-D-printed films convert energy of one form into another (credit: MIT Aug. 2019)

Microscale vibration energy harvesters

Prototype fabrication process

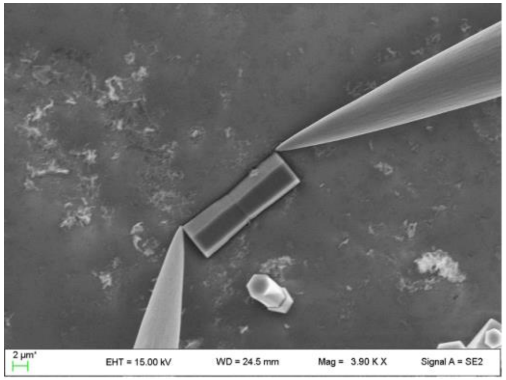


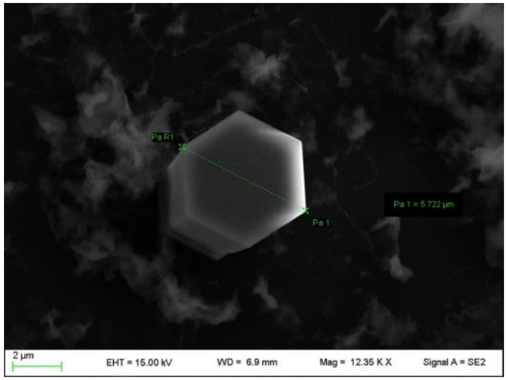


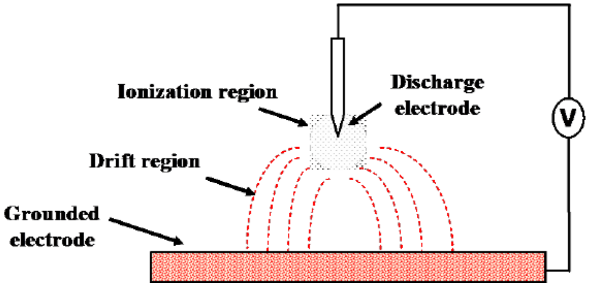


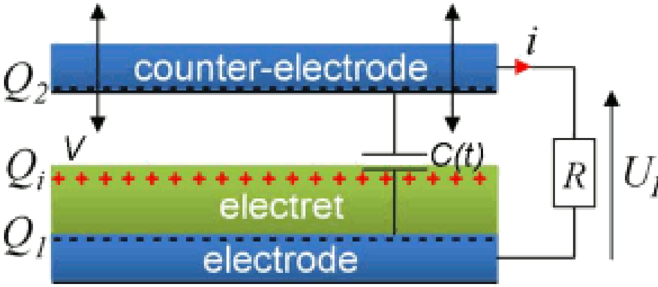
Electroactive materials

- Ricerca su materiali **elettreti** per EH tramite prodotti con scarica a corona
- Ricerca di materiali **piezoelettrici micro/nano strutturati** per energy harvesting









Electroactive materials

IOP Publishing Smart Materials and Structures
Smart Mater. Struct. 27 (2018) 075052 (9pp) https://doi.org/10.1088/1361-665X/aaca55

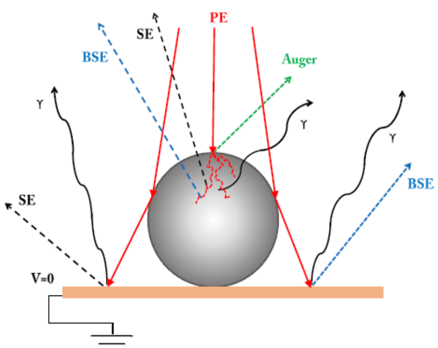
High charge density silica micro-electrets fabricated by electron beam

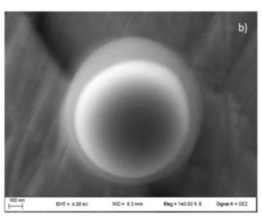
Francesco Bonacci[1], Alessandro Di Michele[2], Silvia Caponi[3], Francesco Cottone[2] and Maurizio Mattarelli[2]

Electrostatic

200 V surface potential

Charge concentration
0.1 C m^-3





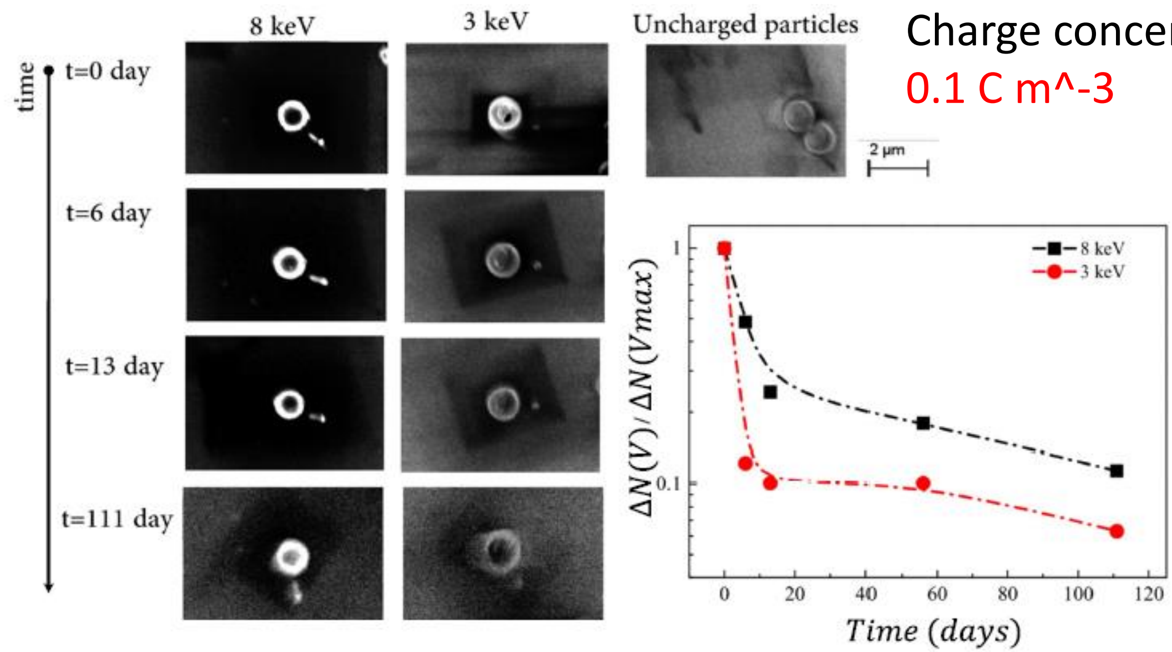
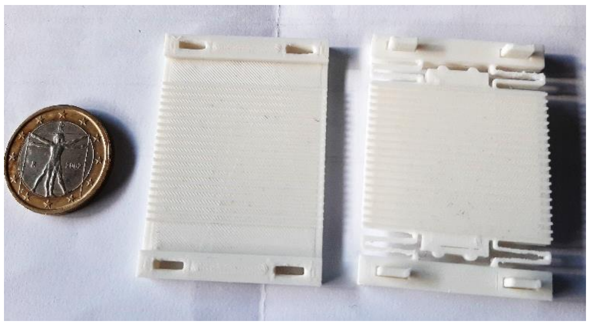


Figure 7. Images from the in-lens detector of the charged (first line, 8 keV and second line, 3 keV) and control particles (third line) at different times from the charging. In the graph: time behaviour of the emitted electrons difference between a charged and a non-charged particle.

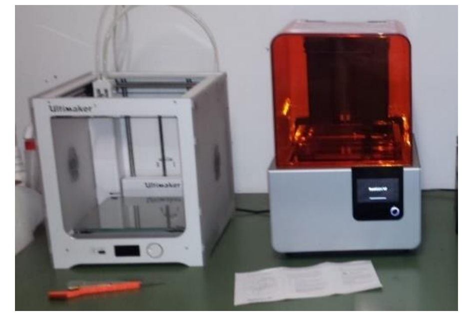
Bonacci, F., Di Michele, A., Caponi, S., Cottone, F., & Mattarelli, M. (2018). High charge density silica micro-electrets fabricated by electron beam. *Smart Materials and Structures*, *27*(7), 075052. https://doi.org/10.1088/1361-665X/aaca55

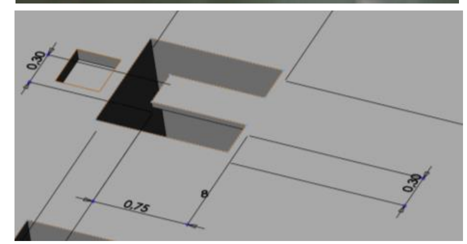
3D printed generators

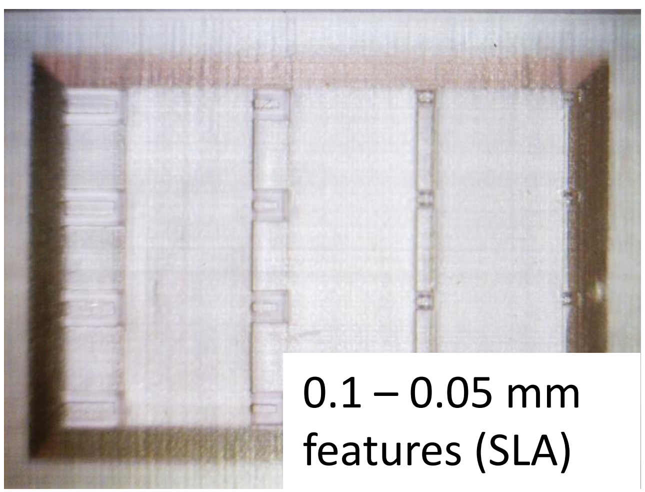
Low-cost rapid prototyping



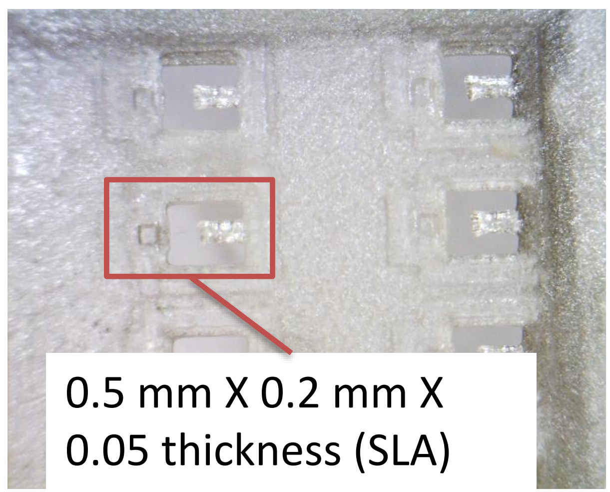
PLA electrostatic capacitive vibration energy harvester (FDM)



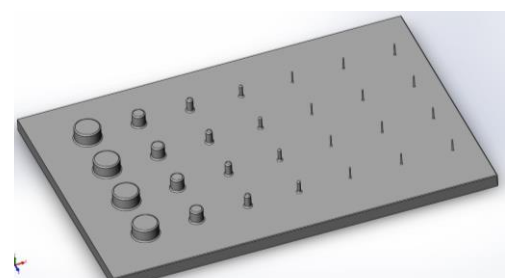




0.1 – 0.05 mm features (SLA)

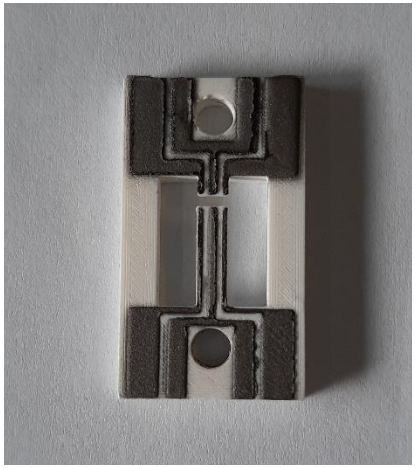


0.5 mm X 0.2 mm X 0.05 thickness (SLA)

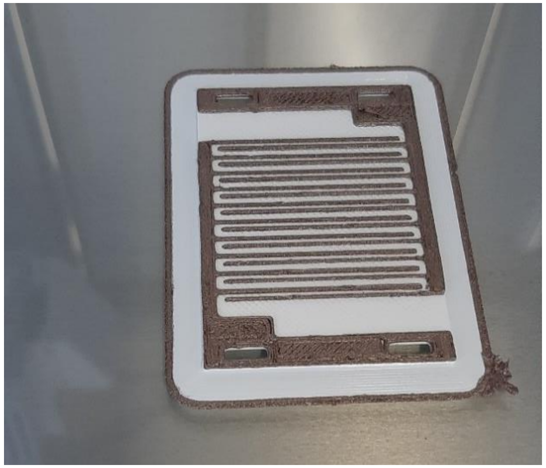


3D printed generators

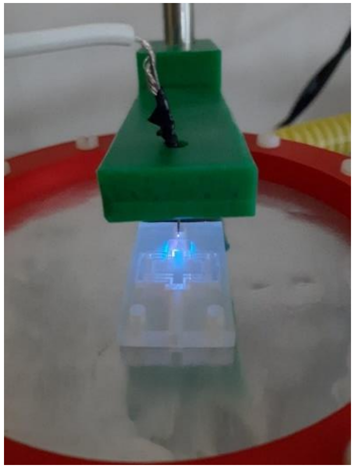
Low-cost rapid prototyping



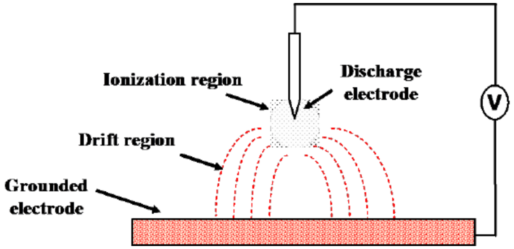
Electrostatic bi-stable energy harvester



Interdigitated capacitive sensor



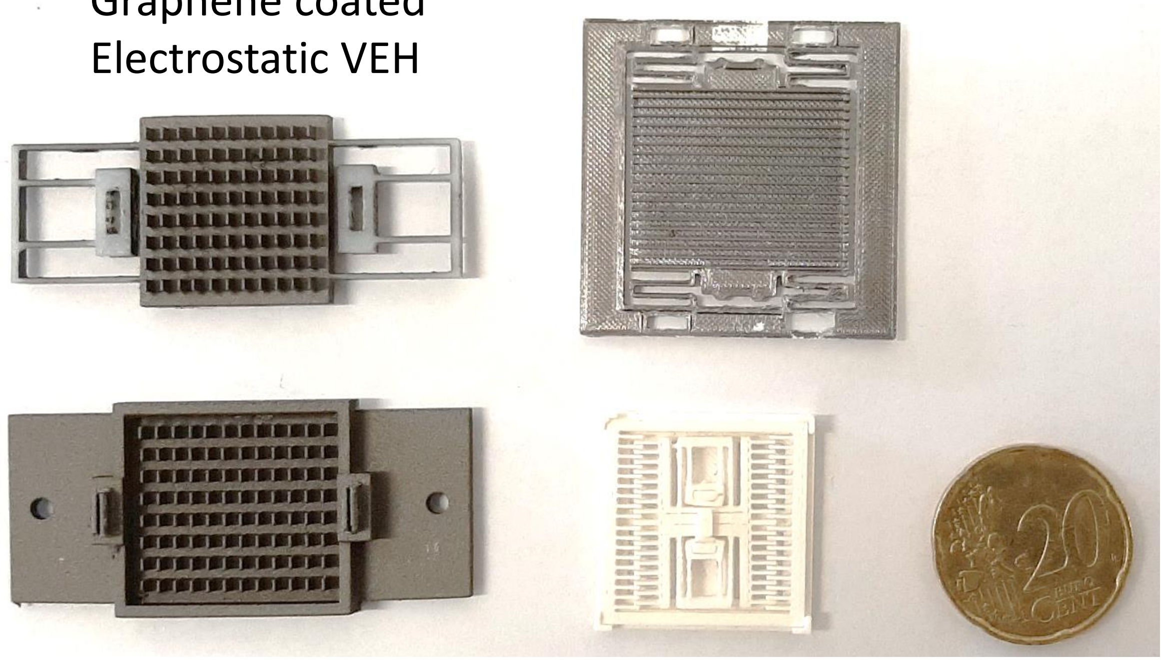
Corona discharge for electrets production



3D printed generators

Low-cost rapid prototyping

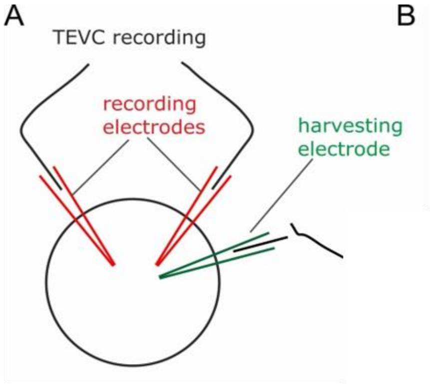
Graphene coated
Electrostatic VEH

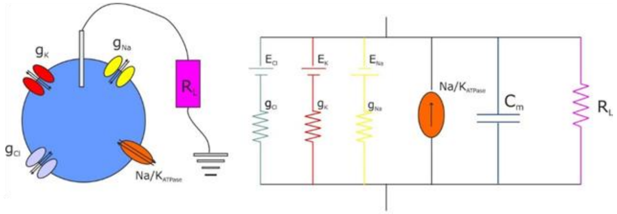


3D printed in-plane electrostatic energy harvester

3D printed Interdigitated capacitive harvester

Energy harvesting from bio cell





$$\frac{dV_m}{dt} = -\frac{I_m}{C_m}$$

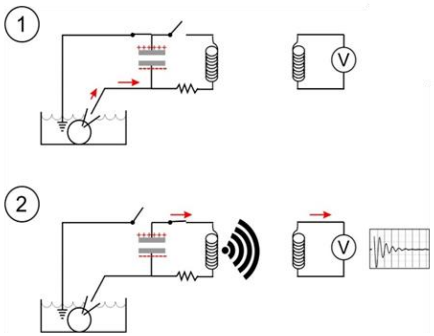
$$\frac{d[ion]_i}{dt} = -\frac{I_{ion}}{z\,F\,Vol}$$

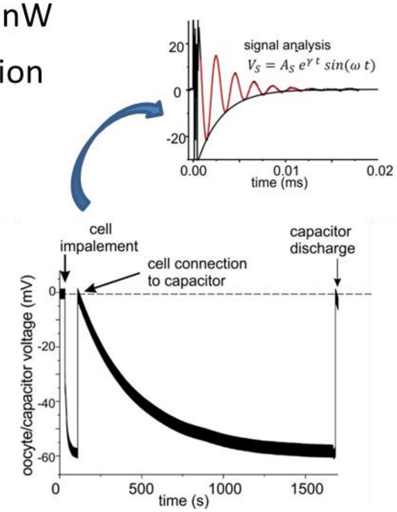
$$P = I_L\,V_m$$

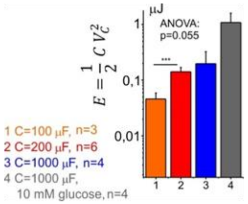
Parameter	Description	Value
r	Cell radius	7 µm
C_S	Specific membranecapacitance	0.01 pF/µm²
g_{KS}	Specific K channel conductance	5*10⁻⁴ nS/µm²
g_{Na}	Specific Na channel conductance	1*10⁻⁴ nS/µm²
g_{Cl}	Cl channel conductance	1*10⁻³ nS/µm²
R_L	Load resistance	variable
ρ	Maximal turnover of the Na/K ATPase	133 ATP/s
D_{ATPase}	Density of Na/K ATPase	3350/µm²
K_O	Extracellular K concentration	3 mM
Na_O	Extracellular Na concentration	142 mM
Cl_O	Extracellular Cl concentration	145 mM
nAA_i	Intracellular impermeable anions	0.198 pmol

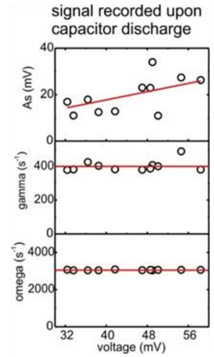
Power harvested from a cell ≈ 1 nW

Power required by next-generation biosensors ≈ 1 µW



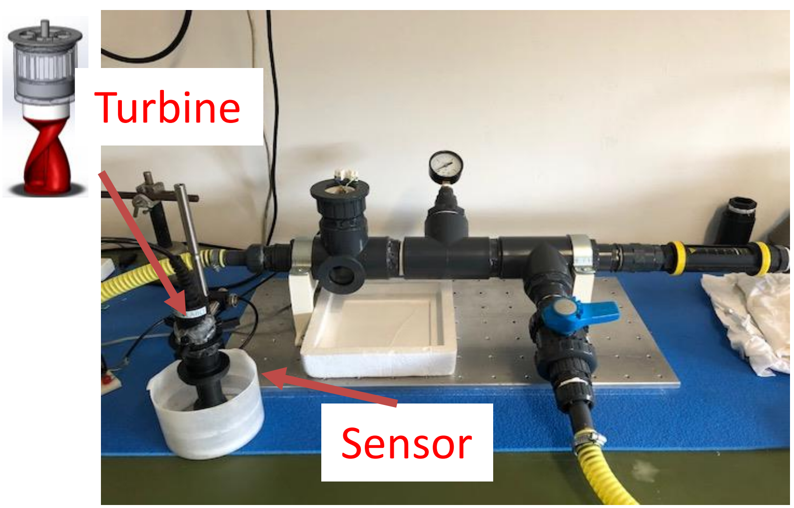


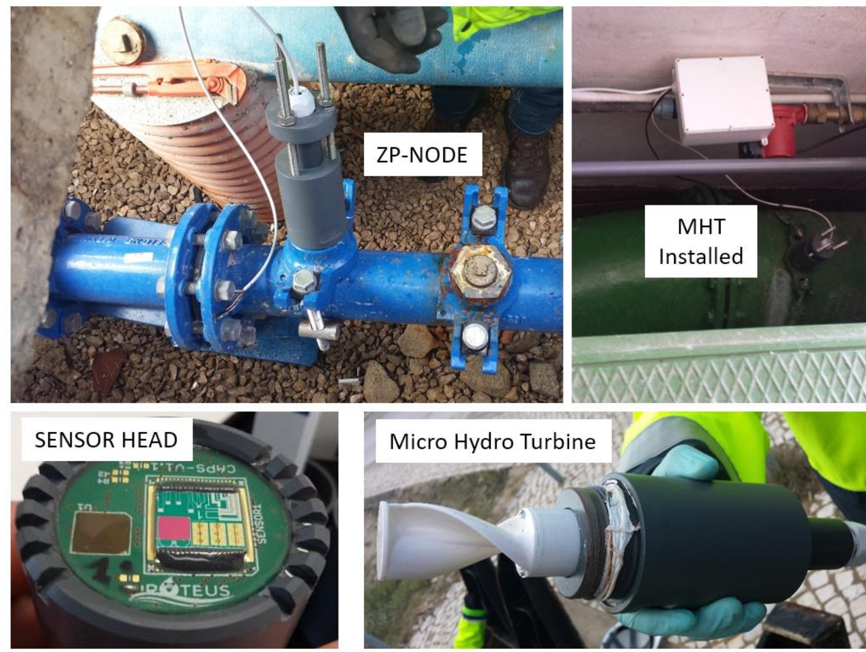




Project PROTEUS
Water Self-powered Monitoring Systems

- 2015-2018 - H2020 project **PROTEUS 4M€**, grant n. 644852, **AdaPtive micROfluidic- and nano-enabled smart systems for waTEr qUality Sensing.** Department of Physics and Geology has received a total grant of **438000€**
- UNIPG has developed the **ENERGY HARVESTING SYSTEMS for powering the water sensor**



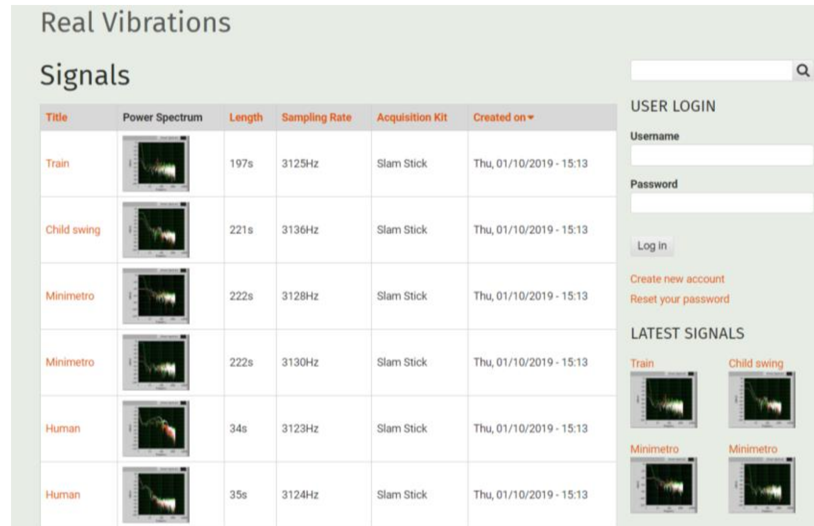


http://www.proteus-sensor.eu/

Project EnABLES – Powering Internet of Things

European Infrastructure Powering the Internet of Things

https://realvibrations.nipslab.org/



Free of charge rapid access to undertake feasibility studies at EnABLES partner sites

https://www.enables-project.eu/

Access Centers

- Tyndall National Institute, Ireland
- Commisariat a L'energie Atomique et aux Energies
- Alternatives (CEA-Leti, CEA-Liten), France
- Fraunhofer IIS, Fraunhofer IMS, Germany
- Stichting IMEC Nederland, Netherlands

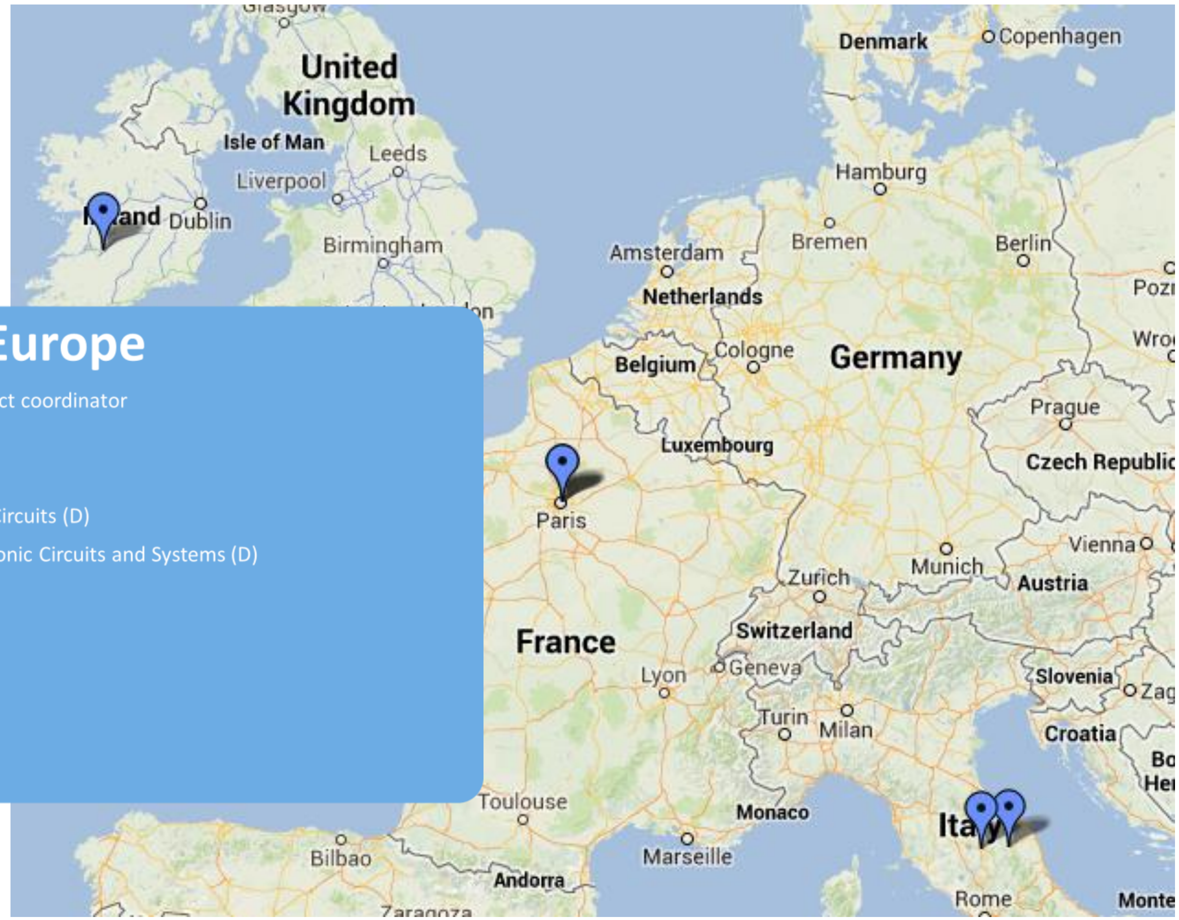
Knowledge Hubs

- Karlsruher Institute of Technology, Germany
- Politecnico Di Torino, Italy
- Alma Mater Studiorum – Universita di Bologna, Italy
- **Università degli Studi di Perugia, Italy**
- University of Southampton, UK

Thesis titles

- Sviluppo di **micro-generatori elettrostatici** nonlineari **stampati in 3D** per l'energy harvesting da rumore vibrazioni
- Studio di **supercapacitori** 3D printed per EH
- Studio di materiali **elettrostatici** e **conduttivi** per la stampa 3D di sistemi di energy harvesting
- Studio e sviluppo di un **sensore di temperatura alimentato** da una **singola cellula**
- **Energy harvesting** da un sistema di cellule viventi interconnesse

Collaborazioni Internazionali



Partners across Europe

- Tyndall National Institute (IRL) – Project coordinator
- CEA-Leti (F)
- CEA-Liten (F)
- Fraunhofer – Institute for Integrated Circuits (D)
- Fraunhofer – Institute for Microelectronic Circuits and Systems (D)
- imec Nederland (NL)
- Karlsruher Institut für Technologie (D)
- Politecnico di Torino (I)
- Università di Bologna (I)
- Università degli Studi di Perugia (I)
- University of Southampton (UK)

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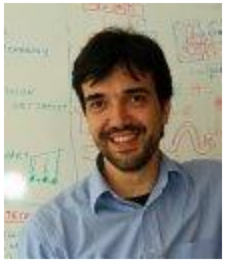

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