A.D. 1308
unipg

DIPARTIMENTO
DI FISICA E GEOLOGIA

Materiali e dispositivi per Energy Harvesting

Giornate di orientamento e proposte di tesi
Fisica della Materia – Dip. Di Fisica e Geologia
24/03/2023

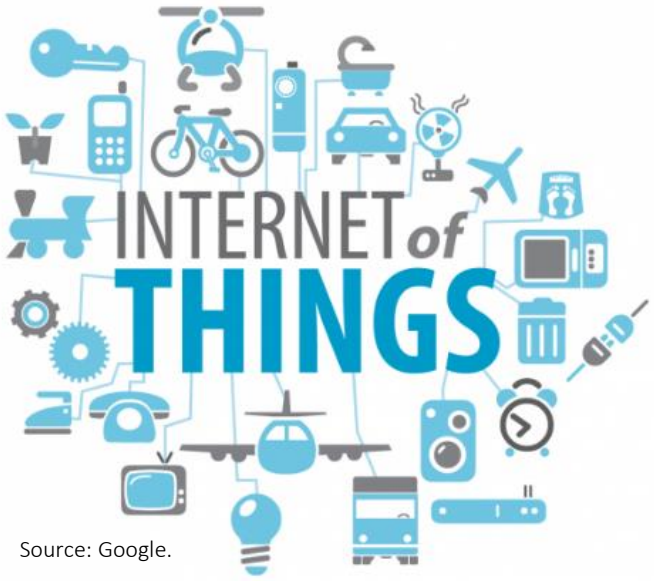
Prof. Francesco Cottone – francesco.cottone@unipg.it

Sommario

- Introduzione
- Micro Generatori MEMS/stampanti in 3D
- Materiali elettro-attivi per energy harvesting
- Energy Harvesting da cellule biologiche
- Generatori betavoltaici

Introduzione

Monitoraggio delle infratrutture con reti di sensori autonomi

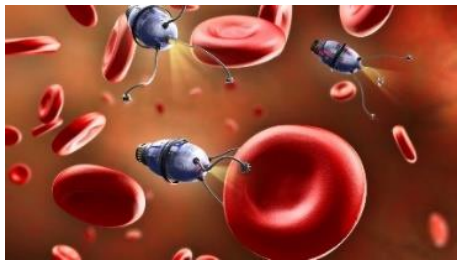


Source: Google.

Healthcare/Body monitoring

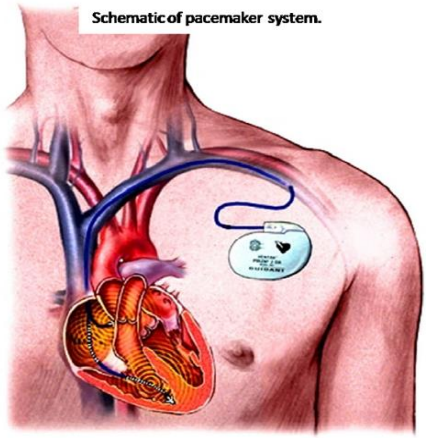
Micro/nano robots

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



Nanorobot **0.1 - 10uW**.

Pacemaker



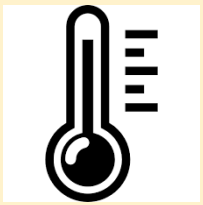
D. Tran, Stanford Univ. 2007

200uW da battito cardiaco

Energy harvesting

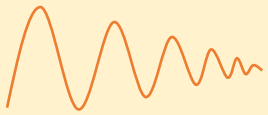
Solar

RF

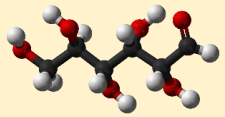


Thermal energy/temp difference

Fluid motion Hydro/wind



Kinetic/ Vibrations



Biochemical

Radioactivity

Ambient energy

Transmitted EM energy

Temporary Energy Storage: battery/supercap

Wireless sensor node

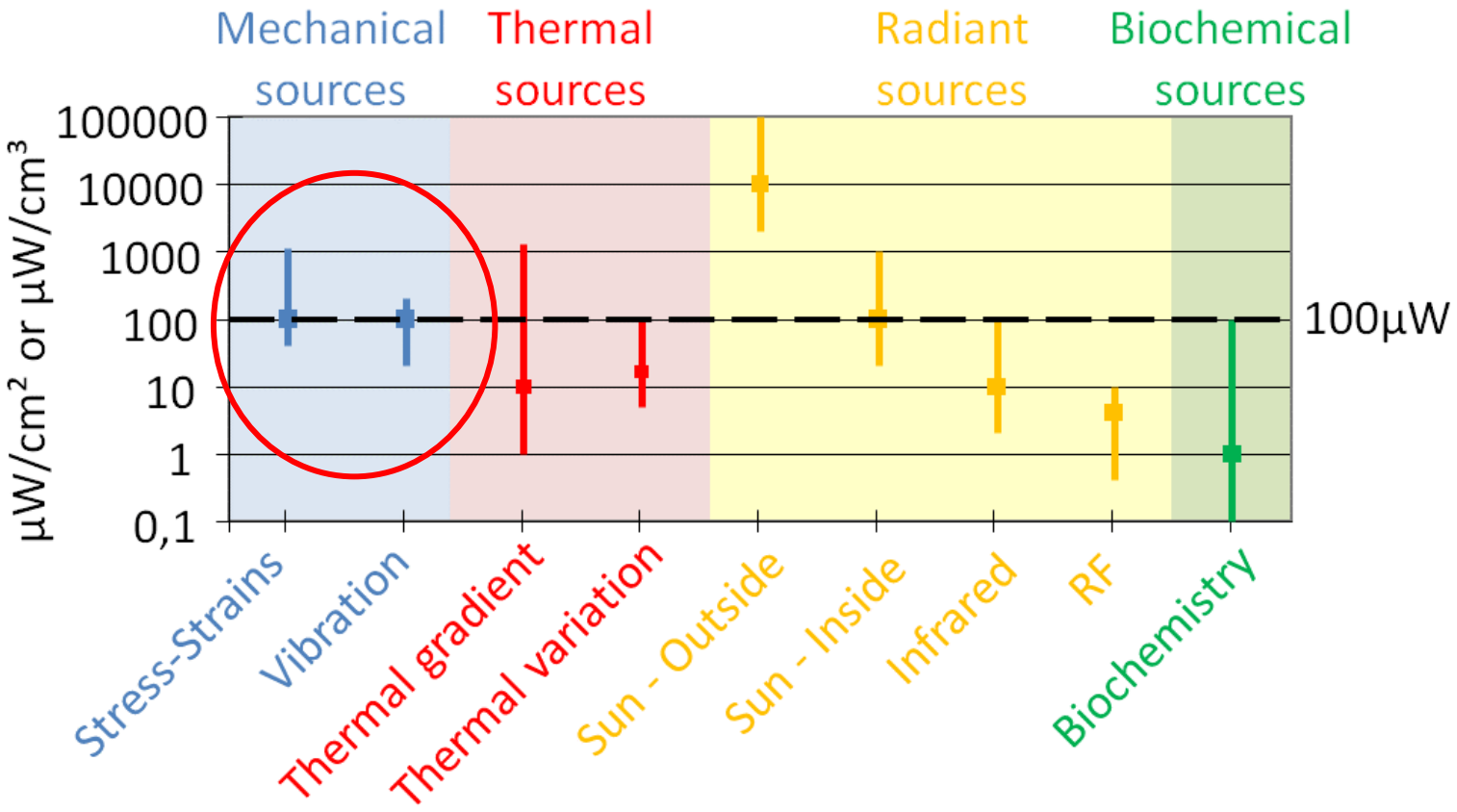
EH

WSN

El. Interface

Wasted thermal energy

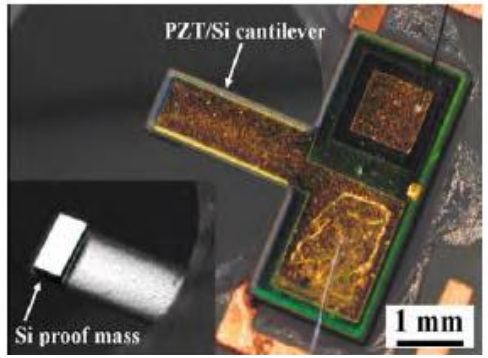
Sorgenti di energia



S. Boisseau et al. 2012

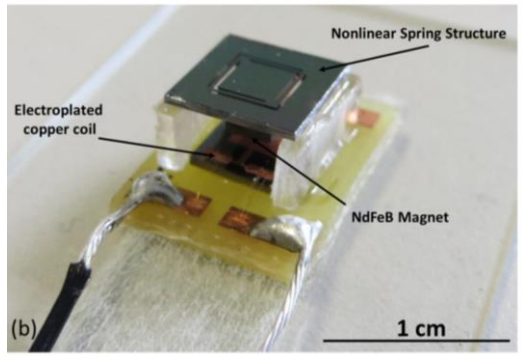
Micro generatori vibrazionali MEMS

Piezoelectric



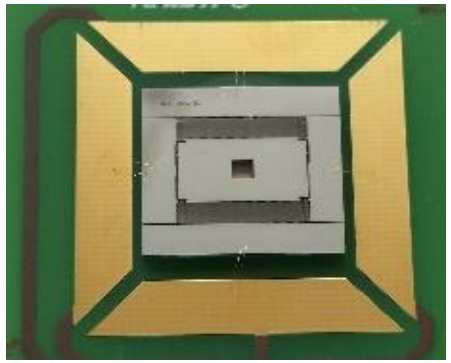
D. Briand, EPFL 2010

Magnetic induction



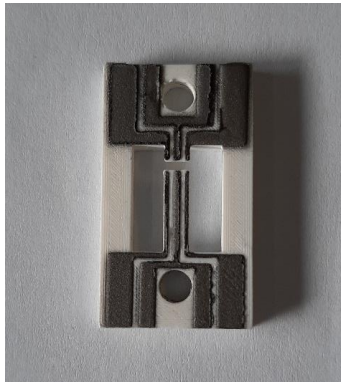
Mallick D. and Roy S., 2015

Electrostatic



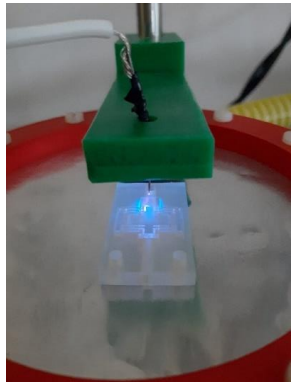
Cottone F., Basset P. 2013

3D printed generators



Electrostatic bi-stable energy harvester

Interdigitated capacitive sensor with PCL/copper nanotube charged filament



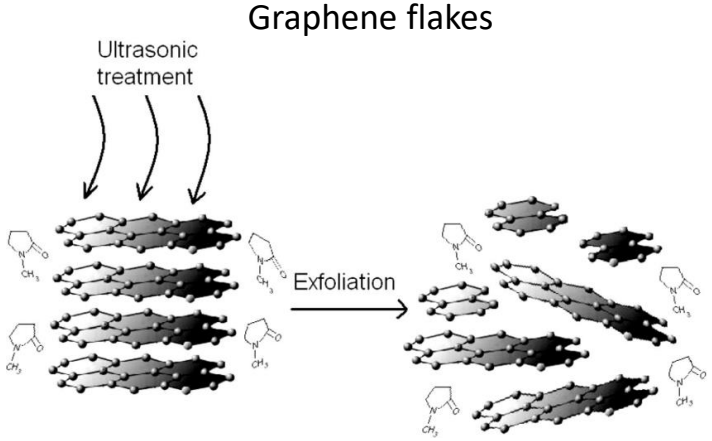
Corona discharge for electrets production

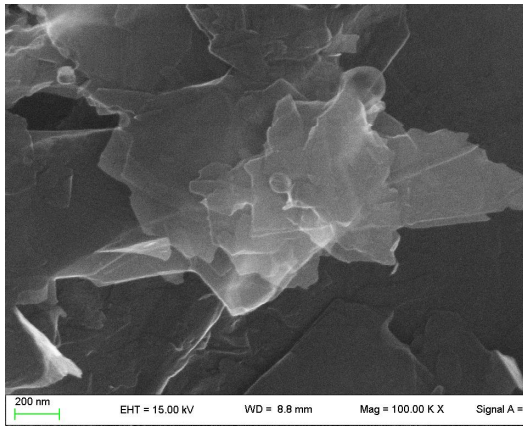
F. Cottone

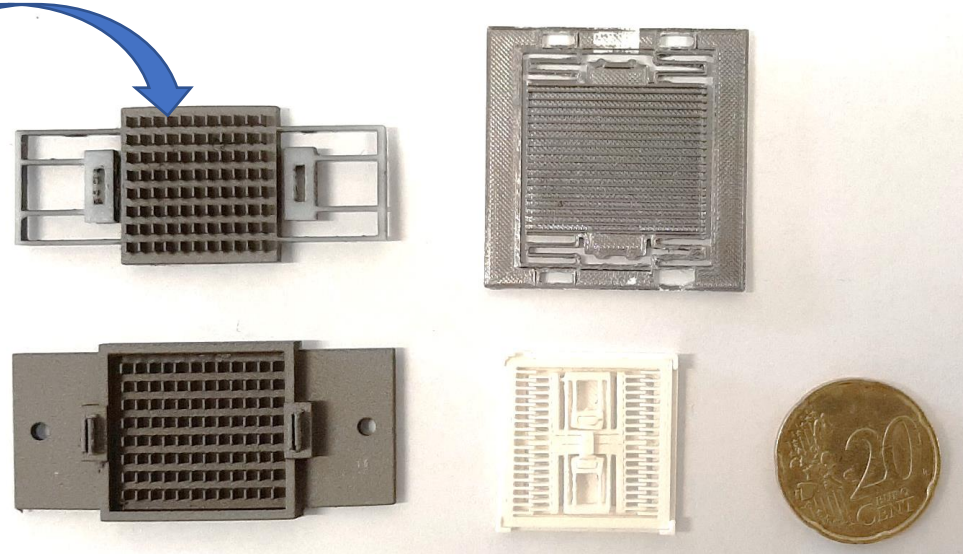
Micro generatori stampati in 3D

- Micro generatori elettrostatici **stampati in 3D** con **Nickel/grafene**

Sintesi del graphene: esfoliazione assistita da ultrasuoni







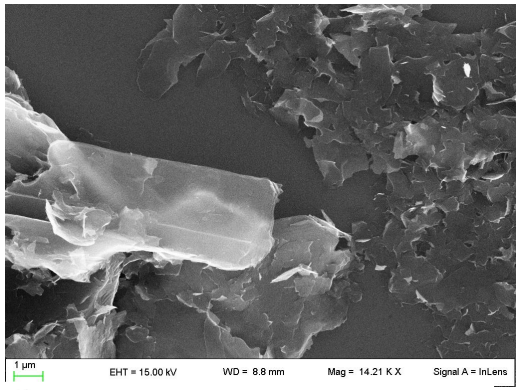
Yukhymchuk, V. O. et al. (2017). https://doi.org/10.15407/ujpe62.05.0432

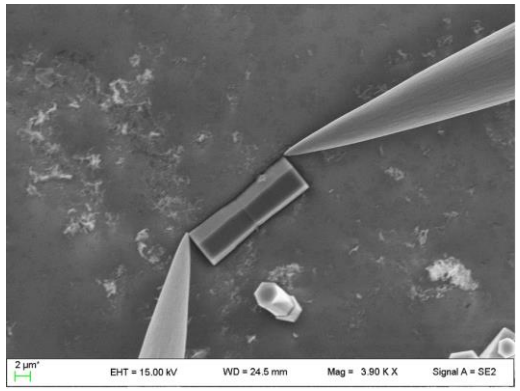
3D printed in-plane electrostatic energy harvester

3D printed Interdigitated capacitive harvester

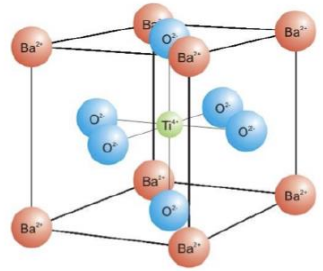
Materiali elettro-attivi per energy harvesting

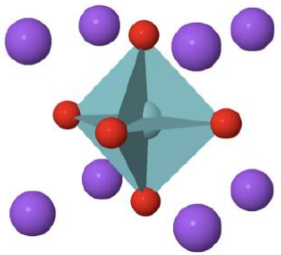
- Materiali **piezoelettrici micro/nano strutturati** Pb-free

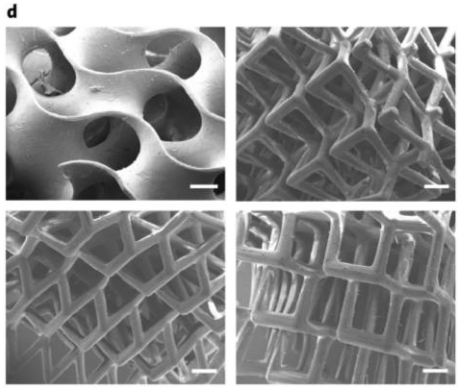


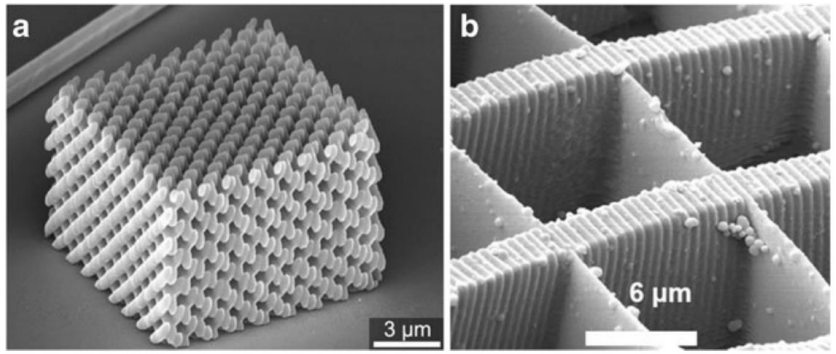


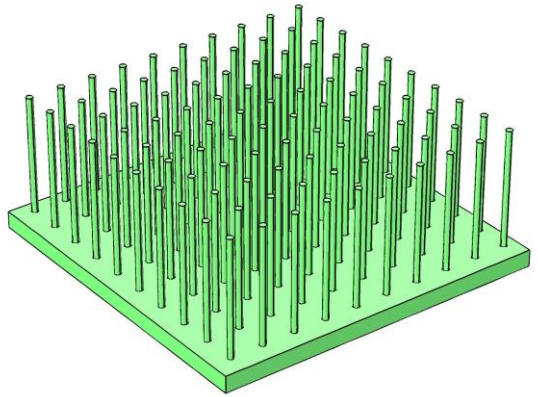
- $BaTiO_3$
- ZnO
- $LiNbO_3$ (LNO)
- $(Na_xK_{1-x})NbO_3$ (KNN)

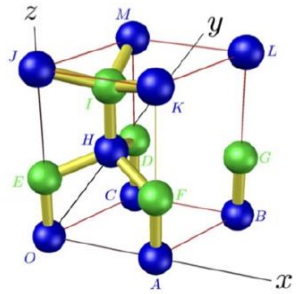










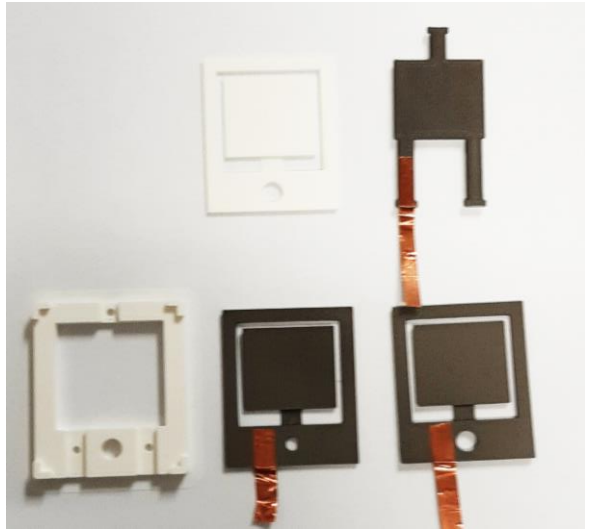


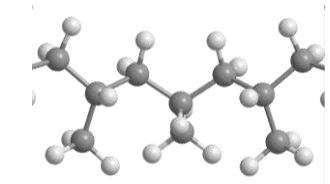
3D printed micro/nano structures (auxetic materials, photonic crystals, metamaterials)

Materiali elettro-attivi per energy harvesting

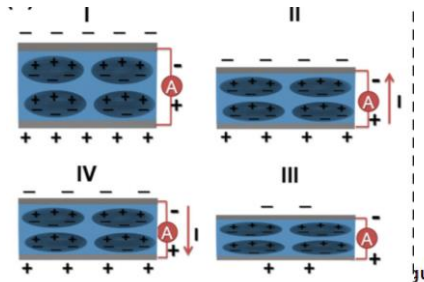
- Materiali polimerici **elettreti** per **energy harvesting:**

3D printed : **PLA, Polipropilene (PP), PET, TPU**

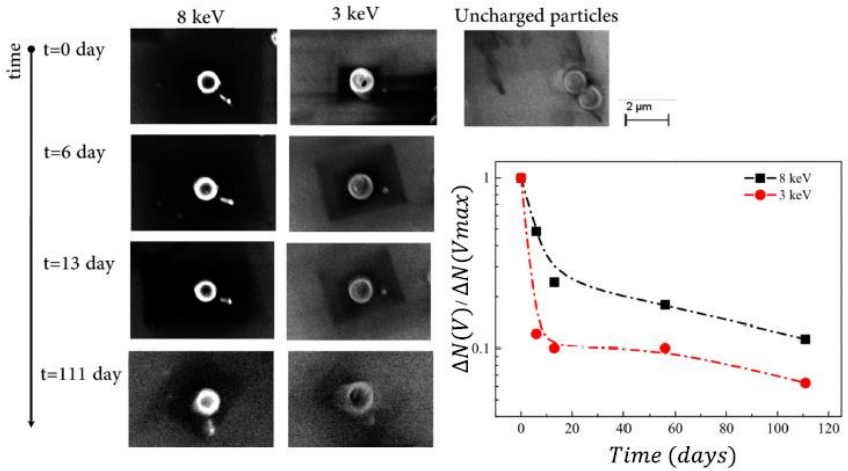


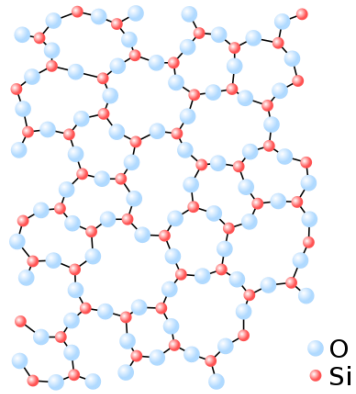


PP



Fused Silica **SiO2** - Micro/Nano Particelle





ure 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 mes from the charging. In the graph: time behaviour of the emitted electrons difference between a charged and a non-charged particle.

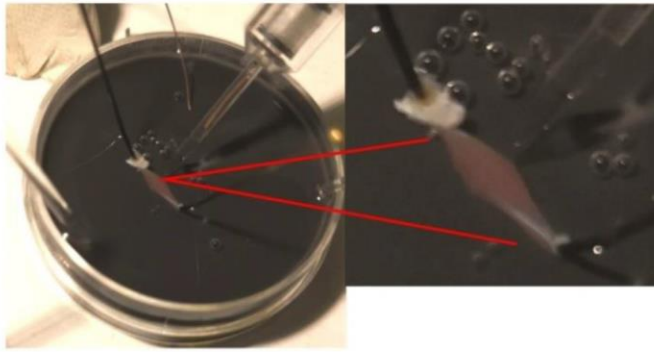
Elettreti con polimeri **cellulari** stampati 3D

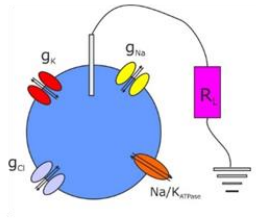
Bonacci, F., Di Michele, A., Caponi, S., Cottone, F., & Mattarelli, M. (2018). https://doi.org/10.1088/1361-665X/aaca55

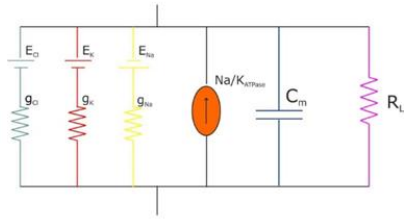
Energy harvesting da cellule biologiche

L. Catacuzzeno
G. Clementi

a)







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

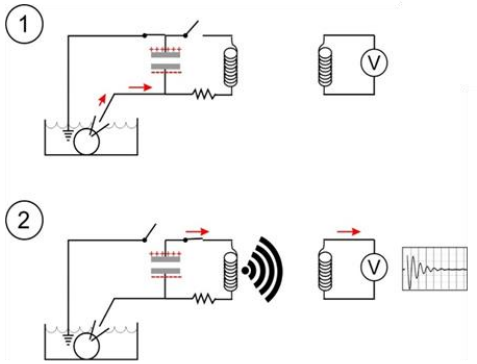
$$\frac{d[ion]_i}{dt} = -\frac{I_{ion}}{z\,F\,Vol}$$

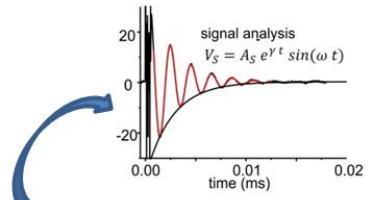
$$P = I_L\,V_m$$

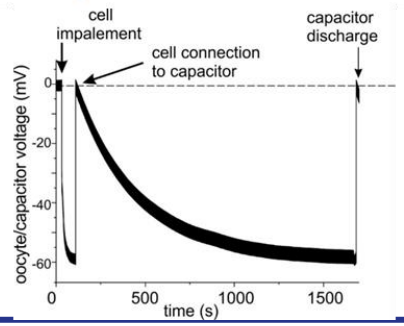
Parameter	Description	Value
r	Cell radius	7 μm
C_S	Specific membranecapacitance	0.01 pF/μm²
g_{KS}	Specific K channel conductance	5*10⁻⁴ nS/μm²
g_{Na}	Specific Na channel conductance	1*10⁻⁴ nS/μm²
g_{Cl}	Cl channel conductance	1*10⁻³ nS/μm²
R_L	Load resistance	variable
ρ	Maximal turnover of the Na/K 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
nA_i	Intracellular impermeable anions	0.198 pmol

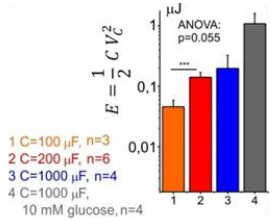
Power harvested from a cell ≈ 1 nW

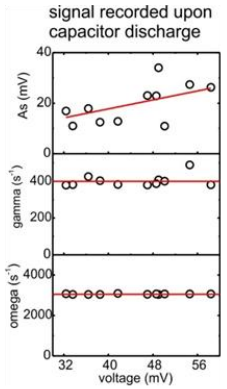
Power required by next-generation biosensors ≈ 1 μW







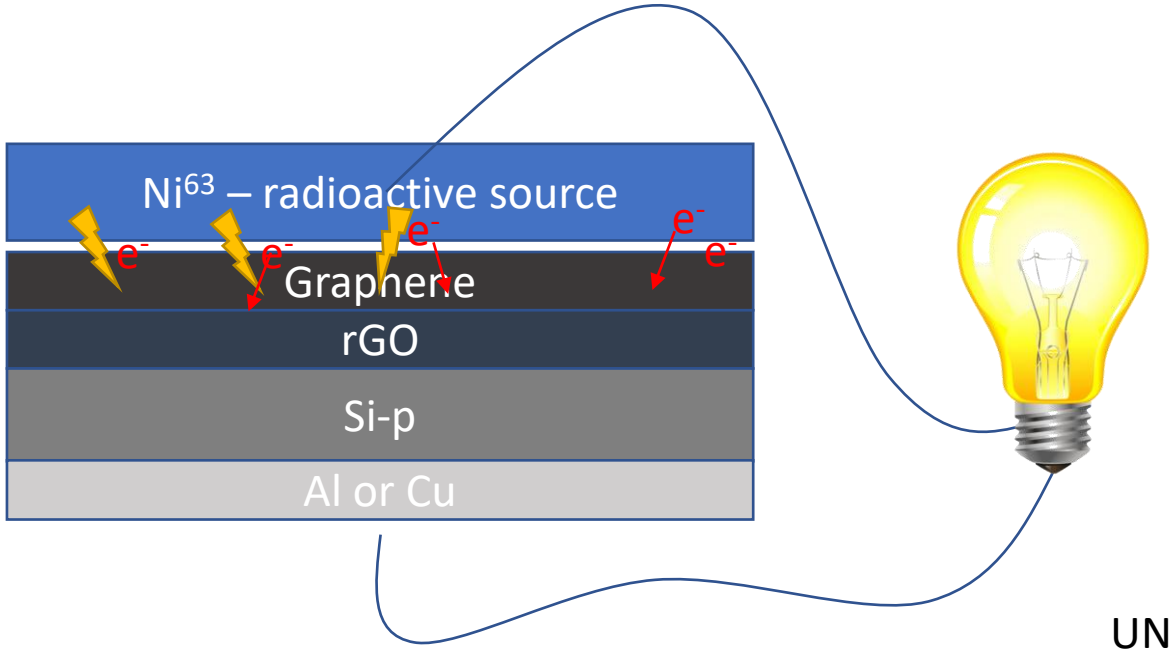




Generatori betavoltaici – progetto Betasmart

- Generatori betavoltaici innovativi basati su diodi **Schottky** al grafene

- **Radioactive source**
  - 3H (12.3 y half-time)
  - 63Ni (100.1 y half-time)
- **Semiconductor /semi-metal**
  - SiC, Si-p
  - Graphene/rGO



UNIPD / UNIPG
Prof. Mengoni
Prof. Cottone
Dr.ssa Carmen Altana

Progetti e collaborazioni in corso

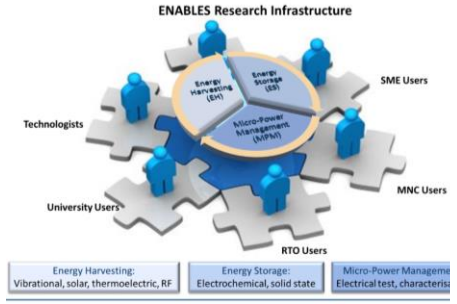
PROGETTI FINANZIATI CON BORSE PON - TRIENNIO 2022 - 2025

- Dottorato 2022 – 2025 – **Gabriele Perna** – Titolo: **Materiali piezoelettrici** innovativi micro- e nano- strutturati per applicazioni di energy harvesting – Tutors: I. Neri, F. Cottone
- RTDA 2022 – 2021 – **Giacomo Clementi** – Titolo: Biogreen - **Energy harvesting da sistemi di cellule** – Tutor: Prof. Gammaitoni
- RTDA 2022 – 2021 – Progetto **BETASMART** – UNIPG/UNIPD – Tutor: Prof. Mengoni, Prof. Cottone

PROGETTI EUROPEI EnABLES 1 e 2 (2022).

WISEPOWER

ESIEE PARIS



Tyndall National Institute (IRL)
Role: Access Provider (EH-Vibrational, EH-Thermoelectric, ES, MPM, SI)

CEA-Leti (F)
Role: Access Provider (ES)

CEA-Liten (F)
Role: Access Provider (EH-Thermoelectric)

Fraunhofer – Institute for Integrated Circuits (D)
Role: Access Provider (EH-Vibrational & Thermoelectric, MPM, SI)

Fraunhofer – Institute for Microelectronic Circuits and Systems (D)
Role: Access Provider (EH-Solar, EH-RF)

imec Nederland (NL)
Role: Access Provider (EH-RF, MPM, SI)

Karlsruher Institut für Technologie (D)
Role: Knowledge Hub (ES)

Politecnico di Torino (I)
Role: Knowledge Hub (ES)

Università di Bologna (I)
Role: Knowledge Hub (MPM)

NiPS Laboratory, Università degli Studi di Perugia (I)
Role: Knowledge Hub (EH-Vibrational)

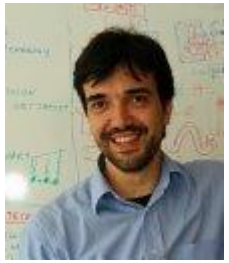
University of Southampton (UK)
Role: Knowledge Hub (EH-Vibrational)

Gruppo di ricerca

Prof. Francesco Cottone
francesco.cottone@unipg.it

Prof. Luca Gammaitoni

Dr. Igor Neri



Dr. Maurizio Mattarelli

Dr. Alessandro Di Michele

Dr. Giacomo Clementi

Dr. Gabriele Perna

ESIEE PARIS

Tyndall National Institute (IRL)
Role: Access Provider (EH-Vibrational, EH-Thermoelectric, ES, MPM, SI)

CEA-Leti (F)
Role: Access Provider (ES)

CEA-Liten (F)
Role: Access Provider (EH-Thermoelectric)

Fraunhofer – Institute for Integrated Circuits (D)
Role: Access Provider (EH-Vibrational & Thermoelectric, MPM, SI)

Fraunhofer – Institute for Microelectronic Circuits and Systems (D)
Role: Access Provider (EH-Solar, EH-RF)

imec Nederland (NL)
Role: Access Provider (EH-RF, MPM, SI)

Karlsruher Institut für Technologie (D)
Role: Knowledge Hub (ES)

Politecnico di Torino (I)
Role: Knowledge Hub (ES)

Università di Bologna (I)
Role: Knowledge Hub (MPM)

NiPS Laboratory, Università degli Studi di Perugia (I)
Role: Knowledge Hub (EH-Vibrational)

University of Southampton (UK)
Role: Knowledge Hub (EH-Vibrational)