A.D. 1308
unipg
DEPARTMENT
OF PHYSICS AND GEOLOGY

Energy Harvesting: Materials and Devices

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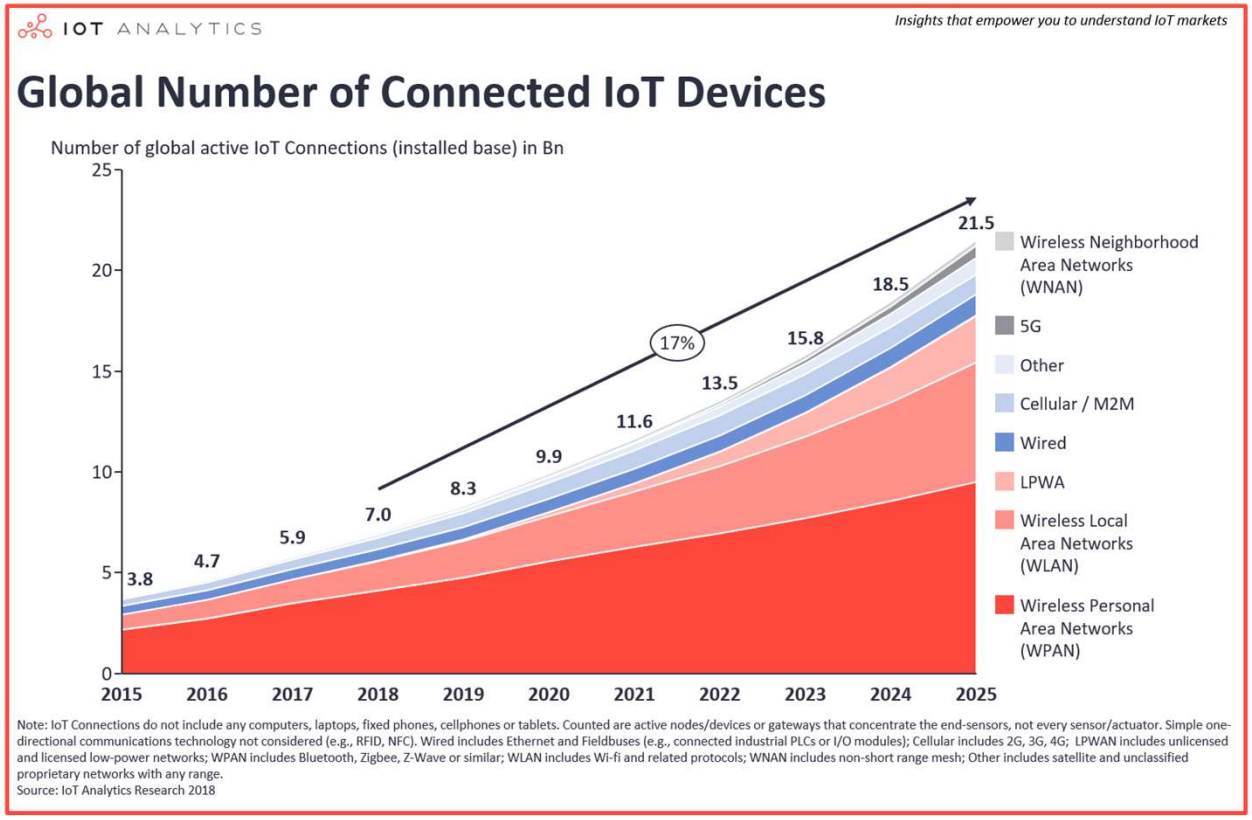
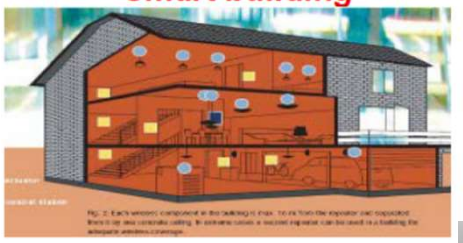
Energy Harvesting for the Internet of Things (IoT)

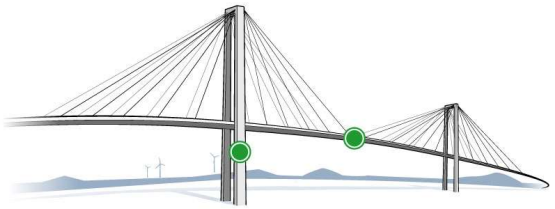


Capacity:	235 mAh
Weight:	3 g
Lithium:	109 mg
Volume	1 cm^3

Smart building



Implantables



Structural Health Monitoring

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Noise in Physical Systems

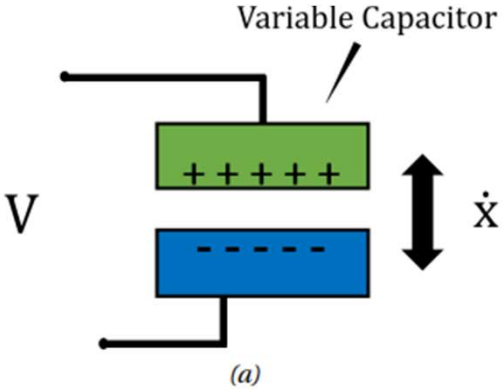
Vibrational Energy Harvesting

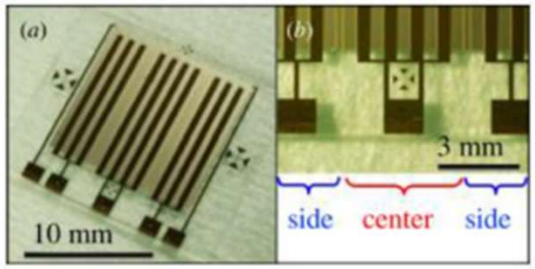
Electroactive materials can change their physical properties when stimulated by an electric field or mechanical excitation (ie: **electret** or **piezoelectric materials**)

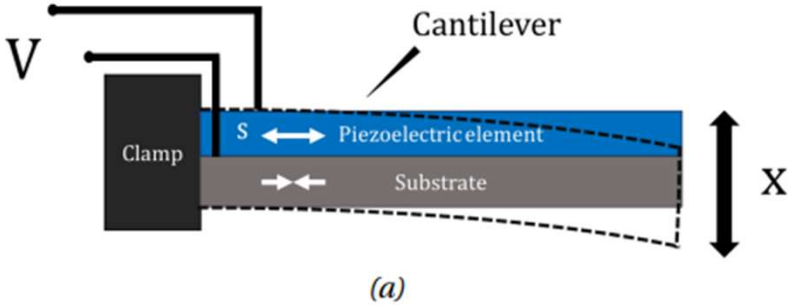
Electrostatic generators:

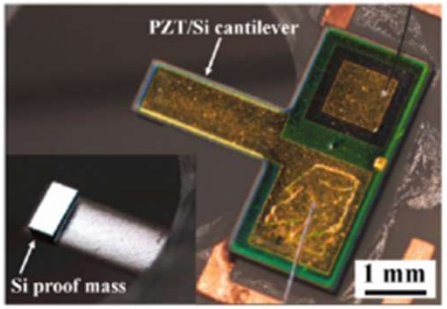
a) Parallel plate electrode variation generates voltage variation (0.1 mW/cm^3)

b) Electret based energy harvester electrode detail









Piezoelectric generators:

a) Displacement of cantilever and strain variation in piezoelectric layer (1 mW/cm^3)

b) MEMS scale PZT cantilever on Si

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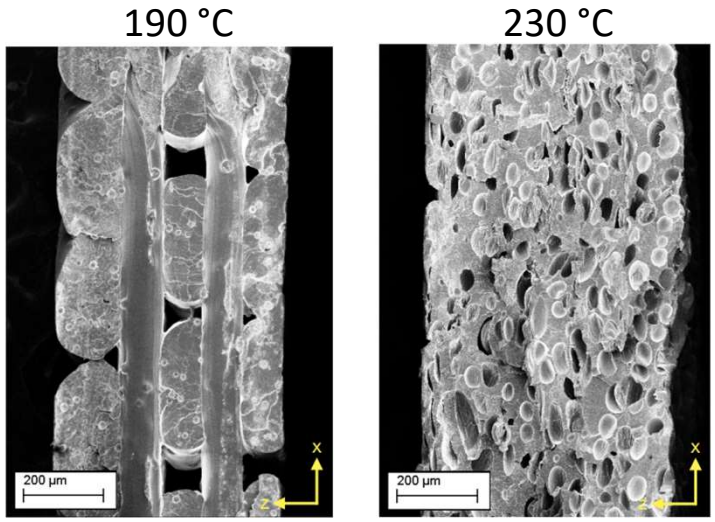
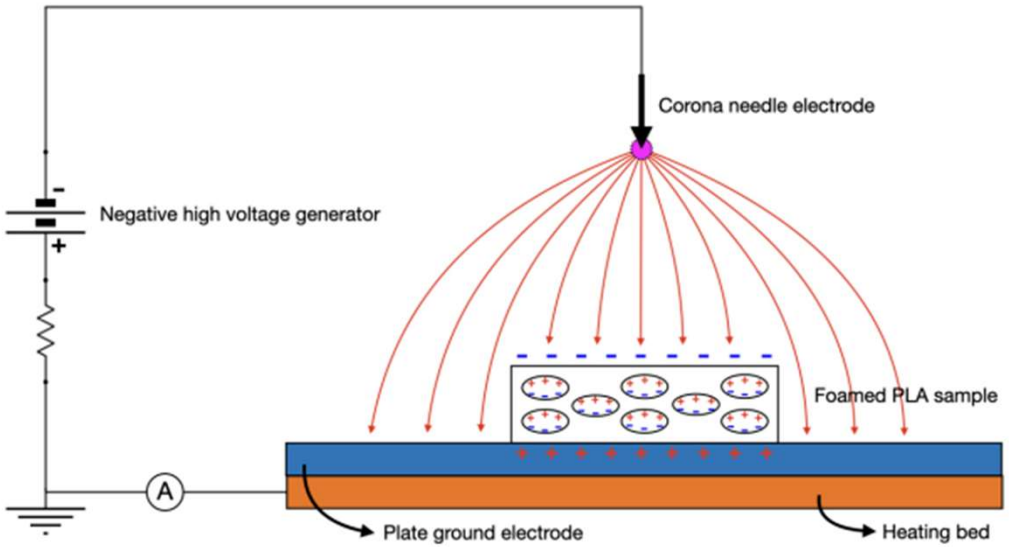
3D printed electroactive materials

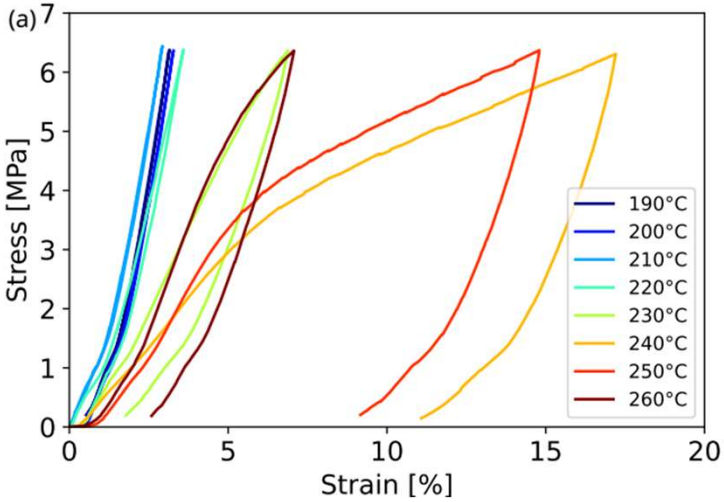
- 3D printed materials that are low-cost and bio degradable and easy to manufacture
- PLA printed at different temperature starts to show foaming structure

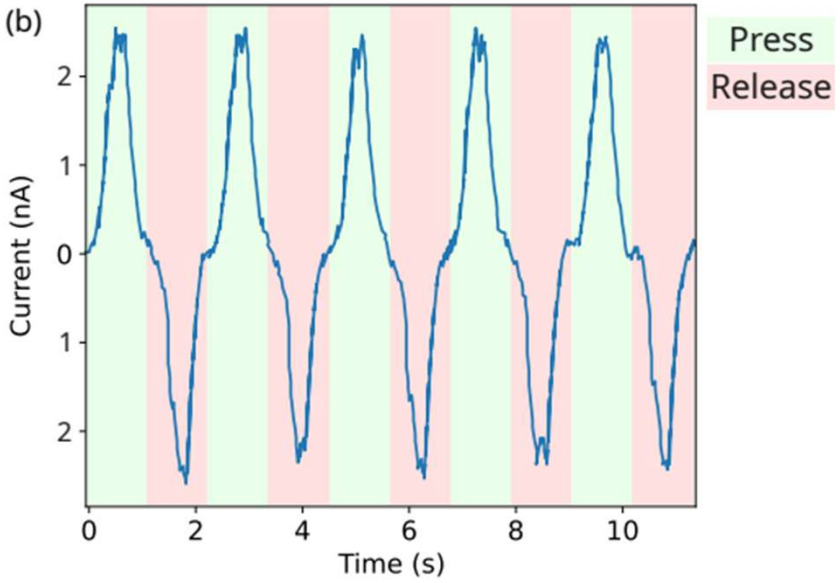
3D-Printed Piezoelectret Based on Foamed Polylactic Acid for Energy-Harvesting and Sensing Applications, Perna et al (2023)





Electromechanical characterization





Bio-Energy Harvesting

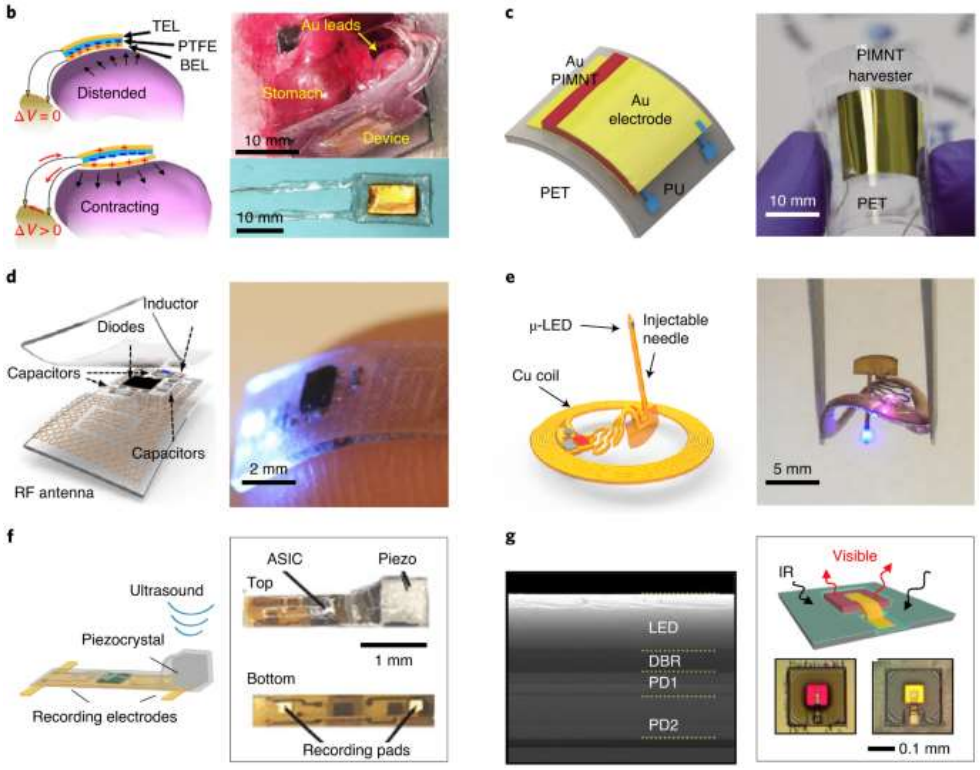
Implantables

Challenges for miniaturized and ultralightweight devices for neuro and bio-engineering:

- **Wireless and fully implantable** systems with electronic interface for control, power harvesting and data communication.
- Batteries with sufficient **storage capacity** for many practical applications have large sizes and weigh more than 2 g.
- Batteries **size** often occupy up to 90% of the volume of implantable devices and account for more than 60% of their weight.

Medical implant devices:

- Sensing or single-cell manipulation
- Targeted drug delivery
- Minimally invasive surgery



Wireless and battery-free technologies for neuroengineering, Won et al (2021)

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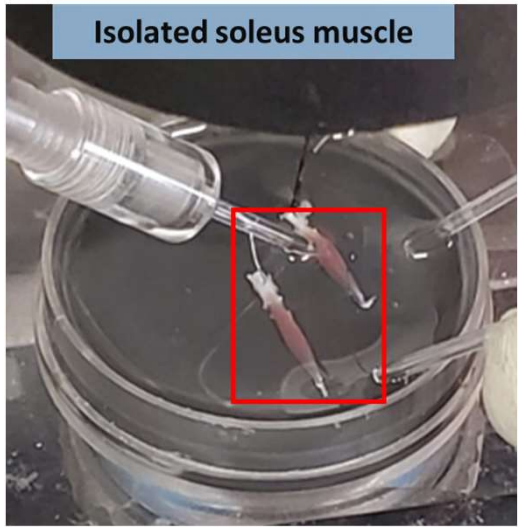
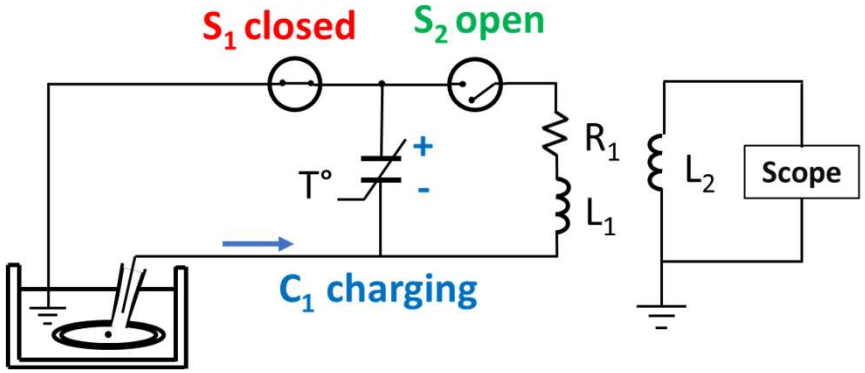
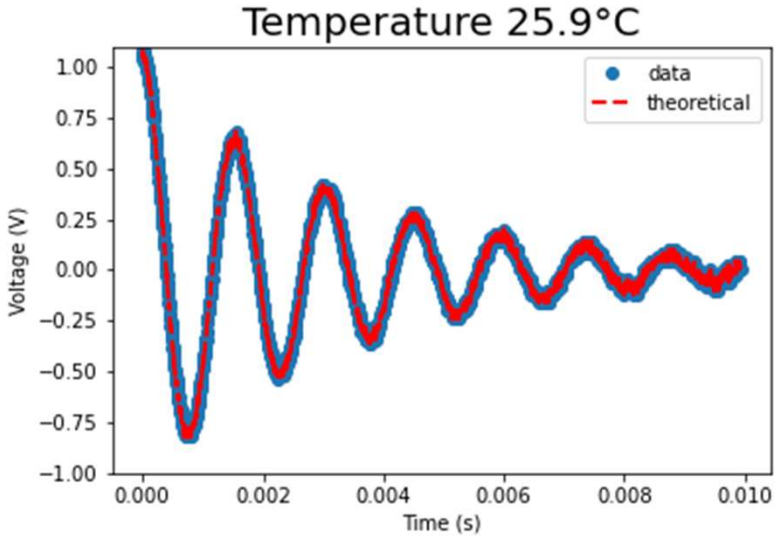
Membrane Potential of Bio Cells



Isolated specimen of mice soleus muscle with electric probe and ground

Self-powered temperature sensors harnessing membrane potential of living cells, Clementi et al (2024)





- Each of these cells is a cylinder with **100 μm diameter** and up to **cm in length**.
- **Higher number of Na/K pumps** in their membrane.
- Membrane potential **can reach -90 mV**!
- Using parameters available, harvested power from skeletal muscle cells is **about 4.5 nW**.

- Possibility of miniaturization to get to higher frequncy bandwidth

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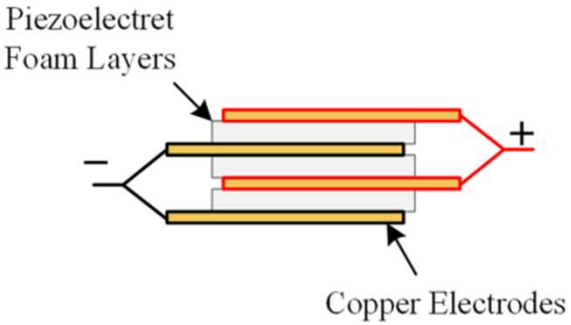
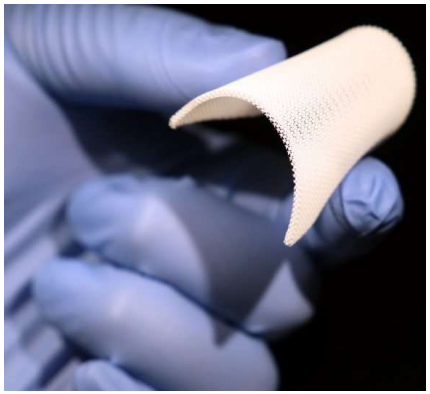
Thesis Projects

Foamed Electroactive materials

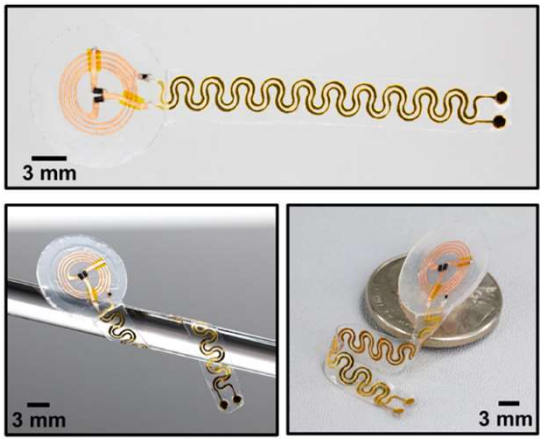


Multilayer piezoelectret foam stack for vibration energy harvesting, Ray et al (2017).



Three-dimensional printing of piezoelectric materials with designed anisotropy and directional response, Cui et al (2019)

Bio Energy Harvesting/Sensing



Battery-free, tuning circuit–inspired wireless sensor systems for detection of multiple biomarkers in bodily fluids, Liu et al (2022).

Thesis projects:

- Characterization and design of 3D printed foamed electroactive devices
- Bio-energy harvesting for autonomous sensors

Funded Projects

- **VITALTY** – Nanostructured and advanced materials and devices for energy harvesting
- **BETASMART** –Prof. Cottone (UNIPG), Prof. Mengoni (UNIPD, INFN)
- **NANOFAB** – Progetto Ateneo – Facility per micro e nano fabbricazione di NEMS/MEMS

VITALITY

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COLLABORAZIONI CON AZIENDE LOCALI

WISEPOWER

EAGLEPROJECTS

COLLABORAZIONI INTERNAZIONALI

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)

ESIEE PARIS

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)

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Noise in Physical Systems

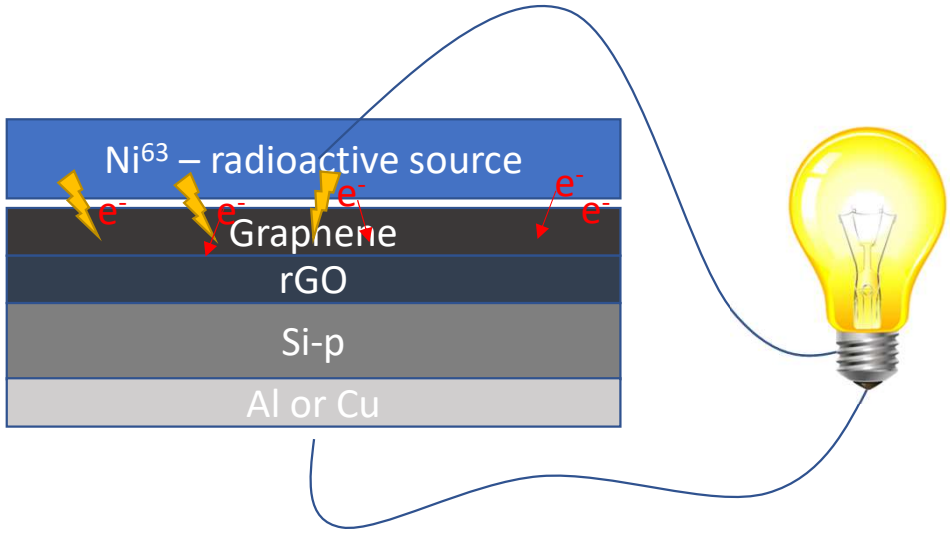
Betavoltaic Generators – Betasmart

Project Collaboration with

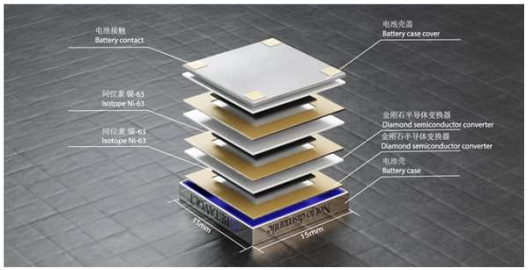
- Prof. D. Mengoni INFN Padova
- Maddalena Pedio CNR Perugia
- Sara Dottorini (tesista)
- A. di Michele

Radioisotope	Maximum energy of β-particles (keV)	Half-life (years)	Maximum power density (W/g)	Availability
H-3	18.6	12.3	0.325	Medium
Ni-63	66.7	100.2	0.006	Low
Sr-90	545.9	28.8	0.164	High
Y-90	2,279.8	0.007	0.780	—
$^{90}Sr + {}^{90}Y$	—	—	0.944	High

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

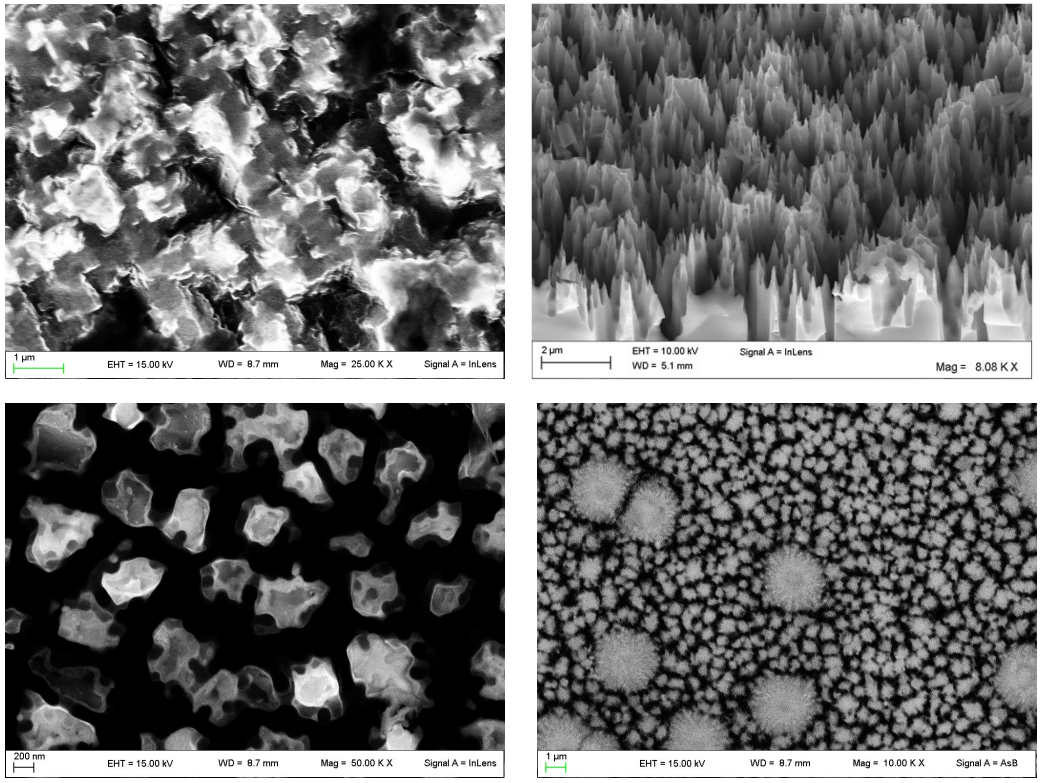


Decay formula is, $_{28}{}^{63}Ni \rightarrow {}_{29}{}^{63}Cu + {}_{-1}{}^{0}\beta$



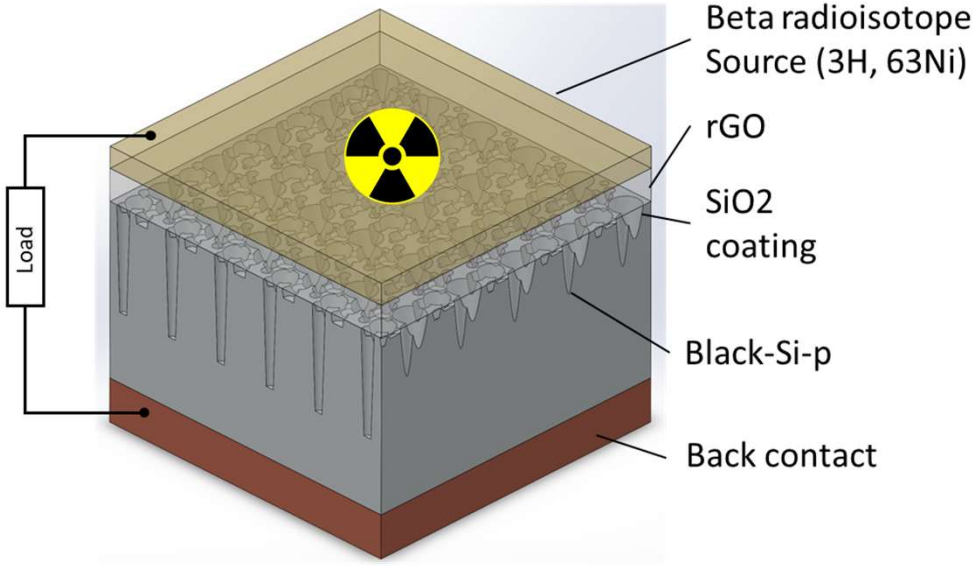
Betavolt-100 microwatts at 3V, 15x15x5 cubic millimeters

Betavoltaic Generators – Betasmart



Ni, Graphene Oxide Deposition on Si-p, Black-Si

SEM image of Black Silicon samples



Structure of nuclear betavoltaic cell

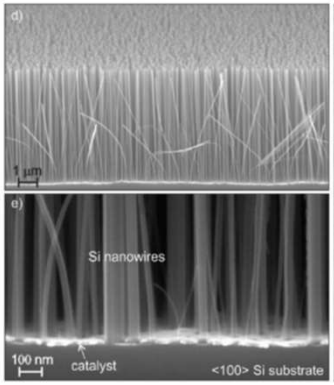
Dip. di Fisica e Geologia

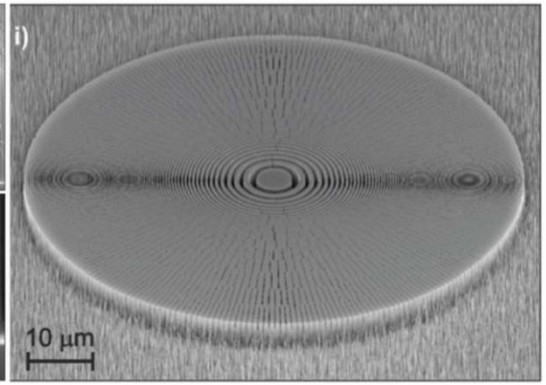
NANOFAB Projects

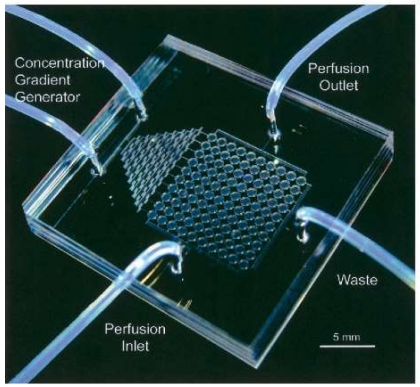
Wet etcher (Idonus)

Plasma Ion Etcher/Coater (SPI)

PECVD furnace KT80 (Kintek)







(a)

Research Group

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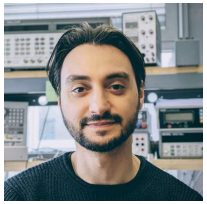

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Thank you for your attention!