

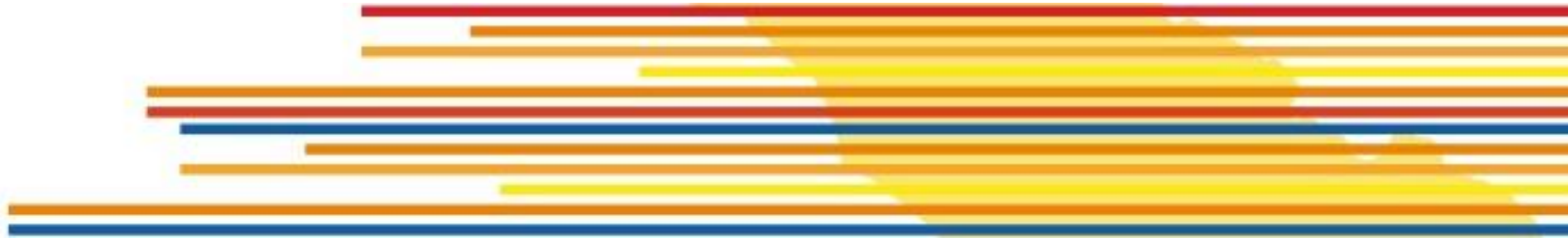
Institute for Microelectronics and Microsystems

Sede di Roma – Area della ricerca di Roma Tor Vergata – Edificio G

Via del Fosso del Cavaliere 100, 00133 Roma, Italy



<http://www.artov.imm.cnr.it/>
<http://aladin.artov.imm.cnr.it/index.html>
<http://www.imm.cnr.it/>



Consiglio Nazionale delle Ricerche

CNR-Research Area of Tor Vergata

CNR Departments

1. Physical sciences and technologies of matter
2. Earth system science and environmental technology
3. Agrifood science
4. Biomedical sciences
5. Chemical sciences and technology of materials
6. Engineering, ITC and technologies for energy and transport
7. Human and social sciences, cultural heritage

National Institute for Astrophysics

Institute of Structure of the Matter
 Institute for Microelectronics and Microsystems
 Institute for Complex Systems

Institute of Atmospheric Sciences and Climate

Institute of Translational Pharmacology

Institute of Acoustic and Sensors "Orso Mario Corbino"

Institute for Space Astrophysics and Planetology

7 Institutes

TorVergata research area



TorVergata research area Competences

ENERGY

MICRO/
NANO/ELETTRONICS

BIOMEDICINE

CLIMATE
ENVIRONMENT

SPACE

Institute for Microelectronics and Microsystems

Department of Physical sciences and technologies of matter

IMM is organized in six different sites:

- Headquarters in Catania (Director: dr. G. Fortunato)
- Research Units in Lecce, Naples, Rome, Bologna and Agrate Brianza.

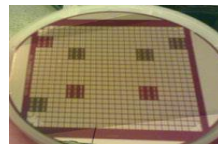
The Institute has a permanent staff of 195 people (117 of them Researchers) and a temporary staff including 47 post-docs and 61 PhD students

IMM activities span from material science and process development to device fabrication and system integration, thanks to the micro-nanofabrication facilities present at the different sites (**clean-room areas totaling >1400 m²**).

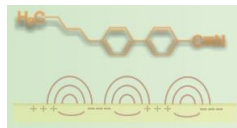
IMM sites in Italy



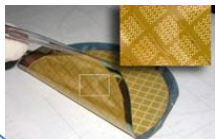
Activity of IMM-Rome



High Frequency Microsystems

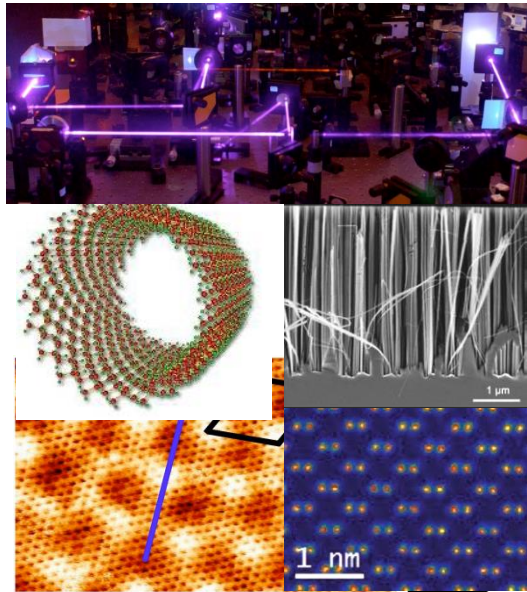


Tunable Photonic Microsystems



Devices for large-area electronics – Flexible electronics.

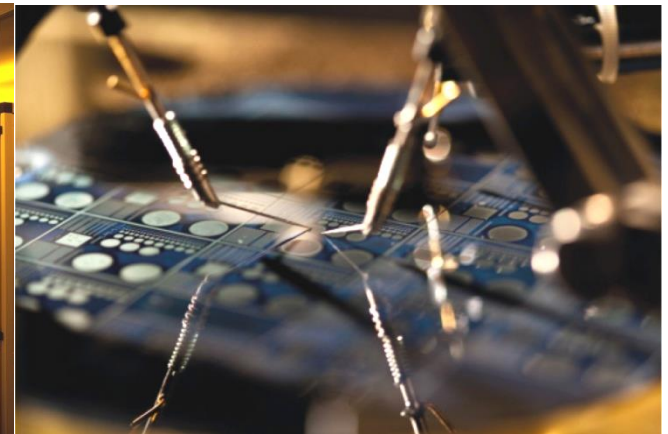
Research activity



Investigation of innovative materials



Micro- and nanofabrication processes



Materials and process integration in complex microsystems

The research activity is focused on innovative solutions for:

- 1) micro and nanoelectronics;
- 2) advanced materials and processes for smart components;
- 3) optoelectronics and photonics;
- 4) sensors and multifunctional micro/nanosystems.

Micro/Nano-fabrication facility - equipment



Photolithography



Organic semiconductor evaporator



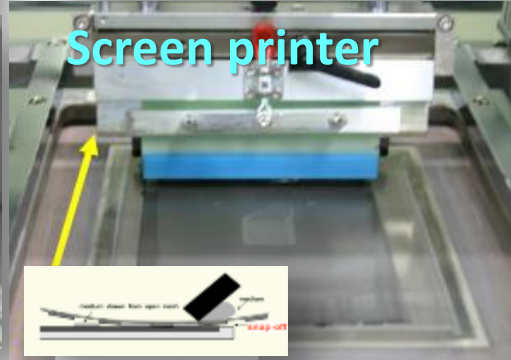
Co-rotating spin coater



Mask aligner



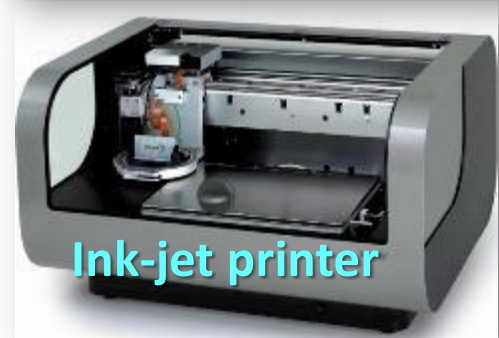
Gravure printer



Screen printer



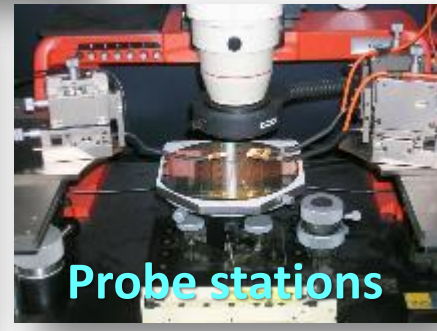
PECVD systems for thin film deposition



Ink-jet printer



Laser annealing

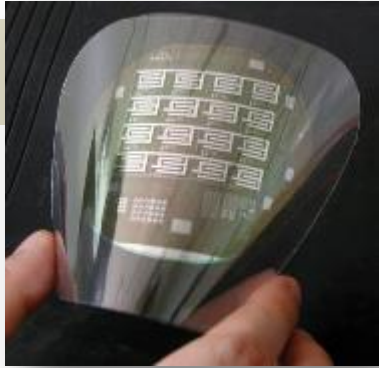


Probe stations



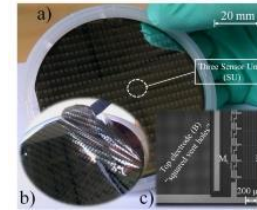
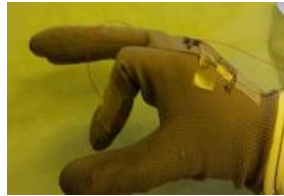
FLEX to FLEX interfacing

Flexible Electronics

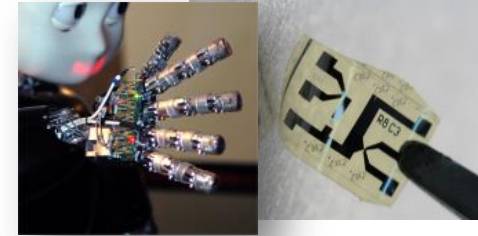


- **Devices for large area electronics based on polycrystalline silicon**
Flexible electronics, Smart sensors, Ultra thin microelectrode array, Thin Film Transistors

Strain Gauges: Bracelet for hand/wrist postures and force estimation, Monitoring of inflatable structures, Safe human-robot interaction

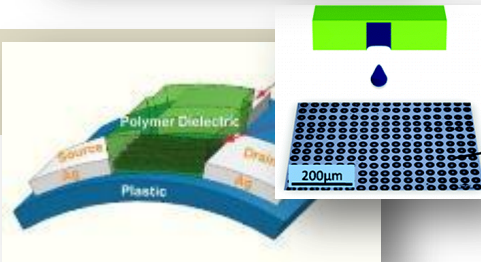


Gas sensors

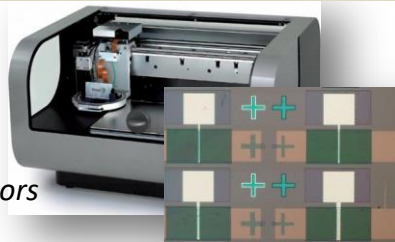


Smart skin for robotics

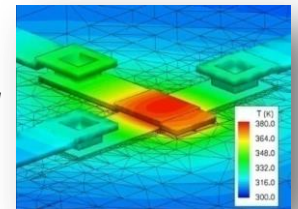
- **Electronics on plastic based on organic and metal oxide semiconductors**
Printing of metals and organic semiconductors, Devices electrical characterization, Numerical simulations



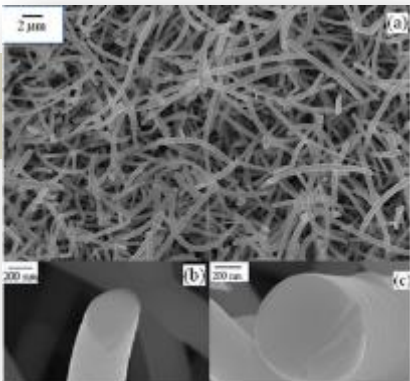
Organic Thin Film Transistors



3D numerical simulation of physical parameters of a thin film transistor



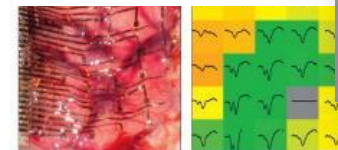
- **Nanostructured materials for photovoltaic cells and large-area devices**
Silicon nanowires, nanotubes, Ultra-sensitive gas sensors



Biosensors

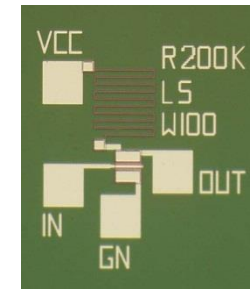


Microelectrodes on ultra-thin substrates

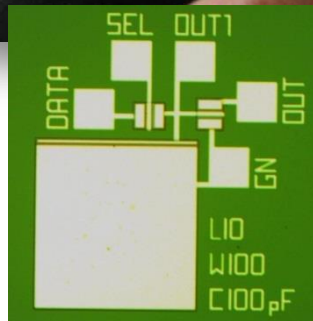


Low Temperature Polysilicon (LTPS) TFT technology on polyimide

Touch-Keypad



inverter



Pixel circuit for OLED Display



RFID

A. Pecora et al., "Polysilicon thin film transistor circuits for integrated flexible sensors", Proc. ITC'10, Hyogo (Japan) 2010, p. 298.

A. Pecora et al., Solid-State Electronics 52 (2008) 348–352

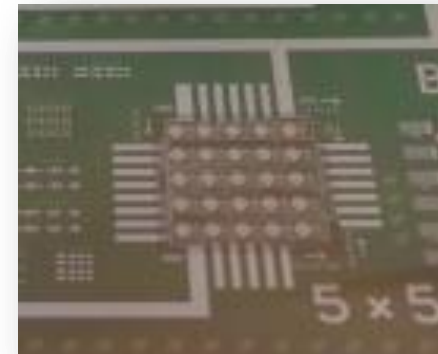
Electronic skin

Piezoelectric flexible tactile sensor based on poly-silicon TFT for humanoid robots



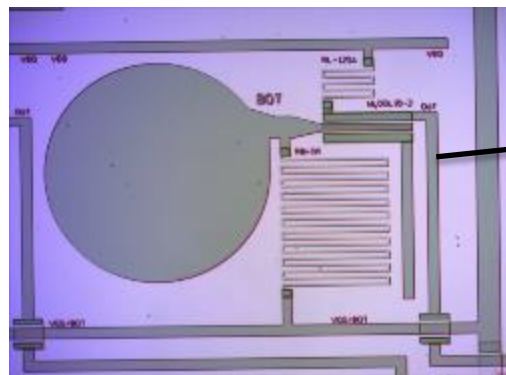
A hand of the humanoid robot iCub

Active matrix tactile sensors

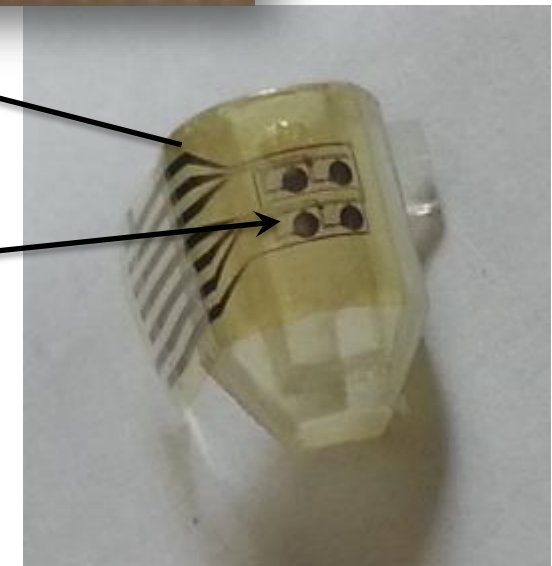


5x5 sensors

2x2 sensors



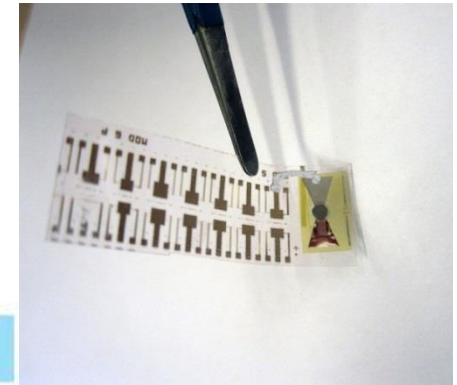
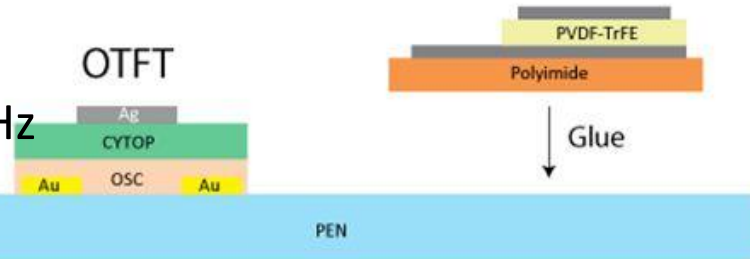
POSFET based on piezoelectric capacitance connected in extended gate configuration with readout circuit based on poly TFTs



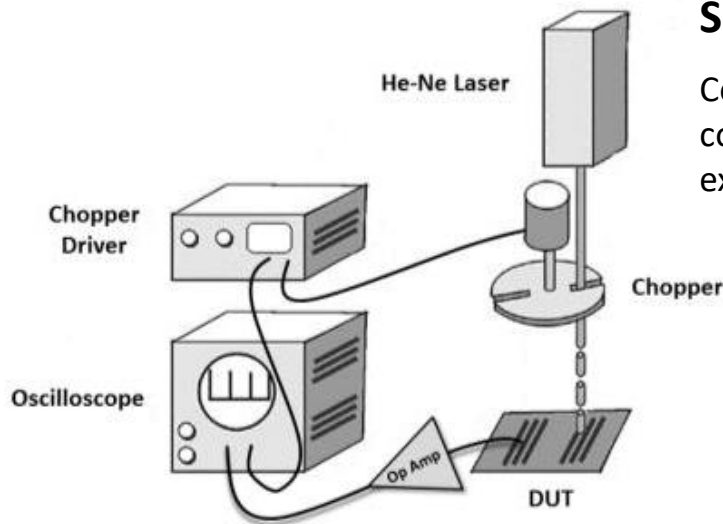
Flexible PVDF-TrFE pyroelectric sensor integrated on a fully printed p-channel Organic-TFT

IR laser source $\lambda = 632 \text{ nm}$
 laser max. power of 5 mW
 Chopper frequency up to 500Hz
 $R_{\text{bias}} - R_{\text{load}}$ in range of $M\Omega$

Device scheme

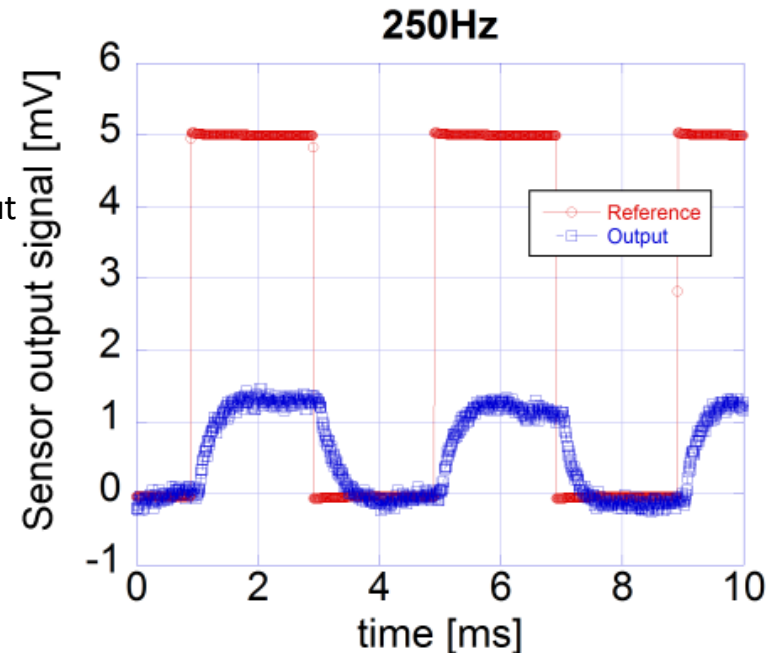


Measurement setup

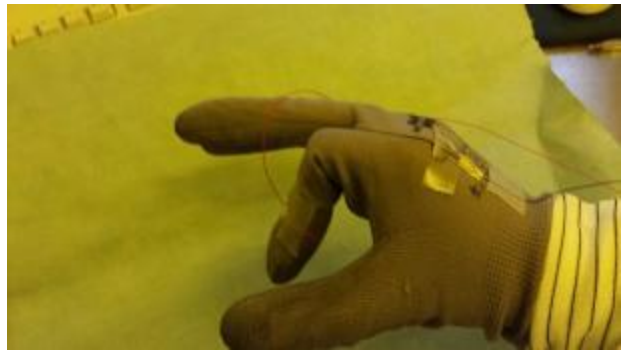


Sensor response

Common-source amplifier configuration; signal without external amplification



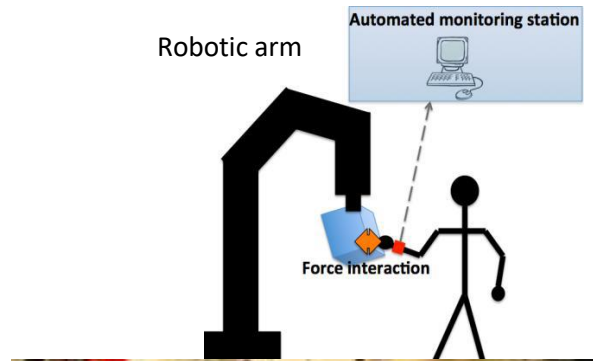
Smart polymer-based materials for strain sensors - Applications



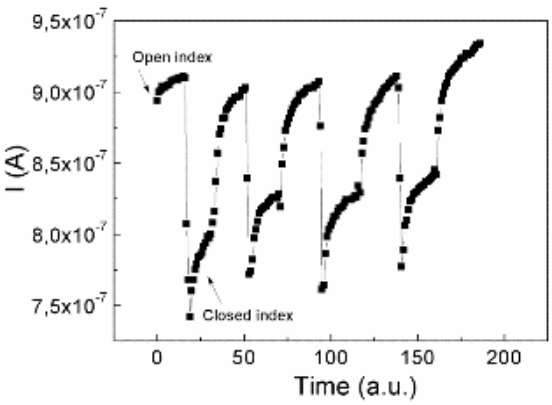
Strain Gauges integration in textile for wearable active clothes.



Bracelet for hand/wrist postures and force estimation



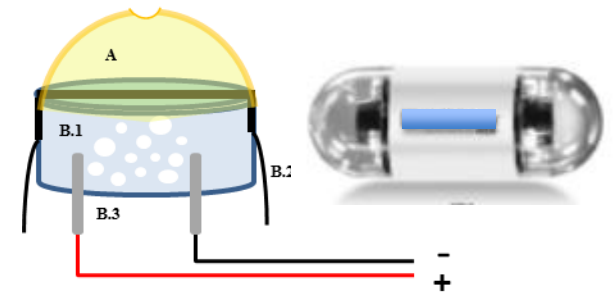
Safe human-robot interaction



Sensor response for two different positions of the finger (open/closed).



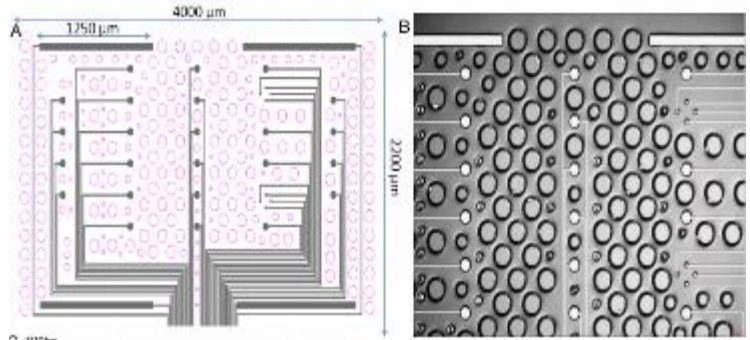
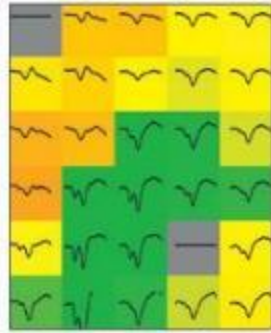
Monitoring of inflatable structures



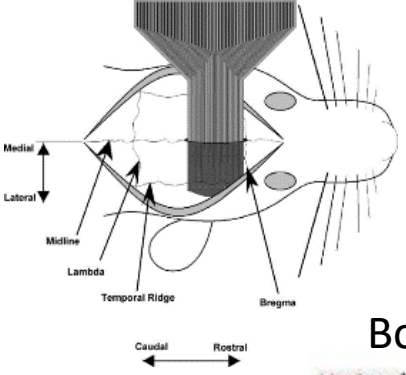
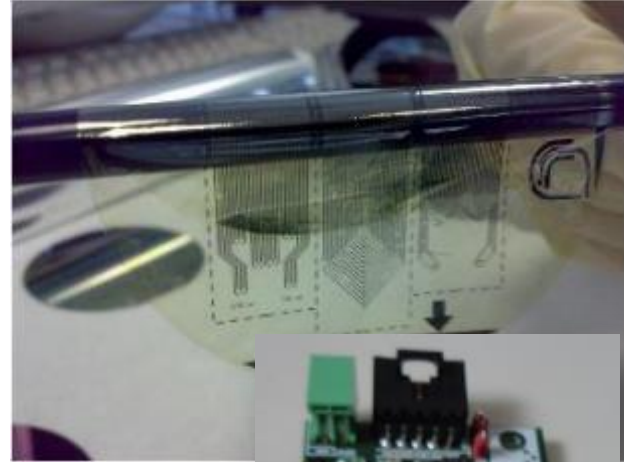
Smart pill for drug delivery

Brain Computer Interface

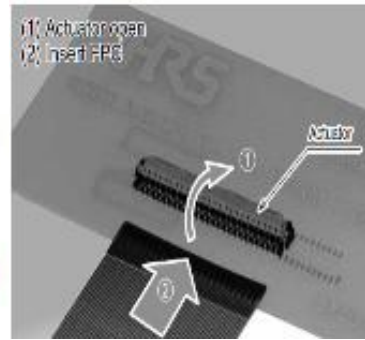
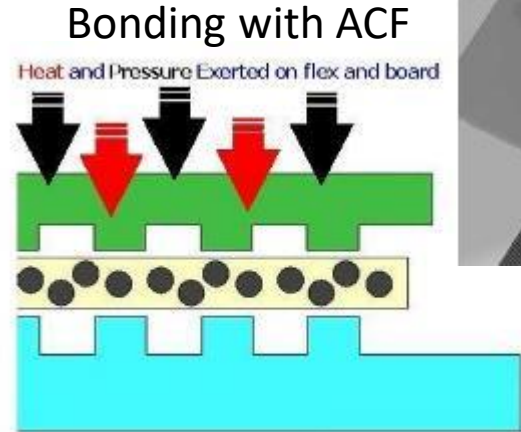
Microelectrodes active grid on ultra-flexible substrates (<10 μm) for the epicortical brain signal recording



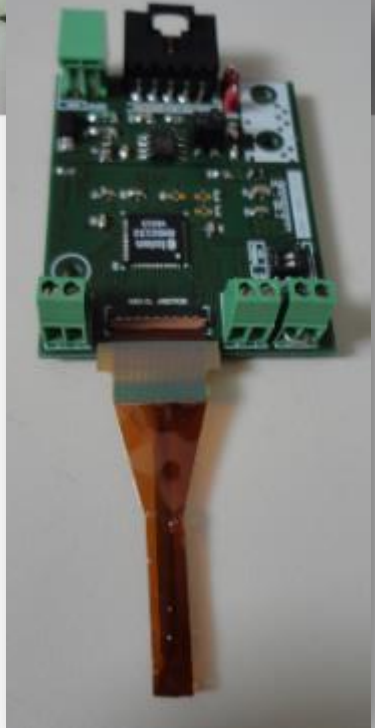
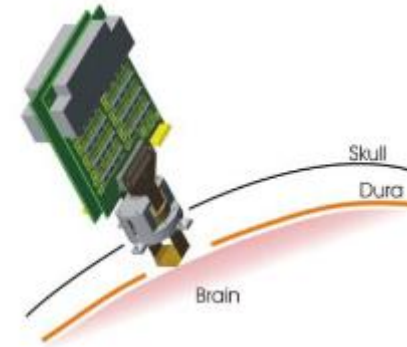
Layout of Ultra Flexible MEAs on polyimide foils.



ZIF Connector on PCB

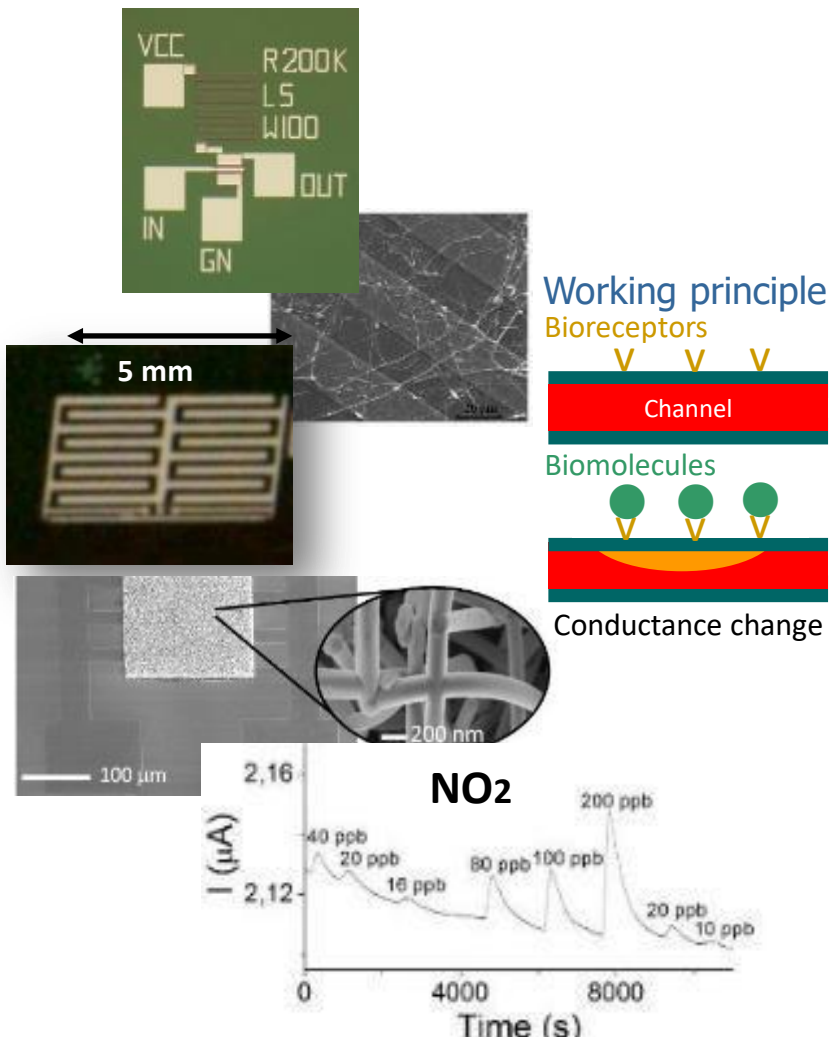


Active PCB has been equipped with a digital electrophysiology interface chip

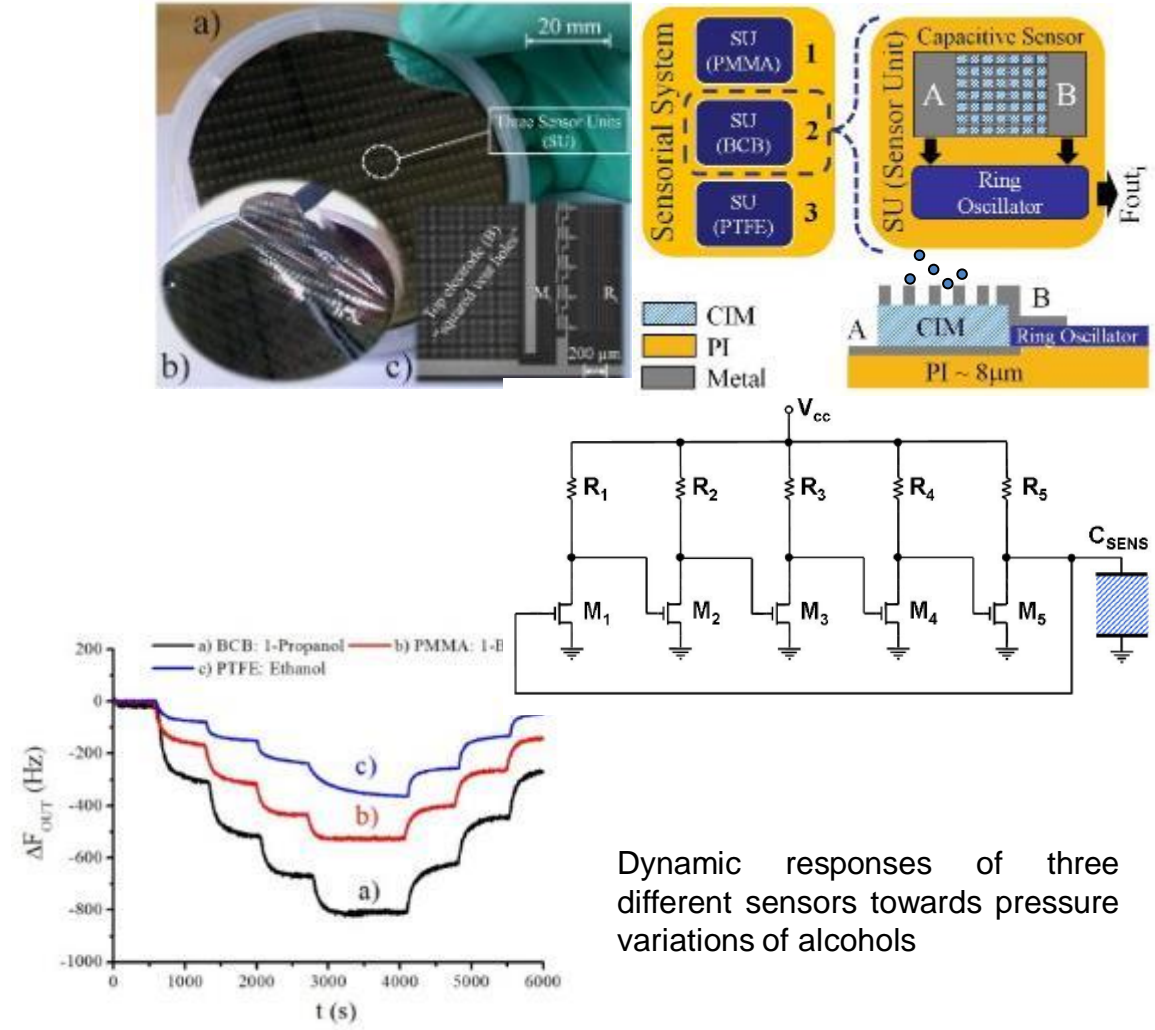


Gas sensor systems on flexible substrates with integrated readout electronics

Resistive sensors



Capacitive sensors



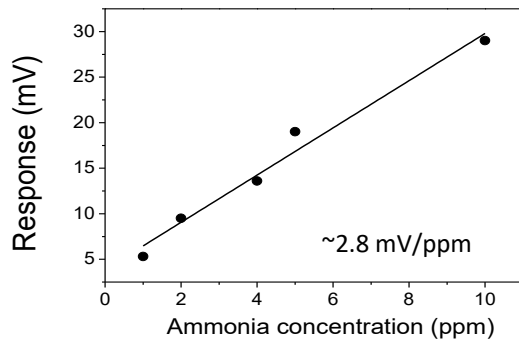
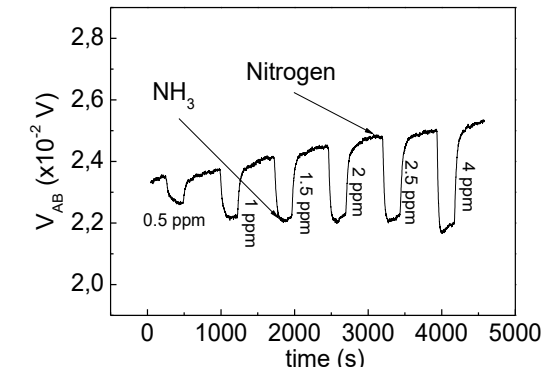
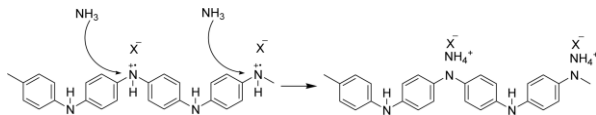
Resistive ammonia sensors

Ammonia sensor -> conductive polymer polyaniline emeraldine base (PANI-EB) doped with camphorsulfonic acid (HCSA) and mixed with polyethylene oxide (PEO)

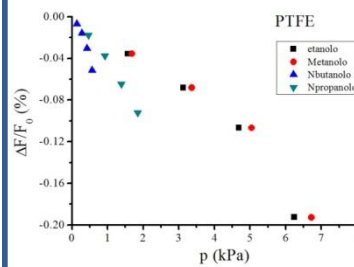
Sensing mechanism: dedoping by deprotonation

The interaction mechanism between ammonia and PANi is controlled by reversible acid/base reactions.

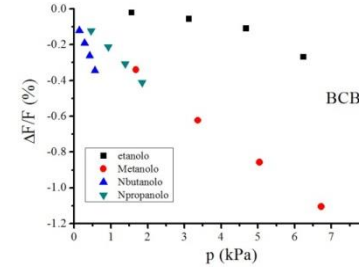
The protons on $-NH-$ groups are transferred to ammonia molecules forming ammonium ions that decrease conductivity of PANi.



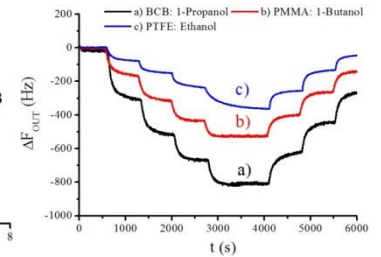
Capacitive integrated VOCs sensor



Responses of the PTFE based SU, in terms of relative frequency shifts ($\Delta F_{OUT} \times 100/F_0$), versus increasing analyte partial vapor pressures

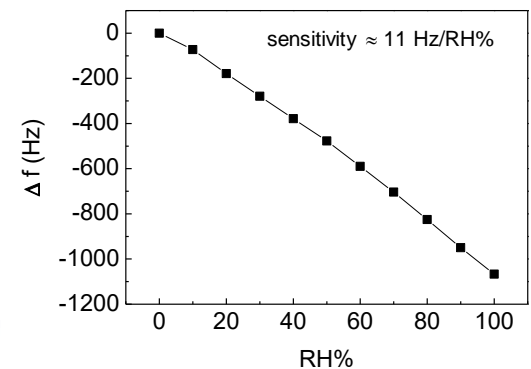
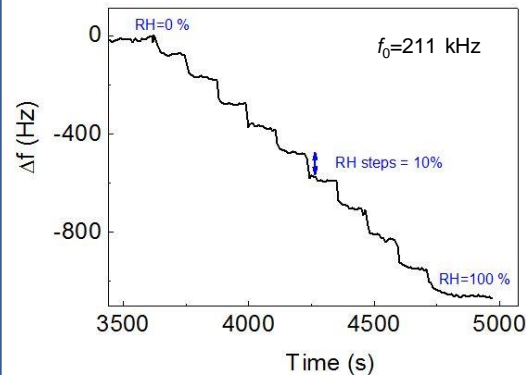


Responses of the BCB based SU, in terms of relative frequency shifts ($\Delta F_{OUT} \times 100/F_0$), versus increasing analyte partial vapor pressures

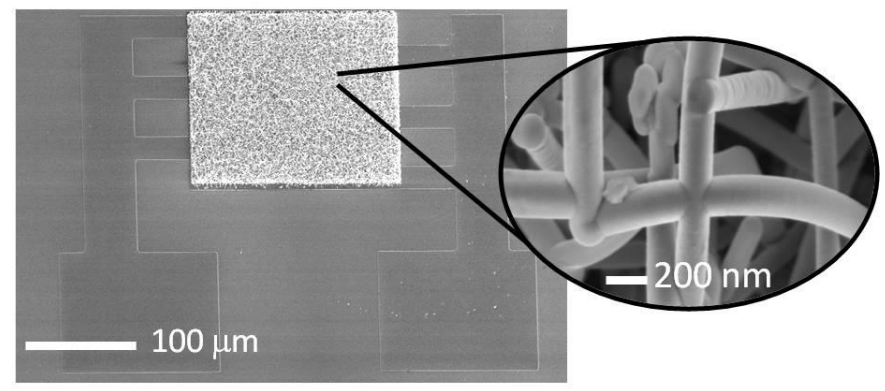
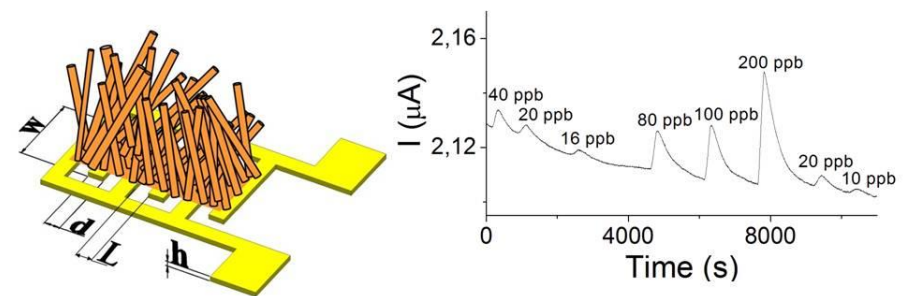


dynamic responses of the BCB, PMMA and PTFE based SUs, reporting the frequency shifts (ΔF_{OUT}) towards pressure variations of alcohols reaching 6240 Pa for ethanol, 563 Pa for 1-butanol, 1848 Pa for 1-propanol

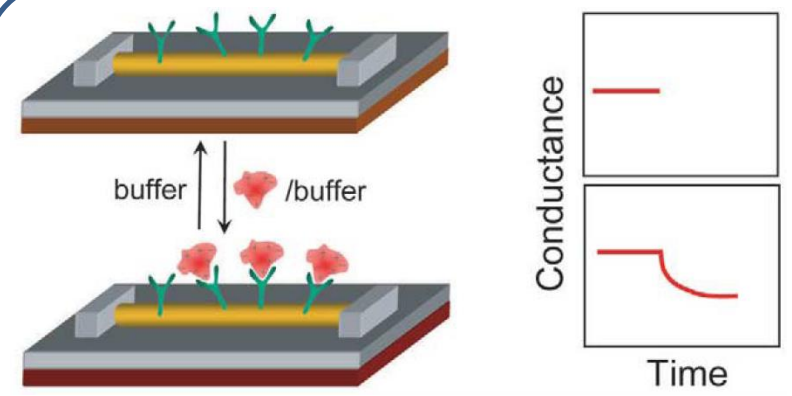
integrated humidity sensor based on BCB



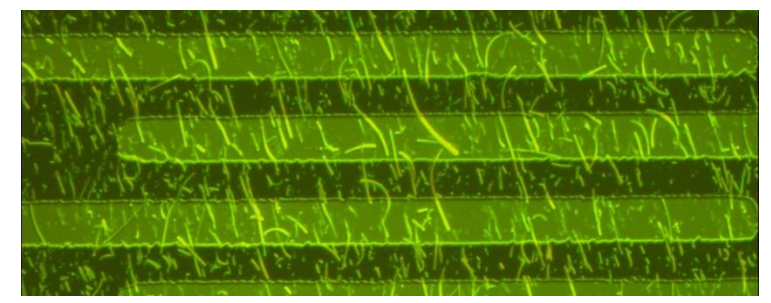
Ultrasensitive NO₂ sensors based on silicon nanowires



Si NW based transistors for bio-sensing applications



Schematic of a Si nanowire-based FET device configured as a sensor with antibody receptors (green), where binding of a protein with net positive charge (red) yields a decrease in the conductance

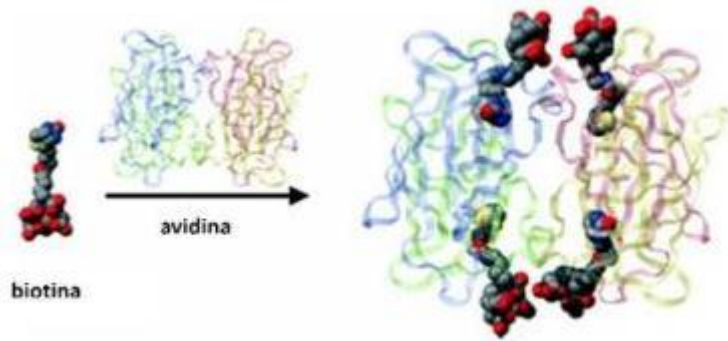


SiNW trasferiti su strutture interdigitate mediante contact printing

M. Cuscunà et al., Low-temperature, self-catalyzed growth of Si nanowires, *Nanotechnology* 21 (2010)
 M. Cuscunà et al., On-chip fabrication of ultrasensitive NO₂ sensors based on silicon nanowires, sottomesso su *NanoLetters*

Biosensors

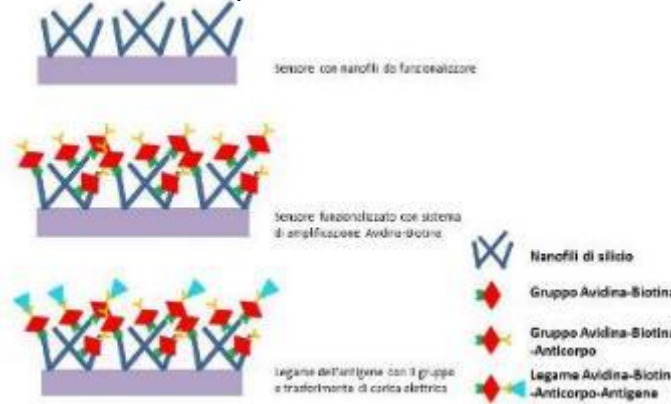
Avidin-Biotin detection



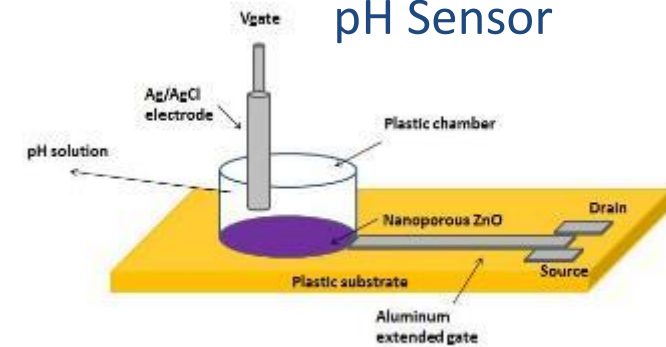
Advantages:

1. Sensitivity
2. Response Time
3. Miniaturization
4. Flexibility

Sensor Concept

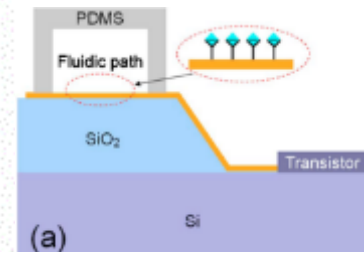
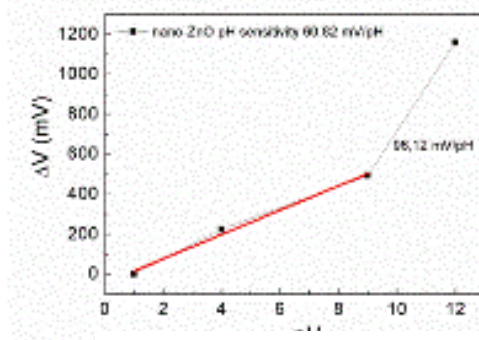
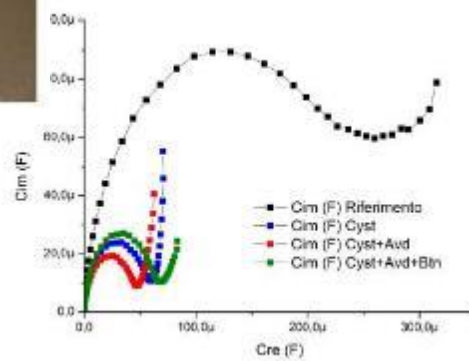


pH Sensor



Measurements conditions:

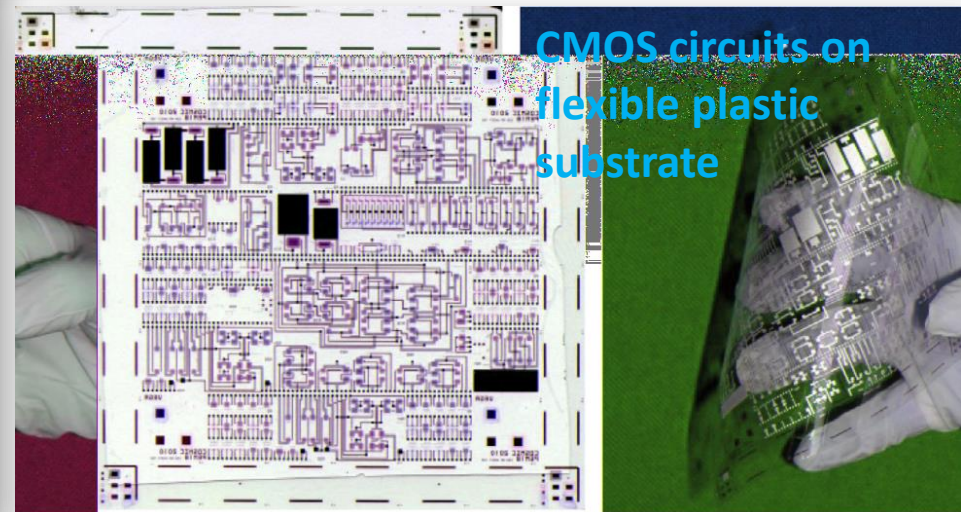
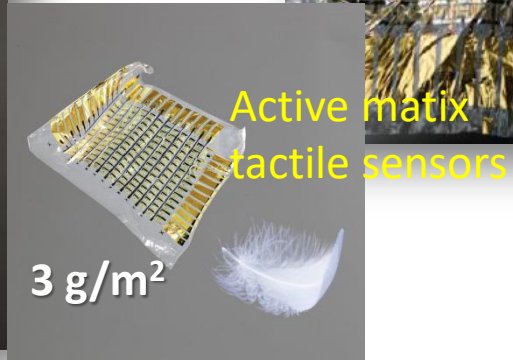
- Room temperature
- Frequency range (10mHz-100 KHz)
- Average on multiple measurements



Extended gate Field Effect Transistor - based biosensor

Organic electronics

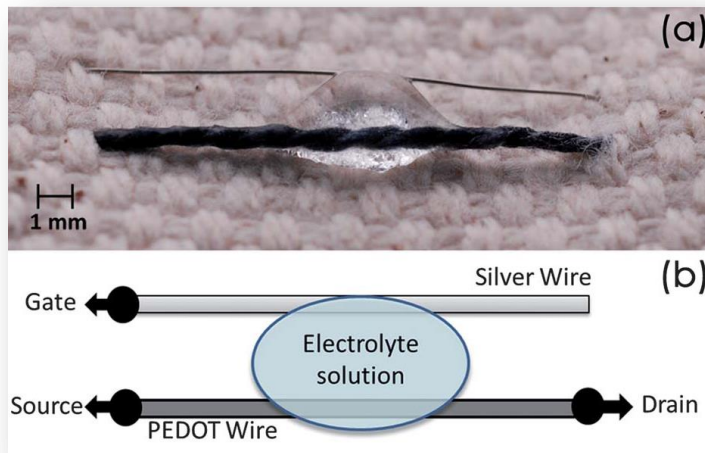
- Low process temperature (<math><100^\circ\text{C}</math>)
- Flexible plastic substrates
- printable
- biocompatibility



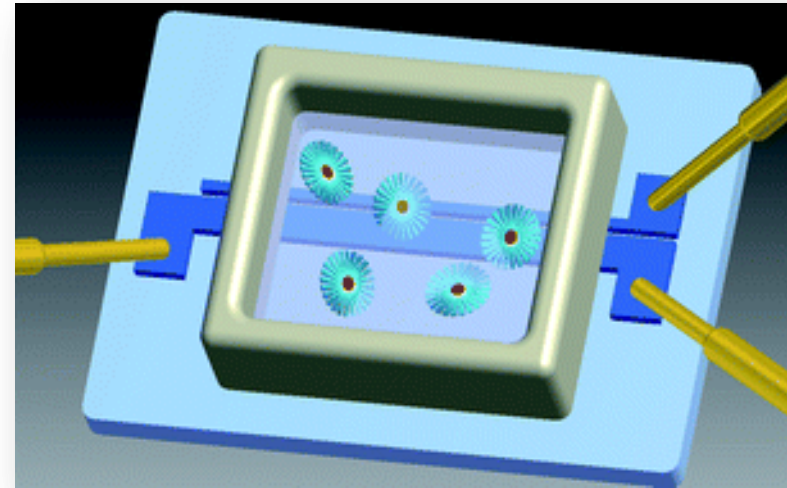
Simple and non-conventional sensors

- Organic electrochemical transistors for ion sensing

OECT on a cotton fiber.



G. Tarabella, *J. of Mat. Chem.* **22**(2012)23830

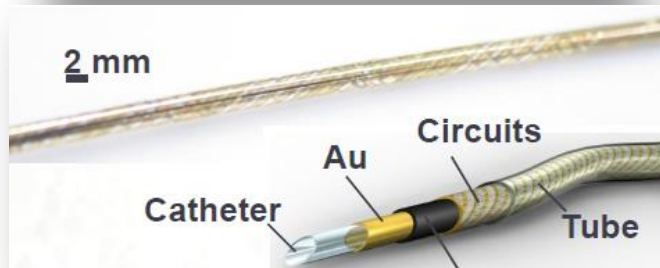
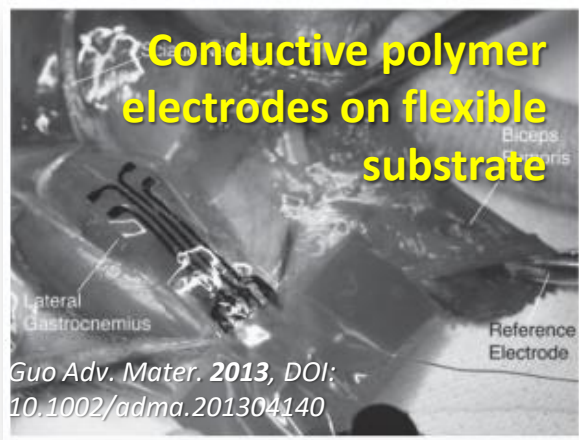


Sweat sensing

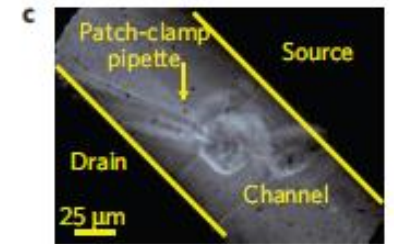
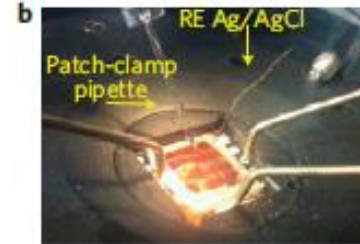
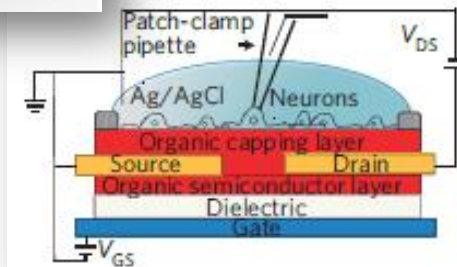
Organic devices: Biomedical applications

Advantages:

- Biocompatibility
- Flexibility and conformability
- Possible biodegradability



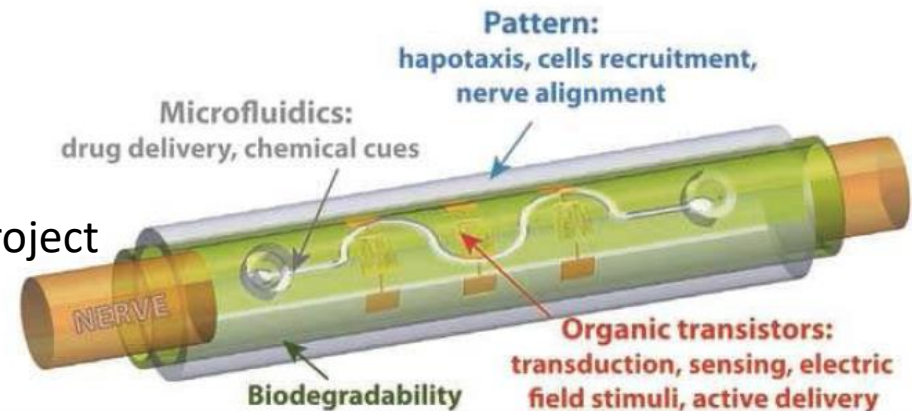
M. Kuribara et al., Nature 2012 DOI: 10.1038/ncomms1721



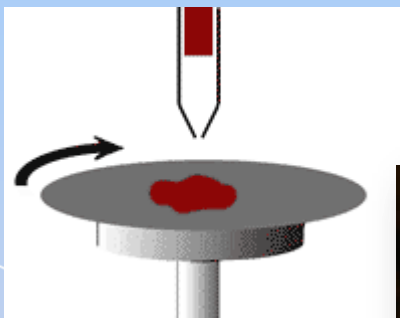
Organic Cell Stimulating and Sensing Transistors (O-CSTs)

For neural activity monitoring (V. Benfenati Nature Materials 12 (2013) 672)

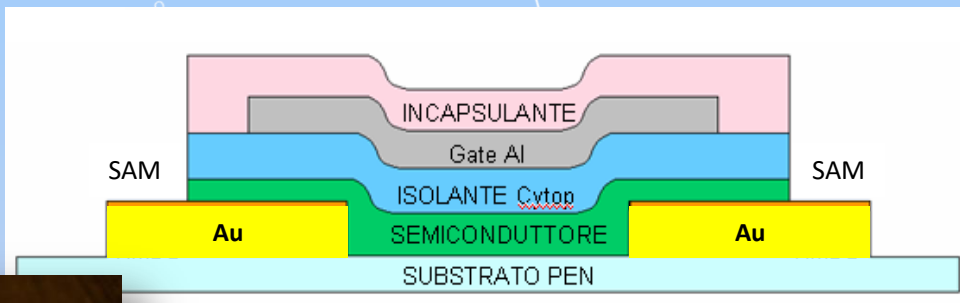
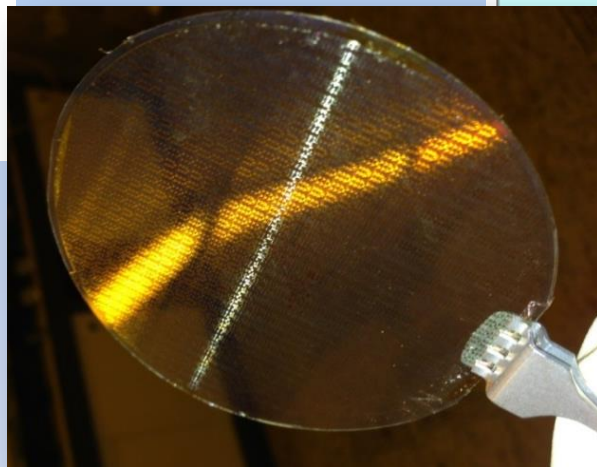
iOne
EU-project



OTFTs and circuits

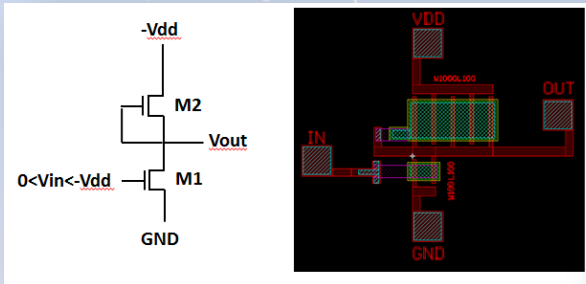


Spin-coating of semiconductor and insulator

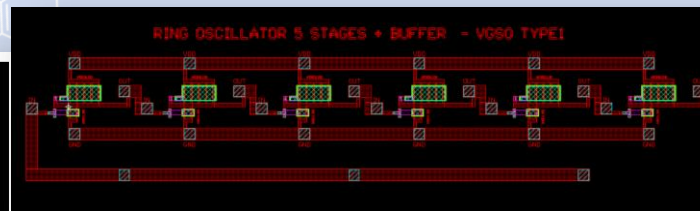
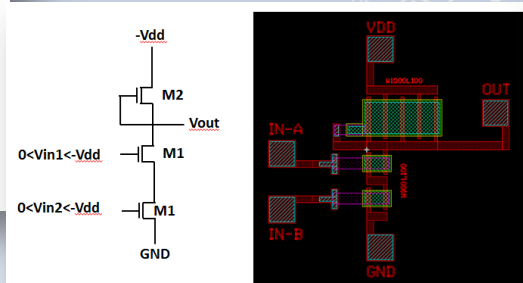


- Organic transistor with high mobility on flexible plastic substrate (max process temperature 100° C)
- EOS project (CNR-INFN) «Elettronica Organica per Strumentazione Innovativa di Ricerca»

inverter



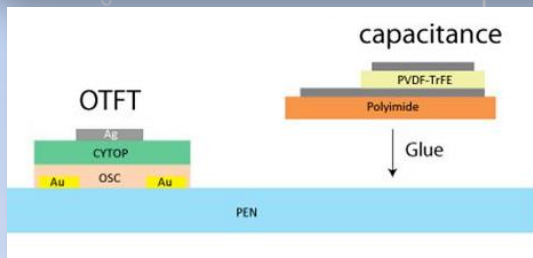
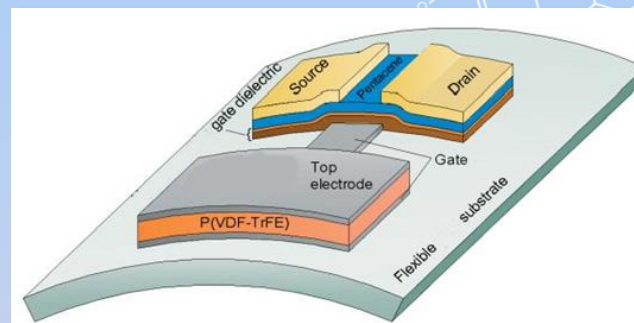
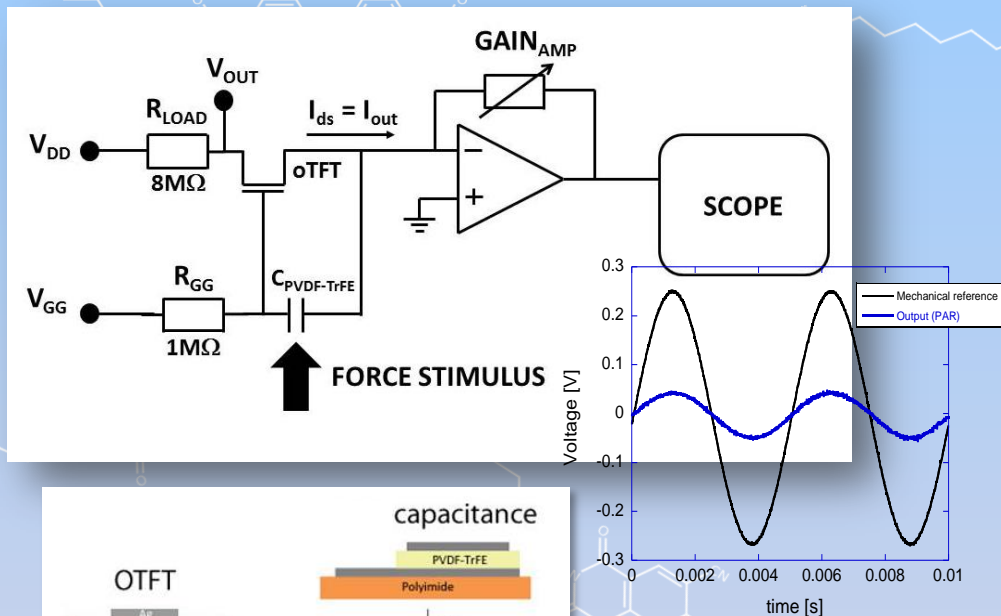
NAND port



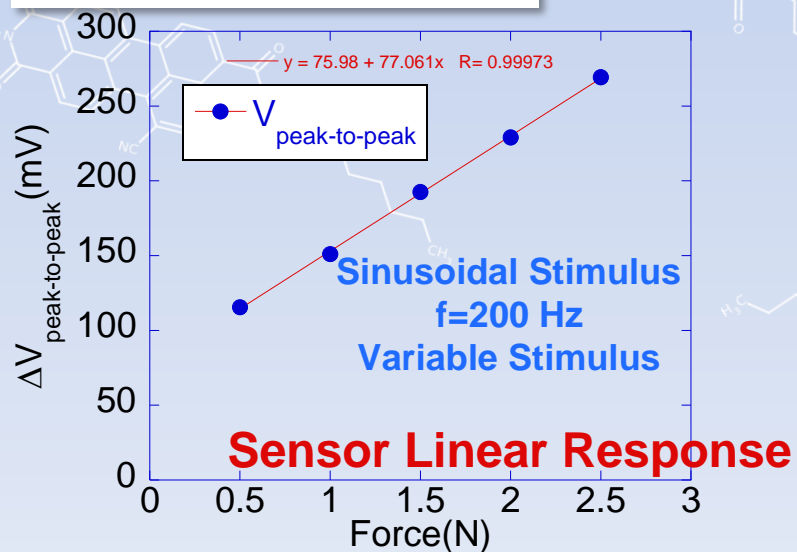
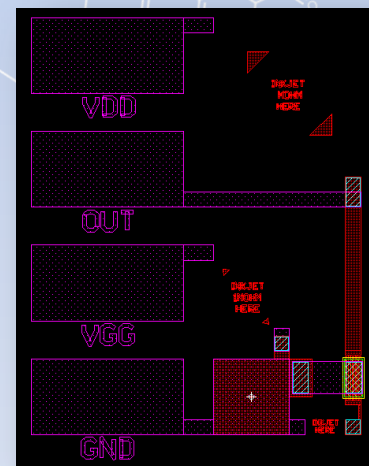
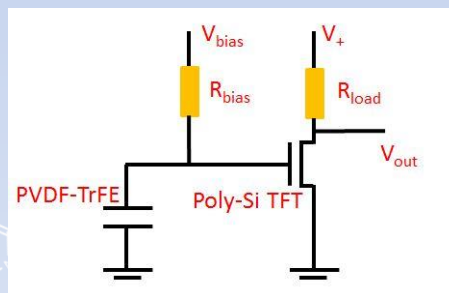
Ring Oscillator

POSFET based on PVDF-TrFE and OTFT

Plasti_ICs Project: "Electronics on Plastics for 'Smart Disposable' Systems"

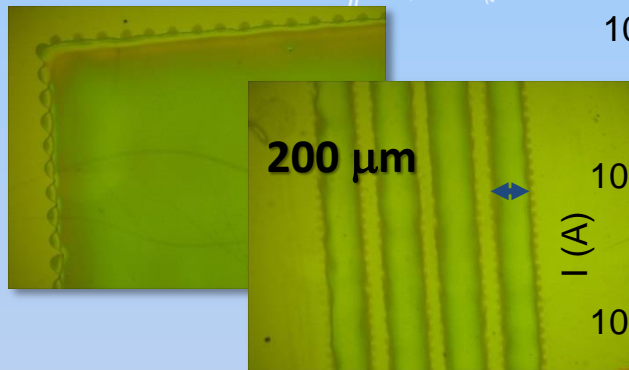
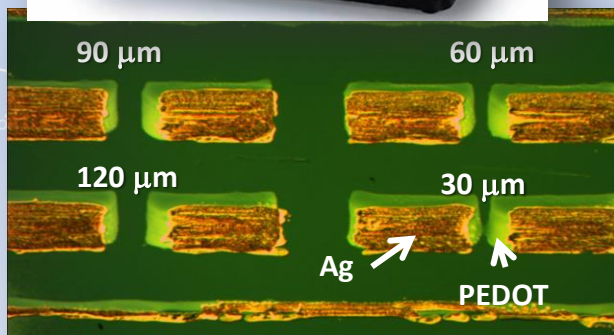


o-POSFET

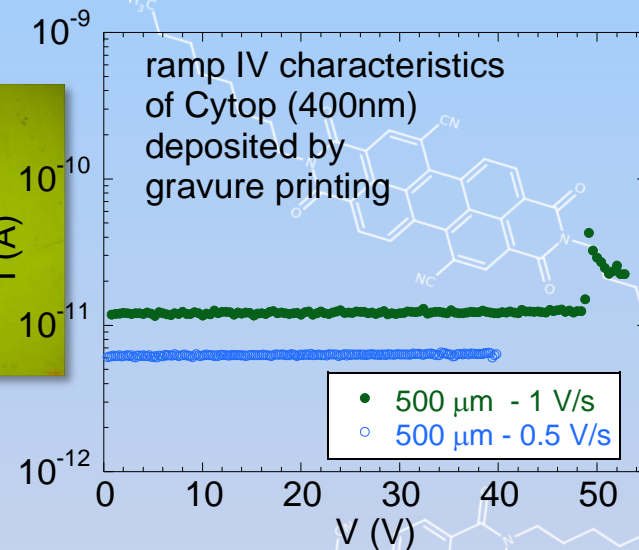


Towards a fully printed process

Deposition by ink-jet printing of source/drain and gate contacts



Deposition by gravure printing of OSC and gate dielectric (CYTOP)



Leaf wetness sensor



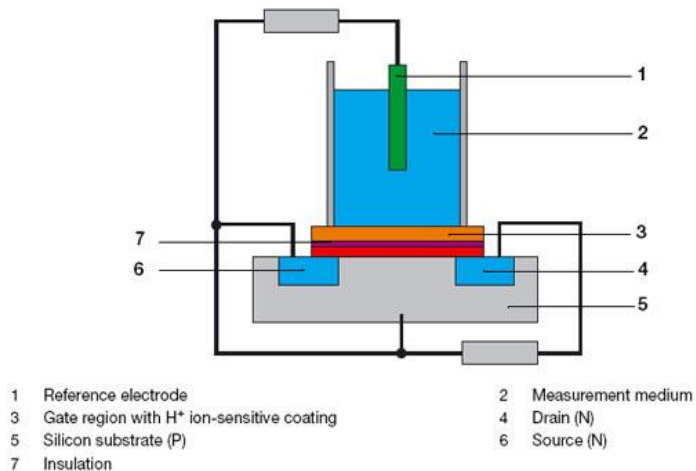
determines continuously the amount of liquid water left on a surface submitted to environmental conditions. This indication allows in particular to measure wetness duration of vegetation cover.

Leaf Sensor



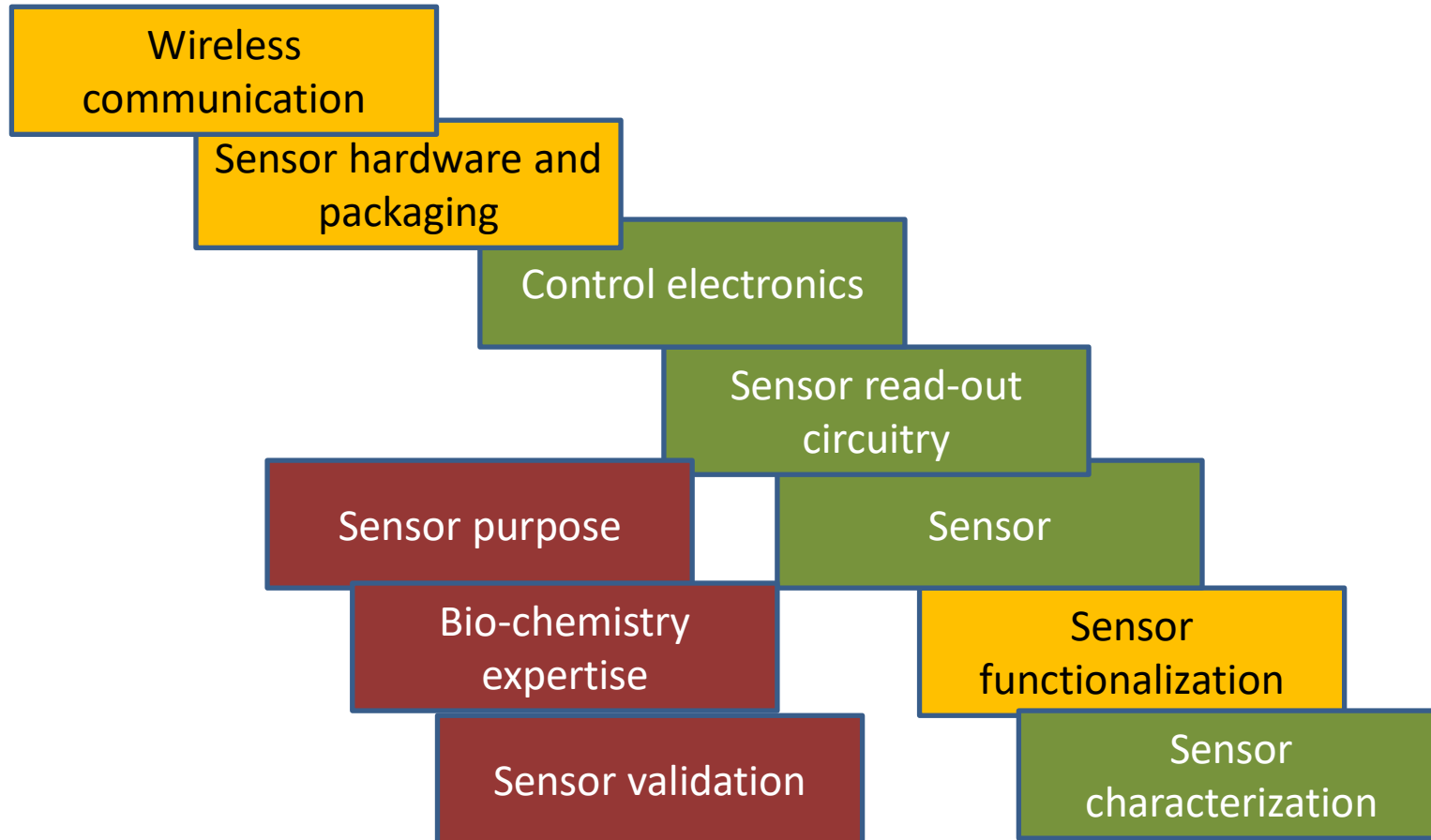
monitoring the indirect measurement of leaf turgidity (moisture level)

ISFETS





What we can do / What we need



other potential applications of Flexible Electronics

Smart Clothing



Indor gas sensors: VOC, ecc.
 Outdoor gas sensors: NH3, NO2, ecc.

Biosensors



Smart medicine blister



biosensor platforms



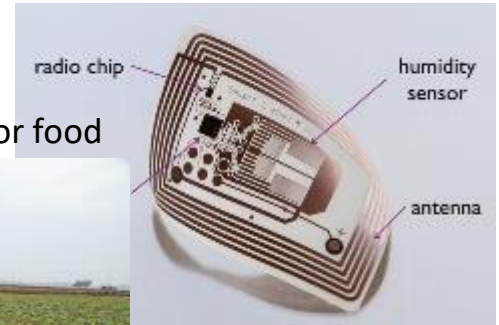
Smart packaging: sensors for monitoring of food quality and safety



Strain gauge



Flexible RFID



Electrochemical sensors for food safety and environmental monitoring



Collaborations with Small Medium Enterprise

Lazio

- **Setel Group Srl** – *Integrated Logistic Support scenario for Defense, Aerospace and Transportation*
- **Unoano Srl** – *Prototipazione rapida 3D*
- **Systemdesign Srl** - *Engineering and Manufacturing services, Renewable Energy, Environmental Monitoring Sensors and Systems..*
- **Geoplanconsulting Srl** - *Aerofotogrammetria e Termografia aerea*
- **Fidia Farmaceutici Spa**
- **Amdl srl** – *Tecnologie per l'aerospazio*
- **MITEC Snc** - *Technological Design RF modules*
- **Fonderie Digitali srl** - *Rapid Prototyping*
- **OA PointGroup srl** - *Informatica*
- **Uxi srl** - *Prodotti web, software, soluzioni ICT*
- **Keplero srl** - *Piattaforme software dedicate al monitoraggio dei dati aziendali, Internet of Things.*
- **Innosensor srl** – *Sviluppo sensori*
- **Isolceram srl** – *Meccanica, innovazioni tecnologiche*
- **Nanesa srl** - *Nanomaterials, conductive pastes and hexagonal allotropic compounds*
- **Augen Srl** - *Telematica & Automazione*
- **ST Microelectronics** - *Semiconduttori*



- **Space exe srl** - *high precision wearable GNSS device for sport applications*
- **OpenPicus Srl** - *Internet on Things*
- **Over Technologies** – *Domotica*
- **Hs Hospital Service S.P.A.** - *tecnologie al servizio della medicina*
- **Aero Sekur Spa** - *Apparecchiature e sistemi per l'aerospazio*



Lombardia

- **BioSAFin Srl** – *WinSix dispositivi implantari, accessori e tecniche riabilitative*



Umbria

- **DiaMetra srl** - *Immunodiagnostic Systems*



Toscana

- **ARGOS Engineering srl** - *Progettazione Meccanica, Industriale, Ferroviaria e Green Mobility*
- **Texe Srl** – *Textiles & Engineering*
- **Hospitex Srl** - *diagnostics instruments*



Molise

- **Micro BioDevices Srl** – *In vitro diagnostic medical instrumentation*



Polonia

- **Tesla** - *Electronic Manufacturing Services*



USA

- **VOC instrumentation, LLC** - *sensor technology*
- **Absolute process instruments Inc.** - *Signal Conditioners, Isolators, Process Transmitters Sensors to Solutions*



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