SEP. 15-17 2025

BRESCIA — ITALY

BOOK OF ABSTRACTS

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SPEAKER SESSIONS

Session 1 — *Mixed ionic-electronic conductors*

Chairperson: Prof. Luca Beverina

Realization of new mixed ionic-electronic conductors and bioelectronic devices	Keynote Speaker	Prof. Antonio Facchetti
Electron Transporting Mixed Conductors for Optoelectronic Bio-Interfaces	Featured Invited Speaker	Prof. Sahika Inal
Crystalline PEDOT:PSS-Based Bioelectronics: Beyond Thin Films	Featured Invited Speaker	Prof. Myung-Han Yoon
Dissipative Charge Transport in Organic Mixed Ionic-Electronic Conductor Channels	Featured Invited Speaker	Prof. Tobias Cramer

Realization of new mixed ionic-electronic conductors and bioelectronic devices

Antonio Facchetti

Georgia Institute of Technology
Northwestern University

In this presentation we report the development of novel ionic-electronic molecular and polymeric ionic-electronic conductors and their implementation in various devices. First, we summarize recent results where a new vertical electrochemical transistor architecture is reported enabling excellent electronic transport for several polymer semiconductors. Next, from the material development we report the synthesis of new n-type molecular materials designed to have ionic channels for efficient ion intercalation. Furthermore, we report a family of naphthalene diimide (NDI) and diketopyrrolopyrrole (DPP) polymers where electrochemical transistor performance is manipulated by the backbone structure, functionalization, blending and device architecture. Finally, we discuss recent implementation of a new n-type polymers for the realization of high-performance and balanced complementary electrochemical OECTs and inverters, which are then used to fabricate neuromorphic circuits capable of sensing, transducing and recording information.

Electron Transporting Mixed Conductors for Optoelectronic Bio-Interfaces

Sahika Inal

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Organic mixed ionic and electronic conductors (OMIECs) provide a versatile platform for establishing electrical communication with biological systems. In this talk, I will demonstrate how n-type OMIECs can be tailored to enable favorable interactions with catalytic enzymes and lipid bilayers, enabling the development of advanced biosensors. Building on this, I will present the aqueous-gated photoelectrochemical transistor (OPECT), a device based on these materials that can respond to both light and electrical stimuli and retain the generated information. By tuning the water uptake in the film and exploiting its strong near-infrared absorption, we create a water-compatible device that mimics the function of biological photoreceptors. Together, these developments highlight the potential of OMIECs to build new classes of adaptive, multifunctional bioelectronic sensors.

Crystalline PEDOT:PSS-Based Bioelectronics: Beyond Thin Films

Myung-Han Yoon

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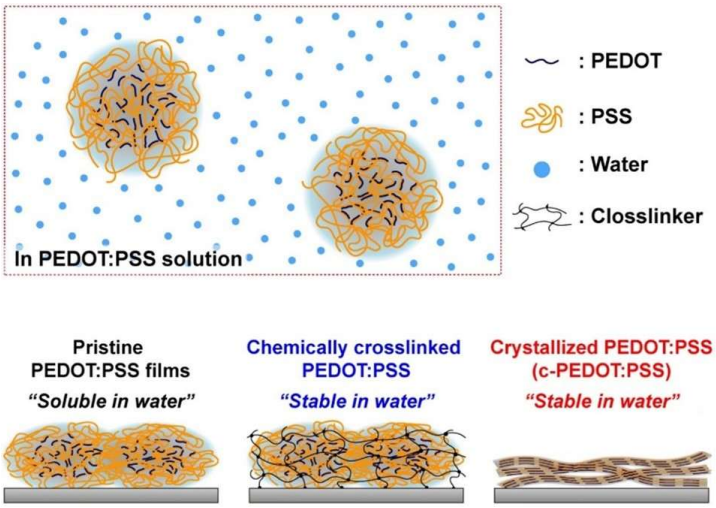
In this research, the solvent-assisted crystallization based on sulfuric acid results in crystallized poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS) films which exhibit excellent electrical/electrochemical/optical properties, long-term aqueous stability, and good biocompatibility for primarily cultured cardiomyocytes and neurons over several weeks.[1] They are successfully employed for high-performance multi-electrode arrays to record and stimulate the electrophysiological activities of primarily cultured cardiomyocytes and chicken retinae tissues.[2] Next, wet-spinning of crystalline PEDOT:PSS microfibers and their self-fusion process are developed for single-strand wearable electrochemical transistors[3] and 3D microfibrillar network-based bioelectronic interfaces. Furthermore, carbon nanotube yarn/PEDOT:PSS core-shell fibers for energy storage devices, PEDOT:PSS/Pt nanoparticles composite materials for electrocatalysis and gas separation[4], and PEDOT:PSS/clay composite-based biodegradable/sustainable electronics are briefly discussed.



Solvent-assisted crystallization of PEDOT:PSS

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2. Kim, S.-M., et al. High-performance, Polymer-Based Direct Cellular Interfaces for Electrical Stimulation and Recording, *NPG Asia Materials*, **10**, 255 (2018).
3. Y. Kim, et al. Single Strand Microfiber-Based Wearable Human Sweat Sensors with Channel Dimension Independent Performance, *NPG Asia Materials*, **10**, 1086 (2018).
4. Saini, N.; Lee, D.-Y.; Yoon, M.-H.*, and Awasthi, K.*, Unveiling the Potential of Pt Nanoparticle-Decorated PEDOT:PSS Membranes for Efficient Gas Separation, *ACS Applied Materials & Interfaces*, **16**, 7700 (2024).

Dissipative Charge Transport in Organic Mixed Ionic-Electronic Conductor Channels

Tobias Cramer

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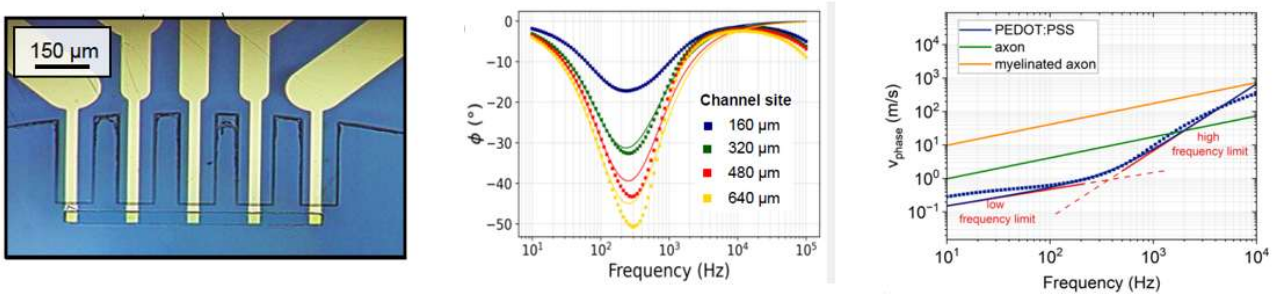
Understanding charge transport in organic mixed ionic-electronic conductors (OMIECs) is crucial for optimizing material properties in bioelectronic and neuromorphic devices. Recent experimental and theoretical findings show how the low-impedance properties of OMIECs are related to the chemical (or volumetric) capacitance c_v of such materials. Of interest for signal amplification in organic electrochemical transistors is the transconductance that was demonstrated to be proportional to the product of c_v and the charge carrier mobility μ_e. A less considered quantity is the velocity of signal transmission through OMIEC channels and the related energy dissipation.

To achieve a quantitative description, we conduct experimental measurements of the phase velocity in microstructured PEDOT:PSS channels of different length at different frequencies. We compare data obtained from direct electrical measurements with local measurements of ionic displacements done with modulated electrochemical force microscopy [1]. Our findings are in excellent agreement to a simplified transmission line model describing charge transport through a mixed ionic electronic conductor channel. By combining the experimental data with the transmission line model, we resolve the dispersion relation for transport in OMIECs. We demonstrate that at relevant frequencies, the phase velocity is fully dominated by the ratio of μ_e/c_v. [2] The results allow us to describe some principal limits in OMIECs based circuits and to compare their efficiency to neuronal signal transmission. We show how the methodology can be applied to optimize transport in OMIECs with polar additives.



Measurement of Signal propagation along OMIEC transmission line. (a) fabricated PEDOT:PSS microstructures (b) phaseshift as a functio of frequency and fit to model (c) phase velocity as a function of frequency and comparison to biological signal transmission

[1] F. Bonafe et al. Adv. Sci. 2024, https://doi.org/10.1002/advs.202308746

[2] F. Fonafe et al. Nat. Commun. 2025, https://doi.org/10.1038/s41467-025-57528-9

SPEAKER SESSIONS

Session 2 — *In Vivo Bioelectronics and Functional Biointerfaces*

Chairperson: Prof. Guglielmo Lanzani

In vivo-manufactured bioelectronics	Keynote Speaker	Prof. Magnus Berggren
Light-Controlled Biointerfaces for Muscular Tissue-Engineered Systems	Featured Invited Speaker	Dr. Vito Vurro
Unraveling the mechanisms of biogenesis of thiophene based microfibers in living cells	Spotlight Invited Speaker	Dr. Claudia Tortiglione
Composite semiconducting polymer-based nanoparticles for the optical modulation of cell function	Spotlight Invited Speaker	Dr. Gabriele Antonio Giuseppe Tullii
Light-controlled electrical behavior of an artificial lipid membrane embedding short photo-switchable molecules	Spotlight Invited Speaker	Dr. Ilaria Cardace

In vivo-manufactured bioelectronics

Magnus Berggren

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Limitations at the electrode-nervous system interface reduces the efficacy of electroceutical recordings and therapies, including those of deep brain stimulation and ECoG. By developing novel polymerization strategies, *in vivo* manufacturing of electrodes within and onto biological structures becomes possible. These protocols include *e.g.* enzymatic, visible light, and electrochemical polymerization strategies. By utilizing various monomers, built up from thiophene and EDOT units decorated with molecular side groups promoting adhesion to specific targets and aggregation, electrode and device systems can be achieved via in vivo manufacturing onto and within a wide range organs and tissues. The resulting bioelectronics amalgamates with the neuronal system in a radically new fashion, blazing the trail for future therapy and recording approaches of relevance for a wide range of neurodegenerative diseases and disorders.

Light-Controlled Biointerfaces for Muscular Tissue-Engineered Systems

Vito Vurro

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Nowadays living cells stimulation is an emerging and hot topic. In particular, contactless and wireless methods are extremely appealing due to a reduced alteration of the analyzed biological systems.[1] In this context, light emerges as a non-invasive, wireless solution with high spatiotemporal precision for bio-stimulation.[2] Material-based light transducers, such as conjugated molecules and macromolecules, have demonstrated efficacy at the interface with living cells and tissues, thanks to their photophysical properties, biocompatibility, and chemical versatility. [3–5]

In this presentation, I will discuss the use of phototransducers for muscular cell activation,[6–8] highlighting their photo-chemical properties.[9,10] Beyond single-cell photopacing, these materials have been employed to stimulate *in vitro* muscular microphysiological systems developed using classical tissue engineering techniques as well as advanced methods like electrospinning and 3D printing.[11,12] The interactions between light and these different tissue types will also be analyzed to understand and optimize photostimulation efficacy in complex biological contexts.

These systems mimic the native properties of muscle tissue and represent a promising platform for the development of bio-hybrid actuators, regenerative medicine tools, drug testing, and disease screening applications.

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3. Dai, Y. *et al.* Soft hydrogel semiconductors with augmented biointeractive functions. *Science* **386**, 431–439 (2024).
4. Hopkins, J. *et al.* Photoactive Organic Substrates for Cell Stimulation: Progress and Perspectives. *Adv. Mater. Technol.* **4**, 1800744 (2019).
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8. Vurro, V. *et al.* Optical modulation of excitation-contraction coupling in human-induced pluripotent stem cell-derived cardiomyocytes. *iScience* **26**, 106121 (2023).
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Unraveling the mechanisms of biogenesis of thiophene based microfibers in living cells

Claudia Tortiglione

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The unmatchable capability of living cells to fabricate complex structure starting from simple building blocks offers new paradigms to seamlessly integrate new electronic structures into the living matter, creating new hybrid devices. We have previously shown the capability of both cells and invertebrate models to produce fluorescent and conductive interface embedded into the animal tissues, starting from thiophene-based compounds, demonstrating the feasibility to biofabricate in situ novel biocompatible and conformable bioelectronic interfaces. By integrating several approaches, from imaging to spectroscopy, we deciphered unique biosynthetic pathway employed by the cells to assemble fluorescent and semiconducting fibers starting from DTTO. Importantly, we reveal their function to alter membrane electrical properties, opening new avenues for externally modulating neuronal excitability. The biofiber potential to serve as innovative material for electrical interfacing living cells will be presented and discussed.

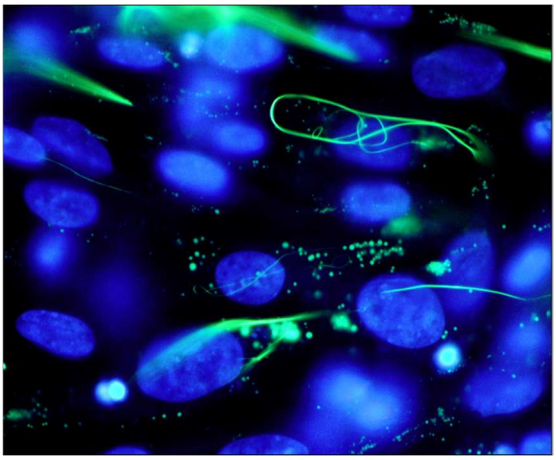

Fig 1. Neuroblastoma cells producing fluorescent and conductive DTTO biofibers. Fluorescence imaging of SHSY5Y cells treated with DTTO. Nuclei are stained with DAPI (blue color), while the fibers and the DTTO appear in green.

Composite semiconducting polymer-based nanoparticles for the optical modulation of cell function

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Precise control of biological functions is crucial for understanding physiological and pathological mechanisms and for developing targeted therapies. Light-based modulation offers significant advantages over traditional electrical methods, such as lower invasiveness and superior spatial and temporal resolution.[1,2] Among the materials explored for light-mediated cell control, conjugated polymers stand out due to their high biocompatibility, flexibility, and stability. When processed into nanoparticles (NPs), these polymers provide further benefits, including less invasive delivery and the ability to target specific subcellular regions.[3,4] A central mechanism for light-based biological control is photoelectrochemical transduction. Conjugated polymer NPs, when optically activated, produce reactive oxygen species (ROS) at safe concentrations, which are vital for various physiological processes, such as angiogenesis.[2,4] However, optimizing the interaction between these NPs and cells, as well as improving phototransduction efficiency, remains an active area of research.

This study presents the development of novel composite, multi-layered opto-nano transducers. These nanoparticles consist of a semiconducting conjugated polymer shell combined with a conductive or semiconductive core. They are fabricated via bottom up, solution-based techniques and their structural and electrochemical properties are characterized in detail. The biological effects of the NPs are investigated by forming interfaces with endothelial cells. The introduction of different organic/inorganic phases within the NP structure leads to sizable improvement of charge dissociation, thus boosting the photocurrent associated to oxygen reduction, the first step in ROS formation. This translates into the modulation of cellular physiology, with a sizable increase in the intracellular ROS production and Ca^{2+} signalling activity, with respect to bare semiconducting polymer NPs. Additionally, a modulation of the angiogenic response of endothelial cells, depending on the type of material and stimulation protocol, is achieved. This approach holds promise in therapeutic/tumoral angiogenesis treatment, where small changes in intracellular redox balance can determine the shift between eustress/distress conditions. Overall, our results support the possibility to employ optimized conjugated polymer-based NPs to regulate cellular functions, in a drug-free, touchless and spatiotemporally controlled manner, opening the way to groundbreaking applications in medicine.

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Light-controlled electrical behavior of an artificial lipid membrane embedding short photo-switchable molecules

Ilaria Cardace[1], Lorenzo Dominici[1], Adriano Cola[2], Antonio Fieramosca[1], Vincenzo Ardizzone[1], Agostina Lina Capodilupo[1], Bruno Rizzuti[1,3], Giuseppe Gigli[1,4], Daniele Sanvitto[1], Luisa De Marco[1]

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Abstract

Bringing together biology and electronics is helping to create new technologies which utilise biological structures for photonic devices thanks to their nanoscale optical features. In this field, photo-switchable molecules, such as azobenzene derivatives, act as photo-responsive elements in lipid membranes, enabling precise light-controlled modulation of membrane properties such as its organisation, fluidity, permeability, and electrical response.[1]

In this study we investigate a novel photo-switchable azobenzene derivative, **TC827**, which exhibits a distinctive photoelectric response when incorporated into artificial lipid membranes. Through a combination of electrical measurement and molecular simulation analyses, it is demonstrated that **TC827** forms 'light-controlled molecular wires' in its trans conformation, resulting in a significant increase in membrane conductivity under dark conditions.[2,3] This effect is reversible, as light-induced cis isomerization suppresses the conductivity enhancement, and it is completely different from the typical behavior of known amphiphilic azobenzene derivatives, which are often incorporated into biological membranes as synthetic photo-switchable lipid molecules. In our system the increase in conductivity is not associated with membrane destabilization due to the chemical structure of **TC827** molecule, which lacks long alkyl chains and features a π-conjugated structure. This characteristic is crucial for the membrane stability, as it reduces the risk of the membrane disruption over time.

The outcomes achieved in these studies may set the ground for future studies aimed at addressing the applicability of these approaches to the design of optoelectronic bio-interfaces.

1. Corrado, F. *et al.* Azobenzene-based optoelectronic transistors for neurohybrid building blocks. *Nat Commun* **14**, (2023).

2. Garner, L. E. *et al.* Modification of the optoelectronic properties of membranes via insertion of amphiphilic phenylenevinylene oligoelectrolytes. *J Am Chem Soc* **132**, 10042–10052 (2010).

3. Cardace *et al.* Light-controlled electrical behavior of an artificial lipid membrane embedding short photoswitchable molecules. *In submission*.

SPEAKER SESSIONS

Session 3 — *Bioelectronic Medicine*

Chairperson: Prof. Annalisa Bonfiglio & Prof. Giuseppe Gigli

Technology for Bioelectronic Medicine	Keynote Speaker	Prof. George Malliaras
Flexible probe with PEDOT:PSS microelectrodes for in vivo chronic stimulation	Featured Invited Speaker	Prof. Charles Rezaei
Tattoo Electrodes, from the transduction mechanism to their applications in biorobotics	Featured Invited Speaker	Dr. Laura Ferrari
Tailoring electropolymerized PEDOT for neuroelectronic applications	Spotlight Invited Speaker	Mr. Niklas Meyer

Technology for Bioelectronic Medicine

George Malliaras

University of Cambridge

Neurological conditions affect one in six people, imposing significant health, economic and societal burden. Bioelectronic medicine aims to restore or replace neurological function with the help of implantable electronic devices. Unfortunately, significant technological limitations prohibit these devices from reaching patients at scale, as implants are bulky, require invasive implantation procedures, elicit a pronounced foreign body response, and show poor treatment specificity and off-target effects. Over the past decade, novel materials and fabrication methods inspired from the microelectronics industry have been shown to overcome these limitations. Recent literature provides powerful demonstrations of thin film implants that are miniaturised, ultra-conformal, stretchable, multiplexed, integrated with different sensors and actuators, bioresorbable, and minimally invasive. I will discuss the state-of-the-art of these new technologies and the barriers than need to be overcome to reach patients at scale.

Flexible probe with PEDOT:PSS microelectrodes for *in vivo* chronic stimulation

Charles Rezaei-Mazinani

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Flexible bioelectronic probes with conductive polymer electrodes offer a promising alternative to rigid devices for chronic brain stimulation. These organic devices, notably featuring higher charge injection capacity and improved biocompatibility compared to inorganic probes, hold significant potential for long-term neural interfacing. However, ensuring long-term stability and consistent physiological responses during extended stimulation remains essential for practical application. Moreover, these probes face challenges, such as cross-talk in case of multi-layer probes and insertion into brain tissue. Here, we present an investigation on chronic stimulation and recording *in vivo,* using cortical and intracortical PEDOT:PSS probes in rodents. In the first study, we assessed cortical probes implanted in the mouse auditory cortex of for electrical stimulation over a three-month period. In the second study, we investigated the performance of two identical intracortical probes for microstimulation and recording of stimulation-evoked responses in the rat hippocampus, conducted continuously over 16 days (24/7 operation). Together, our findings highlight both the robustness and the challenges of flexible PEDOT:PSS probes for chronic *in vivo* stimulation, reinforcing their promise for neuroscience research.

Tattoo Electrodes, from the transduction mechanism to their applications in biorobotics

Laura Ferrari

Tattoo electrodes are micrometric sensors made of polymers. We fabricate them bymade by printing PEDOT:PSS onto commercially available temporary tattoo paper. The result is an ultra-thin and conformable dry electrode that can record high-quality surface electrophysiological signals [1]. Tattoo electrodes have been compared with standard Ag/ AgCl electrodes in many applications, for biomonitoring, and their internal structure and signal transmission mechanism have been fully detailed. We have shown that the signal is transduced through a capacitive coupling across the skin [2], and that tattoos are breathable interfaces able to maintain a stable signal acquisition even during sports activity [3].

We are now translating tattoo technology into real-life applications.

We have improved the interconnections and interfaced tattoos with different kinds of devices, including wearables and benchtop equipment. We have used a learning approach (an autoencoder trained for one-class classification) on EEG tattoo data to identify the optimal wearable setup for alpha wave detection.

We are exploiting tattoos in biorobotics applications [4].

We have applied tattoo electrodes under lower and upper-limb exoskeletons. The lowerlimb exoskeleton used in this study is a robot that transfers assistive torques during hip flexion and extension through a human-robot interface (HRI) at the thigh level [5]. Whereas the upper-limb exoskeleton uses arm cuffs to transfer assistive torque to the user to help the shoulder flexion and extension [6]. Tattoos have been developed as bipolar electrodes and their interconnections have been optimized to reach the robot via a Serial Peripheral Interface (SPI), allowing synchronous and full-duplex data transmission. Thanks to the ultrathin and conformable nature of tattoos, EMG signals have been acquired in direct contact with the HRI, where the electrodes are subjected to high mechanical stress. Such an approach opens novel control algorithms that, by leveraging the information coming from muscles, can be adapted for locomotion recognition and generation of torque profiles. This allows for real-time, adaptive responses of exoskeletons and personalized assistance, crucial in rehabilitation, industrial tasks, and assistive devices. We have developed high-density electromyography (HD-EMG) tattoo matrices to study manipulation. Conformable HD-EMG matrices ensure a drastic reduction of movement artifacts, typical of other dry interfaces, and permit the reaching of complex anatomical regions.

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Tailoring electropolymerized PEDOT for neuroelectronic applications

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Neuroelectronics is the research field that aims at interfacing neurons with microelectronics to measure and stimulate neuronal activity. Over recent years, poly-3,4-ethylendioxythiophen (PEDOT) has gained significant attention in neuroelectronics and neural interfaces due to its mixed ionicelectronic conductivity, biocompatibility, and soft mechanical properties[1]. Coating neural electrodes with PEDOT-based materials enhances the electrode performance by reducing the interface impedance and improving the signal-to-noise ratio (SNR) for recording, while increasing the chargeinjection-limit (CIL) for stimulation[1,2]. Among different fabrication techniques, electropolymerization allows to deposit conductive polymers selectively on conductive surfaces. In addition, the combination of electropolymerization technique and dopant used affects the electrochemical and morphological properties of the resulting polymer, giving control over the deposited material[3,4]. Besides the electrochemical properties of the electrode, its morphology plays an important role in neural interfaces by influencing cell adhesion and viability[3,5]. Here, we present strategies to tune the morphology and electrochemical properties of PEDOT-based electrode coatings, according to the dopant and the specific parameters employed during electropolymerization. PEDOT was deposited in the presence of poly(styrene sulfonate) (PSS^-), hexafluorophosphate (PF_6^-), and perchlorate (ClO_4^-) as dopants *via* potentio- and galvanostatic techniques. The properties of each film were characterized by electrochemical impedance spectroscopy (EIS), cyclic voltammetry (CV), profilometry, and scanning electron microscopy (SEM). Additionally, transient curves of the electropolymerization were analyzed to obtain information about the mechanisms driving the process. The potentiostatic technique, in the presence of molecular dopants, allowed precise tuning of materials´ morphology with the potential applied. The galvanostatic technique did not induce significant changes in morphology but provided high process control in terms of low variability of resulting properties. To further characterize the depositions, atomic force microscopy (AFM) and focused ion beam-SEM can provide additional information on morphology and CIL on the electrochemical properties. This work provides a portfolio of PEDOT films, deposited under varying conditions, enabling tailored material properties to further improve the performance of neural electrodes.

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2. J. Rivnay *et al*., Structural control of mixed ionic and electronic transport in conducting polymers, Nat. Commun. 7 (2016) 11287. 3. M. Skorupa *et al*., Dopant-Dependent Electrical and Biological Functionality of PEDOT in Bioelectronics, Polymers 13 (2021) 1948.

4. C.B. Tran *et al*., A comparison of poly (3,4-ethylenedioxythiophene) polymerized potentiostatically and galvanostatically, Synth. Met. 299 (2023) 117466.

5. S. Baek *et al*., Effects of dopants on the biomechanical properties of conducting polymer films on platinum electrodes, J. Biomed. Mater. Res. A 102 (2014) 2743–2754.

SPEAKER SESSIONS

Session 4 — *Sustainable Technologies for Sensing and Bioelectronics*

Chairperson: Prof. Erika Scavetta & Prof. Antonio Cassinese

Organic Bioelectronics for Health and Sustainability	Featured Invited Speaker	Prof. Fabio Biscarini
Edible Electronics for Future Biosensors	Featured Invited Speaker	Dr. Alessando Luzio
Functional Biopolymers for Sustainable and Biocompatible Bioelectronic Interfaces	Featured Invited Speaker	Dr. Pasquale D'Angelo
Functional 2D Materials and Hydrogels for High-Performance Energy Harvesting and Self-Powered Sensors	Featured Invited Speaker	Dr. Giuseppina Pace
Organic batteries for sustainable energy storage	Spotlight Invited Speaker	Dr. Luisa De Marco
Luminescent persistent radicals for photon management applications	Spotlight Invited Speaker	Dr. Sara Mattiello

Organic Bioelectronics for Health and Sustainability

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I will discuss some of our recent results in the development of electrolyte gated organic transistors (EGOTs) as immunosensors for the detection of biomarkers of clinical relevance. I will highlight how the thermodynamics of biorecognition coupled to the description of the transistor current enables the correct interpetration of the experimental data. Then, I will highlight the resolution of two challenging problems with a novel multiparametric analysis: the resolution of the response to opposite chirality of two aminoacids and the discrimination of different perfluoroalkylsubstances (PFAS) in water by means of fluorine-fluorine interactions. Finally, I will overview our work on organic neuromorphic devices, from sensing, to the performance of logical operations with electrophysiological signals, up to the latest results on the recording of brain cortex signals in human patients for mapping the spatial extension of brain tumors in surgery settings.

Edible Electronics for Future Biosensors

Alessandro Luzio

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Edible Electronics[1] is an emerging field targeting devices that can be safely ingested and that, after functioning, can be digested, as food. In fact, all functional elements—sensing, powering, and circuitry—are fabricated using edible materials, allowing the device to naturally degrade within the gastrointestinal tract. Unlike current technology, edible electronic systems are designed to be low-cost and accessible, enabling widespread use across diverse settings and populations. Their simple, solution-based fabrication ensures affordability without compromising functionality. Moreover, being entirely composed of edible, biodegradable materials, it also offers the chance for minimal environmental impact—an added benefit that reinforces its sustainability. This need is particularly pressing for the multitude of short-lived smart objects and mobile devices envisioned to support the Internet of Things (IoT) paradigm. Relevant applications can be envisioned both in the healthcare and the food supply chain sectors, among all: non-invasive monitoring of the gastrointestinal tract, smart and controlled drug release systems, smart tags for safe and direct food tagging and real-time food quality check. This contribution presents an overview among all the key components required to realize a fully edible monitoring system, including powering systems, communication strategies, sensors and circuits. These technologies have been developed within the framework of the European ERC project ELFO, which pioneered the field of Edible Electronics.

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Functional Biopolymers for Sustainable and Biocompatible Bioelectronic Interfaces

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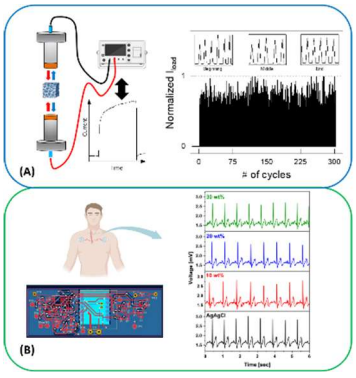
The integration of natural and bioinspired biopolymers into bioelectronic platforms offers a promising route toward sustainable, biocompatible, and high-performance devices. This talk presents recent advancements in the development of bioelectronic systems at IMEM-CNR, focusing on the use of protein-based and synthetic peptide materials.

We explore some representative applications, among which (i) monolithically-integrable pressure sensors with enhanced sensitivity based on silk fibroin functionalized with conductive polymers and plasticizers, processed through a combined foaming and freeze-drying technique to achieve porous, flexible structures with remarkable shape recovery[1]; (ii) gel-free bioelectrodes fabricated from sericin, a silk by-product, loaded with calcium-based kosmotropic agents. These electrodes exhibit long-term skin adhesion and stability, enabling reliable wireless acquisition of biopotentials such as ECG without the need for conductive gels[2]; (iii) peptide-based organic devices, where agarose-peptide hydrogels with ultra-short amino acid sequences are employed to implement bioelectronic transistors and solid-state components, demonstrating the potential of minimalistic biomimetic designs in organic electronics.

These examples highlight the versatility of biopolymers in addressing key challenges in bioelectronics, including sustainability, biocompatibility, and device integration. The talk will also discuss current limitations and future directions for the field.



(A) Fibroin/PVA/$CaCl_2$ electrosponges as wearable/integrable resistive pressure sensors; (b) Sericin-based gel-free, self-adhesive electrodes for longlasting ECG recording by a customized wireless protocol.

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Functional 2D Materials and Hydrogels for High-Performance Energy Harvesting and Self-Powered Sensors

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Novel wearable, flexible, conformable technologies require only few tens of μW up to few mW of power supply to operate. This aspect has boosted the search for sustainable energy sources different from batteries. Among mechanical energy harvesters, triboelectric nanogenerators (TENGs) are novel low-cost and green energy solutions that can efficiently convert the widely distributed and dispersed mechanical energy into a sustainable electrical power source. Various approaches have been explored to boost TENGs power, including novel device architectures, tailoring tribomaterial chemical composition and surface area, interlayer and electrode engineering. [1, 2, 3]

Here, we present our contribution to the field, showing how the electrode work function and capacitance, and in particular the electrochemical capacitance, are relevant factors to be considered for improving TENGs power output.[4,5] The fundamental role played by the optimal engineering of the interface between the triboelectric material and the electrode by the introduction of doped graphene and 2D-transistion metal dichalcogenides (2D-TDMs), will be presented.[6] Insights on the role played by the semiconductive properties of doped-graphene and the phase and metal composition of 2D-TMDs will be highlighted.

We will also describe the composition-function-structure relationships that contribute to the rational design of novel hydrogels for integration into TENGs based tactile sensors and e-skin.[7] The specific role of adhesion forces, water entrapment and electrolytic capacitance in determining device performance will be discussed. Finally, emerging directions in the development of neuromorphic tribotransistors will be introduced.

Overall, this contribution will provide guidelines for the design of novel materials and self-powered electronic devices, thus fostering the integration of sustainable energy harvesters and promoting a transition towards biodegradable, biocompatible and energy autonomous neuromorphic sensing technologies.

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Organic batteries for sustainable energy storage

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Abstract

Energy storage devices play a crucial role in the clean energy transition, enabling the use of renewable energy and supporting the widespread adoption of electric mobility. While Lithium-Ion Batteries (LIBs) offer several desirable features, such as high efficiency and long lifetimes,[1] the rapid growth of their market has raised concerns about the availability of raw materials. Current projections suggest a potential shortage within the next decade.[2] To ensure a truly sustainable transition, it is essential to explore innovative battery technologies that minimize environmental impact while relying on abundant and renewable resources.

In this context, organic redox-active molecules are emerging as highly attractive alternatives. These compounds offer several compelling advantages: they can be derived from biomass or synthesized via green chemical processes[3], are structurally tunable for optimized performance, and can significantly reduce the ecological footprint of battery systems.

This research aims to develop new environmentally friendly systems inspired by organic molecules used in the chemistry of life for the storage of chemical energy and its transformation in electrical energy. The goal is to revolutionize traditional battery electrode design by introducing an innovative architecture that combines organic redox molecules with tailored nanostructures.

This technology has the potential to establish a new paradigm for sustainable electrochemical energy storage, offering exceptional versatility in both electrode materials and electrolytes. Organic batteries based on redox-active molecules not only hold promise for greener production and disposal but also open new avenues for flexible, scalable, and safer storage solutions.

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Luminescent persistent radicals for photon management applications

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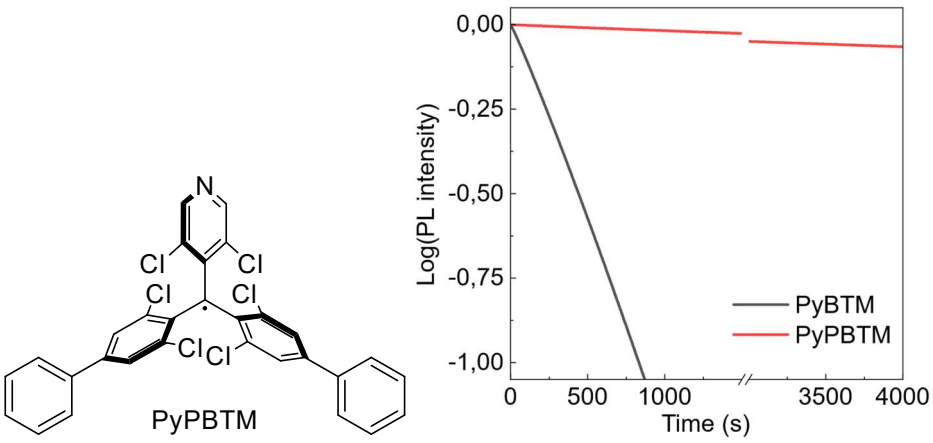
Open-shell luminescent molecules are becoming increasingly studied for their unique properties, such as magnetoluminescence and the absence of heavy atom effects. They possess spin ‘‘doublet” ground states, which allows doublet–doublet transition, and do not suffer from quenching via the triplet state.[1] The biggest concerns regarding their use in applications has been their stability. From the introduction of perchlorotriphenylmethyl radical and tris(2,4,6-trichlorophenyl)methyl radical, which display room temperature luminescence but decompose under UV light, many progresses have been achieved leading to more stable derivatives, especially from the pyridyl bis(2,4,6-trichlorophenyl)methyl radical (PyBTM) family.

This contribution will describe the preparation and applications of extended conjugation PyBTM derivatives. The introduction of further aromatic lateral units allows to increase the materials stability up to the point that their application in luminescent solar concentrators becomes possible.[2] Moreover, unipolar n-type transistor architecture was designed and validated to house a radical emitter, opening the way to exploit electroluminescence from doublet states in Organic Light-Emitting Transistors.[3]



Structure of PyPBTM, a derivative of PyBTM with extended conjugation, and its comparative stability in CH_2Cl_2 solution with respect to PyBTM under irradiation at 370 nm

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SPEAKER SESSIONS

Session 5 — *Organic Neuromorphic Electronics and Bioelectronics*

Chairperson: Dr. Mario Caironi

Organic brain-inspired electronics: learning, processing, and neuromorphic biointerfacing	Keynote Speaker	Prof. Paschalis Gkoupidenis
Organic materials for multifunctional neuromorphic biointerfaces	Featured Invited Speaker	Prof. Francesca Santoro
Learning and adaptivity in organic neuromorphic circuits	Featured Invited Speaker	Prof. Yoeri van de Burgt
Physical Reservoir Computing with Dendritic Polymer Structures – Understanding Internal Dynamics, Scale-up, and Integration in All-Solid-Systems	Featured Invited Speaker	Prof. Hans Kleemann
Neuromorphic organic phototransistor based on a persistent radical for pattern recognition under multimodal electro-optical stimulation	Featured Invited Speaker	Dr. Margherita Bolognesi
Optimization of long-term potentiation procedure through electropolymerization on the gate electrode in solid electrolyte OECT for control applications	Spotlight Invited Speaker	Dr. Giada D'Altri

Organic brain-inspired electronics: learning, processing, and neuromorphic biointerfacing

Paschalis Gkoupidenis
North Carolina State University
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Type of presentation: keynote talk

Organic neuromorphic electronics harnesses ionic and electrochemical processes to emulate core features of synaptic adaptation and neural computation in a realistic and highly efficient manner. In this talk, we will explore how organic and iontronic materials enable the design of neuromorphic devices and circuits that can sense, process, and respond in real time, forming the foundation for both intelligent systems and efficient neuromorphic biointerfaces.

Organic materials for multifunctional neuromorphic biointerfaces

Francesca Santoro[1,2]

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Organic electronic materials are redefining the landscape of neuromorphic interfaces, enabling soft, biocompatible, and multifunctional platforms that seamlessly integrate with living systems. In this work, we present a suite of organic-based neuromorphic devices, centered around organic electrochemical transistors (OECTs) fabricated from PEDOT:PSS and its functional derivatives, to achieve selective, adaptive, and multimodal biointerfacing.
Using neurotransmitter-sensitive gating and tissue-mimetic electrolytes, these organic devices exhibit biologically relevant synaptic dynamics such as short-term facilitation and long-term potentiation. Molecular engineering, including the incorporation of crown ethers and azobenzene moieties, introduces selective ion transport and light-tunable conductance, mirroring the complexity of native synapses. Beyond planar geometries, we employ organic microfabrication techniques to develop pseudo-3D and fully 3D architecture that recapitulate neuronal morphology and guide neural network formation.
Additionally, supported lipid bilayers formed from both synthetic and native neuronal membranes are integrated with the organic device surface, facilitating molecular-level mimicry of post-synaptic interfaces. This hybrid organic-inorganic approach enables precise modulation of ion flow and enhances the fidelity of communication between biological and artificial systems.
Our findings underscore the unique potential of organic materials to support dynamic, adaptive, and selective neuromorphic interfacing, positioning them as foundational components for future biohybrid systems in neuroprosthetics, regenerative medicine, and in vitro brain models.

Learning and adaptivity in organic neuromorphic circuits

Yoeri van de Burgt[1,2,3]

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[2] *Institute for Complex Molecular Systems, Eindhoven University of Technology, Netherlands*
[3] *Eindhoven Artificial Intelligence Systems Institute, Eindhoven University of Technology, Netherlands*

Neuromorphic engineering takes inspiration from the efficiency of the brain and focusses on how to utilise its functionality in hardware. Organic electronic materials have shown promise in accelerating neural networks by performing multiply-accumulate operations in parallel, as well in the manipulation and the processing of biological signals, with applications ranging from neuromorphic accelerators and artificial spiking neurons to adaptive sensors and smart robotics.

This talk describes state-of-the-art organic neuromorphic systems and provides an overview of the current challenges in the field and attempts to address them. I demonstrate device concepts based on novel organic mixed-ionic electronic materials and innovative fabrication techniques, and I will show how we can use these devices in trainable biosensors and smart autonomous robotics. I will present a novel implementation of backpropagation with gradient descent directly in hardware and highlight a manufacturing route towards large-scale integration of organic neuromorphic arrays that are necessary for advanced intelligent computing systems.

Next to that, organic electronic materials have the potential to operate at the interface with biology. This can pave the way for novel architectures with bio-inspired features, offering promising solutions for the manipulation and the processing of biological signals and potential applications ranging from brain-computer-interfaces to bioinformatics and neurotransmitter-mediated adaptive sensing. I will highlight our recent efforts on hybrid biological memory devices and artificial neurons, with an emphasis on spiking behaviour and control.

Physical Reservoir Computing with Dendritic Polymer Structures – Understanding Internal Dynamics, Scale-up, and Integration in All-Solid-Systems

Hans Kleemann

Dresden Integrated Center for Applied Physics and Photonic Materials

Physical Reservoir Computing is an emerging field of research as such recurrent neural networks offer power-efficient real-time classification on edge devices thereby utilizing the inherent temporal dynamics of the underlying physical, chemical or biological system. In particular, the use of organic mixed ionic-electronic conductors enables a close connection to biological systems due to the strong coupling between ionic and electronic conduction as well as the possibility to chemically modify the polymer to interact with bio-molecules. Previously, we have shown a first realization of a physical reservoir composed of polymer dendrites integrated onto a flexible substrate for on-chip heartbeat classification. However, the these systems was limited due to an insufficient complexity and the use of an external delayed feedback line (single-node reservoir), requiring significant data pre-processing and increasing the power consumption.

In this contribution I will discuss the internal dynamics of such dendritic reservoirs and how we tuned them by external parameters such as the ion conductivity or ion mobility. Furthermore, I will demonstrate the integration of such reservoirs into a solid-state electrolyte, which allows us to scale-up the network to a large number of nodes covering the bandwidth relevant for bio-signal processing. The scale-up results in an improvement of the classification accuracy up to 95% without any silicon-based component. Moreover, the scale-up study shows us that the classification accuracy and power consumption can be decoupled in sparse network configurations, enabling us to achieve such a high accuracy with a power consumption of only 100nW. This integration strategy of sparse networks into a solid-state electrolyte opens up new perspectives to further increase the efficiency of intelligent edge devices based on organic semiconductors.

Neuromorphic organic phototransistor based on a persistent radical for pattern recognition under multimodal electro-optical stimulation

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Neuromorphic optoelectronics, integrating optoelectronic and memory functions, find potential applications in artificial vision technologies, optical communication and computing, facial recognition, security monitoring, etc.[1] As a powerful and effective multimodal platform, organic phototransistors (OPTs) can both simulate simple synaptic functions, and complex photoelectric dual modulation and simulation of the visual system. In this work we present an innovative device, an all solution-processed OPT, that comprises a ferroelectric dielectric layer based on the terpolymer PVDF-TrFE-CFE, and a photoactive bulk heterojunction layer (BHJ) based on an organic persistent radical (namely PyPBTM) as the electron acceptor (Figure 1). Recently, we have reported on the use of PyPBTM in organic light emitting transistors (OLET) and OPT for efficient exciton formation and enhanced photo-gain, respectively.[2,3] In the proposed radical-based OPT (r-OPT), neuromorphic characteristics are demonstrated under electrical stimulation at the gate electrode (electrical synapse) and upon multiple optical stimulation with blue and NIR light (optical synapse). Depending on the excitation wavelength, the r-OPT neuroplasticity is modulated: while only short-term plasticity (STP) is emulated by blue light excitation, both STP and long-term plasticity (LTP) characteristics are recorded under NIR light stimulation. Each behavior is correlated by computational investigations to the different photophysical processes occurring under color-selective optical stimulation in the BHJ. LTP characteristics under blue excitation are also demonstrated, when electrical stimulation is combined to the optical one, mimicking the dendrite-like nonlinear integration of inputs observed in neurons. The electro-optical pattern recognition of the r-OPT is demonstrated with both blue and NIR light stimulation combined with electrical stimulation, emulating a dendrite spatio-temporal integration of the incoming stimuli. This opens to the possible use of r-OPT devices in artificial visual systems (AVS)-related applications such as artificial retina, image classification, facial recognition, autonomous driving, security monitoring.

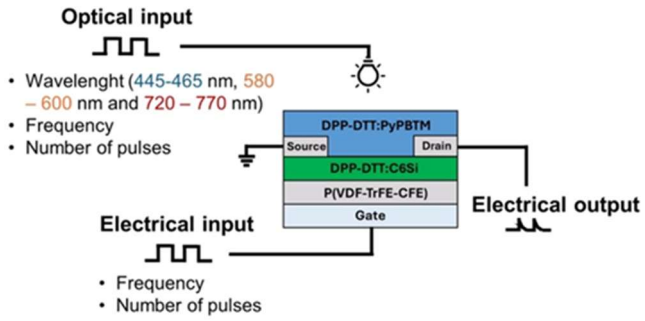

Figure 1 Cross-sectional view of the proposed neuromorphic device, capable of responding under multimodal electrical and optical simulation in virtue of the multifunctional OPT structure.

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Optimization of long-term potentiation procedure through electropolymerization on the gate electrode in solid electrolyte OECT for control applications

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Driven by the growing demand for biocompatible technologies, recent advances in electronic architecture are increasingly focused on neuromorphic functionalities, aiming to emulate synaptic behavior and enhance the efficiency of data processing. On one hand, neuromorphic devices already have the ability of storing information through conductivity variations, mimicking mostly short-term plasticity that relates to an induced strengthening/weakening of the synaptic weight that is dissipated after a characteristic time constant.[1] However, long-term plasticity requires stable modifications on the device structure, in order to obtain permanent data storage. This contribution demonstrates the induction of long-term potentiation through electropolymerization of poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS) on the gate electrode of an organic electrochemical transistor (OECT), achieved via a sequence of training pulses.[2] The induced modifications allow an increase in the gate capacitance, thus boosting the gating ability and defining long-term potentiation. Similarly, depotentiation was investigated by applying a different set of training pulses, overoxidizing the electropolymerized PEDOT. The enhanced I_d modulation can then be restored by training again the gate electrode. This procedure, however, requires the presence of an aqueous electrolyte, that appears challenging for the aspiring integration of said device in an electronic system. Consequently, an agarose hydrogel-based solid electrolyte was implemented. EDOT:ClO_4 was electropolymerized directly onto the gate electrode, to obtain an encapsulated biocompatible OECT-based device with enhanced transconductance and potentiation durability. The final device conductivity is preserved for about three months, surpassing traditional aqueous OECT systems. Moreover, aiming at the control of an external device, the possibility of modulating V_d was investigated. A similar modulation can be applied at a V_d signal, by imposing a constant I_d at the channel and thus inducing PEDOT electropolymerization. The resulting data highlights an ohmic behavior for positive values applied I_d, that are opposed to a non-ohmic yet enhanced V_d modulation for negative I_d.[3]

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SPEAKER SESSIONS

Session 6 — *Multifunctional Organic Transistors for Bioelectronic Applications*
Chairperson: Dr. Maria Rosa Antognazza

Organic devices for in vitro cellular interfacing	Featured Invited Speaker	Prof. Andrea Spanù
Polymer-Based Printed Transistors for Accurate Action Potential Recording and Drug Screening	Spotlight Invited Speaker	Dr. Adrica Kyndiah
Multifunctional Organic Transistor with Light Sensing, Memory, and Light Emitting Characteristics	Spotlight Invited Speaker	Dr. Mario Prosa
Investigation of transport in OECTs with Electrochemical Strain Wave Microscopy	Spotlight Invited Speaker	Dr. Filippo Bonafè

Organic devices for in vitro cellular interfacing

Andrea Spanu

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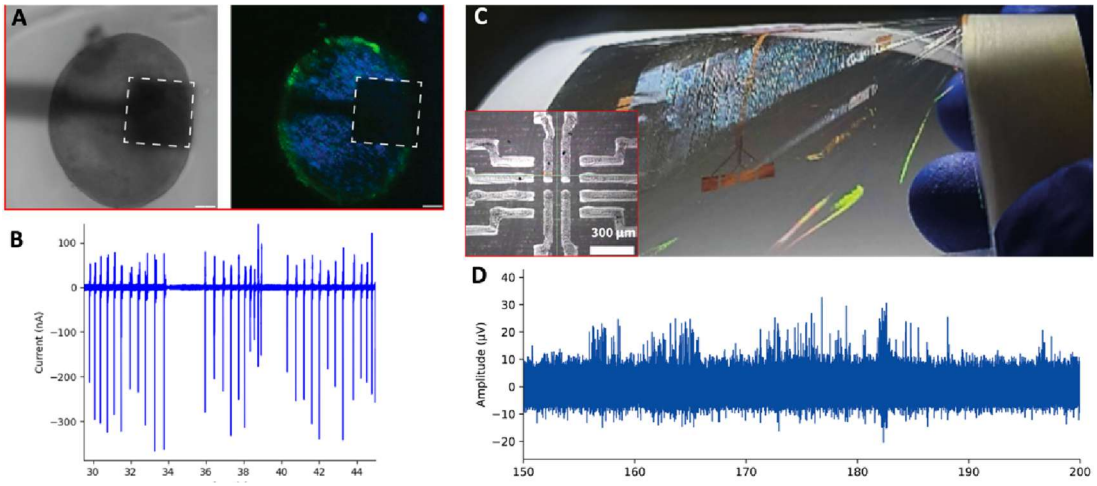
Within the biomedical field, in vitro cellular models still represent the go-to approach for important applications such as the development of effective treatments for neurological disorders and the investigation of complex biomolecular mechanisms at the subcellular level. Recently, the advent of high-performing and reproducible three-dimensional (3D) cell cultures has significantly reshaped the technological foundations of the field, exposing the limitations of the most commonly used devices in in vitro practice (i.e., passive microelectrode arrays [MEAs] and CMOS-based active transducers), particularly their lack of mechanical flexibility and the difficulty in achieving multimodal functionality. In this context, organic bioelectronics offers promising alternatives to the aforementioned standard technological approaches, especially in terms of material properties, costeffectiveness, and versatility. In this contribution, we explore the use of a particular class of organic transistors known as Extended-Gate Organic Field-Effect Transistors (ExG-OFETs) for the detection of the spontaneous electrical activity of 3D neurospheroids[1], as well as other relevant parameters such as cellular metabolic activity and the concentration of Ca^{2+} ions[2], along with the development of new MEAs based on organic materials. These innovative solutions—enabled by accessible fabrication techniques, tailored sensing strategies, and the unique properties of organic materials—offer distinct advantages over standard devices, ultimately supporting the development of multimodal, flexible, and scalable bioelectronic platforms for next-generation applications in neuroengineering, pharmacology, and personalized medicine.



A) Confocal and fluorescence image of a hIPSCs-derived neurospheroid on the sensing area of an ExG-OFET (scalebar:100 µm) (adapted from [1]). B) Spontaneous activity of a hiPSC-derived neurospheroid measured with an ExG-OFET (adapted from [1]). C) Printed ultraflexible MEA on ultrathin Parylene C film (inset: printed microelectrodes). D) Spontaneous activity of hiPSC-derived neurospheroid measured with an ultraflexible MEA.

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Polymer-Based Printed Transistors for Accurate Action Potential Recording and Drug Screening

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Excitable cells such as cardiomyocytes exert their function through a complex interplay of ion channels that regulate selective ion fluxes across the membrane. This process generates Action Potentials (APs), which are rapid changes in the membrane voltage that occur spontaneously or as a consequence of an electrical stimulus. The shape, duration, and amplitude of the AP convey relevant information about the physiological state of the cell. The current gold standard for accurately recording AP is still the patch clamp technique, which remains complex, invasive, and limited in scalability. In contrast, scalable microelectrode arrays (MEAs), while suitable for high-throughput applications, primarily detect the capacitive derivative of the AP signal with significantly lower signal-to-noise ratios and limited insight into subthreshold dynamics. There is a high demand for minimally invasive, high-throughput technologies capable of scalable recording of APs in electrogenic cells. To enable a cost-effective and non-invasive probing platform, we propose planar Electrolyte-Gated Field-Effect Transistors (EGFETs) based on solution-processable semiconducting polymers such as Poly (3-hexylthiophene) (P3HT) and Poly(benzimidazobenzophenanthroline) (BBL). These devices can be effortlessly fabricated over large areas using scalable printing techniques. Remarkably, despite their planar geometry, our devices demonstrated the spontaneous recording of APs with patch-clamp-like quality from a monolayer of human induced pluripotent stem cell-derived cardiomyocytes. We further investigated the effects of drugs on AP shape, duration, and frequency. The simplicity of the architecture, combined with a high signal-to-noise ratio, establishes a promising foundation for low-cost, reliable, and flexible biosensors enabling parallel, high-quality electrophysiological recordings for applications in drug screening and disease modeling.

Multifunctional Organic Transistor with Light Sensing, Memory, and Light Emitting Characteristics

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Neuromorphic electronics is attracting considerable attention due to the ability to mimic the nonlinear and parallel characteristics of the biological neural system that can enable the implementation of brain-inspired computing. In this work, an organic phototransistor that combines light sensing and neuromorphic functionalities is demonstrated by including a stable radical molecule into the polymeric dielectrics of the device. The presence of the radical molecule provides charge modulation and memory effects[1,2] to the phototransistor under different optical stimuli (Figure 1), thus exhibiting synaptic gain under electrical gate pulses, long-term and short-term plasticity, and paired-pulse facilitation.

The capability of the device is further extended by integrating an additional emissive layer resulting in a multifunctional optoelectronic device that acts both as an organic memory phototransistor and light-emitting transistor. Memory effects and a synaptic-like increase on the electroluminescence are obtained upon pre-illumination of the device during subsequent electrical pulses.

This multifunctional platform highlights a promising route toward integrated optoelectronic systems that simultaneously perform light-sensing, memory, and light emission, opening perspectives for artificial retinae, neuromorphic vision sensors, and light-controllable synaptic devices.

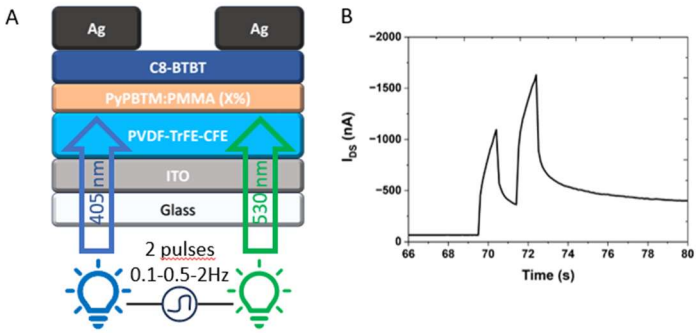

Figure 1. a) Neuromorphic organic transistor incorporating a stable organic radical; b) PPF stimulated by blue and/or green light.

1. Baroni, G., Reginato, F., Mattiello, S., Moschetto, S., Prosa, M., Bolognesi, M., Beverina, L., Toffanin, S., High-Sensitivity Solution-Processed Organic Phototransistor Based on a Bulk Heterojunction with a Persistent Radical as the Electron Acceptor, *ACS Applied Electronic Materials*, **7**, 3694–3703 (2025).

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Investigation of transport in OECTs with Electrochemical Strain Wave Microscopy

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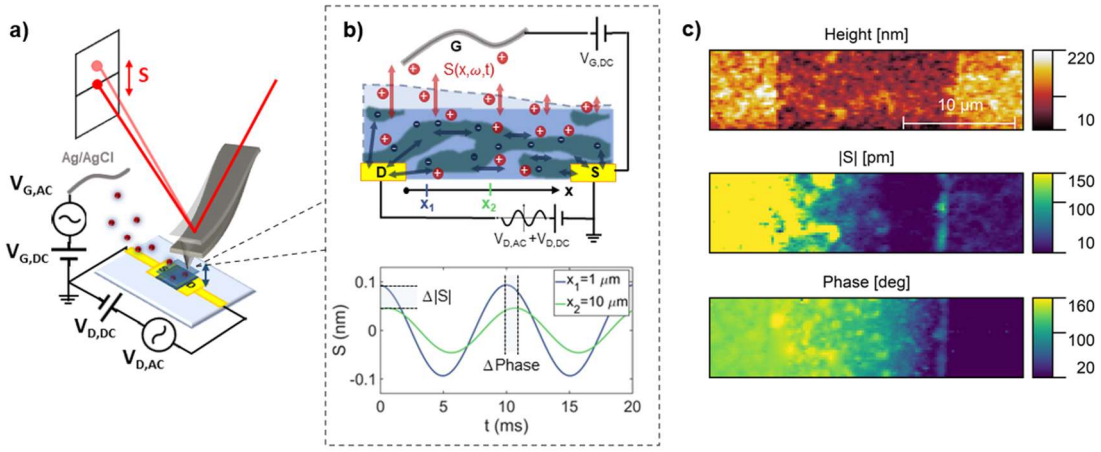
Critical advancements in organic electrochemical transistor (OECTs) for bioelectronic, neuromorphic, and sensing applications[1] require a deeper understanding of microscopic mixed ionic-electronic conduction processes governing device operation. In this work, we introduce electrochemical strain wave (ESW) microscopy to investigate transport processes in the OECT channel at microscopic length scales. ESWs are generated in mixed conductors by charge injection at the electrodes and propagate into the device channel through combined charge transport and swelling.[2] With AFM experiments we map the local amplitude and phase of ESWs in OECTs under different operating conditions. As a result, we demonstrate that quantitative ESW acquisitions can determine carrier concentration-dependent mobility effects in n-type and p-type devices, and reveal microstructural defects in the OECT channel altering local charge transport. Our findings provide a coherent framework to interpret the structure-functionality relation in OECTs mapping transport properties below diffraction limit and without limitations by screening effects or electrochemical side reactions of the probe.



Electrochemical strain wave microscopy on Organic Electrochemical Transistors (OECTs). a) Schematic of the experimental apparatus for mEC-AFM measurements of electrochemical strain waves (ESWs) propagating in OECT channels. b) Conceptual scheme correlating ionic and electronic transport with ESW propagation. c) mEC-AFM maps of local ESW amplitude and phase in operating BBL n-type OECTs.

1. Saleh, A., Koklu, A., Uguz, I. *et al.* Bioelectronic interfaces of organic electrochemical transistors. *Nat Rev Bioeng* **2**, 559–574 (2024)
2. F. Bonafè, M. Bazzani, B. Fraboni, T. Cramer, *Dissipative charge transport in organic mixed ionic-electronic conductor channels. Nat Commun 16, 2499* (2025)

SPEAKER SESSIONS

Session 7 — *Implantable Bioelectronic and Neural Interfaces*

Chairperson: Prof. Francesco Greco

Solid-State OECT Circuits for Miniaturized and Implantable Bioelectronics	Featured Invited Speaker	Prof. Simone Fabiano
Advances in Flexible Electronics for Brain-Computer Interfaces	Featured Invited Speaker	Prof. Eugenio Cantatore
Advances in CMOS Bioelectronics for Brain Interfaces	Featured Invited Speaker	Dr. Luca Berdondini
A scalable approach for integrating microelectronics on tapered optical fiber-based neural interfaces	Spotlight Invited Speaker	Dr. Claudia Latte Bovio
Electrophoretic Ion Pumps for controlled drug delivery	Spotlight Invited Speaker	Dr. Rassen Boukraa

Solid-State OECT Circuits for Miniaturized and Implantable Bioelectronics

Simone Fabiano

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Organic electrochemical transistors (OECTs) are key components for next-generation bioelectronic systems, yet their reliance on liquid electrolytes hinders device miniaturization, circuit integration, and long-term stability. In this work, we introduce a solid-state, photo-patternable electrolyte that enables compact and high-performance OECTs and integrated logic circuits. The platform supports low-voltage operation, fast response, and excellent stability for both p- and n-type devices. We demonstrate complex logic architectures, including NAND/NOR gates and half-adders, as well as solid-state spiking circuits integrated with flexible electrodes for implantable neuromodulation. These results mark a step forward toward scalable, soft bioelectronics with real-world translational potential.

Advances in Flexible Electronics for Brain-Computer Interfaces

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Flexible electronics is an interesting platform for manufacturing Brain-Computer Interfaces (BCIs), as it can enable an high number of electrodes, good signal integrity, and implantable solutions thanks to its biocompatibility and extremely low power dissipation density (<15mW/cm^2). This work showcases these capabilities, presenting an active Analogue Front-End (AFE) fabricated with a-IGZO TFTs on foil that provides active matrix multiplexing for BCIs based on Electrocorticography (ECoG) signals. The circuit, shown in Figure 1, is optimized for low noise (70nV/sqrt(Hz) input referred), and low power consumption (46µW/channel or 3.5mW/cm^2), achieving a best-in-class Noise Efficiency Factor for flexible electronics of 9.8. The talk will illustrate the circuit details, and show that the proposed approach can achieve a 94% accuracy[1] in gesture classification tasks using a database of ECoG in-vivo measurements.

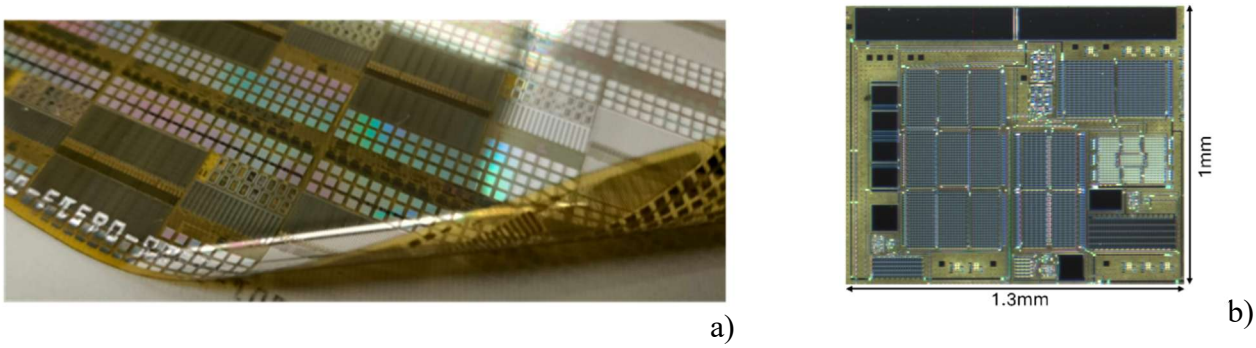

Figure 1: Pictures of the flexible circuits. (a) Photograph of a foil including the flexible electronics. (b) Micrograph of the proposed AFE based on a-IGZO TFTs.

1. K. van Oosterhout, A. Chilundo, M. P. Branco, E. J. Aarnoutse, M. Timmermans, M. Fattori, N. F. Ramsey, E. Cantatore, Brain-Computer Interfaces Using Flexible Electronics: An a-IGZO Front-End for Active ECoG Electrodes. *Adv. Sci.* **12**, 2408576 (2025). https://doi.org/10.1002/advs.202408576

ADVANCES IN CMOS BIOELECTRONICS FOR BRAIN INTERFACES

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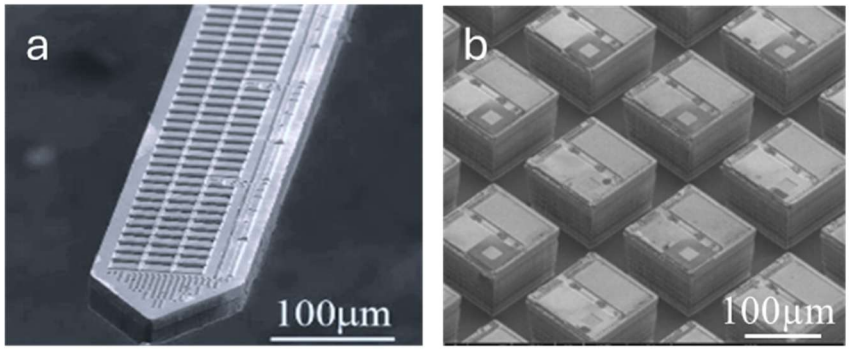
The adoption of microelectronics to realize neuro-devices has enabled the development of monolithic active electrode array featuring hundreds to thousands of closely spaced microelectrodes with embedded signal conditioning circuits for monitoring and modulating neural activity. Leveraging CMOS and micro-/nano-structuring technologies, this progress has led to a significant increase in the number of simultaneously recording electrodes on compact implantable devices for neuroscience research, as well as on superficially interfacing electrode arrays. These advancements have also catalyzed the emergence of dust neuroelectronics, i.e. self-standing wireless implantable micro-devices for neural interfacing.

In this lecture, we will present our contributions to this evolving toolbox, focusing on Active Pixel Sensor (APS)-based CMOS neuro devices. This includes planar electrode arrays for in-vitro applications and, more recently, the development of in-vivo implantable SiNAPS probes[1]. We will also highlight our ongoing efforts within the Crossbrain EIC project aimed at realizing self-standing, wireless microscale devices for next-generation brain-machine interfaces. These novel electrode array technologies open new frontiers in neuroscience research but also introduce significant experimental challenges. To address these, the hybrid integration of organic and CMOS devices is a promising strategy that will be discussed.



SEM Images of micro-structured CMOS-based neuro-devices developed at IIT. (a) Tip of a SiNAPS probe with a dense array of electrode-pixels. (b) View of self-standing µdevices with integrated frontends.

1. Angotzi, G.N., Vöröslakos, M., Perentos, N., Ribeiro, J.F., Vincenzi, M., Boi, F., Lecomte, A., Orban, G., Genewsky, A., Schwesig, G., Aykan, D., Buzsáki, G., Sirota, A., Berdondini, L. Multi-shank 1024 channels active SiNAPS probe for large multi-regional topographical electrophysiological mapping of neural dynamics, *Advanced Science*, Apr;12(16):e2416239 (2025).

A scalable approach for integrating microelectronics on tapered optical fiber-based neural interfaces

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Multifunctional optical fibers are emerging as promising tools for advanced neural interfacing, enabling simultaneous optical and electrical interactions with neural tissue in vivo [1,2]. In this context, Organic Electrochemical Transistors (OECTs) have gained increasing attention due to their high sensitivity, biocompatibility, and compatibility with aqueous environments, making them ideal for bioelectronic applications such as neural recording, biosensing, and optogenetics [3,4]. However, conventional fabrication techniques like photolithography and screen printing limit the scalability and material versatility required for flexible, implantable devices. Capillary printing offers a compelling alternative, providing additive, high-resolution patterning with excellent material efficiency and substrate compatibility [5,6]. In this work, we explore the use of the Hummink capillary-based printing system—an inkjet technology inspired by Atomic Force Microscopy—for the precise deposition of PEDOT:PSS, a benchmark conductive polymer in organic bioelectronics (Figure 1a). By systematically tuning the ink formulation (Figure 1b, c, d)—optimizing viscosity, surface tension, and wettability—we enhance film uniformity, substrate adhesion, and electrical conductivity. These improvements are crucial for the development of high-performance, stable, and scalable OECT-based neural interfaces (Figure 2a, b). Our results underscore the critical role of capillary forces in determining deposition quality and device performance, and pave the way for next-generation printed bioelectronic systems integrating both passive and active functionalities.

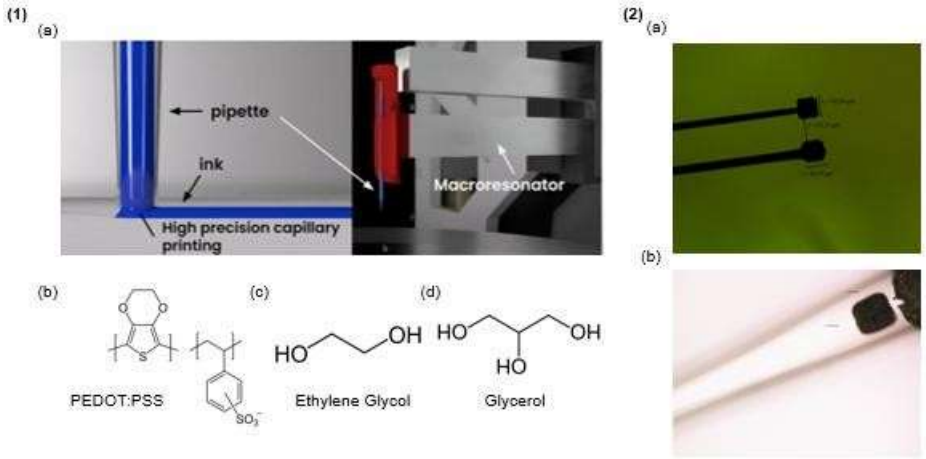

Figure 1. a) HPCaP center around a piezodriven oscillation that excites the macro-resonator attached to a glass pipette filled with ink. *b) Chemical structures of the conducting polymer PEDOT:PSS; c) the solvents EG, and d) glycerol. Figure 2. Optical micrographs showing a) electric tracks printed with silver ink. b) modified PEDOT:PSS printed.*

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Electrophoretic Ion Pumps for controlled drug delivery

Rassen Boukraa*, Sebastian Hecko**, Marle Vleugels*, Christian Bayer***, Donghak Byun*, Moa Hörberg*, Nikolaus Poremba**, Magnus Berggren*, Daniel Simon*, Linda Waldherr***, Hannes Mikula**, Johannes Bintinger**

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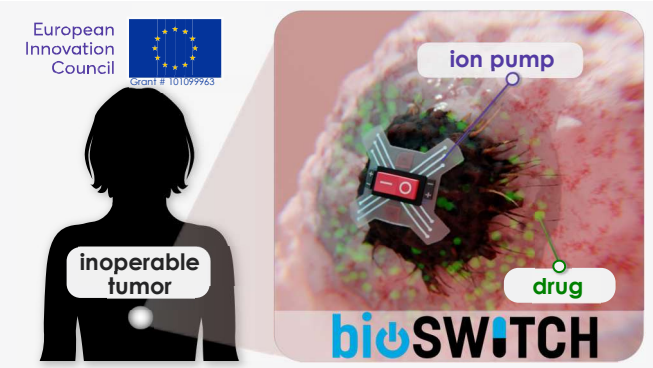

The Biontronic concept, developed as part of the bioSWITCH project, combines electrophoretic ion pump technology with click-to-release chemistry. While ion pumps have generated interest as a means for modulating drug delivery via electrophoretic migration with electronic precision[1,2], these devices are constrained by limitations pertaining to the dimensions and electrical charge of the drug being pumped. Conversely, click-to-release chemistry has the capacity to be tailored for the release of any size of (bio)chemical compound in vitro; however, it cannot alone enable temporal or electronic control of drug dose. The amalgamation of these two domains results in a chemical wave form generator which presents a novel and unparalleled approach to the in vitro delivery of drugs to a precise location with temporal and electronic control.

In this presentation, the Biontronic concept will be introduced, with a particular focus on the ion pump technology that is currently under development. The strategies employed for the optimisation of the electrophoretic drug delivery will also be explained.

1. Arbring Sjöström, T. *et al.* A Decade of Iontronic Delivery Devices. *Adv. Mater. Technol.* **3**, 1700360 (2018).
2. Handl, V. *et al.* Continuous iontronic chemotherapy reduces brain tumor growth in embryonic avian *in vivo* models. *J. Controlled Release* **369**, 668–683 (2024).

SPEAKER SESSIONS

Session 8 — *Biosensors and Fluidic Devices for Health and Environmental Monitoring*
Chairperson: Prof. Carlo Augusto Bortolotti & Prof. Stefano Casalini

An Electrolyte-Gated Transistor combined with CRISPR/Cas13a for RNA detection	Featured Invited Speaker	Prof. Benoit Piro
Graphene- Based Opto-Electronic Platform for Ultra-Sensitive Biomarker Detection — Revealing Amplification Mechanisms at Bioelectronic Interfaces	Featured Invited Speaker	Prof. Gaetano Scamarcio
Tailoring Molecular and 2D Materials for the detection and removal of Emerging Contaminants in Water	Featured Invited Speaker	Dr. Manuela Melucci
Combining microfluidics and organic electrochemical transistors for biofluid-based diagnostics	Featured Invited Speaker	Dr. Valentina Preziosi
Microfluidic Gradient Generator Interfaced with Electrolyte Gated Organic Transistors	Spotlight Invited Speaker	Prof. Pierpaolo Greco
Organic Bioelectronic Devices for Continuous Human Health Monitoring	Spotlight Invited Speaker	Dr. Davide Vurro

An Electrolyte-Gated Transistor combined with CRISPR/Cas13a for RNA detection

Pierre Guermonprez[1], Rassen Boukraa[1], Le Tu Anh[1,2], Louis Renaud[3], Pierre Nioche[4,5], Eric Krejci[6], Aurélie Alleaume-Butaux[4], Nicolas Battaglini[1], Vu Thi Thu[2], Sébastien Sanaur[7], Benoît Piro[1]

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Ribonucleic acids (RNA) detection is a crucial step in the identification of viral or bacterial infections in humans and animals. To date, reverse transcriptase-polymerase chain reaction (RT-PCR) remains the gold standard, but it is based on an amplification step which takes time and can induce transcription errors. However, clustered regularly interspaced short palindromic repeats linked to a Cas endoribonuclease particle (CRISPR/Cas) have recently revolutionized the recognition step of two types of RNA, i.e. the CRISPR-RNA and the target, providing a much better selectivity compared to the naked hybridization on which RT-PCR is based. In this study, we combine the high sensitivity of the CRISPR/Cas13a system with the transduction and amplification capabilities of an electrolyte-gated graphene field-effect transistor (EGGFET) for the detection of specific RNA sequences, which promise selective and sensitive detection, without PCR amplification. In these devices, fabricated on flexible plastic substrates, the active material of the transistors (reduced graphene oxide - rGO) is deposited by additive printing techniques. The rGO is then functionalized using Au nanoparticles decorated with polyU RNA strands immobilized by a thiol-gold bond. In the presence of a specific RNA sequence, the enzymatic function of the CRISPR/Cas13a complex is activated and the polyU RNA strands are cleaved from the Au nanoparticles, inducing a loss of negative charges on the rGO layer. This phenomenon leads to significant shift of the charge neutrality point (CNP) of the rGO, converted into a shift of the transistor's transfer curves. This sensing device was tested for the detection of a SARS-CoV-2 RNA sequence and showed a linear response in the range of 10^{-7} - 10^{2} ng.µL^{-1}. With the optimized device, the LOD was found to be 75×10^{-9} ng.µL^{-1}, which was estimated to be around 10 fM, as expected for an amplification-free CRISPR/Cas-mediated nucleic acid sensor. The sequence of the target RNA to be detected can be adjusted by modifying the corresponding crRNA, making this sensor highly versatile and multipurpose. This work is an important cornerstone for the complete development of a point-of-care RNA sensor. Such an RNA sensor could not only detect the presence of viruses, but could also be used to track bacterial growth in food, after infection in humans or animals, or in diseases where miRNAs are produced.

Graphene-Based Opto-Electronic Platform for Ultra-Sensitive Biomarker Detection — Revealing Amplification Mechanisms at Bioelectronic Interfaces

[1]Matteo Piscitelli, [2]Cinzia Di Franco, [3]Eleonora Macchia, [4]Luisa Torsi, and [5]Gaetano Scamarcio

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We present a novel two-terminal biosensor for the label-free detection of IgM antibodies, achieving a record sensitivity of 10^{-19} M. The sensor features a large-scale bio-functionalized gold interface, capacitively coupled to a bare graphene electrode via a water-soaked paper strip.[1] The transduction mechanism is based on the strong dependence of graphene phonon energies from the Fermi energy. Strikingly, even a few binding events can induce a cooperative electrostatic reorganization of the adsorbed protein layer, resulting in a pronounced shift in surface potential. This amplification mechanism, also at earth of single molecule transistor biosensors,[2] challenges conventional models of protein physisorption, revealing metastable behavior and emergent collective effects driven by single-molecule interactions. Here we review ongoing investigations using Kelvin Probe Force Microscopy (KPFM),[3, 4] PM-IRRAS, and ATR-IR spectroscopy,[5] indicating a non-random secondary structure within the physisorbed layer. Specifically, a preferential β-sheet orientation suggesting an unexpected degree of molecular alignment and functional order.[5] These findings establish a new paradigm for bioelectronic sensing, offering a framework to engineer ultra-sensitive, responsive molecular interfaces at the physical limits of detection, with direct implications for next-generation point-of-care diagnostics.

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5. M. Piscitelli et al, *Advanced Materials Interfaces 2025*; **https://doi.org/10.1002/admi.202400867**

Tailoring Molecular and 2D Materials for the detection and removal of Emerging Contaminants in Water

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The development of advanced materials and technologies for the monitoring and removal of emerging contaminants (ECs)—including per- and polyfluoroalkyl substances (PFAS)—is critical to ensure the safety and sustainability of water resources. This contribution highlights our recent advances in the synthesis, characterization, and application of novel materials for both real-time detection and treatment of ECs in drinking water, at laboratory and pilot-plant scales. The following case studies will be presented:

i) the design of thiophene-based molecular materials, as well as their derivatives in the form of metal-organic frameworks (MOFs) and composites, for the adsorption and photocatalytic degradation of ECs (Fig.1a);[1]

ii) the development of covalently functionalized graphene nanosheets and their composites for use in EC adsorption[2] and sensing applications (Fig. 1b);[3]

iii) the scale-up and industrial implementation of graphene oxide-based composite membranes and filters (Graphisulfone®) developed in collaboration with a leading manufacturer of filtration systems (Fig. 1c).[4,5]

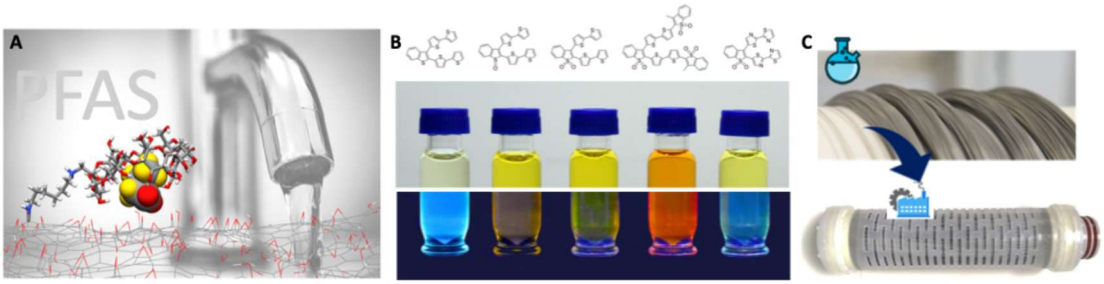

Figure 1. a) ECs monitoring and removal from drinking water: b) tailoring oligothiophene based photocatalysts[1] for ECs degradation, c) graphene oxide-polysulfone membranes and filters from lab to fab.[4,5]

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Combining microfluidics and organic electrochemical transistors for biofluid-based diagnostics

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The use of microfluidic and biosensing technologies has recently opened avenues for the creation of compact and effective diagnostic instruments. This study deals with an innovative integrated lab-ona-chip apparatus coupled with organic electrochemical transistors (OECTs) for the precise analysis of specific biomarkers in biological fluids, including human blood and seminal fluid. In recent years, OECTshave gained significant attention due to their capability to enable ionic-electronic transduction at low voltages (< 1V), as versatile platforms for biosensing applications[1-4]. These devices are made of three electrodes—source, drain, and gate—alongside an active layer of conducting polymer. The polymer channel links the source and drain contacts and is electrically connected to the gate electrode through an electrolyte. By applying a voltage to the gate, ions migrate from the electrolyte into the polymer channel, effectively modulating in a reversible way the electronic current between the drain and source electrodes. In this work, in particular, we show how OECTs based on PEDOT:PSS channels, coupled with microfluidics and driven by antibody-functionalized gates electrodes can be employed for the detection of cardiac biomarkers. The results shed light on both the potential of utilizing such lab-on-a-chip platform in biosensing applications, providing invaluable insights for future advancement in the field of bioelectronics.

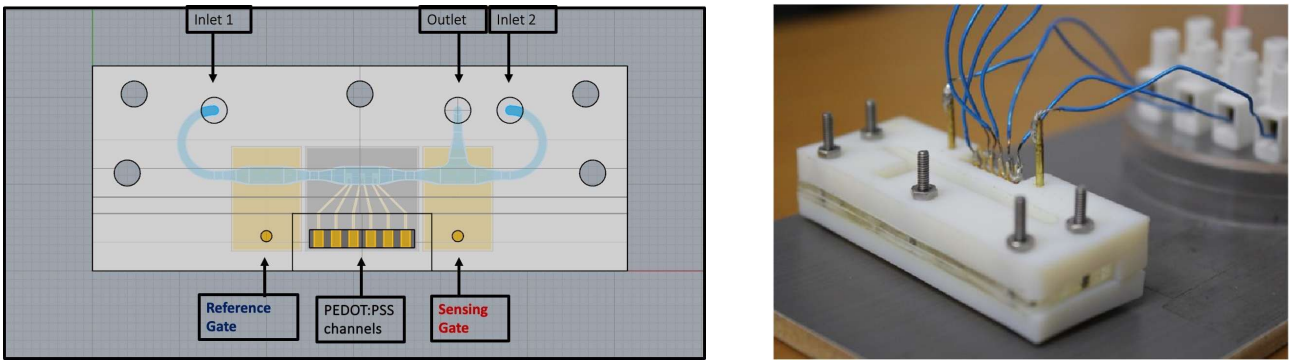

Figure 1: Sketch and image of the lab-on-chip platform combining microfluidics and highly sensitive OECTs.

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Microfluidic Gradient Generator Interfaced with Electrolyte Gated Organic Transistors

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Organic transistor biosensors are predominantly tested in a configuration where the analyte solution is in contact with the functionalized gate inside a static liquid compartment, such ELISA plates. The concentration is assumed to reach equilibrium after a defined period of time, but the depletion induced by the binding events might counter this hypothesis, jeopardizing the correlation between the device response and the analyte concentration. We present here a multi-gate array EGOT device[1], integrated with microfluidic channels that allows to quantitatively measure the solute concentration gradient created in a spatially inhomogeneous solution. The integrated H-cell yields a diffusive concentration profile along the microfluidic channel according to the flow rate of the input streams. The electrolyte bridge between the multi-gate array and the semiconductor chamber is of crucial importance to allow the potential sweep applied at the gate exerting the corresponding effect on the semiconductor electrolyte interface. COMSOL Multiphysics program was used for the FEM simulations of fluid dynamics and estimation of the concentration gradient. Moreover, the ion concentration is output by computing by the Nernst-Planck equation in a simplified geometry. We demonstrate the H-cell based gradient generator by monitoring the formation of self-assembled monolayers on top of the array of parallel Au gate electrodes exposed to the controlled local concentration of alkanethiols. From the analysis of the transfer curves, it is possible to appreciate the effect of diffusing thiols on drain-source current, according to position of the gate along the H-mixer, and the flow rate. At 50 µl/min, the laminar flow separated completely the two solution streams, resulting in the gate electrodes showing almost no effect in presence of concurrent flow of buffer and solution containing alkanethiols, because diffusion is hindered by the dominant convective flow. At flow rate of 2 µl/min, the formation of self-assembled monolayer on top of the gate electrodes induced a progressive increase of the EGOT signal according to the position of the gate along the array. The microfluidic transistor integrated platform is viable for constructing dose curves in reproducible manner and for validating different electrode functionalization strategies where the deposition rates are different at each substrate site.

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Organic Bioelectronic Devices for Continuous Human Health Monitoring

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Monitoring human health over long period of time, continuously and in an unobtrusive way is challenging as requires technologies capable of capturing physiological information such as vital signs, activity levels and molecular biomarkers in real time. This continuous data acquisition would enable the early detection of health issues or pathological changes, allowing a timely medical support. The convergence between organic electronics and biology offers solution in the new frontiers of wearable and implantable devices for health monitoring. Organic electronic materials, in particular conducting polymers, offer advantages for interfacing with biological systems, as they can efficiently transduce biochemical signals into electrical outputs while maintaining mechanical flexibility and biocompatibility.

The presentation will explore a range of device configurations tailored to diverse medical applications and developed in our laboratories, focusing on biosensors that utilize specific bioelements—such as enzymes, molecularly imprinted polymers and antibodies, depending on the target molecules to be detected and monitored. We will introduce the use of enzymes with oxidative activity to detect specific target molecules of predictive and diagnostic interest in biofluids, such as glucose and spermine, using screen printed electrodes (SPEs) or organic electrochemical transistors (OECTs). Beyond enzyme-based detection, the discussion will examine the continuous monitoring of cardiovascular disease biomarkers comparing the use of the traditional approach with antibodies with innovative molecular imprinting techniques for the functionalization of electrochemical devices.

Electrode functionalization with bioelements will also be described for DNA sequence recognition systems, including approaches based on CRISPR-CAS for detecting viral DNA. Finally, this presentation will conclude with results concerning the characterization of the devices and strategies to develop stable PEDOT:PSS biosensors for long-term operations when in contact with complex biological fluids.

SPEAKER SESSIONS

Session 9 — *Technologies for Health, Food, and the Environment*

Chairperson: Dr. Giuseppe Tarabella & Dr. Stefano Toffanin

From Threads to Thrills: Printed PEDOT:PSS Sensors Powering the Future of Smart Textiles	Keynote Speaker	Prof. Beatrice Fraboni
Sweat-Based Health and Sports Monitoring via Electrochemical Systems	Featured Invited Speaker	Prof. Luisa Petti
Solar energy conversion with living photosynthetic microorganism and biopolymers	Featured Invited Speaker	Prof. Gianluca Farinola
Monitoring Food Freshness with Electrolyte-Gated Organic Transistor	Spotlight Invited Speaker	Dr. Matteo Sensi
Sensing with Laser Induced Graphene	Spotlight Invited Speaker	Dr. Marina Galliani
From Lab to Orchard: Sustainable Plant Wearables Using Printed Bioelectronics	Spotlight Invited Speaker	Dr. Sahira Vasquez

From Threads to Thrills: Printed PEDOT:PSS Sensors Powering the Future of Smart Textiles

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University of Bologna, Bologna - Italy

The convergence of textile engineering and printed electronics has catalyzed a new era in wearable technology, enabling seamless integration of sensing capabilities into fabrics. This contribution explores the current state of the art in smart textiles with a specific focus on printed electronic sensors utilizing poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS), one of the most prominent conductive polymers in the field. PEDOT:PSS offers a unique combination of electrical conductivity, mechanical flexibility, biocompatibility, and compatibility with various low-cost printing techniques such as screen printing, inkjet printing, and spray coating.

The talk will present recent breakthroughs in functional textile architectures incorporating PEDOT:PSS-based sensors for monitoring biophysical signals (e.g., ECG, EMG, respiration), environmental parameters (e.g., humidity, temperature), and mechanical stimuli (e.g., pressure, strain, touch). Emphasis will be placed on strategies for enhancing durability, washability, and skin/textile interface performance, as well as approaches for ink formulation and substrate treatment to optimize sensor reliability. We will also discuss integration with wireless modules for real-time data transmission and implications for applications in personalized healthcare, sports performance, and human–machine interfaces.

Finally, we will address existing challenges—such as long-term stability, environmental sensitivity, and scalability—and outline promising directions for future research, including hybrid material systems, stretchable electronics, and sustainable fabrication pathways. This comprehensive overview aims to foster interdisciplinary dialogue and inspire next-generation innovations in smart textile development.

Sweat-Based Health and Sports Monitoring via Electrochemical Systems

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Sweat sensing is a major advancement in wearable technology, enabling minimally invasive, real-time health and sports monitoring. Rich in biomarkers, sweat reflects blood composition, making it effective for tracking various physical conditions. In healthcare, cytokine detection—particularly Interleukin-6 (IL-6) and Tumor Necrosis Factor-alpha (TNF-α)—is gaining momentum for continuous monitoring. In sports, biomarkers like ammonium (NH_4^+) indicate muscle fatigue. Among existing biosensing techniques, electrochemical platforms stand out for their compactness, sensitivity, and rapid response, making them ideal for real-time sweat analysis in wearables. Three-electrode sensors (see Fig. 1, left) allow detection at pg/mL levels by stabilizing the reference electrode, ensuring that changes in the working electrode's potential are due solely to analyte interactions. Electrolyte-gated field-effect transistors (EG-FETs, Fig. 1, right) offer high sensitivity through electrostatic gating, sensing analytes via current or transconductance shifts.

Apart from sensitive and selective biosensor design—using nanomaterials and biorecognition elements—effective sweat sensing also requires seamless system integration. This includes microfluidics for real-time sweat sampling and compact, low-power readout electronics for continuous, accurate monitoring. Conventional electrochemical platforms for cytokine and NH^+_4 detection often lack this integration and mostly rely on rigid substrates and complex, non-wearable-friendly functionalization.

To address these limitations, we developed a flexible screen-printed three-electrode platform for the detection of IL-6 and TNF-α in sweat. Simulation-guided design optimized sensitivity, reduced diffusion, and minimized device size, while gold nanoparticle modification and aptamer biofunctionalization ensured sensitivity and selectivity. Integrated into a microfluidic system that ensures smooth flow and prevents sweat mixing, electrochemical impedance spectroscopy achieved a detection limit of 0.2 pg/mL for both IL-6 and TNF-α, well below their physiological levels. Meanwhile, machine-learning-enhanced threshold-based cyclic voltammetry enabled accurate classification (96.4%) of physiological and pathological levels.

While electrochemical sensors dominate NH_4^+ detection in sweat, EG-FETs offer enhanced signal amplification. These EG-FETs, with planar electrodes modified by uniformly distributed carbon nanotubes and an NH_4^+-selective membrane, show a calibrated sensitivity of 0.6 µA/decade across the physiological range (0.12–2.17 mM). A flexible, coin-cell-powered readout circuit (40 mm x 45 mm polyimide substrate) was tailored, optimizing flexibility by reducing hardware complexity and components.

Our findings show that three-electrode sensors offer simplicity and accuracy but require external amplification, while EG-FET sensors provide built-in amplification and easy digital readout. These findings underscore the critical role of integrating electrochemical platforms with microfluidics and advanced readout systems to realize compact, high-performance wearable devices for next-gen health and sports monitoring.

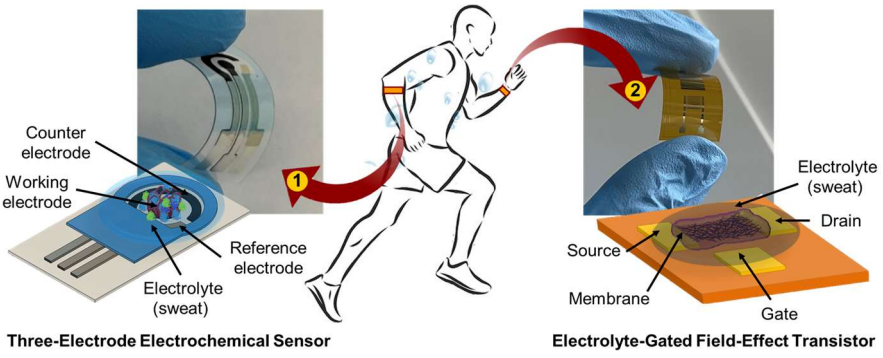

Fig. 1: Three-electrode (1) and electrolyte-gated field-effect transistor (2) biosensors for sweat sensing

Solar energy conversion with living photosynthetic microorganism and biopolymers

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The lecture will report our studies on the use of living photosynthetic microorganisms as biohybrid, materials for solar energy conversion devices. [1,2] Our research group has reported methods to improve the light-harvesting capabilities of photosynthetic microorganisms.[3] At the same time we have developed biopolymer-based interfaces that connect living photosynthetic cells to electrodes for photocurrent generation.[4] Specifically, we have immobilized metabolically versatile purple photosynthetic bacteria onto electrodes using polydopamine as an interfacing layer. This approach preserves the activity of bacterial cells while facilitating the transfer of photo-induced electrons, resulting in sustained photocurrent generation over extended periods.[4] We have also demonstrated that living diatom microalgae can be directly deposited onto ITO surfaces to create biohybrid electrodes capable of withstanding multiple desiccation cycles, maintaining photocurrent generation for up to 15 days.[5] Collectively, these biohybrid systems exhibit remarkable flexibility and sustainability, opening the door to a completely new generation of living platforms for sustainable energy production.

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Monitoring Food Freshness with Electrolyte-Gated Organic Transistor

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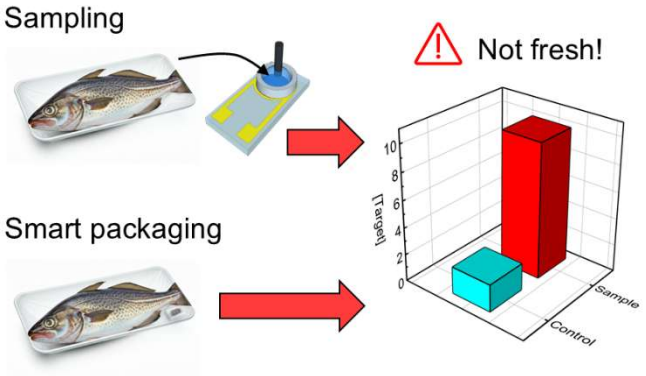
The Food and Agriculture Organization of the United Nations (FAO) reports that 14% of the world's food is lost annually between harvest and retail. It is urgent to reduce food waste from both ethical and economic perspectives. Implementing an efficient monitoring system for the cold chain, from the factory to the consumer, could be a crucial strategy to reduce food waste and simultaneously preserve consumer health. Sensors capable of quantifying the effective food freshness and quality could substantially reduce food waste and enable more effective food chain management.[1] In the field of sensors, electrolyte-gated organic transistors (EGOT) based on organic semiconductors represent a promising technology, achieving outstanding performances in terms of limit of detection, signal amplification, sensitivity, and selectivity. The application of EGOT to food monitoring could take place in principle at two different levels: direct integration in smart packaging or sampling along all the production and transport (cold)chain, from the field to the consumer. We present our results obtained in the field of food sampling analysis with EGOT prototypes for the detection of molecules generated upon degradation of food.[2] In the perspective of integration in smart packaging, we show time-temperature integrators (TTI)[3] based on a rGO/PEDOT:PSS conductive hydrogel to track the thermal history of food products along the cold chain. Furthermore, we will share early findings on food allergens detection.



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Sensing with Laser Induced Graphene

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Among the functional materials used in flexible and bio electronics, Laser-Induced Graphene (LIG) is now under the spotlight. LIG is a conductive carbon nanomaterial characterized by 3D foamy porous structures made of graphene sheets. LIG is obtained via laser irradiation of a polymeric substrate and it stands out for multiple properties ideal to create a variety of smart devices. By embedding LIG into elastomers our group developed piezoresistive stretchable epidermal strain/pressure sensors for epidermal [1] and soft robotic gripper applications [2]. While the combination of a thermoresponsive hydrogel with LIG resulted in a multiresponsive soft actuator [3]. Moreover, we leveraged the LIG high conductivity, tuneable wettability, high surface area, and modulated surface chemistry to develop a fog basking demonstrator [4] and a flexible sweat electrochemical sensor [5].

In our current works, we are now further exploring UV laser technology. By finely tuning the laser parameter and scribing process we obtained, from polyimide tape, a single LIG line with a minimal 35 µm width. We exploit this resolution to fabricate flexible interdigitated electrodes, for fully organic and miniaturized sensors for LIG-based OECTs with 30 µm spaced interdigitated source and drain to develop an antibiotic biosensor. In parallel, we are now replacing synthetic polymers, such as polyimide, with bioderived lignocellulosic materials for sustainable fabrication solutions and devices [6]. In light of this, we recently created a novel almond-shell biodegradable composite which acts both as a bioderived flexible substrate and as a LIG precursor. Thanks to the high quality of this bioderived LIG and the composite changes when exposed to water, we developed a humidity sensor as an example of repurposing nuts biowaste for transient electronics applications [7]. Finally, another versatile route comes from our recent discovery for which a red dye (Eosin Y), in the form of an ink or a paint, is an optimal LIG precursor [8]. High quality LIG is obtained on different surfaces coated with the dye, such as a temperature sensor patterned onto the curvilinear surface of a mug and novel LIG temporary tattoo epidermal sensors. This “paint&scribe” approach opens the way for directly combining LIG technology with printed electronics, allowing new roles for LIG in the next generation of flexible printed sensors.

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From Lab to Orchard: Sustainable Plant Wearables Using Printed Bioelectronics

Sahira Vasquez, Pietro Ibba, Ahmed Rasheed, Paolo Lugli and Luisa Petti

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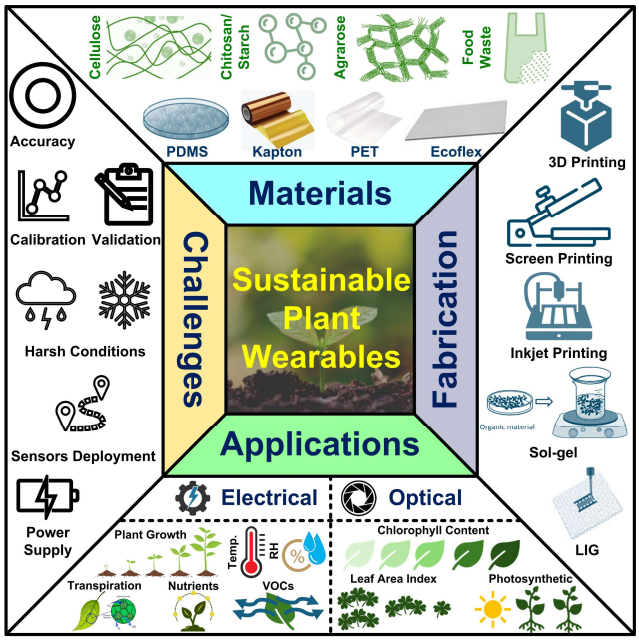
As agriculture becomes increasingly data driven, plant integrated wearable electronics are emerging as minimally invasive tools for the real time monitoring of environmental and physiological conditions. These flexible systems interface directly with plant tissues, enabling continuous sensing without compromising plant health. However, challenges persist in designing sustainable and scalable platforms that are both environmentally responsible and field deployable. This talk presents recent developments in eco-compatible plant wearables, focusing on devices fabricated using commercially available paper substrates and PEDOT:PSS based conductive ink. These impedimetric sensor were printed using low temperature dispense printing and characterized using a custom built modular platform integrating an impedance analyzer, multiplexers, and a Raspberry Pi. Measurements across 500 Hz to 10 MHz revealed a strong correlation between sensor response and relative humidity ($|r| > 0.5$) at low frequencies, confirming a capacitive mechanism driven by moisture uptake. During field deployment, the sensors showed >90% agreement with the reference sensor and exhibited distinct RH signatures near stomatal regions. These results validate this approach as a functional, scalable solution for environmental sensing in agriculture. By aligning the principles of organic bioelectronics with the operational requirements of precision horticulture, this study provides a blueprint for the large-scale adoption of green, printed sensor technologies in sustainable agriculture.



Overview of sustainable plant wearables using printed electronics. Emphasis on eco-compatible materials, fabrication techniques, and real-time sensing of humidity and transpiration near plant canopies.

POSTERS SESSIONS

Electrodeposited Reduced Graphene Oxide Enables Long-Term Memory in Neuromorphic Ambipolar Electrolyte-Gated Transistors

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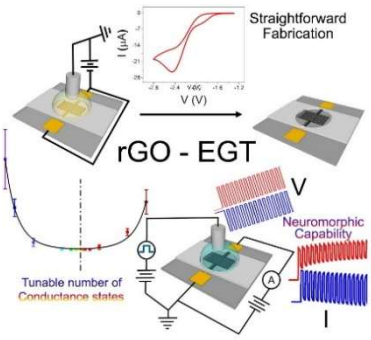
Ambipolar transistors, capable of conducting both electrons and holes, enable the simplification of circuit design by reducing the number of constituting units in circuits and opening new possibilities for low-power electronics, reconfigurable logic circuits, and memory devices[1]. 2D ambipolar semiconductors as graphene and its derivatives, are particularly advantageous in bioelectronics, for their high sensitivity in label-free sensors and their biocompatibility[2]. Here, a novel method for fabricating electrolyte-gated transistors based on reduced graphene oxide (rGO-EGTs) is proposed, which enables precise control over the thickness of deposited rGO. Such rGO-EGTs act as a neuromorphic unit that exhibits tailorable long-term plasticity when driven with pulsed voltage. By applying different numbers of voltage pulses and acting on their amplitudes, it is possible to program multilevel memory with retention timescales over tens of minutes and 6.60 µS writing resolution. This long-term plasticity makes our rGO-EGT promising for nonvolatile memory, computing, and plasticity-based signal pattern recognition.



An electrolyte-gated transistor based on the rGO, which is prepared via a facile and straightforward way, enables ambipolar conduction with a near-zero charge neutrality point. Upon administration of various pulse experiments, the device is capable to perform outstanding neuromorphic functions such as long-term plasticity and multi-state memory

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Nanobody-functionalized nanoporous membrane for the detection of glial fibrillary acidic protein

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Glial fibrillary acidic protein (GFAP) has recently emerged as a potential marker associated with brain injury[1]. GFAP can be released from the central nervous system into the peripheral blood[2], allowing a less invasive and simpler sample collection. In previous work, we demonstrated the potential of an organic electrochemical transistor (OECT), a transducing amplifier, for detecting amyloid protein aggregates using a functional membrane[3]. In this study, we adapt this promising platform into a GFAP sensor by immobilizing customengineered nanobody receptors onto a functional nanoporous membrane. Target binding on the membrane reduces ion flow from the electrolyte into the channel, thereby altering the performance characteristics of the OECT. Our approach preserves the gate electrode and OECT channel from the surface modification steps typically required to immobilize the biorecognition units and deeming these expensive electronic components as single-use parts. We systematically characterize the membrane functionalization process with chemical linkers and nanobodies and explore the device configuration to achieve optimal sensing performance. We compare the performance of our membrane-integrated OECT platform for detecting GFAP with that of other electrochemical transduction methods. This functionalized-membrane integrated OECT technology represents a significant step towards developing less invasive and low-power devices for the diagnosis of brain injury and dementia-like neurological disorders.

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Ion-selective membrane in Organic Artificial Neurons

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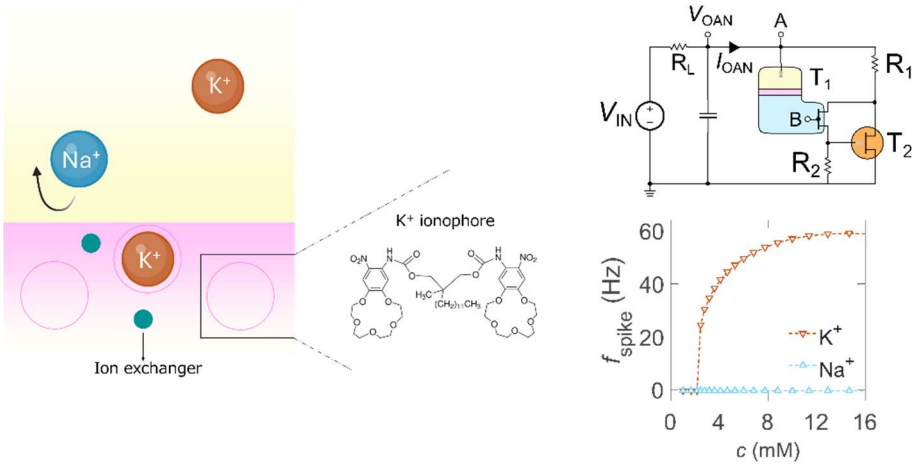
Ion-selective excitation is one of the key elements to obtain biophysical realism in Organic Artificial Neurons (OAN). PVC-based ion-selective membranes (ISM) ensure chemical selectivity by reversibly complexing the target ions and converting their activity into a measurable potential shift. The ion exchanger within the ISM regulates charge balance by swapping co-ions with the surrounding electrolyte, enabling the membrane to transduce target ion activity into a reproducible electrical signal. By integrating the ISM into the OAN, we are able to regulate the neuron oscillatory activity through the ionic concentration of a specific ion. A possibility is to integrate it inside the electrolyte of the transistor T1. Due to the voltage drop at the membrane, the threshold voltage of the transistor changes, modifying its spiking behavior. As shown in the picture below, the system we implemented is selective to the K^+ ion. Once it reached a threshold concentration, a spiking behavior appear at the voltage and current of the OAN. As the concentration further increases, the spiking frequency increases as well. This result demonstrates how our system can be selectively excited based on the selected ISM.



Ionophore exchanger behavior and its integration in the OAN, with the resulting selectivity to the ion concentration. When the sensing ion (K^+ in this case) increases in concentration, a spiking behavior appears in the OAN.

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Integrating microalgae with EGOTs for light-responsive current modulation

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In the last two decades, electrolyte-gated organic transistors (EGOTs) have demonstrated their potential as versatile tools for several applications ranging from biosensing to neuromorphic engineering, and bio-interfacing applications. In parallel, biohybrid electronic devices with different architectures have been recently demonstrated,[1] featuring redox active microorganisms as active components to generate photocurrents by exploiting their native photosynthetic activity. Taking the steps from our previously presented LEGOT,[2] which is a light-responsive organic transistor architecture, which converts light into electrical current by exploiting the efficiency of the photosynthetic bacterial reaction centre, we recently developed a photoresponsive EGOT device gated by a hybrid electrode composed of microalgae embedded in the conductive polymer matrix of PEDOT:PSS integrated on an indium tin oxide (ITO) gate. Upon illumination, the current flowing in the EGOT channel decreases, presumably due to the photosynthetic activity of the microalgae, which induces faradaic reactions at the gate via extracellular electron transfer from the algae to the electrode. This electron flow at the gate electrode alters the charge carrier density in the semiconductor, thereby regulating the source-drain current. Our device demonstrates the potential of biohybrid interfaces in organic electronics and pave the way for the development of light-responsive bioelectronic devices.
We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 1409 published on 14.9.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU– Project Title PhOLcs - Photosynthesis for Organic Light-Powered Electronics – CUP B53D23025230001 - Grant Assignment by the Italian Ministry of Ministry of University and Research (MUR).

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EGOT-BASED TIME TEMPERATURE INTEGRATOR FOR FOOD COLD-CHAIN MONITORING

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Cold chain relies on keeping perishable goods such as fresh food at a constant low temperature from the point of production to the point of consumption. Any break in the cold chain, such as temperature fluctuation, can compromise the safety and freshness of the products, leading to food spoilage and even health risks. Technologies like smart packaging(1) and temperature-monitoring devices such as time-temperature integrators(2) (TTIs) are becoming increasingly important to enhance control, reduce waste, and ensure the overall efficiency of the cold chain. Here we present an innovative TTI device based on a graphene hydrogel (3) operated as an electrolyte gated transistor (EGT). The hydrogel undergoes an irreversible dehydration in response to different environmental conditions like temperature and humidity. We study the process of mass loss (fig. 1) and propose a multiparametric description of the activated de-hydration process to quantitatively relate the loss of mass to the time, the temperature and the relative humidity. The initial mass/volume of the hydrogel is an important factor to tailor the timescale of the dehydration. Since the hydrogel is conductive, by exposing it to different conditions for a certain amount of time, it is also possible to record the effects of the temperature and humidity in time on the electrical characteristics acquired using the hydrogel as gate electrode of the EGT. Transconductance signal S_{gm} was identified as being able to discern between the various exposure conditions(4) (fig. 2).
We are also developing a predictive model to correlate dehydration kinetics with environmental exposure history, enabling precise calibration of the TTI response and quantitative assessment of cold chain integrity. We assessed this on real fresh fish samples packaged from aquaculture(5).

Fig. 1

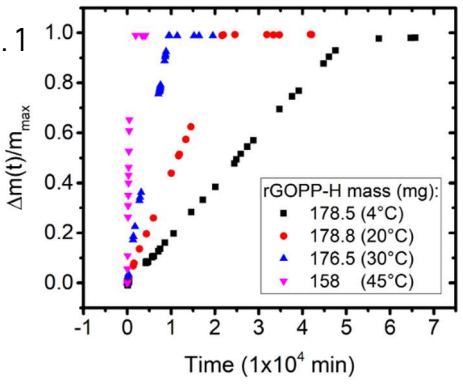
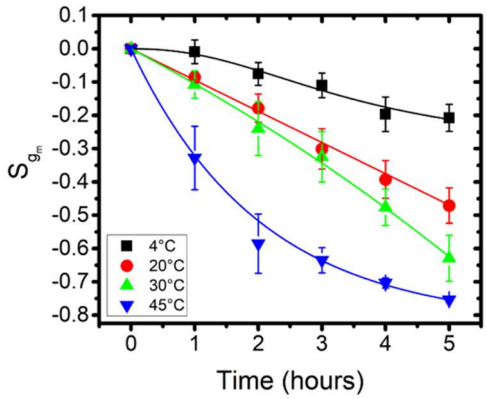


Fig. 2



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A Dual-Mode PEDOT:PSS–PNIPAM Temperature Sensor for Smart Wound Monitoring

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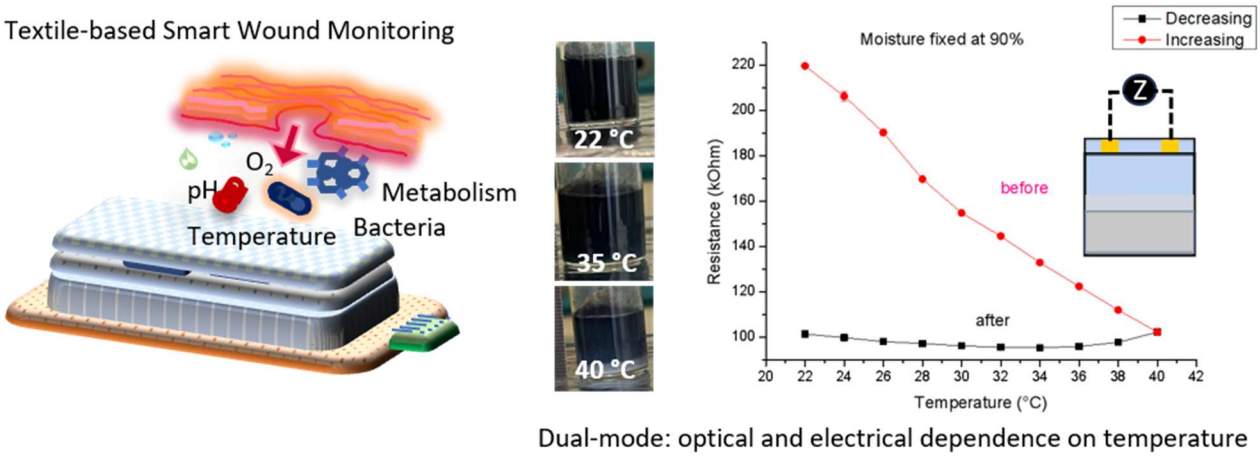
Wound healing is a complex physiological process influenced by a variety of biochemical, physical, and environmental factors. Accurate, continuous monitoring of key biomarkers of the lesion is essential for fast intervention and effective treatment. A key biomarker of both infection and healing progression is local temperature. To address this, the WEAR-ME! Project, funded by the Italian Space Agency, includes the development of an innovative temperature sensor based on a composite hydrogel of PEDOT:PSS and PNIPAM (poly(N-isopropylacrylamide)).
This two-terminal device exploits the phase transition of PNIPAM to detect physiologically relevant temperature changes. Above its lower critical solution temperature (LCST), PNIPAM transitions from hydrophilic to hydrophobic, resulting in changes in both electrical conductivity and optical transparency[1]. By embedding conductive PEDOT:PSS into the hydrogel, we created a sensor that cam combine impedance and optical changes. The first can be electronically measured in real-time as temperature increases. The second involves visible changes in the material appearance from transparent to opaque when exceeding ~36 °C, offering a passive, power-free visual feedback.
The combination of these two processes will enable an early infection detection and tracking of healing progression or worsening, as inflammation subsides and temperature normalizes. Our project aims to integrate the hydrogel-based temperature sensor into a smart textile-based bandage alongside pH and moisture sensors, allowing for a comprehensive wound monitoring for the patients.
Initial results confirm a good and reliable response to temperature changes. Further development focuses on screen-printing scalability and validation in wound models.



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Investigating the Effect of Channel Materials on OECT Stability

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Organic electrochemical transistors (OECTs) are essential components in biosensing and bioelectronics, offering iontronic transduction, signal amplification, biocompatibility, low-voltage operation, mechanical flexibility, and cost-effective fabrication. While most studies focus on enhancing electronic mobility and volumetric capacitance (summarized in the figure of merit μ*Cv), less attention has been paid to the impact of channel materials on device stability and long-term performance.

The effect of different channel materials on OECT stability was investigated. By systematically varying channel composition, the influence on threshold voltage, off-state current, on/off ratio, subthreshold slope, and transconductance under prolonged operation was analyzed. Clear relationships between channel material selection and operational stability were established, providing practical design principles for tailoring OECTs to achieve reliable performance in diverse electronic and bioelectronic applications. The correlation between channel/gate material parameters and overall device behavior was rigorously assessed, leading to guidelines for optimizing OECT design according to specific application requirements.

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Scalable Integration of OECTs through Additive Manufacturing for High-Performance Bioelectronics

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Bioelectronics is gaining momentum as an enabling technology for applications in biosensing, neuromorphic sensing, and wearable healthcare systems. Organic electrochemical transistors (OECTs) are especially promising for these areas, offering efficient ion–electron coupling, mechanical flexibility, and safe operation below 1 V—features that make them ideally suited for technologies interfacing with the human body.

A key challenge, however, lies in combining high device performance with long-term reliability and scalable fabrication. To address this, a high-precision additive manufacturing strategy based on micro-dispensing is presented, enabling the monolithic integration of OECTs and circuits directly on flexible substrates. This approach supports controlled deposition of conductors, semiconductors, and insulators across a wide viscosity range, ensuring reproducibility, robustness, and scalability.

The resulting devices deliver state-of-the-art performance, including an intrinsic gain of 330 V/V and a gain–bandwidth product of 1 MHz, benchmarks that demonstrate their suitability for reliable biosensing and body-interfacing applications. By merging the scalability of additive manufacturing with outstanding electrical characteristics, this work establishes a robust path toward high-performance, long-lasting bioelectronic platforms.

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Scalable Fabrication of Flexible Neurohybrid Synapses

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Organic neuromorphic devices are rapidly advancing as promising platforms for biointerfacing and brain–machine communication. By mimicking short- and long-term synaptic plasticity, these systems can emulate biological information processing and interface with living neurons[1]. Among them, PEDOT:PSS-based organic electrochemical transistors (OECTs) have demonstrated effective neuromorphic behavior in response to both electroactive and non-electroactive neurotransmitters[2,3]. However, progress toward in-vivo platforms requires not only biochemical functionality but also device miniaturization, microfabrication scalability, long-term stability and process reproducibility.

In this work, we investigate how microfabrication strategies influence the structural, electrochemical, and neuromorphic performance of PEDOT:PSS-based OECTs. Building on earlier synaptic device architectures[3], we adapt these systems to flexible Parylene-C (PaC) substrates to support future biointegrated electronics. To enable high-resolution patterning and reproducibility at reduced dimensions, we systematically compare three fabrication approaches based on spin-coated PEDOT:PSS: (i) dry etching, (ii) a germanium-based sacrificial layer, and (iii) a peeling-off method. Each method is evaluated in terms of pattern fidelity, device yield, and electrochemical functionality.

By refining the fabrication pipeline on a flexible, biocompatible substrate, this work lays the foundation for scalable integration of neuromorphic devices on implatable electronics. These results support the development of reliable, miniaturized interfaces for future clinical and bioelectronic applications.

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Design Strategies for Organic Electrochemical Transistors in Bioelectronic Devices

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Organic Electrochemical Transistors (OECTs) are essential components in bioelectronics due to their low-voltage operation, stability in aqueous environments, and ability to convert biological signals into electronic responses. These characteristics make them suitable for biosensing, neural interfaces, and other biomedical applications.

OECT architectures depend on the position of the gate relative to the semiconductor channel. The most common is the top-gated design, with the gate positioned above the channel, typically using a non-polarizable Ag/AgCl pellet in the electrolyte. While effective, this configuration limits integration. The side-gated layout places gate and channel in the same plane, providing more design flexibility.[1] In both designs, the electrolyte is a biological fluid, allowing direct probing of ionic, chemical, or biochemical properties. However, direct contact with the channel can lead to nonspecific adsorption of target molecules.

However, Ag/AgCl gates can release silver ions, which are cytotoxic, limiting their use in directcontact bioelectronic applications. While effective for basic measurements, their toxicity makes them unsuitable for long-term interfacing with biological entities. Using polarizable gold electrodes as gates might avoid cytotoxicity, but this approach also reduces efficiency due to voltage drops at the gate/electrolyte interface, operating in a capacitive, non-Faradaic regime with small gate currents.[2]

Here, we demonstrate a simple approach to enhance OECT gating using PEDOT:PSS, which exhibits volumetric capacitance in electrolyte. Increasing the thickness of PEDOT:PSS gates improves capacitance, reduces voltage drop, and optimizes modulation of channel current. Design parameters are tuned to balance gate and channel capacitance, achieving high-performance OECTs.

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Microfabrication of Organic Electrochemical Transistors for Advanced Biosensing Technologies

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In bioelectronics, organic electrochemical transistors (OECTs) are pivotal in bridging electronic devices and biological systems, particularly for biosensing applications. Current OECT fabrication methods face challenges due to the incompatibility of conductive polymers with photoresist solvents and the complexity of multistep parylene-C coatings. This work introduces a scalable photolithographic fabrication process for high-performance OECTs using the prototypical conductive polymer poly(3,4-ethylenedioxythiophene) doped with poly(styrenesulfonate) (PEDOT:PSS). The method employs a two-layer photoresist approach with controlled cross-linking, enabling patterning of the polymeric channel and encapsulation of electrodes.

The fabrication process yields highly reproducible OECTs with ON/OFF current modulation up to 5×10^3 and transconductance normalized to channel thickness exceeding 200 S cm^{-1}. The impact of scaling polarizable gates functionalized with proteins was evaluated, showing that encapsulated devices preserve their electric performance compared to non-encapsulated counterparts. This demonstrates that the proposed fabrication process enables biomolecule integration without compromising device performance. Systematic variation of the gate-to-channel area ratio provided design guidelines to optimize gating efficiency, balancing gate-channel capacitance while minimizing parasitic redox currents at source and drain electrodes.

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Influence of Electrolyte Solution Composition on Charge Transport Properties of PEDOT:PSS Transistor Architecture

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Poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) has been successfully demonstrated as active material in Electrolyte-Gated Organic Transistors (EGOTs) for biosensing[1] and *in vivo* amplification of electrophysiological signals[2]. To achieve high performance, pristine PEDOT:PSS typically requires additives and chemo-physical post-treatments to enhance its conductivity and stability[3,4]. Among these strategies, significant attention has been given to the influence of the pH of PEDOT:PSS suspension during film casting[5,6]. However, a systematic investigation of the effect of chemo-physical properties of electrolyte solutions on PEDOT:PSS thin films is still lacking. Herein, we report on the effect of pH and the cationic radius on the electronic properties of PEDOT:PSS-based EGOTs. Interestingly, we observe a marked effect of the electrolyte pH on the transfer characteristics of such EGOTs. This influence varies in a hydration-time dependent fashion. In pre-hydrated arrays, variations of electrolyte pH (using 0.9% NaCl as electrolyte) lead to minor current changes, suggesting that Na^+ cations dominate the ionic interactions over H_3O^+ ions. To elucidate the contribution of electrolyte composition to the charge transport properties of PEDOT:PSS channels, we tested EGOTs in the presence of individual cationic species with different chemical properties. By analyzing the transfer characteristics with a newly developed EGOT model, we establish a unique correlation between the multiparametric response of PEDOT:PSS-based EGOTs and the radius of hydrated cations. In summary, our findings highlight the critical role of electrolyte composition in modulating the charge transport properties of PEDOT:PSS thin films, upon mechanistic considerations.

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In Vivo Ischemia Detection Using Implantable Resorbable Organic Sensors

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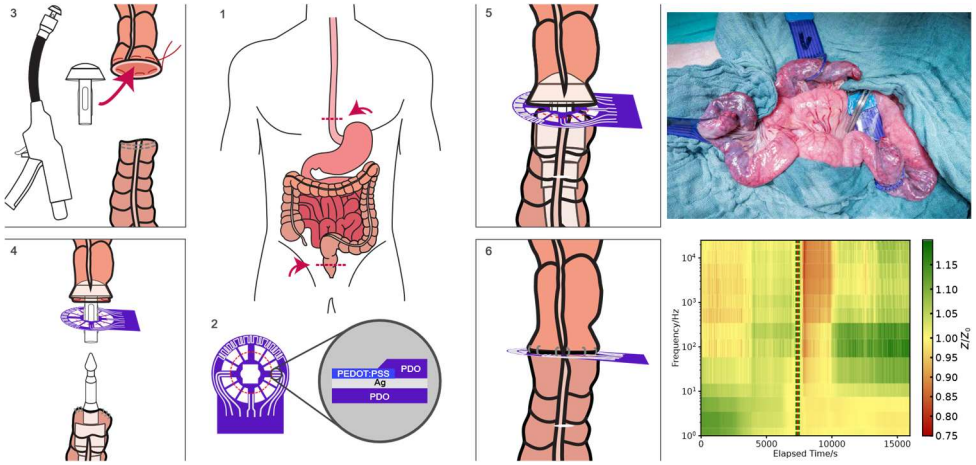
Anastomotic leaks remain among the most serious complications in gastrointestinal surgery, associated with high postoperative morbidity and consequent mortality. Early detection is critical for improving patient outcomes and reducing healthcare costs, yet current clinical practice lacks reliable methods for early recognition. While the exact reasons for anastomotic leaks are not fully understood, insufficient blood supply and resulting ischemia are considered key contributing factors[1–3]. To address this challenge, we developed implantable, bioresorbable bioimpedance sensors on medical-grade Polydioxanone (PDO) substrates.

These sensors were successfully implanted into a porcine animal model and enabled real-time *in-vivo* impedance spectroscopy at the site of a gastrointestinal anastomosis. Following experimentally induced ischemia, we observed distinct changes in the impedance signal. These signals can serve as an early indicator of ischemia, offering a promising route towards the timely detection of anastomotic leaks.



Implantation procedure (left), ischemic tissue (top right) and impedance signal (bottom right) after ischemia induction

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eSoil 2.0: A Sustainable Organic Bioelectronic Aerogel Scaffold for Leafy Greens

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Bioelectronic approaches offer a compelling solution to address sustainability challenges in controlled-environment agriculture. In hydroponics, widely used growth substrates such as rockwool provide only mechanical support and are energy-intensive to manufacture. We previously introduced eSoil 1.0, an organic, conductive aerogel for plant growth[1]. The eSoil scaffold, based on PEDOT:PSS and nanofibrillated cellulose (NFC), enabled a 50% biomass enhancement in barley under electrical stimulation. However, the reliance on costly and highly processed materials, as well as the use of specific crops limits its applicability to large-scale industrial agriculture.

In this work, we present eSoil 2.0 as a more sustainable alternative. We target leafy greens, particularly lettuce (*Lactuca sativa*), grown until the edible stages. Lettuce growth was optimized from seed to 35 days by identifying key factors such as pre-germination treatment, light-mediated seed priming, substrate pH, and shoot and root traits when planting. In parallel, we addressed material sustainability by replacing NFC with low-cost cellulose pulp. The incorporation of carbon-based fillers with good dispersion enabled the formation of a conductive aerogel scaffold. Electrochemical characterization via cyclic voltammetry revealed a preserved capacitive response and long-term charge retention. Additionally, mechanical testing confirmed the scaffold's ability to support robust plant growth. This work demonstrates a low-cost, sustainable biohybrid platform and advances the integration of bioelectronics and plants into next-generation hydroponic cultivation systems.

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Bi-Modal Modulation of Paracellular Permeability in Human In Vitro Barrier Models via Photoactive Polymer Nanoparticles

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Cellular barriers, composed of tightly connected epithelial or endothelial cells, are essential for maintaining physiological homeostasis by regulating the selective exchange of substances between body compartments and protecting tissues from harmful agents[1]. Their dysfunction is associated with various pathologies: for example, intestinal barrier disruption contributes to inflammatory bowel diseases such as Crohn's disease and ulcerative colitis[2], while blood–brain barrier impairment has been linked to neurodegenerative disorders[3]. Despite their protective role, these barriers can be transiently and selectively opened to enhance targeted delivery of therapeutic agents[4]. Paracellular transport, which occurs through the space between adjacent cells, is particularly advantageous for hydrophilic and uncharged molecules that are otherwise poorly membrane-permeable and prone to intracellular degradation. However, its main limitation lies in the need for controlled, reversible, and non-toxic opening of intercellular junctions. Several strategies have been explored to address this, but many face limitations: chemical modulators like calcium chelators may lack specificity and cause inflammation; surfactants can be damaging at high doses; and bioadhesive systems often show limited junction modulation[5]. Physical approaches such as ultrasound or electric fields offer spatial control but require complex technologies and may raise tissue safety concerns[6].

Our approach provides a targeted strategy for transient paracellular opening, triggered by the internalization of light-responsive semiconducting polymer-based nanoparticles (NPs) by endothelial or epithelial cells, followed by barrier restoration upon light activation. The NPs are composed of the conjugated polymer poly(3-hexylthiophene-2,5-diyl) (P3HT) and a hole-transporting layer material, poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS). They exhibit an average diameter of ~250 nm and absorption feature characteristic of P3HT dispersions, with peaks around 520, 560, and 615 nm. Once internalized, the NPs increase intracellular reactive oxygen species (ROS) within the *eu*stress range, supporting physiological cell function[7]. We show that in Human Umbilical Vein Endothelial Cells (HUVECs), this phenomenon initiates a signalling cascade that results in dissociation of junctional proteins, increased paracellular permeability (up to +36%, Transwell assay) and a reduction in TransEndothelial Electrical Resistance (TEER) by up to −55.8%. Upon light activation, photocatalytically generated ROS cause the restoring of junctional protein function. As a result, barrier permeability returns to basal levels, while TEER increases by 115.38%, exceeding original control values. This reversible modulation of barrier function suggests that these NPs may serve not only as tools for targeted drug delivery but also as a potential therapeutic platform for restoring integrity in compromised biological barriers. Furthermore, the possibility of NP functionalization holds potential for enhanced targeting and specific cell internalization, essential for *in vivo* applications where confinement to the target tissue is crucial.

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Tagged *in vivo* Polymerization of Conductive Polymers as Neuroelectronic Interfaces

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Conductive polymers (CPs) have gained increasing interest for bridging the gap between electronics and biological systems, as they provide advantages in contrast to inorganic rigid devices, such as biocompatibility, matching mechanical properties of tissues, mixed ionic and electronic conductivity and tuneable functionality.[1] Further advancements in this direction are provided by the polymerization of CPs *in situ* directly at the cell sites, which allows minimally invasive applications and enables highly localized targeting of specific cells and areas of interest. In this context, polythiophenes, such as the CP obtained from the trimer 2,5-bis(2,3-dihydrothieno[3,4-b][1,4]dioxin5-yl)thiophene (ETE), are promising materials that allow for the introduction of different functionalities on the side chain, as for instance with oleyl groups for cell membrane insertion or ionic groups for self-doping.[1,2] However, local polymerization to target specific neuronal sites as dendrites is still challenging. The *in situ* polymerization can be achieved with genetically targeted chemical assembly (GTCA) where neurons of interest are tagged by expressing recombinant extracellular enzymes. Horseradish peroxidase (HRP) or ascorbate peroxidase 2 (APEX2) yield oxidative polymerization by H_2O_2 consumption, while the engineered laccase (LaccID) uses O_2 improving the biocompatibility of the reaction.[3,4] This project aims to explore tagged *in situ* polymerization of modifiable ETE monomer for seamless integration of bioelectronics and biohybrids formation. To this aim, the recombinant enzymes HRP, APEX2, and LaccID are expressed at the extracellular side of the membrane of neuronal HT22 cell line and primary rat neurons. The assessment of enzyme expression is performed *via* immunostaining and imaging with fluorescence microscopy. Material characterization is performed *via* nuclear magnetic resonance (NMR) spectroscopy and the resulting *in situ* polymerization is investigated through optical microscopy. In further prospect, the side chain of the monomer can be tuned for enhanced conductivity or potential click chemistry exploring alternative neuron tagging methods. Targeting neurons or potentially dendrites will lead to further development towards artificial neurons. In conclusion, a chemical and biological toolbox is combined to conduct research on targeted *in situ* polymerization of conductive biomaterials as neuroelectronic interfaces.

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Passive classification of human hand gestures in real time exploiting dendritic integration with an organic artificial soma

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This study reports on the development of an organic neuromorphic framework for the real-time recognition of hand gesture from electromyographic (EMG) data. The electrodes in the framework are made of organic mixed ionic-electronic conductors (OMIECs), which endow the interfaces with response timescales and paradigms similar to those of biological synapses, including short-term plasticity. The system uses a common dendritic integrator, also known as an artificial soma, as the postsynaptic output and consists of three artificial synapses, each of which is activated by a muscle's EMG signal as the presynaptic input. Using only the raw EMG signals, by simply adjusting a priori the synaptic weights and in the absence of extra computational cost, the system successfully distinguishes between three different hand movements (i.e., Rock, Paper, Scissors from the roshambo traditional game) performed by human healthy subjects. Synaptic clefts are represented by polymeric electrolyte compartments, while synaptic terminals are built on Poly(3,4-ethylenedioxythiophene)/Polystyrene Sulfonate (PEDOT/PSS). In this framework, weight of synaptic connections is modified by acting on the ionic concentration in the electrolyte casting solution, optimizing the classification performance. The output of the classifier is hence a weighted combination of the input presynaptic signals, which yields a dimensionality reduction on the dataset, enabling classification by a simple thresholding strategy. The classification efficiency is evaluated in terms of a newly defined quantitative descriptor. This architecture is a promising building-block for hardware-level, passive, autonomous, and real-time processing of physiological signals in bioelectronic interfaces, due to its adaptability and ease of integration with biocompatible electrode arrays.

Is Printed Electronics a Sustainable Technology? A Framework to Efficiently Implement an Early-Stage Life-Cycle Analysis

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The rise of microelectronic system has been the major driving focus of the global economy for the last couple of decades. As we are now transitioning to the era of the internet-of-things, with an increasing number of small autonomous electronic circuits, e.g, for sensing, we need to urgently consider the environmental impact of this development due to the unsustainable use of natural resources. Thus, to ensure the environmental sustainability of the development, future electronics must prioritize both performance and environmental impact, explaining the interest in flexible and printed electronics. However, the sustainability claims often connected to the field of flexible and printed electronics must be substantiated using analytic methods, providing the motivation for quantitative Life-Cycle Analysis (LCA). Here we demonstrate our approach to implement an LCA for an early-state research topic such as Organic Electrochemical Transistors (OECTs). Using hands-on examples, we will show how to set up an inventory database (the core of the LCA) using a process-of-record (PoR). The PoR contains a plethora of different materials and processes available, and due to its modularity and adaptability, the PoR framework enables researchers to use this database for their own printed devices beyond the OECT example used here. By making LCA a standard tool in printed electronics, the community can move beyond sustainability claims to measurable environmental impact, driving truly responsible innovation in electronics.

Living Bioelectronics for Modulation of Neuronal Activity

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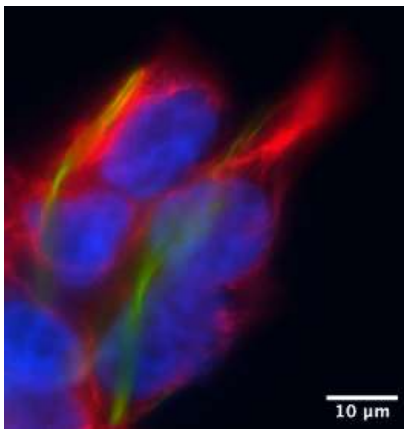
While increased softness and biocompatibility are main advancement in modern bioelectronics, current devices still require invasive implantation to interface living systems, hence lacking true dynamic, integration with host tissues. The innate ability of DTTO oligothiophene to assemble *in situ,* forming fluorescent conductive biofibers directly within living cells and whole organisms[1,2], offers a promising approach to harness seamless cell-integrated bioelectronics, hence enabling living organism to autonomously craft functional conductive interfaces. However, despite electrical conductivity of DTTO biofibers has been demonstrated, to date no studies have investigated their ability to act as living bioelectronics to monitor and perturbate neurons and whole animal activity. Using *in vitro* and *in vivo* models (*i.e. Hydra vulgaris* polyps), here we demonstrate the possibility to harness a new class of living electrodes assembled through the cell's physiological machinery, to ultimately modulate passive and active electrical properties of neurons and whole animal bioelectrical activity.



Vimentin immunofluorescence of neuroblastoma cells with integrated DTTO biofibers. Nulei are stained in blue, DTTO biofiber in green and vimentin in red.

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Biodegradable and biocompatible organic RFID tags

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To date, most bioelectronic devices require wired connections, which makes their implantation inconvenient for patients. As a solution to this shortcoming, wireless power transfer (WPT) is envisioned to remotely control and power bioelectronic systems. High-frequency radio-frequency identification (HF RFID), is a well-established technology for magnetic-field mediated untethered power transfer.
Usually, implanted RFID tags are made of biocompatible but non-biodegradable substrates, with metallic coils (e.g., gold, copper or platinum) featuring high thicknesses, that often require additional surgery for their removal. This work presents a novel straightforward fabrication technique for biodegradable implantable RFID tags built on poly-lactic acid (PLA) substrates equipped with organic coils made of Poly(3,4-ethylenedioxythiophene):Poly-styrene Sulfonate (PEDOT:PSS). Both materials are biocompatible and widely used in medical research and in bioelectronics. Furthermore, since more than 98% of the device weight is constituted by PLA, the final layout is >98% biodegradable.
In particular, RFID coils are achieved in a subtractive fashion by direct laser ablation of PEDOT:PSS spin-cast films supported on PLA. Coils are subsequently insulated by additional PLA films, to create the final working device. Upon interaction with an RFID reader, such devices can generate and sustain a potential difference sufficient to drive an electrolyte-gated organic transistor in the linear regime. Low-power bio-electronic applications involving implantable organic transistors and/or organic neuromorphic architectures, ranging from in situ bio-/chemo-sensing to transduction of electrophysiological data, might benefit of the proposed powering paradigm.

Sericin Electrodes for Long-Term Bio-Signal Monitoring

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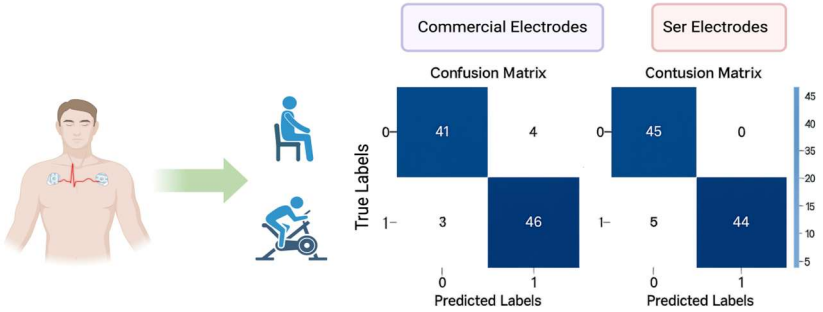
The rapid advancement of medical technologies has significantly increased the presence of medical devices (MDs) in healthcare settings, particularly medical electrodes used to record bio-signals such as electrocardiograms (ECG), electromyograms (EMG), and electroencephalograms (EEG). Despite their clinical importance, the disposable nature of these electrodes contributes to growing environmental concerns due to the use of plastic components and non-biodegradable materials. Additionally, the electrolytic gels commonly used to ensure good skin contact and high-quality signal acquisition tend to dry out over time, degrading signal quality during prolonged monitoring. These gels can also cause skin irritation due to their chemical composition.

This study addresses these limitations by developing a novel composite material for medical electrodes based on silk sericin (Ser) [1], a glycoprotein and secondary component of silk that is typically discarded as a byproduct of silk production. Sericin is biocompatible, biodegradable, and derived from waste, making it an attractive candidate for sustainable biomedical applications. The sericin used in this research is extracted via autoclaving, blended with polyvinyl alcohol (PVA) to enhance mechanical properties, and processed into freestanding films through evaporation. The addition of hygroscopic salts, particularly calcium chloride ($CaCl_2$), imparts self-adhesive properties to the film, improving skin adherence and signal stability over extended periods.

The optimized formulation was used to fabricate ECG electrodes. These electrodes demonstrated the ability to record high-quality ECG signals for up to 6 hours, outperforming standard commercial electrodes. Signal acquisition was carried out using custom-designed electronics, with real-time data visualization through a dedicated mobile application [1].

Performance evaluation involved six volunteers under both resting and stress conditions. Key cardiac intervals (PR, QRS, and QT) recorded with the developed electrodes were compared to those from commercial electrodes. The optimal salt concentration (20 wt%) yielded QRS duration values closely aligned with medical standards. Average percentage errors across all three intervals remained around or below 10% when varying salt concentrations. Furthermore, machine learning models were applied to ECG-derived features related to heart rate variability to assess the discriminative power of the electrodes. Confusion matrix analysis showed that the developed electrodes not only matched the commercial ones in performance but also effectively distinguished between normal and stressed conditions.

This innovative approach demonstrates a promising pathway toward eco-friendly, high-performance medical electrodes, combining sustainability with clinical reliability.



Confusion metrics of ECG signal acquired with Commercial and Ser electrodes

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Fluorophobic Effect Enables Selective Detection of PFAS in Water with Electrolyte-Gated Organic Transistors

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PerFluoroAlkyl Substances (PFAS) are responsible of major environmental pollution worldwide, as they are both persistent and mobile.[1] Environmental agencies impose strict regulations about PFAS in drinking water, hence there is an urgent need for on-field deployable, rapid, reproducible, and distributed monitoring of PFAS. We propose an ultra-sensitive sensor for perfluoroalkyl acids based on an organic transistor whose gate is functionalized with a binary self-assembled monolayer containing a perfluorinated molecule.[2] The device exploits the fluorophobic effect for selectively recognizing different PFAS based on the different number of fluorous interactions, viz. fluorine-fluorine (F…F) contacts, that can be formed. Remarkably, the organic transistor senses differences in the binding energy to linear PFAS surfactants in water of 4±1 kJ/mol, which corresponds to one -CF2- unit.[3] Our device allowed us to quantify PFAS in water down to ppt level of detection.

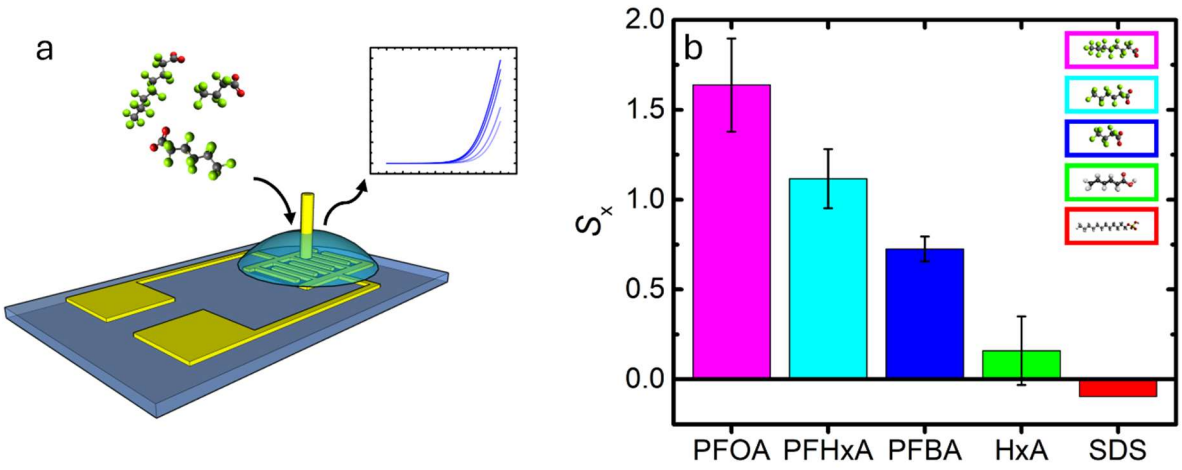

Figure: a) schematic representation of the sensor and of the electrical characterization; b) average signal (S_x) from several independent sensors for 10 nM solutions of different analytes. Three linear PFAS: perfluoro octanoic acid (PFOA, purple), perfluoro hexanoic acid (PFHxA, cyan) and perfluoro butanoic acid (PFBA, blue), and two control molecules: hexanoic acid (HxA, green) and sodium dodecyl sulfate (SDS, red).

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An optoelectronic microfluidic platform to investigate the potential of Hydra vulgaris for biohybrid material fabrication

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The concept of harnessing cellular machinery to fabricate hybrid materials within living tissues represents a transformative approach in materials science[1]. This strategy aspires to create novel materials composed of living cells that integrate the functional properties of both biological and synthetic systems. However, a major challenge remains in endowing materials with truly living attributes. In this context, we have demonstrated that the small freshwater polyp *Hydra vulgaris* can act as a living bioreactor capable of producing conductive biofibers from thiophene-based compounds[2,3]. In particular, we observed that the organic semiconductor oligomer ETE-S (EDOT–thiophene–EDOT trimer) undergoes in vivo polymerization within Hydra's basal disk cells and secreted adhesive material, resulting in the formation of conductive structures[3].
To investigate whether these conductive polymeric structures affect Hydra's electrophysiological behavior, we developed an optoelectronic microfluidic device to enable precise modulation of the organism's physiological microenvironment while allowing real-time monitoring of its electrical activity. The platform is fabricated using polydimethylsiloxane (PDMS), a biocompatible, optically transparent, cost effective, and gas-permeable material. A network of microchannels allows dynamic control of fluid composition and flow, while gently restraining the animal without causing damage. An integrated multi-electrode array enables localized electrophysiological recordings along the main body axis of Hydra in response to environmental changes or addition of several compounds, such as ETE-S. Furthermore, the device's optical transparency permits high-resolution imaging—both bright-field and fluorescent—making it possible to correlate electrical activity with morphological and biological responses under controlled conditions.
These results pave the way for future in vivo strategies that leverage the biosynthetic capabilities of simple multicellular organisms to fabricate functional biomaterials.

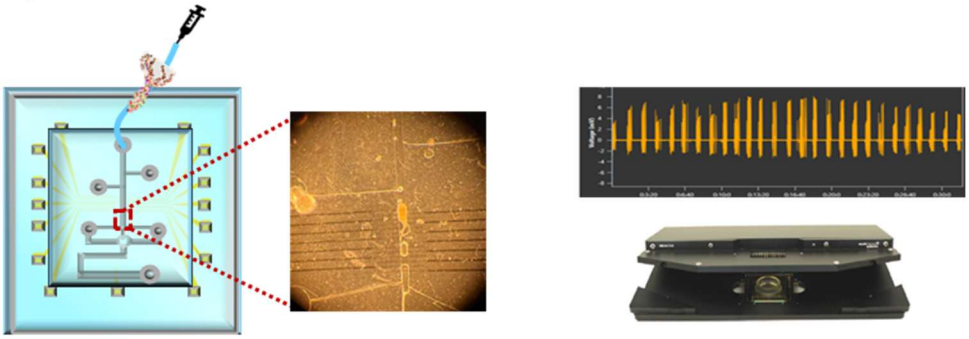

Figure 1. Optoelectronic microfluidic device used to stimulate and records electrical activity of Hydras.

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Integrated bioelectronics with micro-precision dispensing of OECTs

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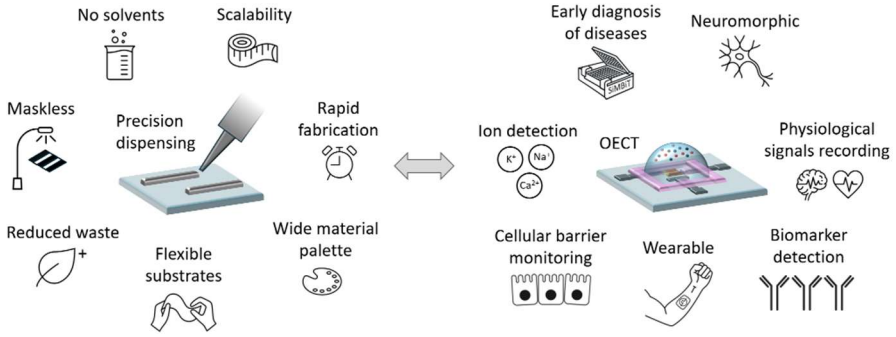
In the last few decades Organic electrochemical transistors (OECTs) have played a pivotal role in bridging the gap between biology and electronic, enabling real-time translation of biological quantities into amplified electronic signals and vice-versa. Thanks to their unique working mechanism, combined with the biocompatibility, the mechanical flexibility of conducting polymers and the low-voltage operating regimes, they have been extensively used in unprecedent, high performance bioelectronics applications such as high sensitivity ion-detection[1], biomarker detection[2], early disease diagnosis[3], neuromorphic electronics[4], electrophysiological signal recording[5] and many more. Conventional fabrication methods based on photolithography and etching can hinder their evolution. In fact, they require polymer, photoresist, developer compatible materials, limiting the fabrication palette and often demanding time-consuming multi-step manual peel-off procedure of sacrificial layers[1]. Moreover, this approach requires the consumption of additional non-functional material during the etching process, increasing the production cost and negatively impacting environmental sustainability. Dispensing technique addresses these challenges by directly depositing functional inks in a mask-free, fully additive process, reducing material waste. This approach affords rapid production of complex patterns and transistor architectures, allows to deposit a wide palette of materials (~30 ÷ 10000 cPs), and permit to define patterns with micrometre resolution, enabling additive, fast, scalable production of highly customizable OECTs, paving the way for advanced, high-density, widely tuneable, integrated bioelectronics.



Overview of the precision dispensing technique advantages and of OECTs bioelectronics applications

1.Romele, P. *et al.* Multiscale real time and high sensitivity ion detection with complementary organic electrochemical transistors amplifier. *Nature Communications 2020 11:1* **11**, 1–11 (2020).

2.Guo, K. *et al.* Rapid single-molecule detection of COVID-19 and MERS antigens via nanobody-functionalized organic electrochemical transistors. *Nature Biomedical Engineering 2021 5:7* **5**, 666–677 (2021).

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4.Yao, Y. *et al.* An organic electrochemical neuron for a neuromorphic perception system. *Proc Natl Acad Sci U S A* **122**, (2025).

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Robust 2D Ti_3C_2-MXene/AuNPs nanocomposite for biosensing application

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Biosensors provide a rapid and affordable approach for monitoring biological and chemical targets with potential in environmental analysis, healthcare, and public safety. Here, we introduce a cost-effective and facile, single-step method to synthesize 2D Ti_3C_2 MXene and gold nanoparticle nancomposites (MX@AuNPs) via a self-reduction approach. The MAX phase was etched with HF + HCl[1] and delaminated using LiCl to obtain stable single/few-layer MXene flakes (Figure-1a). MX@AuNPs were then functionalized by an innovative photochemical immobilization technique (PIT) to covalently attach antibodies. Etching and delamination were confirmed by XRD, SEM, and EDXS; the disappearance of the peak at $2\theta \approx 39°$ indicates the removal of interleaved aluminum while broadening and downshifting of the (002) peak to a lower angle ($2\theta \approx 6°$) reflected increased c-spacing and successful exfoliation[2] (Figure-1b). TEM images showed uniform AuNP decoration[3] on MXene flakes (Figure-1c), and UV-Vis spectra displayed a distinct AuNP peak alongside the MXene signature (Figure-1d). The MX@AuNPs biosensor combines the synergistic properties of MXene and AuNPs, enabling low detection limits and rapid response, offering a promising platform for portable water-quality monitoring and detection of pathogens such as E. coli.

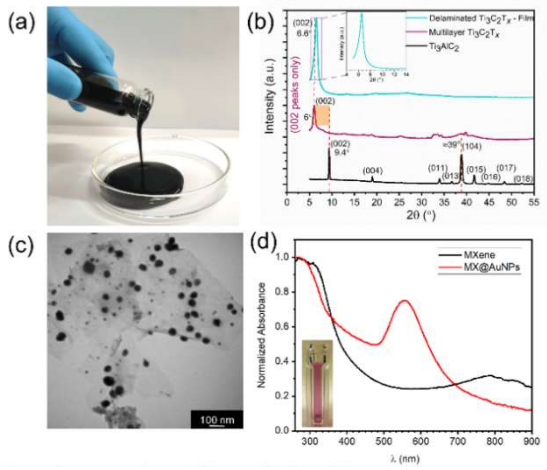

Figure.1 *Production and characterization of MXene and MX@AuNPs. (a) Single to few layer MXene Ink. (b) XRD patterns of Ti_3AlC_2 MAX, Ti_3C_2 multilayers powder, and delaminated MXene film shows successful etching and delamination. (c) TEM images of MX@AuNPs nanocomposites. (d) UV-vis spectra of MXene and MX@AuNPs (Inset shows the shiny purple color of nanocomposite).*

1. Thakur, A. et. al. *Step-by-Step Guide for Synthesis and Delamination of $Ti_3C_2T_x$ MXene, Small Methods*, **7**, 2300030 (2023).
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3. Zheng, Z. et. al. *In situ reduced MXene/AuNPs composite toward enhanced charging/discharging and specific capacitance*, *Journal of Advanced Ceramics,* **10**, 1061–1071 (2021).

Preparation of Crystallized PEDOT:PSS for Electrochemical Biomolecule Sensing

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The development of electrochemical sensors with high sensitivity and selectivity is critical for real-time human health monitoring. Herein, we present a high-performance electrochemical sensor for biomolecules detection, based on the commercially available conjugated polymer poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS). A sulfuric acid treatment was applied to the PEDOT:PSS film to effectively remove excess PSS, thereby regulating its electrical conductivity and crystallinity. As a result, the sensor exhibited excellent performance toward uric acid detection, achieving sensitivities of 4.348 μA/μM·cm² and 1.571 μA/μM·cm² over two linear ranges (1–90 μM and 100–300 μM), with limits of detection (LOD) of 0.207 μM and 0.575 μM respectively. The presence of two linear ranges may be attributed to diffusion limitations within the highly crystallized PEDOT:PSS structure. In contrast, the film with larger PSS content displayed only a single linear range but with lower sensitivity, supporting this hypothesis. Furthermore, the crystallized PEDOT:PSS sensor demonstrated broad electrochemical activity toward multiple biomolecules, including dopamine, xanthine, D-tyrosine, and theophylline, underscoring its potential for multiplexed monitoring of biomarkers in human body fluids for comprehensive health assessment.

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