2ND ITALY KOREA BILATERAL WORKSHOP ON ORGANIC BIOELECTRONICS

MANTOVA, ITALY · 17-19 SEPTEMBER 2025

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The aim of the Second Bilateral Italy-Korea Workshop on Organic Bioelectronics is to foster discussion, collaborations and exchange of scientists between the two multidisciplinary scientific communities. The Lecturers are internationally leading scientists in device physics and engineering, materials chemistry and engineering, biosensors, neuroelectronics and electrophysiology based on organic transistors. They will present their state-of-the-art research on Organic Bioelectronics. This initiative follows the First Bilateral Korea-Italy Meeting held in Busan (South Korea) on 2nd October 2024.

Chairpersons

Prof. Fabio Biscarini
Università di Modena e Reggio Emilia and Istituto Italiano di Tecnologia
Ferrara

Prof. Myung-Han Yoon
Gwanju Institute of Science and Technology, Gwanju

Speakers

- Annalisa Bonfiglio, Istituto Universitario di Studi Superiori IUSS, Pavia
- Carlo A. Bortolotti, Università di Modena e Reggio Emilia
- Mario Caironi, Istituto Italiano di Tecnologia, Milano
- Luciano Fadiga, Istituto Italiano di Tecnologia & Università di Ferrara
- Beatrice Fraboni, Università di Bologna
- Gaetano Scamarcio, Univ. di Bari & Consiglio Nazionale delle Ricerche
- Fabrizio Torricelli, Università di Brescia

- Sungjune Jung, Pohang University of Science and Technology, Pohang
- Kyungkon Kim, Ewha Womans University, Seoul
- Felix Sunjoo Kim, Chung-Ang University, Seoul
- Tae-il Kim, Sungkyunkwan University, Suwon
- Minseok Kwak, Pukyong National University, Busan
- Seung Soo Oh, Pohang University of Science and Technology, Pohang

2nd Italy Korea Bilateral Workshop on Organic Bioelectronics
18th September 2025

- Venue: Salone Mantegnesco, Fondazione Universitaria Mantova (FUM), Via Scarsellini 2

Scientific Programme

08:00-08:30: Welcome: Prof. Carlo Adolfo Porro (UNIMORE Rector, TBC); Prof. Marko Bertogna, UNIMORE provost for Mantova (TBC); Dr. Luisa Lavagnini, FUM coordinator.

- Session I: Chair M.H. Yoon

08:30-09:00: B. Fraboni
09:00-09:30: S. Jung
09:30-10:00: G. Scamarcio
10:00-10:30 S. S. Oh

<u>10:30-11:00: coffee break and group photo</u>

- Session II Chair: L. Fadiga

11:00-11:30: T. Kim
11:30:12:00: F. Torricelli
12:00-12:30: M. Kwak
12:30-13:00: C.A. Bortolotti

<u>13:00-14:00. Lunch at Ristorante Tavola Calda "Il Punto", Via Solferino e San Martino 36</u>

- Venue: Sala Virgilio, Fondazione Universitaria Mantova (FUM), Via Scarsellini 2

- Session III Chair: F. Biscarini

14:00-14:30: L. Fadiga
14:30-15:00: K. Kim
15:00-15:30: A. Bonfiglio

<u>15:30-16:00: Coffee break and informal discussions</u>

- Session IV: chair A. Bonfiglio

16:00-16:30: F. S. Kim
16:30-17:00: M. Caironi
17:00-17:15: Short table tour and closing remarks

Fully-Organic Flexible Detectors For Real-Time Dose Monitoring During Radio/Proton Therapy

Beatrice Fraboni
beatrice.fraboni@unibo.it
Department of Physics and Astronomy, University of Bologna, Italy

The development of detectors for high energy photons, protons and heavy particles is a long-lasting research topic not only for fundamental applications but also, more recently, for medical applications in radio and hadron therapy. There is an increasing demand for sensors able to provide, ideally in-situ and in real-time, an accurate recording and mapping of the dose delivered during a treatment plan. The development of novel high performing, thin and flexible sensors for the detection of ionizing radiation in real-time at affordable costs is rapidly increasing, as the technology currently available still fails to address the requirements of large-area, conformability and portability, lightweight and low power operation.

Organic small molecules and polymers are promising active layers for advanced dosimetry purposes, as their mechanical features allow the development of devices able to adapt to complex contoured surfaces with outstanding portability (low power operation) and lightweight. They also provide the unique possibility to develop human-tissue-equivalent detectors, thanks to their density and composition, which makes them ideal candidates for medical dosimetry applications. Their low average atomic number and density, also grants a low absorption of the incoming radiation, making them extremely radiation-tolerant. The physical process of radiation detection for organic thin- film based detectors will be discussed in two different configurations: 1) the direct one, based on a simple planar device with an organic thin film as active conversion layer, and 2) the indirect one, based on a polysiloxane-based scintillating layer effectively coupled to an organic phototransistor (OPT).

We report on their performance under exposure to intense photons and MeV protons radiation fields and will discuss how to detect and exploit the energy absorbed both by the organic semiconducting layer and by the plastic substrate, allowing to extrapolate information on the irradiation history of the detector. A new kinetic model has been developed to describe the detector response mechanism, able to precisely reproduce the dynamic response of the device under photon/proton irradiation and to provide further insight into the physical processes controlling its response.

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Organic Printed Bioelectronic Platforms for Monitoring In Vivo and In Vitro Human Tissues

Sungjune Jung
sjjung@postech.ac.kr
Department of Materials Science & Engineering, Pohang University of Science and Technology (POSTECH), Korea

Organic bioelectronics has emerged as a transformative field, enabling seamless integration between electronic devices and biological systems through the unique properties of organic semiconductors. In this work, we present two advanced organic printed bioelectronic platforms—one designed for recording neural activity in vivo, and the other for real-time monitoring of 3D-bioprinted in vitro lung tissue models. First, we report inkjet-printed organic voltage amplifiers that monolithically integrate organic electrochemical transistors (OECTs) with thin-film polymer resistors on a highly flexible substrate. These amplifiers exhibit high transconductance and mechanical compliance, enabling robust in vivo recording of brain activity. We also introduce a 3D electrolyte-surrounded OECT array, developed as an active neural interface for implantation into the sciatic nerves of rodents. This platform achieves high-resolution biosignal acquisition across a wide frequency range during mechanical stimulation of peripheral mechanoreceptors. Second, we present a non-invasive tissue-electronic system that integrates large-area, inkjet-printed OECTs with 3D-bioprinted, multilayered human lung tissues. This platform enables continuous, label-free assessment of tissue formation and barrier integrity in both liquid-liquid and air-liquid interface cultures. Notably, we demonstrate its capability to monitor epithelial barrier degradation following H1N1 influenza infection, and to quantify the therapeutic effects of oseltamivir (Tamiflu®) in a dose-dependent manner. Together, these platforms exemplify the convergence of organic electronics, additive manufacturing, and tissue engineering, offering new directions for real-time physiological monitoring, disease modelling, and personalized medicine.

Cooperative Electrostatics at Biointerfaces: Amplification Mechanisms in Single-Molecule Biosensors

Gaetano Scamarcio
gaetano.scamarcio@cnr.it
CNR-Istituto Nanoscienze, NEST Scuola Normale Superiore, Pisa, Italy

By integrating bio-functionalized surfaces into large-area electrolyte-gated transistors [1-3] and graphene-based optoelectronic devices [4] we are developing new sensing platforms capable of probing individual molecular events at the physical limit. Strikingly, even a few binding events can induce a cooperative electrostatic reorganization of the physisorbed protein layer, resulting in a pronounced shift in surface potential. This amplification mechanism at earth of our single molecule biosensors, is supported by experimental evidence using Kelvin probe force microscopy (KPFM), [5] polarization-modulation infrared reflection-absorption spectroscopy (PM-IRRAS), attenuated total reflection infrared spectroscopy (ATR). [6] Our results indicate a non-random secondary structure within the physisorbed layer, challenging conventional models of protein physisorption, and revealing new frontiers in soft matter at the intersection of condensed matter physics, nanotechnology, biophysics, and chemistry. At this crossroads, matter becomes a carrier of information, and molecular interactions can be directly observed and manipulated. This research not only deepens our understanding of complex systems but also opens transformative applications in ultra-early diagnostics, sensing, and next-generation health technologies.

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Live streaming of a single cell's life over a local pH- and mRNA-monitoring nanowire waveguide

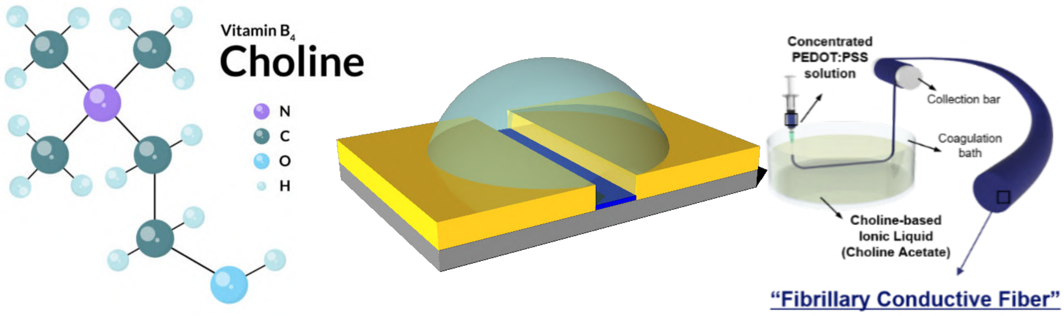
Seung Soo Oh
seungsoo@postech.ac.kr
Department of Material Science and Engineering, Pohang University of Science and Technology (POSTECH), Korea

In this talk, I demonstrate a single-cell analysis technique that enables real-time monitoring of spatiotemporal pH and mRNA concentration changes. The key strategy is a development of a nanowire probe consisting of a nanowire waveguide, fabricated via three-dimensional (3D) writing of nanowires on a tapered optical fiber, and target-sensitive molecule that is covalently attached to the surface of the nanowire waveguide. Unlike conventional single cell analysis methods, this nanowire probe can overcome a variety of critical issues like the real-time monitoring in living cells or precise positioning of the probe across cellular membrane without damaging to single cells, based on the advantage of freestanding nanowire geometry. First, I introduce a pH-sensitive nanowire probe for real-time monitoring of intracellular pH in a single living cell. pH variations of different compartments inside a living cell, organelle-exclusive pH homeostasis, and stimuli-selective pH regulations are successfully monitored to provide a fundamental understanding of the role of subcellular compartments. Second, I introduce a mRNA-sensitive nanowire probe for real-time quantification of intracellular mRNA levels in diverse types of living mammalian cells. In particular, it is revealed that intracellular mRNA level in single living cells can change in real-time, according to cell type, mRNA types, and external stimuli, as a result of homeostasis of single living cells.

Choline ionic liquid-based organic electrochemical transistors for bioelectronics

Tae-il Kim
taeilkim@skku.edu
School of Chemical Engineering, Sungkyunkwan University (SKKU), Suwon, Korea

Biocompatible, biodegradable, and solid-state electrolyte-based organic electrochemical transistors are demonstrated. As the electrolyte is composed of all edible-level materials, which are levan polysaccharide and choline-based ionic liquid, the organic transistor fabricated on the electrolyte can be biocompatible and biodegradable.[1] Compared to the other ion gel-based electrolytes, it has superior electrical and mechanical properties, large specific capacitance (≈40 µF cm^{-2}), non-volatility, flexibility, and high transparency. Thus, it shows mechanical reliability by maintaining electrical performances under up to 1.11% of effective bending strain, 5% of stretching, and low operation voltage range when utilized in organic transistors. Moreover, the choline ionic liquid can modify PEDOT:PSS interface and their functions for enhanced mode operation of OECT.[2] The measured ECG signals from the transistors, compared to signals from electrode-based sensors, has a superior signal-to-noise ratio.[3] The biocompatible and biodegradable materials and devices can contribute to the development of many bioelectronics.



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From Organic Electrochemical Transistors Integrated with Additive Methods to Artificial Neurons for Neuromorphic Biosensing

Fabrizio Torricelli
fabrizio.torrricelli@unibs.it
Department of Information Engineering, University of Brescia, Brescia, Italy

Organic electrochemical transistors (OECTs) are emerging as key components for next-generation bioelectronics, thanks to their biocompatibility, low operating voltage, and high transconductance. This talk presents an integrated strategy that combines advanced additive manufacturing of OECTs with their application in organic artificial neurons for neuromorphic biosensing. Using a fully additive fabrication process, OECTs are monolithically integrated on flexible substrates, enabling real-time amplification of biosignals with minimal distortion. This technological platform is then employed to develop organic neurons capable of operating in liquid environments. By combining experimental results, numerical simulations, and analytical models, the talk explores key neuromorphic behaviors such as spiking activity, excitability, and ion-mediated signalling, under biologically relevant conditions. The proposed framework connects material properties and device architecture to emergent neuron-like dynamics, providing guidelines for device design. Altogether, these advances lay the foundation for intelligent, adaptive, and cost-effective organic biointerfaces capable of sensing, processing, and responding to biological signals in real time.

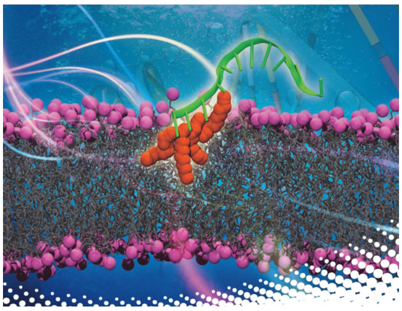
Amphiphilic oligonucleotides interacting with cell membrane: experimental and computational studies

Minseok Kwak

mkwak@pukyong.ac.kr

Department of Chemistry and Industry 4.0 Convergence Bionics Engineering, Pukyong National University, Busan, Korea

This presentation will focus on lipid-modified DNAs with synthetic hydrophobic segments covalently connected to oligonucleotides.
The self-assembled lipid-DNA micelle is a versatile delivery platform where biomolecules such as DNA, RNA, and peptide are co-loaded within the carrier for anti-cancer therapeutics or elsewhere. These materials exhibit both the complementary nucleobase recognition of DNA and the aggregation behavior of amphiphilic macromolecules. Here, successful *in vivo* utilization of the materials in immunology and gene silencing will be demonstrated. Furthermore, we performed molecular dynamics (MD) simulations and experiments to understand the underlying mechanism for phenomena at cell membranes, such as docking and endosome formation. Using fluorescence microscopy and MD simulation, we demonstrated that the interaction between lipid-DNA micelles and cell membranes depended on the presence of lipid moiety. Lastly, the images obtained by confocal microscopy showed that the lipid-DNA accumulated on the cell membrane, and the accumulation induced cellular internalization. Then, we observed that the membrane-docked lipid-DNAs were internalized by forming the endosome into cells using electron microscopy.



Keywords: endosome; cell uptake; drug delivery; immunotherapy; RNAi.

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Electrolyte gated organic transistors as highly sensitive tools for personalized medicine

Carlo Augusto Bortolotti
carloaugusto.bortolotti@unimore.it
Department of Life Sciences, University of Modena and Reggio Emilia, Modena, Italy

Organic electronic devices have proven to be highly interesting alternatives to state-of-the-art, mostly optical assays in the field of biosensing. In particular, electrolyte-gated organic transistors (EGOTs) have been developed in the last decade as ultra-sensitive and promptly reconfigurable tools for the detection of a number of analytes, spanning a wide lengthscale, from neurotransmitters to small proteins, from antibodies to viruses. EGOTs can find application in a number of fields, ranging from healthcare to food safety to environmental problems. Of particular interest is the fact that the well demonstrated potential of EGOTs as ultra-sensitive biosensors could have a tremendous impact on precision medicine, thanks to the combination of extremely low limit of detection, reduced costs and rapid response, allowing for early detection and frequent monitoring of a number of biomarkers essential requisites for personalized therapies. In this talk, I will present a selection of examples of EGOT-based biosensors developed by our group for biomarkers of medical relevance, ranging from small molecules such as uric acid and cortisol to proteins and up to extracellular vesicles. The demonstration of these biosensors could speed-up the transition towards early diagnosis and treatments tailored to the patient. The research leading to these results has received funding from the European Union – NextGenerationEU through the Italian Ministry of University and Research under PNRR – M4C2-I1.3 Project PE_00000019 "HEAL ITALIA" to Carlo Augusto Bortolotti (CUP E93C22001860006).

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Brain Interfaces

Luciano Fadiga
luciano.fadiga@unife.it
University of Ferrara and the Italian Institute of Technology

In recent years we have seen an exponential growth in scientific publications on Brain-Machine and Brain-Computer Interfaces (BMIs). This growth has not been matched by a parallel expansion on the applications front, and in the rare cases where this has occurred, it has been “proofs of concept” rather than interventions that have brought real benefit to the patient. In my exposition I will discuss the advantages and critical issues in designing interfaces with the human brain, addressing in particular the optimization of signal quality, the problem of electrical stimulation, and biocompatibility. In this respect, I will take into consideration the innovation introduced by organic electronics. Finally, I will address the issue of utility: what scenarios can really represent a step forward in improving the quality of life of a severely disabled patient? And why do we forget that the most important interface is always between human brains?

A Novel Approach for Controlling Growth of Perovskite Crystals in Vacuum

Kyungkon Kim
kimkk@ewha.ac.kr
Department of Chemistry and Nano Science, Ewha Womans University, Seoul, Korea

In this presentation, I will discuss a novel method for controlling the growth of perovskite crystals in a vacuum thermal evaporation process by utilizing a vacuum-processable additive, propylene urea (PU). By co-evaporating perovskite precursors with PU to form the perovskite layer (Figure1), PU, acting as a Lewis base additive, retards the direct reaction between the perovskite precursors. This facilitates larger domain size and reduced defect density. Following the removal of the residual additive, the perovskite layer, exhibiting improved crystallinity, demonstrates reduced charge recombination, as confirmed by time-resolved microwave conductivity analysis. Consequently, there is a notable enhancement in open-circuit voltage and power conversion efficiency, increasing from 1.05 V to 1.15 V and from 17.17% to 18.31%, respectively. The incorporation of a vacuum-processable and removable Lewis's base additive into the fabrication of vacuum-processed perovskite solar cells offers new avenues for optimizing these devices.

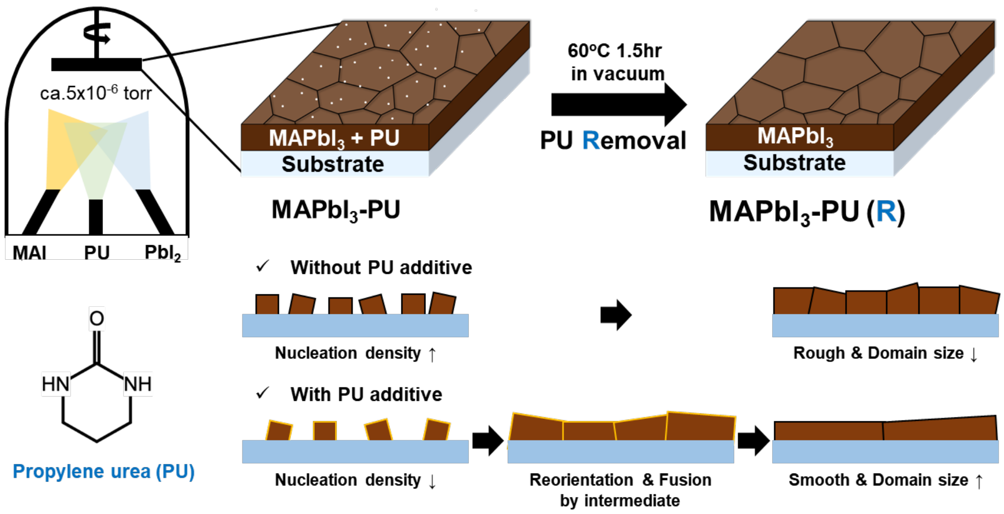

Figure 1. Schematic diagram of the vacuum-processed perovskite fabrication process with a vacuum-processable propylene urea (PU) additive and subsequent removal step for residual PU additive. Schematic representation of perovskite crystal formation without and with PU additive and corresponding chemical structure of PU are also shown.

Multimodal Organic Sensing via Seamless SPR–OFET Integration

Annalisa Bonfiglio
annalisa.bonfiglio@iusspavia.it
Scuola Universitaria Superiore IUSS – Pavia (Italy)

The demand for compact, multimodal, and integrable sensing platforms is growing rapidly across bioanalytical domains, from cellular models to wearable devices. In this contribution, we present an innovative biosensing approach based on the combined use of two transduction modalities: optical detection via Surface Plasmon Resonance (SPR) and electronic readout through Extended-Gate Organic Field-Effect Transistors (ExG-OFETs).

These technologies, recently demonstrated in an integrated platform [1], exhibit a high degree of complementarity: while SPR enables highly specific, label-free detection of molecular interactions at the interface, ExG-OFETs provide fast, low-power, and spatially resolved readouts of electrical signals and ionic changes. Importantly, both approaches are based on material systems and fabrication strategies that are inherently compatible, enabling seamless integration on flexible substrates.

This methodological duality enhances the functional capacity of the system, allowing simultaneous access to orthogonal information streams—chemical, electrical, and molecular—from the same biological sample. Furthermore, the versatility and low-cost nature of organic materials allow these platforms to be adapted to a range of bioanalytical scenarios, from 3D in vitro cellular models to wearable health monitoring applications.

Our results demonstrate how cross-modal integration can drive the next generation of scalable, flexible, and multifunctional biosensing platforms, with the potential to bridge fundamental research and real-world healthcare solutions.

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Hysteresis and Threshold Voltage of Solid-State Organic Electrochemical Transistors

Felix Sunjoo Kim
fskim@cau.ac.kr
Department of Chemical Engineering, Chung-Ang University (CAU), Seoul, Korea

Organic electrochemical transistor (OECT) is considered as a key element in bioelectronics and neuromorphic systems. OECTs can mimic the working mechanism of the nervous system and is compatible with the frequencies of living organisms, because the devices work with ions and charge carriers. In this talk, we present our recent studies on controlling the ion distribution in solid-state OECTs to finely tune their electrical performance, in terms of hysteresis and threshold voltage. We show how ion densities and distribution can alter the timescale of transport and polarization in electrolytic systems, and therefore the device hysteresis. This can determine whether the device would be applicable to highly reliable low-hysteresis applications or highly responsive memory systems. We also show that the threshold voltage and the mode of device operation are a function of the ionic components, as these ions can have interactions with the channel material in different ways and degrees. We conclude that both electrolyte and channel materials in OECTs can be engineered to directly tune the electrochemical processes, including ion transport, accumulation/depletion, and charge transfer, and that our strategy needs to be explored further for system level integration of OECTs.

Recording of Action Potentials with Printed Polymer Transistors

Mario Caironi
mario.caironi@iit.it
Center for Nano Science and Technology, Istituto Italiano di Tecnologia, Milan, Italy

Action Potentials (APs) of excitable cells provide information about cells physiology. Most of electrical tools available to probe APs are either invasive or require complex manufacturing processes. Minimally invasive, high-throughput and high-fidelity recording of APs of electrogenic cells with scalable technologies is in high demand. With the aim of enabling a cost-effective, non-invasive probing platform based on devices that can be easily fabricated and processed from solution with large-area printing techniques, we propose planar Electrolyte Gated Field-Effect Transistors (EGFETs) based on ink-jet printed polymer semiconductors. Despite the planar geometry of the device, we could demonstrate the spontaneous recording of APs of human induced pluripotent stem cells derived cardiomyocytes with patch-clamp like fidelity. The simplicity of the device combined with the high signal to noise ratio opens up new opportunities for advanced electrophysiology tools combining patch-clamp like signal quality and microelectrodes arrays scalability and throughput.


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