HL 2: Focus Session: Biocompatible Organic Semiconductors for Artificial Intelligence

This Focus Session deals with electronic components that interface with biological systems and offer diverse possibilities in research and applications, e.g., in healthcare. Carbon-based organic semiconductors are particularly well-suited to this interface: They enable electronic devices with a broad spectrum of electronic and optoelectronic functions that are biocompatible and often even resorbable by the body. Furthermore, they are particularly well-suited for neuromorphic functions that enable local data analysis computing towards artificial and neurohybrid intelligence. Turning this vision into practice requires extensive interdisciplinary research on semiconductor materials, components, and electronic systems. This Focus Session aims to provide an overview of the current state of the art including new organic materials, devices and core applications in bioelectronic interfaces.

Organized by Karl Leo

Time: Monday 9:30–12:45 Location: POT/0051

Invited Talk HL 2.1 Mon 9:30 POT/0051
Intrinsically stretchable polymers and devices for biosensing applications — •Ulrike Kraft — Organic Bioelectronics Research Group, MPI for Polymer Research, Mainz, Germany

Organic electrochemical transistors (OECTs) currently attract vast interest for biosensing applications due to their, intrinsic signal amplification and low operating voltages, enabling sensing in close contact to the human body and in aqueous environments with liquid analytes. Furthermore, the low elastic modulus of polymers can be tailored to match that of soft biological tissues, drawing increasing interest towards soft and stretchable health-monitoring devices.

The first part of the talk will focus on our work on biosensors based on planar OECTs that are functionalized with antibodies for e.g. the detection of the SARS-CoV-2 spike protein or with aptamers for the detection of e.g. cytokines, which are proteins crucial for immune regulation and inflammatory responses.

In the second part, I will summarize our efforts on stretchable electronics including a fast and reliable transfer-printing method for the deposition of conductive polymer films (e.g. PEDOT:PSS) onto stretchable, biodegradable substrates Taking advantage of this method and infusing the substrates with small-molecule plasticizers that also diffuse into the conductive films, improves the electrical performance as well as the mechanical properties. Lastly, this platform is employed for studying the effect of strain on the figures-of-merit of intrinsically stretchable OECTs.

Invited Talk HL 2.2 Mon 10:00 POT/0051
Complexity in Organic Mixed Ionic Electronic Conductors and its Application in Neuromorphic Computing — •Hans Kleemann — Technische Universität Dresden, Dresden, Germany

Complexity is decisive property enabling systems to work at the edge of chaos, which is necessary for resource-efficient computing and the design of intelligent machines. The complex behavior of a system originates from the nonlinear properties of all its components, resulting in a plethora of different signatures such as multi-state stability, stochastic oscillations, etc. These nonlinear properties and their couplings need to be understood and modeled to develop intelligent & energy-efficient computers.

Organic mixed ionic-electronic conductors (OMIECs) based on conjugated polymers open up a fascinating field of research where the ionic-electronic coupling, in combination with correlation effects at high charge carrier densities enables the implementation of various paradigms of neuromorphic computing. In this contribution, I will discuss the various signatures of nonlinearity and complexity that have been observed in OMIECs in recent years and review the current understanding of these effects. Furthermore, I will discuss how phenomena such as hysteresis and bistability can be employed to design fundamental elements of asynchronous computing, such as spiking neurons or C-elements, providing the foundation for the efficient implementation of approaches of stochastic computing in hardware. Finally, I will present a technology platform that allows us to integrate such devices in all-printed, complementary circuits operating above 1kHz.

Invited Talk HL 2.3 Mon 10:30 POT/0051
Organic Neuromorphic Interfaces for Biohybrid Systems: Material and Structural Biomimicry of Synaptic Plasticity — •Francesca Santoro — Forschngszentrum Jülich

Organic neuromorphic interfaces offer a promising route toward biohybrid systems that emulate neural function. We present PEDOT:PSS-based organic electrochemical transistors that exploit mixed ionic*electronic conduction and biocompatibility to reproduce key mechanisms of synaptic plasticity. Through the integration of biogels and azopolymer-functionalized conjugated polymers, neural activity is modulated by chemical and optical stimuli, enabling short- and long-term plasticity and interactions with neurotransmitters such as dopamine and glutamate. Beyond planar devices, 2.5D and 3D microfabricated organic semiconductor architectures fabricated by two-photon lithography or electrodeposition mimic neuronal morphology and promote cell adhesion and connectivity. The mechanical compliance of these materials supports stable interfacing with soft tissues, underscoring the role of material and structural biomimicry in next-generation organic biohybrid neuromorphic platforms.

15 min. break

Invited Talk HL 2.4 Mon 11:15 POT/0051
Fully-organic flexible detectors for real-time dose monitoring during radio/proton therapy — •Beatrice Fraboni — Department of Physics and Astronomy , University of Bologna, Italy

The development of detectors for high energy ionizing radiation is a long-lasting research topic not only for fundamental applications but also for medical applications in radio and hadron therapy. Innovative sensors are needed, able to provide, in-situ and in real-time, an accurate recording and mapping of the dose delivered during a treatment plan. 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 dosimeters, thanks to their density and composition. 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). A new kinetic model has been developed to describe the organic dosimeter response mechanism under photon/proton irradiation and to provide further insight into the physical processes controlling its response.

I.Fratelli et al Science Advances 11, 7633 (2025) S. Calvi et al., NPJ Flexible Electronics 7,5 (2023)

Invited Talk HL 2.5 Mon 11:45 POT/0051
Organic LEDs and photodetectors for light-based diagnostics and therapy — •Caroline Murawski[1,2], Rabiul Islam[1,2], Siddhartha Saggar[1,2], and Jens P. Weber[1,2] — [1]Institute of Solid-State Electronics, TUD Dresden University of Technology, 01062 Dresden, Germany — [2]Kurt Schwabe Institute for Sensor Technologies, 04736 Waldheim, Germany

Light-based biomedical sensing and therapy enables highly precise, timely and contactless interventions and range from neuronal stimulation via optogenetics over sensing cellular activity by functional fluorescence to monitoring health signals using wearable devices. Organic semiconductors are ideally suited building blocks due to their tunability of material properties, mechanical flexibility and ability for patterning to microscopic shapes. Here, I will present the development of organic LEDs (OLEDs) and photodiodes (OPDs) as light sources and sensors for biomedical applications. The OLEDs are tailored towards high power output and application-specific angular and spectral emission properties. Devices are fabricated on flexible substrates, patterned to sub-mm scale, and applied in optogenetics and fluorescence imaging. Furthermore, I will show flexible OPDs used for photoplethysmography at ambient light conditions and under water.

HL 2.6 Mon 12:15 POT/0051

Reservoir computing with mixed ionic-electronic conductors — •Richard Kantelberg, Hans Kleemann, and Karl Leo — Institut für Angewandte Physik, TU Dresden

Reservoir computing (RC) is a promising paradigm for machine learning that utilizes dynamic systems, termed as reservoirs, to process and analyze complex temporal data. Organic mixed ionic electronic conductors (OMIECs) have emerged as a novel class of materials with intriguing properties, such as their ability to exhibit both electronic and ionic conductivity, as well as their biocompatibility, flexibility, and low power consumption[1]. These features make OMIECs particularly suitable for the development of unconventional computing architectures in the field of bioelectronics[2]. We present recent findings interlinking electronic conductivity, system nonlinearity and reservoir size with the neuromorphic functionality and RC performance of self-organized and structured OMIEC reservoirs. This study includes novel insights into the differences and similarities of p-type, n-type and ambipolar semiconductors in terms of operation speed and energy consumption. The recent progress in reservoir computing using organic mixed ionic electronic provides valuable knowledge for the targeted development OMIEC reservoirs.

References 1.*Paulsen, B. D., Tybrandt, K., Stavrinidou, E. & Rivnay, J. Organic mixed ionic*electronic conductors. Nat. Mater. 19, 13*26 (2020). 2.*van de Burgt, Y., Melianas, A., Keene, S. T., Malliaras, G. & Salleo, A. Organic electronics for neuromorphic computing. Nat. Electron. 1, 386*397 (2018).

HL 2.7 Mon 12:30 POT/0051

Redundant information in physical reservoir computing — •Andreas Hofacker, Richard Kantelberg, Hans Kleemann, and Karl Leo — Dresden Integrated Center for Applied Physics and Photonic Materials (DC-IAPP), TU Dresden, Dresden, Germany

Maximizing the processing power of a physical reservoir given its physical constraints is crucial for practical applications, but remains an open problem. As a basis for such an optimization, a quantity measuring reservoir capability is needed. To address this need, we propose the use of independent component analysis for assessing information content in reservoir outputs. We present evaluations of organic mixed ionic-electronic conductor based physical and simulated reservoirs and show that task-specific performance is linked to information redundancy in the output channels. By leveraging this insight, sparser reservoir readout can be realised without loss of performance.