

SYMPOSIUM BM07

Bioelectronics—Fundamentals, Materials and Devices
November 26 - November 30, 2018

Symposium Organizers

Sahika Inal, King Abdullah University of Science and Technology
Christian B. Nielsen, Queen Mary University of London
Andreas Offenhäusser, Forschungszentrum Juelich
Roisin Owens, University of Cambridge

Symposium Support

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* Invited Paper

SESSION BM07.01: Flexible, Stretchable Active/Passive Materials/Devices for Health Monitoring
Session Chairs: Sahika Inal, Christian B. Nielsen, Tsuyoshi Sekitani and Benjamin Tee
Monday Morning, November 26, 2018
Sheraton, 2nd Floor, Constitution B

8:00 AM BM07.01.01

Bioinspired Wet/Dry Adhesion for Bioelectronics [Changhyun Pang](#)^{1,2}; ¹School of Chemical Engineering, Sungkyunkwan University, Suwon-si, Korea (the Republic of); ²Advanced Institute of Nanotechnology (SAINT), Sungkyunkwan University, Suwon, Korea (the Republic of).

Recently, extraordinary performances of natural creatures living in various conditions have been explored to understand their reversible dry/wet adhesion, including gecko feet, insect secretion, mosquito needles or endoparasitic worm's proboscis, octopus suction cups, and slug's footpad with viscous mucus. Extensive studies on the adhesive properties of such animal skins have revealed various multiscale architectures inducing various physical interactions. The attachment phenomena of various hierarchical architectures found in nature have extensively drawn attention for developing highly biocompatible adhesive on skin or wet inner organs without any chemical glue. Structural adhesive systems have become important to address the issues of human-machine interactions by smart outer/inner organ-attachable devices for diagnosis and therapy.

Breakthroughs in flexible and conductive materials have accentuated the development of wearable or organ-attachable bioelectronics for stable biosignal monitoring and drug delivery. For such medical applications, the devices need to manifest conformal contact on human skin even under dynamic movements, as well as repeatable, long-term attachment without skin irritations or chemical contaminations. Here, we investigated an artificial reversible wet/dry adhesion systems biologically inspired by the suction cups of octopi and amphibian's pad. Our biologically inspired architectures exhibit strong, reversible, highly repeatable adhesion to silicon wafers, glass, and rough skin surfaces under various conditions. Applying these bioinspired architectures to interfacial adhesive layers can attribute to developing skin-attachable or implantable bioelectronics for health diagnosis, controlled drug therapeutics, and achieving multifunctional integrated devices for ubiquitous-healthcare systems.

8:15 AM BM07.01.02

Nanocellulose Printed Circuit Boards for Human Monitoring [Jonathan Yuen](#)¹, Dan Zabetakis¹, Lisa Shriver-Lake¹, Md Qumrul Hasan², David A. Stenger¹, Scott A. Walper¹ and Gymama Slaughter²; ¹Naval Research Laboratory, Washington, District of Columbia, United States; ²Computer Science and Electrical Engineering, University of Maryland, Baltimore County, Baltimore, Maryland, United States.

Flexible and ultrathin substrates supporting microelectronic components have the potential to spur the development of pervasive healthcare and the internet of things by providing sensors and bioelectronics that can provide seamless and imperceptible integration. We will describe our ongoing work to develop sensing electronics on microns-thin bacterial nanocellulose for human monitoring applications. The porosity and hydrophobicity of nanocellulose sheets offer advantages that typical plastics cannot provide, such wicking of analytes and absorption of inks. We have developed a printing method to form nanocellulose printed circuit boards (PCBs), and created a simple low temperature soldering process to form circuit structures using standard surface-mount components on our nanocellulose PCBs. This has been used to create nanocellulose decals that measure human body temperature and perform pulse oximetry. We have also developed self-powered electronics for sensing of bioanalytes, such as glucose. For all applications, the fabrication processes are solution-based and requires only ambient processing, and therefore simple, potentially low-cost, and can be aimed for a wide range of applications.

8:30 AM BM07.01.03

Intrinsically Stretchable Polymer Semiconductors and Electronics as an Emerging Platform for Bioelectronics [Sihong Wang](#); Institute for Molecular Engineering, The University of Chicago, Chicago, Illinois, United States.

The vast amount of biological mysteries and biomedical challenges faced by human provide a prominent drive for seamlessly merging electronics with biological living systems (e.g. human bodies) to achieve long-term stable functions. Towards this trend, the main bottlenecks are the huge mechanical mismatch between the current form of rigid electronics and the soft biological tissues.

In this talk, I will first describe a new form of electronics with skin-like softness and stretchability, which is built upon a new class of intrinsically stretchable polymer materials and a new set of fabrication technology. As the core material basis, intrinsically stretchable polymer semiconductors have been developed through the physical engineering of polymer chain dynamics and crystallization based on the nanoconfinement effect. This fundamentally-

new and universally-applicable methodology enables conjugated polymers to possess both high electrical-performance and extraordinary stretchability.[1] Then, proceeding towards building electronics with this new class of polymer materials, the first polymer-applicable fabrication platform has been designed for large-scale intrinsically stretchable transistor arrays.[2] As a whole, these renovations in the material basis and technology foundation have led to the realization of circuit-level functionalities for the processing of biological signals, with unprecedented mechanical deformability and skin conformability. Equipping electronics with human-compatible form-factors has opened a new paradigm for wearable and implantable bio-electronic tools for biological studies, personal healthcare, medical diagnosis and therapeutics.[3]

[1] J. Xu[#], S. Wang[#] Z. Bao *Science* 355, 59-64 (2017).

[2] S. Wang[#], J. Xu[#] Z. Bao *Nature* 555, 83-88 (2018).

[3] S. Wang[#], J. Y. Oh[#], J. Xu[#], H. Tran, Z. Bao *Accounts of Chemical Research* 51, 1033–1045 (2018).

8:45 AM *BM07.01.04

Human Inspired Bio-Electronic Sensor Skins Benjamin C. Tee^{1, 2, 3}, ¹Materials Science and Engineering, National University of Singapore, Singapore, Singapore; ²Biomedical Institute for Global Health Research and Technology, National University of Singapore, Singapore, Singapore; ³Institute of Materials Research and Engineering, Agency for Science Technology and Research Singapore, Singapore, Singapore.

Human sensory organs such as the skin have evolved to have excellent sensing performance and ultra-robustness. Electronic versions of skin have witnessed tremendous interest and development over the last decade¹. Functional soft, flexible and stretchable materials are crucial to the continued evolution of skin-like sensor applications in emerging robotic systems², new human-machine interfaces and life-like prosthetics³.

Here, I will discuss our recent work in next generation technologies for bio-electronic skins using an integrated hybrid materials approach that synergizes the best qualities of organic and inorganic materials. For example, recent developments in self-healing polymeric systems have propelled the exciting notion that electronic systems can repair themselves when damaged⁴. Bio-inspired digitization of analog signals have also enabled us to develop artificial mechano-receptors that optically interfaces with neurons⁵. These sensor and materials technologies would be extremely applicable in an increasingly advanced cybernetic and Artificial Intelligence (AI) robotics future.

1. Hammock, M. L., Chortos, A., Tee, B. C. K., Tok, J. B. H. & Bao, Z. 25th anniversary article: The evolution of electronic skin (E-Skin): A brief history, design considerations, and recent progress. *Adv. Mater.* **25**, 5997–6038 (2013).

2. Larson, C. *et al.* Highly stretchable electroluminescent skin for optical signaling and tactile sensing. *Science* **351**, 1071–4 (2016).

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4. Tan, Y. J., Wu, J., Li, H. & Tee, B. C. K. Self-Healing Electronic Materials for a Smart and Sustainable Future. *ACS Appl. Mater. Interfaces* **10**, 15331–15345 (2018).

5. Tee, B. C. K. *et al.* A skin-inspired organic digital mechanoreceptor. *Science (80-)*. **350**, 313–316 (2015).

9:15 AM BM07.01.05

Fully Printed All-Polymer Tattoo/Textile Electronics for Electromyography Eloise Bihar¹, Timothee Roberts², Jozina De Graaf², Mohamed Saadaoui³, Esmat Ismailova³, George G. Malliaras⁴, Khaled Salama¹ and Sahika Inal¹; ¹King Abdullah University of Science and Technology, Thuwal, Saudi Arabia; ² Aix Marseille Universite, Marseille, France; ³Ecole des Mines de Saint Etienne, Gardanne, France; ⁴University of Cambridge, Cambridge, United Kingdom.

Driven by the ever-growing needs for developing portable, easy-to-use, noninvasive diagnostic tools, biomedical sensors that can be integrated on textiles or even directly on human skin have come to fruition. Wearable sensor technologies that seamlessly interface electronics with human skin can be especially promising for detecting a wealth of biologically relevant signals ranging from neuro-muscular activity, to electrophysiology, even to metabolite profiles.

In this work, we present a simple and low cost platform fabricated on a tattoo paper used for on-skin electromyography (EMG) measurements. The electrodes comprising the conducting polymer poly(3,4-ethylenedioxythiophene) doped with polystyrene sulfonate (PEDOT:PSS) are directly inkjet-printed on the tattoo paper. Addressing the integration challenge common for stretchable electronic devices, we connect the tattoo electrodes to the acquisition system through a textile in the form of a wristband comprising of printed PEDOT:PSS contacts. While the textile wristband conforms around the “tattooed” skin, it enables a reliable contact with the electrodes beneath due to its conformability around the limb. We show that this tattoo/textile electronics system, which does not rely on gels or expensive metallic materials, is able to detect the biceps activity of the arm during muscle contraction for a period of seven hours, with comparable performance to conventional wet biopotential electrodes. Combining the tattoo electronics with the electronic textile allows for facile integration of skin-like electrodes with external electronics.

9:30 AM BM07.01.06

Fabrication of Fabric Biomedical Electrode Array with Printable Electronic Ink and Hot-Melt Film for Electromyography Seiichi Takamatsu and Toshihiro Itoh; The University of Tokyo, Kashiwa City, Japan.

We have developed fabric biomedical electrode array where silver paste, conductive polymer and ionic liquid gel are printed and insulation layers are formed with hot melt film on the fabric substrate.

Recently, wearable electronic devices such as Microsoft Hololens, google glass, sportsband, or other tools have been developed and commercialized for human healthcare monitoring and information tools. Among wearable electronic devices, wearable ECG or EMG electrodes are promising for human motion sensing tools. Especially for monitoring human hand or foot motion sensing, the biomedical electrode array which is made of fabric is necessary. To make biomedical electrodes array, new fabrication process of fabric multilayer electrodes which consists of biomedical electrode parts to contact human skin and the wiring parts from biomedical electrodes parts to the amplifiers are required. Previous study (S. Takamatsu, et al., "Direct patterning of organic conductors on knitted textiles for long-term electrocardiography," Scientific Reports, vol. 5, 15003(7pp), Oct 2015.) reports single layer fabric electrodes, but the multilayer electrodes has not been fabricated on the fabric and the biomedical electrode array has not been achieved. The most difficult fabrication process to make multilayer electrodes is to construct insulation layer between multiple electrode because most of the insulation inks are dissolved by the solvent of second layer electrode ink (i.e., toluene), or dissolve the first layer electrode with the solvent of the insulation ink. Our new fabrication process of fabric multilayers consists of the electronic ink printing and hot-melt film sticking on the fabric. Laser cut hot melt film is placed on the electrode printed film and heated to stick to the film as insulation layer. Hot melt film has the advantages in which the hot melt film is not dissolved in the solvent of inks and can combine several layers of functional fabric and films.

The developed fabrication process of fabric biomedical electrode array with printable electronic ink and hot-melt film for Electromyography is following steps. 1. Silver paste wiring electrode is printed on the stretchable polyurethane film. 2. Laser cut hot melt film is placed on the electrode and heated. 3. The patterned urethane film is attached on the knit fabric with hot melt film. 4. Conductive polymer of PEDOT PSS and ionic liquid gel is patterned on another knit fabric for making biomedical electrode part. 5. Wiring part fabric and biomedical electrode fabric are attached by hot melt film and glue. By using our

process, the 2x5 array biomedical electrode which has 1cm² biomedical electrodes parts and 0.5 mm wide wiring can be successfully fabricated. The impedance between electrodes and human skin is less than 1 MOhm, which is useful for EMG monitoring. Thus, our process will be useful for wearable multi array of EMG measurement.

9:45 AM BM07.01.07

Sub-300 nm Thin-Film Au/Parylene Dry Electrodes for Motion Artifact-Less sEMG and sECG Monitoring Robert A. Nawrocki^{1,2,3}, Hanbit Jin¹, Sunghoon Lee¹, Tomoyuki Yokota¹, Masaki Sekino¹ and Takao Someya^{1,4}; ¹Univ of Tokyo, Tokyo, Japan; ²Purdue University, West Lafayette, Indiana, United States; ³Birk Nanotechnology Center, West Lafayette, Indiana, United States; ⁴Thin-Film Device Laboratory & Center for Emergent Matter Science (CEMS), Wako, Japan.

Accurate, imperceptible and long-term monitoring of vital biopotential signals promises to revolutionize healthcare industry by shifting from costly and uncomfortable hospital visits to in-home usage. Currently available wearable electronics are typically rigid with non-conformal skin contact resulting in poor data quality, necessitating the integration of such bioelectronics [1] directly onto the skin [2]. Increasing the conformity of the artificial electronic skin to the soft, irregular and stretchable human skin typically results in improved signal quality and user comfort [3].

We report on the fabrication of self-adhesive and conformable to highly irregular three-dimensional soft surfaces, sub-300 nm thin dry electrodes that produce biopotential (sEMG and sECG) recordings of excellent quality (SNR). The electrodes are based on thermally evaporated thin film (100 nm) of Au, sandwiched between two layers (100 nm each) of CVD-deposited biocompatible parylene (parylene/Au/parylene). They are fabricated on glass substrates, with fluorinated polymer (85 nm) and poly(vinyl alcohol) (PVA, 5 μm) sacrificial layers used for delamination and ease of handling. Parylene is etched away at the skin-interface side, allowing for direct Au contact with the skin. Following delamination, electrodes are placed on pre-stretched human skin and sprayed with H₂O to remove PVA, forming a skin/Au/parylene structure. The skin is then dried and relaxed, with the ultra-thin film conforming to the skin grooves via van der Waals forces [4], without any additional adhesives.

These simple-to-fabricate and use, ultra-thin sensors show single-day electrical and mechanical stability of up to ten hours. Their bending stiffness was calculated to be comparable to stratum corneum, the uppermost layer of human skin, at ~0.33 pNm², which is over two orders of magnitude lower than the bending stiffness of a 3.0 μm thin sensor. Compared with the thicker sensor, its impedance also decreased by almost two orders of magnitude. Laminated on a pre-stretched elastomer, the sensor forms wrinkles with a period of 17 μm and amplitude of 4 μm, agreeing with theoretical calculations.

In contrast to wet adhesive Ag/AgCl electrode, with skin vibrations of up to ~15 μm, the sensor demonstrates motion artifact-less sEMG monitoring. Additional impedance and sEMG measurements reveal that the decrease of impedance, as well as the motion artifact-less operation, is likely due to improved skin adhesion of the sub-300 nm thin sensor.

With compatible fabrication to our previously demonstrated sub-300 nm thin electronics [5], this demonstrates a path for integration of skin-laminated systems consisting of sensors and electronics.

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10:00 AM BREAK

10:30 AM BM07.01.08

Multifunctional Silk Adhesive for Epidermal Electronics Ji-Won Seo, Hyojung Kim and Hyunjoon J. Lee; Korea Advanced Institute of Science and Technology, Daejeon, Korea (the Republic of).

In order to improve the signal accuracy and long-term monitoring of electronics on biological skin, it is essential to achieve a conformal and robustly adhered electronics/biological skin interface. Here, we suggest a biocompatible calcium (Ca)-modified silk adhesive for robust epidermal electronics on biological skin. At optimized weight ratio of silk:Ca²⁺ of 70:30, the silk adhesive shows strong adhesion force (> 600 N/m) through enhanced mechanical interlocking at interface. The physical mechanism facilitates a high adhesion on various substrates and a reusability of silk adhesive. Moreover, a water-degradability of silk adhesive shows the easy detachment without any high external force. With the multifunctional characteristics such as reusability, biocompatibility, and water-degradability, we fabricate the practical epidermal electronics: strain sensor, touch sensor, and long-term drug delivery system to demonstrate the potential of the proposed silk adhesive.

10:45 AM BM07.01.09

Deformable Electronic Materials for Two-Way Communication with Biological Systems Darren J. Lipomi; University of California, San Diego, La Jolla, California, United States.

The goal of this project is to create a class of electronic materials that can measure signals and interface with the nervous system for two-way communication with biological systems. The project is exploring two classes of materials. (1) Metallic nanoislands on single-layer graphene for cellular electrophysiology and wearable sensors. We have used these materials to measure the forces produced by the contractions of cardiomyocytes using a piezoresistive mechanism. Separately, we have developed orthogonal methods of stimulating myoblast cells electrically while measuring the contractions optically (a modality we nicknamed as "piezoplasmonic"). We have also used these sensors to measure the swallowing activity of head-and-neck cancer patients who have received radiation therapy and are at risk of dysphagia arising from fibrosis of the swallowing muscles. The combination of strain sensing, surface electromyography, and machine learning can be used to measure the degree of dysphagia. (2) We have developed ionically conductive organogels for haptic feedback. Medical haptic technology has myriad potential applications, from robotic surgery and surgical training, to tactile therapy for premature infants and patients with neurological impairment.

11:00 AM *BM07.01.10

Ultrasoft, Bio-Compatible Electronic Systems for Neuroscience Tsuyoshi Sekitani; Osaka University, Osaka, Japan.

We present an implantable sheet-type flexible electronic sensor system for long-term simultaneous monitoring of an electrocorticogram (ECoG) from the brain surface and local field potential (LFP) from the deep brain. Ultrasoft gel electrodes provide a minimally invasive interface consisting of highly

conductive nano-conductive materials including Ag-based nanowires, thermoplastic polymers, and bio-compatible gels. The gel composite shows conductivity greater than 10,000 S/cm and can be stretched more than 100% without any reduction to its electrical and mechanical performance. Hence, it can be stretched across arbitrarily curved surfaces, including the ultrasoft brain surface.

By integrating ultrasoft gel electrodes, an ultraflexible amplifier, and a wireless Si-LSI platform with a thin-film battery, we intend to demonstrate the applications of long-term implantable wireless sheet sensors, including 64-channel sheet-type electric potential monitoring systems. This wireless system with soft gel electrodes can measure biological signals of less than 1 μ V. Taking full advantage of this system, simultaneous signals from the cerebral cortex in the ECoG and LFP have been wirelessly measured in animal experiments including non-human primates for over a month. Long-term biocompatibility, electrical performance, and mechanical stretchability and durability are discussed for the integration of nanomaterials and processes and wireless low-noise sheet-type systems.

This research is partially supported by the Brain Mapping by Integrated Neurotechnologies for Disease Studies (Brain/MINDS) from Japan Agency for Medical Research and development, AMED.

11:30 AM BM07.01.11

Flexible Biosensors for Non-Invasive Medical Diagnostics Agostino Romeo¹, Paul Eduardo David Soto Rodriguez¹, Ana Moya^{2,3}, Gemma Gabriel^{2,3}, Rosa Villa^{2,3}, Rafael Artuch^{6,5} and Samuel Sanchez^{1,4}; ¹Institute of Bioengineering of Catalonia, Barcelona, Spain; ²National Centre of Microelectronics - Microelectronics Institute of Barcelona, Barcelona, Spain; ³Research Networking Center in Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), Barcelona, Spain; ⁴Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain; ⁵CIBER-ER (Biomedical Network Research Center for Rare Diseases), Instituto de Salud Carlos III, Madrid, Spain; ⁶Laboratory of Hereditary Metabolic Diseases, Hospital Sant Joan de Déu, Barcelona, Spain.

In the last few decades the quality of life has significantly improved due to the achievements of biomedical technology. Innovative healthcare solutions contributed to these advances by decreasing costs and making health assessment easier and more accessible. Versatile **biochemical sensors** targeted to health biomarkers and bioanalytes (metal ions, proteins, amino acids, glucose, lactate, etc.) can non-invasively monitor the health status of the user by analyzing external body fluids (sweat, saliva, tear fluid) alternative to blood.[1,2] **On-demand** biosensing is envisaged due to the versatility of sensing platforms that can adapt to specific needs in terms of target biomarkers and health issues to monitor. To this regard, several recognition systems, including antibodies, enzymes, and inorganic nanomaterials can be used to modify the sensors to achieve high selectivity towards target analytes. In this scenario, recent advances in microfabrication, sensor technologies and data transmission led to the developments of **point-of-care (PoC) diagnostics**. Here we present few examples of biosensors for painless and on-demand self-assessment of health conditions. In particular, we describe a non-invasive **electrochemical** sensor for the non-enzymatic analysis of tear **glucose**. [3] Electrochemical sensing is chosen among other types of transduction because it is well suited for simple, rapid, and cost-effective personalized medicine devices. Electrodes are fabricated on soft and flexible materials using **inkjet printing** and then modified with CuO microparticles (CuO- μ Ps) to carry out **non-enzymatic** detection of glucose. This detection mechanism is based on the CuO-catalyzed electro-oxidation of glucose in alkaline environment, due to the electrochemical conversion of CuO into strong oxidizing Cu(III) species such as CuOOH or Cu(OH)⁴⁻. Glucose detection is achieved by CA, with an excellent linearity observed in the 3–700 μ M range, matching typical glucose levels in **tears**. A sensitivity of 850 μ A mM⁻¹cm⁻² and a limit of detection (LOD) of 2.99 μ M are calculated. This sensor shows good selectivity, reproducibility, and life-time, resulting in a reliable tool for painless and non-invasive self-assessment of diabetes, as confirmed by tests on tear samples.

Personalized and non-invasive sensing technologies allow to easily and frequently monitor the health status of an individual as often as needed. This helps make early-stage detection simpler and more convenient, thus enhancing the efficacy of therapeutic treatments. Rapid and cheap PoC diagnostics also allows improving the life style of patients, by interfering in low or negligible extent to their daily activities.

References

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11:45 AM BM07.01.12

Highly Durable, Ultrasensitive Nanoscale Crack Based Mechano-Sensor for Bio-Signal Monitoring Inspired by Spider's Sensory Organs Byeonghak Park¹, Daeshik Kang² and Tae-il Kim¹; ¹Sungkyunkwan Univ, Suwon, Korea (the Republic of); ²Ajou University, Suwon, Korea (the Republic of).

With increasing demand for the detection of delicate bio-signals for medical electronics, the Internet of Things (IoT), E-skin and flexible integrated circuit (IC) devices, an enhancement in sensitivity has become a major issue in flexible mechanosensors, however, overcoming the limited sensitivity remains problematic. Here, we introduce mechanosensors inspired by spiders having an ultrasensitivity, durability. For ultrasensitivity and durability, we considered the geometrical effects in cracks and self-healable polymers. By controlling crack depth by simple propagating process, the sensitivity of our sensor shows ~15,000 in 2% strain, which is the world best sensitivity value. Due to the high sensitivity, the signal-to-noise-ratio is 6 times higher than before, up to ~35 so that it can be used in sensing human voice clearly. Also, self-healable polymer helps to recover the crack gaps after 25,000 cycles. We introduce the possibility of semi-permanent uses over 1,000,000 cycles in our sensors. The spider inspired sensory system with high sensitivity and durability would provide versatile novel applications such as E-skins, devices for medical applications, and IoT applications etc.

SESSION BM07.02/EP05.02: Joint Session: Bioelectronic Active Materials

Session Chairs: Sahika Inal and Jonathan Rivnay

Monday Afternoon, November 26, 2018

Sheraton, 2nd Floor, Constitution B

1:30 PM *BM07.02.01/EP05.02.01

Interacting Ion and Electron Currents Paul Meredith; Swansea University, Swansea, United Kingdom.

Ionic and electronic conduction mechanisms are underpinned by fundamentally different physics [1]. For example, ions diffuse through a conducting

matrix via centre of mass transport that can be described by classical processes. Electrons and holes are quantum mechanical entities characterised by delocalisation, tunnelling or hopping. These fundamental differences impose radically different length-and-time-scales on ionic and electronic conduction – and generally speaking the solid-state physics of ions and electrons have remained two very different fields requiring different skill sets [2]. However, bioelectronics, where a central challenge is the transduction between ion and electron currents, is a scientific collision point between the two worlds. In my talk I will summarise the major differences between ionic and electronic solid state electrical conduction. I will also describe methods that can probe the relevant time-and-length scales in order to identify and disentangle the native signatures of each carrier type [3, 4]. A number of model systems and devices will be exemplified that allow the study of ion and electron conduction processes, and indeed provide a means to test prototypical concepts in transduction and bioelectronic logic interfaces [5, 6].

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2:00 PM BM07.02.02/EP05.02.02

The Device Physics of Organic Electrolytic Photocapacitors—From the Nanoscale to the Single Cell Level Vedran Derek¹, Marie Jakesova¹, Tobias Cramer², Marek Havlicek³, David Rand⁴, Yael Hanein⁴, Daniel Simon¹, Magnus Berggren¹, Fredrik Elinder⁵ and Eric D. Glowacki¹; ¹Laboratory of Organic Electronics, Department of Science and Technology, Linköping University, Norrköping, Sweden; ²Department of Physics and Astronomy, Università di Bologna, Bologna, Italy; ³Department of Nanometrology and Technical Length, Czech Metrology Institute, Brno, Czechia; ⁴School of Electrical Engineering, Tel Aviv University, Ramat-Aviv, Tel-Aviv, Israel; ⁵Department of Clinical and Experimental Medicine, Linköping University, Linköping, Sweden.

We have recently developed the organic electrolytic photocapacitor (OEPIC), a nanoscale optoelectronic device for eliciting action potentials in neurons. Herein, we cover in detail the physical mechanisms behind the charge generation and dynamics of charging and capacitive coupling in these devices using optoelectronic/electrochemical measurements combined with simulation and modeling. Electrochemical impedance measurements allow corroboration of these models, and reveal the nature of photocapacitive and photofaradaic effects in the devices. Using scanning probe microscopy techniques, we have evaluated the mechanical properties of the nanocrystalline films, finding relatively low Young's moduli in the range of 500 MPa. In order to take a reductive approach compared with previous measurements of neurons and electrogenic tissues, we have validated the performance of OEPICs using nonexcitable cells, *xenopus laevis* oocytes. We find rapid membrane potential changes in the range of tens to hundreds of millivolts are induced by OEPIC devices, showing extremely effective capacitive coupling and explaining previous findings of action potential generation. The overall result of our work is a fuller physical and mechanistic understanding of this novel device platform, and a roadmap for guiding future development.

2:15 PM BM07.02.03/EP05.02.03

The Design of Air Stable, Redox Active Conjugated Polymers and Their Applications in Accumulation Mode OECTs Alexander Giovannitti¹, Reem Rashid², Jenny Nelson¹, Iain McCulloch¹ and Jonathan Rivnay²; ¹Imperial College London, London, United Kingdom; ²Northwestern University, Chicago, Illinois, United States.

Organic electrochemical transistors (OECTs) are receiving a great deal of attention due to the ability to efficiently transduce biological signals. The working principle of OECTs relies on the modulation of the conductivity of an organic semiconductor, which can be modified by applying a potential at the gate electrode and driving electrochemical redox reactions in aqueous solution (doping/de-doping of the organic semiconductor). OECTs can either be operated in accumulation¹⁻³ or depletion mode⁴ where the operation in accumulation mode has the advantage of lowering the operational voltage and therefore improve the power consumption of the device (device is in an off state rather than an on state when no gate voltage is applied). Recently, high performing OECT materials have been reported based on electron rich alkoxybithiophene copolymers which show low oxidation potentials in aqueous electrolytes and enable OECT operation at low voltages.²

However, one drawback of these easily oxidizable polymers is that the copolymers can become oxidized by reactions with oxygen from ambient air. This results in the formation of p-doped polymers and superoxide anions (O₂⁻) where the latter is a reactive radical and might cause harm to biological systems or degrade the organic semiconductor. As a result of this oxidation reaction, a constant gate voltage would need to be applied to keep the material in its neutral state (and the device off).

We will present the development of an air-stable conjugated polymers based on donor-acceptor type copolymer. The copolymer shows reversible redox reaction at potentials below 0.3 V vs Ag/AgCl. When exposed to aqueous ambient conditions, the polymer does not become oxidized. Long-term stability tests were carried out where devices were exposed to ambient conditions for more than 6 months with no sign of degradation. The polymer shows a good stability when charged with up to one hole per repeat unit (polaron) with transconductances in the range of 80 S/cm (at -0.7 V). This work demonstrates the importance of chemical design strategies for the development of accumulation mode OECT materials to mitigate reactions with oxygen in aqueous electrolytes and ambient conditions.

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2:30 PM *BM07.02.04/EP05.02.04

Polythiophene Derivatives as Mixed Organic Ionic and Electronic Conductors Christine Luscombe; University of Washington, Seattle, Washington, United States.

Mixed organic ionic and electronic conductors are being explored for a wide range of applications, from bioelectronics to neuromorphic computing, artificial muscles and energy storage applications. These materials exploit the simultaneous transport properties of ionic and electronic carriers to enable novel device functions. Recently, polymer semiconductors have received significant amounts of attention because of their flexibility, biological compatibility and ease of fabrication. These materials, particularly thiophene-based polymers such as poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate)(PEDOT:PSS) and related derivatives, have demonstrated significant enhancements in performance in a relatively short amount of time, with transconductance values of PEDOT:PSS transistors surpassing those achieved even with graphene.

Through our NSF Designing Materials to Revolutionize and Engineer our Future (DMREF) award with researchers at Cornell University and the University of Chicago, we have been investigating the synthesis of ethylene-glycol functionalized polythiophenes, their thin film morphology, and their ionic and electronic conductivities, and comparing against theoretical predictions. In this talk, the effect on the density of the ethylene-glycol side chains and their pattern of placement on ionic conductivity will be discussed.

3:00 PM BREAK

3:30 PM *BM07.02.05/EP05.02.05

Mixed Conductivity in Conducting Polymer Thin Films [Sabine Ludwigs](#); University of Stuttgart, Stuttgart, Germany.

This talk will give an overview about our recent activities on electronic and ionic conductivity in conjugated and redox polymer thin films with different molecular architectures. Preparation of films is done either by electropolymerization or solution deposition followed by morphology tuning, e.g. by solvent vapor annealing.[1]

We are particularly interested in three-dimensional architectures based on branched monomers such as terthiophenes (3T) or triphenylamines (TPA). TPA redox moieties are useful to allow for electrochemical or chemical crosslinking of as-deposited films. Both, with TPA redox polymers[2] and with polymers which bear TPA as pending redox moieties of linear polythiophenes[3] we could perform successful crosslinking and simultaneous doping of polymer films. The films provide very high stabilities with high electronic conductivities as evidenced by cyclic voltammetry coupled with in-situ conductance measurements and four-point-probe measurements. In the case of 3T we have reported on homopolymer and copolymer films of 3T and ethylenedioxythiophene which allow polymer-analogous reactions to induce ionic functionalities, thereby creating branched conjugated polyelectrolyte films.[4], [5]

To get a better understanding on mixed conductivity in polymer films, we have recently performed a study on electronic and ionic conductivity of linear conjugated polyelectrolytes by impedance spectroscopy and dc-measurements.[6] The clear dependence of the conductivities as function of humidity and degree of doping will be discussed in the talk in more detail.

[1] G.L. Schulz, S. Ludwigs, *Adv. Funct. Mater.* 27, 2017, 1603083.

[2] O. Yurchenko, J. Heinze, S. Ludwigs, *Chem. Phys. Chem.* 11, 2010, 1637.

[3] P. Reinold, K. Bruchlos, S. Ludwigs, *Polymer Chemistry* 8, 2017, 7351.

[4] M. Goll, A. Ruff, E. Muks, F. Goerigk, B. Omiecinski, I. Ruff, R.C. González-Cano, J.T. Lopez Navarrete, M.C. Ruiz Delgado, S. Ludwigs, *Beilstein J. Org. Chem.* 11, 2015, 335.

[5] T.V. Richter, C. Bühler, S. Ludwigs, *J. Am. Chem. Soc.* 134, 2012, 43.

[6] R. Merkle, P. Gutbrod, P. Reinold, M. Katzmaier, R. Tkachov, J. Maier, S. Ludwigs, *Polymer* 132, 2017, 216.

4:00 PM *BM07.02.06/EP05.02.06

Soft Electronic and Ionic Neural Interfaces [Klas Tybrandt](#)^{1,2}, [Dion Khodagholy](#)³, [Flurin Stauffer](#)² and [Janos Vörös](#)²; ¹Department of Science and Technology, Linköping University, Norrköping, Sweden; ²Institute for Biomedical Engineering, ETH Zürich, Zurich, Switzerland; ³Department of Electrical Engineering, Columbia University, New York, New York, United States.

Two-way communication between electronics and neural tissue is key for advancing diagnosis and therapies for neurological diseases and disorders, as well as providing detailed information about brain signaling. Establishing such neural interfaces is a major challenge, as the tissue response to implants can have a detrimental effect on the signal quality and functionality of the implant. Also, electrical stimulation is inherently limited in its stimulation of neural tissue, in comparison to the sophisticated chemical signaling processes within biological tissue. Here, I present our efforts in addressing two critical technological aspects for the creation of versatile neural interfaces; the matching of mechanical properties of tissues and electronics, and the development of fast and low-leakage chemical interfaces. Soft electronic biomedical implants have a demanding set of requirements, including biocompatibility, mechanical and electromechanical properties, long-term stability and electrode performance. To meet these requirements, we have developed a high-performance, long-term stable soft and stretchable composite for neural electrodes. Based on this composite, high-density soft electrode grids were developed and implanted onto brain surface of rats. The electrodes provided high-quality recordings during three months of implantation. Next, I will outline our strategy for creating high-speed low-leakage chemical neural interfaces, by discussing the relationship between delivery delay and leakage, and then present an iontronic approach to achieve low leakage and small delay simultaneously.

4:30 PM BM07.02.07/EP05.02.07

Organic Electronics for Neuromorphic Computing [Yoeri van de Burgt](#); Institute for Complex Molecular Systems, Eindhoven University of Technology, Eindhoven, Netherlands.

Neuromorphic computing could address the inherent limitations of conventional silicon technology in dedicated machine learning applications. Recent work on silicon-based asynchronous spiking neural networks and large crossbar-arrays of two-terminal memristive devices has led to the development of promising neuromorphic systems. However, delivering a parallel computation technology, capable of implementing compact and efficient artificial neural networks in hardware, remains a significant challenge. Organic electronic materials offer an attractive alternative to such systems and could provide neuromorphic devices with low-energy switching and excellent tunability, while being biocompatible and relatively inexpensive.

This talk describes state-of-the-art organic neuromorphic devices and provides an overview of the current challenges in the field and attempts to address them¹. We demonstrate a novel concept based on an organic electrochemical transistor² and show how some challenges in the field such as stability, linearity and state retention can be overcome³.

Furthermore, we investigate chemical doping mechanisms in the active material for improved material functionality and demonstrate that this device can be entirely fabricated on flexible substrates, introducing neuromorphic computing to large-area flexible electronics and opening up possibilities in brain-machine interfacing and adaptive learning of artificial organs.

¹ van de Burgt et al. *Nature Electronics*, 2018

² van de Burgt et al. *Nature Materials*, 2017

³ Keene et al. *J Phys D*, 2018

4:45 PM BM07.02.08/EP05.02.08

Anisotropic Conducting Polymer Films for Bioelectronics [Patricia Jastrzebska-Perfec](#), [Georgios Spyropoulos](#), [Jennifer Gelinis](#) and [Dion Khodagholy](#); Columbia University, New York, New York, United States.

Anisotropic conductive films, which consist of electrically conductive particles dispersed in nonconductive media, are increasingly being applied to establish high-density electrical bonds between electronic boards and chips. However, current anisotropic composites utilize metallic particles, often nickel and epoxy-based media, that require high thermocompression energy for bonding. Therefore, they have limited applicability in thin-film, conformable, and plastic-based devices that are used in bioelectronic applications. Furthermore, these materials are not biocompatible, significantly limiting their use in biological systems. We hypothesized that replacing the metallic particles with conducting polymer particles combined with a biocompatible nonconducting matrix would address this limitation. We developed a novel anisotropic conducting polymer (ACP) consisting of poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) conducting polymer particles dispersed in a matrix of crosslinked chitosan (CS). To determine the permeability of PEDOT:PSS to CS, we characterized the resistances of thin CS-based films sandwiched with PEDOT:PSS and gold pads. We investigated the particle size, structure, density and distribution of pure PEDOT:PSS particles and PEDOT:PSS-coated CS particles. The anisotropy was defined by the ratio of horizontal and vertical impedance between interconnects. We benchmarked the anisotropy of the developed ACPs by geometrically varying an array of gold electrodes. The final ACP, which was created at 70°C with minimal pressure, yielded anisotropy of 10^5 - 10^6 . The ACP was then used to maintain precise connections between a high density conformable implantable neural probe and back-end electronics. It enabled complete chronic *in vivo* implantation of these electronics with minimal encapsulation layers, highlighting applicability for use in bioelectronic and clinical devices

SESSION BM07.03: Neural Interfacing/Implantable Devices I
Session Chairs: Jurgen Kosel, Duygu Kuzum and Roisin Owens
Tuesday Morning, November 27, 2018
Sheraton, 2nd Floor, Constitution B

8:00 AM BM07.03.01

Toward Biocompatible and Degradable Electronics—A Comprehensive Material Approach [Ashkan Shafiee](#)¹, [Elham Ghadiri](#)², [Kunzhao Li](#)³ and [Anthony Atala](#)¹; ¹Institute for Regenerative Medicine, Wake Forest School of Medicine, Winston-Salem, North Carolina, United States; ²Chemistry Department, Wake Forest University, Winston-Salem, North Carolina, United States; ³Biology, Wake Forest University, Winston-Salem, North Carolina, United States.

Over the past 10 years, regenerative medicine has witnessed a significant technological and scientific advancement. For instance, numerous revolutionary progress in stem cell science as well as additive manufacturing, namely 3D printing, have opened up new horizons in research and brought them closer to reality than ever before. However, for more sophisticated indications, fabrication of biological structures such as human tissues and organs may require an optimized procedure to obtain the impeccable final product. Therefore, the need for biocompatible electronic devices is a focus of attention in academia and industry. Moreover, biodegradable electronic devices for healthcare applications can also produce a revolution in the electronics industry and reduce electronic waste products. Currently, thousands of tons of silicon that is used to manufacture computers, cell phones, and other devices are discarded into the environment annually. It is critical that such waste be curtailed. Here, we report a systematic investigation on finding biocompatible/degradable functional electronic materials. To address this aim two different approaches were employed: 1-study the electronic properties of biomaterials, 2- study the biocompatibility of functional electronic materials. Materials with energy band gap between 1 to 3 eV are categorized as semiconductors and bigger than 3 eV as insulators. Various biomaterials were sought in terms of energy band diagram. Most biomaterials showed energy band gap bigger than 3 eV confirming them as insulators, for example, fibrinogen, glycerol, and gelatin showed 3.54, 3.02, 3.0 eV. Meanwhile, a few biomaterials were found as semiconductors such as phenol red in the cell culture medium with 1.96 eV energy band gap. On the other hand, the biocompatibility of organic semiconductors, such as P3HT and PCBM for different cell types such as satellite cells were examined. The cells were exposed to the thin layer of films prepared with the organic materials, and essential biomarkers (Desmin and MF20) were used to determine the consequence effect on the cells, their functionality, proliferation, and differentiation. The outcomes of this research can be used to fabricate biocompatible/degradable electronic devices for medical applications.

8:15 AM BM07.03.02

Nanoelectrode-Integrated Polymer Fiber Probes for Chronic Neural Interfacing [Shan Jiang](#), [Kelly Kedlec](#), [Ana L. Marcano](#), [Junyeob Song](#), [William A. Mills](#), [Ian Kimbrough](#), [Harald Sontheimer](#), [Wei Zhou](#) and [Xiaoting Jia](#); Virginia Tech, Blacksburg, Virginia, United States.

Deciphering complex neural circuits relies on the developments of neural interface devices with good biocompatibility, mechanical compliance, high spatial resolution, and high quality recording. There has been significant development in neural interface devices in the past decades, mostly based on silicon and metal electrodes or contact printed film electrodes. More recently, thermally drawn polymer fibers have been utilized as neural recording probes which exhibit good flexibility and biocompatibility. However, due to the low conductivity of conventional polymer electrodes, the size of a polymer fiber probe is typically much larger compared to the size of a single neuron in order to have the overall impedance fall in the recordable range, resulting in a poor spatial resolution of these probes. Therefore, it is of great importance to reduce the impedance of the polymer electrode while maintaining the miniaturized footprint in order to increase the spatial resolution and minimize the brain damage. In this study, we deposited metallic nanostructures on the tip of the polymer fiber probe to enhance the electrical properties as well as the electrophysiological recording performance. Soft nanolithography patterning technique was utilized to create dense vertical 3D nanopillar nanoelectrodes on the small area of the flexible polymer fiber tips via gold nanohole array masks. Because of the large surface area of the nanopillar nanoelectrode structure, the resulting impedance of the modified electrode has been reduced to be able to capture neural signals. The power density of local field potential (LFP) from both the modified and unmodified electrode showed the better recording performance of the modified one. Finally, we evaluated these nanoelectrode integrated polymer fiber probes in terms of chronic recording and long term tissue response. These results show that nanoelectrode-based surface modification can significantly reduce the impedance of polymer electrodes, thus increase the spatial resolution and improve the electrophysiology recording performance of polymer fiber probes.

8:30 AM *BM07.03.03

Large Scale Integrated Organic Transistors for High-Resolution Electro-corticography of the Human Brain [Dion Khodagholy](#); Columbia University, New York, New York, United States.

As our understanding of the brain's physiology and pathology progresses, increasingly sophisticated materials and technologies are required to advance discoveries in systems neuroscience and develop more effective diagnostics and treatments for neuropsychiatric disease. Localizing brain signals may assist with tissue resection and intervention strategies in patients with such diseases. Precise localization requires large and continuous coverage of cortical areas with high-density recording from populations of neurons while minimizing invasiveness and adverse events. We describe a large-scale, high-density, organic electronic-based, conformable neural interface device (NeuroGrid) with embedded integrated circuitry capable of simultaneously recording local

field potentials (LFPs) and action potentials from the cortical surface. We demonstrate the feasibility and safety recording with such devices in anesthetized and awake subjects. Highly localized and traveling physiological and pathological LFP patterns were recorded, and correlated neural firing provided evidence about their local generation. Application of NeuroGrid technology to disorders such as epilepsy may improve diagnostic precision and therapeutic outcomes while reducing complications associated with invasive electrodes conventionally used to acquire high-resolution and spiking data.

9:00 AM BM07.03.04

Deposition and Improved Adhesion of PEDOT on Microelectrodes Côme Bodart¹, Danny Chhin², Nicolò Rossetti¹, Pauline Chevreau¹, Steen Schougaard² and Fabio Cicoira¹; ¹Chemical Engineering, Polytechnique Montréal, Montréal, Quebec, Canada; ²Chemical Engineering, Université du Québec, Montréal, Quebec, Canada.

Adhesion quality and biocompatibility are the main obstacles to a successful use of conducting polymers coatings on metal microelectrodes for recording and stimulation. Such microelectrodes have very small dimensions, resulting in a high impedance. One way to address this problem is to deposit a conducting polymer, PEDOT, on their electroactive area to lower the impedance and reduce the foreign body reaction [1]. However, the small size of such microelectrodes and the poor adhesion of conducting polymers on most inorganic substrates remain practical difficulties for large scale production. In our recent experiments using electrochemical polymerization, we explored the influence of different solvents (acetonitrile, propylene carbonate) [2] and electropolymerisation methods (potentiodynamic, galvanostatic, pulsed deposition) on the adhesion of an electropolymerized thin layer of PEDOT:BF4 on platinum electrodes. We also investigated the use of a diazonium salt as an anchoring layer for PEDOT on platinum [3]. We evaluated the stability of our PEDOT-coated electrodes *ex vivo* by passive aging in physiological solutions and under repeated electrical stimulations, similar to those used for deep brain stimulation. Finally, we investigated *in vivo* aging to hopefully gain more insights on the stability of our PEDOT coating in contact with living tissues.

[1] Ludwig, K. A., Uram, J. D., Yang, J., Martin, D. C., & Kipke, D. R. (2006). Chronic neural recordings using silicon microelectrode arrays electrochemically deposited with a poly (3, 4-ethylenedioxythiophene)(PEDOT) film. *Journal of neural engineering*, 3(1), 59.

[2] Poverenov, E., Li, M., Bitler, A., & Bendikov, M. (2010). Major effect of electropolymerization solvent on morphology and electrochromic properties of PEDOT films. *Chemistry of Materials*, 22(13), 4019-4025.

[3] Chhin D., Polcari D., Bodart-Le Guen C., Tomasello G., Cicoira F., Schougaard S. Diazonium-based anchoring of PEDOT on Pt/Ir electrodes via Diazonium Chemistry. *Journal of The Electrochemical Society*. (publication pending)

9:15 AM BM07.03.05

Transparent Arrays of Bilayer-Nanomesh Microelectrodes for Simultaneous Electrophysiology and 2-Photon Imaging in the Brain Yi Qiang¹, Kyung Jin Seo¹, Pietro Artoni², Michela Fagiolini² and Hui Fang¹; ¹Northeastern University, Boston, Massachusetts, United States; ²Center for Life Science, Boston Children's Hospital, Boston, Massachusetts, United States.

Transparent microelectrode arrays have emerged as promising tools for measuring neural signals with high spatiotemporal resolution by combining simultaneous electrophysiology and optical modalities. However, scaling down transparent microelectrodes to the size of single neuron is challenging since traditional transparent conductors are limited by their capacitive electrode/electrolyte interface. By reliably stacking individual layers of metal and low-impedance coatings in a same nanomeshed pattern, we demonstrated an innovative bilayer nanomesh approach to address this limitation with system-level, high electrode performance. Specifically, we successfully achieved Au/PEDOT:PSS bilayer nanomesh microelectrodes with site area down to $\sim 314 \mu\text{m}^2$, comparable to the size of a single neuron, while possessing impedance of 130 k Ω at 1 kHz. Furthermore, fabricated 32-channel bilayer-nanomesh microelectrode arrays (MEA) have demonstrated over 90% yield on average, with down to 10% impedance variation among all electrode channels. Meanwhile, the bilayer nanomesh MEAs showed excellent compatibility with state of the art Ultra-Wide Band links for wireless recording and real-time stimulation artifact cancellation with a 100,000 \times signal/error ratio. Finally, *in vivo* electrophysiology recording with simultaneous 2-photon imaging on the mice visual cortex further validated the functionality and significance of our transparent MEA. The highly-transparent 32-channel bilayer nanomesh MEA allowed both wide-field epifluorescence and 2-photon Ca^{++} imaging of visual cortex and surrounding areas with successful detection of visual evoked potentials from multi-unit activity, while with no significant inflammation of the cortex due to the MEA implantation after 20 days. The results here established the bilayer nanomesh microelectrode approach as a practical pathway towards large-scale, high-density transparent arrays, with broad utility in neuroscience and medical practices.

9:30 AM *BM07.03.06

Graphene-Based Neural Interfaces for Probing Brain Activity Yichen Lu, Xin Liu and Duygu Kuzum; University of California, San Diego, La Jolla, California, United States.

The complexity of neural activities has challenged both neuroscience research and clinical practice for decades. Understanding neuronal dynamics and information processing performed by neural populations requires advanced technologies with high-resolution sensing and stimulation capability. Clinical neuromodulation therapies widely used for neurological disorders also depend on the ability to manipulate the dynamics of neural circuits. Conventional neural interfaces offering electrical, optical, or chemical signals have greatly advanced our understanding of neural functions, however, most of these technologies are based on a single functionality. Combining multiple functionalities in a single system has recently been pursued as an integrative approach in new neurotechnology development. Graphene has recently emerged as a neural interface material offering several outstanding properties, such as optical transparency, flexibility, high conductivity, functionalization and biocompatibility. The unique combination of these properties in a single material system makes graphene an attractive choice for multi-modal probing of neural activity. In this talk, I will present our recent work on graphene-based neural interfaces, highlight key applications, and finally discuss future directions and potential advances for graphene-based neurotechnologies in both basic neuroscience research and medical applications.

10:00 AM BREAK

10:30 AM BM07.03.07

A Soft, Conformable, Stretchable Sensor to Record Bladder Wall Stretch Stuart Hannah and Marc Ramuz; Ecole des Mines de Saint Etienne - Centre Microelectronique de Provence, Gardanne, France.

A soft, fully biocompatible, stretchable strain sensor device based on ultra-thin stretchable electronics is reported. The sensor is able to monitor stretch of the bladder wall, via a resistive strain sensing approach. The stretchable sensor is used to determine bladder stretch, and hence volume, without the need for complex and invasive surgical procedures used currently, enabling the development of new safer and cheaper treatment options for various urological conditions. Such instances where a means to monitor bladder stretch could be invaluable are for sufferers of overactive bladder syndrome (OAB), urinary

urge incontinence or after spinal cord injury.

Thermally evaporated Cr/Au thin films (~ 150 nm) on compliant, stretchable polyurethane (PU) film ($\leq 50 \mu\text{m}$), were deposited to produce resistive sensors. The sensors were patterned into a 'dogbone' design by laser patterning, with sensor W and L dimensions on the mm scale. The sensors display a linear response as a function of strain from 0 to 50 %, and as sensor length increases, sensor sensitivity as a function of strain increases. We show that the sensitivity is highest for $L = 6 \text{ mm}$, at $3.18 \Omega/\%$ -strain, which is around 15 times higher than the sensitivity for $L = 2 \text{ mm}$, at $0.21 \Omega/\%$ -strain. Furthermore, cycling tests performed on sensors of various length reveal that the devices display good stability, with virtually no hysteresis.

The highest sensitivity sensors were subsequently tested *in vitro* on an isolated pig bladder. The sensors were attached onto the external wall of the bladder using a biocompatible hydrogel adhesive. The bladder was repeatedly filled and emptied using a syringe system designed to mimic natural bladder behaviour. As bladder volume changes, the sensor changes resistance as a function of stretch, and displays very good repeatability over several bladder filling/emptying cycles. We found a maximum sensitivity of $0.1 \Omega/\text{ml}$ for the most sensitive device. Our sensors pave the way towards completely implantable health monitoring systems of the future.

10:45 AM BM07.03.08

Silk-Inspired Neurotechnology—Soft, Conformal and Optically Transparent Silk Electrode Interfaces for the Cortex [Dr. Anoop Patil](#)^{1, 2} and Nitish Thakor^{1, 2, 3}; ¹Department of ECE, National University of Singapore, Singapore, Singapore; ²SINAPSE, National University of Singapore, Singapore, Singapore; ³Dept. of BME, Johns Hopkins University, Baltimore, Maryland, United States.

Neurotechnology provides a potential platform for novel material-based strategies that can refashion the existing neural interface technologies. The current widely-used neural interfaces are dry, brittle and inorganic in nature, warranting a new soft material candidate for the development of tissue-compliant and mechanically-robust electrode interfaces that show great affinity to the wet surfaces of the biological tissues. Here, we report, soft and excellently conformal electrode interfaces designed on hydrated silk films that can conform to the wet slimy surfaces of the rat cortex. To the best of our knowledge, this is the first such demonstration of functional silk electrical interfaces for the wet *in vivo* environs of the cortex. This work represents a significant step towards soft implantable bioelectronics.

Metallized silk substrate (~15 μm thick) carrying the gold electrode patterns (~ 100 nm thick) is integrated with a patterned silk superstrate (~15 μm thick) to yield a silk electrode array. A flexible interconnect is connected to the array to facilitate electrical readouts from the electrode sites. The silk arrays are then water-annealed (~12 h) to render them nontransient.

We deployed the silk arrays on the rat cortex (S1FL region) to demonstrate the *in vivo* applicability of the nontransient silk interfaces. We noted that the cortical array laminated conformably on the nonplanar surface of the cortex. A rat transient ischemia (TIA) model was employed to demonstrate ECoG recording capability of the silk array. ECoG recordings prior to (serving as baseline) and following induction of stroke provided functional validation of the silk cortical array. A cranial window was created to deploy the silk array. The cerebral blood vessel in which a blood clot is to be induced, was located. The ECoG array was then deployed upon the S1FL region of the cranial window. The selected cerebral blood vessel (diameter 80 μm) was observed clearly via the transparent silk window of the silk array. Injection of Rose Bengal and shining of laser light (CW laser, 532 nm) through the transparent silk substrate induced a blood clot in the cerebral blood vessel. The evoked potentials captured by the individual electrode sites of the silk array prior to the induction of stroke represent the baseline ECoG recordings. These recorded responses were evoked through forepaw stimulation. Induction of blood clot led to a suppression of the evoked ECoG activity, captured cleanly by the silk array.

In this work, we reported the feasibility of realizing nontransient soft conformal silk electrode arrays for interfacing with the cortical surface in rat model. We observed that the silk arrays are soft and could couple intimately to the wet surfaces of the rat cortex. To the best of our knowledge, this is the first such demonstration of silk neurotechnology for the cortex and can impact basic neuroscience research and clinical trial industry.

11:00 AM BM07.03.10

Conductive Polymers Based Electrodes for Monitoring and Stimulating Neuromotor Functions in Small Animals [Nicolò Rossetti](#), [Ada Lee](#), [Prabhjot K. Luthra](#), [Michelle Gaspard](#), [Shalin Bhanot](#), [Côme Bodart](#) and [Fabio Cicoira](#); École Polytechnique de Montréal, Montréal, Québec, Canada.

Conductive polymers have been widely explored as a coating of inorganic substrates for biological signal recording and stimulation, but their poor adhesion to inorganic substrates represents the main limit for their *in vivo* application and current solutions make use of long and complicated processing steps [1-3]. In this work, stainless steel wire electrodes composed of twisted wires have been coated with conductive polymers through electropolymerization for muscle signal recording in small animals. Two solutions consisting in Dopamine:Polypyrrole/PEDOT bilayer and PEDOT processed in propylene carbonate are proposed to increase the polymer adhesion to the metal. The electrodes have been electrochemically characterized, and the adhesion and electrochemical stability have been evaluated through ultrasonication and phosphate buffer solution soaking test. Our work gives new insights on the adhesion enhancement of conductive polymers to inorganic substrates allowing for simple and fast solutions that will improve the durability and efficiency of conductive polymer coated electrodes.

[1] S. Carli et al. "Conductive PEDOT Covalently Bound to Transparent FTO Electrodes," J. Phys. Chem. C, vol. 118, no. 30, pp. 16782-16790, 2014.

[2] L. Ouyang et al. "Enhanced PEDOT adhesion on solid substrates with electrografted P(EDOT-NH₂)," Sci. Adv., vol. 3, no. 3, 2017.

[3] X. Luo et al. "Highly stable carbon nanotube doped poly(3,4-ethylenedioxythiophene) for chronic neural stimulation," Biomaterials, vol. 32, no. 24, pp. 5551-5557, 2011.

11:15 AM *BM07.03.11

Engineering the Next Generation of Neurodevices—New Materials and Clinical Translation [Brian Litt](#); Neurosurgery and Bioengineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States.

The incidence of neurological disorders like epilepsy, Parkinson's disease, stroke, dementia, addiction and major mental illness is growing, as the world's population ages. Response to medications for these conditions has plateaued, paving the way for a revolution in implantable devices as the next wave of effective treatments for these "brain network disorders." Key to developing these new devices are advances in computation, batteries, sensors and closed loop algorithms. New and more versatile materials is one of the main requirements and drivers of innovation in new medical devices and technologies. In this lecture I will outline major applications in the area of neurodevices/ brain computer interfaces, present unmet needs, and discuss the path to clinically translate innovations from the laboratory to patients. I will give examples from our own research and other labs on this path, touch on common failure modes and novel tools for collaboration, bringing engineers, clinicians and industry together to advance clinical care.

1:30 PM BM07.04.01

Highly Stable PEDOT-CNT Nanotube as Neural Electrode Coating Nuan Chen^{1,2}, Baiwen Luo², Nitish Thakor² and Seeram Ramakrishna¹; ¹Department of Mechanical Engineering, National University of Singapore, Singapore, Singapore; ²Singapore Institute for Neurotechnology (SINAPSE), National University of Singapore, Singapore, Singapore.

During the past decades, neural electrodes have been developed as promising interface technology for direct communication with the neural tissues for diagnosis of the nervous disorders and treatment of the injury. Considering the significant material mismatch between the external implant and native tissue, a thin coating is employed on the electrode sites as an intermediate layer to bridge the difference. However, great challenges still exist regarding the long-term performance of the electrode coating *in vivo*.

In this study, a tubular electrode coating made of poly(3,4-ethylenedioxythiophene) (PEDOT) and carbon nanotube (CNT) was designed, targeted to long-term neural recording. The PEDOT-CNT nanotube coating was fabricated and showed compatibility with flexible polyimide electrode. The coating exhibited a 3D network-like structure made of hollow tube with an outer diameter of ~700nm and wall thickness of ~90nm. The electroactivity of the PEDOT-CNT coating was investigated using electrochemical impedance spectroscopy and cyclic voltammetry. The coated electrode sites showed significantly decreased impedance and increase charge storage capacity compared to bared site, which would allow more charge transfer at the interface and increase the sensitivity during neural recording. To test the mechanical adhesion of the PEDOT-CNT nanotube coating, ultrasonic treatment was employed in the study. The PEDOT-CNT nanotube could sustain 20min sonication with less than 20% delamination area while the PEDOT-PSS nanotube showed more than 60% delamination area after 5min treatment. The incorporation of CNT significantly reinforced the nanotube structure and improved the mechanical durability against sonication which would address the delamination issue of PEDOT coating and support chronic recording. We have also studies the different deposition condition and their effects on the morphology, electrical property and mechanical property of the coating. *In vitro* culture of neurons showed positive neuron attachment and neurite extension on PEDOT-CNT nanotube immobilized with poly-lysine and laminin.

1:45 PM BM07.04.02

Conducting Polymers for Stretchable and Healable Electronics Fabio Cicoira¹, Yang Li¹, Shiming Zhang², Floriane Miquet-Westphal¹ and Leslie Liu¹; ¹Ecole Polytechnique de Montreal, Montreal, Quebec, Canada; ²University of California, Los Angeles, Los Angeles, California, United States.

Organic electronic devices, apart from consumer applications, are presently paving the path for key applications at the interface between electronics and biology. In such applications, organic polymers are very attractive candidates, due to their distinct properties of mechanical flexibility, self-healing and mixed conduction.

My group investigated the processing conditions leading to high electrical conductivity, long-term stability in aqueous media as well as robust mechanical properties of the conducting polymer poly(3,4-ethylenedioxythiophene) doped with polystyrenesulfonate (PEDOT:PSS) [1-3]. We have demonstrated that stretchable PEDOT:PSS films can be achieved by adding a fluorosurfactant to the film processing mixture and by pre-stretching the substrate during film deposition. We have achieved patterning of organic materials on a wide range of substrates, using orthogonal lithography and pattern transfer [4-5]. Recently we have discovered that PEDOT:PSS films can be rapidly healed with water drops after being damaged with a sharp blade [6] or show autonomous self-healing if processed in presence of certain additives.

My talk will deal with processing, characterization and patterning of conducting polymer films and devices for flexible, stretchable and healable electronics. I will particularly focus on the strategies to achieve films with optimized electrical conductivity and mechanical properties, on unconventional micro patterning on flexible and stretchable substrates, on the different routes to achieve films stretchability and self-healing.

F. Cicoira et al. *APL Mat.* 3, 014911, 2015.

F. Cicoira et al. *Appl. Phys. Lett.* 107, 053303, 2015.

F. Cicoira, et al. *Appl. Phys. Lett.* 111, 093701, 2017

F. Cicoira et al. *Chem. Mater.* 29, 3126-3132, 2017.

F. Cicoira et al. *J. Mater. Chem. C* 4, 1382-85, 2016.

F. Cicoira et al. *Adv. Mater.* 29, 1703098, 2017.

2:00 PM *BM07.04.03

Multimodal Characterization of Soft Bioelectronics Stephanie P. Lacour; Ecole Polytechnique Federale de Lausanne, Geneva, Switzerland.

Soft bioelectronics incorporates all the functional attributes of conventional rigid electronics in formats that enable reversible mechanical loading and, in the case of implantables, performance under physiological conditions. Understanding the underlying mechanisms of stretchable materials and establishing the performance boundaries of such devices under the multiple operation conditions are fundamental to research efforts in the field. The biomedical context also imposes a challenging experimental environment that is difficult to replicate or predict. There is an unmet need for experimental set-ups that combine multiple modes of loading e.g. mechanical, thermal, electrical, biological, and provide real-time, concurrent probing of the devices.

This talk will describe our recent efforts in constructing multimodal experimental set-ups and establishing standardized tests and experiments that can clearly define the reliability and lifetime for soft bioelectronics. Using stretchable metallization integrated in wearable sensors and spinal implants as test vehicles for the new characterization platforms, we will report on failure modes, repeatability, robustness, and reliability. These metrics are often underestimated in academic research yet critical to advance the translation of soft bioelectronics.

2:30 PM BM07.04.04

Chronic and Acute Stress Hormone Monitoring/Stimulation in Adrenal Gland Yiel Jae Shin¹, SungHyuk Sunwoo² and Tae-il Kim¹; ¹Sungkyunkwan University, Suwon, Korea (the Republic of); ²Seoul National University, Seoul, Korea (the Republic of).

Living organisms mainly use nervous and endocrine systems to control the body and maintain homeostasis independently. Endocrinal signal based on the flow of special chemicals called hormone affects the body chronically and massively. When stress is applied to human body, hypothalamus releases corticotropin-releasing hormone (CRH) to the pituitary gland that generates adrenocorticotrophic hormone (ACTH) which flows into the adrenal cortex, especially adrenal zona fasciculata (AZF) cell in adrenal gland. The adrenal cortex then produces cortisol, a stress hormone that rebalances body functions and performances of neural and muscular system. However, repeated and chronic stress can cause malfunctions in cortisol releasing endocrine system. Chronic stress involves accumulation of excessive and unnecessary cortisol that eventually cause several diseases such as amnesia, depression, fatigue,

anxiety. It is necessary to continuously monitor the cortisol concentration to prevent such diseases which caused by chronic stress. Recently, it was revealed that the electrophysiological (EP) signal induced by ion flux through cellular membrane was responsible for hormone releasing process in corresponded endocrine organs. We assumed that accurate recording of electric signal representing physiological activities of endocrine cells could be applied to characterize cortisol change. Here, we introduce a long lasting, implantable Anchor - like flexible probe that can be used to quantify relationship between cortisol releasing level and electrophysiological (EP) signals from adrenal gland based on flexible EP sensors. This anchor – like probe penetrated through Adrenal Gland, which ensured minimal invasion to organs and stability, low impedance increment over 13 weeks. Through our research, we identified EP signal Frequency was increased in AZF cells, only induced by acute stress or ACTH injection. Thus, our team successfully determined activities of hormonal cells and relative change of cortisol hormone level under stress environment in in vivo animal model. Next, we hypothesized that electrical stimulation of surface of adrenal gland could improve or suppress activity of adrenal gland. We designed elastomer based, conformally attaching stretchable serpentine electrodes. It is known that cortisol secretion is also increased by not only stress but blood loss, therefore we extracted small doses of blood from inferior vena cava (IVC) of rat with every 5 minutes to induce artificial hemorrhage. By comparing Cortisol concentration of Non - electrical stimulated rat with electrically stimulated showed us that high frequency electrical stimulation tend to suppress activity of AZF cell. However, low frequency electrical stimulation improved AZF cell activity, which showed higher cortisol concentration than standard cortisol concentration. This research of Adrenal gland could provide fundamental knowledge to medical applications such as stress regulator.

2:45 PM BM07.04.05

Design of Conductive Gel for Sensing Weak Biosignals with High S/N Ratio Yuki Noda¹, Naomi Toyoshima¹, Teppei Araki^{1,2}, Shusuke Yoshimoto¹, Takafumi Uemura^{1,2} and Tsuyoshi Sekitani^{1,2}; ¹Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Japan; ²Advanced Photonics and Biosensing Open Innovation Laboratory, Suita, Japan.

Conductive gel enabling precise measurement of weak electrical signals are desired for the detection of biomedical signals such as an electroencephalogram (EEG) or a fetal electrocardiogram (ECG). Since these signals are intrinsically weak less than 100 μ V, the noise level has to be lowered to acquire signals with the high S/N. In general, one strategy for obtaining the high S/N ratio signal is to increase the electrode area to lower the contact resistance between skin and electrode or to shorten the length of the wiring to prevent invasion an external noise, however, we propose another option to detect signals with high quality by modifying gels on electrode. Here, we designed the biocompatible conductive gel to obtain weak EEG signals with the high S/N ratio by reducing the contact resistance and mains hum intensity.

The developed gels are based on Amylopectin contained in rice and NaCl. By just printing and heating the precursor solution on a noble metal, conductive gel can be fabricated. The impedance spectrum of gels shows almost frequency-independent characteristics through a range of 0.1 Hz to 100 kHz lower than 1k Ω . Hydrogen-bonded network of Amylopectin gives sufficiently strong adhesive force to the skin with its strength comparable to adhesive plasters. Other components enable to suppress mains hum that is one of the origin of lowing the S/N ratio of EEG signals. By combining the developed gels and the wireless measurement system, we successfully obtained EEG signals from forehead. As with Ten20 conductive paste that is commonly used to measure EEG signals in hospitals, the developed gels can also detect representative brain wave like alpha waves that appears at 10 Hz when eyes are closed. Additionally, the intensity of mains hum appeared between 50-60 Hz are effectively suppressed to about 50% against that of Ten20 conductive paste, meaning that we obtained EEG signals with the high S/N ratio. Our rational design of the biocompatible conductive gel may usher a new strategy for fabrication of "noise-reducing material" in the field of electrical and material science.

3:00 PM BREAK

3:30 PM *BM07.04.06

Bioelectronics with Nanocarbons—From Transparent to Fuzzy Interfaces Tzahi Cohen-Karni^{2,1}; ¹Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania, United States; ²Biomedical Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania, United States.

We focus on developing a new class of nanoscale materials and novel strategies for the investigation of biological entities at multiple length scales, from the molecular level to complex cellular networks. Our highly flexible bottom-up nanomaterials synthesis capabilities allow us to form unique hybrid-nanomaterials. Recently, we have demonstrated highly controlled synthesis of 3D out-of-plane single- to few-layer fuzzy graphene (3DFG) on a Si nanowire (SiNW) mesh template. By varying graphene growth conditions, we control the size, density, and electrical properties of the NW templated 3DFG (NT-3DFG). This flexible synthesis inspires formation of complex hybrid-nanomaterials with tailored optical and electrical properties to be used in future applications such as biosensing, and bioelectronics. Currently, we target the limits of cell-device interfaces using out-of-plane grown 3DFG, aiming at electrical recordings with subcellular spatial resolution (<5 μ m) and μ sec temporal resolution. Last, we have developed a unique transparent graphene-based electrical platform that enables concurrent electrical and optical investigation of ES-derived cardiomyocytes' intracellular processes and intercellular communication. In summary, the exceptional synthetic control and flexible assembly of nanomaterials provide powerful tools for fundamental studies and applications in life science, and open up the potential to seamlessly merge either nanomaterials-based platforms or unique nanosensor geometries and topologies with cells, fusing nonliving and living systems together.

4:00 PM BM07.04.07

Bioinspired Nanowire Devices Utilizing Perylene Diimides Kuo-Yao Lin¹, Andrew Bartlett², Alon Gorodetsky² and Jason D. Slinker¹; ¹The University of Texas at Dallas, Richardson, Texas, United States; ²Chemical Engineering and Materials Science, The University of California-Irvine, Irvine, California, United States.

Despite remarkable examples of difficult-to-produce isolated molecular devices, the scalable nanomanufacturing of such electronics remains at a standstill due to fundamental roadblocks associated with the synthesis of large quantities of modular nanoscale circuit elements. We have introduced a methodology for rapid, scalable production and facile purification of nanowire devices. We have synthesized organic semiconductor moieties, perylene-3,4,9,10-tetracarboxylic diimides (PTCDIs), within DNA-like scaffolds, leveraging the rapid, efficient, and precise coupling afforded by traditional DNA bioconjugate chemistry. These DNA-inspired nanowires enable the self-assembly of active, nanoscale circuit elements at patterned electrodes. The assembly and electrical performance of these arrayed devices have been characterized through scanning microscopy techniques and custom, automated electrical probe measurements under controlled environments and temperature. Current voltage characterization revealed absolute currents of fully well matched duplexes incorporating perylene units were enhanced by twofold over such nanowires incorporating two C-A mismatches and 4.4 fold over conventional DNA nanowires. Temperature dependence revealed a sharp current drop with temperature consistent with the dissociation of the modular duplex. Our unique and economically viable approach offers a new paradigm for the fabrication of nanoscale electronic circuits.

4:15 PM *BM07.04.08

Ink-Jet Printed 3D-Microelectrode Arrays for Neuroelectronic Interfaces and Sensing Applications Nouran Adly¹, Leroy Grob¹, Philipp Rinklin¹, Sabine Zips¹, Lennart Weiss¹, Hideaki Yamamoto³, Ayumi Hirano-Iwata^{4,3} and Bernhard Wolfrum^{1,2}; ¹Neuroelectronics - Munich School of Bioengineering, Department of Electrical and Computer Engineering, Technical University of Munich, Garching, Germany; ²Institute of Complex Systems

ICS-8, Forschungszentrum Jülich GmbH, Jülich, Germany; ³Advanced Institute for Materials Research, Tohoku University, Sendai, Japan; ⁴Research Institute of Electrical Communication, Tohoku University, Sendai, Japan.

Microelectrode arrays are used in a variety of sensing and stimulation applications including electrochemical biosensor platforms and neuroelectronic interfaces. Typically those arrays are produced with state-of-the-art fabrication methods such as photolithography or electron beam lithography, which provide high-resolution capabilities to include thousands of electrodes on a single chip. However, often these methods are expensive and restricted to certain substrate or electrode materials. Thus, they are not ideally suited for low-cost rapid prototyping of devices with alternative geometric features or materials.

Inkjet printing is an alternative low-cost fabrication method that has contributed to the field of printed electronics, recently including the generation of microelectrode arrays. Being an additive process, the material consumption is low and the method can be applied to generate functional structures on a variety of substrates including soft materials such as hydrogels. An inherent disadvantage of this technology however, is the poor lateral resolution, which is typically limited to approximately 20 - 30 μm using conventional inkjet printing platforms. Thus, it is not likely that inkjet printing will be able to compete with standard microfabrication techniques in terms of lateral sensor density. Yet, we show that some of the drawbacks concerning the lateral resolution in inkjet printing can be compensated using 3D-printing approaches. We demonstrate that the distance between individually addressable electrodes can be tuned to $\sim 1 \mu\text{m}$ in lateral and $\sim 100 \text{ nm}$ in vertical direction, which is exploited in electrochemical sensors using redox cycling amplification strategies. Furthermore, we show the possibility of generating defined high-aspect ratio 3D-microelectrode arrays on various substrates with an electrode height of more than 70 μm and electrode radius in the micrometer range. The flexibility of this process allows the fabrication of tailored devices for 3D-neuroelectronic interfaces on rigid as well as soft substrates.

4:45 PM BM07.04.09

Ti₃C₂ MXene Neural Electrodes for Sensitive Detection of Neuronal Spiking Activity Nicolette Driscoll^{1,3,2}, Andrew G. Richardson^{3,4}, Kathleen A. Maleski^{5,6}, Babak Anasori^{5,6}, Oladayo Adewole^{1,2}, Pavel Lelyukh^{5,6}, Lilia Escobedo⁷, D. K. Cullen^{1,2}, Timothy H. Lucas^{3,4}, Yury Gogotsi^{5,6} and Flavia Vitale^{3,2,8}; ¹Department of Bioengineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States; ²Center for Neurotrauma, Neurodegeneration, and Restoration, Corporal Michael J. Crescenz Veterans Affairs Medical Center, Philadelphia, Pennsylvania, United States; ³Center for Neuroengineering and Therapeutics, University of Pennsylvania, Philadelphia, Pennsylvania, United States; ⁴Department of Neurosurgery, University of Pennsylvania, Philadelphia, Pennsylvania, United States; ⁵Department of Materials Science and Engineering, Drexel University, Philadelphia, Pennsylvania, United States; ⁶A.J. Drexel Nanomaterials Institute, Drexel University, Philadelphia, Pennsylvania, United States; ⁷Department of Chemical Engineering, Cornell University, Ithaca, New York, United States; ⁸Department of Neurology, University of Pennsylvania, Philadelphia, Pennsylvania, United States.

High-resolution neural interfaces are essential tools for studying neural circuits underlying brain function and disease. As electrodes are miniaturized to achieve high spatial resolution and resolve individual neuronal spiking activity, maintaining low impedance and high signal quality becomes a significant challenge. Nanostructured materials have the potential to address this challenge by offering a combination of unique electrical and mechanical properties and the ability to interact with biological systems on a molecular scale. Ti₃C₂ MXene, a recently discovered 2D nanomaterial, possesses remarkably high volumetric capacitance, conductivity, surface functionality, and processability in aqueous dispersions, making it unique among 2D nanomaterials. In this work, we seek to evaluate the recording performance of MXene for detection of neuronal spiking activity *in vivo*. We employed a high-throughput microfabrication process for micropatterning MXene onto flexible, parylene-C substrates, and fabricated a 10-channel laminar probe. The laminar probe has 5 sets of side-by-side MXene and gold (Au) electrode contacts (25 μm diameter) arranged in a stereotrode configuration to enable direct comparison of signal quality between the two materials during *in vivo* recording. Electrochemical impedance spectroscopy revealed that the MXene electrodes in the array exhibit remarkably low 1 kHz impedance compared to their Au counterparts: $219 \pm 31 \text{ k}\Omega$ vs. $865 \pm 125 \text{ k}\Omega$, respectively. The MXene electrodes have a rough and layered surface morphology (Ra = 32 nm), which likely contributes to their $\sim 4\times$ improvement in impedance properties compared to Au. We performed acute recording experiments in anesthetized rats and recorded multiunit neural spiking activity on adjacent MXene and Au stereotrode contacts implanted in sensorimotor cortex. Spikes that occurred simultaneously on adjacent MXene and Au electrodes were considered to have been generated by the same neuron, and their signal-to-noise ratios (SNR) were computed and compared. We found that MXene electrodes recorded neural spiking activity with significantly higher SNR than Au electrodes. We also found that MXene electrodes recorded more spikes overall than the Au electrodes, and that the spikes unique to the MXene electrode in a stereotrode pair tended to be low amplitude, suggesting that MXene electrodes have a larger "seeing distance", allowing them to resolve spiking activity from a larger volume of tissue. Finally, we assessed the neuronal biocompatibility of Ti₃C₂ MXene *in vitro* and found that neurons cultured on MXene films proliferated, showed axonal growth, formed synaptic connections, and were as viable as control cultures. This work highlights the suitability of Ti₃C₂ MXene for high resolution neural interfaces and suggests that MXene has significant potential to enhance the performance of neural microelectrodes beyond current capabilities.

SESSION BM07.05: Poster Session I: Bioelectronics—Fundamentals, Materials and Devices

Session Chairs: Sahika Inal, Christian B. Nielsen and Roisin Owens

Tuesday Afternoon, November 27, 2018

8:00 PM - 10:00 PM

Hynes, Level 1, Hall B

BM07.05.01

Wireless Flexible Vertical GaN MicroLEDs for Transparent Optical Stimulator Han Eol Lee, Jung Ho Shin, Jung Hwan Park, Jae Hee Lee and Keon Jae Lee; KAIST, Daejeon, Korea (the Republic of).

With the advent of the hyperconnected era, visual IoT devices attracted great interest. Flexible displays are powerful candidates for interactive visual communication. Inorganic-based micro light emitting diodes (μLEDs) have been regarded as key technologies in RGB micro LED TVs due to their excellent electrical/optical properties, fast response, long lifetime and high stability in harsh environments. Several groups have studied various inorganic LED materials for various applications. Despite previous reports of flexible micro LEDs, GaN f-VLEDs on plastic substrates have not yet been demonstrated due to the difficulty of vertical GaN interconnections. Flexible energy sources for f-LEDs are also required for practical applications of flexible optoelectronic systems.

Herein, we report a flexible 30x30 GaN VLED array through a simple manufacturing process. The GaN LED chip was separated from the sapphire wafer by the ILLO process. Stand-alone microLEDs are isolated by biocompatible layers and are interconnected vertically with AgNW-based conductors by resolving the high step coverage of f-VLEDs. Ultra-thin, transparent and flexible GaN VLEDs are attached to the human nail in a conformal structure with high light output of 30 mW mm⁻². The lifetime of the f-VLED was experimentally investigated by a high accelerated stress test (HAST) and

theoretically estimated by simulation. In addition, our f-VLEDs exhibited excellent mechanical durability during cyclic bending cycles. A wireless power supply system for human skin has been successfully demonstrated by delivering electrical energy to the f-VLED. Finally, the blue f-VLED successfully emitted blue light into the mouse brain without severe tissue damage.

BM07.05.02

Metal Nanoparticles-Grafted Functionalized Graphene Coated with Nanostructured Polyaniline ‘Hybrid’ Nanocomposites as High-Performance Biosensors [Sanju Gupta](#) and Romney Meek; Western Kentucky University, Bowling Green, Kentucky, United States.

We report on the development of next-generation chemical, electrochemical and biological sensors from nanocomposites with broader electrical conductivity and anticipated linear sensitivity, faster response time, specificity and stability. We synthesized metal nanoparticles-grafted functionalized graphene nanosheets with nanostructured polyaniline (PANI) ‘hybrid’ nanocomposites for ascorbic acid (AA) sensing. The versatility of the nanocomposite performance was corroborated by altering the size and areal density of electrodeposited gold (Au_{NP}) and silver (Ag_{NP}) nanoparticles on the graphene-family nanomaterials; GFNs namely, graphene oxide; GO, thermally reduced GO; rGO_{th} and nitrogenated functionalized graphene; NFG. In addition, the globular surface morphology and charge density of electropolymerized polyaniline (PANI) onto GFNs can also influence the biosensor performance. The noble metal nanoparticles are selected due to their higher electrical conductivity, facile synthesis, easier processability, antimicrobial applicability and scalability. The as-synthesized multilayer architectures (PANI|Ag_{NP}|GFN and PANI|Au_{NP}|GFN) on fluoride-doped tin oxide (FTO) coated glass, graphite foil (GF) and graphene rod (GR) electrodes increased the electrical conductivity of the electrodes significantly and reduced the charge transfer resistance dramatically determined while investigating the electrochemical and biosensing properties. We demonstrate the high-performance sensing for the detection of AA analyte over a full detection range (from 1×10^{-12} M to 10×10^{-3} M) with linear sensitivity of $10 \text{ mA mM}^{-1} \text{ cm}^{-2}$ and excellent limit of AA detection $< 1 \text{ pM}$ with higher signal-to-noise ratio following PANI|Au_{NP}|NFG \gg PANI|Ag_{NP}|NFG $<$ Au_{NP}|NFG $<$ Ag_{NP}|NFG. The specificity of the biosensor is also assessed by interaction of electroactive components with AA interfering species commonly found in blood serum samples *i.e.* glucose (Glu) and uric acid (UA). We attribute these findings to synergistic coupling of electrochemically bridged metal nanoparticles and functionalized graphene doped with nitrogen that promotes localized orbital re-hybridization and heterogeneous integration with PANI. They all contribute toward enhanced electroactivity and ensure rapid charge transfer and ion conduction. These multilayer ‘hybrid’ nanocomposite electrodes are also useful as advanced electroanalytical platforms for platinum-free electrocatalysis, electrodes for energy storage pseudocapacitors and enriching biofuel cell development. This work is supported in parts by KY NSF EPSCoR Grant and WKU Graduate School Fellowship.

BM07.05.03

Biosensor for the Simultaneous Monitoring of Breath Isoprene and Acetone [Jan van den Broek](#), Amy Wang, Andreas T. Güntner and Sotiris E. Pratsinis; ETH Zürich, Zürich, Switzerland.

Volatiles from the human body, especially from breath, contain a wealth of physiological and pathological information.¹ Chemo-resistive metal-oxide gas sensors stand at the interface to the human biosystem as they specifically interact with such biomarkers and are capable to measure their concentrations even at the lowest parts-per-billion (ppb) levels.² This way, individual emanating volatiles can be monitored to infer and better understand metabolic states and processes. In specific, breath isoprene has been suggested to be an indicator for the efficacy of blood cholesterol-lowering therapy³ and cardiac output,⁴ while acetone is an established biomarker for fat metabolism.⁵ Thus, online monitoring of these two gases simultaneously by a portable device can be a promising tool to optimize effective weight loss through physical exercise and diet planning. Here, we present a sensor system for the simultaneous detection of isoprene and acetone in complex breath mixtures. It consists of nanostructured films of inorganic metal-oxides designed by flame aerosol synthesis to selectively interact with these biomarkers on a molecular level, resulting in a detectable electrical signal. The resulting biosensor can detect acetone and isoprene simultaneously down to 5 ppb in real time at breath-relevant relative humidity. It shows high selectivity to other major breath markers like methanol, ethanol and ammonia. The biosensor is also tested in vivo by direct sampling of breath through a breath sampler and simultaneously cross-validated by state-of-the-art mass spectrometry. All the components utilized can be readily miniaturized and integrated into a portable device enabling monitoring of these important metabolic tracers.

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BM07.05.04

Transparent, Flexible Deep-Well Micro-Structured PEDOT:PSS/Au Nanorods Based Electrode Array for Neural Recording [Younguk Cho](#) and Ki Jun Yu; Electrical and Electronics Engineering, Yonsei University, Seoul, Korea (the Republic of).

Neural interfaces offer an insight into the mechanism of nervous system by recording signals from neurons. Conventional neuro-electrodes are made of metal that may occur clinical image distortion by its inherent opacity. Electrode transparency is ultimately important factor, because electrical artifacts from light stimulation for opto-genetics hinder the neural recording and interfere with the pinpoint control of neural activity. Ultrathin metal based devices for neural recording have been reported as alternatives with transparency, but the relatively low transmittance rate (<60%) requires novel materials and micro/nanopatterning techniques that offer significant enhancement of signal to noise ratio(SNR) of electrophysiological signals while maintaining its transparency.

Biocompatibility is also important factor to be considered for electrodes that are used for implantable neural arrays. Numerous materials for biocompatible implantable devices with the outstanding electrical properties have been discussed for the electrophysiological recordings or stimulations. However, only small number of reported such electrodes satisfy the conditions where multiple characteristics such as high transparency, flexibility, and high SNR, together with credible bio-stable property require, thereby enabling conformal electrical and optical neural recording simultaneously. Conducting polymers are excellent material choice for the neural electrodes that satisfy the characteristics mentioned above. Recently, poly(3,4-ethylenedioxythiophene)(PEDOT) as the representative conducting polymer is widely used for the neural electrodes due to the good conductivity with a high degree of an optical transparency.

Herein, we present a facile fabrication of deep-well structured PEDOT:PSS/Au nanorods array that can greatly improves SNR of neural recordings compared to the conventional PEDOT:PSS based electrodes. In our work, Au nanorods with three-dimensional(3D) deep-well microstructures by self-assembly are exploited as particles that can greatly enhance electrode conductivity while maintaining its optical transparency. Au nanorods are also suitable for the implantable neural interface design because of its well-known biocompatibility. Electrical and optical characterizations were conducted on both the deep-well microstructure and the plain surface-based PEDOT:PSS/Au nanorod electrode as a point of comparison. These experimental results show the much lower impedance plot and higher optical transparency with the deep-well surface structure compared to that with the planar device. Conducting

cytotoxicity and implantation experiments on animal models also support its good biocompatibility. We expect this novel microstructure electrode array to be the unprecedented candidates for electrodes in a field of biomedical engineering such as an implantable cell regulating device or neural interface.

BM07.05.05

Sensing Applications of Remote-Gate Field-Effect Transistor Combining Polymer Sensing Membrane [Hyun-June Jang](#), Justine Wagner, Hui Li, Qingyang Zhang, Taerin Lee, Jian Song and Howard E. Katz; Materials and Science Engineering, Johns Hopkins University, Baltimore, Maryland, United States.

A field-effect transistor (FET) sensor electrically quantifies analyte levels through the perturbation of source-drain currents by chemical interactions at the gate in a label-free manner. In a typical scheme in FET sensors, specific receptors are placed on the semiconducting layer or the gate of FETs which acts as the sensing layer. There have been many attempts to apply organic/polymer materials in FET sensors due to their unique intrinsic properties such as flexibility and transparency which promotes the FET sensor as a cost-effective means on wearable platforms. However, an immense challenge exists in regards to using organic/polymer materials as the semiconductors, because of their instability under solution-based testing. Water on the dielectrics of OFET biosensors diffuses into the organic semiconducting layer and degrades its semiconducting character.

Therefore, having a remote gate geometry, which separates the sensing component from the FET transducer, is highly desirable for OFET biosensors. This remote gate structure not only protects the semiconductor from damage by solution, but also harnesses the aforementioned advantages of using organic/polymer materials in the sensor platforms. Alternatively, the OFET transducer can be replaced with inorganic FETs that have much higher stability. This is because the essential function of a FET is just to translate input voltage signals from the gate electrodes into output signals in the drain and the sensing membrane, not the FET, crucially determines sensitivity, specificity, and characters of the sensing platform.

Herein, we demonstrate three diverse sensor applications based on the usage of commercial field-effect transistors with remote polymer gate: cortisol sensor, pH sensor, and dopant monitoring sensor. All of these sensors share the same detection system but use different remote polymer sensing membranes. In cortisol sensors, the polymer sensing membrane was made by linking poly(styrene-co-methacrylic acid) (PSMA) with anti-cortisol before coating the modified polymer on the remote gate. The embedded structure of the anti-cortisol in the polymer allowed cortisol molecules to bind near the membrane-substrate interface. A limit of detection of 1 ng/mL was shown in lightly buffered artificial sweat. In the second application, we investigated the intrinsic pH sensitivity of polystyrene, poly(methyl methacrylate), and PSMA, by ranging the pH from 3 to 11. The long and short-term pH sensitivity exposure was compared for each individual polymer. In our last application, we demonstrate new way to quantify dopants concentration on polymers using the remote gate geometric approach. P3HT was deposited on the remote gate structure and the dopant, F4TCNQ, was dissolved in acetonitrile and deposited onto the P3HT layer. We were able to quantify and evaluate the deposition from solutions with varying concentrations of dopant which ranged from 1 µg/ml to 1 mg/ml in contact with the P3HT layer.

BM07.05.06

Eco-Friendly Biodegradable Thin-Film Transistor and Floating Gate Memory Using Indigo Organic Semiconductor [Pilwoo Lee](#), Hunsang Jung, Wonkyu Kang, Kyoungmin Woo and Hyun Ho Lee; Myongji University, Yongin-si, Korea (the Republic of).

In this study, eco-friendly and biodegradable thin film transistor (TFT) devices having floating gate (FG) for memory charging operation have been demonstrated. All materials for fabrications of TFT and its memory TFT were originated from biologically produced and environmentally friendly substrates, where related researches have been in spotlight in order to accomplish an entirely biodegradable electronics.

As a semiconductor material, indigo has been continuously adopted, in literatures which is a natural pigment from plant. The devices have been fabricated on biodegradable carboxymethyl cellulose (CMC) substrate. Gold as a gate electrode was deposited on CMC substrate. Gate dielectric layer was based on lactose or lactose oligomer, which was also known as a good performance dielectric layer with low dielectric losses. The FG material for memory device was also adopted from biological nanoparticles (NPs) such as polylysine, which could be formulated by polymerization of amino acid of lysine. Before an implementation of TFTs on the CMC, all TFTs and memory TFTs could be accomplished on Si substrate. Through this kind of degradable electronic study, recent environmental problems associated with non-degradable plastic could be reduced or eventually resolved in the future.

BM07.05.07

Ternary Metal Chalcogenide (Ni, Co)_{0.85}Se for Biosensing Applications [Niman H. Alsharief](#) and Manuel Quevedo-Lopez; Materials Science and Engineering, University of Texas at Dallas, Richardson, Texas, United States.

Ternary transition metal chalcogenides are an emerging class of materials for a variety of electrochemical and energy applications. Among them, (Ni, Co)_{0.85}Se is an interesting compound because it exhibits several attractive features including: (1) high electrochemical activity due to the presence of electroactive Ni and Co atoms, (2) metallic-like conductivity, which ensures rapid electron transport, (3) ease of nanostructure formation. Here we report a simple two-step hydrothermal process to synthesize nanostructured (Ni, Co)_{0.85}Se. Briefly, sacrificial template of Ni-Co-precursor was first synthesized using a hydrothermal method. In a subsequent step, the Ni-Co precursor was chemically converted into (Ni, Co)_{0.85}Se by selenization in NaHSe solution, resulting in a uniform distribution of Ni, Co, and Se. Thanks to its unique properties, we have implemented (Ni, Co)_{0.85}Se for biosensing application first as generic H₂O₂ sensor, and then as enzymatic sensor for glucose, uric and ascorbic acids. H₂O₂ sensing measurements were performed using 0.1 M PBS as supporting electrolyte under ambient conditions using CV, LSV, and amperometry techniques. The fabricated sensor enables H₂O₂ reduction at a low working potential of 100 mV with a short response time (< 0.1 s). It exhibited a linearity in a wide concentration range from 1-1705 µM. In addition, a long range stability over 3000 s and a very good repeatability is observed, which indicates (Ni, Co)_{0.85}Se as a potential candidate in electrochemical biosensing.

BM07.05.08

Dopamine Receptor Conjugated-Nanohybrids Field-Effect Transistor for Discriminating Dopamine Receptor D1 Agonism and Antagonism [Jinyeong Kim](#) and Oh Seok Kwon; Korea Research Institute of Bioscience & Biotechnology (KRIBB), Daejeon, Korea (the Republic of).

Screening methodologies of potential G-protein-coupled receptor (GPCRs), which transfer external signals into the cell, drugs has been developed for several decades. Recently, the field-effect transistor (FET) has been used in the development of diagnostic tools, leading to high-performance biosensors, especially liquid-ion gated FET biosensors. Therefore, the FET platform can provide the foundation for the next generation of analytical methods. A principle application of GPCRs is screening new drugs, so the development of a GPCR-conjugated analytical device is highly desired. In this study, we firstly proposed a new approach for studying receptor agonism and antagonism by combining the FET and GPCR roles in a dopamine receptor D1 (DRD1)-conjugated FET system, which is a suitable substitute for conventional cell-based receptor assays. DRD1, for the first time, was reconstituted and purified to mimic native binding pockets that have highly discriminative interaction toward DRD1 agonists/antagonists. The real-time responses from the DRD1-nanohybrid FET were highly sensitive and selective for dopamine agonists/antagonists, and their maximal response levels were clearly different depending on their DRD1 affinities. Moreover, the equilibrium constants (*K*) were estimated by fitting the response levels. Each *K* value indicated the

variation in the affinity between DRD1 and the agonists/antagonists: greater K value corresponds to a stronger DRD1 affinity in agonism, whereas a lower K value in antagonism indicates a stronger DA-blocking effect.

BM07.05.09

High-Performance Biosensor Using Multi-Channel System Graphene Field Effect Transistor (GFET) Microfluidics for the Rapid Bacteria Detection [KyungHo Kim](#) and Oh Seok Kwon; Korea Research Institute of Bioscience & Biotechnology (KRIBB), Daejeon, Korea (the Republic of).

Over the past of decades, bacteria monitoring is critical in detecting bacteria from contaminated drinking water and food. A various kind of bacteria detection methods such as electrical or optical sensor has been developed. Nevertheless, although many studies with bacteria detection sensors have been reported for high performance detecting properties, the development of the bacteria sensor still remains as challenge. Herein, we study the demonstration of graphene field-effect transistor (GFET) microfluidics using single-layer graphene micropatterns and characterize its monitoring capacity in bacteria detection. The GFET microfluidics had excellent mechanical/ electrical properties in fluidics and showed high sensitivity and selectivity for a target in bacteria mixture. Based on those results, our GFET microfluidics can provide potential applications in the field of disease diagnostics at early stage.

BM07.05.10

Field Effect Transistor Based *In Vitro* Dopamine Aptasensor [Jiyoon Lee](#) and Oh Seok Kwon; Korea Research Institute of Bioscience and Biotechnology, Yuseong-gu, Korea (the Republic of).

In this study, ultrasensitive and precise detection of a representative brain hormone, dopamine was pursued and demonstrated using functional conducting polymer nanotubes modified with aptamer. The produced aptasensor was composed of a micropatterned gold electrode, carboxylated polypyrrole nanotubes, and specific aptamer molecules. The sensor was constructed by sequential deposition of the PPy-COOH nanotubes and aptamer molecules on the electrode. The sensitivity and selectivity of this sensor were monitored using field effect transistor type measurements. In addition, real dopamine released from PC12 and SH-SY5Y cells induced by high concentration potassium ion (K^+) stimulus were also analyzed and compared with the data obtained from the sensitivity (1 nM) and selectivity tests. This article can provide the feasibility for practical use of simple and efficient field effect transistor type aptasensor.

BM07.05.11

Traditional Conjugated Polymer as Efficient Mixed Conductors for High-Performing Electrochemical Transistors [Priscila Cavassin](#) and Gregorio C. Faria; Universidade de São Paulo, São Carlos, Brazil.

Organic electrochemical transistors have garnered attention for applications in biological interfacing, logic circuits and neuromorphic devices. [1] Despite recent advances in device fabrication and materials development, however, only a narrow class of polymers have been found to stably operate in these new applications. To this end, we have developed general guidelines that allow for the fabrication of OECTs with semiconducting polymers that do not uptake water efficiently. The methodology produces devices that operate stably at room temperature, exhibits excellent transistor characteristics, (e.g., transconductance and volumetric capacitance), and is versatile, making it possible to fabricate OECTs with virtually every conjugated polymer synthesized to date. Using the general guideline here proposed, we have successfully fabricated high-performing OECTs using standard conjugated-polymers, such as, poly(3-hexylthiophene) (P3HT). Additionally, by fitting the transient curve response and transfer curves of our OECTs, we are able to extract key fundamental properties of both the device and the active channel materials, including the volumetric capacitance (C_v), the intrinsic hole/electron mobility (μ), as well as the product μ^*C_v , which has been used as the benchmark for comparing OECT devices. [2] We have used such benchmark to compare our OECTs performance with previously reported materials and show that some of our devices are the best published to date. Furthermore, we showed applications of these devices in biosensing.

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BM07.05.12

Anion-Dependent Doping and Charge Transport in Organic Electrochemical Transistors [Lucas Q. Flagg](#), Rajiv Giridharagopal and David S. Ginger; Chemistry, University of Washington, Seattle, Washington, United States.

We study the effects of different dopant anions on mixed ionic/electronic transport in organic electrochemical transistors (OECTs) based on poly(3-hexylthiophene-2,5-diyl) (P3HT). We show that the electronic transport properties depend on the anion present in the electrolyte, with greater transistor currents resulting from the use of polyatomic anions such as trifluoromethanesulfonylimide (TFSI) as compared to halide anions. Using spectroelectrochemistry, we show the maximum doping level at a given bias is also anion dependent. Furthermore, we find that the average electronic carrier mobility depends on the identity of the compensating counterion. We investigate this effect further using electrochemical quartz crystal microbalance (EQCM) measurements, showing the solvation shell of the dopant anions within the polymer varies drastically depending on the type of anion. Surprisingly, we find that the doping kinetics in these OECTs is faster for larger anions. Lastly, we use electrochemical strain microscopy (ESM) to resolve ion-dependent differences in local swelling on the nanoscale, providing further insight into the interplay between local polymer structure and ion uptake. These measurements show that the chemical properties of the compensating ion are an important design consideration for polymer materials with mixed ionic/electronic conductor applications.

BM07.05.13

Liquid-Ion Gated Field-Effect Transistor (FET) with Human Dopamine Receptor Integrated-Multidimensional Conducting Polymer Nanofiber for Dopamine Detection Seon Joo Park and [Oh Seok Kwon](#); KRIBB, Daejeon, Korea (the Republic of).

Dopamine (DA) has been studied in the field of nervous and cardiovascular systems. Abnormal levels of dopamine is an indicator of neurological disorders, resulting in Alzheimer's and Parkinson's diseases. Therefore, dopamine is a clinically useful diagnostic sign and requires a novel approach with high sensitivity, selectivity and a rapid response. Various sensors have been developed, such as high-performance liquid chromatography (HPLC), mass spectroscopy, and spectrophotometry. However, they are limited by their high cost, low sensitivity, and variable label response.

The field-effect transistor (FET) has been used in the development of diagnosis for several decades. It is gated by changes of charge carrier density in the channel induced by the binding of target molecules, leading to high-performance biosensors. In addition, the FET platform has attracted due to their low cost, easy operation, fast response, label-free operation, parallel sensing as well as high sensitivity.

In this article, we introduced a high performance dopamine sensor based on FET assay. Multidimensional carboxylated poly(3,4-ethylenedioxythiophene) (MCPEDOT) NFs membrane was utilized as the conductive channel of sensor in the FET system. Interestingly, it provided high performance sensing due to enhanced interaction from high surface area and gate-potential modulators. Moreover, hDRD1, G protein-coupled receptors (GPCRs) as the recognition elements, was first expressed in Escherichia coli and modified with the surface of MCPEDOT NFs, leading to high selectivity. As a results, the

hDRD1-MCPEDOT NF-based FET exhibits a rapid real-time response (<2 s) with high dopamine selectivity and sensitivity performance (approximately 100 fM).

BM07.05.14

Nanobioelectronic Nose with Human Olfactory Receptor-Functionalized Graphene Micropatterns for the Analysis of the Spoiled Odor, Trimethylamine Sung Eun Seo and Oh Seok Kwon; Korea Research Institute of Bioscience and Biotechnology, Daejeon, Korea (the Republic of).

Trimethylamine (TMA), an odor from spoiled meat, is a positive proof that we can decide if the food is spoiled or not. We demonstrated the nanobioelectronic nose using the human olfactory receptor (hOR) functionalized graphene field-effect transistor (GFET). At first, the hOR is prepared from the *Escherichia coli* (E. coli) for the sensing of the real food sample's TMA. The nanobioelectronic nose was characterized by SEM, TEM, *I-V* and transfer curve. The real-time responses under liquid-ion gated system showed that the bioelectronics nose with hOR-conjugated GFET had higher selectivity and specificity compared to conventional electronic noses without bio-receptors. Moreover, the nanobioelectronic nose could provide the effective criteria to judge the food's freshness. The most advantage of this research is the quantitative analysis of the popular fish. Moreover, it can be utilized to any other real food samples with only the reactive receptor.

BM07.05.15

High Molecular Density Bio-Electronic Sensor Based on 2D Crystalline Interface and QTY Modified GPCR Proteins Rui Qing¹, Andreas Breitwieser², Giovanni Azzellino¹, Mantian Xue¹, Jiayuan Zhao¹, Uwe Sleytr², Jing Kong¹ and Shuguang Zhang¹; ¹Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ²University of Natural Resources and Life Sciences Vienna, Vienna, Austria.

Bio-electronic is an emerging interdisciplinary subject which utilizes biomolecules in electronics or mimics biological architectures. One important aspect of the field is to fabricate sensors for biomolecules detection, i.e. ligands. Researchers previously designed sensors based on metal-oxide-semiconductor (MOSFET), polymers and inorganic crystalline materials which produce decent sensitivity but lacks selectivity. Recent efforts are devoted to directly connecting biological receptors with electronic systems. G protein-coupled receptors (GPCR), are the largest family of membrane receptors that detects information (molecules and lights) and transduce to cell internal signals to regulate body functions. There are nearly 1000 types of GPCR proteins in human body, each one being highly specific to a particular signal, which make them suitable candidates as sensors in bio-electronic devices.

Based on our previous reported novel approach of QTY modification on GPCR proteins, we were able to obtain water soluble receptors active to their natural ligands without adding any detergent. Recombinant SbpA S-layer proteins can reproduce ordered 2-dimensional crystalline monolayer *in vivo* and were employed as the intermediate layer between biomolecules and electronic substrates. By fusing -Fc region of human IgG protein to GPCR^{QTY} and Protein GG onto SbpA, we successfully formed GPCR-S-layer complex and anchor them onto the electronic active surface, i.e. Si wafer, graphene, etc. SbpA proteins also helped to guide the orientation of attached GPCR^{QTY} proteins and expose their active binding sites. The assembly yields functional molecule monolayer density as high as $2.37-4.73 \times 10^{12}$ molecule/cm². Binding/Elution of the GPCR^{QTY} proteins on the intermediate layer can be regulated by environmental pH. The bioelectronics platform yields detectable electrical and electrochemical signal in response to the biological stimulus from the receptor layer. Coupled with different types of receptor proteins this approach can prove to be a universal platform for bioelectronics and nano-sensing systems.

BM07.05.16

The Charge Carrier Modulation in PEDOT:PSS Films via Chemical Crosslinking with PVA Ji Hwan Kim and Myung-Han Yoon; School of Materials Science and Engineering, Gwangju Institute of Science & Technology (GIST), Gwangju, Korea (the Republic of).

Recently, the charge carrier modulation in semiconducting polymer films has drawn much attention, but there exist a relatively small number of studies on the charge carrier modulation in highly conductive polymer films despite their potential for energy storage and bioelectronics applications. In this work, we report the charge carrier modulation of poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) films and its application to organic electrochemical transistors (OECTs) with finely-tuned threshold voltage characteristics by crosslinking with polyvinyl alcohol (PVA) as a de-dopant. PVA was blended with an aqueous solution of PEDOT:PSS and the PEDOT:PSS-PVA blend films were chemically crosslinked in the solid state. The electrical characterization revealed that the crosslinking with PVA significantly lowered the conductivity from 1800 to 80 S/cm, the volumetric capacitance from 100 to 1 F/cm³, and the hole concentration from 3.3×10^{19} to 7.5×10^{17} /cm³ in the PEDOT:PSS-PVA hybrid films. Despite the inclusion of electrically insulating polymer in the conductive material, however, the resultant OECT devices exhibited relatively high on-current (~1 mA), large current on/off ratio (>10³), and excellent transconductance (>2 mS), which are acceptable for bioelectronic sensors with the customized electrical/electrochemical properties. In addition, the concurrent threshold voltage shift from 0.5 to 0.3 V upon PVA crosslinking suggests that the PEDOT:PSS-PVA hybrid channel can offer finely tunable threshold voltage characteristics to OECT devices without the significant degradation in OECT performance.

BM07.05.17

Nanocurvature Effect on Electrical Properties of Conductive Polymer Thin Films for Bioelectronics Applications Grazia M. Messina, Nunzio Tuccitto, Giovanni Li Destri and Giovanni Marletta; University of Catania, Catania, Italy.

The use of conducting polymers had a great deal in the last decades. It is mainly due to the possibility to employ them in tissue engineering, neural probes, biosensors, drug delivery and bioactuator in order to create an interface with living cells and tissue. Electrical stimulation (ES) is one of the agents that modulate cell-biointerface interaction in Conductive Polymer-based (CP) biointerfaces. The optimization of the CP bioactive interface is crucial since the first contact between biological systems and biomaterials is done at interface.

In this study we investigate the preparation and modification of thin film of P3HT and PEDOT:PSS, in view of tuning their electrical properties by appropriate surface nanostructuring. In particular, we have studied the effect of nanocurvature on the electrical properties of conductive polymer films.

Controlled modification of the nanocurvature of conducting polymer film has been obtained by preparing hexagonally packed arrays of colloidal nanoparticles of different diameter and using these nanostructured surfaces as substrates for the deposition of the conducting polymer thin films.

Interdigitated electrodes, having strips 5mm width, have been used as structure for the electrical measurements. The nanostructured surfaces have been characterized by Atomic Force Microscopy and their electrical properties have been studied by using interdigitated schemes.

In particular, we have found that nanocurvature effect improves the electrical properties of conductive polymer comparing with the flat one. In particular nanoparticles with smaller diameter (147nm) induce an increase of polymer conductivity giving the best result in respect of other nanoparticle dimensions employed in this study (235nm and 403nm). PEDOT:PSS nanostructured films, with different nanocurvature and related electrical properties, were then used as substrate to study on one side the effect of the electroconductive nanostructured substrates and the structure and biological performances of Poly-Lysine and, on the other side, the effect of the poly-Lysine embedding on the electrical properties of the biocomposite system.

This work represents a promising first step in the perspective of controlling the neural cell response by setting appropriate nanostructuring strategies, allowing to produce performant electro- and bioactive polymeric substrates for bioelectronics applications.

BM07.05.18

Highly Sensitive Lactate Sensors Based on Carbon MEMS (CMEMS) Shahrazad Forouzanfar, Chunlei Wang and Nezhil Pala; Florida International University, Miami, Florida, United States.

L-Lactic acid is one of the important metabolites produced during the anaerobic phase of glycolysis, making its precise determination highly important in various fields such as clinical diagnosis, sport, and military activities. Lactate plays a crucial role in several areas of human health, including heart failure, hepatic dysfunction, shock, respiratory insufficiency and systemic disorders. In sports medicine, knowledge of optimal blood lactate levels is vital to ensuring the maximum performance of an athlete during intensive exercise and endurance-based activities.

Various methods have been developed for determining lactate levels, such as optical, nuclear magnetic resonance, liquid chromatography, fluorimetry, and amperometry. Among these methods, electrochemical ones possess advantages such as simple instrumentation, low detection limit, and wide dynamic range, as well as high selectivity and stability. A Carbon-microelectromechanical system (C-MEMS) is one in which Carbon is synthesized through pyrolysis of micro patterned photoresist polymer in an oxygen-free environment under high temperatures. Carbon possesses various remarkable properties such as a wide electrochemical window, low non-specific adsorption of biomolecules, excellent biocompatibility, and low cost. Furthermore, carbon-based materials exhibit good electrical conductivity, as well as good tolerance toward bio-fouling. The surface of the carbon can be functionalized efficiently via various physical, chemical, or electrochemical treatments. C-MEMS devices circumvent the major drawbacks associated with commercialized screen-printed carbon electrodes such as low resolution and miniaturization.

We developed an electrochemical C-MEMS-based sensing platform to detect L-Lactic Acid. The sensing platform of the biosensor—interdigitated carbon micro fingers—was synthesized by pyrolyzation of photo-patterned photoresist polymer in oxygen-free and high-temperature conditions. The surfaces of the fingers were functionalized by an oxidation pretreatment technique involving oxygen reactive ion etching (RIE) to form –COOH on glassy carbon. Taking advantage of having high concentrations of this carboxylic group on the surface of the carbon, we immobilized Lactate Oxidase (LOx) on the surfaces of the interdigitated carbon micro fingers without any other surface pretreatments. We employed various analytical characterization methods such as Fourier-transform infrared spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) for material characterization. Sensing capabilities were measured by cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS). The carbon capacitive sensor demonstrated detection of lactate over a wide dynamic range of 50 nM-5 mM for the electrode area of 0.5×0.5 cm². The sensitivity of this linker-free lactate sensor was found to be 40 nM/cm², making it the first carbon capacitive L-lactate sensor with such high sensitivity.

BM07.05.19

Detection of Hormone Using a Reagent-Free Electrochemical Method Bo Wu, Ye Liu, Amritha Ajithkumar, Yi-Chieh Wang, Akash Kannegulla and Li-Jing Larry Cheng; Oregon State University, Corvallis, Oregon, United States.

We report a bioresponsive electrode to achieve reagent-free electrochemical detection of hormone cortisol. The sensor combines a molecularly-imprinted polymer (MIP) layer that enables selective binding of target cortisol and a ferrocene-decorated polymer layer that offers charge transfer to amplify the detection signal readout in cyclic voltammetry (CV) measurements. Conventional CV-based biosensing requires the introduction of redox reagents, such as ferrocyanide, in analyte solutions to identify the docking of target molecules on the electrode surface. The composite enhances detection signal by offering redox peaks in CV characteristics without adding redox reporters in the analyte which simplifies the workflow to allow real-time detection. The measurement result shows that the current level decreases with the increase of cortisol concentration. The trend stems from the fact that the binding of cortisol in MIP hinders the charge transfer at the electrode-solution interface. The sensor exhibits a large dynamic range up to micromolar concentration and has a detection limit of less than 10 pM, sufficient for the application of salivary cortisol measurement.

BM07.05.20

Hydrogel-Gate Field-Effect Transistors for Multiplex Biosensing Hamed Bay, Richard Vo, Huan-Hsuan H. Hsu, Siran Cao, Zhiming Mo and Xiaocheng Jiang; Tufts University, Medford, Massachusetts, United States.

Nanoscale field-effect transistors (FETs) represent a unique platform for real-time, label-free transduction of biochemical signals with unprecedented sensitivity and spatiotemporal resolution, yet their translation toward practical biomedical applications remains a challenge. Problems such as Debye screening of charge-based signals in high-ionic strength environments, non-specific binding of background biomolecules, and poor life-time have limited their applications in physiologically relevant conditions. Herein we demonstrate the potential to overcome these key limitations by exploiting molecularly encoded functional hydrogel as the gate material. Spatially-defined photopolymerization is utilized to achieve selective patterning of hydrogel on top of individual graphene FET devices with diffraction-limited spatial resolution. Combined with on-chip microfluidic control, bio-specific receptors can be sequentially encapsulated into the hydrogel gate to independently encode selectivity in FET device arrays. The hydrogel-mediated integration of penicillinase, for example, has been demonstrated to effectively catalyze enzymatic reaction in the confined FET microenvironment, enabling real-time, label-free detection of penicillin down to 0.2 mM. When additional enzymes (such as urease and acetylcholinesterase) are incorporated into adjacent devices, highly specific and localized signals can be recorded with minimal cross-talk, thus demonstrating the unique potential of the current strategy in high spatial resolution multiplex sensing. In addition, the passivation of the graphene FET device with a hydrogel layer is found to significantly reduce the nonspecific signal. In a control experiment with 1 mg/ml bovine serum albumin solution, bare graphene devices showed a 5 mV signal, which is inhibited for hydrogel-gate FETs, thereby displaying the possibility for applications in unprocessed physiological fluids. Lastly, longitudinal measurements of hydrogel FET performance show a significant improvement in device lifetime and in maintaining a similar signal amplitude. Hydrogel-gate FETs maintain a signal of 50 mV for up to 7 days. In comparison, devices with free or conjugated enzymes show a 70% signal loss after 4 hours. The current work represents a strategic approach to enable the application of existing nanoelectronic tool sets in physiologically relevant conditions and has potential for use in real time point-of-care diagnostics and in vivo monitoring of disease progression through long-term tissue interfacing applications.

SESSION BM07.06: Electronic Actuators/Novel Architectures I
Session Chairs: Tzahi Cohen-Karni and Bernhard Wolfrum
Wednesday Morning, November 28, 2018
Sheraton, 2nd Floor, Constitution B

8:00 AM BM07.06.01

Microfiber-Based Organic Electrochemical Transistors for Channel Dimension-Independent Single Strand Wearable Sweat Sensors Youngseok Kim¹, Seong-Min Kim¹, Taekyung Lim², Sanghyun Ju² and Myung-Han Yoon¹; ¹Gwangju Institute of Science and Technology, Buk-gu, Korea (the Republic of); ²Kyonggi University, Suwon, Korea (the Republic of).

Herein, we report conjugated polymer microfiber-based organic electrochemical transistors (OECTs) for single strand fiber-type channel dimension-independent wearable sweat sensors. The highly conductive microfibers were fabricated by simple wet-spinning of aqueous poly(3,4-ethylenedioxythiophene):poly(styrene sulfate) (PEDOT:PSS) solutions, and PEDOT:PSS microfiber-based OECTs were successfully constructed showing high on-current (>5 mA), current on/off ratio ($>10^3$), and transconductance (> 80 mS). Owing to excellent electrical/electrochemical characteristics and aqueous stability of PEDOT:PSS microfibers, the resultant OECT devices exhibited the linear response to aqueous cations at the large dynamic range (10^{-4} – 10^0 M) as well as the high device fabrication reproducibility. Moreover, the proposed method for extracting the ion concentration sensitivity is independent of microfiber channel dimensions (e.g., length, width, diameter), leading to the definition of the suitable figure-of-merit even at arbitrary channel dimensions. Finally, we developed single strand fiber-type wearable sweat sensors, and demonstrated that the resultant sensors can perform real-time repetitive measurements of ion concentrations in human sweat samples.

8:15 AM BM07.06.02

Simultaneous Co-Electrodeposition of Plasma Protein/Iridium Oxide Hybrid Film for Electrically Controlled Drug Release Applications [Fu-Erh Chan](#)¹, [Zheng-Ting Tang](#)², [Pochun Chen](#)¹ and [Wei-Chen Huang](#)²; ¹National Taipei University of Technology, Taipei, Taiwan; ²Taipei Medical University, Taipei, Taiwan.

Implantable neurostimulation devices have been attracted considerable attention recently. When a neural stimulating electrode is implanted in vivo, neural disordered disease can be treated by electrostimulation. Additionally, electrically controlled drug release has been particularly attractive for bioelectronics because the electrical signal is portable and controllable on-demand, without the requirement of large or special equipment. However, protein-based bioactives such as growth factors or antibodies are easily denatured to lose their bioactivity in response to external stimulation. It is challenging to develop a bioelectrode system that permits the electrically responsive release of proteins without damage.

In this study, a facile co-electrodeposition method has been developed to form a hybrid film of iridium oxide and plasma protein. We carried out a cyclic voltammetry approach to co-electrodeposit iridium oxide and plasma protein on ITO-coated glass substrates. We characterized and evaluated the hybrid electrolytes and deposited films for bio-electrode applications. We also demonstrated the releasing behavior triggered by an electric field. In addition, the biocompatibility of the hybrid films was also investigated by testing the cell viability.

8:30 AM BM07.06.03

Development of Highly-Conductive Crystallized PEDOT:PSS Microfibers for Wearable Bioelectronics Applications [Myung-Han Yoon](#); Gwangju Institute of Science and Technology, Gwangju, Korea (the Republic of).

Despite the great potentials of polymer microfibers toward human-friendly wearable and implantable bioelectronics, most of the previous polymeric electronics have been limited to thin film-based devices due to the practical difficulties in preparing conductive microfibers with desired characteristics and fabricating free-standing fiber or woven textile devices. Herein, we report highly conductive polymer microfibers prepared by wet spinning and their application to microfibrillar bioelectronics. First, we developed the simple wet-spinning process to form highly conductive crystalline poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) microfibers. PEDOT:PSS microfibers with various cross-sectional areas, compositions, and crystallinity could be prepared by varying wet spinning conditions such as needle size, injection speed, coagulation bath, etc., while the corresponding mechanical, electrical, electrochemical properties were carefully examined. The resultant microfibers showed very high conductivities (>1000 S/cm) and capacitances (>70 F/g) with decent mechanical strength (>1 GPa), which exceed the metrics of PEDOT:PSS microfibers reported in the previous literature. Finally, we successfully proved the potential of conducting polymer microfiber-based bioelectronics by demonstrating the PEDOT:PSS microfiber-incorporated textile for wearable electromyography sensor and the PEDOT:PSS microfiber organic electrochemical transistor for cation concentration sensor in human sweat.

8:45 AM *BM07.06.04

Organic Bioelectronic Fibers and Capillaries [Magnus Berggren](#), [Daniel Simon](#), [Eleni Stavrinidou](#) and [Roger Gabrielsson](#); Linköping University, Norrköping, Sweden.

Organic electronic materials offer mixed ion electron conduction and signal processing and can be manufactured into various flexible and soft device configurations using solution-based processing protocols. While bridging the biology-technology signaling gap, to record and regulate biological functions, it is crucial to develop a bioelectronic form factor that enables signal translation at high spatiotemporal resolution, close proximity and at minimal invasiveness. Fiber and capillary structures are natural and common structures of most biological systems, they serve as confined transportation highways of biological components, biochemicals and signals. Here, developments of organic bioelectronic fibers and capillaries are reported. Conductors, electrodes, transistors and electronic ion pumps have been manufactured into capillary and fiber structures to enable non-invasive integration and high-quality signal translation across the biology-technology gap. For instance, organic electronic ion pumps have been manufactured inside glass capillary structures, with an outer diameter of 60 micrometers, and has been applied to various biological system to deliver signal substances at high spatial resolution. Conductors, electrodes and transistors have been manufactured or have been applied into or onto the vasculature or fibers, of living system, resulting in passive and active bioelectronics for recording and sensing of physiology and bio-signaling. The resulting technology, which utilizes the twinning of living biological components and organic bioelectronic materials, to form active devices have been applied to various biological settings to for instance monitor action potentials and to form small scale bioelectronic circuits.

9:15 AM BM07.06.05

Tandem Organic Electrolytic Photocapacitors for High Performance Optoelectronic Stimulation of Single Cells and Light-Insensitive Retinas [Aleksandr Markov](#)¹, [Marie D. Jakesova](#)¹, [Vedran Derek](#)¹, [David Rand](#)², [Yael Hanein](#)², [Daniel Simon](#)¹, [Magnus Berggren](#)¹, [Fredrik Elinder](#)³ and [Eric D. Glowacki](#)¹; ¹Laboratory of Organic Electronics, Department of Science and Technology, Linköping University, Norrköping, Sweden; ²Tel Aviv University Center for Nanoscience and Nanotechnology and School of Electrical Engineering, Tel Aviv University, Tel Aviv, Israel; ³Department of Clinical and Experimental Medicine, Linköping University, Linköping, Sweden.

The efficiency of devices for bioelectronic applications, including neuronal stimulation, is heavily dependent on the scale and the performance level. With miniaturization of stimulation electrodes, achieving a sufficiently high current pulse to elicit action potentials becomes an issue. We have developed the organic electrolytic photocapacitor (OEP) for stimulation of light-insensitive retinas, previously achieving pixels of 100 μm in diameter. In the work herein, we report on our approach of arranging pixels of photocapacitors vertically in order to substantially increase the photovoltage and charge density without sacrificing lateral area. The tandem devices are created by stacking vertically p-n junctions made of semiconducting organic small molecules with 1 nm recombination layers of gold in between. These devices still do not exceed a total thickness of 300-500 nm. These devices represent a substantial improvement over previously-reported single p-n junction OEPs, and are able to generate five-times higher voltages and at least double the charge densities. We have tested the efficacy of tandem devices using measurements of xenopus oocytes, where we find substantially enhanced stimulation of K^+ channels relative to single-junction devices. Finally, we have used the tandem approach to microfabricate

optoelectronic stimulation pixels (< 50 μm) for retinal prosthesis, validating their performance by measuring light-insensitive retinal extracts. These results corroborate the conclusion that OEPC technology not only has achieved parity with state-of-the-art silicon devices, but can exceed them in miniaturization and performance.

9:30 AM BM07.06.06

Photosynthetic Bacteria-Based Biohybrids for Organic Bioelectronics [Gianluca M. Farinola](#)², Francesco Milano³, Roberta Ragni¹, Marco Lo Presti¹, Simona la Gatta¹, Livia Giotta³, Angela Agostiano^{1,2} and Massimo Trotta²; ¹University degli Studi-Bari Aldo Moro, Bari, Italy; ²Dipartimento di Chimica Università degli Studi di Bari “Aldo Moro”, Bari, Italy, CNR IPCF UOS BARI, Bari, Italy; ³Dipartimento di Scienze e Tecnologie Biologiche e Ambientali, Ecotekne, Monteroni, Lecce, Italy.

The photosynthetic bacterial Reaction Center (RC) is a specific transmembrane multi-subunit protein complex which photogenerates charges to fuel the photosynthetic process [1]. The RC exhibits a conversion efficiency of photons to electrons close to 100%. The possibility of taking advantage of such excellent photoconversion efficiency to create functional nanomaterials and bio-hybrid devices is very attractive [2]. We recently demonstrated that the light harvesting capability of the native RC in the visible spectral region is increased by covalently affixing different tailored molecular antennas, thus obtaining hybrid systems which outperform the native protein in solar light absorption and photogeneration [3,4]. The RC integration in bioelectronic devices is an appealing challenge that has recently been explored. It demands for proper approaches to implement the biological photoconverter in either nanoconstructs and/ or bio-integrated devices.

The lecture will discuss chemical routes to hybrid RC-based materials, focusing on: i) retention of perfectly unaltered functions of the RC photoenzyme in confined environments [5]; ii) creation of functional interfaces between the biological structure and the electrodes' surface. Highly selective chemical strategies to address these systems at the interfaces with electrodes in bioelectronics devices will be presented. The role of organic synthesis and self-assembly techniques in bridging the gap between the biotechnological production of materials and engineering of the devices will be highlighted.

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9:45 AM BM07.06.07

Optoelectronic Stimulation of Cells with Organic Electrolytic Photocapacitors [Eric D. Glowacki](#)¹, Marie Jakesova¹, Fredrik Elinder¹, Daniel Simon¹, David Rand², Yael Hanein², Magnus Berggren¹, Vedran Derek¹, Aleksandr Markov¹ and Rainer Schindl³; ¹Linköping University, Norrköping, Sweden; ²Tel Aviv University, Tel Aviv, Israel; ³Medical University of Graz, Graz, Austria.

We report on nanoscale semiconducting optoelectronic systems that form close interfaces with living cells. The aim is to create devices that transduce impulses of light into signals that can influence the electrophysiology of the cell, while preserving its long-term viability. Organic semiconducting nanocrystalline materials offer the possibility of fabricating such devices such as to be minimally invasive in the biological context. Moreover, many organic semiconductors are nontoxic and safe, and softer than their inorganic counterparts.

The core device concept we have developed is the organic electrolytic photocapacitor (OEPC), a nanoscale semiconducting optoelectronic system optimized for neuronal stimulation. The devices comprise a trilayer of metal and p and n semiconductors. When illuminated in physiological solution, these metal-semiconductor devices charge up, transducing light pulses into localized displacement currents that are strong enough to stimulate cells. The devices are freestanding, requiring no wiring, and are stable in physiological conditions. They are optimized to work in the near-infrared range. We have systematically evaluated the ability of OEPC devices to alter the cell membrane potential of single nonexcitable cells (where photoinduced membrane potential changes in the tens to hundreds of mV ranges are possible), generate action potentials in neuronal cell cultures, and stimulate explanted light-insensitive embryonic retinas.

10:00 AM BREAK

10:30 AM *BM07.06.08

Probing Neural Function with Multifunctional Fibers [Polina Anikeeva](#); Massachusetts Institute of Technology, Cambridge, Massachusetts, United States.

To address the signaling complexity of the neural circuits and match the chemistry and mechanics of the neural tissues our group leverages soft materials processed via fiber-based methods. Thermal drawing allows for scalable production of micro- and nano-structured fibers composed of multiple materials from macroscale models, preforms. By combining optically transparent and conductive polymers, composites, and low melting temperature metals during preform fabrication, we have engineered miniature fibers capable of simultaneous optical, electrical, and chemical and genetic interrogation of the brain and spinal cord circuits. Specifically, we have applied flexible multifunctional fibers to deliver microbial rhodopsin genes and optoelectronically monitor their expression in neuronal cell bodies and axonal terminals. These fibers have permitted optogenetic and chemical control of rodent behavior, and were capable of recording of isolated single-neuron action potentials for over 12 weeks. To further extend the ability to track isolated action potentials, we have recently combined fiber-based fabrication with direct tough-hydrogel integration. These probes exhibited tunable mechanical moduli allowing for deep-brain implantation while producing minimal tissue response and permitting tracking of identifiable action potentials for 6 months. In addition to probing neural activity, fiber-based devices can guide nerve growth. To produce biocompatible nerve guidance scaffolds, we have developed porous fibers, where the pores were established via salt-leaching following thermal drawing. This process allowed for control over the pore sizes in fibers produced from arbitrary polymers with a range of dimensions and cross-sectional geometries.

11:00 AM BM07.06.09

Effective Weight Control via an Implanted Self-Powered Vagus Nerve Stimulation Device [Xudong Wang](#)¹, Guang Yao^{1,3}, Weibo Cai¹ and Lei Kang^{1,2}; ¹University of Wisconsin-Madison, Madison, Wisconsin, United States; ²Peking University First Hospital, Beijing, China; ³University of Electronic Science and Technology of China, Chengdu, China.

In vivo vagus nerve stimulation holds great promise in regulating food intake for obesity treatment. Here we present an implanted vagus nerve stimulation (VNS) system that is battery-free and spontaneously responsive to stomach movement. The VNS system comprises a flexible and biocompatible nanogenerator that is attached on the surface of stomach. It generates biphasic electric pulses in response to the peristalsis of stomach. The simulated satiety signals deceive the brain via vagal afferent fibers, and reduces food intake when the stomach is filled at a certain level. This strategy is successfully demonstrated on rat models. Within 100 days, the average body weight is controlled at 350 g, 38% less than the control groups. This work correlates nerve stimulation with targeted organ functionality through a smart, self-responsive system, and demonstrated highly effective weight control that is superior to other electrical stimulation strategies. This work also provides a new concept in therapeutic technology using artificial nerve signal generated from coordinated body activities.

11:15 AM *BM07.06.10

Miniature, Wireless Neural Stimulation Using Magnetolectric Materials [Jacob T. Robinson](#); Rice University, Houston, Texas, United States.

Wireless neural stimulation is important for implanted bioelectronic devices, and neuroscience experiments in freely moving animals; however many wireless stimulators require batteries or large receiver coils, that limit the ability to make miniature implants. Here we present a new approach for wireless neuromodulation that uses a material to convert magnetic fields that freely penetrate the brain into electric fields that stimulate nearby neurons. Because these materials do not rely on electromagnetic waves for power harvesting, they can be made millimeter sized while retaining high power conversion efficiencies. To create these biocompatible "magnetolectric" materials we fabricated a film of a piezoelectric material polyvinylidene fluoride bonded to a magnetostrictive film of Metglas. We then encapsulated the final films to make them biocompatible. We find that these magnetolectric films can generate voltages above ten volts using alternating magnetic fields with an amplitude of about 1 mT. We also demonstrate that a simple film is able to stimulate cellular activity in vitro in excitable HEK cells and acute brain slices. We also show that light-weight millimeter-scale films enable wireless activation of neural activity in freely-moving rats. Overall, our results show that magnetolectric materials offer great promise for wireless electrical stimulation of specific brain areas. The basic understanding of magnetolectric neural stimulation can also be used to develop novel magnetolectric materials (such as nanoparticles or nanofibers) to achieve even more targeted and less invasive wireless neural stimulation technologies.

11:45 AM BM07.06.11

Wireless Magnetomechanical Neural Stimulation Mediated by Magnetic Nanodiscs [Alexander Senko](#), Danijela Gregurec, Ian Tafel, Pooja Reddy, Dekel Rosenfeld, Siyuan Rao, Michael G. Christiansen, Po-Han Chiang, Seongjun Park and Polina Anikeeva; Massachusetts Institute of Technology, Cambridge, Massachusetts, United States.

A new technique has been developed for magnetic nanoparticle-based neural stimulation. Unlike magnetothermal neural stimulation, which is based on the transfection of neurons to sensitize them to heat, this magnetomechanical approach does not rely on transgenes, making it potentially safer for clinical applications. In contrast to previously reported magnetomechanical stimulation techniques, in which neurons are typically hundreds of microns or less from a magnetic field source, the field required for this technique (1–50 mT, 1–20 Hz) is produced at the scale of an entire rodent model using a simple solenoid and a 200 W audio amplifier. This advantage in stimulated volume is enabled by magnetic nanodiscs with volumes hundreds of times larger than conventional magnetic nanoparticles, but which have favorable colloidal properties due to their disc shape. These magnetic nanodiscs possess a spin vortex state, which nearly eliminates stray field and results in less inter-particle attraction compared to isotropic magnetic particles of similar volume. The neural stimulation technique enabled by these magnetic nanodiscs has been demonstrated to robustly induce calcium influx in sensory neurons in rat dorsal root ganglion (DRG) explant cultures and enhance rat expression of an immediate early gene c-fos in DRGs of adult rats. This technique may find applications in basic studies of neural circuits as well as pave the way for future neuromodulation therapies.

SESSION BM07.07: Electronic Actuators/Novel Architectures II

Session Chairs: Mehmet Kanik and Jacob Robinson

Wednesday Afternoon, November 28, 2018

Sheraton, 2nd Floor, Constitution B

1:30 PM BM07.07.01

On-Demand Generation of Chemical Signals with Electromagnetic Fields for Neuronal Modulation [Jimin Park](#)^{1,2}, Junsang Moon^{1,2}, Po-Han Chiang², Dena Shahriari², Atharva Sahasrabudhe³, Siyuan Rao² and Polina Anikeeva^{1,2}; ¹Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ²Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ³Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States.

The development of electromagnetic tools for neuronal stimulation can significantly enhance our understanding of signaling pathways in the brain and enable treating neurological disorders. To date advances in the design of neural probes and magnetic nanoparticles have provided promising opportunities for electrical and mechanical stimulation of neurons under electromagnetic fields. However, robust chemical stimulation of neurons has not yet been achieved with these systems due to difficulties in generating chemical signals under electromagnetic fields.

Here, we developed two material systems that formed either protons or reactive-oxygen-species (ROS), which are both important chemical species in the nervous system, under electromagnetic field and demonstrated their utility for chemical stimulation of neurons. In the first system, a polymer-magnetic nanoparticle nanohybrid was designed that released protons upon exposure to an alternating magnetic field. Hysteretic heat dissipation by magnetic nanoparticles accelerated the degradation process of biodegradable polymer matrix within the nanohybrid, which in turn led to the release of protons and change in pH of solution. The proton release kinetics from the nanohybrid was regulated by adjusting material properties, synthesis method, and magnetic field conditions. The ability to optimize nanohybrid system indicated its potential for wireless magnetic-field driven stimulation of acid-sensitive ion channels.

The second material system composed of transition-metal based nanoparticles that generated ROS. Inspired by biological enzymes interacting with ROS, an iron-based nanocatalyst, which has a crystal structure and material properties similar to those of these enzymes were designed. Through combined electrochemical and spectroscopic analyses, we confirmed that the catalyst could convert soluble precursor ions to ROS in solution in the presence of electric field. It is noteworthy that, by changing electric field conditions, such as current or voltage, ROS releasing behavior from the catalyst was quantitatively controlled. *In vitro* tests suggested that this system could stimulate ROS-sensitive channels, which may facilitate the studies of the roles of ROS in the nervous system.

We envision that these material systems can broaden the current palette of electromagnetic approaches for neuronal stimulation.

1:45 PM BM07.07.02

A Bioelectronic Solution for a Health Problem—An Implantable Integrated System to Treat Neurogenic Underactive Bladder Faezeh Arab Hassani^{1,2}, Chengkuo Lee^{1,2} and Nitish V. Thakor^{1,2}; ¹Singapore Institute for Neurotechnology, National University of Singapore, Singapore, Singapore; ²Electrical and Computer Engineering, National University of Singapore, Singapore, Singapore.

Bioelectronics shapes a new era aiming to solve the health problems by merging the electronics, and biology science [1]. Incomplete emptying of the bladder may happen due to the atrophy of the detrusor muscle, or disease or damage to the afferent nerve system, i.e. neurogenic underactive bladder (UAB) [2]. For neurogenic UAB patients, the nerve stimulation maybe a solution, however, it may lead to several complications [3]. Using of catheters is the other treatment for these patients, but this treatment is not without shortcomings [2]. Therefore, we proposed a device that could physically contract the bladder muscle to void [4-6]. The recently proposed device, is an implantable integrated system that consists of a sensor to detect the fullness status of the bladder, and an actuator to initiate assisting the bladder muscle for the consequent voiding [6].

The shape memory property of shape memory alloy (SMA) components allows the voluntary activation and voiding of the bladder by patient. The actuator was designed by using of two flexible polyvinyl chloride (PVC) sheets as the substrate for the SMA components. A spring SMA with the transition temperature of 45°C was the main component for the actuation that resulted in a bi-stable bending of the PVC sheet during one 20 s cycle of activation. Two compression and restoration phases was designed for the device for multiple activations. We have designed, fabricated, and experimentally tested various designs and configurations for the actuator on anesthetized rat animal models [4-6]. The recent SMA spring-based actuator provided a substantial voiding percentage of about 80% with the reduced total energy consumption compared to the originally proposed devices. We have tested various types of sensors for the integration with the actuator from commercial piezo-resistive force sensors [5], quantum tunnelling composite-based sensors [7], and finally triboelectric energy harvesting (TEG) sensors [6]. The wet sponge-based TENG sensor consists of water and polydimethylsiloxane (PDMS) as the two materials with different electron affinities. The output triboelectric voltage can be used as a feedback control signal to the patient for initiating the activation of the actuator and voiding.

The integration of a sensor with the actuator is necessary for neurogenic UAB patients. However, the integrated sensor should be flexible enough not limiting the voiding capability of the actuator, and at the same time provide repeatable output signal to the patient. Our future work, is focusing on designing new solutions to assist the lost sensation of neurogenic patients.

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2:00 PM *BM07.07.03

Nanowires as Electromagnetic Bio-Transducers Jorgen Kosel¹, Aldo I. Martinez Banderas¹, Ainur Sharip¹, Antonio Aires Trapote², Nouf Alsharif¹, Aitziber Lopez Cortajarena³, Jasmeen Merzaban¹ and Timothy Ravasi¹; ¹King Abdullah University of Science and Technology, Thuwal, Saudi Arabia; ²IMDEA Nanociencia and Nanobiotechnology Unit associated to Centro Nacional de Biotecnología (CNB-CSIC), Campus Universitario de Cantoblanco, Madrid, Spain; ³CIC BiomaGUNE, Parque Tecnológico de San Sebastián, San Sebastian, Spain.

Unique features of magnetic nanowires render them attractive materials for biomedical transducer applications. Due to the high aspect ratio, they are characterized by single magnetic domain properties, which can be exploited by electromagnetic interrogation. This allows utilizing such nanowires as remotely operated nanorobots, i.e. induce motion, produce heat or sense their location. Their versatility is further enhanced by surface functionalization, making them cell-specific targeting agents or drug delivery vehicles. Magnetic nanowires are fabricated by a facile and efficient method using electrodeposition into nanoporous membranes. Iron nanowires are highly biocompatible, and they can be further optimized by annealing, resulting in nanowires with an iron core, an iron oxide shell and tailored magnetization. In combination with polymer matrices, nanowires are employed as ultra-low power flow sensors, for realizing bioinspired artificial skins with tactile sensing capabilities, or to trigger remotely controlled drug delivery particles. Magnetic nanowires are readily internalized by cells via phagocytosis. When applying an alternating magnetic field, they kill cancer cells by a magnetomechanical effect. When further functionalizing the nanowires with drugs, they deliver these drugs into cells, and a combined treatment effect can be obtained together with a magnetic field and/or laser irradiation. The later exploits a photo-thermal effect, that utilizes the near infrared light absorption of iron oxide. Surface coating with antibodies give nanowires specific targeting capabilities, as will be shown for the case of anti-CD44 antibodies to target leukemic cells. The nanowires also have excellent properties as magnetic resonance imaging contrast agents, providing high transverse magnetic relaxivities. This enables high-resolution cell tracking in combination with their manipulation. Nanostructured substrates for cell growth can be produced, when partially releasing the nanowires from the nanoporous membranes. Due to mimicking the mechanical properties of cellular environments, stem cells growing on top of such substrates show alterations in their differentiation behavior. Thereby, nanowire dimensions modify the stiffness of the cellular environment, affecting the cells' behavior. A mechanical stimulus can be applied via activating the substrate by an electromagnetic field, providing means for additional manipulations of the cell faith. Differentiation of mesenchymal stem cells into osteoblasts can be achieved on such substrates by electromagnetically induced mechanical stimuli within a few days. With the growing relevance of nanomaterials in biomedical applications, multi-functionality of nanoprobables is being discovered and exploited. Combining a high capacity for functionalization, with diagnostic capabilities and therapeutic functions, iron nanowires are ideal candidates for these theranostics approaches.

2:30 PM BREAK

SESSION BM07.08: Cell/Material Interface I
Session Chairs: Damia Mawad and Paul Molino
Wednesday Afternoon, November 28, 2018
Sheraton, 2nd Floor, Constitution B

3:30 PM *BM07.08.01

Engineering Materials for Bioelectronics Molly Stevens; Imperial College London, London, United Kingdom.

An important aim of regenerative medicine is to restore tissue function with implantable, laboratory-grown constructs that contain tissue-specific cells that replicate the function of their counterparts in the healthy native tissue. In this talk I will describe our recent work in the development of materials for bioelectronics including polymers and functionalised nanoneedles. I will also describe our new imaging technologies for monitoring and elucidating the cell-material interface.

4:00 PM BM07.08.02

An Artificial Mechanosensory Nerve Based on Flexible Organic Electronics Yeongin Kim¹, Alex Chortos², Wentao Xu^{3,4}, Yuxin Liu⁵, Jin Young Oh^{6,7}, Donghee Son⁶, Jiheong Kang⁶, Amir Foudeh⁶, Chenxin Zhu¹, Yeongjun Lee³, Simiao Niu⁶, Jia Liu⁶, Raphael Pfattner⁶, Zhenan Bao⁶ and Tae-Woo Lee³; ¹Department of Electrical Engineering, Stanford Univ, Stanford, California, United States; ²Department of Materials Science and Engineering, Stanford University, Stanford, California, United States; ³Department of Materials Science and Engineering, Seoul National University, Seoul, Korea (the Republic of); ⁴Institute of Photoelectronic Thin Film Devices and Technology, Nankai University, Tianjin, China; ⁵Department of Bioengineering, Stanford University, Stanford, California, United States; ⁶Department of Chemical Engineering, Stanford University, Stanford, California, United States; ⁷Department of Chemical Engineering, Kyung Hee University, Yongin, Korea (the Republic of).

Complicated real-world tactile information is efficiently processed by the biological mechanosensory system. The basic building blocks of the biological mechanosensory system are mechanoreceptors, neurons, and synapses. We fabricated flexible organic devices to emulate the building blocks and the signal processing of a biological mechanosensory nerve. Our organic artificial mechanosensory nerve [1] consists of pressure sensors, organic ring oscillators, and organic synaptic transistors. A cluster of pressure sensors receive pressure inputs, which are converted to voltage pulses by a ring oscillator. A synaptic transistor integrates the voltage pulses from multiple ring oscillators. We used our artificial mechanosensory nerve to detect movement and large-scale textures of an object and distinguish braille letters. Also, our artificial mechanosensory nerve and biological motor nerves in a detached insect leg formed a hybrid reflex arc to actuate the muscles of the leg. Our flexible organic artificial nerve can be used in neurorobotics and neuroprosthetics.

[1] Yeongin Kim, Alex Chortos, Wentao Xu, Yuxin Liu, Jin Young Oh, Donghee Son, Jiheong Kang, Amir M. Foudeh, Chenxin Zhu, Yeongjun Lee, Simiao Niu, Jia Liu, Raphael Pfattner, Zhenan Bao, Tae-Woo Lee. "A bioinspired flexible organic artificial afferent nerve." *Science* **360**, 998-1003 (2018).

4:15 PM *BM07.08.03

Tailoring Properties of Polymer Bioelectronics Through Blends Rylie Green, Josef Goding, Omaer Syed, Estelle Cuttaz, Julian Heck and [Catalina Vallejo Giraldo](#); Imperial College London, London, United Kingdom.

Bioelectronic medicine has numerous promising applications for the treatment of diseases and disorders of the nervous system. The key limiting factors to the development of next-generation neural interfaces are the low charge transfer area, poor tissue integration and limited flexibility of conventional metallic electrode arrays. Flexible bioelectronics have commonly been approached through the incorporation of conductive nanomaterials within a flexible polymer matrix. These approaches require a critical mass, or percolation threshold, of the incorporated conductor for the material to have adequate properties. The high loadings required to reach this percolation threshold are typically associated with considerable degradation of the mechanical properties. Other approaches include the layering of conductive materials on top or in-between layers of a flexible substrate. Problems arise due to the mechanical mismatch between the flexible and conductive layers leading to failure of the composite after multiple mechanical loadings. These approaches generally require the material to be used in a thin-film format to achieve the required flexibility making them unfit for transporting charge over longer distances in the body. This study explores the development of bulk, flexible conductive materials through the incorporation of both pre-polymerised CP components within flexible, insulative polymer matrices and additional post-processing CP growth for increased conductivity. It has been shown that both free-standing conductive hydrogels (CHs) and newer electrically conductive elastomers (ECEs) can be tailored for both mechanical and electrochemical properties. The creation of novel monomers consisting of both conductive and processable polymers has been used to demonstrate the fabrication of high resolution electrode arrays with both interconnects and interfacing electrodes produced through melt extrusions.

4:45 PM BM07.08.04

Integration of Nanofiber-Based Conduits with Bone Marrow Stem Cells for Potential Application in Neural Tissue Engineering [Jiajia Xue](#) and Younan Xia; The Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology, Atlanta, Georgia, United States.

Seeding nerve guidance conduits with Schwann cells can improve the outcome of neural tissue engineering while bone marrow stem cells (BMSCs) can differentiate into Schwann cells under appropriate conditions. We have investigated the differentiation of BMSCs into Schwann cells on scaffolds comprised of electrospun nanofibers. We changed the alignment, diameter, and surface properties of the fibers to optimize the differentiation efficiency. The uniaxial alignment of fibers not only promoted the differentiation of BMSCs into Schwann cells but also dictated the morphology and alignment of the derived cells. Coating the surface of aligned fibers with laminin further enhanced the differentiation and thus increased the secretion of neurotrophins. When co-cultured with PC12 cells or chick dorsal root ganglion, the as-derived Schwann cells were able to promote the outgrowth of neurites from cell bodies and direct their extension along the fibers. Furthermore, we constructed a multi-tubular conduit with a honeycomb structure from the electrospun fibers by mimicking the anatomy of a peripheral nerve. A bilayer mat of electrospun fibers was rolled up to form a single tube, with the inner and outer layers comprised of aligned and random fibers, respectively. Seven such tubes were then assembled into a hexagonal array and encased within the lumen of a larger tube to form the multi-tubular conduit. By introducing an adhesive to the regions between the tubes, the conduit was robust enough for handling during surgery. The seeded BMSCs were able to proliferate in all the tubes with even circumferential and longitudinal distributions. Under chemical induction, the BMSCs were transdifferentiated into Schwann-like cells in all the tubes. The cellular version holds great promise for the potential repair of large defects in thick nerves peripheral nerve repair.

SESSION BM07.09: Poster Session II: Bioelectronics—Fundamentals, Materials and Devices

Session Chairs: Sahika Inal, Christian B. Nielsen and Roisin Owens

Wednesday Afternoon, November 28, 2018

8:00 PM - 10:00 PM

Hynes, Level 1, Hall B

BM07.09.01

Self-Assembling Peptide-Based Tissue-Like Hydrogel for Highly Effective Neural Interface [Jiyoun Nam](#)¹, Hyung-Kyoung Lim², Minah Suh^{2,3} and Yong Ho Kim^{1,2,3}; ¹SKKU Advanced Institute of Nanotechnology (SAINT), Sungkyunkwan University, Suwon, Korea (the Republic of); ²Center for Neuroscience Imaging Research, Institute for Basic Science (IBS), Suwon, Korea (the Republic of); ³Department of Biomedical Engineering, Sungkyunkwan University, Suwon, Korea (the Republic of).

The biomechanical dissimilarity between rigid electrodes and soft neural tissues is a recurring problem in recording neural activity from the live brain, yet the development of stable neural interface that enables a complete biointegration remains a challenge. Self-assembling peptide has great advantages in developing a new biomaterial because along with its inherent biocompatibility, chemical and physical properties in macroscopic level can be controlled by

sequence modulation. However, unwanted proteolytic degradation of α -peptide based material imposes challenges on chronic utilization. Here, we presented a biocompatible, and biostable neural interface with a peptidomimetic foldamer-based biopolymer hydrogel which forms a complex with carbon nanotubes (CNTs). We utilized a β -peptide as a molecular building blocks to form the hydrogel because it has not only the ability to mimic natural peptides, but excellent structural and proteolytic stability. To endow conductivity into β -peptide-based hydrogel, hierarchical assembly of β -peptide was designed to self-assemble into nanofiber that associate with carbon nanotubes (CNTs). Transmittance electron microscopy images revealed the end-to-end assembling of β -peptide nanofibers and tight wrapping of the nanofibers around CNTs. The mechanical properties of β -peptide/CNTs hydrogel was founded to completely mimic the viscoelastic behavior of neural tissue. The intercortical and epidural neural signal recorded with the conductive hydrogel were founded to be augmented, especially in high frequency range, due to increased contact area and tight coupling with neural tissues. We expect the tissue-like hydrogel-based neural interface will suggest many possibilities for developing advanced neural implants with secured signal reliability and recording sensitivity.

BM07.09.02

Shape-Reversible Magnetic Hydrogel Drug Carriers for Remote Neural Modulation Cindy Shi², Siyuan Rao^{1,3} and Polina Anikeeva^{2,1}; ¹Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ²Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ³Simons Center for Social Brain, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States.

Minimally invasive magnetothermal technology that uses heat dissipation from magnetic nanoparticles (MNPs) in the presence of an alternating magnetic field offers the convenience of remotely controlling heat-sensitive processes. We applied this remote control capability of MNPs to enable an on-demand release of pharmacological substances to modulate neuronal activity. Thus, we developed a magnetic hydrogel that permitted local drug release with reversible shape contraction triggered by the heating of MNPs under an external magnetic field. By adjusting the composition of the MNPs and the hydrogel, drug loading capacity and release efficiency were optimized. When preloaded with clozapine-N-oxide, a substrate for the designer receptors exclusively activated by designer drugs (DREADDs), the magnetic hydrogel enabled the remote manipulation of neural activity in DREADD-expressing neurons upon exposure to magnetic field. The biocompatibility and chemical stability of the thermally responsive hydrogel were investigated. The introduced magnetic hydrogel drug carrier provides the remote release of pharmaceutical drugs for neural modulation with a long-lasting carrier lifetime and can potentially be expanded to other chemicals and pharmacological agents.

BM07.09.03

Electrical Performance after Mechanical Stress of Hafnium Oxide Capacitors on Deformable Softening Polymer Substrate Ovidio Rodriguez Lopez^{1,2}, Gerardo Gutierrez-Heredia^{3,4}, Alexander J. Polednik¹, Adriana C. Duran-Martinez², Edgar Guerrero⁴, Aldo Garcia-Sandoval² and Walter Voit^{2,4}; ¹Department of Electrical and Computer Engineering, The University of Texas at Dallas, Richardson, Texas, United States; ²Department of Biomedical Engineering, The University of Texas at Dallas, Richardson, Texas, United States; ³Centro de Investigaciones en Optica, Leon, Mexico; ⁴Department of Material Science and Engineering, The University of Texas at Dallas, Richardson, Texas, United States.

Recently, the microfabrication of thin film devices on flexible substrates has attracted great interest due to the broad field of applications where they can be used. In particular, the biomedical field has taken advantage of this technology for the development of chronic and implantable devices based on stimulating and recording electrodes. However, its commercial production remains elusive because of the rigorous demand of these applications. High performance, reliability, stable behavior, and resilience to the periodic mechanical stress of the electronic circuits are some characteristics needed for the fabrication of these devices. Therefore, further research on electronic components such as transistors, diodes, and capacitors among others devices is needed to develop reliable complex circuits on flexible substrates. This work presents the electrical performance of hafnium oxide (HfO₂) thin-film capacitors on a softening polymer, as a flexible substrate. The softening polymer used as the substrate is a shape-memory polymer (SMP), which has been previously used for implantable devices. It is well known that SMP has the capability to retain a certain shape after being deformed and return to its original state when an external stimulus is applied. The metal-insulator-metal capacitors were fabricated using gold as top and bottom contacts and HfO₂ as a dielectric, deposited by atomic layer deposition (ALD) at 100°C. This study centers on the electrical characterization after a mechanical stress of the HfO₂ capacitor fabricated on SMP. Different HfO₂ thicknesses were used. Capacitors of each thickness (20, 30, 40 and 50 nm) were measured and compared with capacitors fabricated on silicon with the same structure. The devices were evaluated after 10², 10³, 10⁴ and 10⁵ cycles of bending with a 5 mm bending radius. Electrical parameters such as capacitance density, dielectric constant, leakage current and breakdown voltage of these devices were evaluated. This research might pave the way towards the fabrication of complex circuitry based on thin film devices using SMP as softening substrate, and assist in the development of implantable electronic, where mechanical resilience is required.

BM07.09.04

Improving the Compatibility of Semiconducting Polymers for Biological Interfacing David Ohayon¹, Weiyuan Du¹, Sahika Inal¹ and Iain McCulloch^{1,2}; ¹KAUST, Thuwal, Saudi Arabia; ²Imperial College London, London, United Kingdom.

Organic semiconductor polymers have been extensively used as efficient bio-transducers thanks to their unique mixed ionic and electronic conductivity. Their applications include biosensors, drug delivery, neural interfaces, etc. Nonetheless, if these semiconductor materials are able to translate biological signals from cells, the translation is not always easy and sometimes not as efficient as it could be. The main limitation of organic polymers in bioelectronic devices rises from the poor adhesion of cells to the typically hydrophobic nature of the material and its neutrally charged and low surface energy surface. These problems are usually overcome by simply coating a protein layer on top of the semiconducting thin film, enhancing the cell adhesion by providing adequate functional groups for the cells to attach. However, adding an interlayer moves the cells further away from the semiconductor surface, which might hinder the sensing ability of the polymer film to transduce biological events. We report here the synthesis and characterization of lysine functionalized semiconducting polymers, based on a diketopyrrolopyrrole (DPP) backbone, for enhanced cell adhesion and growth for neural interface applications. We show here by incorporating lysine functional groups directly on the polymer side-chain, we are able to not only get rid of the intermediate protein layer for proper neurons adhesion and growth, but also to drastically improve the electrochemical performance of the polymer in aqueous media. These initial results are promising to use such biofunctionalized polymers to record/stimulate neural signals more effectively as the cells adhere directly to the protein-like surfaces.

BM07.09.05

Inkjet Printed Stretchable Organic Electrochemical Transistor with Petal-Molded Substrate Yuanzhe Li, Naixiang Wang, Anneng Yang and Feng Yan; Hong Kong Polytechnic University, Hong Kong, China.

Organic electrochemical transistor (OECT) modifies its channel current by injecting ions from the electrolyte. The employment of organic polymer as the channel material is so central to OECT that it deeply affects most all aspects of the device. It gives OECT excellent biocompatibility and contributes to its successful application as biological interfacing. The organic nature also provides space for solution processing, where powerful patterning method such as

inkjet printing can be introduced and therefore realize the high-throughput, roll-to-to fabrication of OECT.

However, the benefit of organic channel still hasn't been exploited to its limit. When we have device-level integration with rigid metal electrode, for instance, gold, the intrinsic stretchability of organic polymer is greatly wasted. The poor mechanical performance of gold electrode is now a bottleneck and may risk the device being missed as an effective solution for wearable electronics, which are widely considered as next generation of human-computer interaction medium.

Encouragingly, efforts have been made in various aspects to bypass the limit imposed by rigid electrodes. Both prestretching of substrate and laser-patterning of electrodes achieve considerable improvements by creating buffer for electrodes so that the device is practically not deformed even under great strain.

The place we cut into is when this inevitable deformation finally occurs, and more and more cracks are tearing the electrodes into pieces. We propose with periodic ridge morphology, it is possible to suppress the expansion of the crack and make it stay at the ridge of each nearest pit. To make this kind of periodic structure, we no longer use expensive and complicated photolithography techniques, but instead turn to nature for inspiration and find the petals as an ideal mold for replicating its honeycomb structure. Gold electrodes and poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) channel are then deposited on molded polydimethylsiloxane (PDMS) substrate by magnetic sputtering and inkjet printing respectively. Fabricated devices show stretchability up to 30% under multi-axial strains.

Given that the proposed principle works at different stages of device deformation and there is no conflict in the manufacturing process, it should function well as an augment to existed solutions, paving way for devices with even higher stretchability by adopting hybrid strategies.

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BM07.09.07

Progress Towards a Silicon-Based Cochlear Nucleus Hearing Prosthesis [Nicholas Nolte](#), Pejman Ghelich and Martin Han; University of Connecticut, Storrs, Connecticut, United States.

Over the past decade, we have developed a silicon-based neural recording and stimulation electrode array for a cochlear nucleus hearing prosthesis. The current design and fabrication process are presented and published *in vivo* results are summarized. The materials used in the array include the silicon and silicon oxide of the silicon-on-insulator wafer, titanium/platinum/gold for the interconnects, silicon oxide and silicon nitride for passivating layers, and titanium/iridium for the electrode sites. Deep reactive ion etching defines the shape of the array, with the buried oxide layer in the silicon-on-insulator wafer serving as the etch stop. Backside thinning with an SF₆-based dry etch precedes manual release of the array from the wafer. Mechanical grinding sharpens the tips of the array's shanks into sharp points rather than a vertical wedges. Finally, the arrays are cleaned, packaged, and sterilized. *In vivo* testing in cat auditory brainstem demonstrates the viability of the array. The array's physical sharpness and stiffness allowed for successful implantation into cochlear nucleus and inferior colliculus, which are considered deep and difficult-to-reach targets, using an inserter tool. Once in tissue, the array's 3D multi-shank layout allowed for tonotopic stimulation in different tissue volumes throughout the cochlear nucleus. The electrode and passivation materials proved to be sufficiently long-lasting and biocompatible to allow for *in vivo* recording and stimulation for over one year. Other applications include any situation in which mechanical robustness, a 3D multi-shank layout, and stable long-term stimulation and recording performance are desired, such as in the spinal cord or for deep brain stimulation. In the future, we plan to push this device towards human clinical use as an alternative hearing prosthesis to the cochlear implant for patients with ossified cochleas or damaged auditory nerves.

BM07.09.08

Controlled Corrosion for Electrochemically Modified Surfaces in Nanofabrication Process [Francis McEachern](#) and Geraldine Merle; Surgery, McGill University, Montreal, Quebec, Canada.

Pseudomonas aeruginosa (PA) is a ubiquitous and drug-resistant bacteria responsible for approximately 27% of hospital-acquired infections (Alatrakchi et al, 2016). Current diagnostic standards rely upon labor-intensive bacterial culturing, which demand multiple measures over several days for conclusive results. Fortunately, the development of electrochemical biosensors proves an encouraging avenue for further diagnostic advance. Biosensors are small, relatively simple to fabricate, easily implantable and can provide real-time measurements with excellent spatial and temporal resolution. Pyocyanin (PYO) is a redox-active toxin uniquely expressed by PA, and stands as a novel biomarker for PA infection. Due to its unique oxidation window (at 0.59 V), PYO proves to be a viable target to which we may tailor future electrochemical diagnostic tools (Alatrakchi, 2016). Previous studies have indicated that PYO can be clinically isolated from patient samples and validated effectively via square-wave voltammetry (Sismaet et al, 2017).

Our research focuses on tuning everyday medical tools into powerful analytical devices to provide a dichotomous yes/no response to the presence of biomarkers in real-time. Minimally invasive, low-cost stainless steel acupuncture needles (AN) were modified via a two-step process: 1) controlled corrosion microfabrication, and 2) polymer free deposition of carbon nanoparticle (CNP). Following physical, electrical and chemical characterization of the probe (AFM, CV, SEM, microCT, EIS, compressive strength testing with Instron), we validated this electrochemical detection needle with *in vitro* and *in vivo* measurements of PYO.

We successfully developed a well-controlled corrosion environment that produces reproducible and robust pitted needles. These pitted needles exhibit high capacitance, increased SSA, and a homogeneous porosity with the presence of large voids. Despite the porosity, the structural integrity of the pitted ANs remained high according to the compressive strength analysis using the ballistic gel simulating human tissue. Adding CNPs on the surface of the pitted needles enhances drastically the electron transfer, and maximize the signal to noise ratio. PYO has been successfully detected *in vitro* in clinically viable concentrations (2-100µM), and the testing on clinical isolates from patients has yet to be applied (Alatrakchi, 2016). This finding potentially removes one of the remaining obstacles to highly efficiency point-of-care diagnostics and the ability to tailor antibiotic therapy using inexpensive materials and equipment.

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BM07.09.09

Multi-Frequency Assessment of the Electrical Impedance Myography Parameters on 3D Malignant Breast MD Nurul Anwar Tarek¹, Ahmed H. Jalal², [Fahmida Alam](#)² and Mohammad Ahad¹; ¹ECE, Georgia Southern University, STATESBORO, Georgia, United States; ²ECE, Florida National University, Miami, Florida, United States.

Electrical properties such as conductivity and permittivity of biological material have notable dependency on frequency. These frequency dependent changes in biomaterial properties can play a prominent role in impedance signature of Electrical Impedance Myography (EIM). EIM is a non-invasive painless four electrode measurement tool, measuring the impedance based on the response of the low amplitude alternating current. In this study, multifrequency Electrical impedance Myography assessment was performed using an applied range of frequencies for getting valuable insight of the biomaterials. In this paper, the objective of our study is to explore the effects of different sized malignant tumor in female breast tissue on the multi-frequency signature of EIM. In this study, a finite element model of a female breast has been developed based on electro-biophysical data for each malignant tissue within a frequency range of 2 GHz to 3 GHz and log frequency vs resistance and log frequency vs reactance of EIM have been analyzed for various sized tumor on breast. It is found that the slope of log reactance vs. frequency and resistance vs log frequency decrease with increasing tumor size. For instance, the percentage deviation of log reactance slope for 8 mm tumor and 6mm tumor from 2 mm (1mm radius) tumor size is 4.12% and 0.412% respectively. The study provides evidence that evaluation of the frequency dependent impedance data can provide rich assessment of the abnormal biological tissue.

BM07.09.10

Biomimetic Modification of Biopolymers for Electrochemical Synthesis of Organic-Inorganic Composites [Amanda Clifford](#) and Igor Zhitomirsky; Materials Science and Engineering, McMaster University, Hamilton, Ontario, Canada.

A conceptually new approach has been developed for the fabrication of organic-inorganic composite films for orthopaedic coatings and biosensors, using cathodic electrophoretic deposition (EPD). This technique is based on the biomimetic modification of biopolymers such as chitosan (CHIT), and poly-L-lysine (PLL) with a catechol containing moiety, 3,4-dihydroxybenzaldehyde (DHBA), utilizing a Schiff base reaction. CHIT is a naturally occurring biopolymer, which has been used for a variety of biomedical applications due to its structural similarity to glycosaminoglycan, which is the primary component in the extracellular matrix of bone and cartilage. The surface morphology and roughness of PLL allow for remarkable cell adhesion, and as a result it has been used in the past as a coating agent to promote cell adhesion as well as for drug delivery applications. Benefits of biopolymer modification with catechol group include superior adhesion to inorganic nanoparticles, as well as tissue adhesion in the presence of body fluid. Catechol modification also imparts redox-activity upon the coating, which is useful for in-situ reduction of metallic nanoparticles and biosensing applications. These unique properties allow catechol modified biopolymer films to be used as reducing, capping, dispersing and film forming agents for the fabrication of advanced nanocomposite films utilizing cathodic EPD. In the following work, catechol-modified CHIT polymer was used for the in-situ reduction of Ag⁺ to silver nanoparticles, and the unique redox properties were utilized for the development of photoelectrochemical (PEC) DNA biosensors. Modified CHIT and PLL were both used for fabrication of nanocomposite coatings, containing advanced functional bioceramics such as hydroxyapatite (HA) and rutile (TiO₂), to improve osseointegration for orthopaedic and dental applications. Preliminary cell testing revealed that composite PLL-DHBA films containing HA and TiO₂ promoted cell proliferation due to its hydrophilic nature and rough surface morphology. These techniques pave the way for the continued development of biomimetic materials processing, and the fabrication of advanced multi-functional materials for use in a variety of biomedical applications, from orthopaedic coatings to DNA biosensors.

BM07.09.11

Following Anticancer Drug Activity in Cell Lysates with DNA Devices Dimithree Kahanda^{1,2}, Naveen Singh³, David Boothman³ and [Jason D. Slinker](#)¹; ¹The University of Texas at Dallas, Richardson, Texas, United States; ²Department of Biosciences, Rice University, Houston, Texas, United States; ³Department of Biochemistry and Molecular Biology, Indiana University Simon Cancer Center, Indianapolis, Indiana, United States.

There is great need to follow the selectiveness of anticancer drug activity and to understand the mechanisms of biological activity. Here, multi-electrode chips with DNA monolayers are used to track anticancer drug activity in cellular lysates and correlate cell death activity with DNA damage. Cells were prepared from the triple-negative breast cancer (TNBC) cell line, MDA-MB-231 (231) to be proficient or deficient in expression of the NAD(P)H:quinone oxidoreductase 1 (NQO1) enzyme to represent cancerous and control cells. Cells were lysed and added to chips, and the impact of β -lapachone (β -lap), an NQO1-dependent DNA-damaging drug, was followed with DNA electrochemical signal changes arising from drug-induced DNA damage. Devices showed a 3.7-fold difference in the electrochemical responses to NQO1+ over NQO1- cell lysates, as well as 10 to 20-fold selectivity to controls deactivating DNA damaging pathways. Concentration dependence study revealed that 1.4 μ M β -lap correlated with the onset of cell death from viability assays and the midpoint of DNA damage on the chip, and 2.5 μ M β -lap correlated with the midpoint of cell death and the saturation of DNA damage on the chip. Results indicate that these devices could inform therapeutic decisions for cancer treatment.

BM07.09.12

DNA Sizing and Quantification Using Multi-Frequency Impedance Cytometry Jianye Sui¹, Neeru Gandotra², Pengfei Xie¹, Zhongtian Lin¹, Curt Scharfe², Mehdi Javanmard¹ and [Hemanth Maddali](#)¹; ¹Rutgers, The State University of New Jersey, Piscataway, New Jersey, United States; ²Yale University, New Haven, Connecticut, United States.

In recent decades, DNA quantification has attracted substantial research efforts due to its significance in disease diagnosis and analysis. A number of DNA quantification methods have been established. Traditional methods to quantify nucleic acids usually use fluorescent labels or dyes and require bulky instruments for excitation. Previously, Saleh et al. demonstrated quantification of biomarkers through resistive pulse sensing using a DC measurement to detect changes in particle diameter due to analyte binding on the surface of a bioactivated colloid [1]. In this work, we proposed a new approach for label-free nucleic acid strand recognition by using multi-frequency impedance flow cytometry.

The process begins by amplifying (PCR) and biotinylating target DNA, and immobilizing the DNA onto streptavidin coated magnetic beads. The cytometer consists of a pair of electron-beam deposited gold electrodes on glass wafer, with a Polydimethylsiloxane (PDMS) microfluidic channel embedded on top. Various quantities of DNA on the surface of the bead will affect the surface conductance, permittivity, and charging profile and thus modulate the frequency-dependent impedance response. When a bead flowed through the sensing region, it partially blocks ions conducted between two electrodes. Thus, there is a frequency-dependent impedance increased. By probing peak intensities at different frequencies, beads coated with differing quantities of DNA can be differentiated from each other. The impedance response is captured in real-time at 8 frequencies using a multi-frequency lock-in-amplifier.

Different beads immobilized with a series of DNA quantities (ranged from 0.1 ng to 1000 ng) to the surface were investigated using impedance flow cytometry. The bare magnetic streptavidin coated beads that had no DNA captured were used as a negative control. We implemented multi-frequency analysis, which provides a more comprehensive result, since the impedance response of different samples at single frequency may not be separable. The peak intensity increased as frequency increased from 100 kHz to 5 MHz and then decreased as frequency increased to 15 MHz. Results showed that using multi-frequency analysis, we can differentiate beads with different concentrations of DNA. In addition, a study on the effect of different DNA lengths on impedance responses was performed. We demonstrated that as the length of DNA increased, the impedance responses increased linearly. The results of these studies suggest that this approach can be applied for DNA quantification using small sample volumes using a miniaturized electronic chip.

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BM07.09.13

Artificially Well-Designed Biomonomer for Prevention of Nonspecific Electrical Signal Shogo Himori, Shoichi Nishitani and Toshiya Sakata; The University of Tokyo, Bunkyo-ku, Japan.

[Introduction]

An artificially well-designed biointerface is required for a new strategy of biosensor such as an enzyme-free glucose sensor. A solution-gate field-effect transistor (FET) is based on the potentiometric measurement of intrinsic ionic or biomolecular charges at the gate surface of the FET without enzymatic reactions. Moreover, an extended-Au film-gate FET enables a highly-sensitive detection of small biomarkers, because the Au film exhibits a strong catalytic action, resulting in the oxidation of organic compounds such as uric acid and glucose. However, the selective detection of small biomarkers, which involves a signal to noise ratio, with the Au film electrode is not sufficient for a real sample containing impurities. In this study, we have designed an Au film/solution interface for the selective detection of small biomarkers and investigated the effect of diazonium monolayer on the prevention of nonspecific signals based on non-targeted small biomarkers.

[Methods]

An Au(Cr) film was fabricated by sputtering on a glass substrate. The Au electrode was modified by nitro group-terminated aryldiazonium monolayer in acetonitrile including 1 mM 4-nitrobenzenediazonium tetrafluoroborate (NBD), 25 mM tetrabutylammonium hexafluorophosphate (nBuPF₆), and 2 mM DPPH via cyclic voltammetry (CV), which was in the potential range of +0.3 V to -0.7 V at the scan rate of 50 mV/s. The immobilization density of NBD monolayer was controlled via CV treatment. On the other hand, the same method was applied for the modification of NBD multilayer in the solvent without DPPH. The change in the surface potential was monitored using the NBD-grafted FET. In particular, uric acid was used as a small biomarker and introduced onto the Au film electrode with the different densities of NBD monolayer or NBD multilayer. The concentration of added uric acid was changed in the range of 5 μ M to 1 mM. The thickness of diazonium film was analyzed by laser microscope. Besides, the surface coverage was calculated by reduction from nitro group of NBD to amino group.

[Results and Discussion]

The uric acid response for the NBD monolayer-grafted FET was smaller than that for the NBD multilayer-grafted FET. That is, the NBD monolayer-grafted FET suppressed the nonspecific electrical signal based on the interaction of uric acid with the Au film. This is because the surface coverage by the NBD multilayer was insufficient, that is, there were some vacancies among the grafted NBDs, through which uric acid approached to the Au surface. On the other hand, the grafting density of NBD monolayer on the Au film was higher than that of NBD multilayer. Moreover, the effect of NBD monolayer on the prevention of nonspecific signal was enhanced with increasing potential cycles via CV method, resulting in the increase of immobilization density.

[Conclusions]

Our work suggests a new strategy of selective detection of small biomarkers using the extended-Au film-gate FET biosensor.

BM07.09.14

Observation of Local Ionic Concentration of the Selected Cations at the Hippocampal Neuron with Nano-Pipette Jong Wan Son¹, Tomohide Takami², Woong Sun³ and Bae Ho Park¹; ¹Konkuk Univ, Seoul, Korea (the Republic of); ²Kogakuin University, Hachioji, Japan; ³Korea University, Seoul, Korea (the Republic of).

Selected cationic currents at the cell membrane inside and outside of hippocampal neuron were measured using nano-pipette probes. A polyvinyl chloride film was prepared in the nano-pipette probes, and the film contains each crown ether ligands that collector of potassium, sodium or calcium cations. The currents of the collected cations were detected through a silver wire electrode and the currents were recorded with a sub-picoampere current measurement system, developed from the techniques of T Ω -gap impedance scanning tunneling microscopy. Depending on the position of the nano-pipette probes, the local ionic concentration at hippocampal neuron is measured as the selected cationic currents. We also demonstrate the progress of our work about real-time measurements of ionic concentration when stimulate the hippocampal neurons.

BM07.09.16

Magnetochemical Technique for Remote Manipulation of Neurons Siyuan Rao^{1,2}, Ritchie Chen², Ava LaRocca³, Michael G. Christiansen³, Alexander W. Senko³, Cindy Shi³, Po-Han Chiang¹, George Varnavides³, Seongjun Park⁴, Junsang Moon³ and Polina Anikeeva^{1,3}; ¹Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ²Simons Center for Social Brain, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ³Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ⁴Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States.

Targeted delivery of neuromodulators within the brain is essential in linking the activity of their molecular targets to behavior. However, existing delivery methods are often non-specific, e.g. intravenous and peritoneal systemic administration, or invasive, e.g. implantation of microfluidic devices. To facilitate spatially-restricted and remotely-controlled delivery of neuromodulators to neural circuits of interest, we sought to gate the release of small molecules using non-invasive stimuli. Here, we coupled weak alternating magnetic fields (AMFs) in the low radiofrequency range to trigger the release of chemical compounds entrapped within liposomes loaded with magnetic nanoparticles. Multiple micro-dosages with minimal leakage could be delivered upon liposome permeabilization through localized heating of magnetic nanoparticles. When combined with chemogenetic neuromodulation approaches, we find that the activation times can be decreased from hours to seconds at multiple time points within genetically-defined neural populations. This scheme was also applied to control over endogenous receptor function using magnetochemical delivery of known antagonists and agonists, demonstrating applications of this approach to various ligand-receptor pairs. We anticipate that the magnetochemical tools will facilitate investigation of neural circuits during behavioral experiments and enable neuromodulation studies in rodent models incompatible with permanently implanted hardware.

BM07.09.17

Nanowell Array Impedance Platform for Multiplexed Label-Free Quantification of Cytokines in Serum at Femtomolar Level Detection

Limits Pengfei Xie, Tuan Le and Mehdi Javanmard; Rutgers, The State University of New Jersey, Piscataway, New Jersey, United States.

Protein microarrays, on which thousands of discrete proteins are printed, provide a valuable platform for functional proteomic analysis. A protein microarray provides a multi-functions platform for the comprehensive and high throughput studies. Label-free techniques avoid interference due to the tagging molecules, which is the fundamental preparation for the labeling based detection methods. Detection of proteins in blood using label-free impedance based techniques is difficult due to high salt concentration of the matrix, which results in screening of the charge of the target proteins. In this work, we describe a novel sensing configuration where sensitivity benefits from the high salt concentration of the matrix, and demonstrate robust performance through testing in rat serum. To be exactly, we developed a platform with nanowell array sensor, which can monitor multiplexed cytokines in serum at femtomolar level. The nanowell impedance sensor involves the fabricating the micro-wells array patterned electrodes with nanometer level gap, and the continuous impedance measurement using lock-in amplifier based automatic monitor platform. And we have demonstrated the ability of the platform with 100 femtomolar level cytokines detection of mouse TNF-alpha, IL6, IL10 and CXCL2. The titration curves of all 4 cytokines ranging from 10 fM up to 1 nM are also plotted in this work.

BM07.09.18

Electronic Quantification of Surface Markers on Cancer Cells Based on Bead-Cell Aggregate Sizing and Multi-Frequency Impedance

Spectroscopy Zhongtian Lin², Siang-Yo Lin¹, Pengfei Xie², Joseph Bertino¹ and Mehdi Javanmard²; ¹Cancer Institute of New Jersey, Rutgers University, New Brunswick, New Jersey, United States; ²Department of Electrical and Computer Engineering, Rutgers University, Piscataway, New Jersey, United States.

Rapid analysis of surface markers on the membrane of cancer cells can be used for point-of-care device for monitoring patient's response to various cancer treatments. Here, we introduced a microfluidic sensor for quantification of proteins on membrane of cancer cells using multi-frequency impedance cytometry. To demonstrate proof-of-concept, we successfully detected "activated" matriptase on the surface of cultured breast cancer cells. Activated matriptase is overexpressed in most epithelial cancer cells. In order to target the cancer cells, magnetic beads were coated with an anti-matriptase monoclonal antibody (M69) that recognizes activated matriptase. The beads then form aggregation with cancer cells as a result of expression of matriptase on the cells' membrane. The magnetic beads and the bead-bound cancer cells were extracted from the test sample via immuno-magnetic separation. Multi-frequency electrical impedance cytometry was applied to the bead-cell mixture which enable differentiating between unbound beads, non-target cells and bead-cell aggregates. This method can be used for detection and quantification of membrane bound protein (i.e. matriptase) levels, as the concentration of matriptase expressed on the cancer cells is related to the size and quantity of peaks from bead-cell aggregates.

The biochip consists of two microelectrodes on a glass substrate with a PDMS micro-channel above it. Gold electrodes were fabricated using standard photolithography, electron beam evaporation, and lift-off processing. The micro-channels are 400 μm wide and 20 μm high connecting to a sensing region which is 100 μm wide and 20 μm high. M69 coated 2.8 μm sheep anti-mouse IgG beads were mixed with cancer cells off chip. A portion of the beads bind together with cancer cells in the positive assay which form effectively large aggregates compared to the negative control assay where beads were not treated with M69. The mixture is then injected into the inlet of micro-channel. As beads and bead-cell aggregates pass over the microelectrodes that is connected to a multi-frequency lock-in amplifier and AC voltage source, a frequency dependent increase in impedance was detected. The amplitude of the current peak is proportional to particle size. Utilizing simultaneous multiple frequencies measurement of peak intensity, we can demonstrate the quantification of the number of bead-cell aggregates which allows for estimation of matriptase expression levels.

BM07.09.19

Conducting Polymers for Axonal Regeneration—Effect of Surface Topography on Modulation of Axonal Growth Martin Antensteiner, Anthony M. Kisucky and Mohammad Reza Abidian; Biomedical Engineering, University of Houston, Houston, Texas, United States.

Nerve injuries in the peripheral nervous system caused by trauma (i.e. nerve lesions) or debilitating disorders such as Parkinson's disease have affected more than 20 million people and are estimated to account for 2.8% of all trauma cases in the United States. Autografts are the clinical gold standard for the treatment of nerve gaps, the disadvantages of which include a limited supply of donor nerve, inability to reconstruct complex nerve gaps, sensory deficits in the distribution of the donor nerve, painful dysesthesias following sensory nerve harvest, and structural/ultrastructural nerve mismatch. To overcome these limitations, artificial conduits have been widely investigated to bridge nerve gaps. However, functional recovery after nerve injury remains a challenge. Biocompatible Conducting Polymers (CP) can be utilized to guide neurons and eventually repair nerve injuries such as nerve gaps due to their unique electrical, physical, and chemical properties. However, few works address the effect CP roughness has on axonal regeneration. In this work, we have investigated two common biocompatible CPs, poly(pyrrole) (PPy) and poly(3,4-ethylenedioxythiophene) (PEDOT), fabricated using galvanostatic (GSTAT) and potentiostatic (PSTAT) methods, and characterized the surface roughness of these two polymers. While PPy is well-known for its electrical conductivity and physical stability, PEDOT displays superior chemical stability and electrical conductivity, making it an ideal candidate for artificial conduits.

Electrodeposition was performed on microfabricated Au electrodes using a solution of EDOT or Py monomer and poly(styrenesulfonate) under GSTAT (0.1 to 1.5 mA/cm²) or PSTAT (0.5 to 0.95 V) deposition modes over intervals ranging from 1 to 10 minutes. Each surface was analyzed with materials confocal microscopy (MCM) to measure the CP film thickness and surface roughness. Additionally, the impedance and charge storage capacity (CSC) of the films were measured with impedance spectroscopy and cyclic voltammetry, respectively. Preliminary data suggests a dual dependence of all measured properties (roughness, thickness, impedance, and CSC) on both deposition time and applied charge. For example PPy/GSTAT films on Michigan neural electrodes, roughness (Rq) increased from 2.14 \pm 0.25nm to 12.0 \pm 0.84nm; CSC also increased from 5.7mC/cm² to 98.7mC/cm²; finally, impedance at 100Hz decreased from 8.94e4 Ω to 3.83e4 Ω . These measurements were taken from films deposited at 1min, 0.1mA/cm² and 10min, 1.5mA/cm² respectively. PPy properties exhibited generally linear trends, and PEDOT properties tended to display nonlinear trends. Dorsal root ganglion (DRG) cells will be cultured on these CP films and neurite outgrowth will then be assessed as a function of surface roughness. These results can be leveraged to improve the control of regenerating axons via surface cues.

BM07.09.20

Galactoside Sensors Based on Langmuir and Langmuir-Blodgett Films of Lipids and Synthetic Polymers Felipe T. Araujo, Laura O. Peres and Luciano Caseli; Federal Univ of Sao Paulo, Diadema, Brazil.

The structure of an enzyme must be conserved when it is incorporated in nano-electronic devices since its catalytic activity will determine the device's function as sensors of interest. Among the systems able to keep the main conformational structures of polypeptides, we can mention the Langmuir-Blodgett (LB) films, which are monomolecular layers transferred from the controlled passage of solid supports through a floating monolayer at liquid-gas interfaces. In this sense, LB films composed of amphiphiles can be useful not only to immobilize enzymes, but also to keep their structure and enhance their stability for the construction of robust biosensors. Particularly, beta-galactosidases (BGL) are enzymes that catalyze the hydrolysis of beta-galactosides in monosaccharides by breaking a glycosidic bond, being therefore useful for galactoside sensors, which is commonly employed in molecular biology as a

marker to monitor gene expression. In this work, we investigated the interaction of a BLG in LB films of stearic acid (HSt) and poly (9,9-dioctylfluorene) - co-thiophene (PDF-TF). The fatty acid and the polymer were co-spread on the air-water interface and the enzyme was inserted into the aqueous subphase of the lipid monolayer. The adsorption of the enzyme at the monolayer was studied by surface-area pressure isotherms, surface-area potential isotherms, vibrational spectroscopy and Brewster angle microscopy (BAM). The mixed monolayer was transferred to solid supports by the LB methodology and the enzymatic activity of beta-galactosidase was evaluated against lactose. Fluorescence and infrared spectroscopy confirmed the cotransfer of the enzyme along lipid and polymer molecules, and the sensor performance could be evaluated by using UV-vis spectroscopy. As a result, beta-galactosidases could be incorporated in nanostructured devices such as HSt/PDF-TF LB films for sensing performance as a proof-of-concept experiment, with the fatty acid serving an immobilization matrix and the polymer as signal facilitator.

Acknowledgements: FAPESP, CAPES and CNPq

BM07.09.21

Long-Range Electron Transfer in Photosystem I Montse Lopez Martinez^{1,2,3}, Manuel Lopez Ortiz^{2,3}, Maria Elena Antinori², Emilie Wientjes⁴, Roberta Croce⁵ and Pau Gorostiza^{2,3,6}, ¹Department of Materials Science and Physical Chemistry, Universitat de Barcelona, Barcelona, Spain; ²Institute for Bioengineering of Catalonia - The Barcelona Institute of Science and Technology (BIST), Barcelona, Spain; ³Networking Research Center on Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), Barcelona, Spain; ⁴Laboratory of Biophysics, Wageningen University, Wageningen, Netherlands; ⁵Biophysics of Photosynthesis-Physics and Astronomy, VU University Amsterdam, Amsterdam, Netherlands; ⁶Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain.

Electron Transfer (ET) is essential for biological processes such as cell respiration and photosynthesis. It takes place between redox proteins, and within large protein complexes where electrons are transferred over long distances with outstanding efficiency. Photosystem I (PSI) is a type I reaction center in oxygenic photosynthesis that acts as a natural photodiode. It allows electron conduction through the protein complex upon light illumination, with efficiency close to unity [1]. The importance of its biological role, together with its outstanding properties, makes PSI one of the most investigated ET systems in biology.

Electrochemical Scanning Tunneling Microscopy (ECSTM) is an excellent tool to study ET proteins that offers single molecule resolution imaging in aqueous solution, in nearly physiological media while maintaining full electrochemical control. Beyond imaging, ECSTM allows performing current-voltage and current-distance electrochemical tunneling spectroscopies (ECTS). Using current-distance spectroscopy, the distance decay factor β of an ET system can be directly measured by recording the current flowing between the electrodes while changing the distance between them [2, 3]. We have characterized for the first time individual PSI complexes on Au (111) electrodes under electrochemically-controlled conditions using ECSTM. PSI was immobilized onto Au surfaces through electrostatic interactions with an 8-mercaptopentanoic acid SAM, where it retained its electrochemical activity and photocurrent generation ability. We obtained ECSTM images where we can resolve individual PSI molecules with an apparent height of ~ 0.4 nm, in good agreement with previous reports of STM images of PSI in air [4]. We also studied ET between PSI bound to a functionalized Au electrode and the conductive probe of the ECSTM setup. Using current-distance spectroscopy we measured the distance decay factor β for a range of electrochemical potentials, at positive and negative bias. The majority of the obtained β values were in the range of $4-6 \text{ nm}^{-1}$, in agreement with previously reported values for other ET proteins [2]. However, we have found conditions displaying remarkably low β values ($< 2 \text{ nm}^{-1}$) that indicate the presence of long-range electron transfer (LRET) between protein and probe through the aqueous solution. We will discuss the dependence of these currents with the electrochemical conditions and their possible biological interpretations in the framework of the photocurrent generation mechanism.

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SESSION BM07.10: Biosensors—Materials and Fundamentals

Session Chairs: Sabine Ludwigs and Klas Tybrandt

Thursday Morning, November 29, 2018

Sheraton, 2nd Floor, Constitution B

8:00 AM BM07.10.01

Development of Naphthodithiophene Diimide-Based Copolymers for N-Type Organic Electrochemical Transistors Iuliana P. Maria¹ and Iain McCulloch^{1,2}, ¹Department of Chemistry, Imperial College London, London, United Kingdom; ²Physical Science and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia.

Organic semiconducting polymers hold great potential to act as electrically active materials at the interface with a biological environment due to their biocompatibility, soft nature and ability to support both ionic and electronic transport. Recently, functionalization with polar ethylene glycol chains of thiophene-based polymer backbones led to p-type materials with high transconductance and stability in accumulation mode organic electrochemical transistors (OECTs).¹ When a similar side-chain engineering strategy was employed for n-type OECT materials based on naphthalene-1,4,5,8-tetracarboxylic-diimide (NDI) units, a high stability for n-type doping in aqueous solution and a high volumetric capacitance were observed. However, the overall performance of the device was limited by the poor electron mobility of the material.² In search of n-type OECT materials with improved electron mobility, we report the design and synthesis of a series of copolymers containing more planar and rigid naphtho[2,3-b:6,7-b']dithiophene-4,5,9,10-tetracarboxylic diimide (NDTI) units as the electron acceptor building block. The properties of these copolymers will be discussed in the context of OECTs in comparison with the NDI analogues, elucidating strategies for backbone engineering in order to develop high-performance electron transport materials for bioelectronic applications.

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8:15 AM BM07.10.02

Novel P-Type Small Molecules for Organic Electrochemical Transistors Zachary S. Parr¹, Benjamin Poggi¹, Jonathan Rivnay² and Christian B. Nielsen¹, ¹SBCS, QMUL, London, United Kingdom; ²Biomedical Engineering, Northwestern University, Chicago, Illinois, United States.

Conducting and semiconducting organic materials have existed for over forty years and have seen a broad range of applications from transistors to photovoltaics to logic circuits to OLEDs and more recently biosensors. Among the biosensing devices developed in recent years the most promising has been the organic electrochemical transistor (OECT). Much of the research into OECTs has mainly involved PEDOT:PSS which has proved itself a champion material for biosensors. Very recently, it has been demonstrated that traditional p-type conducting polymers can be modified with polar ethylene glycol sidechains to allow for mixed ionic and charge conductance affording a polymer with higher transconductance than comparable PEDOT:PSS devices with this design methodology also affording the first n-type biosensing device¹⁻³. Ionic conductance or capacitance combined with charge mobility are the two critical material properties required to achieve high transconductance (g_m), the figure of merit of an OECT. With this in mind, we have investigated the potential of small molecule semiconducting materials which often display very high charge mobility in OFETs as materials for OECTs via modification of the conjugated small molecule with ethylene glycol side chains.

We have designed and synthesised a series of molecules primarily based on EDOT oligomers via direct arylation end capped with phenyl groups functionalised with tri-ethylene glycol side chains. The molecules have been fully characterised structurally, electrochemically and optically and exhibited repeatable, stable redox behaviour in aqueous environment with low onsets of oxidation as well as strong electrochromism in thin films. Finally, the molecules have been characterised operationally in the OECT regime. We have achieved OECT devices which can be solution deposited and promising OECT performance is achieved for a number of the molecules. This promising initial result opens an avenue to achieve scalable synthesis of attractive materials for OECTs based on small molecules which with some further structural modification and optimisation of side chain length and solid state morphology are likely to compete with the properties of reported OECT polymers as well as afford access to significantly more varied processing methodologies than for polymer systems.

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8:30 AM *BM07.10.03

Organic Mixed Conductors for Bioelectronic Devices [Jonathan Rivnay](#); Northwestern University, Evanston, Illinois, United States.

Polymeric materials capable of ionic-to-electronic signal transduction are important for enhancing bi-directional communication in bioelectronics. Prototypical conducting polymers such poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate), PEDOT:PSS, have enjoyed prolonged success as organic bioelectronic mainstays, but they are challenging to study, and may suffer from stability issues and other potentially disqualifying drawbacks. Studying the strengths of PEDOT-based systems, we are able to establish design rules in order to develop new conjugated mixed conductors. Introducing glycolated side chains to carefully selected semiconducting polymer backbones, for example, has produced a class of high performance bioelectronic materials that feature high volumetric capacitance, and enabled electrochemical transistors with transconductance >10mS (device dimensions ca. 10 μ m), and steep subthreshold switching characteristics. A sub-set of these materials outperform PEDOT:PSS and show significant promise for low power, biocompatible devices for implantable bioelectronics. These materials and devices have led to enhanced sensing circuits with the potential for hybrid integration with inorganic transistors.

9:00 AM BM07.10.04

Imaging Ion Dynamics on the Nanoscale with Time-Resolved Electrostatic Force Microscopy [Jeff Harrison](#)¹, Dean Waldow², Phillip Cox¹ and David S. Ginger¹; ¹Chemistry, University of Washington, Seattle, Washington, United States; ²Pacific Lutheran University, Tacoma, Washington, United States.

Ionic transport processes govern performance in many classic and emerging devices, ranging from battery storage to modern mixed-conduction electrochemical transistors. Here, we study local ion transport dynamics in polymer films using time-resolved electrostatic force microscopy (trEFM). We compare time-domain behavior using both local trEFM and macroscopic electrical impedance spectroscopy (EIS). We use poly(exo-N-(2-(2-methoxyethoxy)ethyl)-7-oxabicyclo[2.2.1]hept-5-ene-2,3-dicarboximide)(Poly-ONDI) films doped with lithium bis(trifluoromethane)sulfonimide (LiTFSI) as a model system. Our results show that the local polymer response measured in the time domain with trEFM follows stretched exponential relaxation kinetics, consistent with the Havriliak-Negami relaxation we measure in the frequency-domain EIS data for macroscopic samples of the same polymers. Furthermore, we show that trEFM data correlate with bulk samples in EIS—changes in ion dynamics with increasing temperature, increasing salt concentration, and increasing volume fraction of ethylene glycol side chains in the polymer matrix evolve with the same trend in both measurement techniques. We conclude from this correlation that trEFM data reflect, at the nanoscale, the same ionic processes probed in conventional EIS at the device level. Finally, as an example application for emerging materials syntheses, we use trEFM and infrared photoinduced force microscopy (PiFM) to image a novel diblock copolymer electrolyte for next-generation solid-state energy storage applications.

9:15 AM BM07.10.05

The Influence of Water on the Ion-to-Electron Transduction of Organic Semiconductors [Achilleas Savva](#)¹, Camila Cendra Guinassi², Alberto Salleo², Jonathan Rivnay³ and Sahika Inal¹; ¹Biological and Environmental Science and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia; ²Department of Materials Science and Engineering, Stanford University, Santa Clara County, California, United States; ³Department of Biomedical Engineering, Northwestern University, Evanston, Illinois, United States.

Organic electrochemical transistors (OECTs) comprised of organic (semi)conducting channels operate in aqueous, biological media and translate low magnitude ionic fluctuations of biological origin into measurable electrical signals.^[1] The growing technological interest in these bio-transducers makes the fundamental understanding of the ion-to-electron conversion extremely important for the design of new materials and devices.^[2] One crucial aspect that has been so far disregarded is the water taken up by the film during device operation. Here we show the influence of water taken up by a p-type organic semiconductor film^[3] on the efficiency, reversibility and speed of charge generation induced by electrolyte anions, penetrating inside the film. The efficiency of ion-to-electron transduction is linked to the performance of the accumulation mode OECTs comprising the polymer in the channel. We find that when less water is incorporated into the polymer film alongside the dopant anions, the OECT ON current is higher, the device is more reversible, stable and switches faster.^[4] This work gives insights into the impact of a swollen channel material on the performance of OECTs and lays the foundation for future materials design for efficient ion-to-electron transduction.

[1] S. Inal et al., *Benchmarking organic mixed conductors for transistors*, Nature Communications 1767 (2017).

[2] A. Savva, Shofarul Wustoni, S. Inal, *Ionic-to-Electronic Coupling Efficiency in PEDOT:PSS Films Operated in Aqueous Electrolytes*, J. Mat. Chem. C,

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9:30 AM BM07.10.06

Low Voltage Current-Driven Organic Electrochemical Transistor for Biomedical Applications [Leona V. Lingstedt](#)¹, Matteo Ghittorelli², Fabrizio Torricelli², N. Irina Craciun¹, Paschalis Gkoupidenis¹ and Paul W. Blom¹; ¹Max Planck Institute for Polymer Research, Mainz, Germany; ²Information Engineering, University of Brescia, Brescia, Italy.

Detection of ion concentrations plays a fundamental role in biomedical diagnostics, health and environmental monitoring, water and food controlling, as well in the security and agriculture industry.^[1] Here we show an organic electrochemical transistor (OECT) in a current-driven configuration providing highly sensitive ion detection at low voltages.^[2] The ion sensitivity normalized to the supply voltage is larger than $1200 \text{ mV V}^{-1} \text{ dec}^{-1}$, which is the highest value ever reported for ion-selective transistors. The bias current determines the range of ion concentration and the sensitivity is not limited by the supply voltage, thus overcoming the fundamental limit. A potential application is demonstrated by the integration of the current-driven OECT with an ion-selective membrane, exhibiting a sensitivity of $1035 \text{ mV V}^{-1} \text{ dec}^{-1}$, normalized to the supply voltage.

We were able to extend this concept by interfacing organic electronics with biological systems. The integration of OECTs with human cells, enables the assessment of barrier tissue layer properties in a non-invasive and label-free method. Measuring the paracellular transport provides information about the integrity and function of the barrier tissue as disruption or dysfunction can be an indicator for disease or toxicity. The OECT, resembled in the inverter-like topology, is sensitive to cell coverage and shows minute-respond to toxins due to barrier rupture. Pushing this technology to greater sensitivity, this proposed approach may open opportunities in toxicology, drug delivery, disease diagnostics and fundamental research in molecular biology.

[1] J. Rivnay, S. Inal, A. Salleo, R. M. Owens, M. Berggren, G. G. Malliaras, *Nat. Rev. Mater.* **2018**, 3, 17086.

[2] M. Ghittorelli, L. Lingstedt, P. Romele, N. I. Crăciun, Z. M. Kovács-Vajna, P. W. M. Blom, F. Torricelli, *Nature communications* **2018**, 9, 1441.

9:45 AM BM07.10.07

Polymer OFET Biosensors with High Performance and Stability [Mark Nikolka](#)^{1,2}, Amir Foudeh¹ and Zhenan Bao¹; ¹Stanford University, Stanford, California, United States; ²University of Cambridge, Cambridge, United Kingdom.

Due to their ease of processing, conjugated polymers are promising candidates for a range of optoelectronic applications ranging from flexible displays and light emitting diodes (OLEDs) to organic photovoltaics (OPV). Recently, surprisingly high levels of performance and stability have been demonstrated especially for low disorder conjugated polymers exhibiting charge carrier mobilities well above $1 \text{ cm}^2/\text{Vs}$ and operational stabilities compatible with demanding state-of-the-art OLED displays [1,2]. However, these advancements so far have not been translated into the emerging field of biosensors where similar performance and stability requirements prevail. Here we demonstrate how high mobility, low disorder polymers can be utilized in platforms for pH-sensing and bio-sensing. In particular, we demonstrate a highly stable sensors platform based on the dual-gate mechanism. In this architecture a sensing signal is transduced and amplified by the capacitive coupling between a low-k bottom-dielectric and a high-k ionic elastomer top-dielectric that is in contact with an analyte solution. We show that our platform design exhibits a high stability in various aqueous environments of different salt concentrations making it particularly interesting for biosensing applications where high selectivity is desired.

1. Venkateshvaran D.*, Nikolka M.* *et al.*, Approaching disorder-free transport in high-mobility conjugated polymers, *Nature*, **515**, 384–388 (2014)

2. Nikolka M.*, Nasrallah I.* *et al.*, High operational and environmental stability of high-mobility conjugated polymer field-effect transistors through the use of molecular additives *Nature Materials*, **16**, 356–362 (2016)

10:00 AM BREAK

SESSION BM07.11: Biosensors—Analytical
Session Chairs: Sahika Inal, Damia Mawad and Bernhard Wolfrum
Thursday Morning, November 29, 2018
Sheraton, 2nd Floor, Constitution B

10:30 AM *BM07.11.01

Physical Biology at the Semiconductor-Based Biointerfaces [Bozhi Tian](#); University of Chicago, Chicago, Illinois, United States.

Although there are numerous studies on either semiconductors or biological components, our understanding of the fundamentals at the semiconductor-based biointerfaces has been limited. As different types of energy (such as electrostatic, mechanical, thermal, and chemical energies) display diverse scaling behaviors and can converge, an appropriate selection of the length scale is critical for promoting new scientific discoveries. My group integrates material science with biophysics to study several semiconductor-based biointerfaces. We synthesize new forms of semiconductor materials and use them to probe biological dynamics, with particular focus at the sub-micrometer and sub-cellular length scales. In particular, we have recently identified a biology-guided two-step design principle for establishing tight intra-, inter-, and extracellular silicon-based interfaces in which silicon and the biological targets have matched mechanical properties and efficient signal transduction. We proved light-controlled non-genetic modulations of intracellular calcium dynamics, cytoskeleton-based transport and structures, and cellular excitability, highlighting the utility of these new interfaces. Additionally, we demonstrated an uninformed search-based optical cellular-modulation approach that mimics naturally occurring extracellular signals, *i.e.*, random, fast and multisite input signals.

11:00 AM BM07.11.02

Flexible Organic Electrochemical Transistors for Biosensing [Anneng Yang](#) and [Feng Yan](#); Hong Kong Polytechnic University, Hong Kong, China.

Flexible fabric biosensors can find promising applications in wearable electronics. However, high-performance fabric biosensors have been rarely reported due to many special requirements in device fabrication. We report the preparation of organic electrochemical transistors (OECTs) on Nylon fibers. By

introducing metal/conductive polymer multilayer electrodes on the fibers, the OECTs show very stable performance during bending tests. The devices with functionalized gates are successfully used as various biosensors, including glucose, uric acid and protein sensors, with high sensitivity and selectivity. The fiber-based OECTs are woven together with cotton yarns successfully by using a conventional weaving machine, resulting in flexible and stretchable fabric biosensors with high performance. The fabric sensors show much more stable signals in the analysis of moving aqueous solutions than planar devices due to a capillary effect in fabrics. The fabric devices are integrated in a diaper and remotely operated by using a mobile phone, offering a unique platform for convenient wearable healthcare monitoring.

11:15 AM BM07.11.03

Selective Chemical Sensors Based on All PEDOT Organic Electrochemical Transistors [Erika Scavetta](#), Beatrice Fraboni, Tobias Cramer, Federica Mariani, Isacco Gualandi and Marta Tessarolo; Univ of Bologna, Bologna, Italy.

Organic Electrochemical Transistors (OECTs) are devices which find growing interest in the field of biological and chemical sensing. Although the OECT transduction is based on electrochemical reactions, the transistor architecture offers several advantages with respect to amperometric sensors, such as signal amplification, the use of easy and cheap readout electronics, low supply voltage (usually < 1 V), low power operation (< 100 μ W), bio-compatibility. Moreover, OECT configuration does not require freestanding reference electrodes used in conventional electrochemical setups and offers design freedom in terms of device geometries and substrates (flat/flexible). In addition to their inherent robustness, versatility and ease of integration, OECTs can be miniaturized and fabricated with low-cost materials [1], on any kind of substrate, including textile and plastic.

Our research group has reported the fabrication of OECTs wherein the channel and all the electrodes are made by PEDOT:PSS (poly(3,4-ethylenedioxythiophene) poly(styrene sulfonate)) and their use as chemical sensors for a wide class of analytes. The selectivity and sensitivity to the target analyte can be given by a proper functionalization of the gate material and/or acting on the transistor operation mode.

This contribution describes our most recent results on OECT based chemical sensors exploiting the functionalization of the gate PEDOT electrode, as assessed by the following two applications:

The first application is the use of PEDOT doped with pH dyes (BTB and MO, i.e. Bromothymol Blue and Methyl Orange, respectively), as the gate electrode to develop an OECT sensor for pH monitoring. The developed sensor can reliably operate with a super-Nernstian sensitivity, that can be reached thanks to the amplification offered by the transistor architecture. The optimised configuration was realised on a PET substrate and the performance of the resulting flexible OECT was assessed in artificial sweat within a medically relevant pH range.

The second application is the design and synthesis of a new composite material based on Ag/AgCl nanoparticles (NPs) and PEDOT:PSS that allowed us to fabricate a novel kind of OECT-inspired sensor, integrating an Ag/AgCl gate electrode into the semiconducting polymer in the form of NPs. Such sensor combines an intrinsically amplified response associated to the transistor design with a simple two terminal electrical connection, which offers great advantages in terms of read-out electronics, adaptability to new and unconventional geometries and faster response time. The efficacy of such a simple connection has been demonstrated through the development of a textile sensor for real-time sweat monitoring.

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11:30 AM BM07.11.04

Direct Metabolite Detection with an Accumulation Mode Organic Electrochemical Transistor [David Ohayon](#)¹, Anna-Maria Pappa², Alexander Giovannitti³, Iain McCulloch³,¹ Roisin Owens² and Sahika Inal¹; ¹KAUST, Thuwal, Saudi Arabia; ²Chemical Engineering and Biotechnology, University of Cambridge, Cambridge, United Kingdom; ³Chemistry, Imperial College London, London, United Kingdom.

Lactate serves as a decisive indicator for critical healthcare conditions. Excessive lactate levels have detrimental effects and can result in conditions such as hemorrhage, respiratory failure, and tissue hypoxia. Regulation of lactate metabolism depends on the ability to accurately measure its concentration in biofluids and is important for diagnosis of diseases. There is, however, very few commercially available sensors to detect lactate and their fabrication involves tedious steps of enzyme immobilization. In this work, we report an all-polymer microscale transistor platform for direct enzymatic lactate detection. Our biosensor is an organic electrochemical transistor (OECT) based on an n-type polymer, which incorporates hydrophilic side chains to enhance ion transport/injection and to facilitate enzyme conjugation. The detection mechanism is based on direct electron transfer between the enzyme (lactate oxidase)/lactate and the polymer. The device shows excellent sensitivity, selectivity and a wide analyte concentration range (10 μ M - 10 mM). We show that by tuning the device operation parameters, the sensitivity and dynamic range of the device is controlled, demonstrating possible applications for lactate detection in different biological fluids where the lactate concentration range varies. Contrary to most of the sensors up to date, the working principle of these devices is unique and therefore outperforms other OECTs despite the absence of an electron mediator.

11:45 AM BM07.11.05

Nanoparticles for Improving Performance of Enzymatic Electrodes [Renata Biliewicz](#)¹, Michal Kizling^{1,2}, Maciej Dzwonek¹, Aleksandra Rekorajska¹, Agnieszka Wieckowska¹ and Pawel Kryszinski¹; ¹Faculty of Chemistry, University of Warsaw, Warsaw, Poland; ²College of Inter-Faculty Individual Studies in Mathematics and Natural Sciences (MISMAP), Warsaw University, Warsaw, Poland.

We describe the influence of gold nanoparticles (AuNPs) and nanoclusters (AuNCs) on the mechanism of bioelectrocatalytic reactions. Below a certain size the monolayer-protected AuNCs show a series of oxidation states and a clear HOMO-LUMO gap [1]. We propose that AuNCs can change their role in the bioelectrocatalytic processes when their size decreases below 2nm. Fructose dehydrogenase (FDH) used here is a heterotrimeric membrane-bound enzyme complex, insensitive to oxygen, consisting of three domains. Subunit I is the catalytic dehydrogenase domain containing FAD as the cofactor. Subunit II contains 3 paramagnetic heme C moieties acts as an electron acceptor to subunit I [2].

We show that AuNCs ca. 1nm in size lead to larger FDH catalyzed currents of fructose oxidation and smaller overpotentials which reflects improved electronic communication between the electrode and the active sites [3]. The catalytic wave appears at a potential close to that of the beginning of clusters HOMO-LUMO gap. The effect of the smallest gold clusters is of special interest and features such as low-coordination sites, adsorptive properties of the AuNC surfaces, thiol monolayer organization have to be considered in the discussion of the improved catalytic current densities and lower overpotentials. Such behavior may be also understood as mediation of the enzymatic processes by the AuNCs as opposed to larger, plasmonic AuNPs, for which direct ET process (DET) is observed. Controlled switch from DET to mediated MET mechanism of electron transfer by decreasing AuNPs to cluster sizes might be considered for other oxidoreductases as well.

We also show that under influence of magnetic field superparamagnetic iron oxide NPs interact with paramagnetic heme centers of FDH subunit II leading to suitable orientation of the enzyme molecule and enhancement of DET. Closer approach of heme sites to the support results in the decreased fructose oxidation overpotential and Michaelis-Menten constant. Improved performance of enzymatic electrodes achieved through application of Au clusters or magnetic NPs holds great promise for third generation biosensors and biofuel cells.

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SESSION BM07.12: Biosensors—Interfacing Cells
Session Chairs: Bozhi Tian and Catalina Vallejo Giraldo
Thursday Afternoon, November 29, 2018
Sheraton, 2nd Floor, Constitution B

1:30 PM BM07.12.01

A Novel Approach to Monitor Cell Adhesion, Proliferation and Detachment Based on Highly Stable Electrolyte-Gated Transistors Francesca Scuratti^{1,2}, Giorgio Ernesto Bonacchini², Caterina Bossio², Maria Antonietta Loi³, Maria Rosa Antognazza² and Mario Caironi²; ¹Politecnico di Milano, Milan, Italy; ²Center for Nano Science and Technology, Istituto Italiano di Tecnologia, Milan, Italy; ³University of Groningen, Groningen, Netherlands.

A recent trend in toxicology and drug development focuses on enhancing the effectiveness and comprehension of drug testing experiments performed on cell cultures, with the aim of limiting the exploitation of animal models, as well as to allow for more cost-effective and up-scalable protocols. To this scope, organic electrochemical transistors have proved to be valuable tools for assessing cell-drug interactions *in vitro*, able to perform measurements with enhanced sensitivity and temporal resolution compared to standard electrochemical cell-substrate impedance spectroscopy and other well-established optical probes. Although this approach has proved to be useful in different applications, it does require complex read-out electronics, as well as non-trivial signal processing and analysis for data interpretation, being based on impedance spectroscopy techniques.

In this work, we propose carbon-nanotube based electrolyte-gated transistors as a novel tool to electrically monitor cell adherence and proliferation, able to operate consistently in aqueous environment and in conjunction with more established optical techniques. By exploiting the changes in the capacitive coupling occurring at the electrolyte/semiconductor interface as cells adhere on the active material, information on proliferation and detachment can be easily extracted from the quasi-static variation of the drain-source current in time, without any need for electrochemical spectroscopy or other frequency-dependent techniques. This particular sensing approach is validated by monitoring over a time span of three days the adhesion and growth of several cell lines via quasi-static measurements, and corroborated by means of standard and fluorescence optical microscopy. Indeed, in all instances the behaviour of the output current follows the expected changes in interfacial impedance that result from cell-proliferation on the active layer, corresponded by a full recovery of the initial currents upon inducing cell detachment from the device.

Thus, by establishing a direct relation between presence of adhered cells and electrical output, we demonstrate that carbon-based electrolyte-gated transistors constitute a promising technology to perform large-scale and cost-effective *in vitro* monitoring for toxicology and drug development applications, able to operate complementarily to state-of-the-art optical and electrochemical techniques.

1:45 PM BM07.12.02

Integrating Native Cellular Membranes with Organic Transistors Anna-Maria Pappa¹, Han-Yuan Liu², Charalampos Pitsalidis¹, Rohit Singh², Alberto Salleo³, Susan Daniel² and Roisin Owens¹; ¹Cambridge University, Cambridge, United Kingdom; ²Cornell University, Ithaca, New York, United States; ³Stanford University, Palo Alto, California, United States.

Cellular membranes represent an obvious, yet relatively neglected target for developing new drugs. Using membrane models (*e.g.*, supported lipid bilayers, SLBs) for sensing and drug screening is limited by incompatibility at the biotic/abiotic interface, lack of molecular complexity, and lack of integrated functionality to transduce at the molecular level. We have recently demonstrated that SLBs are compatible with electroactive materials able to transduce molecular interactions of toxins with a model membrane. In parallel our teams have developed methods to assemble *complex* (native) membrane structures into planar supported bilayers on solid supports, using materials directly harvested from live cells. By using hydrated polymer-based transducers, instead of solid supports one can achieve a fluid environment- close to the physiologically relevant environment- *i.e.*, facilitating mobility of the transmembrane proteins, which is essential for such native plasma membrane systems. These features enhance the native structural and functional properties of the membrane and ensure the credibility of our platform to be physiologically relevant and predictive of membrane molecular interactions. In this work, we demonstrate the formation of native SLBs on top of the conducting polymer *poly*(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) transistors. We characterize the native SLBs using both optical and electronic methods. Real time monitoring of the native SLB formation reveals useful information regarding dynamics of membrane fusion and allows for sensitive detection of minute changes on the membrane properties. This work is a first step towards the use of native plasma membranes with highly-sensitive, label-free and fast electrical readout to transduce membrane-compound interactions, essential for diagnostics and drug discovery applications.

2:00 PM BM07.12.03

Biosensor Prototype Based on Carbon Nanotubes for Detection and Hyperthermia Treatment of Cervical Cancer Cells Giovanni S. Caro¹, André Marra¹, Darinel Ortiz², Ismael Jiménez², Javier Avalos², Gerardo Morell¹ and Brad R. Weiner¹; ¹University of Puerto Rico at Río Piedras, San Juan, Puerto Rico, United States; ²University of Puerto Rico, Bayamón, Puerto Rico, United States.

Current treatments for cancer include surgery, chemotherapy, and radiation, as well as combinations of these. Although widely utilized, these treatments are not entirely effective. Our primary aim is to develop a non-invasive radiofrequency-based biosensor that is able to detect cancerous cells as well as provide therapy using localized heat with the aid of nanotechnology. This wireless radiofrequency (RF) sensor employs carbon nanotubes (CNTs) to enable the detection of cancer cells and the selective treatment via hyperthermia. The sensor is a gold resonant coil LRC circuit for wireless transmission and in its capacitive component contains CNTs that were deposited and functionalized. The detection relies on the phase change of the RF signal in the presence of cancer cells. The heat treatment is then administered through photothermal therapy. We demonstrate *in vitro* the use of CNTs for both the detection and selective hyperthermia treatment of cervical cancer cells (HeLa). The results show that phototherapy using CNTs excited RF and NIR radiation is a promising method against cancer cells, which can further be combined with CNT targeted drug delivery for more effective cancer treatments.

2:15 PM BM07.12.04

A 3D Biomimetic Transistor for the Development and Monitoring of a Human Gut Model Charalampos Pitsalidis, Chrysanthi Maria Moysidou, Janire Saez, Aimee o. Withers and Roisin Owens; Department of Chemical Engineering and Biotechnology, University of Cambridge, Cambridge, United Kingdom.

The human gut is host to over 100 trillion bacteria that are essential for human health. Those bacteria can affect the function of the gastrointestinal tract (GI), via immunity, nutrient absorption, energy metabolism and intestinal barrier function. Animal studies remain one of the sole means of assessing the

importance of microbiota on development and well-being, however issues due to ethics as well as cost and relevance concerns, have pushed the development of *in vitro* models. Advances in 3D cell culture materials and techniques have fostered the development of organ and tissue models that accurately mimic *in vivo* systems to study biological phenomena. While 3D tissues can be generated, technology that can accurately assess the functionality of these complex models in a dynamic manner is not well compatible with the biological tissue. Here, we report the development of a biomimetic 3D organic electrochemical transistor (OECT) consisting of poly(3,4-ethylene dioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) scaffold, designed to mimic the gut architecture. As such, the transistor-scaffold serves the dual purpose of hosting and real-time monitoring the 3D human model of the gut. The system was carefully designed to facilitate vascularization and promote homogeneous growth of cells. The inclusion of cells within the pores of the scaffold was found to significantly affect the transistor characteristics, while dynamic measurements over a prolonged period of time (>3weeks) provided useful information regarding the dynamics of cell growth. This platform represents a first step towards the development of an *in vitro* model of the gut-brain axis that aims to study host-microbiome interactions and consequences for pathophysiology of the GI tract and the brain.

2:30 PM *BM07.12.05

Organic Electrochemical Transistors for Electrical Cell-Substrate Impedance Sensing with Single Cell Resolution Sven Ingebrandt¹, Felix Hempel², Jessica Ka Yan Law², Fabian Brings¹ and Xuan Thang Vu¹; ¹Institute for Materials in Electrical Engineering, RWTH Aachen University, Aachen, Germany; ²Informatics and Microsystem Technology, University of Applied Sciences Kaiserslautern, Zweibrücken, Germany.

Electrical Cell-substrate Impedance Sensing (ECIS) is a well-established technique in the field of bioelectronics and several commercial platform technologies are available. We developed a similar technique, which is using ion-sensitive field-effect transistors (ISFETs) as transducer elements and we coined the term Field-Effect Transistor Cell-substrate Impedance Sensing (FETCIS) [1]. In early works we utilized different designs of silicon ISFET arrays. However, they are very tedious to fabricate and devices are opaque. Nevertheless, we applied our ISFETs in practical cell assays such as adhesion, migration, wound healing, apoptosis and toxicological influences with single cell resolution [2-4].

In recent years, organic thin-film transistors (OTFT) gained a lot of attention in the field of biosensing. Their versatility, easy fabrication and their biocompatibility make those devices a new and exciting alternative for cell-sensing applications [5]. We developed arrays of electrochemically-gated OTFTs (OECTs) out of poly(3,4-ethylenedioxythiophene) doped with polystyrene sulfonate (PEDOT:PSS). OECTs offer a completely novel, ionic gating mechanism compared to the classical, purely capacitive coupling to silicon ISFETs. We realized a wafer-scale fabrication protocol for OECTs. Devices exhibited excellent sensor characteristics with transconductance values exceeding those of our silicon ISFETs [2]. Sensors were optimized to a frequency level of 1-10 kHz. We present FETCIS assays with individual HEK 293 cells and with tight junctions forming MDCK cells [6]. An extended FETCIS model including the ionic gating mechanism of OECTs can explain the recorded frequency spectra and can be utilized to extract cell-related parameters from the bioassays. In future OECTs could be produced such cheap that sensing in disposable standard plastic dishes would be possible. This could be a very interesting alternative to the classical sensor types in ECIS.

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SESSION BM07.13: Biosensors—Performance
Session Chairs: Sven Ingebrandt and Christian B. Nielsen
Thursday Afternoon, November 29, 2018
Sheraton, 2nd Floor, Constitution B

3:00 PM BM07.13.01

Integrated Biosensor for Point-of-Care Sepsis Diagnosis Jouha Min¹, Maria Nothing⁵, Georg F. Weber⁵, Cesar Castro^{1,3}, Filip K. Swirski¹, Hakho Lee^{1,4} and Ralph Weissleder^{1,4,2}; ¹Center for Systems Biology, Massachusetts General Hospital, Boston, Massachusetts, United States; ²Systems Biology, Harvard University, Boston, Massachusetts, United States; ³Cancer Center, Massachusetts General Hospital, Boston, Massachusetts, United States; ⁴Radiology, Massachusetts General Hospital, Boston, Massachusetts, United States; ⁵Surgery, University of Erlangen-Nuremberg, Erlangen, Germany.

Sepsis is an often fatal condition that arises when the immune response to an infection causes widespread systemic organ injury. A critical unmet need in combating sepsis is the lack of accurate early biomarkers that produce actionable results in busy clinical settings. Here, we report the development of a point-of-care platform for rapid sepsis detection. Termed IBS (integrated biosensor for sepsis), our approach leverages i) the pathophysiological role of cytokine interleukin-3 (IL-3) in early sepsis, and ii) a hybrid magneto-electrochemical sensor for IL-3 detection. The developed platform produces test results within 1 hour from native blood samples, and detects IL-3 at a sensitivity of <10 pg/mL; this performance is >5-times faster and >10-times more sensitive than conventional enzyme-linked immunosorbent assays, the current gold standard. Using clinical samples, we show that high plasma IL-3 levels are associated with high organ failure rate and thus greater risk of mortality, confirming the potential of IL-3 as a sepsis diagnostic biomarker. With further system development (*e.g.*, full automation, data security measures) and rigorous validation studies, the compact and fast IBS could become a practical clinical tool for timely diagnosis and proactive treatment of sepsis.

DOI: 10.1021/acsnano.7b08965

3:15 PM BM07.13.02

Nanopatterned Bulk Metallic Glass Biosensors Emily Kinser^{1,2,3} and Themis Kyriakides¹; ¹Yale University, New Haven, Connecticut, United States; ²IBM T.J. Watson Research Center, Yorktown Heights, New York, United States; ³3M Corporate Research Lab, Maple Grove, Minnesota, United States.

Nanopatterning as a surface area enhancement method has the potential to increase signal and sensitivity of biosensors. Platinum-based bulk metallic glass

(Pt-BMG) is a biocompatible material with electrical properties conducive for biosensor electrode applications, which can be processed in air at comparably low temperatures to produce nonrandom topography at the nanoscale. Work presented here employs nanopatterned Pt-BMG electrodes functionalized with glucose oxidase enzyme to explore the impact of nonrandom and highly reproducible nanoscale surface area enhancement on glucose biosensor performance. Electrochemical measurements including cyclic voltammetry (CV) and amperometric voltammetry (AV) were completed to compare the performance of 200 nm Pt-BMG electrodes vs Flat Pt-BMG control electrodes. Glucose dosing response was studied in a range of 2 mM to 10 mM. Effective current density dynamic range for the 200 nm Pt-BMG was 10-12 times greater than that of the Flat BMG control. Nanopatterned electrode sensitivity was measured to be 3.28 $\mu\text{A}/\text{cm}^2/\text{mM}$, which was also an order of magnitude greater than the flat electrode. These results suggest that nonrandom nanotopography is a scalable and customizable engineering tool which can be integrated with Pt-BMGs to produce biocompatible biosensors with enhanced signal and sensitivity.

3:30 PM BM07.13.03

Stimuli-Responsive Polymer-Grafted Gate Field-Effect Transistor for Bioanalytical Sensor Akane Fujita², Tsukuru Masuda¹, Aya M. Akimoto², Taira Kajisa³, Ryo Yoshida² and Toshiya Sakata²; ¹School of Life Science and Technology, Tokyo Inst. of Tech., Tokyo, Japan; ²School of Engineering, The University of Tokyo, Tokyo, Japan; ³PROVIGATE Inc., Tokyo, Japan.

Bioanalytical tools such as biosensors are being developed for in situ monitoring of biological phenomena. As one of them, a biologically coupled gate field-effect transistor (FET) is based on a potentiometric detection of the changes in ionic charges induced by biomolecular recognition events and cellular activities in a real-time, label-free, and noninvasive manner.

Meanwhile, poly(*N*-isopropylacrylamide) (PNIPAAm) is one of the most widely studied thermoresponsive polymers, and exhibits hydrophilic/hydrophobic phase transition in aqueous media across the lower critical solution temperature (LCST). Thanks to the thermo-responsivity, PNIPAAm-modified surfaces can exhibit hydrophilic/hydrophobic changes in response to temperature, and they have been studied for various applications including flow control, bioseparation, and cell culture dishes. Here, we hypothesized that the PNIPAAm-modified surface would be useful as a signal transduction interface in the semiconductor-based biosensor.

In this study, we have clarified the dynamic electrical behavior of a thermoresponsive PNIPAAm film on the gate of FET device [1]. Our findings will be useful for the application of semiconductor-based biosensors.

PNIPAAm was modified by atom transfer radical polymerization (ATRP) on the Ta₂O₅ gate of FET devices. At first, the ATRP initiators were modified on the Ta₂O₅ surfaces with hydroxyl groups by silane coupling method, and then the PNIPAAm chains were grafted on them by surface-initiated ATRP. The phase transition behavior of the grafted-PNIPAAm film induced by the temperature change from 25 °C to 40 °C was analyzed from the electrical properties of the FET device. Moreover, the phase transition time of the grafted-PNIPAAm film was measured in real time using the PNIPAAm-grafted FET device. The surface potential of the PNIPAAm-grafted FET became more negative than that of the non-grafted FET, as the temperature increased from 30 °C to 35 °C. This is because the phase transition of the grafted-PNIPAAm film from a hydrated state to a dehydrated state occurs across LCST, which is 32 °C in aqueous media. In this case, the capacitance of the grafted-PNIPAAm film should be altered because water has high permittivity. Thus, the change in the physicochemical structure of PNIPAAm from swelling to deswelling was converted into the change in the electrical characteristic of FET device. Moreover, we have found that the surface-modified polymer needed several hours to complete the phase transition using the PNIPAAm-grafted FET. Our work suggests a new strategy of biointerface based on a stimuli-responsive polymer for the semiconductor-based biosensor.

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3:45 PM BM07.13.04

Mechanism of Label-Free, Potentiometric Sensing of Neuropeptide-Y in Artificial Sweat Using Graphene Field Effect Transistors Ahmad E. Islam^{1,2}, Rhett Martineau^{1,2}, Cameron M. Crasto^{1,2}, Hyunil Kim^{1,2}, Michael Brothers^{1,2}, Rahul Rao^{1,2}, Ariana Nicolini¹, Cheri Hampton^{1,2}, Benji Maruyama¹ and Lawrence F. Drummy¹; ¹Air Force Research Laboratory, Wright Patterson AFB, Ohio, United States; ²UES, Inc., Dayton, Ohio, United States.

Label-free, potentiometric bio-sensing is an emerging method for rapid, specific and sensitive detection of biomarkers to probe a wide range of physiological conditions. Neuropeptide Y (NPY) is one such biomarker, which is involved in regulation of important biological and pathophysiological functions such as food uptake, energy homeostasis, circadian rhythm and cognition. NPY is also an indicator of susceptibility to stressful or threat-related events. We have recently shown pM sensitivity for NPY detection in artificial sweat using graphene field effect transistor (GFET) functionalized with a peptide-based bio-recognition element (BRE). We used in-operando Transmission Electron Microscopy (TEM) imaging to examine the structure of NPY and its interfacing with BRE and graphene. We visualized the operation of the sensors in real-time to optimize their performance.

Here, we expand our understanding of NPY sensing by thoroughly analyzing the electrical and optical responses of graphene using electrolyte-gate GFET and Raman spectroscopy measurements. In particular, we study the GFET responses in an artificial sweat environment formulated using a range of salt concentration (~ 10-100 mM) and pH (~ 4.5-7.0), as measured in sweat [1]. In these pH ranges, the charged states of BRE and NPY are away from their isoelectric points (as calculated using Henderson-Hasselbalch equation). This charged states result consistent changes in the Dirac point and mobility of graphene after the BRE functionalization and after adding NPY at different concentrations (~ 1 pM - 10 μM ; this covers the range of NPY measured in depressive disorder patients [2]). In addition, a two-dimensional plot of the shifts in the graphitic G and G' peaks (generally observed at ~ 1600 cm^{-1} and ~ 2700 cm^{-1} , respectively) obtained from Raman spectroscopy [3] confirms the magnitude of the Dirac point shift measured electrically and suggests changes in strain on the graphene layer after attachments of BRE and NPY. Overall, these complimentary electrical and optical measurements reveal the mechanism of NPY sensing using graphene during potentiometric sensing and suggest pathways for sensing of other biomarkers that have similar charged states and isoelectric points.

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4:00 PM BM07.13.05

Chip-Based Potentiometric Sensor for Flavivirus Diagnostic Using 3D Surface Molecular Imprinting Vincent Ricotta³, Yingjie Yu³, Nicholas Clayton³, Ya-Chen Chuang³, Yantian Wang³, Steffen Mueller¹, Kalle Levon², Marcia Simon⁴ and Miriam Rafailovich³; ¹Codagenix Inc, Farmingdale, New York, United States; ²Chemical and Biological Sciences, Polytechnic Institute of NYU, Brooklyn, New York, United States; ³Materials Science and Chemical Engineering, Stony Brook University, The State University of New York, Stony Brook, New York, United States; ⁴Oral Biology and Pathology, Stony Brook University, The State University of New York, Stony Brook, New York, United States.

The latest Zika virus (ZIKV) pandemic caused great international concern from explosively proliferating throughout the Americas. This arbovirus is

primarily transmitted through the bite from an infected mosquito, but infection has also been spread through perinatal transmission, sexual contact, blood transfusion, and physical contact. Although asymptomatic, ZIKV became a major health crisis due to the link with the steep rise in cases of microcephaly and Guillain-Barré syndrome with infection. With no viable vaccine or reliable and economically feasible diagnosis in sight, the World Health Organization has called for the rapid development of flavivirus diagnostics. Unfortunately, antibody-based detection systems can result in false positive results and RNA-based detection systems are costly, time-consuming, and impractical for testing in remote regions. In this study, a potential point-of-care (POC) diagnostic system was developed using a chip-based potentiometric sensor to detect flaviviruses using a 3D molecular imprinting technique. The co-adsorption of ZIKV and alkanethiols formed a crystalline self-assembled monolayer (SAM) on the surface of the gold chips. The crystalline SAM behaved as lock-and-key complexes by forming cavities on the surface of the chips specific to the size and confirmation of the targeted virus. Re-adsorption of the targeted ZIKV to the cavities yielded surface charging on the chips which was measured in real-time potentiometrically. The formation of these crystalline SAM was verified using cyclic voltammetry. The removal and re-adsorption of the targeted virus was verified using electrochemical impedance spectroscopy supporting the molecularly wired mechanism. This chip-based potentiometric sensor system was able to detect 10^{-1} PFU/mL ZIKV in a buffered solution under 20 minutes without any sample manipulation. This sensor was tested against Dengue virus at clinical viral loads and showed no sign of cross-reactivity. When tested against human saliva samples containing clinical viral loads, this sensor was able to detect 10 PFU/mL ZIKV among the pool of bio-macromolecules. The high sensitivity and high selectivity demonstrated here proved that this lab-on-a-chip diagnostic has the potential to become a POC detection system for rapid and accurate screening of flaviviruses. *This work was supported by the NSF, Inspire #1344267. This work was performed in part at the Advanced Science Research Center NanoFabrication Facility of the Graduate Center at the City University of New York.*

4:15 PM BM07.13.06

PEDOT:PSS Derivatives as the Active Layer of Planar Organic Electrochemical Transistor (OECT) with Ultra-Low Fouling Surface and High Sensitivity for Bacteria Sensing Shin-Ya Chen, Erjin Zheng, Priyesh Jain, Hao Dong, Zhiyin Niu, Shaoyi Jiang and Qiuming Yu; University of Washington, Seattle, Washington, United States.

The need for rapid, sensitive, and reliable pathogen detection is of utmost importance on the global scale from food safety, biomedical diagnostics, homeland security to environmental monitoring. With the emerging technology of Internet of things/everything and flexible/wearable electronics, thin film transistor-based bacterial biosensors employing conducting polymer materials could hold promise to offer ubiquitous bacteria detection with low-cost and high-performance. Organic electrochemical transistors (OECTs) represent a very promising class of organic thin film transistors (OTFTs) that have recently fueled scientific interest as performing transducers in sensing applications. OECTs offer the advantages of simple electrical readout, low operation voltage, inherent signal amplification, straightforward miniaturization, and ease of fabrication on flexible substrates including paper. Therefore, they are excellent candidates for disposable biosensors. However, the commonly used conducting polymer poly(3,4-ethylenedioxythiophene) doped with poly(styrenesulfonate) PEDOT:PSS lacks of functionality and non-fouling properties, which limits the application as the active layer for OECT biosensors. In this work, we present the development of zwitterionic carboxybetaine PEDOT conducting polymers (PEDOT-CB) and print it on paper or PET substrate to form a planar OECT. PEDOT-CB offers both functionality to chemically link antibody to the sensor surface and non-fouling properties to allow direct detection in complex media. We synthesized EDOT-CB monomer and chemically polymerized to PEDOT-CB. The UV-Vis absorption spectroscopy and electron spin resonance (EPR) spectroscopy measurements were conducted to determine polaron and bipolaron populations in the oxidized PEDOT-CB. The conductivity of the PEDOT-CB:PSS thin films was measured using the four-probe approach. We printed planar OECTs on paper and PET substrate using inkjet printing method. Small molecules were added to further increase the conductivity and to improve the microstructure to allow efficient link antibody. Surfactant was added to improve the adhesion of PEDOT-CB:PSS on paper (or PET) substrates. The dimension of channel length/width and gate length/width were optimized to achieve high transconductance under certain gate voltage (V_G) and source-drain voltage (V_D). The anti-E-coli antibody was immobilized on PEDOT-CB:PSS gate via the NHS/EDC chemistry. The drain current (I_D) was recorded with time after a certain concentration bacteria solution was added to the PDMS well under the V_G and V_D that produced the maximum transconductance. The limits of detection were determined for bacteria in buffer solution, artificial urine, and milk to demonstrate the ultra low fouling capability.

4:30 PM BM07.13.07

Quantitative Characterization of Thermal Transport Properties in Soft Materials Using Thin, Conformable Resistive Sensors Kaitlyn E. Crawford^{1, 2, 3}, Yinji Ma⁴, Siddharth Krishnan^{2, 3}, Chen Wei³, Daniel Capua², Yeguang Xue³, Shuai Xu³, Zhaoqian Xie³, Sang Min Won², Limei Tian², Chad Webb², Yajing Li³, Xue Feng⁴, Yonggang Huang³ and John A. Rogers^{3, 2}; ¹University of Central Florida, Orlando, Florida, United States; ²University of Illinois at Urbana-Champaign, Urbana, Illinois, United States; ³Northwestern University, Evanston, Illinois, United States; ⁴Tsinghua University, Beijing, China.

Devices, particularly wearable systems, for measuring the thermal properties of the skin can provide vital information about physiological health status. Designs that 1) minimize the mechanical mismatch at the skin-device interface, 2) maximize conformal contact between skin and device, 3) eliminate any constraints in natural motions of the skin, 4) avoid any thermal load on the skin, and 5) operate in a physically imperceptible, non-irritating manner, are particularly attractive. Recent reports describe approaches to such skin-like, or 'epidermal', devices and outline their capabilities for precision, continuous measurements of hydration, cutaneous wound healing, blood flow, temperature, thermal conductivity and thermal diffusivity. Building on this platform, the presented project describes the development, validation and application of advanced methods for using such devices in a transient plane source model to yield the thermal conductivity in a computationally efficient, accurate manner that avoids experimental uncertainties associated with previous approaches. The device architecture consists of a resistive sensor formed with photolithographically defined serpentine metal wires (15-20 μm wide; Cr/Au 8/100 nm thick). The resistive sensors have circular layouts with radii selected between 0.5 mm – 2.0 mm, and can be used simultaneously as a temperature sensor as well as a thermal actuator via Joule heating. Temperature profiles of thermal actuation on soft materials, including skin, are modeled with finite elemental analysis and are compared with a newly introduced scaling law for determination and confirmation of thermal conductivity. An application example focuses on characterization of erythema as a sign of skin injury. Erythema is a physiological phenomenon characterized by a reddening of the skin caused by vasodilation of near-surface capillaries that appears following exposure to heat/cold stresses, pressure, infection, inflammation, allergic reaction, and prolonged exposure to solar radiation (sunburn). Results show that the near-surface thermal conductivity changes in a manner that can be used for non-invasive monitoring of erythema recovery as a function of time. Further, the results provide a foundation to extend the use of the resistive sensors and scaling laws to facilitate rapid, noninvasive thermal measurements on broad classes of biological and non-biological soft materials, as well as the opportunity to further study skin injury in clinically relevant settings.

Crawford, K. E. et al. *Extreme Mechanics Letters* **2018**, 22, 27-35.

4:45 PM BM07.13.08

Fully Organic, Flexible and Biodegradable Components for Bioinspired Electronics Meng Xu, Ramendra Pal, Sayantan Pradhan and Vamsi K. Yadavalli; Chemical and Life Science Engineering, Virginia Commonwealth Univ, Richmond, Virginia, United States.

The integration of naturally derived and synthetic polymers provides exciting opportunities to develop physiologically compliant bioelectronic systems and functional scaffolds for tissue regeneration. The combination of protein biomaterials and intrinsically conducting polymers enables the formation of

functional biocomposites with properties different from conventional silicon or metal-based paradigms. In particular, silk proteins can provide mechanically strong, optically transparent, biocompatible, and biodegradable matrix materials. Conducting polymers such as poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) can provide electrical/ionic conductivity, electrochemical properties and chemical stability in biological environments. Coupled together, our group has demonstrated photopatternable, water-based conductive inks comprising PEDOT:PSS and in-house synthesized photoreactive silk proteins that can be used in facile, room-temperature, aqueous techniques to form flexible substrates and sensors.[1, 2] Here we will discuss recent results that show how these composite inks can function as the starting point to develop diverse components of flexible, fully organic bioinspired electronics. These include electroactive coating materials for conventional electrodes, flexible electrodes, biosensors, and energy storage devices.[3-5] These systems in multiple formats are formed without the use of metals or other charge collector support materials, making them programmable, and completely biodegradable. The use of proteins as the matrix of the composite improves interfacing with biological surfaces. Electroactive biomolecules such as ascorbic acid and dopamine, and analytes such as glucose can be detected sensitively and selectively using enzymes. For the first time, we demonstrate how even large biologically relevant macromolecules such as vascular endothelial growth factor (VEGF) can be detected *in situ* in a flexible, conformable format [6]. We discuss the mechanical, biochemical and electrochemical characterization and microfabrication. Such systems can provide applications towards real-time health monitoring of disease in addition to the measurement of biophysical parameters. Utility of these elements as bio-sensors, opto-electronic devices and flexible energy storage systems are envisioned.

References:

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SESSION BM07.14: Poster Session III: Bioelectronics—Fundamentals, Materials and Devices
 Thursday Afternoon, November 29, 2018
 8:00 PM - 10:00 PM
 Hynes, Level 1, Hall B

BM07.14.01

Electrical-Based Detection of Human Embryonic Stem Cells Using Two-Dimensional Materials [Sophia Chan](#)¹, Yaw Sing Tan², Kan-Xing Wu³, Christine Cheung^{3,4} and Desmond Loke¹; ¹Singapore University of Technology and Design, Singapore, Singapore; ²Bioinformatics Institute, Agency for Science, Technology and Research (A*STAR), Singapore, Singapore; ³Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore, Singapore; ⁴Institute of Molecular and Cell Biology, Agency for Science, Technology and Research (A*STAR), Singapore, Singapore.

With stem cell-based treatments gaining momentum, there has been a need to monitor/validate stem cells in real-time (e.g. monitoring pluripotent stem cells prior to differentiation, validating the removed residual pluripotent stem cells after differentiation). This will reduce the risk of teratoma formation. Current detection techniques require labelling and these techniques hinder real-time monitoring as they are destructive, expensive and time-consuming. Instead, label-free techniques such as electrical-based detection (EBD) methods are promising for real-time measurements. Here, we observed a unique bioelectric signal of human embryonic stem cells using direct current-voltage measurements facilitated by few-layered 2D-MoS₂ sheets. A 1.828 mA cell signal was achieved as well as multiple cell reading cycles demonstrating $I \sim 1.9$ mA. Native stem cell proliferation, viability and pluripotency were preserved. Molecular dynamics simulations elucidated the origin of the 2D-MoS₂ sheet-assisted increase in current flow. This paves the way for the development of a broadly applicable, fast and damage-free stem cell detection method capable of identifying pluripotency with virtually any complementary-metal-oxide-semiconductor circuits.

BM07.14.02

High Performance Electrochemical Transistor for Adrenaline Detection [Nileshi Saraf](#)¹, Madison Pepler¹, Sudipta Seal¹ and Eric Woods²; ¹University of Central Florida, Orlando, Florida, United States; ²University of Houston, Houston, Texas, United States.

Epinephrine also known as Adrenaline is an excitatory neurotransmitter which plays an important role in fight and flight response. The abnormalities in the level of epinephrine are the direct symptoms of some diseases such as cardiomyopathy, orthostatic hypertension, stress and other heart related diseases. The detection of epinephrine has been done using various methods but all these methods exhibit low detection limit, require skilled labor and show interference from alike molecules. To this end, a PEDOT: PSS based organic electrochemical transistor (OECT) has been developed to detect the presence of epinephrine. The device uses aptamers as biorecognition molecule which specifically binds to epinephrine and causes change in the transfer characteristics. A range of common interfering agents were also tested against the device and no change in current was observed, indicating high specificity of the present approach. The present approach not only provides a simple and novel testing tool but also demonstrates low detection limit of 90 pM which is by far the lowest that has been achieved using any technique. The current approach can be further used for the detection of various biomolecules by designing the aptamer for the specific molecule.

BM07.14.03

Robust Aptamer-Based Plasmonic Sensor to Detect the Extracellular Domain of Human Epithelial Growth Factor Receptor Type 2 in Serum [Jung-Hoon Kim](#)^{1,2}, Jihye Choi^{3,2}, Minhee Ku², Jin-Suck Suh³ and Jaemoon Yang^{3,2}; ¹Brain Korea 21 PLUS project for Medical Science, Yonsei University, Seoul, Korea (the Republic of); ²Systems Molecular Radiology Laboratory, Yonsei University, Seoul, Korea (the Republic of); ³Department of Radiology, College of Medicine, Yonsei University, Seoul, Korea (the Republic of).

The extracellular domain of Human epithelial growth factor receptor type 2 (ECD-HER2) is a well-known biomarker to prognosis various kind of metastatic cancer such as breast, ovarian, and gastric cancer. Investigating the ECD-HER2 in serum has been used antibody-based detection method called the enzyme-linked immunosorbent (ELISA), which is using costly many processing steps such as adding a binding buffer, exchanging washing buffer, and dilution steps for quantitative analysis the ECD HER2 protein level in serum. Also, antibody-based ELISA should be conducted in certain conditions due to its denaturation property depending on heating and pH in the buffer.

Oligonucleotide-based recognizer called aptamers have been widely studied for substituent molecules of antibody because the aptamers have not only highly specific binding property to target molecules but also thermal and pH stability [3]. Gold nanorods (GNRs) have been widely used as optical sensors

which retain its unique extinction spectrum within the visible range. This is because the electrons at the surface of gold nanorods oscillate collectively corresponding to light injection named localized surface plasmon resonance. Furthermore, this extinction spectrum is easily tunable in dealing with the morphological transformation of GNRs, chemical coatings and refractive index changing around the vicinity. In here, we developed anti-HER2 aptamer-based surface plasmon resonance sensors (HER2-APlaS) with robustness by a simple drop-coating method to detect ECD-HER2 in serum. To immobilize the GNRs on substrates with homogeneous, we introduced surface microscale grooved patterning on a polymeric substrate for controlling the dispersivity. Also, dopamine, well-known chemically adhesive materials, was used as inhibiting the aggregation of GNRs, enhancing immobility on the substrate, and giving the covalently binding available site to anti-HER2 aptamers. We used as pyrimidine modified third generation aptamers which have high stability in serum. Assembled all these advantages of described materials, HER2-APlaS was conducted real-time binding kinetic experiments in a small volume of pure medium and 50 % rat serum system without any laborious buffer changing system like ELISA. According to our results, HER2-APlaS has both evident selectivity in detecting ECD-HER2 protein and also has quantitatively analysis availability, which has 4 ~5 ng/mL of the limit of detection.

BM07.14.04

Wireless Injectable Microsystem for Programmable *In Vivo* Pharmacology and Optogenetics Yi Zhang¹, Philipp Gutruf⁴, Catro Daniel², Michael Bruchas² and John A. Rogers³; ¹Biomedical, Biological, and Chemical Engineering, University of Missouri, Columbia, Missouri, United States; ²Washington University School of Medicine, St Louis, Missouri, United States; ³Northwestern University, Evanston, Illinois, United States; ⁴University of Arizona, Tucson, Arizona, United States.

Neuroscience research of the last decade has been revolutionized by many technological advancements. Pharmacology and optogenetics represent two distinct, and sometimes complementary, tools used in neuroscience research to study the central and peripheral nervous systems. Advanced interrogations of underlying neural circuits and biology are often frustrated, however, by technological limitations that prevent the use of these approaches to study natural behaviors of untethered, freely moving animals. Traditional fiber-optic cable for optogenetics and bulk metal cannula connected with external mechanical pump for pharmacology impart significant damage to fragile tissues, limit the natural behavior of freely moving animals, affect social interactions and movements in complex, naturalistic 3D environment, and lead to persistent irritation at the biotic/abiotic interface due to mechanical mismatch and micromotions. Here, we present a wireless, battery-free optofluidic device that combine soft microfluidic and μ -ILED probes for programmable pharmacology and optogenetics, designed to offer a technology that eliminates all key disadvantages of previously reported approaches. This study yields a technology for broad distribution to the neuroscience community, with a revolutionary unified set of capabilities in targeting specific neuronal populations in freely-moving animals over an unlimited period of time. In addition, the same platforms can easily be adapted for a wide range of other types of passive or active electronics functions, including electrical stimulation.

BM07.14.05

Testing the Viability and Reusability of Hemoglobin Biosensors Utilizing SAM Surface Molecular Imprinting and Natural Surface Roughness Indices Yehoshua Auerbach¹, Nicholas Clayton², Miguel Hulyalkar³, Andrew Todt⁴, Rebecca Isseroff^{2,1}, Vincent Ricotta² and Miriam Rafailovich²; ¹Lawrence High School, Cedarhurst, New York, United States; ²Dept. of Materials Sciences and Chemical Engineering, Stony Brook University, The State University of New York, Stony Brook, New York, United States; ³South Side High School, Rockville Centre, New York, United States; ⁴Lake Oswego High School, Lake Oswego, New York, United States.

We have shown that molecular imprinting (MI) technology, together with potentiometric detection, can be used to produce sensitive, yet robust, biosensing systems with real-time electrochemical readout that can be utilized for point of care diagnostics. Real time detection of biomarkers is essential when rapid, critical decisions need to be made, such as during medical procedures when cancer is suspected, or when public health is threatened, as in the recent Zika virus epidemic or in dealing with a suspected attack by biological agents. The biosensor that we developed was tested against standard methods, such as ELISA, and was found to have comparable or better sensitivity, with sample sizes which were at least an order of magnitude smaller. Furthermore, the results from the technique are obtained within minutes, using inexpensive potentiometric readout technology which can even be wirelessly transmitted. These biosensors utilize surface molecular imprinting of a self-assembling monolayer (SAM) of hydroxy-terminated alkanethiol chains that are able to form a crystalline 'lock-and-key' structure around a target analyte; this allows the sensors to detect and differentiate between bio-macromolecules of similar size and shape with high selectivity and sensitivity. Therefore, they can be used as a quick yet accurate analysis of many chemical and biological processes, such as stem cell differentiation. The sensors are also very versatile, and can be used to detect molecules with sizes ranging over several orders of magnitude, and of widely varied chemical composition and structure.

In order to fully exploit the advantages of these biosensors, especially in remote, economically disadvantaged areas, it is important to understand and quantify the durability and reusability of the sensors. Polished and unpolished biosensor chips were created to A) test the viability of hemoglobin detection using molecular imprinting techniques, and B) to test if these sensors can be washed and reused after adsorption testing. The successful reabsorption of hemoglobin even after washing indicates that these biosensors can be reused, extending the life and usefulness of the device. Further work is in progress to determine the number of uses for the device, and the optimal method for storage. Preliminary work seems to show that vacuum sealing of the sensors with a commercial device is adequate, indicating that convenient long-term packaging of the sensor can be achieved, in turn enabling shipping and storage.

BM07.14.06

Magnetic Nanodisks for Simultaneous Mechanical and Thermal Neuronal Stimulation Danijela Gregurec¹, Alexander W. Senko¹, Andrey Chuvilin², Pooja Reddy¹, Ashwin Sankararaman¹, Po-Han Chiang¹, Dekel Rosenfeld¹, Francisco Garcia¹ and George Varnavides¹; ¹Massachusetts Institute of Technology, Cambridge, Massachusetts, United States; ²CIC nanoGUNE, San Sebastian, Spain.

Wireless schemes based on hysteretic heating of magnetic isotropic nanoparticles in high-frequency alternating magnetic fields (AMFs) have already permitted modulation of neural activity. We present a novel approach for neuronal modulation based on magnetite nanodisks (MNDs). These anisotropic iron oxide nanomaterials exhibit a characteristic vortex alignment of magnetic spin with zero net magnetization in the absence of external magnetic field. Such magnetic configuration fosters the colloidal stability in physiological solutions essential for applications in biomedicine. We synthesize a geometric palette of MNDs from 40 nm to 250 nm in diameter. Consistent with geometry, MNDs exhibit direction-dependent hysteresis loops and their specific loss power (SLP) at frequencies of 75-150 kHz up to 1000 W/g is comparable to the spherical magnetite nanoparticles, but at 5-10 times lower particle count owing it to the size of MNDs. Targeted activation of heat-gated channels is thus permitted at high frequency AMFs. Furthermore, the magnetization in the presence of weak magnetic fields assumes an "in-plane" orientation revealing a large magnetic moment that allows MNDs to transduce magnetic fields to mechanical torques at slow-varying magnetic fields. We show how the mechanical torques are further transduced to the mechanical stimuli of neuronal cells. These stable, biocompatible MNDs robustly mediate calcium influx in mechanosensitive sensory neurons from rat dorsal root ganglia (DRGs) upon application of weak (23 mT), slow-varying (1-5 Hz) magnetic fields. Finally, MNDs allow for multiplexed stimulation of neurons by selectively activating mechanoreceptors at 1-5 Hz magnetic fields, while heat dissipation and consequent activation of heat-gated ion channels is allowed at frequencies of around 100 kHz.

8:00 AM BM07.15.01

Nanostraw Platform for Intracellular Delivery into Fungal Cell Eytham Souibgui and Nicholas A. Melosh; Stanford University, Stanford, California, United States.

Major advances in nanotechnology have facilitated the development of powerful tools to study biology at the cellular level. Here, we report a nanostraw platform providing an intracellular access to introduce exogenous components such as nucleic acids, proteins and synthetic molecules directly into the cell. This platform is composed of a cargo reservoir, a polymer membrane with protruding nanostraw and a cell culture reservoir. Cargo delivery is performed by electrical pulse allowing the cargo diffusion through the nanostraw to reach the intracellular compartment. This technology allow an access into the cell without perturbing vital functions and promise high transfection efficiency of mammalian cell. Nanostraws with different dimensions i.e. length and diameter can be optimized to interface with different cell types. In this study we evaluate the ability of the nanostraw platform to delivery of exogenous components into fungal cells. Fungi are described to be responsive of human and plants diseases and also widely used in industrial process to produce antibiotic compounds, enzymes and recombinant proteins. In all of these research areas, genetic modification using exogenous DNA is widely used to study these organisms. However fungal cells are different from mammalian cells as they are surrounded by cell walls which serve as barriers reducing the delivery of exogenous compounds into the cell. The most commonly used techniques to delivery DNA into fungal cells require the production of protoplasts (cell whose cell wall has been removed) and result in low transformation efficiency in many strains. In this context, nanostraw technology is a promising tool to increase fungal transformation efficiency and develop genetic engineering of fungi.

8:15 AM BM07.15.02

Surface-Initiated Hydrogel Adhesives for Seamless Cell-Electronics Integration Han N. Nguyen, Huan-Hsuan H. Hsu and Xiaocheng Jiang; Tufts University, Medford, Massachusetts, United States.

The electronic detection and interpretation of cell-derived signals represents an important approach to understanding, interrogating, and directing many biologically significant processes. The intrinsic mismatch in biophysical and biochemical properties between living systems and artificial electronics, however, has made it challenging to establish a compatible bioelectric interface for effective signal coupling and transducing, thus limiting many potential applications. Here, we report the use of biocompatible and photo-crosslinkable hydrogels as surface-initiated “adhesives” for seamless cell-electronics integration, where nanometer-thick hydrogels are grown directly from device surface to immobilize living cells with intimate proximity and minimal invasiveness. A custom-built projection stereolithography system is used to spatially control the visible light irradiation and precisely program cell “placement” with diffraction-limited resolution. In particular, we have demonstrated the technique’s capability to incorporate living cells with different nano-electronic platforms, including both passive (microelectrode arrays) and active (field-effect transistors) type of transducers. By designing and modulating the hydrogel structure at the cell/device interface, highly-localized, device-specific microenvironment can be created, allowing real-time, ultrasensitive bioelectrical and biochemical detection at single-cell level. A variety of cell types, including adherent (H1975 and HL1), floating (Jurkat and human white blood cells) and bacterial cells, have been reliably immobilized without compromising cell viability and functionality. Additionally, a broad range of biomaterials, including photo-crosslinkable polyethylene glycol, gelatin, hyaluronic acid, and silk have been tested and optimized as cell adhesives, which helps modulate interface biochemical/biophysical properties to overcome limitations posed by challenging material requirements of many applications. Lastly, we have demonstrated the possibility to integrate multiplex cells with large-scale, addressable device arrays, which enables high-spatiotemporal resolution studies of signal propagation at network levels. The current work represents a strategic approach to overcome the intrinsic mismatch at traditional bioelectronic interfaces and is expected to open up new opportunities for a wide range of applications in biomedical sensing, prosthetics, and hybrid information processing.

8:30 AM *BM07.15.03

Organic Bioelectronics—Addressing the Interface Challenge Damia Mawad; School of Materials Science and Engineering, Centre for Advanced Macromolecular Design, Australian Centre for NanoMedicine and ARC Centre of Excellence in Convergent Bio-Nano Science and Technology, University of New South Wales, Sydney, New South Wales, Australia.

Bioelectronics is considered the future of medicine as it is not only contributing to the basic understanding of biological systems but also to clinical diagnostics and therapeutics through tissue-electronics interfaces. A major challenge facing their successful medical applications is the development of compatible and functional interface technologies that enable biological to electronic signal transduction. This central consideration is driving the “rise of organic bioelectronics” [1]. Critical to this rise has been the incorporation of conducting polymers (CPs) as the electrically active component. CPs are soft, flexible and mechanically tunable; thus more compatible with tissue than inorganic electronics. The attractive properties of CPs have largely been demonstrated in *in vitro* applications while their *in vivo* application is limited to coatings for inorganic electrodes to allow for more intimate electronic contact between the device and the tissue [2]. Examples of the challenges that have been hindering the translation into the complex physiological environment include electronic stability and integration with the host tissue. A lack of versatile chemistries for functional CPs underpin these challenges. By manipulating the chemistry of CPs and employing controlled design strategies, we develop novel bioelectronics that address the aforementioned limitations. New generation CPs are synthesized with demonstrated biocompatibility and ease of processability [3-6]. Conductive constructs such as a hydrogel doped with large polyelectrolyte or free standing patch doped with small anion were fabricated. Functionalized CPs allowed the fabrication of conductive hydrogels that not only possessed tailored physical properties, such as swelling ratios and mechanical properties, but also displayed electroactivity dependent on the chemical composition of the network. Incorporated as the active material in organic electrochemical transistor, these functional CPs exhibited good transconductance and provided surface functionalization with relevant biomolecules. In simple fabrication processes, we introduced porosity in a conductive patch and demonstrated its electronic stability in response to cyclic stretching mimicking the contraction cycle of the heart as well as its stability in the oxidized form after 2 weeks implantation *in vivo*. By modifying the chemistry of CPs, these macromolecules could be fine-tuned into functional materials opening the way for the development of novel multifunctional bioelectronics capable of effectively electro-coupling with biological tissues.

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9:00 AM BM07.15.04

Molecularly Engineered Conducting Polymers with Biomimetic Properties Jadranka Travas-Sejdic^{1,2}; ¹Polymer Electronics Research Centre, The University of Auckland, Auckland, New Zealand; ²MacDiarmid Institute for Advanced Materials and Nanotechnology, Wellington, New Zealand.

With the vision of mimicking the many functions found in nature, such as stretchability, healing and sensing, the next-generation applications including organic electronics, tissue engineering and biosensors will require new electronic materials with biomimetic features. The main challenges in developing biomimetic materials for such applications concern mechanical compliance of such material with soft biological interfaces. Organic electronic materials, notably conjugated polymers, offer many advantageous properties - the most valuable being versatile synthesis by molecular design, ease of chemical functionalisation and solution processability.

Herein, we demonstrate that the valuable biomimetic properties can be expressed through molecular design and side chain functionalisation of conjugated polymers. The simple yet versatile synthetic procedure we present enables one to fine-tune the electrical and mechanical properties without disrupting the electronic properties of the conjugated polymer. We exemplify various biomimetic properties, including stimuli-responsiveness,¹ bio-sensing,² anti-fouling,³ intrinsic stretchability and self-healing,⁴ by grafting polymeric side chains that affords such properties.

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9:15 AM BM07.15.05

Dimensionality Explored at the Nanoscale in Bioelectronics Francesca Santoro, Fabrizio A. Pennacchio, Leonardo Garma and Laura Matino; Istituto Italiano di Tecnologia, Napoli, Italy.

The interface between biological cells and non-biological materials has profound influences on cellular activities, chronic tissue responses, and ultimately the success of medical implants and bioelectronic devices. For instance, electroactive materials in contact with cells can have very different composition, surface topography and dimensionality. Dimensionality defines the possibility to have planar (2D), pseudo-3D (planar with nano-micropatterned surface) and 3D conductive materials (i.e. scaffolds) in bioelectronics devices. Their success for both *in vivo* and *in vitro* applications lies in the effective coupling/adhesion of cells/tissues with the devices' surfaces. It is known how a large cleft between the cellular membrane and the electrode surface massively affects the quality of the recorded signals or ultimately the stimulation efficiency of a device.

However, this field is hindered by lack of effective means to directly visualize in 3D cell-material interface at the relevant length scale of nanometers. In this work, we explored the use of ultra-thin plasticization technique to cells for the first time on materials which differ in dimensionality, particularly focusing on the optimization of this procedure for 3D cell-materials interfaces which have been unexplored so far. We have characterized how cells differently elongate and deform their membranes in response to the dimensionality of the electroactive materials. In this way, we are able to define a set of optimal conditions for cell-chip coupling which enable an appropriate approach for designing bioelectronics platforms for both *in vivo* and *in vitro* applications.

9:30 AM *BM07.15.06

Characterising Material Properties and Biological–Material Interactions for Conducting Polymer Biomaterials Paul J. Molino^{1,2}, Michael Higgins^{1,2} and Gordon Wallace¹; ¹ARC Centre of Excellence for Electromaterials Science, University of Wollongong, Wollongong, New South Wales, Australia; ²ARC Research Hub for Australian Steel Manufacturing, University of Wollongong, Wollongong, New South Wales, Australia.

Conducting polymer materials have attracted considerable interest for a suite of specific biological applications due not only to their ability to transfer charge, but the ability to tailor a suite of material properties that mediate biological interactions. Polymer morphological, chemical, electrochemical and mechanical properties can easily be tuned by varying the monomer, dopant species, and polymerisation conditions and method, providing an avenue to adapt and optimise polymer properties for particular applications. This presentation will focus on the ability to use quartz crystal microbalance (QCM-D) and atomic force microscopy (AFM) to not only characterise the polymer physical and mechanical properties, but to also provide critical information on the nature of protein and cell interactions with the nanostructured conducting polymer surfaces.

QCM-D provides a highly sensitive measurement of the mass and viscoelastic properties of protein in *real-time*, providing a temporal study of the dynamic process of protein binding and organisation on nanostructured conducting polymer surfaces. This approach has been used to identify variations in protein mass and viscoelastic properties on conducting polymers as a function of surface nanoroughness, the identity and loading of the dopant anion in the polymeric film, and the redox state of the polymer film. More recently advances in high speed atomic force microscopy (HS-AFM) has enabled the dynamic interactions of individual protein molecules on nanorough conducting polymer films and in aqueous buffer to be studied at near video rate imaging speeds (i.e. 10 images/s). This approach is now being used to obtain new information relating to dynamic protein interactions with surfaces and nanoparticles, providing structural details not possible using other optical techniques. Finally the ability to use QCM-D to study cell – surface interactions will be discussed, demonstrating its ability to present information relating to the physical interaction between the cell and surface, which provides complimentary information to optical microscopy methodologies.

10:00 AM BREAK

10:30 AM BM07.15.07

Precise Control of ERK Activation in Epithelial Cells by Local AC Electric Fields Quan Qing¹, Houpu Li¹, Liang Guo², Yuan Wang¹, Min Zhao² and John Albeck²; ¹Arizona State Univ, Tempe, Arizona, United States; ²University of California, Davis, Davis, California, United States.

Different types of electric fields (EF) have demonstrated great potential to trigger the extracellular-signal-regulated kinase (ERK) signaling pathway. However, it remains difficult to precisely modulate both the amplitude and frequency of the ERK activities by EF with high spatial and temporal resolution. In addition, to date the mechanism of how EF couples with ERK has been generally complicated by EF induced change of membrane potential, permeability of ions such as Ca^{2+} , or exogenous chemical signals such as pH, and reactive oxygen species (ROS). Here we used customized planar microelectrode arrays and a dynamic single-cell reporter of ERK to demonstrate non-invasive ERK activation with precise timing by bipolar symmetric AC EF pulses with no Faradaic processes involved. The ERK activities can be repeatedly synchronized and modulated in localized region close to the electrodes. We show that the ERK activation was initiated directly by EF-induced EGF-independent phosphorylation of epidermal growth factor receptor (EGFR), and did not involve changes in pH, Ca^{2+} or ROS. Our results on EF coupling to ERK signaling pathway enable precise synchronization and modulation of ERK activities with single-cell resolution, and can serve as a new platform for a wide range of biomedical applications.

10:45 AM BM07.15.08

Biological Model Membranes Supported on Organic Electrochemical Surfaces Han-Yuan Liu², Anna-Maria Pappa¹, Charalampos Pitsalidis¹, Rohit Singh², Alberto Salleo³, Roisin Owens¹ and Susan Daniel²; ¹University of Cambridge, Cambridge, United Kingdom; ²Cornell University, Ithaca, New York, United States; ³Stanford University, Palo Alto, California, United States.

Supported lipid bilayers (SLB) are emerging as a model system for investigating the function of membrane proteins, and protein-lipid interactions, and for developing new biotechnology for biosensing applications. So far, most of them have been shown on hydrophilic and smooth surfaces, such as silica based surfaces, due to the ease of vesicle fusion and SLB formation. Even though silica based surfaces serve well for SLB assembly, they have several drawbacks, as the material is electronically insulating, inflexible, and causes protein denaturation because of the interactions with the surface. Poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), is a promising surface for SLB formation because it possess electronic transducer properties, which is unlike the typical inorganic substrate. PEDOT:PSS can not only allow the transduction of signal, but also preserve transmembrane protein function. However, it is challenging to induce vesicle fusion because of surface structures and physicochemical properties. There are a variety of stimuli for triggering the vesicle fusion (pH, osmotic shock, temperature) even under unfavorable circumstances. In this work, we systematically investigated lipid vesicle interactions with conductive polymer, PEDOT:PSS. Recently, we further leveraged native cell membrane vesicles derived directly from live cells as an intermediate to incorporate native membrane species (lipid, membrane protein, etc.) into a SLB on PEDOT:PSS. The platform presented here, which is a biological model membrane supported on an organic electrochemical material with functional proteins, can be applied towards a myriad of technological purposes from drug discovery to pathogen detecting. This study is likely to pave the way for the next generation of bioanalytical sensor interfaces.

11:00 AM BM07.15.09

Engineering M13 Bacteriophage Platforms for Synthesis of Nanotheranostics and Novel Materials Uyanga Tsedev, Fred C. Lam, Ching-Wei Lin, Alan Ransil and Angela Belcher; MIT Koch Institute, Cambridge, Massachusetts, United States.

Here, we are expanding on the functionality of M13 bacteriophage as an engineerable biomaterial. M13 bacteriophage, a naturally monodisperse, multifunctional nanostructure, is especially well-suited for active material templating and assembly. The phage consists of thousands of distinct protein subunits organized in a high aspect ratio, filamentous viral capsid; approximately 900nm in length and 6nm in diameter. Both the major and minor coat proteins are amenable to mutation, and thus can be chemically tuned for such capabilities as programmable assembly; the binding, nucleation, and capping of inorganics and nanoparticles; chelation of metal ions; and expression of targeting ligands or even enzymes. All of these characteristics have made the M13 bacteriophage a competitive biomaterial—we have previously demonstrated its versatility in the formulation of nanofoams, aerogels, and hydrogels for novel inorganic material synthesis as well as its use as a tumor specific vehicle for the delivery of imaging agents to ovarian cancer models. Now, to further improve on the medical and material applicability of M13, we first describe the blood brain barrier (BBB) crossing of M13 with peptide display on the capsid of M13; and second, the assembly of M13 of smaller sizes, termed ‘incho’ phages.

BBB targeting optimizes for the *in vivo* trafficking properties of the phage nanoprobe and allows delivery past the BBB; functionalizing the phage as a nanotheranostic for medical imaging and therapy applications, particularly in the case of difficult to reach disease sites associated with glioblastoma and neurodegenerative illnesses. Second window near infrared (NIR-II) imaging of glioma targeted phage, complexed with single walled carbon nanotubes (SWNT) or small molecule NIR-II dyes such as IR1050, reveals localization of the phage to glioma, and opens up the possibility for phage based shuttling of high drug loads to the tumor cells and simultaneous, inexpensive NIR-II tracking of the therapy progression.

Metal nanofoams can also be synthesized using an M13 bacteriophage template. For the first time, we demonstrate that the properties of metal nanofoams can be tuned by altering the length of M13 with incho-phage of sizes ranging from 50nm to 980nm. The morphology of metallized foams made from differing incho-phage struts reveals optimal lengths and concentrations for the crosslinking of the foam material and the resulting porosity. Batteries made using these foams can vary in ion transport capability, giving us biological control over their electrochemical properties. This can be extended to catalysis and other fields where nano-structured materials could provide significant impact including filtration and desalination, tissue or antimicrobial scaffolds, electromagnetic composites, hydrogen storage, wearable energy devices, and more.

11:15 AM BM07.15.10

Silicon Nanowire and Electrospun Nanofibre Polymer Interfaces and Devices to Alter Non Excitable Brain Cell Morphology and Functionality Emanuela Saracino¹, Ana I. Borrachero-Conejo¹, Luca Maiolo¹, Davide Polese¹, Francesco Formaggio², Grazia P. Nicchia³, Maria G. Mola³, Marco Caprini², Michele Muccini¹, Luigi Ambrosio¹, Roberto Zamboni¹, Vincenzo Guarino¹, Annalisa Convertino¹, Valentina Benfenati¹ and Guglielmo Fortunato¹; ¹CNR-Consiglio Nazionale delle Ricerche, Bologna, Italy; ²FABIT, University of Bologna, Bologna, Italy; ³Bioscienze, Biotechnologie e Biofarmaceutica, University of Bari, Bari, Italy.

Nanostructured interface capable to modulate structural, molecular and functional properties of brain cells has a huge potential to improve our understanding of the central nervous system. Astrocytes, that are the majority of non neuronal brain cells, are key players in brain physiology and pathology. Nonetheless, the astrocytes/material interaction needs to be considered in engineering implants targeting the brain, as they are the first cells reacting to brain injury. Here we define and validate the use of innovative nanostructured materials interface based on gold coated silicon nanowires (Au/SiNws) and electrospun nanofibers made of biodegradable polymers such as polycaprolactone (PCL), as substrates where to culture and to study astrocytes physiology in an *in-vivo*-like morphological and functional phenotype. Nonetheless, the possibility to modulate and record astrocytes electrophysiological properties by Au/SiNws and PCL interface based device. We performed cell viability assays, fluorescent and confocal imaging, revealing that astrocytes adhere and grow on Au/SiNws and PCL nanofibers without need of additional coating. Au/SiNws mached nanowires induce morphological stellation of astrocytes and arborisation of processes. PCL nanofibers substrate topography promotes elongation of process sprouting from astrocytes cell body. Analyses of gliotic markers indicates that both substrates are not inducing inflammatory reactions. The functional properties of cells grown on Au/SiNws and PCL nanofibers were defined. Notably, Au/SiNws based device enable recording extracellular signals from astrocytes unreported previously and not recordable on Au/Si flat device.

Our results validate PCL nanofibres and Au/SiNws as novel glial interfaces that enable the growth, differentiation and recording of astrocytes *in vitro*. These glial interfaces are representing the first class of devices enabling to dialogue with non excitable brain cells.

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