Innovations in Large-Area Electronics Conference

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***Invited Speaker**

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***Invited Speaker**

SESSION 1: KEYNOTE

1.1 Stitch-by-stitch: How Innovations in LAE Enable Textiles to Transform the Way Humans Connect Across Daily Life

Tony Chahine, Myant

Myant believes that connectedness is a fundamental human need.

We rely on our ability to understand and interact with our bodies, communities, and environments in order to live better, healthier, and more productive lives. When we feel connected to our bodies, we might notice our teeth clenched in anxiety before speaking to a crowd and do some breathing exercises to calm the nerves. We notice that Dad has been a little slow getting out of bed this week and check in to make sure he isn't coming down with an illness. That is the power of connectedness.

But as much as technology has created new ways to connect people across distances, the quality of these connections pales in comparison to what we need. Myant exists to create a better connection between you and your body, your community, and your environment. We are creating a human connection platform (the Myant Platform) which leverages textiles that sense and react to the body (Skiin) and other sources of biometric data as a way to digitize your physical self, your psychological state, and your surrounding context. Through the use of AI, the Myant Platform is finding new ways to connect people to care , lower barriers of access to medical care, to predict and prevent diseases and workplace accidents, and so much more.

We are not building this future alone. This talk will explore how partners in the LAE world (technology developers, wearables manufacturers, and others) can work with Myant to unlock this new connected future and create value for all of society.

Biography

Tony Chahine, CEO of Myant Inc, is an entrepreneur with a passion for solving big problems. Based on an unwavering belief that everyone, especially the very young, the sick and the old should have the right to participate in our connected world, Chahine founded Myant, the world's first end-to-end textile computing company headquartered in Toronto, Canada.

Myant knits and integrates sensors and actuators into textile to create an ubiquitous platform for human-computer interface that, thanks to its bidirectional capabilities, enables better health and wellness through data collection, analysis and personalized responses. In creating continuous and ambient access to the human body, Myant is leading the development of Society 5.0 and creating a more harmonious union of humans and the digital world.

SESSION 2: MANUFACTURING I

2.1 Dr Simon Ogier, SmartKem Ltd

Dr Simon Ogier (FInstP), is an internationally recognized expert in the field of organic thin-film transistors. Since 2001 he has worked to develop high performance organic semiconductors for transistor applications within companies such as Avecia, Merck, CPI and more recently with NeuDrive Limited. From 2007 whilst at CPI Simon had a major role in establishing the UK's National Printable Electronics Centre (PETEC), housing a range of state-of-the-art fabrication equipment for pilot scale production of plastic electronic devices.

2.2 Dr Vincenzo Pecunia, Soochow University

Vincenzo Pecunia is an Associate Professor and Principal Investigator at the Institute of Functional Nano & Soft Materials, Soochow University, China. There he founded and now leads the Pecunia Group of Thin-Film Optoelectronics, which investigates environmentally-friendly, printable semiconductors. Prior to establishing his own group, Vincenzo worked over six years at the Optoelectronics Group of the Cavendish Laboratory, University of Cambridge, UK. Whilst there, he earned his PhD in Physics. Drawing from his research experience, Vincenzo has authored the books 'Organic Narrowband Photodetectors' and 'Organic and Amorphous-Metal-Oxide Flexible Analogue Electronics'.

2.3 Dr Matthew Dyson, IDTechEx

Dr Matthew Dyson has an MRes and PhD in Physics from Imperial College London, in which he investigated processing/structure/property relationships in organic semiconductors. This was followed by post-doctoral research at Eindhoven Technical University, investigating organic photodetectors and sub-band gap states. At IDTechEx Matthew analyses companies within the printed/flexible/organic electronics space across the globe, assesses new technologies from both a technological and commercial perspective, and identifies challenges and trends.

2.4 Dr (Sam) Yun Fu Chan, CPI

Dr. (Sam) Yun Fu Chan (PhD in Chemistry, University of Reading) is a Senior Scientist. He has over 14 years of industrial experience and has extensive expertise in Optoelectronics such as OLEDs, LECs, OTFTs, OPV and ALD Barrier Coating, as well as Laser processing and Battery. A post-doctoral researcher (University of Reading), he furthered development of novel electronically-conducting materials with potential applications as "molecular wires". As a Synthetic Inorganic Chemist for OLED-T Ltd, he designed, synthesised and characterised novel electroluminescent OLED materials. He was also a Materials Chemist at Polymetronics Ltd where he designed and optimised OLED devices used for the treatment of skin cancer.

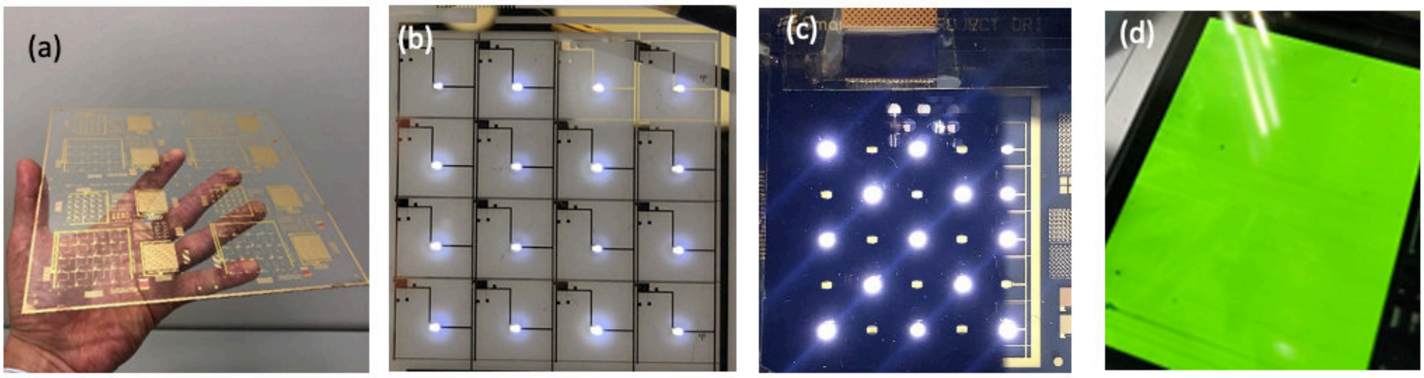
2.5 Dr Aneta Wiatrowska, XTPL

With XTPL since September 2016, as technology director Aneta is responsible for all areas involved in the process of printing with XTPL method. In 2013-2015 she participated in a prestigious post-PhD scholarship under the EU Marie Curie (LUMINET) project at the Philips Research Center in Eindhoven, where she worked primarily on the synthesis, protection and characterization of hygroscopic lutetium iodides, LuI3 doped with lanthanides and synthesis and characterization of scintillating nanoparticles and production of polyurethane based composites containing previously synthesized scintillating nanoparticles. Earlier in 2013, she honored her doctoral dissertation at the Faculty of Chemistry at the University of Wroclaw, where she worked for 4 years on new X-ray memories and was a contractor for 4 EU-funded research and development projects.

2.1 Low Temperature, Robust OTFT Technology

Dr Simon Ogier, SmartKem Ltd

SmartKem is a UK manufacturer of organic semiconductor inks that can be used to fabricate flexible, active matrix organic-TFT (OTFT) devices processed at temperatures as low as 80˚C. The organic semiconductor, organic gate insulator, passivation layer and base layer are solution coatable making them compatible with existing a-Si flat-panel display lines. Sputtering processes are used to deposit the metal conductors and all liquid inks can be slot die coated. Device performance at short channel length, L=5 μm is typically 2.5cm2/Vs enabling many applications in displays and sensors on plastic substrates. The Company has recently made a range of prototypes including active matrix driven mini-LED backlights and AMOLED display demonstrators. Increasing the gate capacitance of our OTFTs has enabled low voltage operation with turn on voltages (Vto) <2V. This in turn, allows off-the-shelf source drive ICs to be used to address the matrix and delivers low power consumption for backplane driving. High performance can also be achieved using non-precious metal electrodes commonplace in existing a-Si processes, thereby making the transition across to a plastic compatible OTFT technology easier for manufacturers. This talk will describe the design and fabrication of the devices and will provide data relating to the excellent thermal bias stress performance of the material set, making it a perfect choice for future plastic based electronic products.



(a) SmartKem OTFT mini-LED backplanes fabricated on an 8” square substrate, (b) 4x4 10mm pitch array of mini-LEDs driven by OTFT, (c) 5x5 5mm pitch array showing checkerboard pattern (d) QVGA monochrome AMOLED display

2.2 Printed Ambipolar Deep-Subthreshold TFTs for Easy-to-Fabricate Ultra-Low-Power Electronics

Dr Vincenzo Pecunia, Soochow University

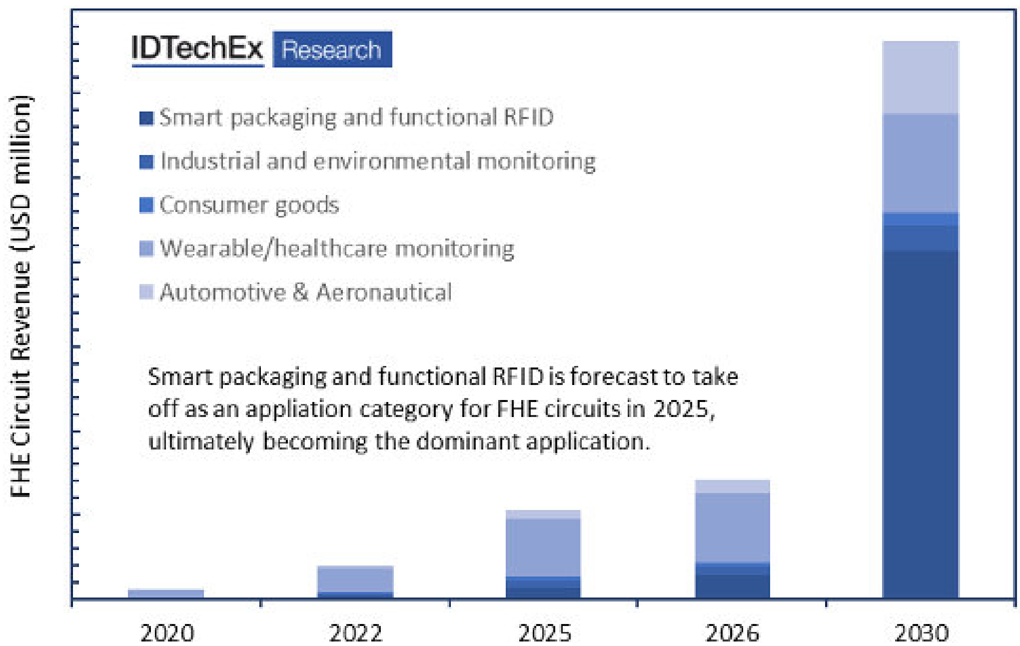
Authors: Vincenzo Pecunia, Luis Portilla, Jianwen Zhao (2_, Liping Sun (3), Fengzhu Li, Malo Robin, Zheng Cui (2), Luigi G. Occhipinti, (4) Thomas D. Anthopoulos (5)
(1) Soochow University, (2) Suzhou Institute of Nano-tech and Nano-bionics, (3) ShanghaiTech University, (4) University of Cambridge, (5) King Abdullah University of Science and Technology

Printed thin-film-transistor (TFT) electronics has formidable potential to contribute to the realisation of low-cost smart sensors nodes for the Internet of Things (IoT) device ecosystem [1-2]. Crucially, electronics with ultra-low power consumption has been recognised as key to realising the full potential of the IoT [3]. Indeed, ultra-low-power electronics could function with the limited power supplied by compact energy harvesters (e.g., mm/cm-scale solar cells, radio-frequency harvesters, compact thermoelectric modules), thereby overcoming the sustainability and feasibility challenges associated with battery-powered operation [3]. In spite of the recent progress, an outstanding challenge in printed electronics has been to develop a robust and simple approach to ultra-low-voltage (< 0.5 V) and ultra-low-power (< 1 nW per gate) circuit operation, as required for its use with compact energy harvesters. While simple [4], unipolar solutions are problematic in regard to noise immunity and robust large-scale circuit integration. On the other hand, while ensuring low static power dissipation, complementary solutions developed to date require the use of manifold materials and process steps [5], which counters the aim of developing an easy-to-fabricate and low-cost route to TFT electronics. In this talk we present our recent breakthrough in ultra-low-power and easy-to-fabricate printed electronics [6]. Our platform relies on the newly-established concept of deep-subthreshold ambipolar TFT electronics, which involves the use of TFTs with balanced ambipolar characteristics in the deep-subthreshold region. We implemented this concept with high-performance ambipolar TFTs comprising printed semiconducting carbon nanotubes and hybrid nanodielectrics. By fine-tuning their flatband voltage in the 0.1 V range through the application of a self-assembled monolayer at the active interface, we engineered their characteristics to deliver state-of-the-art mobilities and symmetric subthreshold slopes for both electron and hole conduction. To demonstrate the viability of a deep-subthreshold ambipolar route to printed TFT electronics, we integrated the TFTs into digital logic gates in CMOS fashion. These circuits exhibited complementary-like characteristics with large gains and ample noise margins while operating at record-low levels of supply voltage—in the 0.2–0.5 V range—and power consumption—down to the picowatt range per gate. Crucially, such circuits were realised with only one semiconductor and one single source-drain metal, thereby illustrating the strength of the deep-subthreshold ambipolar concept to deliver electronics that is also easy to fabricate. By allowing the facile realisation of complementary-like and ultra-low-power circuits, our deep-subthreshold ambipolar platform enables electronics that can meet the power dissipation requirements for battery-less smart sensors for the ongoing IoT revolution.

2.3 Trends in Emerging Manufacturing Methods for Flexible Hybrid Electronics

Dr Matthew Dyson, IDTechEx

A substantial challenge in commercializing large area and/or flexible electronics is developing reliable, cost effective and high throughput manufacturing methods. To date much focus has been devoted to roll-to-roll (R2R) printing, but its increasingly recognised that many applications of large area and flexible electronics will require both printed and placed functionality. This emerging approach is known as Flexible Hybrid Electronics (FHE). It represents a compromise that combines the attributes of printed electronics, including flexibility, light weight and compatibility with continuous and even digital manufacturing methods, with the superior functionality of conventional placed components. FHE can be concisely expressed with the phrase 'print what you can, place what you can't'. Figure 1 below shows a 10-year market forecast for FHE, demonstrating that wearable technology is the most promising market in the short to medium term due to its compatibility with higher value products and high-mix low-volume manufacturing. However, in the longer term the greatest market for FHE will likely come from smart packaging. However, for FHE to be employed in low-cost and/or large area electronics that will facilitate high volume applications such as smart packaging and functional RFID, innovation in manufacturing approaches is required, especially with regard to component placement. Here, we will review the emerging manufacturing techniques for large area electronics, emphasising their technological and commercial readiness levels, advantages/disadvantages, the applications to which they are best suited, and forecasts for adoption. These emerging technologies include various methods of direct component transfer that can replace pick-and-place, laser induced forward transfer (LIFT), field-aligned anisotropic conductive adhesives/films, and patterning via laser ablation. In summary, we will illustrate the potential for FHE across a wide range of applications, and outline what we believe to be the trends in emerging manufacturing methods required to facilitate its widespread adoption. [1] Dyson MJ, Ghaffarzadeh K. 2020. Flexible Hybrid Electronics: 2020-2030. IDTechEx, UK Figure 1: Market forecast (by revenue) for the adoption of FHE for various applications. These forecasts are based on a granular analysis of over 20 sub-categories, the benefits offered by FHE in each category, and price forecasts for application specific components and assembly method.



2.4 Ultrafast Laser Microwelding of Optoelectronic Device Built on Ultra-Thin Flexible Glass (UltraWELD Project)

Dr (Sam) Yun Fu Chan, CPI

The rapid development of organic light-emitting devices (OLEDs) in recent years makes them increasingly competitive in flat-panel display and solid-state lighting applications [1]. In particular, the flexibility of the OLEDs becomes a very attractive feature and has potential applications in flexible devices. But their very high sensitivity to moisture and oxygen means that they require appropriate encapsulation to prevent lifetime issues. The use of interlayer (e.g. a polymer) to seal around the encapsulated device remains the root cause in hermeticity problems. Ultra-thin flexible glass is a good candidate of encapsulation material, combining exceptional hermeticity with high transparency and the ability to conform to a curved surface. Alternative option such as direct welding of the flexible glass package is thus an attractive option, and this has been demonstrated that it is possible using an ultrafast (picosecond pulsed) laser [2]. This process relies on the very high peak intensity from a laser beam that is tightly focused through the top sheet of glass to provide a focal spot in the vicinity of the glass-glass interface. Non-linear absorption results in the generation of free electrons in a highly localised focal volume, leading to plasma formation. CPI have been working with partners including Herriot Watt University (HWU) in the Innovate UK UltraWELD project to develop a new approach to encapsulate ultra-thin flexible glass OLEDs (FOLEDs) using an ultrashort pulsed IR laser with a short pulse duration. In this paper we summarise the novel process for manufacture FOLEDs and a new low temperature plasma Atomic Layer Deposition (ALD) Aluminium oxide (AlOx) barrier thin film for direct encapsulation as a barrier film to protect moisture and water degradation at CPI. And combining the two processes of ALD coating on the flexible OLEDs with an interlayer-free ultrafast laser microwelding of two 100 µm thick flexible OLED substrates (one as cover glass) using a Trumpf picosecond laser system at HWU (5.9 ps, 400 kHz at 1030 nm) with a specific laser welding pattern to produce a working laser welded FOLED demonstrator.

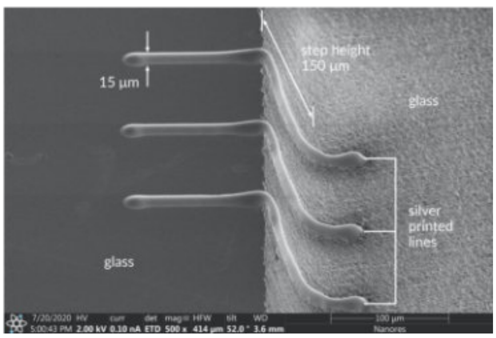
References [1] S. Reineke, F. Lindner, G. Schwartz, N. Seidler, K. Walzer, B. Lussem, K. Leo, White organic light-emitting diodes with fluorescent tube efficiency, Nature 459 (2009) 234–238 [2] J. Chen, R.M. Carter, R.R. Thomson, and D. P. Hand (2015), Avoiding the requirement for pre-existing optical contact during picosecond laser glass-to-glass welding, Optics Express 23, 18645-18657 Acknowledgement – The authors We acknowledge financial support from Innovate UK under grant No. 103763, UltraWELD and continuing technical support from Leonardo UK

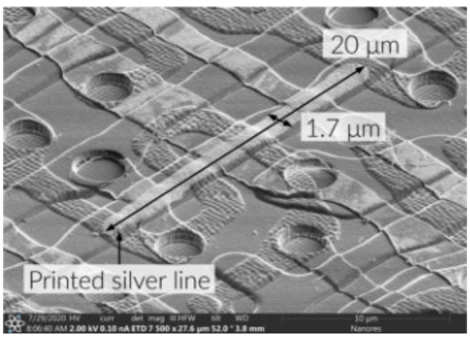
2.5 High-Resolution Printing of Micrometer-Size Conductive Structures for Large-Area Electronics

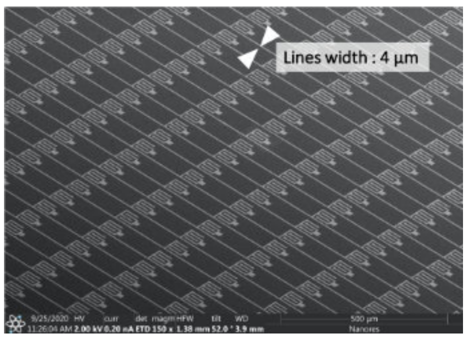
Dr Aneta Wiatrowska, XTPL

Authors: Aneta Wiatrowska (1), Karolina Fiączyk (1), Łukasz (1), Jolanta Gadzalińska (1), Mateusz Łysień (1), Ludovic Schneider (1), Filip Granek (1)
(1) XTPL

Today's large-area electronics (LAE) require technologies that offer high throughput, reliability, precision, and low cost at the same time. Additive manufacturing gives means to address these seemingly contradictory challenges. In this contribution we will introduce an ultra-precise deposition (UPD) technology to print micrometric conductive structures on a wide variety of complex substrates. We will demonstrate how UPD can tackle current challenges in LAE: integration in flexible hybrid electronics, lean manufacturing, reliability of LAE systems, as well as ongoing miniaturization of semiconductor components and devices. During the UPD process, highly-concentrated silver or copper ink (even 85% wt. of metal content) is directly deposited on the substrate. We are able to extrude such a highly concentrated ink through a nozzle with the diameter in the range from 0.5 to 10 µm. This results in the printed feature size from 1 to 10 µm. Such combination of high-viscosity inks (10'000 to 1'000'000 cP) and fine printed features defines a unique operating range for the UPD technology and allows to make arbitrarily-shaped interconnectors on challenging substrates. In Figure 1 we show a set of continuous silver lines with the width of 15 µm, printed on the steep vertical step with the height of 150 µm. Therefore, the step is ten times higher compared to the line width. Since lines can be printed on steps much higher than the line width, such interconnectors are a robust alternative for standard wire bonding techniques and can be used, among others, in microLED arrays. Therefore, UPD paves the way for making highly conductive and mechanically robust metallization schemes in LAE systems. Hybrid substrates consist of materials with very different wetting properties (contact angles), including metals, semiconductors, insulators, and their junctions. Despite different contact angles, structures printed on such substrates are uniform, cover junctions without discontinuities, and without excessive wetting at the borders of different materials. This is mainly due to the high-viscosity of the deposited inks. As a result, we obtain uniform printing behaviour on complex substrate topographies. A good example of such substrate with micrometer scale topography is a transistor array of a modern OLED display. In Figure 2 we show a continuous silver line with a width of 1.7 µm and length of 20 µm printed on an OLED substrate. This also demonstrates how precisely the printing nozzle can be positioned in all three dimensions during the process. Finally, proper sintering (thermal or laser) ensures a full adhesion and structure stability. In Figure 3 we demonstrate the capabilities of the UPD technology for mass production. The figure shows 7500 printed segments for transistors with the line width of 4 µm. The key feature of UPD in this case is not only the line width, but also the ability to reduce the interline distance to single micrometers. Moreover, the shape to be printed can be defined arbitrarily, which supports lean manufacturing.







SESSION 3: BIOELECTRONICS

3.1 Prof Dr-Ing Thomas Stieglitz, University of Freiburg IMTEK

Thomas Stieglitz received a Diploma in electrical Engineering from Technische Hochschule Karlsruhe, and a PhD and the habilitation degree from the University of Saarland. In 1993, he joined the Fraunhofer Institute for Biomedical Engineering, where he established the Neural Prosthetics Group. Since 2004, he is a full professor for Biomedical Microtechnology at the Albert-Ludwig-University Freiburg, in the Department of Microsystems Engineering (IMTEK), Dr Stieglitz is co-founder and scientific consultant of CorTec GmbH and neuroloop GmbH, two spin-off companies which focus on neural implant technology and neuromodulation, respectively. Dr. Stieglitz is member of the IEEE EMBS German Biomedical Engineering Society where he is chair of the Neural Prostheses and Intelligent Implants section and founding member of the International Functional Electrical Stimulation Society (IFESS).

3.2 Dr Stuart Higgins, Imperial College London

Dr Stuart Higgins is a Research Associate within the group of Professor Molly Stevens. He has a background in organic electronics, previously researching complementary circuits and organic rectifiers at both Imperial College and the University of Cambridge. In recent years he has explored the fundamentals of cell – biomaterial interactions within the Stevens Group, and is currently holds a Cancer Research UK Early Detection Award to explore the application of organic bioelectronic devices to the early detection of cancer.

3.3 Dr Gemma Bale, University of Cambridge

Dr Gemma Bale is the Gianna Angelopoulos Lecturer in Medical Therapeutics. Her work focuses on developing new, non-invasive brain monitoring techniques for the measurement of cerebral oxygenation and metabolism in areas where traditional brain monitoring isn't possible. Gemma studied Physics (BSc) at Imperial College London where she became interested in using optics for medical applications. To pursue this, she undertook a Masters in Photonics Systems Development at UCL and the University of Cambridge, and discovered near-infrared spectroscopy (NIRS) – a non-invasive technique that can monitor the brain.

3.4 Alessandra Lo Fiego, Imperial College London

Alessandra is a PhD student in Professor Molly Stevens' group. Her research focuses on the development of new material platforms for bioelectronic medicine applications.

3.5 Dr Roozbeh Ghaffari, MC10/Epicore Biosystems

Dr. Roozbeh Ghaffari obtained his BS and MEng degrees in electrical engineering from the Massachusetts Institute of Technology in 2001 and 2003. He received his PhD degree in biomedical engineering from the Harvard Medical School-MIT Program in 2008. Dr. Ghaffari co-founded and served as CTO at MC10 Inc (acquired by Medidata Inc). Hecontributions in soft bioelectronics, micro/nano-scale systems, and auditory neuroscience research have been recognized with a number of awards. Dr Ghaffari joined the Center for Bio-integrated Electronics at Northwestern University in 2017, where he serves as Associate Professor in the Dept. of Biomedical Engineering, and is Director of Translational Research at the Querrey-Simpson Institute for Bioelectronics. He is also co-founder and CEO of Epicore Biosystems, Inc., developing a proprietary wearable microfluidic sensing platform.

SESSION 3: BIOELECTRONICS

3.1 Flexible Bioelectronics – Microimplants for Neuroprosthetic and Bioelectronic Medicine Applications

Prof Dr-Ing Thomas Stieglitz, University of Freiburg IMTEK

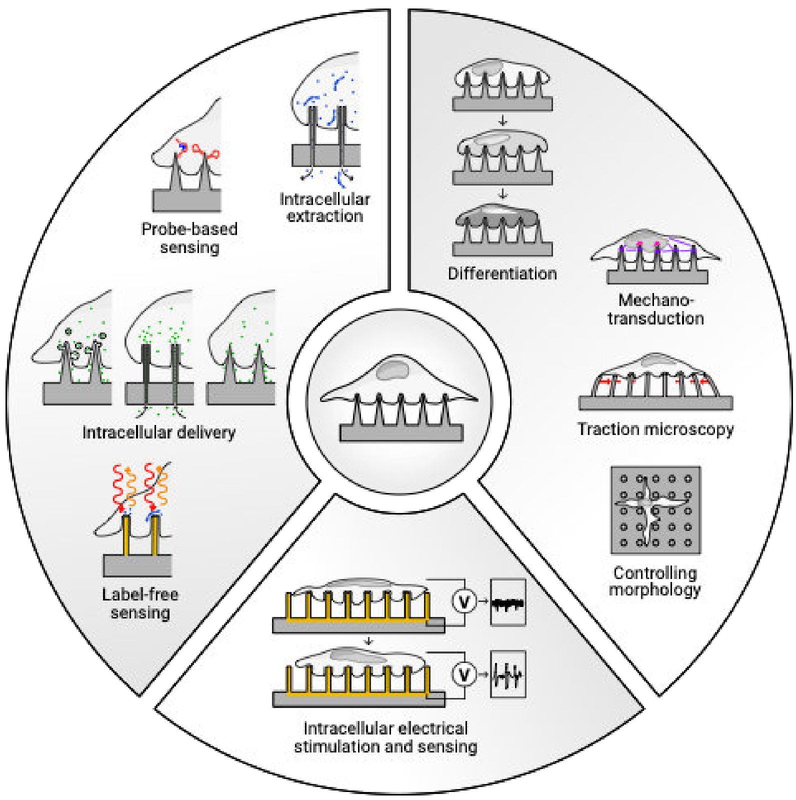
Bioelectronic devices cover the wet interface between electronic and biological circuits and systems. They need to establish stable and reliable functional interfaces to the target structure in chronic application in neuroscientific experiments but especially in clinical applications in humans. Proper selection of substrate, insulation and electrode materials is of utmost importance to bring the interface in close contact with the neural target structures, minimize foreign body reaction after implantation and maintain functionality over the complete implantation period. Our work has focused on polymer substrates with integrated thin-film metallization as core of our flexible neural interfaces approach and silicone rubber with metal sheets. Micromachining and laser structuring are the main technologies for electrode array manufacturing. Different design and development aspects from the first idea to first-in-human studies are presented and discussed. Reliability data from long-term ageing studies and chronic experiments show the applicability of thin-film implants for stimulation and recording and ceramic packages for electronics protection. Examples of sensory feedback after amputation trauma, vagal nerve stimulation to treat hypertension and chronic recordings from the brain surface display opportunities and challenges of these miniaturized implants. System assembly and interfacing microsystems to robust cables and connectors still is a major challenge in translational research and transition of research results into medical products.

3.2 Insights for Bioelectronics from High-Aspect-Ratio Nanostructured Cell – Biomaterial Interfaces

Dr Stuart Higgins, Imperial College London

Authors: Stuart G. Higgins (1), Molly Stevens (1)
(1) Imperial College London

In the past few years, the large-area electronics community has increasingly focused on bioelectronics. Highly conjugated polymers have been used to create new organic bioelectronic devices for interfacing with the human body.[1] These systems nominally provide a wide range of advantages: mixed-mode electronic and ionic conductivity, desirable and tailorable mechanical properties. However, many interfaces are predominantly planar, in part due to the inherited legacy of organic electronic fabrication methods. In our research, we study the impact of nanotopography on cellular interfaces.[2,3] We do this using a class of nanostructures called nanoneedles. The surfaces of silicon substrates are patterned with conical, 3 – 6 μm tall needles, with tips less than 50 nm in diameter (Figure 1). They provide an ideal system for studying extreme cell – biomaterial interactions. High-aspect-ratio nanostructures have a variety of desirable physical and biological properties. They vastly increase the interfacing area available, but beyond this they can directly stimulate the complex cytoskeletal machinery of cells, changing cellular morphology and gene expression.[4] They have been combined with conductive surfaces and, more recently, with conjugated polymers to create new bioelectronic interfaces. Here, we will discuss our latest findings in the interaction of cells and biomaterials, placing our findings in the context of developing future three-dimensional bioelectronic interfaces. We will identify the key considerations and opportunities for these systems. [1] S. G. Higgins, A. L. Fiego, I. Patrick, A. Creamer, M. M. Stevens, Adv. Mater. Technol. 2020, 2000384. [2] A. Belessiotis-Richards, S. G. Higgins, B. Butterworth, M. M. Stevens, A. Alexander-Katz, Nano Lett. 2019, 19, 4770. [3] H. Seong, S. G. Higgins, J. Penders, J. P. K. Armstrong, S. W. Crowder, A. C. Moore, J. E. Sero, M. Becce, M. M. Stevens, ACS Nano 2020, 14, 5371. [4] S. G. Higgins, M. Becce, A. Belessiotis-Richards, H. Seong, J. E. Sero, M. M. Stevens, Adv. Mater. 2020, 32, 1903862.



3.3 Developing Novel Optical Techniques to Monitor the Brain Metabolism in Newborn Brain Injury

Dr Gemma Bale, University of Cambridge

Perinatal injury to the developing brain is a significant cause of neonatal morbidity and mortality. The pathophysiology of hypoxia-ischaemic encephalopathy (HIE) is complex and the current understanding and therapeutic interventions are based on the findings of cerebral metabolic changes and neural recovery following injury.

Early cot side markers of neuronal injury that correlate with disease severity would likely facilitate a more targeted therapeutic approach. There is an urgent clinical need to detect those neonates at most risk, who may benefit from redirection of clinical care and/or adjunct therapies. Early detection and assessment of brain neurological status requires sensitive, robust and easy to measure cot side biomarkers.

Continuous wave near-infrared spectroscopy (NIRS) yields measures of cerebral haemodynamics (oxy- and deoxy-haemoglobin: HbO2 and HHb) and tissue oxygenation. Using broadband NIRS (bNIRS) it is possible to additionally report changes in mitochondrial redox state during oxidative metabolism through cytochrome-c-oxidase (oxCCO), which is the terminal electron acceptor in the electron transport chain, and thus can provide a direct marker of tissue oxidative metabolism.

A novel bNIRS instrument (8 channels, 770-906nm) was developed specifically for neonatal monitoring of brain tissue oxCCO. To date, we have monitored 84 neonates with HIE or another form of acute brain injury from the first day of life.

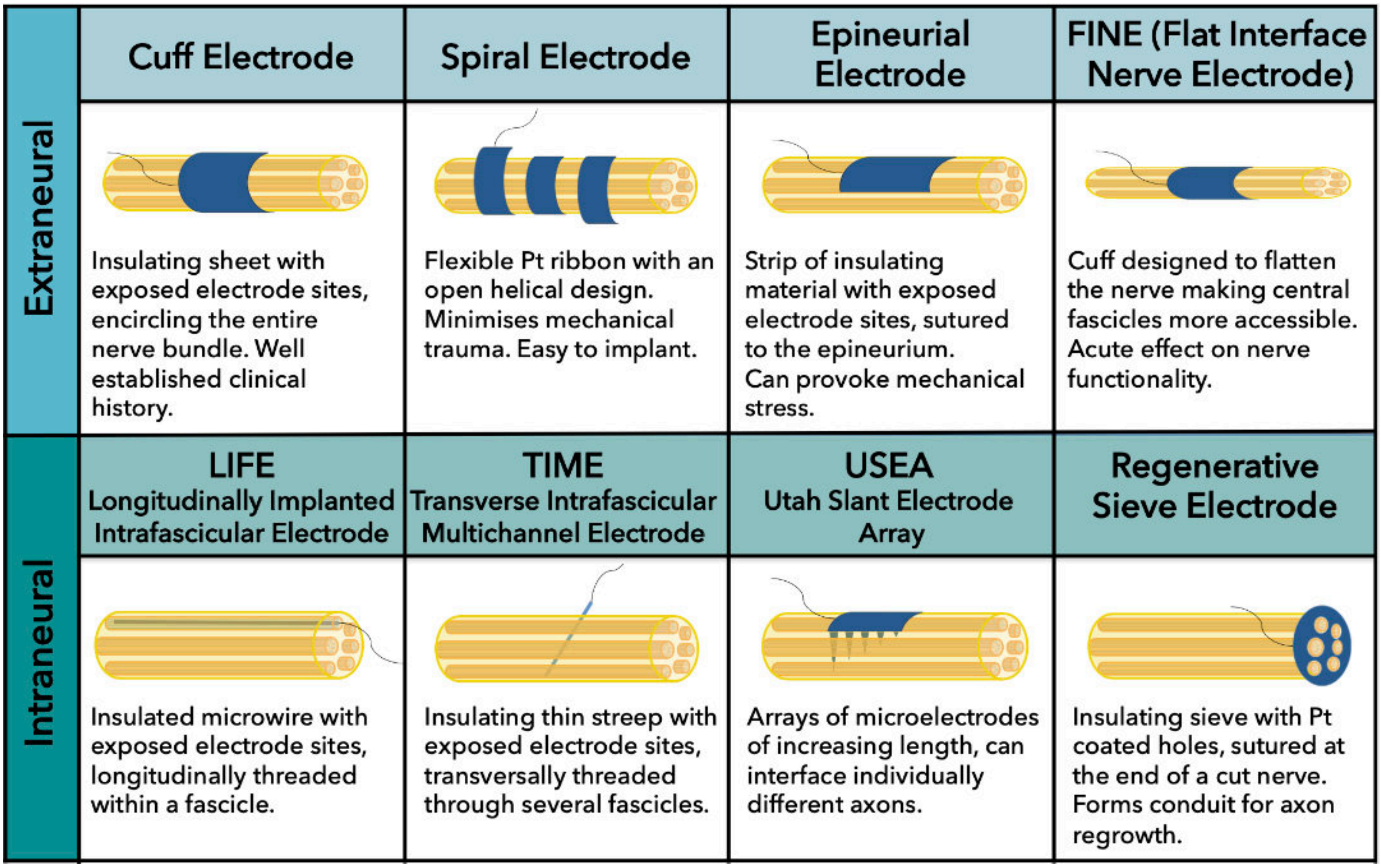
Our results have demonstrated (i) that relationship of brain oxygenation and oxCCO during spontaneous desaturation events can be indicative of the severity of the brain injury; (ii) the association between the brain tissue oxCCO and blood pressure fluctuations is highly correlated in infants with severe HIE; and (iii) the relationship between brain oxygenation and oxCCO during rewarming after therapeutic hypothermia was dependent on the severity of injury. In addition, we have demonstrated that the continuous metabolic measurement of oxCCO can provide unique information regarding brain health during neonatal seizures.

3.4 Developing New Conjugated Polymers for Bioelectronic Medicine

Alessandra Lo Fiego, Imperial College London

Authors: Alessandra Lo Fiego (1), Adam Creamer (1), Luke Salter (1), James Foote (1), Stuart G. Higgins (1), Molly Stevens (1)
(1) Imperial College London

Bioelectronic medicine, based on the electrical modulation of nerve activity to affect pathophysiological functions, holds the promise of alternative treatment for chronic conditions that until now have been poorly tractable. Towards this goal, broader and longer-term animal studies are required. At present, these studies are limited by the high cost and poor reliability of the available Peripheral Nerve Interfacing (PNI) technologies.1 The development of next generation PNIs will be driven by the development of more biologically compliant materials. In particular, organic conjugated polymers (CPs) are ideal candidates for the electrical interfacing of biological systems,2 and ideally be compatible with bio-specific interfaces such as high-aspect-ratio nanostructures.3 While PEDOT:PSS is considered the gold standard conducting polymer in both organic electronics and for biomedical applications, it has numerous practical downsides. Here we report on the development of soluble and functionalisable analogues of PEDOT for implantable electrodes for biomedical applications.



3.5 Soft, Skin-Interfaced Systems with Physiology and Biochemical Sensing Capabilities

Dr Roozbeh Ghaffari, MC10/Epicore Biosystems

Unusual classes of electronics and microfluidics enabled by recent advances in materials science and mechanics can be designed with physical properties that approach the mechanical properties of human skin. These systems are referred to as epidermal electronics and epifluidics by virtue of their stretchable form factors and soft mechanics compared to conventional packaged electronics and sensors. In this talk, I present an overview of recent advances in novel materials, mechanics, and designs for emerging classes of fully-integrated epidermal electronics and soft microfluidic systems. These devices incorporate microfabricated arrays of sensors, microfluidic channels and biochemical assays, configured in ultrathin, stretchable formats for continuous monitoring of kinematics, cardiac, mechano-acoustic, neuromuscular, and electro-chemical signals. Quantitative analyses of strain distributions and circuit performances under mechanical stress highlight the utility of these wearable systems in the clinical and home environments. I will conclude with representative examples of these epidermal devices, which began as feasibility projects in research publications a few years ago, and have now entered the commercialization phase with leading industrial partners.

SESSION 4: PANEL DISCUSSION

4.1 Panel Discussion: Translation of Bioelectronic Devices into the Clinic

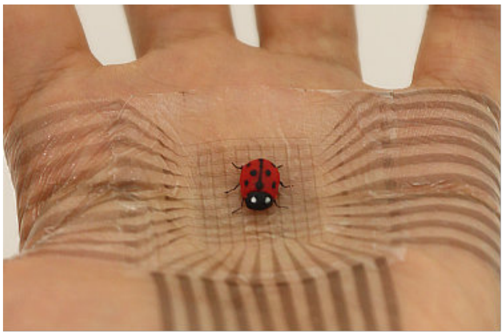
Chaired by Dr Alison Burdett, Sensium Healthcare

SESSION 5.2: KEYNOTE

5.2 Skin-inspired Electronics & Sensors

Prof Zhenan Bao, Stanford University

Skin is the body's largest organ, and is responsible for the transduction of a vast amount of information. This conformable, stretchable, self-healable and biodegradable material simultaneously collects signals from external stimuli that translate into information such as pressure, pain, and temperature. The development of electronic materials, inspired by the complexity of this organ is a tremendous, unrealized materials challenge. However, the advent of organic-based electronic materials may offer a potential solution to this longstanding problem. Over the past decade, we have developed materials design concepts to add skin-like functions to organic electronic materials without compromising their electronic properties. These new materials and new devices enabled arrange of new applications in medical devices, robotics and wearable electronics. In this talk, I will discuss several projects related to engineering conductive materials and developing fabrication methods to allow electronics with effective electrical interfaces with biological systems, through tuning their electrical as well as mechanical properties. The end result is a soft electrical interface that has both low interfacial impedance as well as match mechanical properties with biological tissue. Several new concepts, such as "morphing electronics" and "genetically targeted chemical assembly - GTCA" will be presented.



Biography

Zhenan Bao is Department Chair and K.K. Lee Professor of Chemical Engineering, and by courtesy, a Professor of Chemistry and a Professor of Material Science and Engineering at Stanford University. Bao founded the Stanford Wearable Electronics Initiate (eWEAR) in 2016 and serves as the faculty director. Prior to joining Stanford in 2004, she was a Distinguished Member of Technical Staff in Bell Labs, Lucent Technologies from 1995-2004. She received her PhD in Chemistry from the University of Chicago in 1995. She has over 500 refereed publications and over 65 US patents with a Google Scholar H-Index >160. Bao is a member of the National Academy of Engineering and the National Academy of Inventors. She is a Fellow of MRS, ACS, AAAS, SPIE, ACS PMSE and ACS POLY. Bao was selected in Nature's 'Ten people who mattered' in 2015 as a 'Master of Materials' for her work on artificial electronic skin. She was awarded the inaugural ACS Central Science Disruptor and Innovator Prize in 2020, the Gibbs Medal by the Chicago session of ACS in 2020, the Wilhelm Exner Medal by Austrian Federal Minister of Science 2018,ACS Award on Applied Polymer Science 2017, the L'Oréal-UNESCO For Women in Science Award in the Physical Sciences 2017, the AICHE Andreas Acrivos Award for Professional Progress in Chemical Engineering in 2014, ACS Carl Marvel Creative Polymer Chemistry Award in 2013, ACS Cope Scholar Award in 2011, the Royal Society of Chemistry Beilby Medal and Prize in 2009, and the IUPAC Creativity in Applied Polymer Science Prize in 2008. Bao is a co-founder and on the Board of Directors for C3 Nano and PyrAmes, both silicon-valley venture-funded start-ups. She serves as an advising Partner for Fusion Venture Capital.

SESSION 6: MANUFACTURING II

6.1 John Tingay, Paragraf
John has led the development of capital equipment for the semiconductor and electronics industries for over two decades across wide-ranging technology areas from front end to packaging applications. In these positions John has been responsible for bringing novel technologies and processes to the industry and supporting the introduction of products by top tier consumer electronics companies. John has held Non-Executive positions in high technology companies in semiconductor and advanced imaging markets with experience of the business and technology acquisition process from a multinational corporate viewpoint.

6.2 Tanay Topac, Stanford University
Tanay Topac is a PhD Candidate in the Structures and Composites Laboratory at Stanford University working on development of bio-inspired multi-sensory systems. With a main focus on UAV wings, his research goal is to build sensor networks that bring nervous system-level situational awareness to human-made systems. In addition to his research on statistical and numerical modeling for design of application-specific multi-sensory devices, Tanay also develops AI-based models for high-level state estimation of complex physical systems.

6.3 Ziam Ghaznavi, Emerson & Renwick
I focus on the development of precision high-throughput nanomanufacturing systems and processes for next generation flexible optoelectronic, energy, and microelectronic applications. My expertise coincide with novel Roll-to-Roll manufacturing including atmospheric and vacuum technologies. I received my BS in Mechanical Engineering from Texas A&M University in College Station and MS in Mechanical Engineering the University of Texas at Austin where I am also currently pursuing my PhD.

6.4 Jiajie Yang, University of Cambridge
Jiajie Yang is currently a research student at University of Cambridge, reading for his PhD degree in electrical engineering. He has a background in both mechanical and electrical engineering where he holds a bachelor's degree and a master's degree in the respective areas. He is actively exploring innovative manufacturing technologies for e-textile and active matrix display.

6.5 Dr Sarah Karmel, Photocentric
Dr Sarah Karmel is currently Head of the Chemistry Department at Photocentric Limited, where she looks after the development of novel photopolymer materials for 3D printing applications. Sarah is leading also our research on 3d printed batteries, in which she and the team focus on designing and manufacturing electrodes and battery cells with improved electrochemical performance using 3d printing.

6.1 Adoption of Graphene as an Electronic Material

John Tingay, Paragraf

The properties of Graphene as an electronics material are well documented and devices have been demonstrated in low numbers in the laboratory that exploit these attributes. As presented at this conference last year the methods available to that point had limitations that prevented the full capabilities for graphene being shown in the final devices. The problems of contamination, damage and throughput from transfer methods and deposition on metal catalysts all limited the paths to commercial exploitation.

Paragraf has been enabling the transition to the adoption of graphene by the use of a method to grow graphene directly onto semiconductor substrates, eliminating the problems and providing a manufacturing method that works within the existing semiconductor landscape. The subsequent research and commercialisation of sensors and semiconductor devices requires many more processes to be developed.

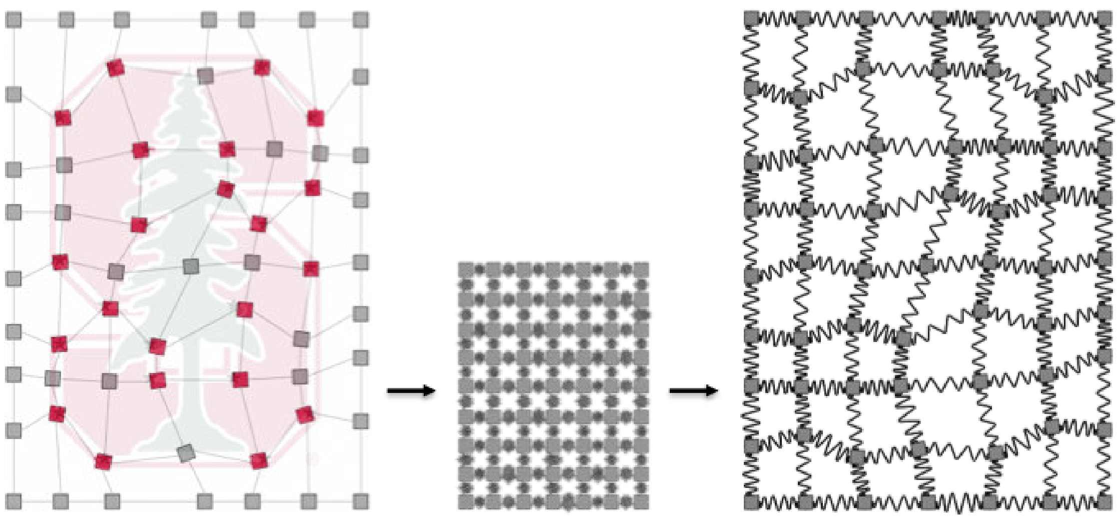
In this talk the challenges of making real devices at volume from graphene will be discussed, the effects on device performance, the supply chain and infrastructure needed to enable graphene as a realistic production material and how existing semiconductor processes work with graphene. It will look at the some of the feedback and learning from the production of sensors and look at some of the more complex structures that are being examined for solid state devices.

6.2 Inverse Design Technique for Precision Deployment of Large-Scale Stretchable Sensor Networks

Tanay Topac, Stanford University

Authors: Tanay Topac (1), Xiyuan Chen (1), Fu-Kuo Chang (1)
(1) Stanford University

Stretchable electronic devices are being employed in growing range of applications. Of particular interest to the current study, island-bridge layout devices incorporate electronics with varying functionalities into singular, compact, and lightweight forms. Bridges that join functional islands are generally designed as serpentine patterns and enable significant device size increase upon stretching, while not varying the characteristics of sensors or signals. Although a wide application variety of such devices exist in the smaller size spectrum, their large area applications remain sparse. The main reason of this sparsity is considered to be the exponential increase in fabrication cost with growing device size. That being stated, structural health monitoring and system state estimation applications usually exist in large scales and benefit from instrumentation of compact distributed sensing systems in which sensors are positioned at task-critical locations. Motivated by these competing limitation and aspiration, we present an island-bridge layout design technique that paves the way for building stretchable devices with maximal target location coverage. As with the limited fabrication size, our design goal is to attain the smallest possible fabrication-scale footprint given prescribed island positions on the target application. In the core of our methodology lies interrelated global-level device and local-level serpentine modeling schemes that make non-uniform devices possible. In global level, stretching of the full device is simulated across varying bridge configurations via a reduced-order surrogate finite element analysis (FEA) model. Each completed simulation is coupled with a model-based constrained nonlinear optimizer to iteratively modify the bridge properties, leading to a configuration that yield desired island placement. The local model on the other hand characterizes the stretching behavior of serpentines with changing design parameters to enable generating detailed designs from converged surrogate properties. Design inversion in this task is achieved through solving a secondary minimization problem via mixed-integer nonlinear programming technique. Our methodology is customizable and flexible to allow for varying serpentine patterns, device sizes, and micro-fabrication constraints. Its working principles and functionality are demonstrated by means of designing a "S" shaped large area electronic device consisting of 63 islands. Validation of spatial accuracy of island locations has been performed both numerically and experimentally through simulation of detailed device assembly and stretching a full-size MEMS/CMOS fabricated device, respectively. Close correlation is achieved in both cases, proclaiming the robustness of the technique developed.



6.3 Roll-to-Roll Reactive Ion Etching Nanoscale Features in Si for Next Generation Flexible Electronics

Ziam Ghaznavi, Emerson & Renwick

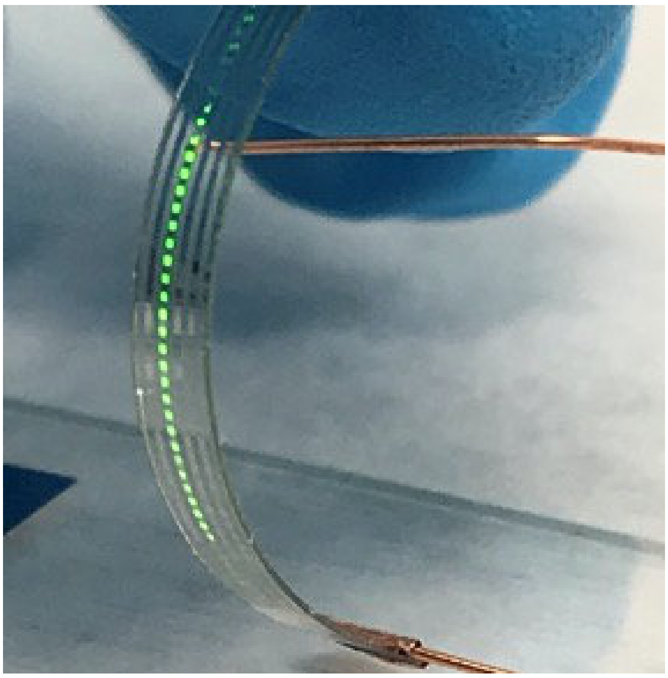
Roll-to-Roll (R2R) processing has garnered significant research interest from industry in recent years due to its potential ability to simultaneously address throughput and cost requirements for next generation flexible electronics and the Internet of Things (IoT). However, a complete ecosystem of R2R tools including patterning, deposition, and etch is needed in order to facilitate the transition of device fabrication from wafer-scale to the continuous regime. Many prospective applications also require nanoscale control and repeatability for yield management which necessitates thorough characterization of each process step and an in-depth understanding of the underlying physics of these R2R tools compared to their wafer-scale counterparts particularly during pattern transfer i.e. etching. This work demonstrates progress towards process development and control on an exemplary semiconductor device fabrication scheme utilizing Emerson & Renwick's Genesis R2R platform. Specifically, we successfully demonstrate etching nanoimprinted patterns of nanopillars into Si in a continuous R2R fashion with submicron resolution. Process verification details include quantifying etch niformity, directionality and material selectivity at varying web speeds. Furthermore, we discuss the systematic characterization of the constituent processes and equipment by intelligent Design of Experiment (DOE) allowing for process parameter tuning to meet desired etch targets.

6.4 Transfer Printed Full Colour Flexible Quantum Dot Light-emitting Diode for Large Area Lighting

Jiajie Yang, University of Cambridge

Authors: Jiajie Yang (1), Sang Yun Bang (1)
(1) University of Cambridge

Quantum-dot light-emitting diodes (QLEDs) have unique assets for optoelectronics properties such as a sharp emission bandwidth, wide colour tunability and high luminescence efficiency1, those properties make it an excellent candidate for the next-generation display applications2. The method of colloidal QD (cQD) synthesis is undergoing the solution phase, the fabrication of QLEDs have advantages of compatibility with solution processing. The ease of deposition during the fabrication process means a cost saving comparing to convectional solid-state LED fabrication process, where expensive vacuum depositions are required. In addition, with direct deposition techniques, for example inkjet printing, QDs thin film could be deposited in a predefined pattern without lithography, removing the risk of making contact with chemicals which could adversely affect the property of QD; however, inkjet printing suffers from extra steps of ink formulization, which introduces undesired chemical reaction by controlling the viscosity of ink for designated inkjet printer. On the other hand, simple and novel transfer printing technique has high throughput capability and enable to reproduce the pattern with a high fidelity because of the 'dry' process nature of transfer printing where QD layers transferred from individual donor substrate to targeted substrate with elastomer stamps.2 Moreover, Those advantages over the aforementioned technique manifest its huge potential for patterning large area full-colours red-green-blue (RGB) display or lighting by using 'pick and place' method. In this research, QLEDs are fabricated on a flexible substrate using transfer printing technique. Moreover, these flexible QLEDs are cut into long strips and then weaved in a textile using traditional manual loom. The result is a fully rollable and foldable RGB QLED e-textile which can be used for large area smart lighting purpose.



6.5 Visible Light 3D Printing of Batteries

Dr Sarah Karmel, Photocentric

At Photocentric, we have innovated in photopolymer chemistry since 2002 by developing new, more active formulations. In the last 5 years, we have focused our efforts on inventing a new, low-energy method for 3D printing using the visible light emitted by LCD screens to selectively cure photopolymer. One of our main research projects focuses on the green manufacturing of battery cells by 3d printing. Currently, battery cells are manufactured using a conventional multi-step casting process, involving a large amount of materials waste and hazardous solvents such as NMP- all of which can be removed by 3D printing. Furthermore, the performance of batteries is determined by geometrical factors and the porosity of the electrodes which is limited by their fabrication methods. By using 3D printing, we can design the battery electrode, controlling micro and macro porosity to enhance the electrochemical performance, resulting for example in a higher energy density and therefore longer range. In addition, we have an accurate control over the geometry of the battery through 3D printing software, making a battery in the size and shape required for the respective application. In this talk, I would like to walk you through the fabrication process of battries via 3d printinf, from the design of all components, the formulation of suitable materials, a suitable 3d printer onto the performance of the 3d printed parts and all the challenges along the way.

SESSION 7: SUSTAINABILITY

7.1 Dr Maria Smolander, VTT

Dr. Maria Smolander is a research team leader of the "Flexible sensors and devices" research team. Her expertise areas include e.g. development and testing of printed indicator and sensor concepts as well as printable power sources. Maria gained her PhD from the Helsinki University of Technology in 1995. She is a certified IPMA-C Project manager and has been involved as project manager or WP leader in several EU and national projects dealing with functional solutions and power sources for different applications. Currently she acts as the member of the Executive Board and Work Package leader of Flexible Electronics in Graphene Flagship.

7.2 Dr Rosa Cuéllar Franca, University of Manchester

Dr Rosa M. Cuéllar-Franca is a Lecturer in the Department of Chemical Engineering and Analytical Science at The University of Manchester. Prior to her appointment, she held a postdoctoral research position at the same institution for 2.5 years, working on the EPSRC funded programme grant "A coordinated comprehensive approach to carbon capture and utilisation". She received her PhD in Sustainable Chemical Engineering from The University of Manchester in 2013. Her research focuses on the sustainability assessment of novel products and processes on a life cycle basis, to identify areas of improvement and optimum trade-offs between impacts.

7.3 Rob Hornby, National Physical Laboratory

Rob is a Research Scientist at the National Physical Laboratory (NPL) in the UK. He obtained his Masters in Physics from the University of Oxford in 2016 before joining the Dimensional Metrology group at NPL. His research in the field of surface metrology aims to bridge the gap between science and industry by applying metrology best practice to industrial measurement problems. Current research interests revolve around using non-contact optical methods for high speed in-line inspection and measurement for quality control, with wider interests including computer vision with machine learning techniques, and automation for research reproducibility.

7.4 Prof Michael Turner, University of Manchester

Mike Turner is Professor of Materials Chemistry and Director of the Organic Materials Innovation Centre within the School of Chemistry. He obtained his first degree and a PhD from the University of Bristol, working with Professor Selby Knox on the synthesis of new organometallic complexes, before moving to the United States to work with Professor Harry Allcock investigating new routes to polyphosphazenes. Professor Turner is coordinator of the Organic Materials for Electronics Consortium and was Senior Editor for Reactive and Functional Polymers 2002-8. He is principal investigator for the Knowledge Centre for Materials Chemistry at the University of Manchester.

7.5 Dr Jeff Kettle, University of Glasgow

I've been based in the James Watt School of Engineering since 2020. I studied at Cardiff and Swansea Universities, where I worked on III-V LEDs, and then worked in a variety of industrial and academic settings, before being made a lecturer at Bangor University in 2012. During my time as a lecturer, I acquired grant funding from the Royal Society, Royal Academy of Engineering, Interreg, Welsh Government, InnovateUK and European Commission, worth around £2m.

SESSION 7: SUSTAINABILITY

7.1 Sustainability in Flexible Electronics

Dr Maria Smolander, VTT

Global consumption of materials is increasing rapidly and the amount of electronic waste is growing. Sustainable development is becoming a widely adopted strategy by several sectors including flexible electronics. To contribute sustainable development goals, sensors and electronics complying with ecodesign and circular economy principles are extremely important. For instance, in areas like medical diagnostics or intelligent packaging where single-use sensors are implemented these principles have a crucial role.

Combination of environmentally friendly and renewable materials, material-efficient, green processes and use case specific product needs are can all contribute in realisation of sustainable solutions.

Printed and hybrid assembly based manufacturing processes as additive manufacturing processes offer low emissions and losses in order to reduce the use and waste of materials. Hence, these deposition technologies are considered more material-efficient than traditional electronics manufacturing methods. Additive manufacturing enables also a possibility to use wide selection of substrate materials including bio-based, compostable and recyclable materials, such as cellulose based materials and bio-based plastics.

In addition, the non-metallic alternatives like graphene-based materials as conductive tracks and antennas as well as the power sources based on sustainable materials have a crucial role in the reduction of environmental load of flexible electronics.

7.2 Measuring the Environmental Sustainability of Graphene Using Life Cycle Assessment: Challenges and Way Forward

Dr Rosa Cuéllar Franca, University of Manchester

The discovery of graphene has opened significant innovation possibilities across numerous fields including electronics, healthcare, composite materials and renewable energy. Whilst these innovations can bring meaningful improvements to our quality of life and help us address major societal challenges we currently face, there is a need to ensure that solutions are developed in a sustainable way to avoid burden shifting, i.e. tackling one problem at the expense of others. To achieve this, we must adopt what is known as a life cycle thinking approach, where every aspect of the life cycle of graphene-based materials is assessed using suitable metrics, i.e. from the extraction of the carbon source and preparation methods, to the application of these materials and their fate at their end-of-life. Life cycle assessment (LCA) is an environmental management tool that quantifies and translates environmental burdens into potential impacts, e.g. greenhouse gases emissions into global warming potential, and is widely used in the environmental sustainability assessment of products, processes or activities throughout their life cycle. Although several LCA studies of graphene-based materials can be found in the literature, which have looked at the global warming potential and primary energy demand of main production processes and few applications, none of these studies have considered specific waste management options for graphene. Moreover, these studies have mostly relied on experimental data at laboratory scale or generic data and assumptions due to the lack of access to industrial scale data, which can be attributed to the relative novelty of these processes (among other factors). This presentation will discuss the knowledge gained to date and the methodological issues that must be overcome in order to obtain representative life cycle environmental impact data that captures the functionality of graphene-based materials, giving enhanced understanding of the main hot spots and opportunities for improvement.

7.3 Dimensional metrology of lithium ion battery electrodes and cells to enable a circular economy

Rob Hornby, National Physical Laboratory

Authors: Rob Hornby (1), Jarred Olson (1) , Giannis Chatzopoulos (1), Juyeon Park (1), Christopher Jones (1), Gareth Hinds (1), Jude Majasan (2), James Robinson (2), Rhodri Owen (2), Dan Brett (2), Carl Reynolds (3), Emma Kendrick (3), Laura Allerston (4), Gary Dunn (5), Daniel O'Connor (1)
(1) National Physical Laboratory, (2) University College London, (3) University of Birmingham, (4) Aceleron Ltd, (5) Tevva Motors Ltd

Electrification of transport is key to the future of mobility, and its rapid adoption is being driven by environmental concerns and government strategy combined with increasing consumer demand in efficient and performant electric vehicles. This is increasing the demand for raw materials such as lithium and cobalt for battery production, raising issues around cost and sustainability of the supply chain. Compounding this problem, inconsistent quality in electrode manufacturing can lead to accelerated aging of cells, reducing the useful lifetime of a battery pack [1]. Lithium-ion batteries (LIBs) typically reach their End of Life (EoL) in automotive applications with 70-80% of their initial capacity left. This presents many opportunities to use them in second life applications as part of a circular economy, reducing the demand both for raw materials and new batteries [2]. To enable this, we propose an EoL triage process involving metrology and testing to aid in selecting second life applications for LIBs (Figure 1). Metrology can be applied during manufacturing and through life as well as at EoL, enabling quality and process control, reducing waste, and improving cell performance. We present various metrology techniques including chromatic confocal thickness profilometry, which can be configured for process control in roll-to-roll electrode manufacturing as well as external 3D measurement at EoL. This sensor technology can measure thickness variations typical of cells at different states of health and charge (on the order of micrometres to millimetres [3]), as well as material thicknesses typical in electrode manufacture, with uncertainties down to 1 µm (k = 2). Figure 1. A proposed triage concept for end of life lithium ion cell metrology exploiting the link between cell appearance, dimensions and electrochemical performance. At each step, a cell may be selected for disposal, recycling, repurposing, remanufacturing, refurbishment, repair, reuse, or further measurements.

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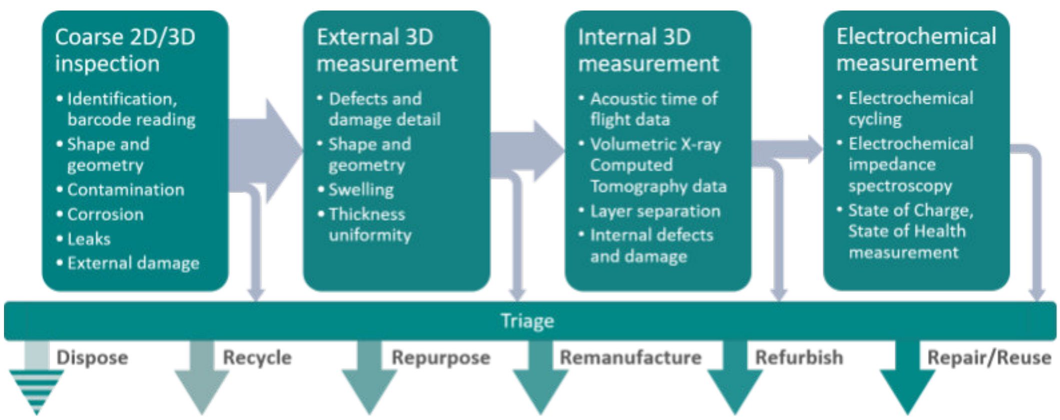

7.4 Aqueous Synthesis and Processing of Conjugated Polymer Nanoparticles for use in Organic Electronic Devices

Prof Michael Turner, University of Manchester

The use of organic semiconductors (OSCs) promises to deliver next-generation electronic and energy devices that are flexible, scalable and printable. Unfortunately, realizing this opportunity is hampered by increasing concerns about the use of volatile organic compounds (VOCs), particularly toxic halogenated solvents that are detrimental to the environment and human health. Conventional methods for the synthesis, purification and deposition of conjugated polymers as thin-films in high performance organic electronics devices involves the use of large quantities of volatile organic solvents (VOCs) and this is particularly problematic for manufacturing scale-up. The processing of polymer semiconductors from colloidal dispersions in water has emerged as a more environmentally benign processing approach for organic transistors and solar cells. These aqueous inks are usually obtained by an emulsification process, where conjugated polymers are dissolved in haloarenes and dispersed into a continuous phase with water using a surfactant. Evaporation of the organic solvent generates a nanoparticle dispersion. Using this approach a halogenated solvents required to ensure good solubility for uniform dispersion, and prior synthesis is needed before emulsification. To overcome these issues, we will discuss a cradle-to-grave process to achieve high performance p- and n-type OSC devices based on indacenodithiophene and diketopyrrolopyrrole semiconducting polymers that utilizes aqueous-processes, fewer steps, lower reaction temperatures, and a significant reduction in VOCs (>99%) and avoiding all halogenated solvents (see Figure 1). The process involves an aqueous mini-emulsion polymerization that generates a surfactant-stabilized aqueous dispersion of OSC nanoparticles at sufficient concentrations to permit direct aqueous processing into thin-films for use in organic field-effect transistors. Promisingly, the performance of these devices is comparable to those prepared using conventional synthesis and processing procedures optimized for large amounts of VOCs and halogenated solvents. Ultimately, the holistic approach reported addresses the environmental issues and enables a viable guideline for the delivery of future OSC devices using only aqueous media from synthesis, purification and thin-film processing. 1

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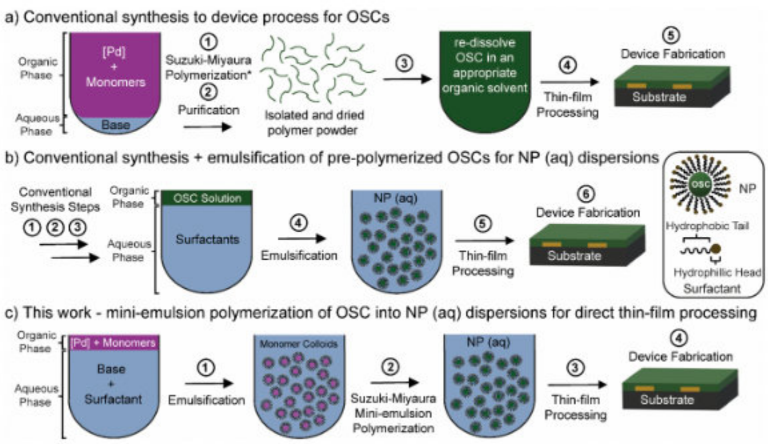


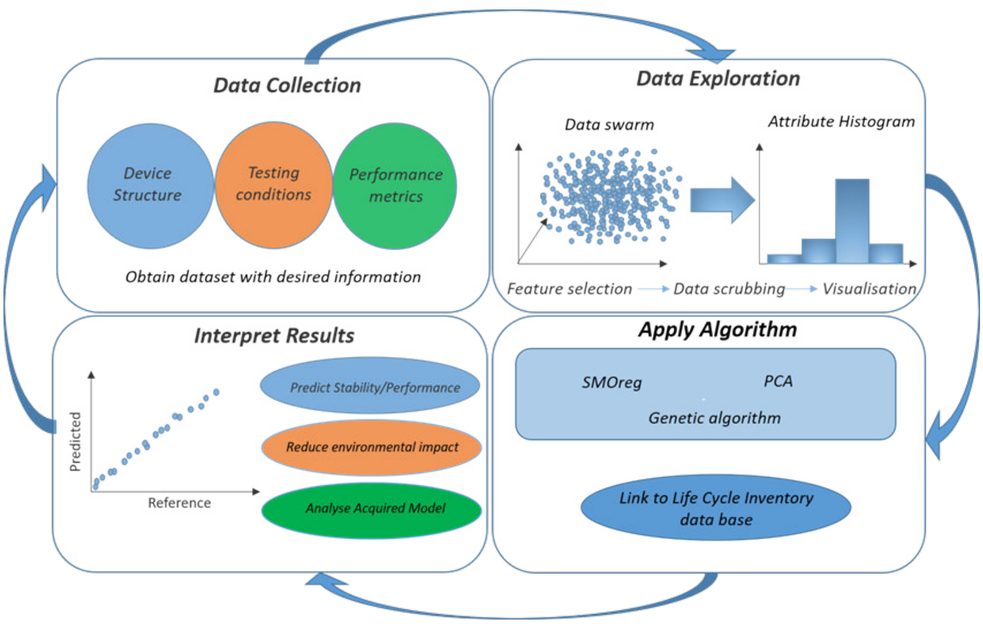
Figure 1. Simplified schematic description of the overall synthesis-to-device process in water for OSCs

7.5 Using Machine Learning to Enhance the Reliability and Sustainability of Large Area Electronic Components

Dr Jeff Kettle, University of Glasgow

Authors: Jeff Kettle (1) , Tudur David, (1)
(1) University of Glasgow

The body of available data in large-area electronics (LAE) has become large enough to enable the use of more advanced statistical analysis i.e. machine learning techniques, which potentially could provide insights beyond what is provided from individual studies. In many LAE components, there are numerous materials and processes that can be used. However, these selections in the material selection and processing options which result in trade-offs between the performance, reliability and environmental impact of the final product and identifying the best combination of materials and processes is clearly a major challenge. During the design phase, these three attributes of the technology are often studied independently of one another. In this presentation, we will report how machine learning (ML) can be used to assess this trade-off between performance, reliability, and environmental impact at the design stage. In this presentation, we will report the results of a case study using an Organic Photovoltaic (OPV) energy harvesting device. For this work, a large database of around 2000 samples has been used. Machine learning algorithms have been applied so that the main factors that influence performance, stability and environmental impact can be identified. These factors are related to materials, processing, and device geometry used in each sample. Through the application of ML, interesting trends can be extracted from the underlying patterns within the dataset that goes beyond the standard approach of acquiring specific information by directly measuring the performance and stability due to one or more changes. By integrating with a life cycle inventory database, we are able to predict the performance, stability, and embodied energy of the OPVs to within 30% accuracy. Furthermore, by deploying data analytical approaches in this manner, it is possible to determine which materials and usage conditions have the greatest impact on device performance, stability, and ultimately, environmental impact. Finally, we will also discuss some of the challenges of using ML models in this manner including the way in which laboratory data can introduce biases and random noise in the data, as well how we can overcome the variability in material properties and non-uniformly of the employed testing protocols. Despite these challenges, this approach could provide a step-change in the way that new LAE devices and systems are designed in the future.



SESSION 8: PANEL DISCUSSION

8.1 Panel Discussion: Introducing LAE to Manufacturing

Chaired by Dr Luigi Occhipinti, University of Cambridge

SESSION 9: NOVEL DEVICES & SYSTEMS I

9.1 Prof Dr Gerwin Gelinck, HOLST/TU Eindhoven

Gerwin Gelinck received his Ph. D. degree in Physical Chemistry from the Technical University in Delft, The Netherlands, in 1998. In that same year Gerwin joined the Philips Research as a Senior Scientist. In 2002 he was co-founder of Polymer Vision, an internal start-up in the Philips Technology Incubator. From 2002 to 2006 he was Chief Scientist of Polymer Vision. In 2007 Gerwin joined Holst Centre, where he managed the research program on organic and oxide transistors and its applications. Since 2019 he is CTO of TNO/Holst Centre. He is also part-time professor in the group of Molecular Materials and Nanosystems (M2N) of the Applied Physics Department at the University of Eindhoven.

9.2 Dr Dimitra G. Georgiadou, University of Southampton

Dr Dimitra Georgiadou is leading the Organic & Flexible Nanoelectronics Theme in the Centre for Electronics Frontiers at Zepler Institute for Photonics and Nanoelectronics, University of Southampton. Previously she was Industrial Fellow at the Department of Materials, Imperial College London (ICL), working with PragmatIC, a UK-SME developing flexible radiofrequency electronic devices for the Internet of Things, and Marie Skłodowska-Curie Fellow at the Department of Physics (ICL), where she is still an Academic Visitor. Dimitra has so far co-authored 53 publications in peer-reviewed journals. Her research interests are the fabrication and optimisation of nanoscale opto/electronic devices by applying novel materials concepts and alternative patterning techniques.

9.3 Dr Vincenzo Pecunia, Soochow University

Vincenzo Pecunia is an Associate Professor and Principal Investigator at the Institute of Functional Nano & Soft Materials, Soochow University, China. There he founded and now leads the Pecunia Group of Thin-Film Optoelectronics, which investigates environmentally-friendly, printable semiconductors. Prior to establishing his own group, Vincenzo worked over six years at the Optoelectronics Group of the Cavendish Laboratory, University of Cambridge, UK. Whilst there, he earned his PhD in Physics. Drawing from his research experience, Vincenzo has authored the books 'Organic Narrowband Photodetectors' and 'Organic and Amorphous-Metal-Oxide Flexible Analogue Electronics'.

9.4 Sanghoon Baek, Pohang University of Science & Technology

Sanghoon Baek is an integrated master's & Ph.D. student from Pohang University of Science and Technology (POSTECH), South Korea. He obtained his undergraduate degree in Mechanical engineering (2015) from POSTECH, and he is currently studying on organic thin-film transistor based sensor arrays in Creative IT Engineering department, POSTECH, under the supervision of Professor Sungjune Jung. He has visited Research Center for Organic Electronics in Yamagata University, Japan, to work on a three-dimensionally stacked organic preamplifier for a lactate sensor. He has also visited InnovationLab GmbH and Karlsruhe Institute of Technology, Germany, to work on monolithically inkjet-printed active matrix organic photodiodes.

9.5 Woojo Kim, Pohang University of Science and Technology

Woojo Kim received the B.S. degree in electrical engineering from Kyunghee University, Seoul, South Korea, in 2016, where he is currently pursuing the Ph. D. degree in creative IT engineering. His current research interests include the design and fabrication of flexible printed electronics circuits and systems.

9.1 Solution Processed Photodetectors for Large-Area Imaging Applications

Prof Dr Gerwin Gelinck, HOLST/TU Eindhoven

Both organic and metal halide perovskite photodetectors are increasingly attractive for light sensing applications as they combine high photogeneration yield with low fabrication costs. Visible-light photodiodes are proposed for use in indirect-conversion X-ray detectors, fingerprint scanners and intelligent surfaces for gesture recognition. Near-infrared (NIR) detectors find applications in biomedical imaging and optical communications. For all the applications above, the dark current density (Jd) is a crucial performance parameter. Minimizing Jd improves important figures of merits such as the signal-to-noise ratio (SNR), the linear dynamic range (LDR) and the specific detectivity (D*). The first part of the presentation will discuss the different intrinsic dark current processes that can occur in these devices and show that depending on the device stack, thermal generation or injection from the electrodes form the dominant contribution to Jd in OPDs.

With this emerging technology reaching performances on par with amorphous silicon (a-Si:H) photodiodes, market introduction is imminent. A major R&D focus in further development of OPD technology is therefore to demonstrate the advantages of organic photodiodes in high-resolution, flexible large-area photodetectors. In the second part of the presentation, we will present recent developments at Holst Centre in realizing prototypical applications. We will demonstrate semi-transparent optical fingerprint/palmprint scanner of 6x8cm that can measure person's unique fingerprint ridge patterns and heartbeat at the same time. We present the first ever prototype of a curved X-ray photodetector on a plastic substrate. The curved detector was integrated into a demonstration system that creates three-dimensional reconstructions of objects. The curved prototype paves the way for smaller optical and 3D imaging X-ray systems with better, more uniform image quality.

9.2 100 GHz Zinc Oxide Schottky Diodes Processed from Solution on a Wafer Scale

Dr Dimitra G. Georgiadou, University of Southampton

Schottky diodes are indispensable components of radiofrequency (RF) rectifiers. The cutoff frequency (fcutoff) of the diodes defines the end application that can extend from RF tags and contactless cards, usually operating at 13.56 MHz, to 5G and 6G networks, which require operation at millimetre wave bands reaching above 100 GHz. The ubiquitous implementation of the different types of RF rectifiers from smart homes and industrial Internet of Things to autonomous vehicles and wearable devices renders their low-cost reliable fabrication at large scale a necessity, while the potential of directly attaching them to flexible or curved surfaces opens up a vast new range of commercial opportunities. The operating frequency of RF rectifiers can be tuned both by applying optimisation strategies at the semiconductor material level and by accounting for device architecture design and geometrical aspects. In short, to increase the cutoff frequency and the output (rectified) voltage, a high mobility semiconductor is required with suitable metal contacts to form Schottky barriers and ohmic contacts, minimising thus resistance losses in the bulk and at the respective interfaces. Careful electrode geometry optimisation can tune also the capacitance, so that the RC constant reaches a minimum and fcutoff a maximum (fcutoff = 1/RC).

We have demonstrated Schottky diodes with intrinsic cutoff frequencies above 100 GHz and used them to construct RF rectifier circuits delivering output voltages of 600 mV at 2.45 GHz and 260 mV at 10 GHz. We achieved this by using an abundant semiconductor, zinc oxide, processed from solution, and an Aluminium doping methodology to improve its transport properties. The doped Al-ZnO film was then deposited on coplanar Al and Au electrodes separated by a nanogap <15 nm. These electrodes were patterned on glass or plastic 4" and 6" wafers with a high throughput and high yield (>97%) low-cost technique we have introduced in the past, named adhesion lithography (a-lith). These results are of immediate relevance to low-power sensor nodes and wearable electronics, while p-type diodes are also possible to manufacture with this technique leading to the realisation of flexible complementary RF circuit topologies.

9.3 Lead-Free Perovskite-Inspired Semiconductors for Indoor Photovoltaics

Dr Vincenzo Pecunia, Soochow University

Authors: Vincenzo Pecunia (1), Robert L.Z. Hoye (2), Yueheng Peng, Tahmida N. Huq, Jianjiun Mei, Luis Portilla, Robert A. Jagt (3), Luigi G. Occhipinti (3), Judith L. MacManus-Driscoll (3)
(1) Soochow University, (2) Imperial Colllege London, (3) University of Cambridge

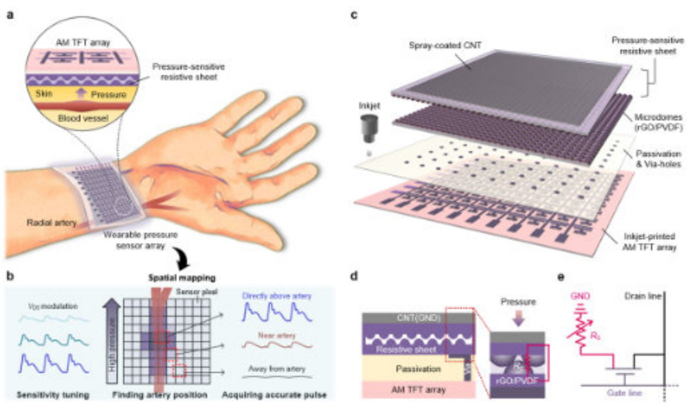
Over the past few years, the photovoltaics community has launched a search for lead-free perovskite-inspired semiconductors that could replicate the impressive photovoltaic performance of lead-halide perovskites, but without the toxicity limitations of the latter [1-2]. A large number of lead-free perovskite-inspired semiconductors have thus been explored, which can deliver photovoltaic functionality in thin-film form and can be processed via facile, low-temperature methods compatible with deposition on low-cost plastic substrates. Therefore, lead-free perovskite-inspired semiconductors have raised hopes as a route to thin-film photovoltaics that can be fabricated with low material and energy consumption, and that is non-toxic, inexpensive, and mechanically flexible. The community researching on lead-free perovskite-inspired semiconductors, however, has thus far taken the narrow view of solely considering these materials for outdoor solar photovoltaics, attaining efficiencies yet to approach those of mainstream lead-based perovskites. Going beyond this narrow view, in this talk we discuss the capabilities and potential of lead-free perovskite-inspired semiconductors for indoor photovoltaics (IPV), an area of considerable technological and commercial value in relation to the rapidly growing demand for wireless Internet of Things (IoT) devices [3]. Indeed, using IPV to power the billions of IoT devices that are soon to enter our daily lives would overcome the practical and sustainability challenges associated with battery-powered operation [4]. With a focus on two representative lead-free perovskite-inspired semiconductors, Cs3Sb2ClxI9-x [5] and BiOI [6], we show that their photovoltaic efficiency under indoor illumination is four times higher than under solar AM 1.5G illumination, already reaching levels within the IPV efficiency range of a-Si:H—the industry standard for IPV. Additionally, through power-dependent measurements and optical loss analyses, we identify their efficiency bottlenecks and discuss strategies for future improvements of their IPV performance beyond industry-standard a-Si:H. Finally, we demonstrate printed TFT logic gates powered by millimetre-scale Cs3Sb2ClxI9-x and BiOI IPV devices, which points to the realization of 'smart dust' for ubiquitous edge computing. By illustrating the capability and potential of two representative lead-free perovskite-inspired semiconductors for IPV, our findings highlight the formidable opportunity that photovoltaic materials of this class provide to sustainably power the ongoing IoT revolution.

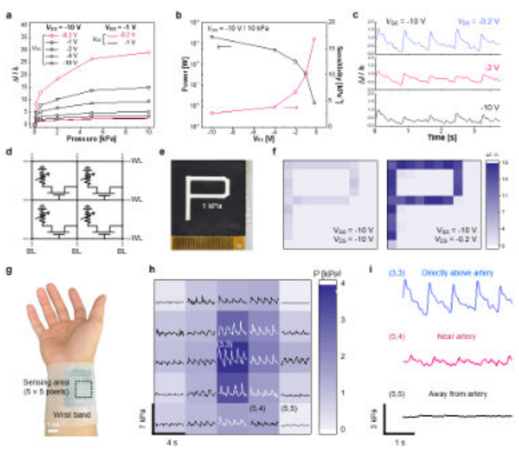
9.4 Inkjet-Printed Active Matrix Pressure Sensor Arrays for Two-Dimensional Pulse Measurement

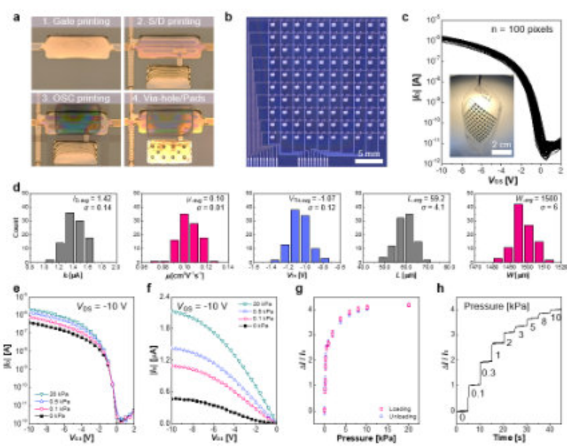
Sanghoon Baek, Pohang University of Science & Technology

Authors: Sanghoon Baek(1), Sungjune Jung (1)
(1) Pohang University of Science & Technology

Pulse wave analysis is clinically crucial especially for cardiovascular diseases such as hyperlipidemia and arteriosclerosis. Attempts have been made to record arterial pulse waveform continuously and non-invasively with wearable pressure sensors. However, the accuracy of the acquired signal with single pixel sensor is poor because measuring physical pulsation with pressure sensor is heavily sensitive to the position of the sensors, hindering real-world applications. Here, we introduce two-dimensional (2D) arterial pulse measurement with pressure sensor arrays based on inkjet-printed active matrix for accurate pulse tonometry analysis. As high yield and uniformity of the transistor array are essential for reliable spatial signal mapping, design rules and optimization process for inkjet-printed ultrathin large-area arrays are developed, resulting in 100 % yield and high uniformity (relative standard deviation <10 %). Pressure-sensitive resistive sheets with microstructures are integrated on the top of the transistor array to form wearable active matrix pressure sensor array. The device shows fast response with minimal crosstalk, which is suitable for spatial arterial pulse measurements. In consideration of transistor device physics, operating voltage is strategically modulated to maximize the sensitivity while minimizing the power consumption for practical wearable applications. Finally, arterial pulse signals are measured and mapped two dimensionally not only for exactly locating the artery but also for acquiring accurate pulse wave from the pixel that gives maximum output. The developed device overcomes the inaccuracy of pulse wave signal measured by single pixel pressure sensors arisen from the sensor position, and suggests its opportunities in medical applications such as arterial catheter injection or pulse tonometry analysis.







9.5 Reverse-Offset-Printed Organic Nonvolatile Memory Thin-Film Transistor

Woojo Kim, Pohang University of Science and Technology

Authors: Woojo Kim (1), Jimin Kwon (2), Yasunori Takeda (3), Shizuo Tokito (3), Sungjune Jung (1)
(1) Pohang University of Science & Technology, (2) Stanford University, (3) Yamagata University

Reverse-offset-printed organic nonvolatile memory thin-film transistors (TFTs) are demonstrated on a large-area substrate for the first time. Finely patterned electrodes are fabricated by reverse-offset printing with 15 um line width and 10 um channel length through three steps of ink coating, patterning and transfer using Ag-nanoparticle ink. Memory devices are configured in a bottom-gate bottom-contact TFT structure with a high-k gate blocking insulator poly(vinylidene fluoride-co-trifluoroethylene). A blend ink, which consists of a small-molecule p-type organic semiconductor dithieno[2,3-d;2′,3′-d′]benzo[1,2-b;4,5-b′]dithiophene and a tunneling polymer polystyrene, are fabricated using air-pulse nozzle printing. The tunneling layer is formed during the active layer printing process with blended ink by phase separation of small-molecule and polymer. The printed nonvolatile memory TFTs with the phase-separated tunneling layer exhibited significantly improved Vth shifts (~3 times), programmed/erased current ratio (>1000 A/A), switching speed (<100 ms) and data retention (>10 y). We believe our finding is applicable to wearable electronics, smart Internet-of-Things devices and neuromorphic computing devices.

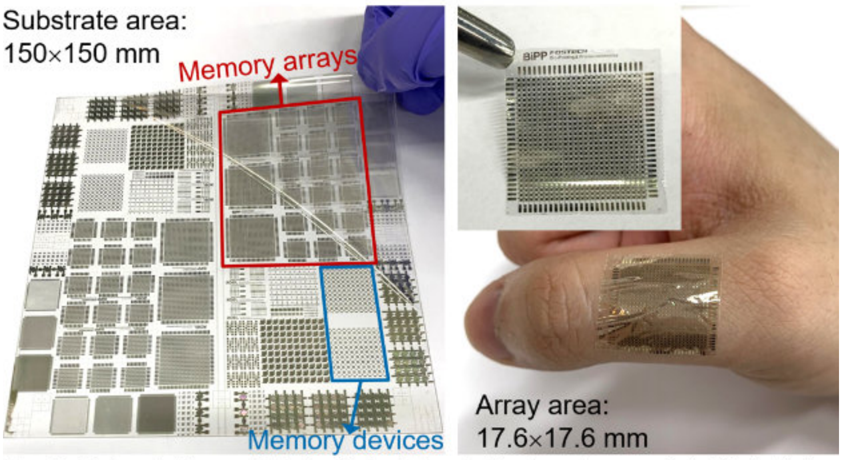


Figure 1. a) Photograph of large-area fabrication of various devices, circuits and arrays by reverse offset printing (substrate area = 150×150 mm).

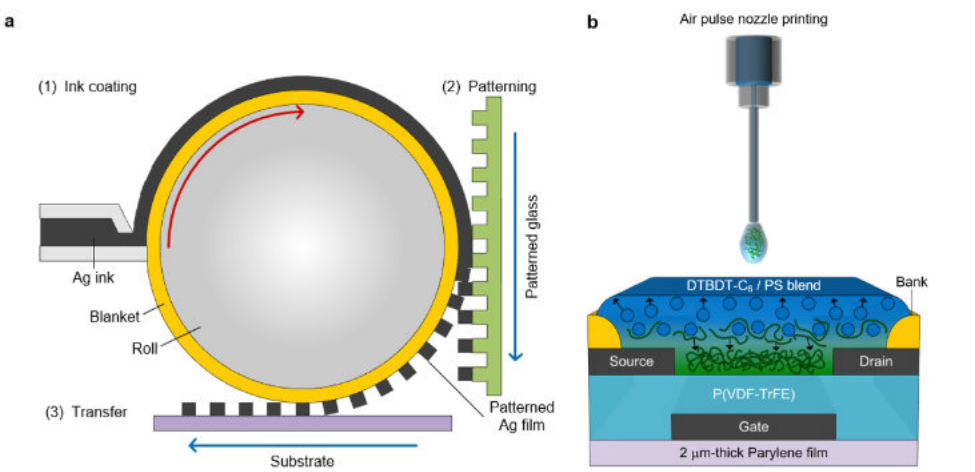


Figure 2. a) Schematic illustrations of the reverse offset printing method, which consisted of three parts: (1) ink coating, (2) patterning, and (3) transfer. b) Schematic cross-section of a bi-layered polymer electret NVM TFT fabricated by air-pulse nozzle printing with a DTBDT-C_6/PS blended ink.

SESSION 10: APPLICATIONS

10.1 Dr Steve Bennington, Q5D

After doing my PhD at Birmingham University, I worked for over 20 years as a scientist. My role was to take national scale scientific infrastructure projects from concept to reality and then to run teams to exploit these facilities as a service for academia and industry. In 2006 I became a visiting professor at University College London. From work at UCL I was able to spin-out a hydrogen storage company, Cella Energy Limited in 2011. After leaving Cella in 2016 I co-founded Krino Partners, a consultancy business. In April 2019 we set up Q5D Technologies, a spin-out of M-Solv and CEL-UK. The new company uses a highly flexible 5-axis platform to add electrical functionality to components by embedding wiring or using laser sintered printed electronics.

10.2 Dr Ton Van Mol, TNO/Holst Centre

Dr Ton van Mol graduated with honours from Eindhoven University of Technology in Chemical Technology in 1997, and received his PhD in the area of thin film technology in 2001. He worked at Sandia National Laboratories (Livermore) as visiting scientist and joined TNO in 2003 as senior scientist in the area of flexible solar cells. In 2005, Ton helped set-up the open innovation initiative between IMEC and TNO called Holst Centre, where he had various roles, such as Program Manager and Business Development Director before he took Managing Director in 2013.

10.3 Dr May Wheeler, FlexEnable

May is a Principal Engineer and Project Manager at FlexEnable. Her current research interests include improving the optical performance of flexible display technologies and development of sensing technologies based on organic electronics. Prior to joining FlexEnable May worked as a device physicist at Cambridge Display Technology where she worked on OLED optimisation, optical biosensing and was seconded to RIKEN in Japan to work on a collaborative project in the field of energy harvesting. May has a BSc, MPhys and PhD in condensed matter physics and previously held a post-doctoral research fellow position at the University of Leeds, specialising in molecular electronics and thin film magnetism. May is an inventor on >10 filed patents and an author of >10 peer reviewed publications.

10.4 Dafydd Ravenscroft, University of Cambridge

Dafydd is currently undertaking a PhD at the University of Cambridge studying Sensor Technologies. His research concentrates on the development of novel sensors for medical applications.

10.5 Ana Lúcia Poças, CeNTI

Ana Lúcia Poças has a master's degree in Chemical Engineering from the Faculty of Engineering of the University of Porto (FEUP), with the specialization in Biotechnology field. Since 2018 she is a researcher at Smart Materials department, at CeNTI, collaborating on several research and development projects, with national and international companies. In these projects, she has been working on the study and development of flexible sensors (capacitive, resistive, and electrochemical) using screen printing technology, as well as the respective integration.

10.1 Automotive and Aerospace Lightweighting

Dr Steve Bennington, Q5D

Q5D's technology is the fusion of two technologies: laser sintered printed electronics from M-Solv, which makes it possible to print with copper or silver ink and then use a laser to cure and sinter the ink into tracks that have 30-50% the conductivity of the solid metal; and innovative 5-axis additive manufacturing robotics from CEL-UK which are able to accurately deposit the conductive inks and dielectrics or even augment a surface by creating complex shapes from engineering polymers. This technology makes it possible both to add high-quality conductive tracks on large curved surfaces or create complex structures with compact three-dimensional circuitry for surface mounted components.

Additionally, the robotic tools can embed wire or cable making it possible to automate the manufacture of structures which can carry both power and data, which we believe is a unique capability.

In this talk I will describe the technology and some of the work that the company is doing in the aerospace and automotive sectors.

10.2 Flexible Electronics for Human-Centric Health Care

Dr Ton Van Mol, TNO/Holst Centre

Reverse-offset-printed organic nonvolatile memory thin-film transistors (TFTs) are demonstrated on a large-area substrate for the first time. Finely patterned electrodes are fabricated by reverse-offset printing with 15 um line width and 10 um channel length through three steps of ink coating, patterning and transfer using Ag-nanoparticle ink. Memory devices are configured in a bottom-gate bottom-contact TFT structure with a high-k gate blocking insulator poly(vinylidene fluoride-co-trifluoroethylene). A blend ink, which consists of a small-molecule p-type organic semiconductor dithieno[2,3-d;2′,3′-d′]benzo[1,2-b;4,5-b′]dithiophene and a tunneling polymer polystyrene, are fabricated using air-pulse nozzle printing. The tunneling layer is formed during the active layer printing process with blended ink by phase separation of small-molecule and polymer. The printed nonvolatile memory TFTs with the phase-separated tunneling layer exhibited significantly improved Vth shifts (~3 times), programmed/erased current ratio (>1000 A/A), switching speed (<100 ms) and data retention (>10 y). We believe our finding is applicable to wearable electronics, smart Internet-of-Things devices and neuromorphic computing devices.

10.3 High-performance Materials and Processes Optimised for Flexible Displays and Other OTFT Applications

Dr May Wheeler, FlexEnable

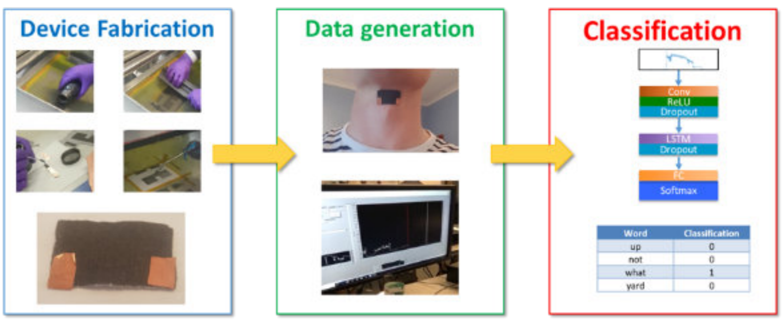
FlexEnable is at the forefront of flexible electronics based on organic thin film transistors (OTFTs). Using FlexiOM, FlexEnable's proprietary organic materials, enables OTFT technology that not only outperforms its amorphous Si counterpart electrically but it holds advantages such as flexibility, robustness and thin form factor. These advantages put OTFT technology in a prime position for advances in ultra-lightweight conformable displays and OTFT devices. Backplanes based on OTFTs can be used in combination with both small and large area electronics. FlexEnable's technology requires only low temperature processing which allows the use of a wide range of substrates that would not survive high temperature processes. For example, FlexEnable's organic liquid crystal display (OLCD) technology is fabricated on low cost and optically perfect flexible TAC substrates in place of glass. FlexEnable's OTFTs show better stability, mobility and a lower leakage current than a-Si TFT, meaning no trade-off in OLCD performance compared to glass LCD, and increased sensitivity for sensing applications. OLCD has unique attributes – conformable, thinner, lighter, shatterproof, and low cost. Each of these attributes has value in its own right depending on the application. The record-breaking flexibility of the OTFTs has led to a breakthrough in borderless displays where edges can be folded behind the backlight to create cutting-edge designs for notebooks and tablets. Another advantage of FlexEnable's low temperature OTFT process allows displays to be built using polarisers as substrates, which means dual cell displays can be made to massively improve display contrast. Building displays on polarisers reduces the gap between the cells to previously unobtainable levels, allowing pixel level dimming and OLED-like contrast from a much simpler display stack. The resulting dual cell OLCD is particularly suited to TVs, monitors and automotive displays. In this presentation, the recent advances in FlexEnable's OTFT based technology will be shown, and the implications for next generation technologies, in particular for borderless and dual cell displays will be presented. We will also provide an update on some of the other disruptive technologies we are working on in partnership with other companies and research institutes including biosensors and image sensors.

10.4 Wearable Piezoelectric Haptic Sensor for Silent Communications

Dafydd Ravenscroft, University of Cambridge

Authors: Dafydd Ravenscroft (1), Tasnim Chowdhury (1), Ioannis Prattis (1), Luigi G. Occhipinti (1)
(1) University of Cambridge

Sensors are an important component of healthcare monitoring systems, providing the ability to detect and measure various signals with high accuracy in real-time. The monitoring of small vibrations in the throat can be used to develop silent communication systems. These systems are important for those who cannot rely on physical voice signals. Silent communication technology can also be used in other situations such as in locations of high noise or where secure and reliable delivery is required. Various approaches to silent speech recognition have been made in recent years. Ultrasensitive strain gauges on thin flexible wearable smart patches have been demonstrated to be capable of detecting and transforming even minute movement of the muscles associated with speech. This includes movements associated with residual capabilities of people affected by hearing and speech impairment. These signals are converted into a meaningful set of patterns with words then predicted through pattern recognition algorithms and machine learning techniques. Hence, our research focuses on the development of wearable mechanical sensors able to convert such movements into phonation predictions. We created a graphene-based strain gauge sensor which, combined with machine learning algorithms, can record and decode such non-audio signals (Figure 1). We developed a method in which graphene oxide is printed onto polyester fabric to produce a highly flexible and wearable sensor to pick up small throat movements. A framework for interpreting this information was designed which uses machine learning techniques, including artificial neural networks, to predict intended words from the recorded signals. A dataset of 15 unique words and four movements, each with ten repetitions was developed and used for the training of the machine learning algorithms. The results demonstrate the ability for such sensors to be able to predict spoken words. We produced a word accuracy rate of 55% on the word dataset and 85% on the movements dataset. This provides an initial proof-of-concept demonstration of the ability for strain sensors to be used for silent communication. After the signals are processed and associated with words, the user receives a feedback that confirms the correct processing. Therefore, a system architecture where the sensing element is combined with a printable piezoelectric polymer-based actuator via aerosol-jet printing on the same smart patch substrate is well suited to provide a haptic feedback to the wearer. Several device architectures have been investigated to maximise both the sensitivity and the effectiveness of the haptic feedback of the sensor/actuator towards use in wearable silent communication smart patch systems. This innovative technology can also be applied to a wide range of other applications and biocompatible compliant substrates, such as for hearing improvements, advanced monitoring for heart rate and sleep, and applications that require conversions of ambient mechanical energy into electrical signals. In addition to this, there is a rich opportunity to develop energy autonomous wearable technology that can harvest energy from the human body and convert it into electrical energy to power such devices, in the attempt to overcome known limitations in further development of smart patch wearable electronics.



10.5 Development of Large Area Printed Sensors for Smart Buildings

Ana Lúcia Poças, CeNTI

Authors: Ana Lúcia Martins de Almeida Poças (1), Daniela Campanhã (1), Ricardo Carvalho (1), Marcos Freitas (1), José Silva (1), Vasco Machadom(1), Jose Matos (1), Ricardo Maia (1), Pedro Henriques (1), Helena Sá (1), Ana Rute Sampaio (1), Pedro São Marcos (2)
(1) CeNTI, (2) Revigres

Nowadays, the integration of novel functionalities to improve energetic efficiency, safety, and comfort for the end user, is a tendency in growing [1]. The smart building concept encourages the use of printed electronic technologies, which enable the application of flexible and lightweight sensors in a wide range of materials, commonly used in construction industry. With printing technologies, it became possible to obtain larger sensors, even on non-flat substrates, without compromising the cost of various electronic systems [2]. The work presented has been realized within the scope of REVIPOLISHED, a project which intends to develop innovative solutions for ceramic tiles, with a strong sense of energy efficiency and sustainable solutions. Moreover, REVIPOLISHED is also focused on R&D of embedded sensorization devices and smart systems, which can interact with lighting control systems, or even detect human presence in smart buildings. Capacitive sensing has been widely utilized for many applications, including pressure and level measurement, proximity, and touch sensing, due to its lower power consumption and faster response, when compared to other sensing mechanisms, such as, resistive sensing [3]. Nonetheless, when concerning the usage of capacitive sensors as detection/touch sensing, it is crucial to define the operating mode (mutual or self-capacitance) according to the final application. As the final application of the REVIPOLISHED project includes the detection of body presence, self-capacitance mode was used. Therefore, the thickness and dimensions of the ceramic tile were considered to improve the design of the capacitive sensor. Electromagnetic simulation was performed to improve the sensitivity and reduce the noise of the sensor. It allowed the selection of the most promising and cost efficient design (Figure 1), with a capacitance variation of 53 picoFarad, minimizing the need for laboratory development testing. In conclusion, this smart tile will allow the development of a floor capable of detecting body presence, and simultaneously activating the lights in a room, contributing to energy efficiency. Additionally, a mobile application will be implemented, to warn the final user that someone has stepped on the floor, such as an intruder, for example. The project consortium is constituted by REVIGRÉS, the promoting company, and CENTI, an R&D entity, as co-promoter. With an overall investment of 803 661.56 €, REVIPOLISHED project is co-financed by Portugal 2020, under the Operational Programme for Competitiveness and Internationalization (COMPETE 2020), in the amount of 514 628.01 € from European Regional Development Fund (ERDF).

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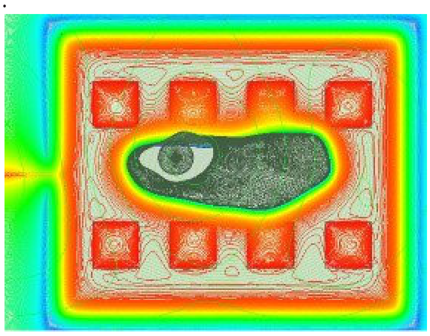


9.1 Large Area Electronics for Advanced Physiological Monitoring: Applications for COVID-19 and Beyond

Dr Steve Xu, Sibel Health

Recent advances in soft, flexible electronics has enabled demonstrations of a growing number of medical sensing capabilities. Some of these advances have now even translated to commercialized devices. However, the majority of these platforms are still largely limited to the measurement of basic vital signs such as heart rate and physical activity. We describe advances in materials science, electrical engineering, and computer engineering that allow for new monitoring capabilities for large-area electronics. Specifically, we illustrate the ability for sensor networks multiplexed together to assess the full spectrum of symptoms related to COVID-19 infection with a focus on respiratory digital biomarkers. Furthermore, we illustrate the ability for large-area electronics to recapitulate complex human motion as a way for diagnosis and treatment tracking in a wide range of neurological disorders. Finally, we illustrate the ability for large-area electrodes coupled to soft flexible sensors to capture electropotential signatures to derive fetal heart rate and monitor brain activity. Patient data will also be presented to illustrate the clinical utility of these new systems.

Biography

Steve Xu MD, MSc is currently the Medical Director of the Querrey Simpson Institute for Bioelectronics at Northwestern University. He is also an Assistant Professor in the Department of Biomedical Engineering at Northwestern University McCormick School of Engineering, and the Department of Dermatology and Pediatrics at Northwestern's Feinberg School of Medicine. He received his undergraduate degree in bioengineering from Rice University summa cum laude.

He completed his medical training at Harvard Medical School with special honors as a Soros Fellow, and a Masters in Health Policy and Finance with Merit from The London School of Economics as a Marshall Scholar. Finally, he completed an NIH-funded T32 post-doctoral fellowship in Northwestern's Department of Materials Science and Engineering under John Rogers PhD. Dr Xu has authored more than 100 peer-reviewed publications and is listed as an inventor on 11 pending and granted patents.

Xu has developed several wearable technologies with a focus on maternal, fetal, and neonatal health. His publications have appeared in The New England Journal of Medicine, Science, and Nature, garnering press attention from sources such as The New York Times, CNN, The Washington Post, and The Los Angeles Times. As part of his collaborative research efforts, several of his joint inventions have been licensed to early stage companies for the commercialization of the core technology. To date, these companies have raised more than $20 million USD and launched sensors in over 20 countries across 6 continents.

SESSION 12: NOVEL DEVICES & SYSTEMS II

12.1 Dr Mario Caironi, IIT - FLEEP Technologies

Mario Caironi obtained his Ph.D. in Information Technology with honours at Politecnico di Milano (Milan, Italy). In 2007 he joined the group of Prof. Sirringhaus at the Cavendish Lab. (Cambridge, UK) as a post-doc, working for 3 years on high resolution printing of downscaled organic transistors and circuits, and on charge transport in high mobility polymers. In 2010 he was appointed as Team Leader at the Center for Nano Science and Technology@PoliMi (CNST) of the Istituto Italiano di Tecnologia. In 2014 he entered the tenure track at the same institution, obtaining tenure in 2019.

12.2 Dr Ravinder Dahiya, University of Glasgow

Ravinder Dahiya is Professor of Electronics and Nanoengineering at University of Glasgow. His group (Bendable Electronics and Sensing Technologies (BEST)) conducts fundamental research on high-mobility materials based flexible and printed electronics leading to electronic skin and its application in robotics and wearable systems. Prof. Dahiya is Fellow of IEEE. He is the President-Elect (2020-21) and Distinguished Lecturer of IEEE Sensors Council.. He holds prestigious EPSRC Fellowship and received Marie Curie Fellowship and Japanese Monbusho Fellowship in past.

12.3 Aimee Wyatt, CPI

Aimee Wyatt received a Masters degree and graduated in Chemistry from Durham University in 2015. She has since worked at CPI as a scientist in the Printable Electronics business unit, working on collaborative and commercial research projects in this field. Her position primarily focuses on the characterisation, printing and evaluation of materials and devices for a number of different applications, including IoT enabled devices, wearable electronics, sensors and batteries.

12.4 Dr Feras Alkhalil, PragmatIC

Dr Feras Alkhalil, Principal Scientist and Director of R&D, joined PragmatIC in September 2015 and leads the research and development activities at PragmatIC. He received his MSc and Ph.D. from the University of Southampton in Microelectronics System Design and Solid-State Electronics, respectively. Feras is a visiting fellow at Durham University Department of Physics since September 2017.

12.5 Dr Simon Johnson, CPI

Dr Simon Johnson, Chief Technologist within Printed Electronics at the Centre for Process Innovation. In his current role Simon acts as a knowledge expert in Printable Electronics, supporting strategic and development activities in the business. While at CPI Simon has developed the electronics design and integration team to provide product design capability in the field of flexible electronic systems. He has lead the development of processes for the assembly of hybrid flexible electronic systems including printed sensors, wireless sensor systems and roll to roll circuit design. In previous roles as an academic at the University of Durham and also in industry, Simon has worked in many aspects of electronics from electronic device design and development to electronic systems and software development.

12.1 From Polymer Transistors Operating at Radio-Frequencies to Edible Electronics

Dr Mario Caironi, IIT - FLEEP Technologies

Printed polymer field-effect transistors (FETs) have been considered for many novel applications towards large area and flexible electronics, since they can enable pervasive integration of electronic functionalities in all sorts of appliances, their portability and wearability. However, solution-processed polymer FETs fail to achieve the minimum speed required for example to drive high-resolution displays or to read the signal from a real-time imager, where a transition frequency (fT), i.e. the highest device operative frequency, above 10 MHz is required. In this contribution, I will show that is possible to fabricate organic FETs operating above 100 MHz, approaching the ultra-high frequency bandwidth, opening opens a route for cost- and energy-efficient manufacturability of flexible and conformable electronics with wireless-communication capabilities. By exploiting part of the fabrication strategies developed for radio-frequency polymer FETs, I will also present and discuss our vision towards edible electronics, a field at an embryonic stage aiming at a technology safe for ingestion, environmentally friendly, cost-effective, and degraded within the body after performing its function, either digested or even metabolized. Examples of tattoo electronics made with edible and potentially edible materials will be presented.

12.2 Electronic Skin – from Energy Sink to Energy Source

Dr Ravinder Dahiya, University of Glasgow

Electronic or tactile skin (eSkin) with various types of sensing and electronic devices distributed over large flexible and conformable substrates has received considerable interest in recent years. It allows robots and prosthetic limbs to gather tactile information from large area contacts and to exploit the same to operate in unstructured environment or to improve human-robot interaction. It is also used for measurement of vital health parameters. The continuous operation of large number of sensors and the readout electronics often make it challenging to use eSkin, particularly in applications such as robots running on batteries. At the same time, presence of devices on large area offers an opportunity to solve the energy issue and this lecture will focus on the same. This lecture will present the first energy generating eSkin with intrinsic tactile sensing but without using any touch sensor. With distributed array of miniaturized solar cells and infrared light emitting diodes on soft elastomeric substrate, the eSkin could sense multiple parameters (proximity, object location, edge detection, etc.) and generate about 380 mW from the palm size area (>100 W over the whole body). This new approach also extends the application of solar cell from energy generation alone to simultaneously acting as touch sensors.

12.3 A Highly Uniform Thermoformed Lighting Panel for Automotive Applications

Aimee Wyatt, CPI

In this paper we describe the results and process development for the production of highly uniform, 3D, large area lighting modules. The principle motivation for this development is the increasing use of lighting in functional and ambient Use Cases within the automotive sector. From exterior tail-lights, illuminated grilles and branding, to interior illuminated trim on doors, instrument panels, floors and roof liners. The automotive sectors vision is for luminous surfaces which provide personalisation, brand identification and messaging. The integration of lighting must be balanced with conserving module thickness, reducing weight and increasing fuel efficiencies. The integration of lighting modules within structural parts of vehicles can help to achieve this by the removal of additional fittings and reduction in wiring requirements. However, this requires the close integration of LEDs with 2.5D and 3D parts which presents challenges for conventional electronics assemblies. Thermoforming has been shown to be an effective technology for this type of assembly, but for lighting components uniformity of illumination is an essential element of the performance and aesthetics of the part. The use of discrete light sources (LEDs) normally requires a diffuser layer which is separated from the sources by a dimension which is similar to the pitch of the LEDs. This results in structures with considerable depth or requires the use of an excessive number of LEDs. DesignLED develop large area, ultra-thin and light-weight LED light-guide modules for automotive, and other sectors. These modules use patented light-guide technologies for the integration of the light source inside the light-guide, with surface scattering elements generating homogenous, luminous surfaces. The development work reported in this paper aimed to extend this technology to 2.5D and 3D thermoformed parts and addresses the challenges of product design, materials selection, electronics assembly and optical performance to achieve a highly effective and thin formed part. The development of novel inks and adhesives by Dycotec which address the challenges of thermoformed printed electronic circuits has resulted in high performing, conducting and formable inks which can withstand extensive stretch during the forming process. A novel formulation of conducting adhesive suitable for use in thermoformed circuits and applied using stencil printing is reported and its performance assessed The results of the successfully developed manufacturing process for these novel lighting parts is presented, with a range of applications highlighted. Details describing the thermoforming and over- moulding processes and the optical design of the 3D parts, with careful consideration of light blocking components and 3D structure of the parts, is also included.

12.4 Towards Ubiquitous Flexible Sensor Electronics

Dr Feras Alkhalil, PragmatIC

The key global challenges we presently face encompass health and wellbeing, sustainable and secure food supplies, need for greener cities and tackling climate change . To achieve the challenging goals laid out by governments and NGOs in these areas, requires innovative approaches that can be deployed in a decentralised and democratised way. PragmatIC is a world leader in the design, development and manufacture of ultra-low-cost Flexible Integrated Circuits (FlexICs). Designers can leverage PragmatIC's innovative technology with its novel form-factor using our FlexIC Foundry™ offering to create ubiquitous low-cost smart systems. Enabling platforms that include sensors and memory, to monitor the environment around them and determine outcomes at a fraction of the cost and environmental impact of traditional silicon solutions. Such platforms would enable a step change in tackling grand challenges such as early disease screening, remote monitoring, wellbeing, animal and plant welfare, waste reduction through food spoilage monitoring, pollutants and ambient sensing and industrial sensing, supporting healthy living and improved quality of life. In this talk, we will present novel technologies that we are developing for our FlexIC Foundry platform, including Schottky rectification, low power complementary metal oxide technology, analogue interface blocks and non-volatile memory. These technology capabilities will enable designers to create even more innovative designs with PragmatIC's FlexIC Foundry.

12.5 Novel Hybrid Circuit Assembly for Battery Free Smart Garments

Dr Simon Johnson, CPI

Authors: Simon Johnson (1), Mark Catchpole (2), Neil Parker (1), Andrew Hamilton (1), Maarten Cauwe (3), Pieter Bauwens (4)
(1) CPI, (2) Conductive Transfers, (3) IMEC, (4) University of Gent

We present results of an investigation into the development of a manufacturing process for hybrid assemblies on smart garments. The objective of the work was to demonstrate the successful fabrication of complex circuits on fabrics based on Conductive Transfers' novel printed circuit technology. The battery free circuits aimed to provide capacitive touch control of a smartphone music streaming app. from the cuff of a runner's jacket. Successful assembly of a range of component types has been demonstrated. A number of working circuits are discussed. Motivation and Results: The ability to integrate electronic functionality into garments has applications in a wide range of markets including healthcare, wellbeing and sport. Conductive Transfers have a well-established screen printing process for the application of conducting tracks to a range of fabrics and are developing this process in partnership with CPI to allow the addition of sophisticated electronics functionality to be added for sensing and other applications. The attachment of fine pitch components to printed conductors on fabrics presents a range of challenges which are discussed in this paper. Provision of power to such circuits poses problems which have been addressed by the use of energy harvesting techniques based on NFC power transfer, which can also be used for data transmit and receive. Demonstrator circuits designed in partnership with IMEC have been built which show successful operation of a range of standard commercial components on flexible and stretchable fabrics using the Conductive Transfers process. These are shown in figures 1 and 2. This paper presents the exciting results of this study, part of which was undertaken within the InSCOPE H2020 program.

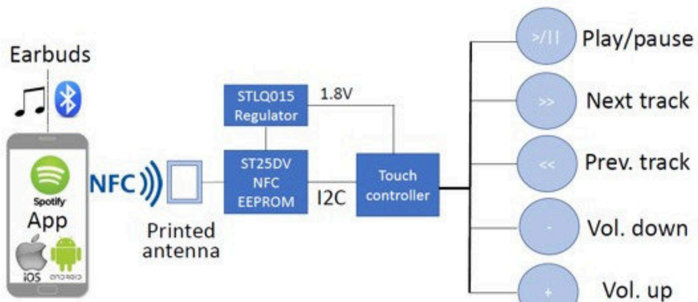


Figure 1 Example architecture for garment integration

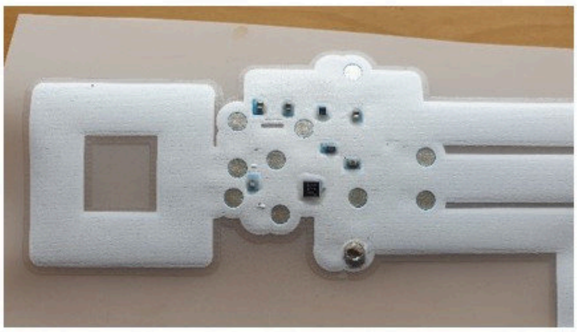


Figure 2 Example circuits with complex COTS components on printed fabrics

SESSION 13: HIGH PERFORMANCE MATERIALS

13.1 Dr Ted Sargent, University of Toronto

Ted Sargent received the B.Sc.Eng. (Engineering Physics) from Queen's University in 1995 and the Ph.D. in Electrical and Computer Engineering (Photonics) from the University of Toronto in 1998. He has been a faculty member at UofT since 1998; and spent sabbaticals at MIT (Microphotonics Center), UCLA (Fulbright Visiting Professor), Berkeley (Somorjai Visiting Miller Professor), and Harvard (Rowland Institute Visiting Distinguished Scholar). He is University Professor in the Edward S. Rogers Sr. Department of Electrical and Computer Engineering where he holds the Canada Research Chair in Nanotechnology. He serves as Vice President – Research for the University of Toronto. He founded and served as CTO of InVisage Technologies. His publications have been cited 50,000 times [Scopus].

13.2 Dr Martin Heeney, Imperial College London

Martin Heeney is a Professor of Organic Materials Chemistry and Royal Society Wolfson Fellow at Imperial College London. He has extensive expertise in the design and synthesis of conjugated materials and their application. His research interests include the design, synthesis and characterisation of solution processed organic materials for a variety of optoelectronic applications.

13.3 Dr Atif Aziz, University of Cambridge

Dr Atif Aziz is a senior research associate at the Nanoscience Centre, University of Cambridge. His area of research is studying the physical, electrical, thermal and mechanical properties of nanomaterials and nanoscale devices. At present, he is working on Carbon Nanotubes and copper composites, high conductivity CNT inks and functional nanofibers. He did his PhD from Cavendish Lab, University of Cambridge and had been working as a research associate at the Materials Science Department, University of Cambridge. Before his current job, he was an experimental office at the Lancaster University, where he set up a nanofabrication facility for Quantum Technology Centre and had also been the manager of the Cambridge Graphene Centre.

13.4 Dr Khaled Parvez, University of Manchester

Dr Khaled Parvez received his Bachelor degree in Chemistry from Shah-Jalal University of Science & Technology, Bangladesh in 2006 and Master's degree in Polymer Science from Chungju National University, South Korea in 2010. Then he joined Prof. Klaus Mullen's group at the Max Planck Institute for Polymer Research, Germany, where he obtained his PhD in October 2014. During his PhD, he made significant contribution to the development of electrochemical exfoliation of graphene for industrial scale production. In June 2016 he joined in Prof. Cinzia Casiraghi's group at the University of Manchester as a research associate, where he is currently working on inkjet printing of 2D materials based electronics devices.

13.5 Filipe Richheimer, National Physical Laboratory

Filipe Richheimer completed his BSc and MSc in Engineering Physics at Instituto Superior Técnico, University of Lisbon. During his MSc he studied magnetic field reconstruction on scanning magnetoresistive probe microscopy. He joined the Electronic and Magnetic Materials group at the National Physical Laboratory in 2017 as a Marie Skłodowska-Curie Early Stage Researcher Fellow on the H2020 project SPM2.0. He is currently completing his PhD at the University of Surrey focusing using tip-enhanced optical spectroscopy and electrical modes of SPM to study emerging electronic materials such as organic-inorganic perovskites and 2D materials.

13.1 Large-Area LEDs and Photodetectors for Consumer Electronics

Dr Ted Sargent, University of Toronto

I will review recent advances in using quantum dots, perovskites, and organics, often in combination, to produce high-brightness color-true displays, and to achieve high-speed photodetectors for infrared time-of-flight 3D sensing.

13.2 Tuning Conjugated Polymers by Post-Polymerization Modification

Dr Martin Heeney, Imperial College London

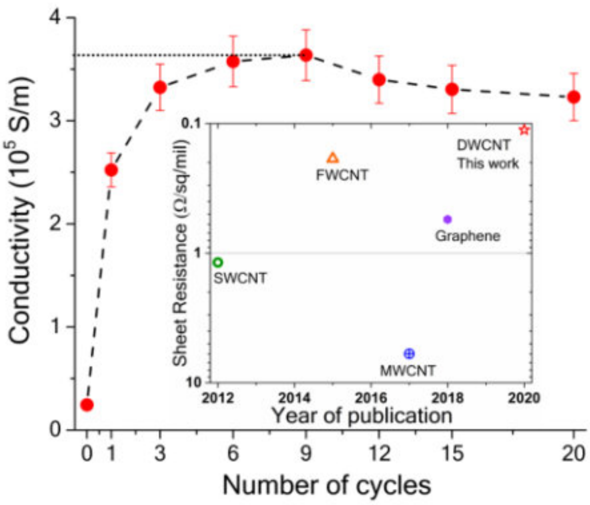
The direct functionalization of a conjugated polymer backbone is a powerful method to introduce a variety of functional groups. Provided functionalization chemistries can be developed with close to quantitative yields, then post-polymerization reactions can be used to tune the optoelectronic performance of the conjugated backbone, enabling the synthesis of libraries with consistent dispersity and length. Here I will discuss our recent work towards enabling such functionalization in quantitative yields. I will discuss how such techniques can be used to make novel block and graft co-polymers that exhibit stimuli-responsive properties, and illustrate the use of such polymers as emissive nanoparticles with reactive surfaces that can undergo biorthogonal reactions.

13.3 A scalable, high viscosity, and very conductive DWCNT ink for printable electronics and EMI shielding

Dr Atif Aziz, University of Cambridge

Authors: Atif Aziz, (1) Mohamed Basel Bazbouz (1), Mark Edward Welland (1)
(1) University of Cambridge

Carbon-based electronics have seen tremendous progress over the last two decades. However, commercially viable products are still scarce due to the shortage of a facile, environmentally friendly, simple, industrially compatible, and scalable fabrication processes. Carbon materials are chemically very stable and cheap which gives them an advantage over silver inks. However, the use of carbon-based materials as commercial printable conductors has been unattractive due to insufficiently low sheet resistance. In this talk, I will demonstrate that water-based double-walled carbon nanotube (DWCNT) ink can have a very good conductivity of 3.6±0.2x10^5 S/m, and sheet resistance ~0.1 Ω/▫/mil, which can be a good competitor for commercial-scale conductive printing. We have developed a very simple one-step process, which uses a microfluidization system, to disperse a very high concentration (10mg/ml) of CNT in water. DWCNT ink has a viscosity of more than 1Pa-s at a shear rate of 100 s-1. This ink can also easily be diluted in water without any further processing. The inset of the figure below compares the best-reported sheet resistances values, of un-doped carbon films made with multi-walled CNT (MWCNT), single-wall CNT (SWCNT), a few walled CNT (FWCNT), and graphene (GR) conducting inks, with our results of double-walled CNT (DWCNT). Using this ink, we have achieved the highest conductivity and the sheet resistance values to date. [1] The figure also shows the electrical conductivities of DWCNT films as a function of the processing cycles. In the talk, I will explain the microfluidization process and the effect of processing cycles and other parameters on conductivity. Due to good dispersion and conductivity, these printed and free-standing DWCNT films also show excellent thermal as well as electromagnetic shielding (EMI) properties. Summary of the properties: Electrical conductivity: 3.6±0.2x10^5 S/m Sheet Resistance: 0.11 Ω/▫/mil Thermal Conductivity: 43±4 W/m/K Viscosity: >1 Pa-s @ 100 s-1 Areal density of free-standing film: 1.2 gm/m^2 EMI shielding of a 10µm thick film: -60 dB These CNT films also show very good resilience to mechanical deformation and can easily be deposited using, screen printing or spray-coating for making thin-film devices. Using a lab-scale system, the conductive ink has been produced at a rate of 0.5 L/hr which can easily be further scaled up to 50L/hr. The Material cost for these inks is also less than £100/L, making this ink a very viable technology for commercial-scale printing. References [1] Aziz A, Bazbouz M B, Welland M E. Double-Walled Carbon Nanotubes Ink for High-Conductivity Flexible Electrodes. ACS Appl. Nano Mater. 3 (2020) 9385.

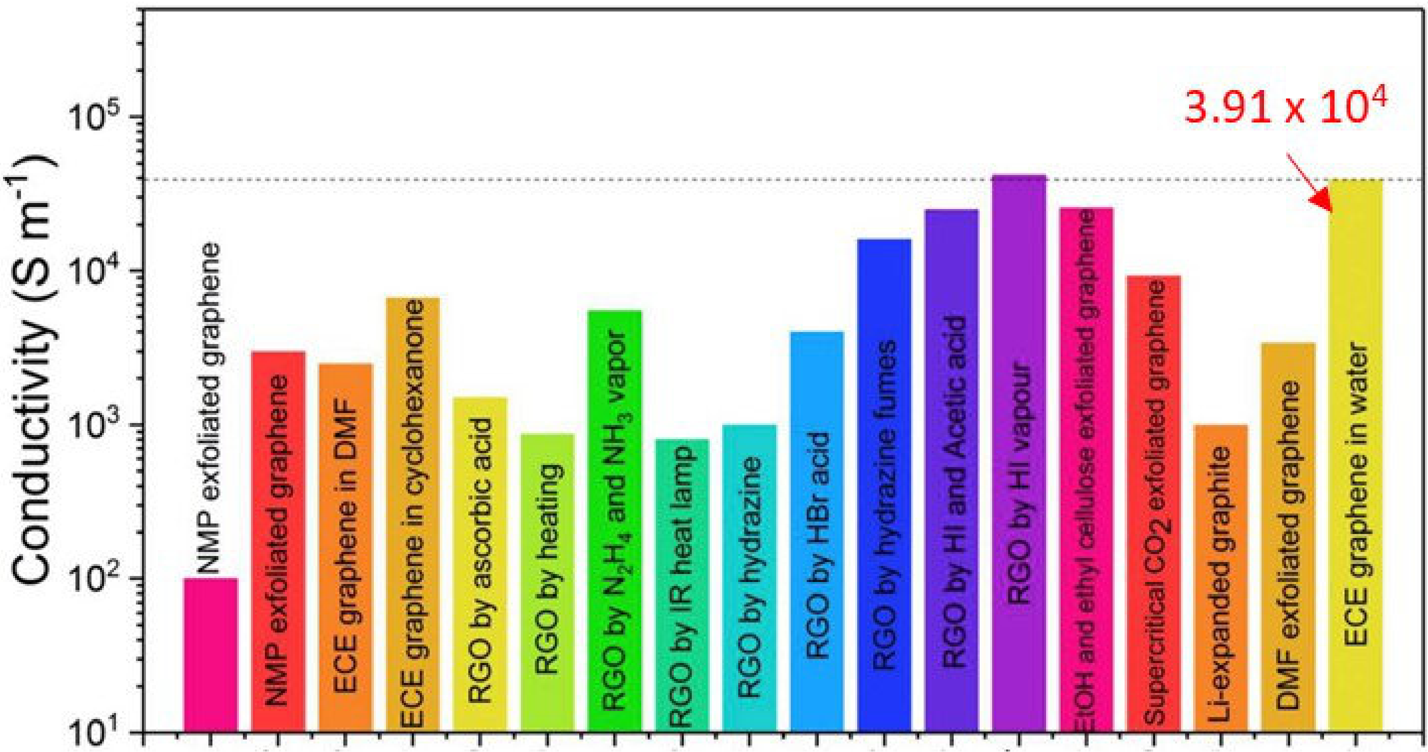


13.4 Water-based inkjet printable inks made by electrochemically exfoliated graphene

Dr Khaled Parvez, University of Manchester

The field of printed electronics has developed rapidly, driven by printing techniques offering low-cost and simple methods for devices fabrication, whilst demonstrating compatibility with most substrates including those that are soft and flexible [1]. Inkjet printing of graphene inks are very attractive for applications in flexible and foldable electronics, such as wearable electronics and the Internet of Things. However, the ink preparation is still very time consuming as high concentrations can be achieved only with prolonged sonication (>24 h) or with expensive setups [2, 3]. In this work, we demonstrate a water-based inkjet printable ink made from electrochemically exfoliated graphene. The printable ink production is achieved in less than 5 h, leading to a stable (for over a month) formulation with concentrations up to 2.25 mg mL-1 [4]. The formulated ink consists of over 75% single and few-layers graphene with average lateral size of 740 nm. Such ink formulation allows stable jetting, rapid ink drying (<10 sec) as well as ensuring wetting of untreated substrates such as paper and glass. Thermal annealing of the printed films allows to achieve high C/O ratio which translates into one of the highest electrical conductivity (i.e. ~3.91 x 104 S m-1) reported so far for solution-processed inkjet printable graphene, without the use of any harsh chemical processing.

References: [1] P. Calvert, Chem. Mater. 13 (2001) 3299-3305. [2] D. McManus, S. Vranic, F. Withers et al. Nat. Nanotechnol. 12 (2017) 343-350. [3] F. Torrisi, T. Hasan, W. Wu, Z. Sun, A. Lombardo et al, ACS Nano 6 (2012) 2992-3006. [4] K. Parvez, R. Worsley, A. Alieva, A. Felten, C. Casiraghi, Carbon 149 (2019) 213-221.



13.5 Nanoscale investigation of degradation mechanisms in triple-cation perovskite films

Filipe Richheimer, National Physical Laboratory

Authors: Filipe Richheimer (1), David Toth, Bekele Hailegnaw (2), Mark A. Baker, (3) Robert A. Dorey (3), Ferry Kienberger (4), Fernando Castro (1), Markus C. Scharber (2), Georg Gramse (2), Sebastian Wood (1)
(1) National Physical Laboratory, (2) Johannes Kepler University, (3) University of Surrey, (4) Keysight

Organic-inorganic halide perovskites have outstanding optoelectronic and material-processing properties that make them promising candidates for absorber materials in next-generation solar cells. The highest performing perovskite cells reach power conversion efficiencies that are in line with those of monocrystalline silicon devices, whilst allowing for scalable, low-temperature deposition methods. A major hindrance to commercialisation of perovskite photovoltaics is the poor operational stability.[1] Under operation, degradation mechanisms driven by both extrinsic (oxygen, moisture) as well as intrinsic (temperature, light, voltage bias, current) stressors, some of which lead to irreversible structural and performance changes. Within a device structure, extrinsic degradation agents may be largely mitigated by effective encapsulation engineering. However, mitigation of intrinsic drivers demands a detailed understanding of the underlying mechanisms and solving these issues could involve changes in elemental composition or surface passivation. In the present work we investigate the nanoscale spatial dependence of early degradation product formation in a triple-cation mixed halide perovskite film, a state-of-the-art composition for efficiency and stability.[2] Using atomic force microscopy (AFM) based measurements in a dry nitrogen environment (simulating effective encapsulation), we observe nucleation of nanoscale (10 nm to 100 nm sized) grains on the perovskite film surface. We distinguish between the effects of electrical current injection and photoexcitation using co-localised electrical AFM and optical illumination to both induce and study the formation of nanograins. By considering the density of nanograins and their positions at grain boundaries and on grain faces, we propose a local field-induced mechanism driven by heterogeneous charge accumulation within the film microstructure resulting in nanograin formation. Specifically, we identify underlying A-site cation volatility enhanced by the local electrostatic environment. Understanding of this mechanism opens doors to potential solutions such as homogenising charge distribution under operational conditions, increasing operational and long-term stability.

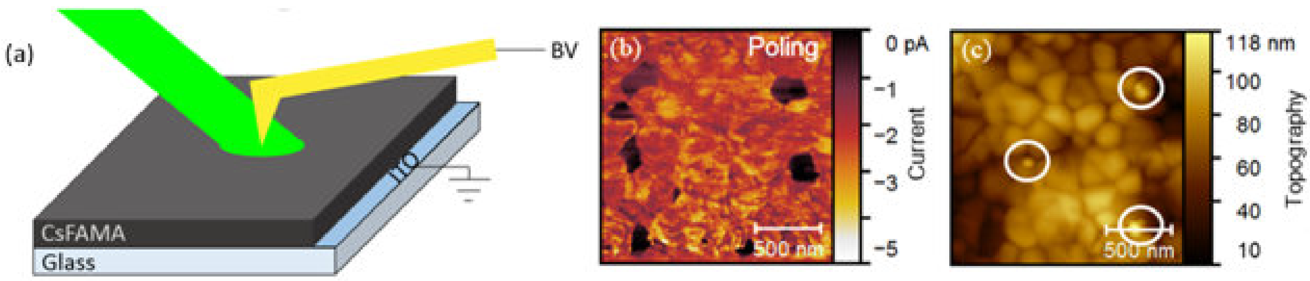


Figure 1. AFM based poling experiments inducing surface nanograins. (a) Schematic of experimental setup used for poling experiments with light and bias. (b) Conductive-AFM map of triple-cation perovskite surface. (c) AFM topography map after poling experiment showing nanograin structures highlighted by white circles.

SESSION 14: POSTER & SPEAKER PRIZES

Speaker Prize

Sponsored by CPI

Poster Prize

Sponsored by Inseto & FOM

innoLAE

SESSION 15: POSTERS

15.1 Manufacturing

15.1.1 **Kyle Homan, Optomec**
Silver Soldering Solutions using Traditional Reflow Processes on Aerosol Jet Printed Circuits

15.1.2 **Andrew Clarke, Swansea University**
Organic photovoltaics: narrowing the performance gap between laboratory-scale and industrially compatible manufacturing methods

15.1.3 **Kai Zhang, University of Oxford**
Scalable Manufacture of Thin Film Capacitors with roll-to-roll process and flexographic printing technique

15.1.4 **Dr Konstantin Livanov, OrelTech**
Plasma metallization: the future of printed electronics

15.1.5 **Dr David Williamson, FOM Technologies**
Thin Films, Built to Scale

15.1.6 **Youngmin Jo, Pohang University of Science and Technology**
Programmable a-InGaZnO Gate Array with Laser-Induced Forward Transfer

15.2 High Performance Materials

15.2.1 **Dr Yameng Cao, National Physical Laboratory**
Quantifying and enhancing spatial homogeneity in 2D materials

15.2.2 **Anna-Marie Stobo, CPI**
Formulation of Inks for SLA Printing of Solid-State Batteries with Controlled Geometry

15.2.3 **Prof Ioanna Zergioti, National Technical University of Athens**
Laser Induced Forward Transfer of Graphene for Flexible Touch Sensors

15.2.4 **Oliver Read, University of Manchester**
Size-Thickness Characterisation of Defect-Free Nanosheets Produced by Pyrene-Assisted Liquid Phase Exfoliation in Water

15.2.5 **Dr Xiuju Song, University of Manchester**
Humidity Sensors Based on Water-based, defect-free and biocompatible 2D Materials Inks

15.2.6 **Dr Omar Kassem, University of Manchester**
Water-based and inkjet printable inks of 2D anatase TiO2

15.3 Novel Devices & Systems

15.3.1 **Balder Nieto, Durham University**
Emerging Photovoltaics levelized cost of energy: Impact of initial efficiency, degradation and module cost

15.3.2 **Dr Mujeeb U. Chaudhry, Durham University**
Low Power/High Efficiency Light-Emitting Transistors for Display Applications

15.3.3 **Dr José Ávila-Niño, CIDETEQ**
Study of the Doping of PEDOT:PSS in Organic Electrochemical Transistors

15.3.4 **Ana Lúcia Poças, CeNTI**
Development of Printed Humidity and Temperature Sensors for Smart RFID Labels With Wireless Energy Charging and Communication Functionalities

15.3.5 **Afshin Dianatdar, University of Groningen**
Polypyrrole- Carbon Fiber Composite For Flexible Energy Storage

15.3.6 **Matteo Hogan, University of Kent**
Polymers for Printed Energy Storage and Integrated Electronics

15.3.7 **Eva Bestelink, University of Surrey**
Multimodal Thin-Film Transistors with Constant Transconductance for Ultra-Compact Analog Circuits

SESSION 15: POSTERS

15.4	**Bioelectronics**
15.4.1	Ijeoma Patrick, Imperial College London Using Fluorine-Substituted Organic Semiconducting Polymers in Organic Field-Effect Transistors for in vitro Biological Interfacing
15.5	**Applications**
15.5.1	Dr Joana Fonseca, CeNTI Active Defrosting Printed Systems for Windows Frames
15.5.2	Panagiotis Mougkogiannis, University of Manchester Prediction of OFET Gas sensor responses by a Quantitative Structure Activity Relationship (QSAR) Model
15.6	**Sustainability**

We are still accepting "Late News Abstracts"

(See our website for further details)

Further poster abstracts will be added as they are submitted.

SESSION 15.1: POSTERS - MANUFACTURING

15.1.1 Kyle Homan, Optomec

Kyle Homan is an Applications Engineer based out of Optomec's European office in Switzerland. Mr. Homan is responsible for developing proof of concept applications for prospective clients using Aerosol Jet technology as well as acting in a support role for existing customers in Europe. Before joining Optomec in 2018, Mr. Homan was a research assistant at the University of Massachusetts Lowell for the Raytheon UMASS Research Institute (RURI) and Printed Electronics Research Collaborative (PERC) focusing primarily on high frequency printed electronics. Mr. Homan obtained his Master of Science in Electrical Engineering degree from the University of Massachusetts Lowell.

15.1.2 Andrew Clarke, Swansea University

Andrew is a final year EngD student at Swansea University working under the supervision of Dr Wing C. Tsoi and Prof James R. Durrant. His research focusses on addressing some of the challenges currently impeding the commercialisation of organic photovoltaics (OPVs). One key focus to date has been on understanding the factors affecting the photostability of OPV devices for both indoor and outdoor applications. More recently, Andrew has been working in collaboration with ARMOR on the fabrication of larger area slot-die coated OPV devices. In this work he has been investigating the reasons behind the differing performances of OPV devices manufactured with different fabrication methods and using this insight to optimise the slot-die coating process for the photoactive layer.

15.1.3 Kai Zhang, University of Oxford

Kai Zhang is a finishing PhD student in Department of Materials, University of Oxford. This research is funded by EPSRC Impact Acceleration Account project, and it is aiming to explore a scalable manufacturing process for thin film capacitors. In my PhD research, I have fabricated organic thin film transistors (OTFTs) and a series of OTFT-based signal conditioning circuits with semi-industrial techniques, and the scalable manufacturing process will facilitate future development of flexible and wearable electronics.

15.1.4 Dr Konstantin Livanov, OrelTech

Dr Konstantin Livanov is the CTO and co-founder of OrelTech. Konstantin is an expert in surface chemistry and composite materials with experience in nanoparticle synthesis and electron microscopy. He has a Ph.D. in chemistry from the Weizmann Institute of Science.

15.1.5 David Williamson, FOM Technologies

David Williamson holds a PhD in Chemical Engineering from the University of Bath and currently works as Head of Science at FOM Technologies A/S.

15.1.6 Youngmin Jo, Pohang University of Science and Technology

Main author is currently pursing the Ph.D degree in creative IT engineering with Pohang University of Science and Technology (POSTECH), Republic of Korea.

15.1.3 Scalable Manufacture of Thin Film Capacitors with roll-to-roll process and flexographic printing technique

Kai Zhang, University of Oxford

Flexible electronics materials have been researched over decades, and the application of flexible electronics have been developed, such as flexible solar cells, displays, and sensors. It is forecast that more flexible and wearable application will be created and accepted by the public, as a result, the demand of flexible electronics will increase significantly in next decade with the development of 5G communication techniques [1]. To satisfy the potential demand of flexible electronics, a scalable manufacture process is needed for industry, and the roll-to-roll (R2R) processing is a very promising reliable solution. Considering the patterning of thin film layers for electronics devices, there are two main streams of printing techniques: contact printing and contactless printing. The former includes screen-printing, flexographic printing, gravure printing and soft lithography, which apply the printing plate directly on the substrate to transfer the material of interest. In contrast, contactless printing techniques apply the objective materials onto substrate with methods, such as by laser direct writing, aerosol printing and inkjet printing [2]. The pattern may be formed directly from the printing technique, or by use of a mask to ensure only localised deposition. In this work, a flexographic processes to deposit a temporary liquid mask to allow for patterned metallization by PVD is integrated with roll-to-roll process and is used to create metal patterns on thin film substrate as electrode materials and conductive tracks for flexible electronics. The patterning mechanism of flexographic printing employs a layer of oil mask to cover specific area and then the uncovered areas will be coated with metal materials during evaporation or sputtering, and the masking oil will evaporate immediately when heated metal particles contact [3]. This results in a high-throughput method with potential to deposit a wide range of metallic materials. However, the residual oil associated with flexographic metallization must be effectively removed to prevent contaminations of subsequent layers. To remove the residual oil, four different surface treatment techniques are used, inline electron beam, plasma treatment, hollow cathode plasma treatment, and Corona charge treatment. The cleaning effect is examined by a conductive bridge test, in which multiple conductive bridges are metallized to connect isolated electrodes, and the interfacial resistance of the connection to the conductive bridge will decrease as the content of residual oil is reduced. Contact angle testing is also used to examine the variance of surface chemical condition. In addition, surface morphological characters will be examined as well. Building on the pattern metallization, the same a flexographic printing technique is used to pattern dielectric materials onto the metallized substrate with evaporation of tripropylene glycol diacrylate (TPGDA) monomer over the liquid mask and then applying electron beam to initiate a cross-linking reaction to form a pattern of stable, flexible, insulating materials on the substrate. Morphological properties and the curing degree will be characterized to conclude a reliable processing method to develop flexible capacitors with flexographic printing integrated roll-to-roll process.

15.1.2 Organic photovoltaics: narrowing the performance gap between laboratory-scale and industrially compatible manufacturing methods

Andrew Clarke, Swansea University

Authors: Andrew Clarke (1), Richard Pacalaj (2), Helen Bristow (2), James Durrant, (2) Wing C. Tsoi (1), Trystan M. Watson (1), Charline Arrive (3), Uyxing Vongsaysy (3)
(1) Swansea University, (2) Imperial College London, (3) Armor Group

In order to meet our ever-increasing demand for energy whilst also addressing the concerns of climate change it is necessary to shift away from the burning of fossil fuels towards greener sources of energy generation. Consequentially, it is foreseen that solar power will contribute significantly to our future energy supply. Currently, most solar energy generation relies on silicon-based photovoltaic (PV) technologies. Whilst the cost of silicon PV has dropped significantly over the past decade, it still has some downsides. For example, the relatively high weight of silicon PV increases installation costs, limits potential applications, and presents environmental concerns associated with shipping and transportation. One technology that has the potential to overcome many of the limitations of silicon PV is organic PV (OPV). OPV devices are comparatively much lighter, are solution processable and can be fabricated with less energy intensive methods on both flexible and rigid substrates. OPV device efficiencies are also rapidly increasing and are now approaching 20% under AM1.5G conditions, bringing increased commercial interest. However, for the successful commercialisation of OPV to be realised, several stumbling blocks remain. One of the major outstanding challenges facing OPV is the difficulty in translating the high device performances achieved with small-scale laboratory manufacturing methods over to larger area, industrially compatible methods. In this work we study a polymer:non-fullerene OPV system and, through a range of advanced characterisation techniques, including the use of high-resolution multi-mapping methods, we attempt to unravel the reasons behind the differing performances of spin-coated, doctor-blade coated and slot-die coated devices. Further, we show that through careful optimisation of the slot-die coating process it is possible to drastically narrow the efficiency gap between the different coating methods and we explain the reasons behind the improved performance.

15.1.4 Plasma metallization: the future of printed electronics

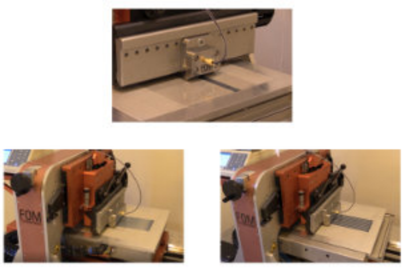
Dr Konstantin Livanov, OrelTech

A clear trend in today's electronic devices is a shift from classical electronics towards lighter and more flexible, both physically and metaphorically, analogues. Printed OLEDs and solar cells, foldable touchscreens and paper-based PCBs are quickly turning from a bold dream to reality. All of these devices and more require metal contacts and circuitry, printing of which has been a well-known bottleneck in the industry. A well-established approach has been top-down deposition of nanoscale particles or wires followed by heat-based sintering, typically in the form of either direct heating or absorption of light (flash UV, laser sintering). High temperatures generated in this process often play a limiting role in the choice of substrates and other associated materials. In addition, sintering is often time-consuming, which is detrimental for roll-to-roll processes, especially in large-area applications. If we look at some manufacturing lines currently in production, for example, we would find that sections of the roll have to be stopped for sintering, which disqualifies them from being real roll-to-roll. An alternative, plasma based sintering or plasma metallization, offers some clear advantages. First, it is not based on heat transfer, but rather on chemical interaction with the target. In combination with specially designed conductive inks, it leads to a bottom-up growth of polycrystalline metal layers with unique properties and special relevance to the printed electronics industry. Plasma metallization is not only energy-conservative and tunable, but also a cold process which does not damage the substrate. And finally, plasma metallization is typically an order of magnitude faster than heating and perfectly suitable for both stack-by-stack and roll-to-roll applications. These factors suggest that plasma processes and specifically plasma metallization are bound to be instrumental in manufacturing of printed electronics products and the development of new applications.

15.1.5 Thin Films, Built to Scale

Dr David Williamson, FOM Technologies

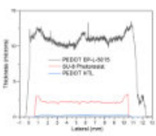
Solution processing of organic and inorganic semiconductors has opened up novel pathways to fabricating advanced thin film devices such as flexible and tandem solar cells, light emitting diodes, transistors, sensors (photo, molecular, piezo) and more, with simple procedures promising compatibility with large scale roll-to-roll manufacturing. Similarly, casting of viscous slurries has been a standard technique in the commercial production of conventional Li-ion batteries and capacitors for decades, which is an important point of consideration for ongoing optimization of conventional Li-ion devices, as well as the development of next-gen solid state batteries and post-lithium chemistries. From the perspective of both researchers developing new solution processed thin film devices, as well as industry establishing large scale production lines, there is a need to demonstrate the scalability of novel processes beyond fundamental research and small areas. At the same time, the tools employed during production of lab samples must afford high quality data, flexible parameter control for experimentation and rapid iteration, and be compatible with a typical lab-scale environment and workflow. Even the smallest true roll-to-roll platforms fail to meet these requirements for experimentation below the pilot production level due to their prohibitive CAPEX and OPEX pre-requisites, and lack of experimental adaptability. As a proxy, more compact, convenient coating and printing techniques such as spin coating, blade coating, inkjet and screen printing are often used to produce solution processed thin films in the lab environment. However, these suffer from a variety of significant weaknesses in the context of lab-scale thin-film research. Spin coating is inherently unscalable beyond areas of a few cm^2, while also failing to replicate material challenges that will be faced during R2R scaling, such as difficult coating of fullerene acceptors in printed solar cells. Blade coating struggles to reach sub-micron thickness with good uniformity. Inkjet is limited in practical throughput speeds, as well as material viscosity and solids content. Screen printing suffers from poor uniformity, repeatability and experimental adjustability due to the hardware modifications required for any material parameter adjustment. Despite the limitations of these technologies in the context of thin film R&D, their lab-scale use remains widespread due to limited comparisons of the performance of these technologies in an R&D setting. Slot-die coating is an established industrial technology with the potential to circumvent many of these limitations at the lab scale due to outstanding flexibility in material compatibility, film thickness range and uniformity, and ease of adjustment. Here we present an overview of the benefits of slot-die coating as a highly flexible research platform, as well as a comparison with other technologies in thin film R&D. This presentation is intended to prompt discussion on the importance of high quality, scalable techniques in modern research, as well as consideration of how existing industrial techniques can be effectively re-invented in a lab-scale form factor to meet the needs of modern academia and industry in bringing new thin film technologies to market.

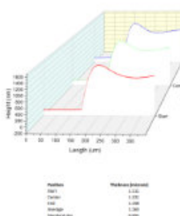


PARAMETER	SPIN COATING	BLADE COATING	SLOT-DIE COATING
Thickness range	~ 10 nm - 100 um	~ 1 - 30 um	~ 10 nm - 100 um
Coating speed (m/min)	-	0.1 - 1,000	0.1 - 500
Max. coating area (cm²)	10 x 10 typically << 25 cm²	400 x L	400 x L
Viscosity range (cP)	< 1,000	< 40,000	< 20,000*
Layer uniformity (%)	< 5	< 10	< 5
Web roughness effect	-	Large	Small
Throughput method	Batch	Continuous	Continuous, intermittent and batch possible
Delivery method	Volumetric, pre-metered	Mechanical, self-metered	Volumetric, pre-metered
Material waste	Very high	Moderate	Very low
Thickness Predictability	Moderate	Moderate	High

*Viscosity range depends on whether the application requires solution processed Slot-Die Coating versus melt based extrusion coating. Extrusion is achievable in a Slot-Die apparatus and functions with much higher viscosities.

Best performance





15.1.6 Programmable a-InGaZnO Gate Array with Laser-Induced Forward Transfer

Youngmin Jo, Pohang University of Science and Technology

Authors: Youngmin Jo (1), Jimin Kwon (2), Jan-Laurens van der Steen (3), Auke Jisk Kronemeijer (3), Sungjune Jung (1)
(1) Pohang University of Science and Technology, (2) Stanford University, (3) TNO,

The gate array is one of most widely used semi-custom methodologies to design and manufacture application-specific integrated circuits in silicon semiconductor industry. It begins with a host of uncommitted transistors on a prefabricated chip, which are interconnected to form many NAND and NOR logic gates. Further interconnection of these logic arrays with the help of metal layers on top of the arrays creates circuits with specific functionality. This technology has been an attractive solution for many electronic systems requiring small or medium volume production because of its low development costs and fast prototype turnaround time. Similar approaches have been adopted to the field of flexible and organic printed electronics to develop application-specific printed integrated circuits. Ishida, et.al. introduced the customizable organic sea-of-gates with inkjet-printed interconnects. Sirringhaus and his colleagues demonstrated the programmable array of logic devices with solution-processed uncommitted organic thin-film transistors (OTFTs) that were later programmed by additive inkjet printing of conductive silver wires and conjugated polymer resistors. Our group has developed the 3D integration of printed OTFTs on plastic foil with high yield, uniformity, and year-long stability. The 3D stacking of three dual-gate organic complementary transistors enabled to demonstrate a programmable 3D NAND array as a new route to design printed flexible digital circuitry. However, an example of programmable gate array technology based on amorphous oxide TFTs has not been demonstrated to date despite its advantages of high performance, reliability, and scalability to large area. In this poster, we propose the use of pseudo-CMOS NOR gates based on dual-gate a-InGaZnO TFTs to demonstrate a gate array programmable by laser-induced forward transfer (LIFT) printing. After evaluating the electrical characteristics of dual-gate TFTs in their top gate and bottom gate modes, we designed and fabricated a pseudo-CMOS NOR gate with the reduced number of TFTs over a conventional one. As a proof-of-concept, we finally demonstrated a negative-edge-triggered D flip-flop by programming NOR gate arrays with the LIFT method.

SESSION 15.2: POSTERS - MATERIALS

15.2.1 Dr Yameng Cao, National Physical Laboratory

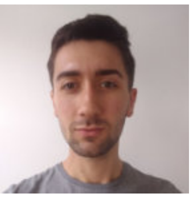
Dr Yameng Cao is a Higher Research Scientist at NPL. His expertise is in optical characterization of semiconductors devices, including III-V nanostructures, 2D materials, and hybrid-perovskites, using techniques including photoluminescence and Raman spectroscopy. He is currently developing novel spectral imaging techniques for fast in-line characterization of wafer-scale luminescent materials.

15.2.2 Anna-Marie Stobo, CPI

Anna-Marie Stobo is a Senior Research Scientist at CPI, based in the North East of England. She is a materials scientist with a research-based MSc from Durham University and BSc in Chemistry from Newcastle University. She has been working in conductive ink formulation for 8 years and has a growing interest in novel materials for additive manufacturing.

15.2.3 Prof Ioanna Zergioti, National Technical University of Athens

Prof Ioanna Zergioti is a Professor at the NTUA, School of Applied Mathematics and Physical Sciences. She studied Physics at the University of Crete and she received the degree at the Foundation for Research and Technology-Hellas, for her work on the growth of thin nanocrystalline Carbide films and mechanisms using laser based processes. In the frame of her PhD research, she worked for the fall semester of 1996 in the Mechanical Engineering Department at the University of California, Berkeley on the LIFT process. After her PhD, she worked as a post-doctoral researcher in the Max Planck Institut fÃ¼r Biophysikalische Chemie in GÃttingen, on Laser matter interactions studies. Then, she worked as a post-doctoral researcher at Philips CFT on Laser Sintering of sol gels for electronics until 2000. Her main research activities are related to the laser printing, patterning, sintering for organic electronics and sensors applications as well as laser matter interaction studies.



15.2.4 Oliver Read, University of Manchester

Ollie is a second-year PhD student from The University of Manchester working in the Casiraghi group on the production and characterisation of solution processed 2D-materials.

15.2.5 Xiuju Song, University of Manchester

Xiuju Song, Marie Curie Fellow of University of Manchester, Her research focused on the systhesis of 2D materials for wearable electronics.

15.2.6 Dr Omar Kassem, University of Manchester

Dr Omar Kassem. Postdoctoral research associate in Casiraghi group at the University of Manchester. The main scope of my work is focused on printing 2D materials for flexible electronics applications.

15.2.1 Quantifying and enhancing spatial homogeneity in 2D materials

Dr Yameng Cao, National Physical Laboratory

Authors: Yameng Cao (1), Sebastian Wood (1), Filipe Richheimer, (1) James Blakesley (1), Robert Young, Fernando Castro (1)
(1) National Physical Laboratory

The emergence of wafer-scale two-dimensional (2D) transition metal dichalcogenide (TMD) films and devices [1] motivates the growing need to quantify the spatial quality of 2D materials. For both research activity and industrial uptake, quantifying how the spatial homogeneity changes with processing (for instance film-transfer and defect-passivation) is crucial to the understanding of defect-physics across multiple length-scales as well as the fabrication of reproducible samples and devices. In this context, single point spectroscopy is clearly insufficient to quantify optical properties in 2D materials and can even be misleading. For instance, we show that photoluminescence (PL) enhancements of a monolayer tungsten disulphide (WS2) can be observed locally while the rest of the sample remains highly inhomogeneous, which is detrimental for manufacturing yield as inconsistent spatial properties will limit device reproducibility. We demonstrate that, by combining spatial-statistics and population modelling, spatial-homogeneity in the PL intensity is closely linked with spectral weighting and that reducing the extent of spectral inhomogeneity (statistical variance) leads to homogeneous PL enhancement. The techniques presented here are expected to be applicable to similar 2D materials and scalable to wafer-scale processes.

This work was funded by the UK Department for Business, Energy and Industrial Strategy (BEIS) through the National Measurement System. Robert Young acknowledges support by the Royal Society through a University Research Fellowship (grant UF160721) [1] K. Kang, K. H. Lee, Y. Han, H. Gao, S. Xie, D. A. Muller, and J. Park, Layer-by-Layer Assembly of Two-Dimensional Materials into Wafer-Scale Heterostructures, Nature 550, 229 (2017).

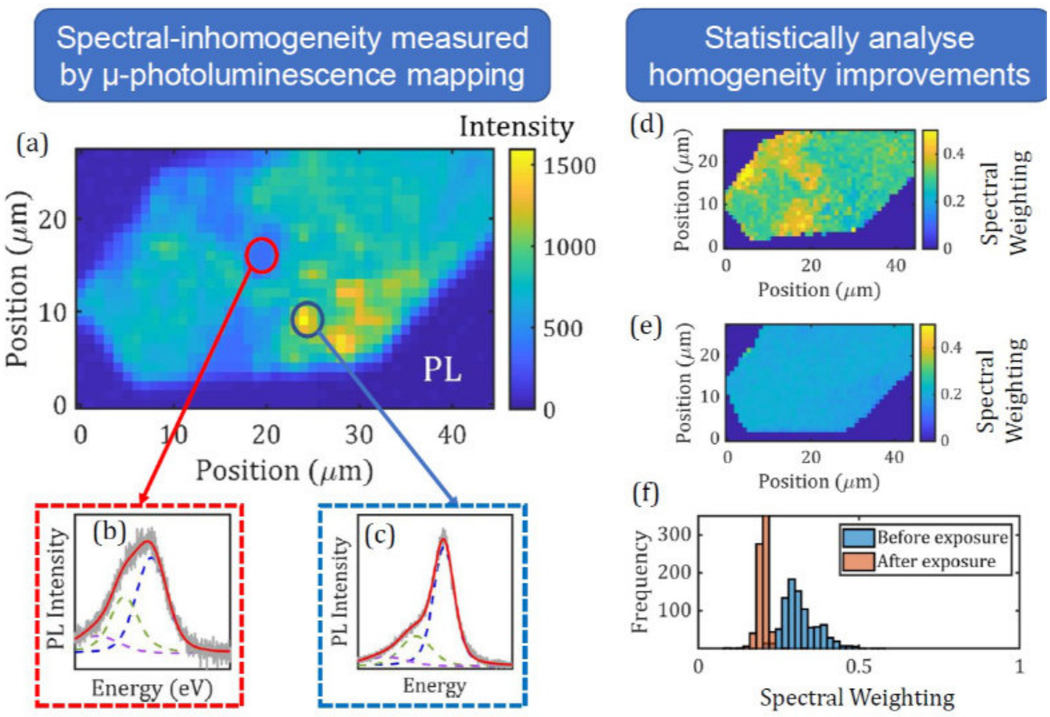


Figure 1 (a) Photoluminescence map of a mechanically exfoliated tungsten disulphide (WS_2) monolayer, with contrasting spectral behaviour in different locations (b) and (c). Spectral weighting (anti-)correlates strongly with the inhomogeneities in PL (d). A simple laser-exposure across the flake leads to a strong reduction in spectral weighting as well as enhancing the spatial homogeneity (e), (f).

15.2.2 Formulation of Inks for SLA Printing of Solid-State Batteries with Controlled Geometry

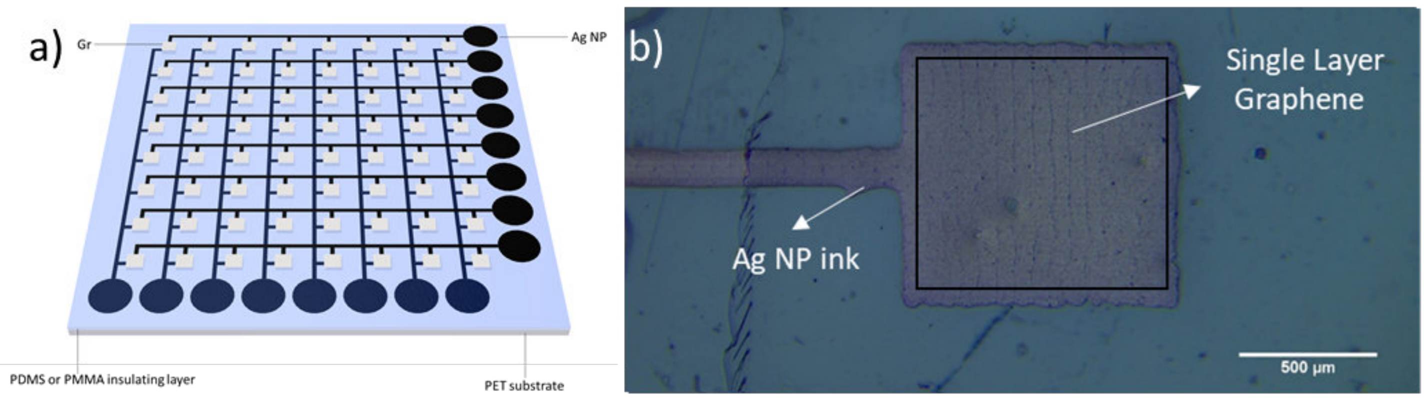
Anna-Marie Stobo, CPI

"3D Printing Solid-State Batteries with Controlled Geometry" is an IUK funded project collaboration between CPI, Photocentric and Johnson Matthey. Solid-state batteries are an area of keen interest due to the potential for high energy density and removal of the hazardous liquid electrolyte, however it is limited by restrictive manufacturing processes. Additive manufacturing, in particular SLA printing, could be key to enabling this technology for two reasons: 1) Digital processing allows easy design changes to create custom configurations for bespoke applications, 2) Ability of AM to create complex structures e.g. lattices to fully control the porosity of electrodes. CPI's role in this project is to formulate novel resins by incorporating functional materials into acrylic photopolymer binders. We are currently working with industrially relevant anode, cathode and electrolyte materials to create a functional solid-state battery, the size of a 14 mm coin cell. To support this activity CPI have developed several characterisation methods to enable fast assessment of these novel photocurable battery inks while minimising material usage, such as 1) Inverse gas chromatography (IGC) to aid selection of binders to match surface energy of particles, and 2) UV-DSC to inform on ink curing to enable early identification of unsuitable materials. This presentation/poster will discuss challenges and considerations when working with these materials, as well as highlighting the potential for this technology to be disruptive in the battery space.

15.2.3 Laser Induced Forward Transfer of Graphene for Flexible Touch Sensors

Prof Ioanna Zergioti, National Technical University of Athens

Current technological trends in flexible and large area electronics highlight the need for precise deposition of highly resolved features, using digital fabrication methods which do not alter their structural and electronic properties upon transfer. In this direction, LIFT has been reported as a reliable, high resolution and digital fabrication tool for flexible electronics, sensors and optoelectronic components [1,2]. This paper will demonstrate a flexible touch-sensing configuration relying on Graphene sensing electrodes. In particular, we will present the fabrication and the performance characterization of the flexible touch sensor and demonstrate the advantages of employing LIFT as the key- enabler fabrication technology. The controllable transfer of Graphene pixels with lateral size ranging from from 15-100 µm, and form factors suitable for applications in flexible and large area electronics has been achieved. The touch sensor consists of an array of parallel plate capacitors (Fig 1a) comprising Graphene as the top electrode, PDMS as the dielectric and Ag nanoparticle (NP) based bottom electrodes. LIFT has been employed both for the digital transfer of the Graphene top electrodes and the printing of the bottom electrodes (Fig. 1 b). Raman spectroscopy and SEM have confirmed the transfer of single layer Graphene pixels on the predesignated sites on the substrate. Four-point probe IV measurements have yielded a sheet resistance in the order of 500 Ohm/sq. Preliminary performance evaluation of the capacitive sensors has shown a reference capacitance in the order of 2-4 pF and confirmed a more than 50% increase of capacitance, owing to the deformation of the dielectric's thickness when stress is applied on the configuration. These results are promising for the development of sensitive Graphene based touch sensor with thin, flexible and lightweight form factors.



15.2.4 Size-Thickness Characterisation of Defect-Free Nanosheets Produced by Pyrene-Assisted Liquid Phase Exfoliation in Water

Oliver Read, University of Manchester

Authors: Oliver Read (1), Yu Young Shin (1), Marco Zarattini (1), Chen-xia Hu (1), Cinzia Casiraghi (1)
(1) University of Manchester

Extensive research into 2-dimensional (2D) materials has been undertaken since the isolation of graphene, owing to its exceptional properties including high electrical and thermal conductivities, mechanical and chemical stability and high optical transparency [1]. Liquid-phase exfoliation (LPE) is one of the most promising routes for large-scale production of solution processed 2D materials. In this process, ultrasound is used to exfoliate the bulk crystal in a suitable stabilising solvent [2]. Typically, organic solvents such as N-methyl-pyrrolidone are used. It has been shown that the size-thickness distributions of nanosheets produced by LPE are dependent on the interlayer and intra-layer binding strength of the material, so each 2D material shows a unique size-thickness relation regardless of the experimental conditions [3]. Water, owing to graphenes hydrophobic nature, can be used for LPE only if stabilising agents are used. In particular, pyrene derivatives have been shown to be effective [4-8], owing to their π-π interactions with graphene, whilst hydrophilic functionalisation provides electrostatic stabilization against re-stacking. This method has been used to produce highly concentrated dispersions and inks of mostly few-layer and defect-free nanoflakes of a range of different layered materials [8]. The dispersions are stable over time and have been used to make several devices by inkjet printing, including photodetectors [8], capacitors and transistors [9]. In this work we show an extensive atomic force microscopy characterization study of the size-thickness relationships of graphene, MoS2 and WS2 nanosheets produced by LPE in water using different pyrene derivatives. Our results show that the average size of produced nanosheets is roughly independent of pyrene functionalisation, whereas the exfoliation efficiency varied with pyrene structure. Exfoliation using the bis-pyrene stabiliser was most efficient, producing thinner graphene nanosheets on average with comparable size. Whereas, the transition metal dichalcogenide nanosheets produced were significantly smaller than graphene when the same stabiliser was used. The nanosheets size was shown to scale with thickness and layer number by a power-law with a comparable exponent, regardless of stabiliser type or material class, which was attributed to processes occurring during sonication. The relation observed is off-set towards different sizes and thicknesses depending on the material or stabiliser used and can be affected by centrifugation and different methods of estimating the layer number. These findings possibly suggest that an alternative exfoliation mechanism involving intercalation of the pyrene derivatives occurs, as opposed to exfoliation in common solvents [3]. Further design and optimisation of pyrene derivatives may provide a route to the scalable production of 2D-material dispersions with desirable size and thickness required for applications in printed electronics and life sciences.

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15.2.5 Humidity Sensors Based on Water-based, defect-free and biocompatible 2D Materials Inks

Xiuju Song, University of Manchester

Authors: Authors: Xiuju Song (1), Liming Chen (1), Wuliang Yin (1), Cinzia Casiraghi (1)
(1) University of Manchester

2-dimensional (2D) materials show great promise in sensing applications due to their unique chemical and physical properties, high surface area-to-volume ratios and ultra-high surface sensitivity to the environment [1]. In particular, solution processed 2D materials offer a simple and low cost way to fabricate a wide range of sensors [2]. Our group has recently demonstrated stable, highly concentrated and defect free 2D materials (graphene, hBN, MoS2, WS2, etc) based inks [3], produced by liquid-phase exfoliation assisted by pyrene derivatives [4, 5]. These inks have been exploited for a wide range of printed devices, from photodetectors [3] to memories [3], and from capacitors [6] to transistors [7]. In this work we make a comparative analysis on the relative humidity (RH) sensing ability of the different 2D materials inks available in our group. The devices are made by dropcasting the material onto a pre-fabricated comb electrode and then an AC voltage is applied to measure how the impedance changes with the RH. The devices are also measured at fixed RH, but at different temperature, in order to investigate cross-sensitivity issues. We found that graphene shows the poorest performance due to its metallic nature. The best 2D material shows a sensitivity 3 order of magnitude larger than the state-of-art polydopamine [8] in a wide range of relative humidity from 7% to 93% [9]. The humidity sensor was further investigated for the real-time human activities monitoring.

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15.2.6 Water-based and inkjet printable inks of 2D anatase TiO2

Dr Omar Kassem, University of Manchester

Authors: Omar Kassem (1), Marco Zarattini (1), Khaled Parvez (1), Alexandre Felten (2), Cinzia Casiraghi (1)

(1) University of Manchester, (2) Université de Namur

Graphene, a single layer of graphite, is the most famous 2-dimensional (2D) material. However, the family of 2D material is very large and contains crystals with complementary properties to those of graphene [1]. In addition, to traditional 2D materials obtained by top-down exfoliation of layered bulk crystals, additional 2D materials can be made by using bottom-up approaches. The interest for non-layered 2D nanomaterials, such as metal oxides, noble metals and metal chalcogenides, has strongly increased because the 2D dimensionality can give rise to different properties, compared to the 3D counterpart [2-4]. In particular, the family of 2D Transition Metal Oxides (TMOs) has attracted significant attention due to their enhanced catalytic properties [5], colossal magnetoresistive effect [6], and superconducting properties [7]. Amongst TMOs, anatase TiO2 is one of the most famous material because of its outstanding photocatalytic properties, combined to nontoxicity, low cost and environmentally friendly nature [8]. In this work, 2D anatase TiO2 nanosheets were successfully synthesized by hydrothermal process, without the use of any toxic capping agent, in contrast to all previous works. Structural characterization was carried out by X-ray diffraction and Raman spectroscopy, which confirmed the formation of the anatase phase. Using atomic force microscopy, the average lateral size and the thickness of TiO2 nanosheets were estimated to be 50 nm and 3 nm respectively. X-Ray Photoelectron Spectroscopy (XPS) was used to investigate the composition and electronic states of the nanosheets. The material was then successfully formulated into a water-based printable ink [9], and deposited on flexible substrates, such as plastic and paper by using a drop-on-demand piezoelectric inkjet printer. The droplet ejection was stable and no satellite droplets or nozzle clogging were observed, making this ink to be ready to be exploited in devices.

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SESSION 15.3: POSTERS - DEVICES

15.3.1 Balder Nieto, Durham University

Balder Nieto is a Mexican fourth year Engineering PhD student in Durham University, UK, and his focus is on improving the lifetime of Organic Photovoltaics (OPVs) and analyzing the viability of emerging PV through Levelized Cost of Energy (LCOE) modelling. He held his first international oral presentation at the Berlin nanoGe conference in Nov of 2019, which was very well received by the audience. The work presented in this conference was published as a scientific article in the Solar Energy Materials and Solar Cells journal.

15.3.2 Dr Mujeeb U. Chaudhry, Durham University

Dr Mujeeb U. Chaudhry is an assistant professor of electronics at Durham University, UK. He obtained his Ph.D. degree from the Institute of Semiconductor and Solid-State Physics of Johannes Kepler University Linz, Austria. He then joined the Centre for Organic Photonics and Electronics at The University of Queensland, Australia. In 2016, he moved to Durham University, UK on a research fellowship. His research interests are organic semiconductors, optoelectronics, and low-cost processing.

15.3.3 Dr José Ávila-Niño, CIDETEQ

Dr José Ávila-Niño received his PhD. and M.Sc. in Applied Science from the Universidad Autónoma de San Luis Potosí, Mexico in 2012 and 2008 respectively. After that, he got experience in the fabrication of organic memories and organic transistors doing postdoctoral studies at Bangor University, UK (2014-2015) and Instituto Potosino de Investigación Científica y Tecnológica (2016-2017) Dr. José Ávila-Niño is currently working at IDETEQ in the state of Querétaro, México, which is a government center of research in Electrochemistry and he is now developing in the fabrication of energy storage, sensors, and electronics based on polymers.

15.3.4 Ana Lúcia Poças, CeNTI

Ana Lúcia Poças has a master's degree in Chemical Engineering from the Faculty of Engineering of the University of Porto (FEUP), with the specialization in Biotechnology field. Since 2018 she is a researcher at Smart Materials department, at CeNTI, collaborating on several research and development projects, with national and international companies. In these projects, she has been working on the study and development of flexible sensors (capacitive, resistive, and electrochemical) using screen printing technology, as well as the respective integration.

15.3.5 Afshin Dianatdar, University of Groningen

Afshin Dianatdar completed his BSc. degree in chemical engineering in University of Tabriz (Iran) and his MSc. in chemical engineering in Iran University of Science and Technology. Subsequently, he worked for a year as a Senior Associate of chemical department in Samsung C&T Corporation. On November of 2017, he started his PhD in University of Groningen with research focus on vapor-phase synthesis of conductive polymers.

15.3.6 Matteo Hogan, University of Kent

Matteo Hogan was born in Vicenza, Italy. He received the B.Sc. and M.Sc. degrees in physics from the University of Kent, Canterbury, U.K., where he has submitted his thesis for his Ph.D. degree. He is experienced with in-situ cycling XAS measurements of lithium-ion batteries and electrochemical analysis. His current research interests include the development and manufacturing of materials for energy storage, solid state batteries and integrated electronics.

15.3.7 Eva Bestelink, University of Surrey

Eva Bestelink graduated with a BEng in Electronic Engineering with Nanotechnology at University of Surrey in 2018 and joined the Advanced Technology Institute under the supervision of Dr Radu Sporea. Her PhD research focuses on unconventional contact-controlled thin-film transistor (TFT) architectures, particularly the newly-invented multimodal transistor (MMT). Eva's main interest in research is the exploitation of contact effects to optimise device and circuit performance and/or create novel functionality for low-cost, large area electronics.

15.3.1 Emerging Photovoltaics Levelized Cost of Energy: Impact of Initial Efficiency, Degradation and Module Cost

Balder Nieto, Durham University

Emerging Photovoltaic (PV) devices based on organic (OPV) and perovskite (PVK) absorber layers are attractive to academia, researchers and industry due to their rapidly improving power conversion efficiency (PCE) and their ability to convert light into electricity using minimal amounts of active material, resulting in low-cost manufacture [1,2] of lightweight and flexible solar cells. However, one of the main roadblocks for commercialization of these emerging technologies is that they degrade faster than the already established silicon PV modules, which offer warranties of less than 0.7% degradation rate per year during their 25-year lifespan [3]. The established metric by which energy generation technologies are compared is the Levelized Cost of Energy (LCOE), which accounts for the accumulated energy and associated costs over the lifetime of a project. Here, an LCOE model quantifies for the first time the impact of rapid degradation at the start of a module's life (burn-in) that is characteristic of emerging PV technologies. This LCOE model is used to examine the importance and inter-relationship of degradation (burn-in and linear), module cost and initial efficiency of emerging PV devices from a cost-competitive point of view, using PCE and degradation data sourced over a 7-year period in the literature as an input. It is found that devices with 'champion' initial power conversion efficiencies are not those with 'champion' LCOE due to largely uncorrelated degradation. This shows that degradation plays a significant role in determining the LCOE, in turn suggesting that measurement of degradation in emerging photovoltaics should be given greater prominence if LCOE is to be optimised. Further, the optimal route to optimise LCOE is shown to depend critically upon the present module cost, initial efficiency, and following degradation offered by a technology, which means that optimal strategies to improve LCOE are specific to individual active layer compositions. Notwithstanding this challenge, the data suggest that if modules can achieve the same characteristics as some of the cell level OPV and PVK devices examined here, emerging PV can compete on wholesale electricity markets. The framework presented here will also help ascertain how emerging PV technologies may prove economically viable in different markets and applications. For example, measures which can affect fixed costs, such as rooftop installation, printing on materials, encapsulation in panes, low light performance, and so on, can be evaluated using an LCOE approach. As such, an LCOE modelling approach influences not only technology choice, but also the direction of research to applications for that technology, extending beyond the wholesale market approach considered here.

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15.3.2 Low Power/High Efficiency Light-Emitting Transistors for Display Applications

Dr Mujeeb U. Chaudhry, Durham University

Organic light emitting diode based active matrix (AM-OLED) displays have been successfully commercialised for mobile phones and televisions but require each colour pixel to be coupled to a transistor that modulates current and hence the light emission. The traditional silicon backplane used for this is still significantly more energy intensive, complicated and costly to manufacture than the OLED components and the two are not readily integrated. In addition, the intrinsic non-uniformity in polycrystalline-silicon backplane transistors severely limits display size and their fabrication processes do not obviously map onto the potential of OLEDs, especially those processed from solution on flexible substrates using high-throughput printing and coating. The development and integration of novel low-cost backplane circuitry is therefore needed. Organic and solution processed metal-oxide semiconductors might provide a suitable alternative to silicon, but their mobility remains lower than required for conventional thin-film transistor design, again especially for low-temperature-processing compatible with plastic substrates. This drives a need for new classes of device that make pixel fabrication simpler and lower cost. Light emitting field -effect transistors (LEFETs) integrate light-emission of an OLED with logic functions of a transistor into a single device configuration. This integration provides access to low cost and simplified display pixels as it removes the requirement of separate high mobility-driving transistors. The fabrication challenges in lowering their operating voltages and enhancing their emission efficiency along with the technological advantages and potentials s of LEFETs will be presented.

15.3.3 Study of the Doping of PEDOT:PSS in Organic Electrochemical Transistors

Dr José Ávila-Niño, CIDETEQ

Organic Electrochemical Transistors (OECTs) are devices that work mainly as transducers that convert an ionic signal into an electrical signal, and they show attractive advantages such as compatibility with flexible substrates, biocompatibility, easy manufacture, and low operating voltage (<1 V). The active material in this device is the conducting polymer poly (3,4-ethylenedioxythiophene) poly (styrene sulfonate) (PEDOT: PSS) in which redox reactions occur due to the presence of ions in an electrolyte [1]. As the PEDOT: PSS film is in contact with an electrolyte, the PEDOT:PSS film changes their resistance according to the number of ions. Positive ions in the electrolyte cause a reduction of the PEDOT+ chains, therefore the device change from a conductive state (ON) to a non-conductive state (OFF) [2]. The OECT used gold electrodes as source and drain and an Ag/AgCl reference electrode as a gate electrode. The ON/OFF ratio must be sufficiently high for applications as sensors of small quantities of ions. Doping the PEDOT:PSS films with a high boiling point solvent improves until three orders of magnitude the films' conductivity due to the reordering of the PEDOT+ conductive chains [3]. In this work, we found that a high electric conductivity of the PEDOT:PSS films are related to better performance (higher ON-OFF ratio and higher transconductance) of the OECTs. In conclusion, we found that the EG-doped PEDOT:PSS films are an attractive option for application in ionic detection.

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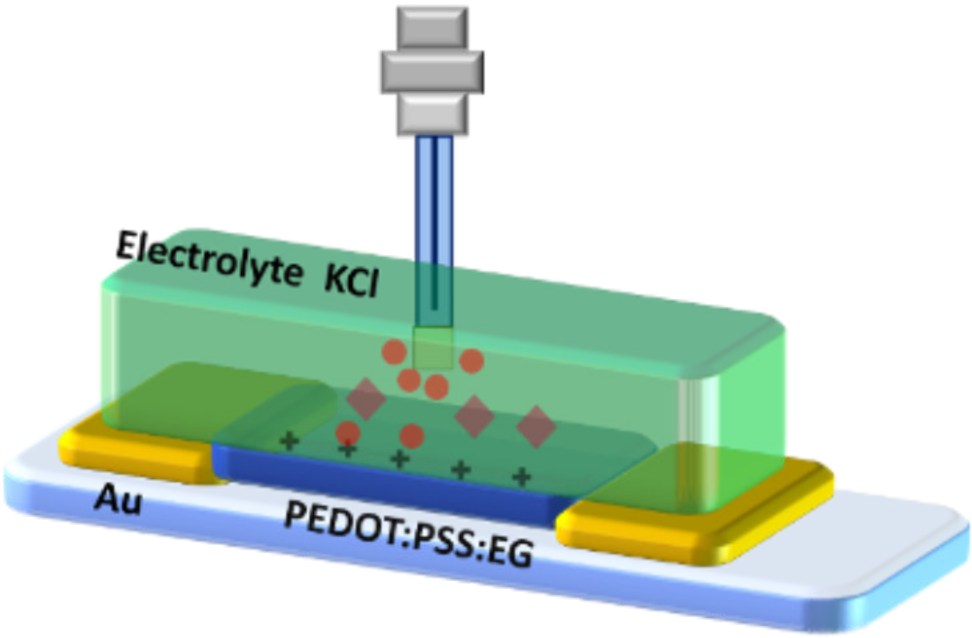

15.3.4 Development of Printed Humidity and Temperature Sensors for Smart RFID Labels With Wireless Energy Charging and Communication Functionalities

Ana Lúcia Poças, CeNTI

Authors: Silvia Reis (1), Rui Mesquita (1), João Silva (1), André Pinto (1), Sarah Brito Bogas (1), Jose Matos (1), Ana Lúcia artins de Almeida Poças (1), Joana Diniz da Fonseca (1), Paulo Soeiro (2), Jorge Guimarães Sousa (2), Gonçalo Silva (2), Joana Pimenta (1), Hugo Filipe Simões Costa (1), Paulo Castanheira (2)
(1) CeNTI, (2) Visabeira Global

Project Vi-TAG aims to develop fully customized and bespoke solutions to the logistics and transport sectors, by integrating wireless sensing/monitoring technologies based printed and integrated electronics systems, coupled with wireless communication capabilities, into box storage structures and other handling equipment. Vi-TAG is developing a smart RFID label integrated with systems with wireless energy charging and with greater autonomy, sensing and communication, directly in the outside of transaction box goods. The objective is to create a solution that is adaptable to different environments (inside and outside the distribution van) and production units, ensuring that it does not negatively interfere with production activities, but rather as a boost for greater fluidity of service. Therefore, the proposed solution includes the development of a printed smart RFID label, integrated in cartons, or other material/substrate carrying the goods, with 3 or more types of integrated sensors, responsible for collecting information about the environment surrounding the box, and by sending this data to the company's stock management software. The printed RFID antennas but also the temperature and humidity sensors were processed using a combination of different screen-printed and wet coating technologies using several substrates for subsequent integration by lamination to produce a full smart RFID TAG. The study describes the manufacturing and morphological and electrical characterization of RFID UHF printed antenna and printed temperature and humidity sensors exposed to different environments and atmospheric conditions. The project consortium is constituted by VIATEL, the promoting company, and CeNTI, an R&D entity, as co-promoter. With an overall investment of 466.647,14 €, Vi-TAG project is co-financed by Portugal 2020, under the Operational Programme for Competitiveness and Internationalisation (COMPETE 2020), in the amount of 301.189,44 € from European Regional Development Fund (ERDF).

15.3.5 Polypyrrole- Carbon Fiber Composite For Flexible Energy Storage

Afshin Dianatdar, University of Groningen

Authors: Afshin Dianatdar (1), Francesco Picchioni (1), Ranjita K.Bose (1)
(1) University of Groningen

Intrinsically conductive polymers (ICPs) have recently attracted a lot of interest in the field of wearable energy storage devices.[1] However, in their unmodified form, they do not dissolve in common organic solvents,[2] which makes their wet processing challenging. Therefore, they need to be structurally modified (which negatively impacts their conjugation) and later be dissolved in toxic halogenated solvents, which is undesirable for potential scale-up and commercialization.[3] Additionally, coating substrates such as paper, plastic, or fabric, that are attractive options in wearable electronics is challenging, due to compatibility issues as well as surface defects that arise during wet processing. To this end, solvent-free methods for ICPs processing has been extensively explored in the past decade. Among dry methods, oxidative chemical vapor deposition (oCVD) has shown to be a promising one providing the possibility for a one-step ICP synthesis and film formation on any desired substrate.[4] oCVD draws on the traditional chemical vapor deposition (CVD) which is typically used for inorganic coatings. Since CVD is a mature and well-understood technology, we expect oCVD to also have a strong potential for industrial adoption.[5] In this work, polypyrrole as one of the most promising ICPs with widespread applications in wearable electronics has been synthesized by oCVD. A record conductivity of 137 S/cm is achieved by tuning the reaction condition at a low temperature of 40 C. The deposition rate and doping level could be controlled by reactor pressure, substrate temperature and reactants ratio. These parameters are also used to uniformly and conformally coat the 3D network of the fabric, resulting in a high specific surface area. The polymer-coated fabric was then tested for energy storage application by cyclic voltammetry, galvanostatic charge-discharge measurements and cycling stability. The results show that ICPs processing could be used as a promising method for coating of unconventional substrates (fabric in this case). Due to its compatibility with roll-to-roll manufacturing , it is an attractive option for scale-up and commercialization in the future.

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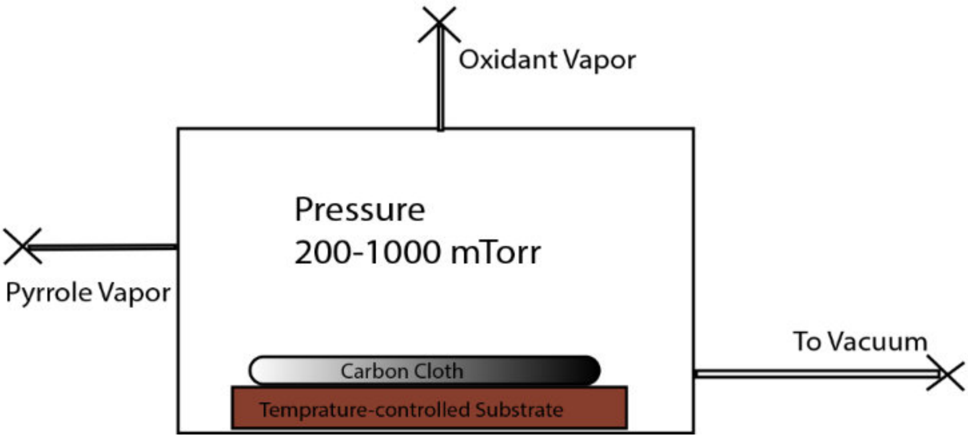
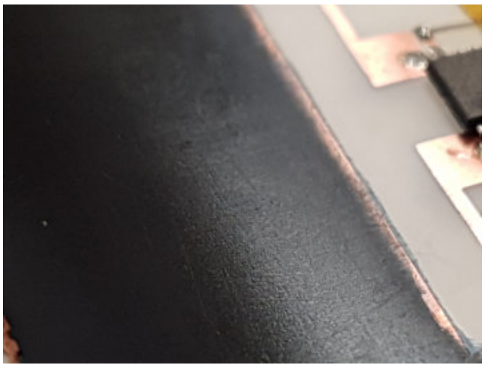


15.3.6 Polymers for Printed Energy Storage and Integrated Electronics

Matteo Hogan, University of Kent

Authors: Matteo Hogan (1), John Batchelor (1), Robert Horne (1), Maria Alfredsson (1)
(1) University of Kent

For energy storage in the portable electronics market, Li-ion batteries remain the preferred choice for many applications, due to their high specific energy. However, current battery technologies have flaws associated with both their chemistries, manufacturing methods and architecture. Battery and device architectures are regularly kept as separate entities during product design, and only put together in the final design, unnecessarily increasing device footprint, costs and weight. Herein, we explore an alternative approach to these limitations, by developing energy storage materials suitable for use in printed electronics and integrated battery-antenna systems. With the aim of developing a printed, all-solid-state, flexible, wearable, on the body battery antenna system. Presented are polymer based electrode and electrolyte materials with the ability to form free-standing films for use in printed, flexible and stretchable lithium-ion batteries. The PEGDA based solid polymer electrolyte membrane (PEM) shown in Figure 1 exhibits strong performance characteristics, including strong mechanical properties, high ionic conductivities and high thermal stabilities, along with impressive electrochemical performance and rate capabilities. PEDOT:PSS conducting polymer is explored as a novel electrode material and as an alternative anode material due to its ability to be processed in aqueous solutions, its dual-conducting nature and its ability to form free standing films Figure 2. Its dual-conducting characteristic allows for the removal of inactive materials from the electrode such as conductive additives (carbon black), which can increase energy density. PEDOT:PSS is commercially available and already widely used in the field of printed electronics, here we explore its use as an electrochemically stable, energy storage material with the potential of forming current collector free batteries. Both of these materials are designed to be printed directly onto and fully integrated with printed electronics for sensing and antenna applications. Their flexibility allows for use in low profile, body-worn electronics without unnecessary bulk or weight. Figure 3 shows a PEDOT:PSS anode material printed directly onto a RFID slotline antenna.



15.3.7 Multimodal thin-film transistors with constant transconductance for ultra-compact analog circuits

Eva Bestelink, University of Surrey

Authors: Eva Bestelink (1), Olivier de Sagazan (2), Radu A. Sporea (1)
(1) University of Surrey, (2) Université de Rennes 1

Display technology has dominated the large area electronics (LAE) application space for decades, where thin-film transistor (TFT) uniformity and reliability of operation are paramount. But when it comes to flexible and/or low-cost fabrication, such as roll-to-roll or inkjet printing, device variability suffers, necessitating additional support circuitry. This ultimately impacts yield, as circuit failure increases with component count [1]. Hence, there is a need for robust devices that can withstand imprecise manufacturing and allow for highly compact circuits in various materials. The multimodal transistor (MMT) is a multi-gate contact-controlled TFT, which offers extended functionality beyond other architectures. Its unique operation is enabled by charge injection over an energy barrier at the source, which is exclusively modulated by the current control gate (CG1 of Fig. 1a). The channel gate, CG2, simply permits or denies current flow without affecting its magnitude [2]. One of the MMT's features is its inherent ability to produce a drain current that is linearly dependent on CG1 voltage, i.e. constant transconductance (gm = dID / dVCG1), and can be designed to produce a directly proportional dependence of output on input (Fig. 1b) during saturation (Fig. 1c), where the output characteristics are extremely flat, due to the source energy barrier. These features cannot be replicated in conventional TFTs, which produce a quadratic dependence of output on input, and linearization techniques generally require large circuits for current conditioning or stability. Aside from benefits including low operating voltages, power efficiency, high gain and robust operation, the MMT's linear behaviour would be highly advantageous in analog circuits for bio-sensing, signal processing at the edge and/or neuromorphic computation. As MMTs are material agnostic, they can be manufactured alongside conventional TFTs, where circuit designers can leverage the benefits of each architecture. Fig. 1. a) Top-view photomicrograph of a microcrystalline silicon multimodal transistor (MMT). CG1 controls charge injection in the source-CG1 overlap region (S) and CG2 controls the on/off switching in the channel (d). b) Device geometry can be tailored to produce a directly proportional dependence of drain current on CG1 voltage (constant transconductance, gm). CG2 is biased to allow for current flow without affecting its magnitude. Simulations performed in amorphous silicon, highlighting material agnostic behaviour. c) MMT output characteristics with low operating voltage and high gain, demonstrating linear dependence in saturation. Acknowledgements The project was supported through EPSRC grants EP/R511791/1 and EP/R028559/1. Device prototyping was performed on the NanoRennes platform.

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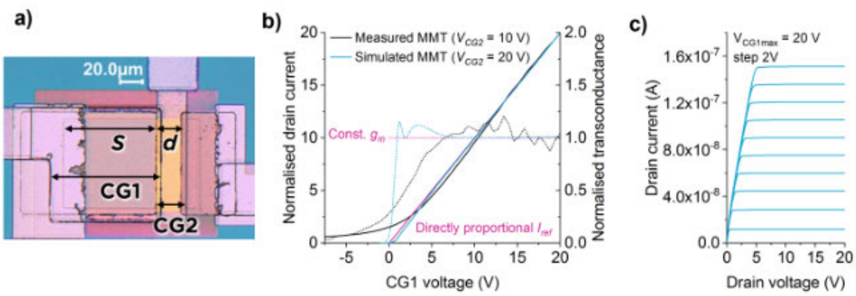


SESSION 15.4: POSTERS - BIOELECTRONICS

14.4.1 Ijeoma Patrick, Imperial College London

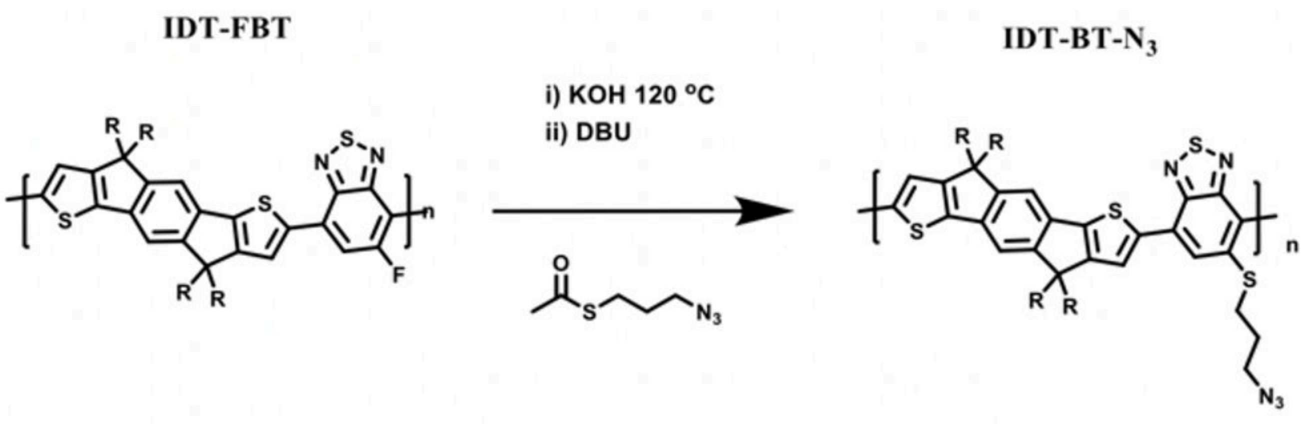
Ijeoma is a 2nd year PhD student in the group of Professor Molly Stevens, Department of Materials. Her research is focused in organic bioelectronics, developing organic transistor-based biosensing platforms for in-vitro diagnostics

15.4.1 Using Fluorine-Substituted Organic Semiconducting Polymers in Organic Field-Effect Transistors for in vitro Biological Interfacing

Ijeoma Patrick, Imperial College London

Authors: Ijeoma Patrick (1), Adam Creamer (1), Stuart G. Higgins (1), Martin Heeney (1), Molly Stevens (1)
(1) Imperial College London

Conjugated polymers are attractive choices for bioelectronic applications. They can form flexible devices which comply to the "soft" nature of biological tissues, conduct electrical and ionic charges and are compatible with low-temperature solution processing. The structure of organic materials can be synthetically tuned to provide material, electrical and biological properties. Functionalisation of organic semiconductor surfaces with biomolecules can enhance cellular adhesion and biorecognition elements grafted onto an organic transistor-based device transduce biological events into electronic signals. We previously reported a novel strategy for the direct functionalisation of organic conjugated polymers, post-polymerisation, on fluorinated polymer nanoparticles via a quantitative nucleophilic aromatic substitution reaction. This allows the incorporation of reactive handles (azide, carboxylic acid) onto the backbone which and through copper-free click chemistry a wide variety of biomolecules can be conjugated to the thin film surface whilst leaving the bulk of the polymer unmodified to preserve charge transport. Here we investigate the fluorine-substituted version of the high field-effect mobility conjugated polymer indacenodithiophene-co-benzothiadiazole (IDT-FBT) as the active layer in organic field-effect transistor-based biosensors and present a versatile material platform for diagnostics applications.



SESSION 15.5: POSTERS - APPLICATIONS

15.5.1 Dr Joana Fonseca, CeNTI

Joana Fonseca holds a PhD in Chemistry and is a researcher at CeNTI since 2010, working in the area of printed electronics and embedded systems. Possesses extensive expertise in polymeric-based electrochromic devices, ranging from their design and construction to their characterization, and in capacitive sensors embedded in non-conventional substrates such as textiles, artificial leather and thermoformable polymeric substrates. During In the last years, she has been involved in several national and European industry driven projects as Project Manager. She has also been a mentor of several Master's and Ph.D. students in the field of OLAE.

15.5.2 Panagiotis Mougkogiannis, University of Manchester

Panagiotis Mougkogiannis has just completed a PhD program at the University of Manchester investigating organic field effect transistors for gas sensing.

15.5.1 Active Defrosting Printed Systems for Windows Frames

Dr Joana Fonseca, CeNTI

Authors: Joana Diniz da Fonseca (1), Daniela Campanhã (1), Sarah Brito Bogas (1), Ana Lúcia Martins de Almeida Poças (1), Isaque Sá (1), André Leite (1), Frederico Ferreira (2), André Almeida (3)
(1) CeNTI, (2) Amiito Tech, (3) Eco Steel

Over the last years, there is a tendency for home automation solutions become more autonomous, to improve comfort, security, air quality and even power saving. Benefiting from the last technologic advances in sensing, data analysis and actuation systems, they can monitor parameters such as temperature, humidity and noxious gases concentration, with high liability and precision and perform autonomously several actions from open a window to improve air quality to regulate in customised manner a temperature of a room. From a partnership between CeNTI, a Portuguese Centre of Nanotechnology and Smart Materials, and ECOSTEEL, a renowned Portuguese windows manufacturer, has resulted in a funded R&D project SmartFRAME. The project aims to develop a window frame with new features that allow effective ventilation, automatic sealing, gesture control, among others, to improve energy efficiency, comfort, security, and the ability to interact with the end-user. For the different sensing and actuation functionalities, new manufacturing technologies were investigated to lower costs and/or improve performance. As a relevant project result, printed technologies were successfully employed to develop heating systems for the intelligent windows frame, to prevent the formation of ice that can result in the occurrence of floods, as well as the condensation on glass surfaces. Comparing to more conventional systems, the printed systems present some advantages. They are more flexibly, lightweight, are easier to adapt to several surfaces and have low production costs. The research work was focused not only on the optimization of flexible, thin and efficient heating systems but mainly in maximizing the energy efficiency of the overall system. The developed heating bands were dimensioned to operate at 24 V, with a maximum power of 80 W/m. Good uniformity heating power was verified along 2.5 m length. These heating circuits were characterized in a climate chamber at low temperatures simulating real conditions, frames at -10 °C and -20 °C, with water accumulation. The optimized systems were able to defrost water accumulated in a typical window frame as well as to increase the water temperature. The system also revealed to have a short response time, increase the water temperature to 10 °C in approximately 10 – 15 min.

The project consortium is constituted by ECOSTEEL, the promoting company, and CeNTI, an R&D entity, as co-promoter. With an overall investment of 755.872,39 €, SmartFRAME project is co-financed by Portugal 2020, under the Operational Programme for Competitiveness and Internationalisation (COMPETE 2020), in the amount of 525.099,65 € from European Regional Development Fund (ERDF).

15.5.2 Prediction of OFET Gas Sensor Responses by a Quantitative Structure Activity Relationship (QSAR) Model

Panagiotis Mougkogiannis, University of Manchester

Authors: Krishna Persaud (1), Panagiotis Mougkogiannis (1), Michael Turner (1)
(1) University of Manchester

Gas sensors based on Organic Field Effect transistors operating at low voltages (3V) with a diketopyrrolopyrrole sensing layer were investigated. These were solution processed bottom-gate bottom-contact devices previously described [1]. The interaction between volatile molecules and the sensing layer to produce a signal is a complex process and there has been controversy over proposed sensing behaviour models [2]. This study measures the response of organic field effect transistors (OFETs) towards amines and alcohol vapours. An empirical model considering Antoine's constant (AntC) and enthalpy energy (ΔHV) descriptors was found to be a good predictor the response characteristics of the OFET devices. The responses to a series of alkyl amines, ammonia, trimethylamine, triethylamine, dibutylamine, n-butylamine and propylamine over a range of concentrations were investigated. It is observed that the highest sensitivity (SEN) is to dibutylamine (10 %ppb-1) and the lowest is to triethylamine (0.015 %ppb-1). There was good agreement between the predicted sensitivity and the experimental data. For example, the theoretical sensitivity for dibutylamine and triethylamine is 0.013 %ppb-1 and 14.73 %ppb-1 respectively. Levels of sensitivity were also found to follow the Quantitative Structure Activity Relationship (QSAR): Log S_EN = -131 (±20)+0.5 (±0.1)AntC+1.03 (±0.16) (ΔH_V) The empirical findings in this study provide a new tool for investigating the sensing mechanisms involved when OFETs interact with volatile organic compounds. This approach will prove useful in expanding our understanding of how dispersion, polar and hydrogen bond forces influence analyte-sensor interactions and the transduced signal. OFETs manufactured using printable electronics technologies have been demonstrated to be promising volatile chemical sensors with good sensitivity and selectivity at room temperature.

Acknowledgement - The authors would like to thank the CIMLAE - EPSRC Centre for Innovative Manufacturing in Large-Area Electronics for funding this work, the University of Manchester for a PhD studentship, Daniel Tate for synthesis of the semiconductors used. References [1] Tate D, Danesh E, Tischler V, Faraji S, Majewski L, Turner M & Persaud K 2017, Fully solution processed low voltage OFET platform for vapour sensing applications, Paper presented at ISOCS/IEEE International Symposium on Olfaction and Electronic Nose 2017, Montreal, Canada, 28/05/17 - 31/05/17 pp. 1. DOI: 10.1109/ISOEN2017.7968929 [2] Lienerth P, Fall S, Lévêque P, Soysal U, Heiser T. Improving the selectivity to polar vapors of OFET-based sensors by using the transfer characteristics hysteresis response. Sensors and Actuators B: Chemical. 2016 Mar 31;225:90-5.