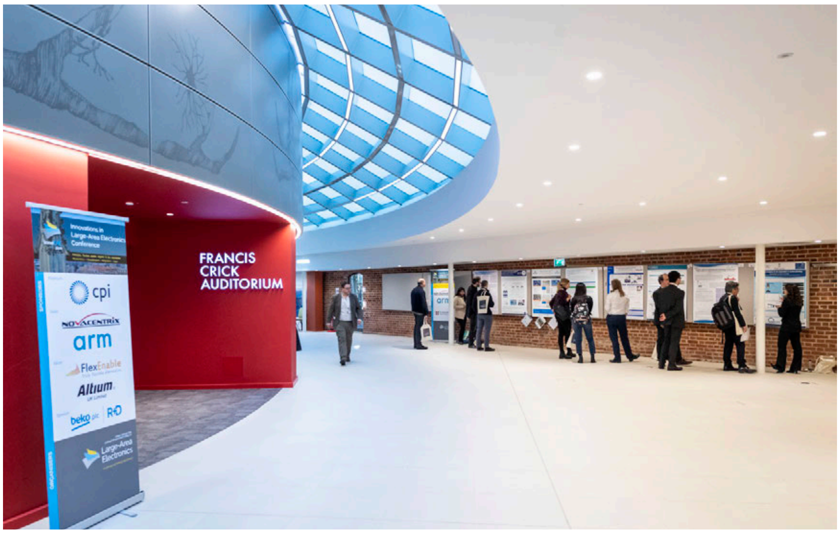
Innovations in Large-Area Electronics Conference

21 JANUARY - 22 JANUARY 2020

Wellcome Genome Campus Conference Centre, Cambridge UK



CONFERENCE PROGRAMME

innoLAE 2020

PLATINUM

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SILVER

arm

NOVACENTRIX

Semitronics

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CONFERENCE PROGRAMME

DAY ONE

08:30 Registration

09:00 ***Session 1*** — FCA

Mr Chris Rider Chair, innoLAE 2020 — *Welcome*

09:15 *Keynote 1.1* **Dr Emre Ozer*** Arm — *Thinking Out of the Box to Enable Low-cost Smart Objects with Flexible Electronics*

10:10 *Refreshments, Exhibition*

10:40

Session 2 **Novel devices and systems** — FCA

2.1 **Dr Yoeri van de Burgt*** TU Eindhoven
Organic Electronic Materials for Neuromorphic Computing and Adaptive Biointerfaces

2.2 **Mr Abhishek Chandramohan** PragmatIC
Low Cost Thin Film Schottky for Flexible Electronics Application

2.3 **Dr Kiron Prabha Rajeev** Neudrive Limited
High mobility OTFT devices; material formulation, process development and applications

2.4 **Dr Ulrike Kraft** University of Cambridge
Improving the operational stability of polymer transistors through passivation of water-induced traps

2.5 **Dr Kris Myny*** IMEC
Flexible thin-film transistor platform for healthcare patches

Session 3 **LAE for Energy** — RFP

3.1 **Dr Pritesh Hiralal*** Zinergy
The combination of Thin Energy and Flexible IoT - Adapting Printed Batteries for Long Range communications

3.2 **Dr Yun Fu Chan** CPI
Enhancement of Lithium Anode by Plasma Surface Modification, Physical Vapour Deposition and Atomic Layer Deposition Coatings for High Performance of Li-S Batteries (LiFE Project)

3.3 **Mr Pavlos Giannakou** University of Surrey
Inkjet Printing as a Facile Route towards Low Cost Electrochemical Energy Storage

3.4 **Mr Mahmoud Wagih** University of Southampton
A Broadband Outlook on Flexible and Textile RF Energy Harvesting and Wireless Power Transfer: from Near-Field to 5G

3.5 **Dr Joe Briscoe** Queen Mary University of London
Methylammonium lead triiodide photovoltaic devices produced using scalable aerosol-assisted chemical vapour deposition

12:45 *Lunch, Exhibition*

14:00 ***Session 4*** **Plenary** — FCA

Plenary 4.1 **Mr Mike Clausen** CPI — *Large Area Electronics – Scaling up to volume manufacture*

Keynote 4.2 **Professor Mark Poliks*** Binghampton University — *Flexible Hybrid Electronics -- "Unpackaged" Electronics for the Next Generation of Wearable Devices*

15:05 *Refreshments, Exhibition*

15:25

Session 5 **Applications enabled by advanced manufacturing** — FCA

5.1 **Dr Barbara Stadlober*** Joanneum Research
Ferroelectric Polymer Sensors for Flexible Electronics

5.2 **Mr Merijn Giesbers** TNO / Holst Centre
Integrated Electronic Functionalities in 3D printed products

5.3 **Mr Michael Johnson** Imperial College London
In-situ manufacturing of thin-film spacecraft, landers and rovers

5.4 **Dr Sanjiv Sambandan** University of Cambridge / Indian Institute of Science
Self-healing printed thin film transistor circuits

5.5 **Dr Mario Caironi*** IIT Milano
Direct-Written and Low-Voltage Polymer Field-Effect Transistors Operating at Radio-Frequencies

Session 6 **Bioelectronics** — RFP

6.1 **Dr Eleni Stavrinidou*** Linkoping University
Plants-Electronics interface

6.2 **Mr Ben Woodington** University of Cambridge
Development of a minimally invasive spinal cord interface utilising thin film electronics

6.3 **Dr Christian Nielsen** Queen Mary University of London
New Semiconducting Materials for Organic Bioelectronic Applications

6.4 **Dr Vincenzo Curto** University of Cambridge
High-density flexible probes for the neural interface

6.5 **Prof Josep Samitier*** IBEC Barcelona
Bioelectronics for organ-on-a-chip monitoring

Session 7 **Emerging Technology for Displays (SID)** — BMP

7.1 **Dr Guillaume Fichet** FlexEnable
Low cost, organic LCDs on Plastic - flexible displays for every surface

7.2 **Mr Sang Yun Bang** University of Cambridge
Scalable full-colour transfer printed quantum dot light-emitting diode onto active matrix display

7.3 **Dr Clément Talagrand** Bodle Technologies
LTPS driven microheater array for phase-change material based reflective display

7.4 **Dr Grigorios Rigas** M-Solv Ltd
Advanced Manufacturing of flexible touch sensors for next generation foldable displays

7.5 **Mr Russell Bailey** Pro-Lite Technology Ltd
Display metrology and the challenges measuring flexible displays

17:30 ***Poster session and drinks reception***

19:45 **Conference Dinner** ***(coaches depart at 19:00)*** — Queens' College

CONFERENCE PROGRAMME

innoLAE 2020

DAY TWO

Time		
08:30	*Tea/coffee*	
09:00	***Session 8*** FCA	
	Mr Chris Rider Chair, innoLAE 2020	*Welcome to day 2*
09:10	*Keynote 3* **Professor Sir Richard Friend*** University of Cambridge	*Thin Film Electronics – Limits to Performance*
10:00	*Poster Prize announcement*	
10:15	*Refreshments, exhibition*	
10:40	***Session 9*** **High performance materials for LAE** FCA	***Session 10*** **Wearables for healthcare** RFP
	9.1 **Dr Selina Ambrose*** Promethean Particles *Large-Scale Continuous Manufacture of Nanomaterials for Conductive Inks*	*10.1* **Dr Alison Burdett*** Sensium *Early detection of postoperative patient deterioration through wearable wireless monitoring*
	9.2 **Dr Aiman Rahmanudin** University of Manchester *Bottom-up Chemical Approach for Engineering Thin Films of Organic Electronic Materials for Field-Effect Transistors*	*10.2* **Dr Abiodun Komolafe** University of Southampton *Wearable functional e-textiles based on flexible filament circuits*
	9.3 **Mr Thomas Eldridge** CHASM Advanced Materials Inc. *Innovative approach to large format touch screens through flexible hybrid transparent conductive films*	*10.3* **Mr Michael Kasimatis** Imperial College London *Monolithic Solder-on Nanoporous Si-Cu Contacts for Stretchable Silicone Composite Sensors*
	9.4 **Professor Pedro Barquinha** NOVA.ID.FCT *Autonomous flexible electronics with zinc-tin oxide thin films and nanostructures*	*10.4* **Dr Russel Torah** University of Southampton *EU-H2020 project WEARPLEX - Wearable multiplexed biomedical electrodes*
	9.5 **Dr Luigi Occhipinti *** University of Cambridge *Graphene and two-dimensional materials, from production to applications in sensors and opto-electronics*	*10.5* **Mr Yasin Cotur** Imperial College London *Flexible acoustic transducer for monitoring vital signs*
12:45	*Lunch, exhibition*	
13:45	***Session 11*** **Sensors** FCA	***Session 12*** **Advanced manufacturing processes and equipment** RFP
	11.1 **Dr Firat Güder*** Imperial College London *Near "zero-cost" paper-based electrical gas sensors for measuring food quality*	*12.1* **Professor Duncan Hand** Heriot-Watt University Picosecond laser microwelding: a novel technique for hermetic joining of transparent materials
	11.2 **Professor Gregory Whiting** University of Colorado Boulder *Biodegradable printed sensors for monitoring soil conditions*	*12.2* **Dr James Blakesley** National Physical Laboratory *A new tool for high-speed quantitative functional imaging of large-area electronics*
	11.3 **Dr Daniel Tobjörk** Cambridge Display Technology Ltd. *OTFT gas sensors for applications in post-harvest monitoring*	*12.3* **Mr Vikram Turkani** NovaCentrix *Next Generation Paper: Cost-Effective Printed Electronics Techniques Advancing Augmented Book Manufacturability*
	11.4 **Dr Robert Valentine** CPI *Fabrication of a printed, flexible temperature and humidity sensor device that is technology enabler for IoT*	*12.4* **Dr Ivor Guiney*** Paragraf Ltd *Next Generation Large Area Graphene for Electronics*
	11.5 **Mr Pelumi Oluwasanya** University of Cambridge *Wearable sensors for personal exposure monitoring*	*12.5* **Mr Thomas Kolbusch** Coatema *Silver nanowires application on big scale for flexible displays and flexible electronics*
15:50	***Close/refreshments***	

**** invited speakers***

LOCATIONS

FCA: Francis Crick Auditorium

RFP: Rosalind Franklin Pavilion

BMP: Barbara McClintock Pavilion

Queens' College: Coach transport for the conference dinner will leave the conference centre at 7 pm

1.1 Thinking Out of the Box to Enable Low-cost Smart Objects with Flexible Electronics

Emre Ozer

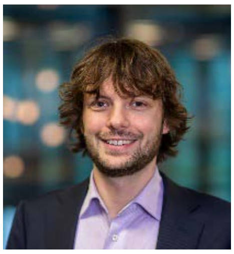
Arm Ltd., 110 Fulbourn Road, Cambridge, United Kingdom

Flexible electronics will enable disruptive smart objects where each smart object is an integrated system made of low-cost components manufactured using flexible electronics principles. A key challenge to realise the low-cost smart objects is to develop some form of (ideally flexible) processing engine that has to meet the computational requirements of the applications and be low-cost at the same time. Addressing this challenge requires out-of-the-box thinking in terms of target application space, use-case scenarios as well as the technological advantages and limitations of flexible electronics.

Biography

Emre Ozer is a Principal Research Engineer and joined Arm Research in 2005. He received his PhD in the Department of Electrical and Computer Engineering at North Carolina State University in 2001. His research interests are energy-efficient CPUs, fault tolerance, machine learning for embedded systems, bespoke hardware design and flexible electronics. He has published over 50 international conference/journal articles and holds over 25 US patents. He is currently the project coordinator of an InnovateUK funded project PlasticARMPit, developing bespoke ML compute engines on plastic that are tightly coupled to plastic e-nose sensors

SESSION 2: NOVEL DEVICES AND SYSTEMS



2.1 Dr Yoeri van de Burgt

Yoeri van de Burgt obtained his PhD degree at Eindhoven University of Technology in 2014. He then worked at a high-tech startup in Switzerland, after which he moved to the US where he obtained a Postdoctoral Fellowship at the department of Materials Science and Engineering at Stanford University. During his postdoc his research focused on organic neuromorphic materials and electrochemical transistors. At the end of 2016, van de Burgt returned to Eindhoven as an assistant professor where he currently leads the Neuromorphic Engineering group. He has also been a visiting professor at the University of Cambridge (UK) and was recently awarded an ERC Starting Grant from the European Commission. In 2018 he was nominated for the New Scientist Talent Award.

2.2 Mr Abhishek Chandramohan

Abhishek Chandramohan is with PragmatIC, where he is working as a device development engineer in the research and development department. Prior to this, he worked as a Marie Curie Fellow at Durham University where his research focussed on semiconductor nanowire based device fabrication and application. He has 9 years of experience in microfabrication, material metrology, device characterisation, electrical test and data analysis. His current research interests are flexible metal-oxide devices and the data science pertaining to it.

2.3 Dr Kiron Prabha Rajeev

Kiron Prabha Rajeev is currently working as the Head of OTFT Technology at Neudirve Limited,

2.4 Dr Ulrike Kraft

In her PhD at the Max Planck Institute for Solid State Research and the Technical University of Freiberg, Ulrike studied low-voltage, organic thin-film transistors focusing on their environmental stability, dynamic performance and contact resistance. In her postdoctoral research at the Stanford University, which was funded by a Feodor-Lynen Research Fellowship from the Alexander von Humboldt foundation, Ulrike studied and developed novel intrinsically stretchable materials, devices and circuits for wearable applications such as on-skin sensors for health monitoring.Ulrike is now continuing her research on organic electronic devices as a Research Associate at the University of Cambridge investigating the operational and environmental stability of polymer transistors.

2.5 Dr Kris Myny

Dr. Kris Myny received a PhD in electrical engineering from the KULeuven, Leuven, Belgium in 2013. He is now a Principal Member of Technical Staff and R&D Team Leader at imec and specializes in circuit design for flexible thin-film transistor applications. His work has been published in numerous international journals and conferences, amongst which in Nature Electronics and several ISSCC contributions. He is a senior member of IEEE. He was listed as one of Belgium's top tech pioneers by the business newspaper De Tijd and received in 2018 the European Young Researcher Award for design on thin-film electronics. In 2016 he received a prestigious ERC Starting Grant from the European Commission to enable breakthrough research in thin-film transistor circuits (FLICs). He is a member of the Young Academy of Belgium 2019-2024.

2.1 Organic Electronic Materials for Neuromorphic Computing and Adaptive Biointerfaces

Yoeri van de Burgt[1]

[1]Microsystems, Institute for Complex Molecular Systems, Eindhoven University of Technology

Neuromorphic computing could address the inherent limitations of conventional silicon technology in dedicated machine learning applications. However, delivering a compact and efficient parallel computing technology that is capable of embedding artificial neural networks in hardware remains a significant challenge.

Organic electronic materials have shown great potential to overcome these limitations. This talk describes state-of-the-art organic neuromorphic devices and provides an overview of the current challenges in the field and attempts to address them. I demonstrate a novel concept based on an organic electrochemical transistor and show how crucial challenges in the field such as stability, variability and linearity can be overcome.

Next to that, bioelectronics has made an enormous progress towards the development of materials and devices that are capable of sensing, monitoring and control of a biological environment. Nevertheless, fully autonomous bioelectronic applications demand not only the acquisition of biological signals, but also local low power data processing, storage and the extraction of specific features of merit. This can pave the way for novel architectures with bio-inspired features, offering potential applications ranging from brain-computer-interfaces and robotics to adaptive biointerfaces. I will highlight our recent efforts for hybrid bioelectronic neuromorphic devices.

2.2 Low cost thin film Schottky for flexible electronics application

Abhishek Chandramohan[1], Feras Alkhalil[1], Catherine Ramsdale[1] and Richard Price[1]

[1] *PragmatIC, Explorer 1, Thomas Wright Way NETPark, Sedgefield, Co Durham TS21 3FF*

PragmatIC, a world leader in ultra-low cost, flexible electronics, will describe its novel thin film Schottky diode architecture which has been validated on its unique FlexLogIC® manufacturing system. A robust Schottky diode is key to enable highly optimised designs for a wide range of electronic subsystems to be implemented in oxide-based flexible electronics, including: DC and RF rectification, voltage regulation, sample and hold circuitry, electrostatic discharge (ESD) protection, etc.

The first implementation of this new functionality will be in PragmatIC's ConnectIC® range of flexible integrated circuits (FlexICs), which are designed to bring connectivity to a wide range of everyday items, in diverse markets such as, food and beverages, pharmaceutical and healthcare, personal and home care, and interactive toys and games, markets previously inaccessible due to the cost of traditional silicon integrated circuits. Now with FlexICs there is the potential to enable trillions of smart objects that can engage with consumers and their environments.

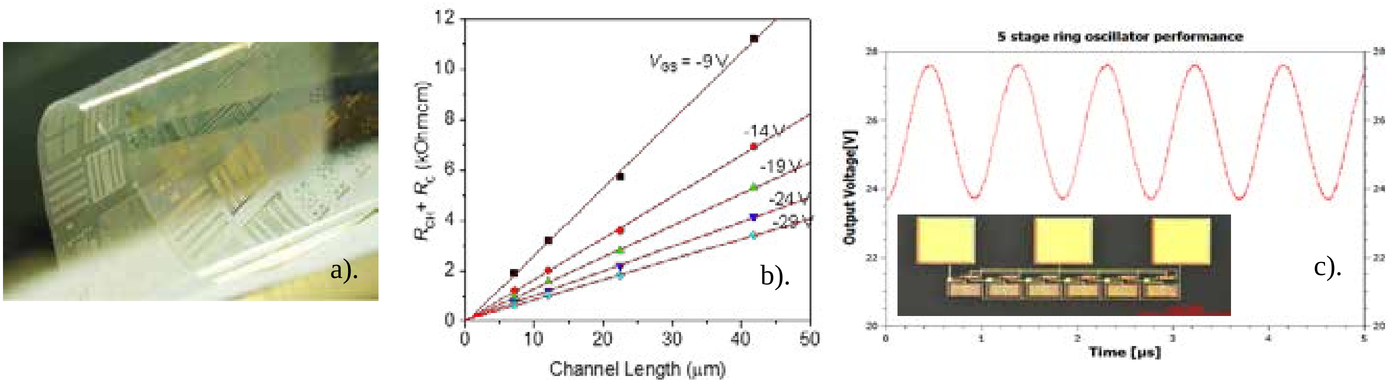
In the future, Schottky is key to broadening our portfolio of FlexICs and forms a cornerstone of our bespoke FlexIC design services that enable development of new functionality and third-party FlexIC design based on our PDK.

2.3 High mobility OTFT devices; material formulation, process development and applications

Kiron Prabha Rajeev, Shashi Pandya, Mahdi Arabnejad, Ray Fisher
NeuDrive Ltd, 11, Broadwalk Walk, Buxton, United Kingdom, SK17 6JR

Dynamically flexible displays (DFDs) require all components of the display to remain functional during repeated bending cycles of the device. Robustness of the transistor backplane is influenced by the materials used in the construction, with existing inorganic semiconductors struggling to meet the high strain values required for rollable or foldable portable display devices. Organic semiconductor (OSC) technology has been shown to be a good candidate for this application due to the inherent flexibility of organic materials. Additionally, the low temperature organic thin-film transistor (OTFT) processing enables a wide range plastic substrate types and thicknesses to be used for the DFD.

NeuDrive develops OSC formulations based on small molecule soluble semiconductors and high permittivity semiconducting binders. These material sets enable uniform (<5% standard deviation) transistor performance with high linear mobility (>4cm^2/Vs). Width-normalised contact resistances of OTFTs are measured at <200 Ohm.cm and consequently the high mobility is maintained at channel lengths of less than 10 microns. 5 stage ring oscillators made with 7 micron channel lengths operate at 1MHz [1]. This presentation will detail the device properties achieved with the formulations, the low temperature (115°C) fabrication process to make integrated circuits, and the application of OTFT to display backplane and biosensor devices.



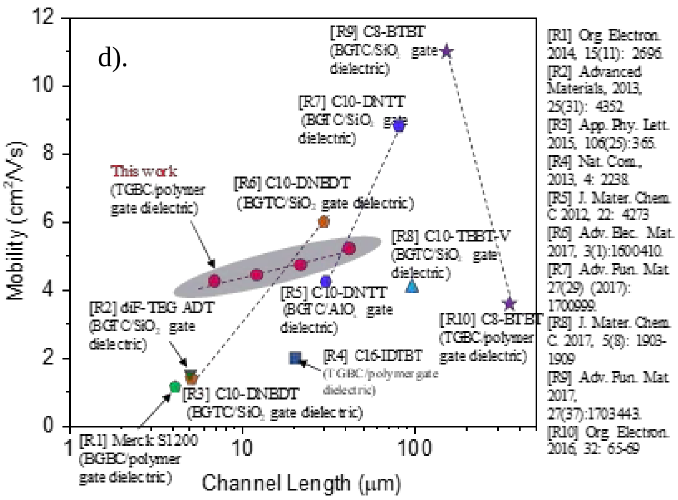


Figure 1. a). PEN substrate with OTFT based sensor and logic devices b). Width-normalised total resistance against channel length of an OTFT made using small-molecule and polymer blend OSC material c). 5-stage ring oscillator with operating frequency of over 1MHz d). Mobility vs channel length comparison with literature

[1] S. Ogier *et al. Organic Electronics*, **54,** 40 (2018) p 40-47

2.4 Improving the operational stability of polymer transistors through passivation of water-induced traps

Ulrike Kraft[1], Malgorzata Nguyen[1], John Armitage[1], Mark Nikolka[1], Iain McCulloch[2], Christian B. Nielsen[3], Henning Sirringhaus[1]

[1] *Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*

[2] *Department of Chemistry, Imperial College London, London, United Kingdom*

[3] *School of Biological and Chemical Sciences, Queen Mary University, London, United Kingdom*

Organic-based electronics are of great potential for applications such as flexible, bendable displays, conformable sensor arrays and artificial skin. Their advantages range from their mechanical flexibility and their large-area printability to compatibility with low-temperature processing and thus compatibility with not only glass substrates, but also with bendable plastic and paper substrates.[1] Furthermore, organic semiconductors can be customized and adapted through molecular design and chemical synthesis. Significant advances in the development of organic semiconductors let to charge carrier mobilities exceeding that of amorphous silicon and contact and interface engineering and device optimization enabled megahertz operation of organic transistors.[1]

A remaining challenge however, is the environmental and operational stability of organic devices. One unanimously reported cause of such operational instabilities are water induced traps that affect the performance of various devices, such as thin-film transistors and diodes [2-4]. In organic transistors, such traps induce undesired shifts of the threshold voltage during operation and therefore are especially problematic when targeting sensing applications or active matrix displays. In the latter case, the transistors supply the currents to illuminate the pixels at a specific brightness and stable operation is a requirement. Recent findings show that water-induces traps can be passivated by the addition of particular (non-doping) molecular additives, leading to significant improvements in the device performance and the operational stability of polymer transistors [2]. We will show that threshold voltage shifts during operation can be remarkably reduced, as measured in both constant-current and constant-voltage stress experiments, discuss the underlying mechanisms and extend the concept from on-state bias stress to off-state bias stress stability.

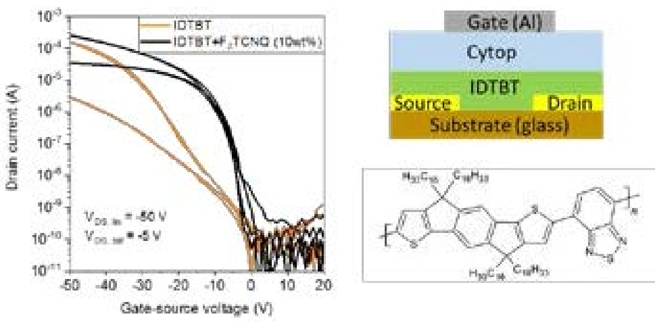


Figure 1: Improved transistor performance of top-gate, bottom-contact IDTBT thin-film transistors (channel length: 20 µm, channel width: 1mm) with (black) and without (orange) 10 wt% of F_2TCNQ, device architecture of the organic transistors and chemical structure of IDTBT (indacenodithiophene-co-benzothiadiazole).

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[1] U Kraft, T. Zaki, J. N. Burghartz, E. Weber, B. Murmann, H. Klauk, *Low-Voltage, High-Frequency Organic Transistors and Unipolar and Complementary Ring Oscillators on Pape*r. Advanced Electronic Materials 5 (2019) 1800453.

[2] M. Nikolka, I. Nasrallah, B. Rose, M. K. Ravva, K. Broch, A.Sadhanala1, D. Harkin1, J. Charmet, M. Hurhangee, A. Brown,S. Illig, P.Too, J. Jongman, I. McCulloch, J.-L. Bredas, H. Sirringhaus, High *operational and environmental stability of high-mobility conjugated polymer field-effect transistors through the use of molecular additives.* Nature Materials, 16 (2016) 356−362.

[3] M. Kettner, M. Zhou, J. Brill, P. W. M. Blom, R. T. Weitz, *Complete Suppression of Bias-Induced Threshold Voltage Shift below 273 K in Solution-Processed High-Performance Organic Transistors.* ACS Appl. Mater. Interfaces, 10 (2018) 35449−35454.

[4] P. A. Bobbert, A. Sharma, S. G. J. Mathijssen, M. Kemerink, D.M. de Leeuw, *Operational Stability of Organic Field-Effect Transistors.* Advanced Materials, 24 (2012) 1146–1158.

2.5 Flexible thin-film transistor platform for healthcare patches

Kris Myny
imec, Kapeldreef 75, 3001 Heverlee, Belgium

The field of wearable healthcare patches is gaining more attention due to the high potential of continuous monitoring of vital signs. Consequently, patients can leave the intensive care unit of a hospital sooner or can be further monitored at home. Long-term monitoring may also find its benefits in preventive healthcare in future. Wearable medical patches require several specifications, such as the necessity to be comfortable to wear for a long period, to have embedded lightweight integrated electronics, to have ideally no wiring to external units and to preserve a long battery lifetime. Flexible electronics based on thin-film transistors provide many opportunities for healthcare patches, as this is an ultrathin, flexible, stretchable and lightweight circuit technology. It also offers to monolithically integrate sensors and electrodes, amongst others by direct printing techniques. In this presentation, I will elaborate on flexible thin-film transistor technologies and their design challenges focusing on healthcare patches. Furthermore, the architecture of the readout electronics of a healthcare patch will be discussed. The main circuit blocks are comprising of wireless communication interfaces, such as RFID/NFC and capacitive identification [1], memory elements and analog-to-digital converters based on thin-film transistors. The integration of those critical IP blocks resulted in our recent work regarding a flexible NFC-enabled ECG patch [2]. Finally, this presentation will summarize by detailing a roadmap paving the way for flexible electronics in the field of wearable healthcare patches.

References

[1] N. Papadopoulos, et al.; “Touchscreen tags based on thin-film electronics for the Internet of Everything”, accepted to Nature Electronics
[2] M. Zulqarnain, et al.; “A flexible ECG patch with NFC compatible RF communication”, submitted to Flexible Electronics

Acknowledgement – I would like to thank my coworkers at imec and TNO/Holst centre; M. Zulqarnain and E. Cantatore from TUe for their valuable contributions to this work. Part of this work has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program under grant agreement No 716426 (FLICs project) and No 732389 (CAPID project).

SESSION 3: LAE FOR ENERGY

3.1 Dr Pritesh Hiralal

Dr. Pritesh Hiralal, studied Physics at Manchester and completed his Ph.D. in Engineering at the University of Cambridge. He has spent time in business in Spain and set up Casa Hiralal S.L. and Zendal Backup. He has spent time in industry at the Nokia Research Centre working on high power energy storage, and has published 40+ papers and 10+ patents in the field. He has consulted for materials as well as energy storage device companies. He spent time as a Research Associate as well as an adjunct lecturer at the University of Cambridge. He is a co-founder and CEO of Zinergy and for the last 3+ years has been focusing on taking the business from the lab to the market.

3.2 Dr (Sam) Yun Fu Chan

Dr. (Sam) Yun Fu Chan (PhD in Chemistry, University of Reading). Senior Scientist at the Centre of Process Innovation Ltd (CPI) (2010 to date), he has over thirteen years of industrial experience in Optoelectronics research including OLEDs, LECs, OTFTs, OPV and ALD Barrier Coating, as well as Laser processing and Battery since 2005, previously at Polymertronics Ltd (Materials Chemist, 2008 to 2010), OLED-T-Ltd (Synthetic Inorganic Chemist, 2006 to 2008), University of Reading (Post-doctoral Researcher, 2005 to 2006). Since joining CPI in 2010, he has participated and technically led some of the eleven UK-funded and three European projects, managed commercial and IUK projects. He is author of 4 scientific papers, 13 international conference papers and is author of 4 patents.

3.3 Mr Pavlos Giannakou

Pavlos Giannakou received his BEng in Mechanical Engineering from the University of Surrey in 2017. He is currently a PhD candidate under Dr Maxim Shkunov’s supervision in Advanced Technology Institute at the University of Surrey in United Kingdom. His current research is focused on printed electronics and energy storage, particularly supercapacitors.

3.4 Mr Mahmoud Wagih

Mahmoud Wagih received his BEng in electrical and electronic engineering from the University of Southampton in 2018. He is currently pursuing his PhD at the University of Southampton. In 2017 he worked as a research assistant supported by Intel, investigating novel transmission lines. In 2018, he was a hardware engineering intern at Arm, UK. His current research interests lie in RF energy harvesting, wearable antennas, micro-power management and wireless sensor networks. He has several journal and conference publications on these topics. Mr. Wagih is a graduate student member of the IEEE and a reviewer for 2 IEEE Journals. He was the recipient of the Best Undergraduate Project Prize at the University of Southampton, 2018, and the recipient of the Best Student Paper Award at the IEEE MTT-S Wireless Power Transfer Conference, Wireless Power Week 2019 London, U.K.

3.5 Dr Joe Briscoe

Dr Briscoe is a Lecturer in Functional Materials in the School of Engineering and Materials Science, Queen Mary University of London. He has expertise in the low-cost, solution-based synthesis of a range of nanostructured functional materials, and their use in sustainable energy devices, including photovoltaics, piezoelectric energy harvesters, and photo(electro)catalysis. Dr Briscoe's current research focusses on a range of new materials, structures and material combinations for use in nanostructured, low-cost devices. This includes earth-abundant and biomass-derived materials, oxide-based devices, hybrid organic-inorganic lead-halide perovskites and dye-sensitised solar cells (DSSC). He continues to develop ZnO nanorod energy harvesters including exploring commercial applications.

3.1 The combination of Thin Energy and Flexible IoT – Adapting Printed Batteries for Long Range communications

Pritesh Hiralal[1], Dilek Ozgit[1], Suchanuch Sachdev[1], Karolina Spalek[1]

[1] *Zinergy UK Ltd, Future Business Centre, Kings Hedges Road, CB4 2HY, Cambridge, UK*

The advent of printed large area electronics has started delivering exciting innovations over the last few years. A key enabler for fully thin devices is printed energy! Over the last 3 years, Zinergy has embarked on a mission to develop simple, low cost, printed energy storage devices which are compatible with other printed electronic devices.

Printing is a very versatile technique for batteries. It allows to control not only size and shape of devices, but also via thickness control and ink formulations there is a toolkit to adapt the battery´s power requirements to a large set of applications, from high energy, low current applications to high power. Printing batteries allows a degree of freedom in design not possible with traditional batteries.

In this paper we discuss one such optimisation, the adaptation of printed batteries for IoT applications with long range communication ability. We talk about the adaptations required to allow long range communication and high pulse currents, and show possibilities and results.

This capability has allowed the production of smart labels which can amongst other things track locations of goods or measure other parameters and communicate of ranges of a few km. Results of field trials will be shown as well as a projection of possibilities we expect in the coming years.

Acknowledgement - The authors would like to thank the team at Zifisense for their support with this work.

Figure 1. Zinergy Powered Smart label

3.2 Enhancement of lithium anode by plasma surface modification, physical vapour deposition and atomic layer deposition coatings for high performance of Li-S batteries (LiFE Project)

(Sam) Yun Fu Chan[1], Andrew Cook[1], Robert Douglas[1], Paolo Melgari[1] Alf Smith[1] & Shaun Thomas[1], Marco Carboni[2], Jokin Rikarte[2], Ulderico Ulissi[2] & Jacob Locke[2]

[1] Centre for Process Innovation Ltd, Neville Hamlin Building, Thomas Wright Way, Sedgefield, County Durham, United Kingdom

[2]OXIS Energy Ltd, Culham Science Centre, Abingdon, OX14 3DB, United Kingdom

Lithium -sulphur (Li-S) batteries are a potential alternative to the current Li ion batteries due to their high theoretical capacity (1675 mAh g^{-1}), high theoretical energy density (2600 Wh Kg^{-1}), and favourable cost-effectiveness [1]. The development of a suitable Li metal anodes that is able to suppress the formation of dendrites remains the most limiting factor in long cycle-life Li-S batteries and plays a key role in the success of this technology [2,3]. In order to overcome this issue, pre-processing of the pristine lithium foil is critical. Another key factor in improving Li-S battery efficiency can be achieved through protection of the Li anode. Direct deposition of a protective coating on Li anode can significantly improve the adhesion properties and homogeneity of Li anode, and therefore reduce the defectivity within the overall Li-S battery [4]. Atomic Layer Deposition (ALD) and Molecular Layer Deposition (MLD) have been identified as potential deposition techniques for the production of a protective layer. The main benefits of these techniques are that they produce coatings which are highly conformal, dense and pinhole-free and the process can be controlled to a high degree of accuracy to produce ultrathin films at the nanoscale [5].

In this paper, we summarise the processes developed for the enhancement of Li anode and the technical challenges for handling and processing of Li foils in the laboratory and clean room environments (non-dry room environment) at CPI. Firstly, the pre-processing of Li metal to clean and smooth the surface. The subsequent Physical Vapour Deposition (PVD) sputter coating of a ceramic thin film as an electrolyte. ALD and/or MLD coatings have been produced at low growth temperatures even down to room temperature. All treated Li anodes produced at CPI were used for manufacturing Li-S battery cells by OXIS Energy, and the test data showed the sputtered ceramic and/or ALD/MLD protection layers provide a comparable or better performance when compared with reference cells produced at OXIS Energy.

References

[1] Manthiram, Arumugam, et al. “Rechargeable lithium-sulphur batteries.” Chemical reviews 114.23 (2014): 11751-11787.

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3.3 Inkjet printing as a facile route towards low cost electrochemical energy storage

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The push towards self-powered electronics through energy harvesting, calls for the development of high-performance supercapacitors that can enable sustained, autonomous operation of electronic devices for applications such as wearable electronics, biomedical implants and internet-of-things. Low cost supercapacitors with high energy density can potentially serve as commercially attractive devices towards stand-alone and maintenance-free power sources when combined with energy harvesters. Therefore, great efforts have been devoted in either extending the energy density of these storage systems by using pseudocapacitive electrode materials, which store energy by fast surface redox reactions enhancing the storage ability of the system, or/and by utilising high-throughput, low cost fabrication techniques to keep the cost/stored-energy ratio low. Typical fabrication methods, such as photolithography and electrode rolling/stacking that are commonly used in conventional energy storage systems, have not only caused the devices to lack a variety of form factors and flexibility needed for countless new Internet-of-Things applications, but also rose the overall cost of the devices due to excessive material waste and complex processing. In the past decade, the development of digital printing technology in the field of printed electronics, has triggered an explosion of new ideas and alternative fabrication strategies that led to lean and cost-efficient manufacturing processes. In this research, we demonstrate the fabrication and integration of high-performance, fully solution processed, co-planar NiO micro-supercapacitors through inkjet printing (Figure 1). Inkjet printing is a readily scalable process and the devices can be fabricated on large, flexible substrates at the fraction of the cost of traditional supercapacitor fabrication methods. The nanoparticle-based thin film NiO electrodes showed up to 14 orders of magnitude higher electrical conductivity than single crystal NiO. The enhanced conductivity of the electrodes was reflected in the low relaxation time constant of just 30 ms, which is among the lowest achieved for any supercapacitor. A magnesium perchlorate-based aqueous electrolyte with extended operating voltage window was developed to enable the operation of the devices up to 1.5 V. The devices showed remarkable areal and volumetric specific capacitances of up to 155 mF cm^{-2} and 705 F cm^{-3} respectively, surpassing a few of the best micro-supercapacitors known to date. This work provides a compelling platform to simplify the fabrication process of supercapacitors, with focus on digital design, low cost scalable manufacturing, and direct integration with printed electronics.

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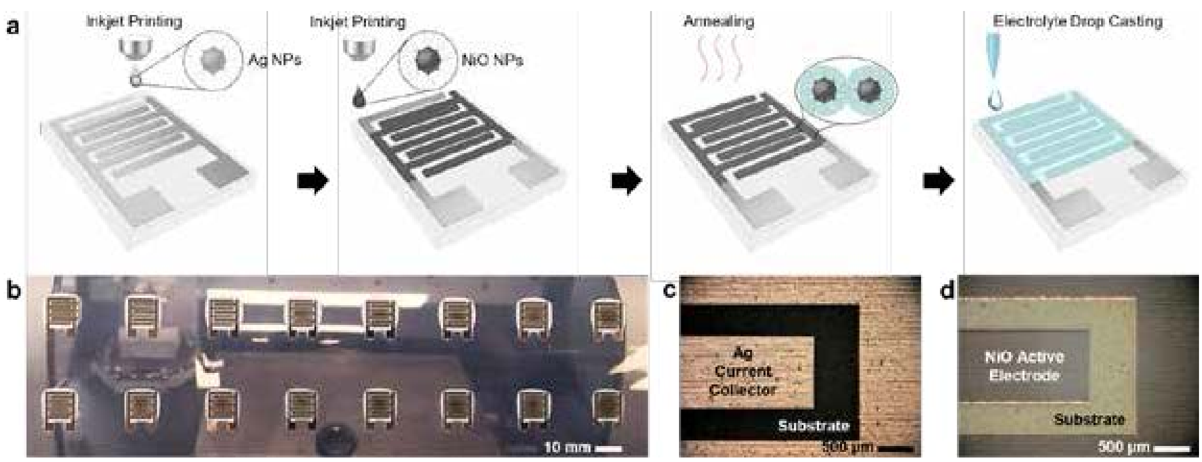

Figure 1. (a-d) Scalable fabrication process of NiO supercapacitors through inkjet printing.

3.4 A broadband outlook on flexible and textile RF energy harvesting and wireless power transfer: from near-field to 5G

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Wireless power transfer (WPT) and Radio Frequency (RF) energy harvesting (EH) are increasingly seen as an enabling technology for power-autonomous Internet of Things (IoT) [1, 2]. RFEH and WPT are a particularly attractive power source for flexible, printed, and e-textile systems due to their compatibility with standard fabrication processes, abolishing the need for specific materials and transducers. This work provides an overview on flexible WPT at multiple frequencies (6.78 MHz to 26 GHz) and techniques from near-field WPT to Millimetre-wave WPT and RFEH. Figure 1 shows our developed flexible and textile WPT and RFEH coils and antennas.

Near-field power transfer has been utilized for high-efficiency charging of consumer electronics as well as RFID. The coil shown in Figure 1-a has been fabricated using embroidered fabric Litz wires and utilized in two modes of operation at 6.78 MHz: resonant inductive coupling and radiative near-field WPT. The coupled WPT achieves the highest reported efficiency of 82% in human proximity [1]. The radiative approach achieves unmatched separation-independence, in a 27 m^3 volume, but is limited to µW power levels due to the FCC's regulations.

Ambient RF sources, such as cellular networks, possess similar energy densities to ambient energy sources such as human vibrations. A broadband antenna, Figure 1-b, has been developed to recycle the energy from cellular networks, independent of polarization, with bandwidth covering the whole UHF cellular and license-free spectrum. The antenna has been matched to a flexible low-cost rectifier using lumped inductive matching, creating the first triple-band fully-textile rectenna, achieving up to 36.7% RF-DC efficiency at -20 dBm (10 µW). An alternative packaging approach has been proposed: a coplanar-waveguide (CPW) rectenna yarn (Figure 1-c) has been presented for fully-concealed textile RFEH at 915/868 MHz, improving reliability and integration in textile weaves.

With the anticipated growth of the wireless-powered IoT market traffic-related issues may arise, and the "recycling" of ambient energy could overload existing networks. Millimetre-wave (mmWave) WPT, as part of future 5G networks, presents a potential solution to the traffic issues and promises improved energy coverage compared to sub-6 GHz bands [2]. As the main challenge in mmWave antennas and circuits are the high-cost of the RF-substrates and fabrication processes, the proposed antenna in Figure 1-d has been presented to overcome the efficiency barrier and present the first textile mmWave antenna for 5G WPT/RFEH, achieving up to 77% radiation efficiency at 26 GHz [2]. A fully-distributed rectifier has been designed and fabricated to achieve a 1V DC output across the full 5G spectrum (24-26 GHz) from 10 dBm of mmWave power.

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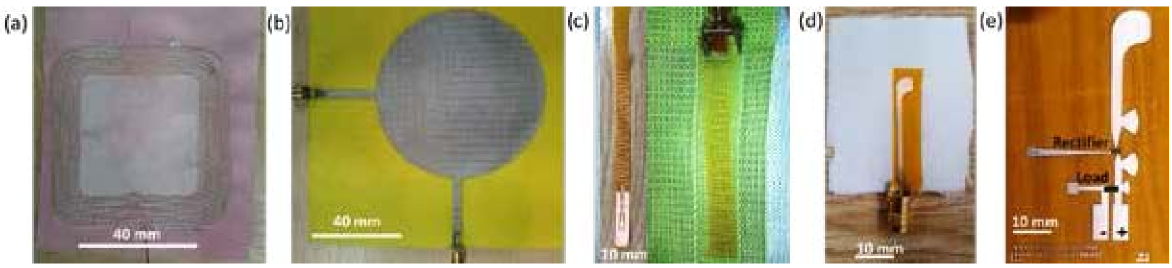

Figure 1. Developed WPT and RFEH flexible and textile antennas and harvesters: (a) 6.78 MHz WPT coil, (b) Broadband (0.7-3 GHz) dual-polarization ambient RFEH fully-textile antenna, (c) 868 MHz CPW voltage doubler concealed rectenna yarn, (d) 5G mmWave textile antenna (e) Flexible mmWave broadband voltage doubler.

3.5 Methylammonium lead triiodide photovoltaic devices produced using scalable aerosol-assisted chemical vapour deposition

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Hybrid organic-inorganic metal halide perovskite research has progressed rapidly, with photovoltaic (PV) devices reaching over 20% efficiency [1]. Currently solution processing techniques are widely used within the research community, and therefore scalable synthesis routes still need to be developed. In this study we demonstrate the growth of methylammonium lead triiodide (MAPI) films via aerosol assisted chemical vapour deposition (AACVD). This is a scalable deposition process, working at atmospheric pressure, relatively low temperatures and requiring less complex equipment than conventional CVD, thus is able to produce large areas of material at low cost.[2]

The films were deposited by sequentially passing aerosolized precursor solvent solutions into a reactor containing a heated substrate. XRD measurements confirm the composition as MAPI. UV/vis absorbance measurements further validated the film composition, giving an optical bandgap value of ~ 1.54 eV. We also measure the band positions using ambient photoemission spectroscopy (APS) and Kelvin Probe, giving valence band and Fermi level positions of -5.37 eV and -4.82 eV, with the conduction band at -3.82 eV from the UV-Vis-determined band gap. SEM imaging revealed a film with large grains (1-2 µm), with film thicknesses ranging from 500-1500 nm. These films were then used to fabricate working photovoltaic devices in the n-i-p structure by depositing MAPI onto mesoporous TiO_2 films, which were found to assist in uniform film deposition. Working devices were completed with a p-type layer of either organic spiroOMeTAD or inorganic CuSCN and Au top contacts. CuSCN films are found to give improved PV performance due to better filling of the slightly rough AACVD MAPI surface, and are also deposited using a scalable spray-coating technique (Figure 1). We also show that we can deposit CuSCN scalably on MAPI using the AACVD process.

This report represents the first ever working PV devices using hybrid perovskites deposited by AACVD, and thus opens up a new avenue for the scalable deposition of such devices.

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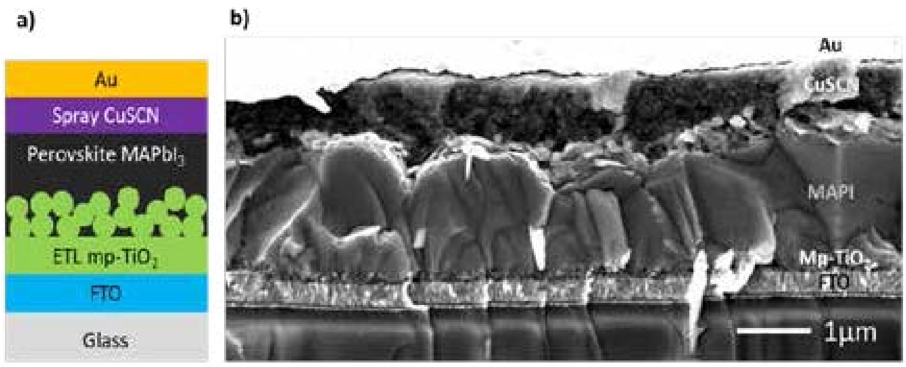

Figure 1. Schematic (a) and SEM cross-section (b) of the TiO_2/MAPI/CuSCN/Au device.

4.1 Large Area Electronics – Scaling up to volume manufacture

Mike Clausen

Centre for Process Innovation, The Neville Hamlin Building, Thomas Wright Way, NETPark, Sedgefield, County Durham, United Kingdom, TS21 3FG

Technologies for Large Area and Printable Electronics are well established and are steadily moving along the Technology Readiness Level scale. It is apparent that most electronic systems which make use of these technologies will be hybrids of conventional solid-state components and a range of the newer technologies. The next stages for the evolution of printable and LAE include its integration as part of the electronic and system engineer's toolbox. In this talk, CPI will briefly review the progress made in the design, prototyping and production of a 10000-part pilot production run for a fully integrated smart label using NFC technology

Biography

Mike is the Head of Technology within the CPI Printable Electronics platform. He is responsible for providing technical leadership, developing technologies so that they can be translated to innovative products capable of commercialization in the future. Mike has 25 years' experience within the electronics field working within research and development, mass production and customer service environments. He has worked for medium size British companies and major international blue chip organisations such as Fujitsu Microelectronics, NXP, Filtronic Compound Semiconductors and RFMD. His knowledge base spans Operations management, process engineering and integration, technology development, yield enhancement and project management.

4.2 Flexible Hybrid Electronics – "Unpackaged" Electronics for the Next Generation of Wearable Devices

Mark D. Poliks[1]

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Flexible Hybrid Electronics (FHE) integrates "un-packaged" devices from thinned silicon wafers with flexible and printed circuits in formats that can be thin, light-weight, flexible, bendable, conformal, potentially stretchable and disposable. FHE is ushering in an era of "electronics on everything," leading to improved wear-ability and performance for the next generation of smart monitoring products. NextFlex is a consortium of companies, academic institutions, federal and state governments with a shared goal of advancing U.S. Manufacturing of Flexible Hybrid Electronics. This presentation describes NextFlex FHE research and development projects underway as part of the NextFlex New York Node.

Biography

Mark D. Poliks is Empire Innovation Professor of Engineering, Professor of Systems Science and Industrial Engineering, Professor of Materials Science and Engineering and Director of the Center for Advanced Microelectronics Manufacturing (CAMM) at the State University of New York at Binghamton. He serves as Chair of the Smart-Energy Transdisciplinary Area of Excellence at the Binghamton campus. In 2006 he established the first research center (CAMM), to explore the application of roll-to-roll processing methods to flexible electronics and displays, with equipment funding from the United States Display Consortium (USDC) and the Army Research Lab. His research is in the areas of industry relevant topics that include: high performance electronics packaging, flexible hybrid electronics, medical and industrial sensors, printed RF components, materials, processing, aerosol jet printing, roll-to-roll manufacturing, in-line quality control and reliability of electronics. He has received more than $20M in research funding from Federal, New York State and corporate sources and more than $30M in equipment funding from federal and state sources. He is the recipient of the SUNY Chancellor's Award for Excellence in Research. He leads the New York State Node of the DoD NextFlex Manufacturing USA and was named a 2017 NextFlex Fellow. He received FLEXI awards for leadership in Technology and Education from the FlexTech Alliance in 2009 and 2019. He has authored over one-hundred technical papers and holds forty-eight US patents. He was the General Chair of the 69th IEEE ECTC and will serve as a IEEE Electronics Packaging Society Distinguished Lecturer from 2020-2023.

5.1 Dr Barbara Stadlober

Dr. Barbara Stadlober is Principal Investigator at the Institute for Surface Technologies and Photonics of the JOANNEUM RESEARCH Forschungsgesellschaft mbH (JR) located in Graz/Weiz, Austria. She studied experimental physics at the Karl-Franzens University Graz, received her PhD from the Walther Meissner Institute (TU Munich) and then joined the technology development team at Infineon Technologies Austria. She joined JR in 2002 and is currently head of the Research Group "Hybrid Electronics and Patterning". Her interests range from organic thin film transistors over printed ferroelectric sensors (PyzoFlex® technology) and 3D user interfaces to R2R-nanopatterning of multifunctional surfaces, biomimicry/Bionics, microoptical elements and flexible microfluidics. She has authored over 90 peer-reviewed papers and is an inventor of more than 10 patents.

5.2 Mr Merijn Giesbers

Merijn Giesbers Msc. studied Physics at the Radboud University in Nijmegen. Upon completion of his studies he joined TNO as a researcher on the topic of additive manufacturing. His work has been mostly focused on laser-based processes. Mr. Giesbers is currently researcher at Holst Centre, where he works on novel printing techniques for printed electronics.

5.3 Mr Michael Johnson

Michael is a Ph.D. student at Imperial College London. His research focus is integrated self-optimising cyber physical systems for space exploration and includes a number of Interplanetary CubeSat and Thin-Film spacecraft flight projects to demonstrate the utility of this approach on orbit. Michael obtained his first degree in Physics from Imperial College. He has worked on ChipSat, Thin-Film and CubeSat projects at institutions including Cornell University, where he co-created the first KickStarter funded CubeSat/ChipSat mission that launched a record 105 spacecraft into low earth orbit in April 2014, the California Institute of Technology, where he co-lead the Keck Institute for Space Studies "Small Satellites: a Revolution in Space Science" study, and the University of Cambridge, working on space manufacturing and large aperture self-aligning space telescopes.

5.4 Dr Sanjiv Sambandan

Sanjiv Sambandan is a lecturer at the Department of Engineering, University of Cambridge, Cambridge, UK, He holds a joint appointment at the Indian Institute of Science, Bangalore, India. Prior to academia he was with the Electronic Material and Device Lab, Xerox Palo Alto Research Centre, California, USA.

5.5 Dr Mario Caironi

Mario Caironi obtained his Ph.D. in Information Technology with honours at Politecnico di Milano. In 2007 he joined the group of Prof. Sirringhaus at the Cavendish Lab. (Cambridge, UK) as a post-doc, working on high resolution printing of downscaled organic transistors and circuits. In 2010 he was appointed as Team Leader at the Center for Nano Science and Technology@PoliMi (CNST) of the Istituto Italiano di Tecnologia (IIT, Milan, Italy). In 2014 he entered the tenure track at the same institution, obtaining tenure in 2019. He is currently interested in solution based high resolution printing techniques for micro-electronic, opto-electronic and thermoelectrics devices, in the device physics of organic semiconductors based field-effect transistors, in biomedical and/or implantable sensors and electronics for the healthcare.

5.1 Ferroelectric Polymer Sensors for Flexible Electronics

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Ferroelectric polymers from the PVDF-family have proven to be multifunctional and self-sustaining materials with a broad deployment in printed and flexible electronics. They can be used in large and flexible form factors for detecting mechanical excitations such as pressure variations, force touch and impact, for sensing human-body radiation and proximity, as vibration sensors for structure-borne sound detection and acoustics, as fast and precise strain sensors, as stretchable vital parameter sensors for movement, ECG and respiratory rate monitoring, as well as piezoelectric energy harvesting elements, just to name a few [1]..

The sensors are entirely fabricated by screen printing, which is one of the most common techniques used in printed electronics for the fabrication of large-area flexible components and multifunctional devices. Screen printing is highly tolerant to the type and form factor of substrates, the rheology of ink materials, provides sufficient alignment accuracy for multilayer printing and can be done in a sheet-to-sheet or roll-to-roll scheme. The printed ferroelectric polymer sensors come in two versions; (i) either they have a sandwich-type structure of four layers that are printed onto a flexible or stretchable substrate (e. g. plastic films, paper, and textiles up to A3) and response accurately, fast and reproducibly to pressure and temperature changes over large dynamic ranges or (ii) a two layer structure that is highly sensitive to lateral strain and vibrations [2].

By optimizing the design, the printing and drying/annealing processes as well as the poling conditions and the source material, functional sensors with a yield of more than 99% with less than ± 2% deviation in the remnant polarization were demonstrated. It is also interesting to note that extended aging tests under definite climate and shock conditions revealed more than 98% preservation of the remnant polarization for high molecular weight PVDF-TrFE polymers. Based on such sensors various applications like flexible and/or 3D user interfaces [3, 4] (Figure 1) and large-area force, impact and proximity sensors, ultrathin object-integrated microphones and condition sensors, smart floors as well as medical patches will be presented either in a passive sensor (array) configuration or as an active sensor matrix with an OTFT-backplane.

Finally, we developed a printable nanocomposite material, which allows reducing the cross-sensitivity between the pyro- and piezoelectric sensing modes. This material is composed of inorganic and preferentially lead-free ferroelectric nanoparticles blended in a ferroelectric polymer matrix [5], [6]. By exploiting the fact that the piezoelectric coefficient in inorganic ceramics has an opposite sign to that one of the ferroelectric polymer either the piezo- or the pyroelectric activity can be suppressed by independently defining the poling direction of particles and matrix in a two-step poling procedure.

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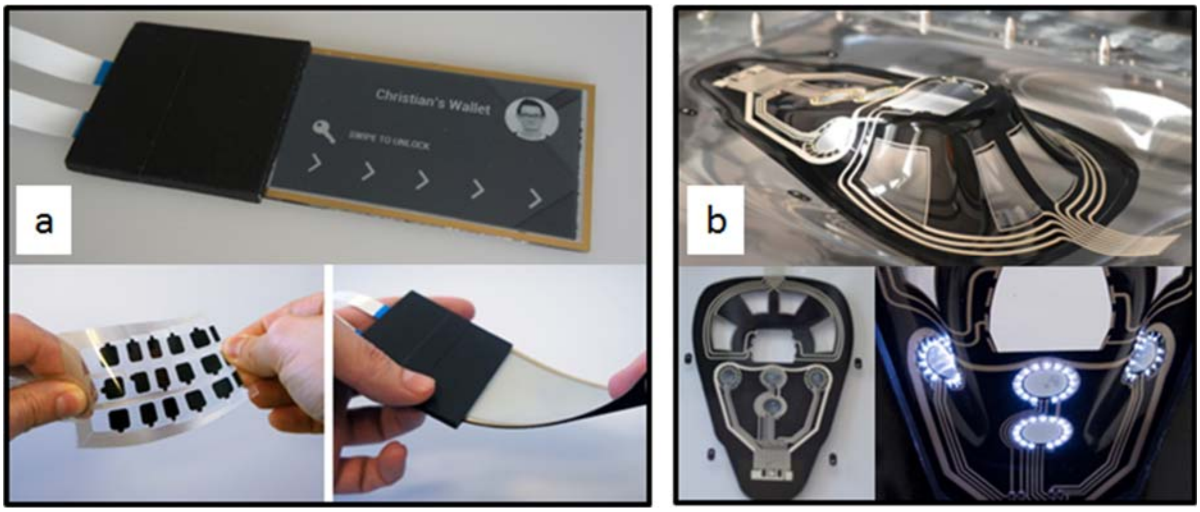

Fig. 1 a) Flexible smart card made of a bendable user interface based on printed piezoelectric sensors integrated with a flexible electrophoretic display, b) 3D-curved user interface made of printed and high pressure formed piezoelectric sensors keys with integrated LEDs for backlighting. [1].

5.2 Integrated electronic functionalities in 3D printed products

Merijn P. Giesbers[1], Stefan. C. L. van Waalwijk van Doorn[1], Rob Hendriks[1]

[1] TNO / Holst Centre, High Tech Campus 31, Eindhoven, Netherlands

There is a trend in the electronics industry towards light weight, flexible and easy to integrate technologies to create more user friendly and organically shaped products.

Combining 3D printing technologies with printed electronics creates a new approach to integrating electronic functionalities. This enables embedded electronics to become freeform as well, creating new functionalities inside the structural part. Market segments are e.g. automotive, displays, clothing and personalized goods.

At Holst Centre, we have made significant progress in developing and integrating print techniques into additive manufacturing. Our most promising print technique for high resolution integration is LIFT (Laser Induced Forward Transfer) printing, allowing ultrafine deposition of conductive materials onto 3D structured / 3D formed products. Combining this with e.g. stereolithography (SLA) allows to create “3D printed structural electronics”.

Apart from its application in 3D printed electronics, LIFT enables printing on both rigid, flexible or stretchable substrates. Compared to traditional printing strategies like screen printing, inkjet and dispensing, a high resolution is reached, while having the capability to print high viscous materials in non-contact mode, allowing printing on sensitive or non-flat surfaces. Furthermore, we have shown that LIFT is not limited to inks, but even components, such as bare die LEDs can be transferred in a fast and accurate way using this method.

In this talk we present the electronics requirements, how 3D printed electronics will support these requirements, and the resulting properties will be complemented with technological demonstrators.

5.3 In-situ manufacturing of thin-film spacecraft, landers and rovers

Michael Johnson[1,2], Julie McCann[1]

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[2] *PocketSpacecraft.com, 42 Triangle West, Bristol, United Kingdom*

Access to space has long been a bottleneck for space missions, whether commercial, scientific or educational. The time from mission concept to first data being received from a spacecraft in its intended orbit typically ranges from years (in low earth orbit) to decades (for interplanetary missions) due to a combination of programmatics, launch schedules and celestial mechanics. We have developed an alternative approach that potentially reduces this schedule to as little as hours per mission, by manufacturing thin-film spacecraft, landers and rovers in-situ.

The CubeSat revolution [1] has demonstrated that a wide range of space missions can be implemented in a restricted envelope (typically based around 0.25 to 6x multiples of 10x10x10cm/1.3kg units) if the benefits of lower costs and faster time to orbit are compelling enough. Space missions that might previously have been implemented with spacecraft with masses of the order of hundreds or even thousands of kilograms have been implemented as CubeSats and have successfully operated as far away as Mars. The standard CubeSat unit was chosen to be a one litre spacecraft with one watt of photovoltaic power if covered with standard space rated solar cells that could be designed, built and launched within the time constraints of a typical American Masters degree program. The authors have demonstrated that spacecraft with similar functionality to CubeSats can be designed and built in the laboratory at gram (printed circuit board based) [2] and milligram (thin-film printed spacecraft) [3] scales using manufacturing techniques that are compatible with the space environment in a matter of hours.

A spacecraft printer CubeSat has been designed that allows milligram scale thin-film printed spacecraft, landers or rovers to be designed on earth, transmitted to the spacecraft printer, whether in low earth orbit (<1s) or on the surface of Mars (<24 minutes), and printed in-situ. The CubeSat combines several additive manufacturing, finishing and testing processes in a single integrated device permitting fully functional self-contained spacecraft and other exploration platforms based on an up to 2500mm^2 polyimide substrate to be deployed. Proof of concept printed spacecraft and missions such as a Solar Weather Buoy and a Mars Meteorological Microlander integrating avionics, communications, instrumentation and power subsystems have been developed and tested in simulated space environments. On-orbit demonstrations of printed spacecraft and spacecraft printer are planned in 2020.

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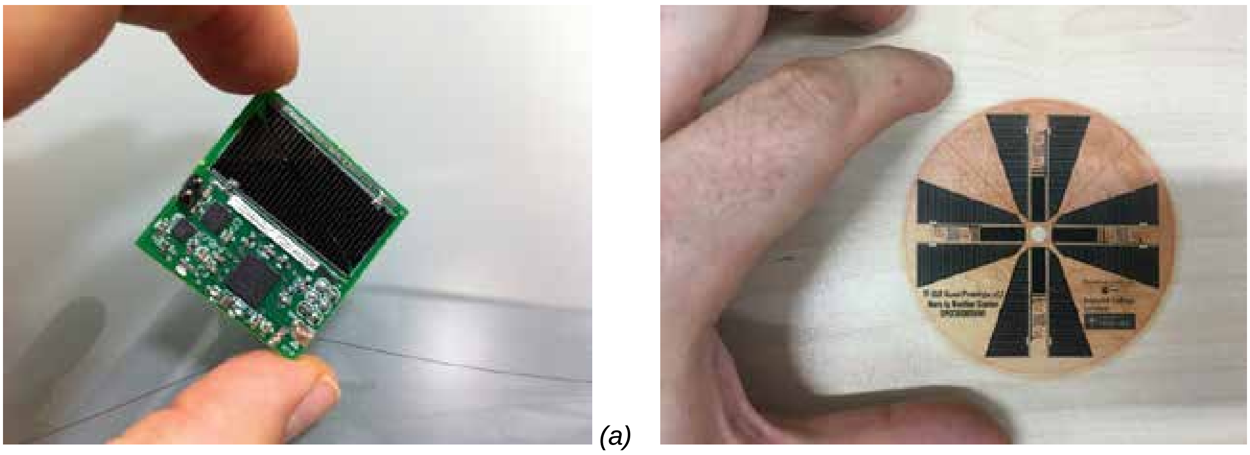

(a) *(b)*

Figure 1. a) gram scale printed circuit board and b) milligram scale printed spacecraft

5.4 Self-healing printed thin film transistor circuits

Li Ding[1], Pushkaraj Joshi[1], James Macdonald[2] and Sanjiv Sambandan[1,3,4]

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Thin film transistors (TFTs) are the building blocks of large area electronic systems. Amongst the several methods to manufacture TFTs, additive ink jet printing offers on demand, bespoke integrated circuits on rigid and flexible substrates. However, inkjet printed electronics are subject to reliability related problems in devices and interconnects. Interconnects of thin film circuits on flexible substrates experience open circuit failures due to mechanical and thermal stress, electrostatic discharge and chemical corrosion.

There have been several approaches to improve the reliability of interconnects. The first is the development of novel materials enabling stretchable conductive materials. The second is the development of novel geometries and fabrication processes permitting meandered and helical interconnects. The third is the development of self-healing interconnects permitting the real time repair of interconnects.

Self healing interconnects have been demonstrated using liquid metals, micro-encapsulated conductive ink that spill upon mechanical fracture of the shell and electric field assisted self-healing (eFASH) using dispersions of conductive particles in insulating fluids [1] (Fig. 1). In eFASH, a dispersion of conductive particles in an insulating fluid is contained over a current carrying interconnect. Upon the occurrence of an open circuit fault field appearing in the open gap polarizes the particles in the dispersion resulting in them chaining up due to dipole-dipole interaction. These chains form bridges across the gap and heal the fault.

Here we demonstrate the self-healing of open circuit faults in ink-jet printed TFT circuits on flexible substrates using eFASH. Successful healing on TFT circuits show complete restoration of dc and ac characteristics. The noise performance of the heal is also analysed and is shown to be within acceptable limits. Most importantly, the heals are shown to permit bending and flexing showing strains of 12 to 60 depending on the strain rate. The ability of eFASH to address interconnect failures during circuit operation in real time promises highly reliable printed TFT circuits.

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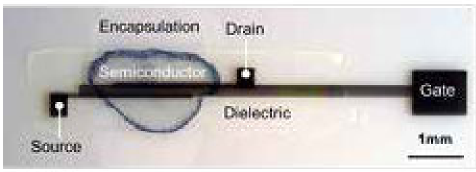

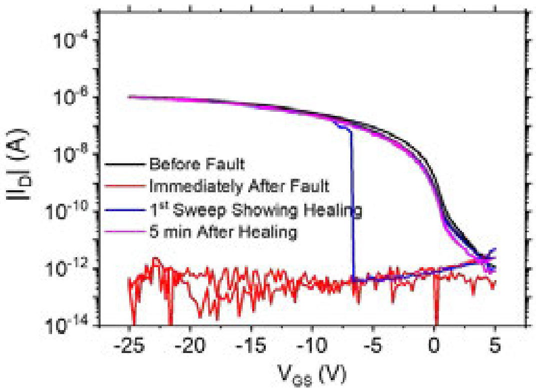

Figure 1. Self Healing TFT circuits

5.5 Direct-Written and Low-Voltage Polymer Field-Effect Transistors Operating at Radio-Frequencies

Mario Caironi[1]

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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, printed polymer FETs fabricated with scalable tools 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 (f_T), i.e. the highest device operative frequency, above 10 MHz is required. Such goal is even more critical to achieve with low operating voltages and on cheap plastic foils. Here, we demonstrate that high-frequency, low-voltage, polymer field-effect transistors can be fabricated on plastic with the sole use of a combination of scalable printing and digital laser-based techniques. These devices achieve f_T in the MHz range already at 2 V, and reaches a record 14 MHz f_T at 7 V [1]. These devices can be successfully integrated into a rectifying circuit on plastic operating at 13.56 MHz, allowing to supply a DC voltage to RF devices and tags fabricated with cost-effective production processes. The progress into radio-frequency operation is supported by S-parameters measurements [2], a standard in high-frequency electronics, yet seldom applied to polymer electronics. Such characterization tool allowed also to assess the progress to even higher f_T values, enabled by recent efforts on the reduction of capacitive parasitism, thus exploring a radio-frequency range never achieved with organic electronics before.

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Figure 1. Logo of the ERC project HEROIC

6.1 Dr Eleni Stavrinidou

Eleni Stavrinidou received her Bachelor's degree in Physics in 2008 from Aristotle University of Thessaloniki and then her Master's degree in Nanotechnology from the same university. She joined the group of Prof. George Malliaras at the Ecole Nationale Supérieure des Mines de Saint-Étienne where she completed her PhD on Microelectronics in 2014. Her work focused on understanding and engineering ion transport in conducting polymers. Eleni then joined the Laboratory of Organic Electronics of Linköping University working with Prof. Magnus Berggren. During her post-doc she developed organic electronic devices integrated within living plants, introducing the concept of Electronic Plants. Since 2017 Eleni is an Assistant Professor in Organic Electronics at Linköping University and leader of the Electronic Plants group. She received several grants including a Marie Skłodowska-Curie Fellowship, a Swedish Research Council (VR) Starting Grant and she is the Coordinator of the HyPhOE-FET-OPEN project. In 2019 she received the L'ORÉAL-UNESCO For Women in Science prize in Sweden. Her research interests focus on electronic interface with plants for plant control - optimisation, energy applications, hybrid systems and electronic materials-plant tissue interaction.

6.2 Mr Ben Woodington

Ben Woodington is a PhD student from the Sensor Technologies CDT, working within the Bioelectronics Group at the University of Cambridge. His research is focused on the development of shape adaptive, flexible implants for sensing and stimulating the spinal cord, with a particular focus on pain management and paraplegia. After completing his undergraduate studies in Chemistry, he worked as a medical device engineer, where he concentrated on the development and scale-up of novel respiratory devices for the treatment of asthma and lung cancer.

6.3 Dr Christian Nielsen

Christian Nielsen received his PhD from the University of Copenhagen in 2004. He has since held academic and industrial research positions in the US and the UK. He joined Queen Mary University of London in 2016 and is jointly affiliated with the Materials Research institute and the School of Biological and Chemical Sciences. His research focuses on the design and synthesis of new semiconducting materials for organic electronic and bioelectronic applications with the aim of elucidating structure-property relations and providing new tailored materials to advance the understanding and performance of devices such as solar cells, field-effect transistors and biosensors.

6.4 Dr Vincenzo Curto

Vincenzo Fabio Curto received his BSc and MSc in Chemical Engineering from the University of Palermo in 2010. In 2013, he earned his PhD from Dublin City University under the supervision of Prof. Dermot Diamond, working on wearable microfluidic chemo/bio-sensors for sports applications. He was then awarded a Marie Curie Intra-European Fellowships (IEF) to develop microfluidic cell culture systems coupled with on-line electronics monitoring systems in the Department of Bioelectronics of the Ecole des Mines de St. Etienne. As a postdoctoral researcher in Cambridge, he is developing high-density neural probes for speech rehabilitation under the BrainCom FET project.

6.5 Professor Josep Samitier

Josep Samitier is professor of Electronics and Biomedical Engineering at the Department of Electronics and Biomedical Engineering at the University of Barcelona (UB), director of the Institute of Bioengineering of Catalonia (IBEC) Barcelona Institute for Science and Technology (BIST), group leader of the Nanobioengineering group at IBEC and group leader in the Centro de Investigación Biomédica en Red de Bioingeniería, Biomateriales y Nanomedicina (CIBERBBN). He is coordinator of the Spanish Nanomedicine Platform (NanomedSpain), president of the Catalan Association of Research Entities (ACER) and full member of the Institut d'Estudis Catalans. In 2003 he was awarded with the City of Barcelona Prize in the category of Technological Innovation.

6.1 Plants-Electronics interface

Eleni Stavrinidou[1]

[1] *Laboratory of Organic Electronics, Department of Science and Technology, Linköping University, 601 74, Norrköping, Sweden*

Plants are complex biological organisms that comprise our primary source of food, but are also a source of oxygen, renewable energy, materials, medicines and regulators of the ecosystem. The interface of plants with electronic materials and devices has not been widely explored although there are many possibilities from controlling plant functions, to energy, sensing and bio-hybrid systems. We demonstrated that water-soluble conducting polymers and oligomers can self organize or polymerize in vivo, with the plant acting as the catalyst and template for the chemical reaction. We manufactured analogue and digital circuits in the organs of a plant as well as supercapacitors for energy storage. Our latest findings show that the conjugated oligomers organize and form conductors in parallel with the growth of the plant. The polymerization of the conjugated oligomers is driven from the lignification process, integrating the conducting polymers in the cell wall. The biohybrid system is further explored in energy applications.

In addition, we are developing bioelectronic devices to sense and actuate plant functions. We fabricated a capillary based organic electronic ion pump (c-OEIP) that enables implantation in soft tissue. The c-OEIP is used to control the stomata in leaves. Stomata, the microscopic pores in the leaves of plants are fundamental to the plant function as they control the photosynthesis and transpiration rate. By delivering abscisic acid, ABA, also known as the stress hormone, we trigger the stomata closure on demand. The stomata next to the c-OEIP close faster than the ones further away implying dose dependence and revealing the signal propagation kinetics. No significant wound effect from the insertion of the c-OEIP is observed signifying the potential of our method as non-invasive. Furthermore, we developed sensors based on organic electrochemical transistors for biomolecules monitoring in in-vitro and in-vivo plant systems. With this technology we can offer new tools for fundamental understanding of plant physiology but also adaptation of plants to environmental changes.

6.2 Development of a minimally invasive spinal cord interface utilising thin film electronics

Ben Woodington[1], Vincenzo Curto[1], George Malliaras[1], Damiano G. Barone[2], Christopher Proctor[1]

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[2] *University of Cambridge, Department of Clinical Neurosciences, Cambridge Biomedical Campus, Cambridge, CB2 0QQ, UK*

Implantable bioelectronic devices for diagnosing and treating disease are emerging as a prominent component of modern healthcare. However, there remains a technical and clinical barrier within the development of new tools to interface with the central nervous system. Overcoming these barriers could improve the lives of people suffering from conditions such as Parkinson's, chronic pain and paralysis.

The risk and cost of the surgery associated with device implantations concerning the central nervous system remains a limiting factor. So much so that patients are restricted from potentially life changing treatment due to high levels of surgical risk. Furthermore, potential avenues of research into treatment are limited due to the inherent risk of translation.

We present a flexible, shape adaptive implant which can be used to interface with the spinal cord. The device is fabricated from biocompatible materials and can be used to stimulate and sense the posterior tracks of the spinal cord. The technology is fabricated using scalable manufacturing techniques in order to create a conformable interface which is 100-200 times thinner than commercially available spinal cord stimulators. We demonstrate in a human cadaveric model that the device can be implanted with a minimally invasive procedure, without the need for laminectomy in contrast to the current surgical practice required for commercially available technologies. The device has potential to be applied in the areas of pain management, Parkinson’s disease and rehabilitation and builds upon our understanding of the translation of implantable bioelectronic devices.

6.3 New semiconducting materials for organic bioelectronic applications

Christian B. Nielsen[1]

[1] *Queen Mary University of London, Mile End Road, London, UK*

The emerging research field of organic bioelectronics has developed rapidly over the last few years and elegant examples of biomedically important applications including for example in-vivo drug delivery and neural interfacing have been demonstrated.

The organic electrochemical transistor (OECT), capable of transducing small ionic fluxes into electronic signals in an aqueous environment, is an ideal device to utilise in bioelectronic applications. To date, nearly all OECTs have been fabricated with commercially available PEDOT:PSS, heavily limiting the variability in performance. We have previously shown that tailor-made semiconducting polymers are fully capable of matching the performance of PEDOT:PSS. To capitalise on this discovery and the versatility of the organic chemistry toolbox, further materials development is needed. In my talk I will discuss our recent work in this area covering examples of both molecular and polymeric semiconducting materials and their performance in bioelectronic devices.

6.4 High-density flexible probes for the neural interface

Vincenzo F Curto[1], Andreas Genewsky[2], Gerrit Schwesig[2], Anton Sirtota[2], George Malliaras[1]

[1] *Electrical Engineering Division, Department of Engineering, University of Cambridge*

[2]*Bernstein Center for Computational Neuroscience and Munich Cluster for Systems Neurology (SyNergy), Ludwig-Maximilians Universität München, Germany*

The development of new tools to interface with the brain will provide new understanding on how the brain works as well as for the diagnosis and treatment of neurological disorders. Therapeutic treatment of neurodegenerative diseases such as Parkinson's disease has made remarkable progress over the last decades. As an example, Deep Brain Stimulation (DBS) is a new technology that involves a surgical procedure for the implantation of electrodes (stimulators) inside a targeted region of the brain. The DBS device is now a common tool to cure neurodegenerative diseases when traditional drug therapies fail to alleviate pathological symptoms, e.g. tremors. However, clinically implanted electrodes for DBS are relatively large and rigid, arising general concerns about their long-term use and biocompatibility.

Here a potential novel approach is proposed to improve the interface between the electrodes and the brain. Highly-conformable and flexible organic substrates used for the fabrication of novel neural implants can dramatically limit neural tissue damage during implantations. Device geometries can be specifically tuned to target different areas of the brains, cortical or sub-cortical regions. Moreover, novel conducting polymer materials employed for the fabrication of these electrodes guarantee high signal-to-noise ratio during recording and show excellent properties when used for stimulation. The potential impact of this research is significant, including the possibility to reduce brain immune response and attain safer stimulation parameters with mechanically flexible implants and improved implantable electrode interfaces using organic technologies. Here, novel high-density neural probes and their in vivo use on rodent models will be presented.

a) b)

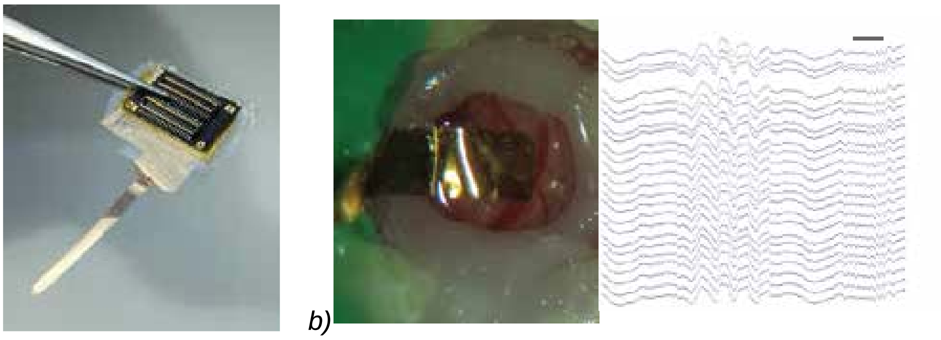

Figure 1. a) Parylene based high density flexible 64 channels cortical neural probe. b) Photograph of an implanted neural probes through a craniotomy window on a mouse model. On the right, chronic (3 weeks) recording of cortical brain activity.

6.5 Bioelectronics for organ-on-a-chip monitoring

Josep Samitier, Roberto. Paoli, Maider Badiola, Maria. J.Lopez, Monica. Mir

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The relation between bioelectronics and microfluidics has allowed in the last 30 years to miniaturize a whole analytical lab on a small chip, performing sample extraction, conditioning, and analytes quantification, or detection, in a simple to use and completely automated microchip.

Organ on a chip try to reproduce tissue microenvironment by engineering geometrical, mechanical and biochemical relevant factors into a microfluidic device including different cell types in a specific three-dimensional (3D) configuration to simulate biological systems with a concrete function. Constant evolution and improvements on microfluidics, bioelectronics, nanobiotechnology and 3D cell culture could to partially close the gap between conventional 2D in vitro cell cultures and animal model-based studies. A step forward in the field of OC technologies is the integration of 3D living cells cultures in microfluidic devices (µFD) together with sensing systems for in situ continuous monitoring. This enables a broad range of possibilities applied to biomedical sciences, impossible to implement using classical techniques. The future of personalized medicine requires to mimic human physiological systems in vitro for drug screening and efficiently treatment monitoring in a fast and reproducible way. In addition, bioelectronics and organ on a chip integration could provide new approaches to address keynote questions in biology and to develop novel dynamic disease models, basically for the pathologies where there are not gold standards tests. In this framework, we will analyse the main challenges and how the integration of bioelectronic devices can be used in organ on a chip to mimic different organs as spleen, heart, kidney or neuromuscular tissues, between others.

7.1 Dr Guillaume Fichet

Dr Guillaume Fichet is Programme Manager at FlexEnable. After graduating from the European School of Chemistry, Polymers and Materials Science (ECPM, Strasbourg), he received his PhD in organic electronics from the University of Cambridge (UK) in 2005 on the topic of OLED light output improvement. Guillaume joined the company in 2005 and was instrumental in developing its flexible display technology platform and scaling the process for high volume manufacture. He now has over 15 years of experience in flexible electronics technology. Guillaume is also an expert on the plastic processing and manufacturing plastic coatings and has a track record of successfully delivering on large commercial projects.

7.2 Sang Yun Bang

Sang Yun Bang is currently a Ph.D. student under Professor Jong Min Kim in Electrical Engineering Division at the University of Cambridge. His research is integrating metal oxide thin-film transistors backplane with red-green-blue patterned quantum dot light-emitting diodes using a transfer printer for display application. Prior to this, he received MS degree in Electrical Engineering from New York University and obtained BS degree in Electrical Engineering from the University of Illinois at Urbana-Champaign.

7.3 Dr Clément Talagrand

Clément is a micro and nano scale Engineer at Bodle. Before starting this adventure, Clément obtained his Master's Degree specialising in micro and nano technology at "Ecole Nationale Supérieure de Chimie, Biologie et Physique de Bordeaux". He then graduated from "Ecole des Mines de Saint-Etienne" with a PhD. His research focus on IGZO-based thin film transistors, studying both the optical and electrical properties of this material, on flexible substrates and deposited by inkjet printing.
Bodle Technologies was founded in 2015, and based in Oxford. Our core technology is centred on the creation and manipulation of colour reflected off a surface by changing the refractive index of ultra-thin functional layers. This elegant, yet highly enabling piece of engineering was first discovered, and developed at Oxford University and first published in Nature in 2014 by two of our co-founders, Prof Harish Bhaskaran and Dr Peiman Hosseini.

7.4 Dr Grigorias Rigas

Dr Grigorios (Greg) Rigas leads the Advanced Manufacturing group at M-Solv Ltd, which focuses on the development of novel processing techniques for large area printed electronics. After graduating as an Electronic Engineer in Greece, Greg moved to Surrey to pursue an MSc in Nanotechnology and Nanoelectronics. In 2013, he was awarded a 4-year scholarship from the National Physical Laboratory (NPL) to pursue a PhD at the University of Surrey (UoS). Under the supervision of Dr. Fernando Castro (NPL) and Dr. Maxim Shkunov (UoS), he (co)-authored more than 10 peer-reviewed journals, a book chapter and, presented in more than 20 conferences. Greg is the recipient of a series of academic awards including the 2017 Postgraduate Award for an Outstanding Researcher from the Institution of Engineering and Technology (IET). His current research interests are within the field of printable biomedical devices and energy harvesting-storage configurations.

7.5 Mr Russell Bailey

Pro-Lite is a supplier of specialist equipment and services with a technical focus in the following areas of photonics: instruments for measuring light and the optical properties of materials; photometry; lasers and laser safety equipment; opto-mechanics and nano-positioning equipment; optics and optical materials; and spectroscopy and spectral imaging.

7.1 Low cost, organic LCDs on plastic - flexible displays for every surface

Presenting author Guillaume Fichet[1]
[1] *FlexEnable, 34 Cambridge Science Park, Cambridge, CB4 0FX, Cambridge, UK*

FlexEnable has developed a new glass-free display technology known as Organic Liquid Crystal Display (OLCD). OLCD is the lowest cost flexible display technology and its attributes of area-scalability and high brightness with long lifetime, provide for the first time a flexible display solution for applications beyond flagship smartphones. As well as being conformable, ultra-thin, ultra-light and shatterproof, these displays can be made on existing glass TFT LCD lines, providing a uniquely low-cost and fast time-to-market solution for flexible displays. Therefore OLCDs can enable unique product concepts such as borderless notebook and tablet displays and thin, high-performance dual cell displays offering ultra-high contrast ratios. Applications for OLCD include consumer electronics, automotive displays, digital signage, TVs and monitors - representing an $80+Bn addressable market that is currently served only by glass displays. This talk will provide an update on the latest breakthroughs in OLCD technology and the exciting new product designs it enable with particular focus on automotive applications.

Figure 1. Ultra-narrow border organic LCD achieved by folding down the borders behind the display for the first time

Figure 2. Example of two 12,1” curved OLCD displays, perfectly integrated into cockpit design and offering ideal and intuitive user interactions. Source: Novares

7.2 Scalable full-colour transfer printed quantum dot light-emitting diode onto active matrix display

S.Y. Bang[1], S. Han[1], Jong Min Kim[1]

[1] *University of Cambridge, Electrical Engineering Division, 9 JJ Thomson Ave, Cambridge, United Kingdom*

Colloidal quantum-dot light-emitting diodes (QLEDs) are prosperous material and device structure for the next generation electroluminescent display application having the advantages of colour tunability, high luminescence and sharp emission bandwidth.[1] Solution-process techniques, involving spin-coating, inkjet printing and spray deposition mainly used to improve the performance for monochromatic lighting. However, when the possibilities of tuning the charge transport layers with recommended materials become practical method, the merits of large-area deposition, easy control of precursor composition, and low-cost has been vanished. Besides, a non-uniformity, rough surface morphology, and poorly defined interfaces were major drawback for patterning full-colours of the individual red-green-blue (RGB) QDs for display application.[2]

Instead of introducing lithography techniques, which require multiple steps of process with chemicals, the result provides a simple direct-contact patterning method using a transfer printer. Accordingly, the ‘dry’ process fosters lithography free colloidal quantum dot (c-QD) film processing to respond room temperature, closed-packed density and void free c-QD monolayer, which will enable numerous form factor from solid substrate to the flexible device while fulfilling the exceptional quality of c-QD layers. In order to increase the transfer yields, surface modification on donor substrate was critical parameter to control c-QD monolayer. Figure 1 clearly shows clean edges and sharp outlines of RGB QDs on the donor substrate and targeted substrate. Here, we present high-performance QLEDs on thin-film transistor (TFTs) backplane allocating distinguished charge transport layers for individual colours of c-QD. The transfer printing process not only patterned QD layers for pixelated display, but also made ease of implementing the optimized electron and hole transport layer for superior illumination sources for future large-area and flexible optoelectronic devices.

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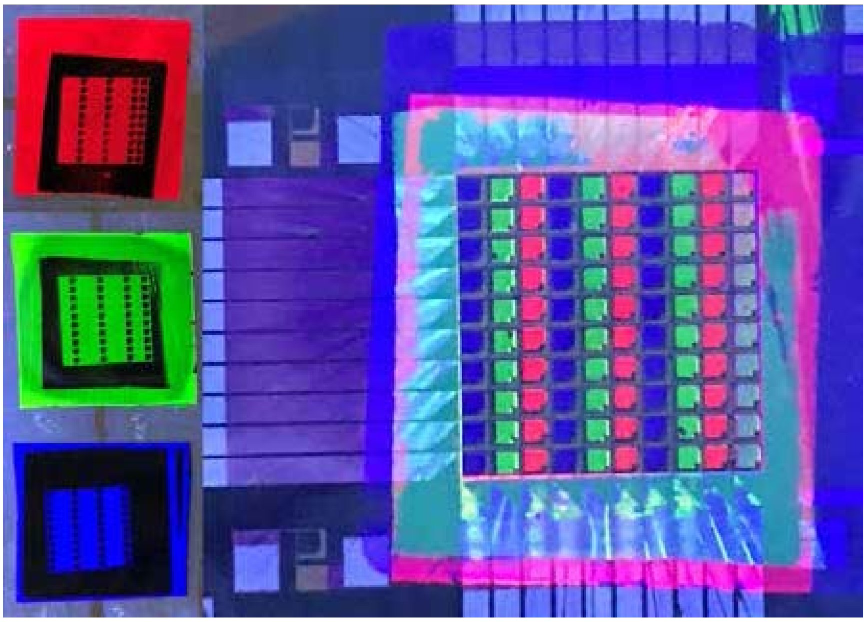

Figure 1. Photographs of the transfer printed RGB QD pixels onto the active matrix TFT backplane of PL

7.3 LTPS driven microheater array for phase-change material based reflective display

Ben Broughton[1], Sergio Garcia Castillo[1], Roberto Ricci[1], Graham Triggs[1], Clement Talagrand[1], Lokeshwar Bandhu, Peiman Hosseini[1]

[1] *Bodle Technologies Ltd, Oxford, UK*

Phase-change materials, developed for re-writable optical data storage applications have been developed to show a striking visible colour difference when switched between their two stable, solid states [1]. Modulating this switch by thermal, rather than optical or direct electrical, means, via joule heating from a buried microheater, has enabled efficient, uniform, reversible switching of phase-change materials over display pixel sized areas [2]. Recently, Bodle technologies has extended this approach, using a low-temperature polysilicon (LTPS) backplane array of diode or thin-film transistors (TFTs) to demonstrate a new type of reflective display [3]. The display is ultra-thin, long-term bistable, exhibits sub-microsecond pixel response times and while currently 2-colour only, has potential for full colour capability. This paper will outline the fundamental mechanism of the display, and detail the development of the custom large area, thin film electronic backplane needed to meet the unusual thermo-electro-optical drive requirements.

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Acknowledgement - The authors would like to thank Lu Feng and Yao QiJun from Tianma Microelectronics Co, Shanghai for their work on the design, fabrication and supply of the LTPS p-i-n diode backplane.

7.4 Advanced Manufacturing of flexible touch sensors for next generation foldable displays

Dr. Grigorios Rigas[1], Dr. Adam Brunton[1]

[1] M-Solv Ltd, Oxonian Park, OX5 1FP, Oxford, UK

At the dawn of the new decade, the long-awaited reinvention of the display technology is gradually being introduced to the mass market. Touch enabled flexible devices, such us smartphones, rollable displays and interactive whiteboards are only few of the examples that came to fruition recently, paving the way for a plethora of new concepts and applications. However, this design diversity is introducing significant challenges in the manufacturing of critical components, such as the capacitive touch sensor. Abstract shapes need to be efficiently implemented at a low cost and with minimum alterations to the equipment involved.

Additive and subtractive manufacturing (A&SM) is currently reinventing the way we fabricate our electronic devices. Solution-based materials deposition and laser processing by, for example: ablation, modification, sintering or material transfer are rather complementary techniques as they are implemented on very similar machine platforms. In addition, they are compatible with high-speed sheet to sheet or roll-to-roll processing, if necessary, in controlled environments (cleanroom, low H_2O, low O_2). By combining these processes, new concepts can be realised in a less wasteful and, more cost-effective way than ever before. By employing the benefits of A&SM, M-Solv recently developed a series of patented approaches covering the complete manufacturing cycle of arbitrary sized and shaped flexible touch sensors.

In this talk, two of the recently developed technologies called “One Step Metallisation” (OSM) and “One Step Jumpers (OSJ), will be discussed. Case studies from both small prototypes to full scale production lines will be presented.

7.5 Display metrology and the challenges measuring flexible displays

Presenting author Russell Bailey[1], co-author Robert Yeo[1]

[1] Pro-Lite Technology Ltd, Innovation Centre, University Way, Cranfield, Bedfordshire, UK

Displays are a rapidly evolving technology and with every new revolution we have new challenges in metrology.

With the advent of smartphones and tablets manufacturers have been at the forefront in increasing the performance of displays. Increasing the resolution, the contrast, the colour gamut, the dynamic range and the display luminance, all these aspects need to be measured.

New technologies and miniaturisation introduce defects that need to be characterised and corrected. Display moiré, edge effects, line defects and pixel level defects are more prevalent in certain display technologies. Typically these defects are caused by the manufacturing process, for example edge effects caused by the adhering process deforming the display or contaminants trapped in one of the layers of the display.

A curved display adds new challenges and solving these is important to ensure that curved displays are accurately measured and specifications are correct.

This talk will give a brief overview of photometry and the methods of measuring displays. We will then go onto discuss the unique challenges that we face measuring flexible displays and some of the solutions available to mitigate these issues.

8.1 Thin Film Electronics – Limits to Performance

Richard Friend

University of Cambridge

Applications for thin film semiconductor devices are huge, covering displays, solar cells and transistor/logic devices. The electronic performance of thin film semiconductors is however is generally not as high as for the 'single crystal' electronics of silicon and III-V materials, because disorder, in the bulk and at interfaces, tends to compromise electronic functionality. Nevertheless, two families of materials now perform very well, and in this talk I will explore current successes and future opportunities.

Organic LEDs and solar cells have shown remarkable improvements in performance, with close to unity quantum yields. However, the voltage efficiencies are still relatively low, and there are real opportunities to make step changes in performance. For LEDs, phosphorescent emission is widely used to avoid triplet exciton losses. Charge injection is often across the singlet energy gap, but the triplet emission is lowered by the exchange energy and this raises the drive voltage. For solar cells, performance is limited by relatively low luminescence yields, which reduces open circuit voltages, currently by 0.3 V and more. I will discuss new materials and device designs.

Lead halide perovskites now provide remarkably high performance thin film solar cells; single junction perovskite cells demonstrate efficiencies above 20% and, with bandgap tuning, provide the high gap semiconductor for tandems with silicon. This is enabled by a remarkable tolerance to the presence of chemical and structural defects, as evident most clearly from the very high luminescence efficiencies now achieved, close to 100%. This enable thin film LEDs and I will discuss recent results which demonstrate very high internal quantum efficiencies.

Biography

Professor Sir Richard Friend FRS FREng holds the Cavendish Professorship of Physics at the University of Cambridge and is Director of the Winton Programme for the Physics of Sustainability. He has pioneered the physics, materials science and engineering of semiconductor devices made with carbon-based semiconducting polymers. His research group was first to demonstrate using polymers efficient operation of field-effect transistors and light-emitting diodes. These advances revealed that the semiconductor properties of this broad class of materials are unexpectedly clean, so that semiconductor devices can both reveal their novel semiconductor physics, including their operation in efficient photovoltaic diodes, optically-pumped lasing, directly-printed polymer transistor circuits and light-emitting transistors.Professor Friend has also been directly involved in the process of commercialisation of this technology, forming several spin-out companies from the University of Cambridge including Cambridge Display Technology, Plastic Logic and Eight19

SESSION 9: HIGH PERFORMANCE MATERIALS FOR LAE

9.1 Dr Selina Ambrose

Selina completed her PhD in Chemical Engineering at the University of Nottingham in 2012 then joined the technical team at Promethean, working on the continuous-flow synthesis of a wide range of nanomaterials. She has held the position of Technical Manager since February 2018, where she now oversees all the R&D activity at the company..

9.2 Dr Aiman Rahmanudin

Dr Aiman Rahmanudin is a Research Associate at the Organic Materials Innovation Centre in the University of Manchester. Aiman completed his PhD at the Ecole Polytechnique Fédérale de Lausanne in Switzerland with Professor Kevin Sivula developing a molecular engineering approach towards the morphology control and processability of organic semiconductors for optoelectronic applications. His research interests are in the design, synthesis and processing of π-conjugated semiconducting materials for organic electronic devices.

9.3 Mr Thomas Eldridge

Tom Eldridge is Director of Business Development for EMEA at CHASM Advanced Materials, which is a materials developer and manufacturer producing carbon nanotubes, inks, and transparent conductive films for printed electronics and battery applications. Tom has over ten years' experience, most of that time focused on applications development and commercialisation of nanomaterials and nanotechnology. He holds a BSc degree in Physics & Philosophy from Kings College London and is a member of the Institute of Physics (IOP).

9.4 Professor Pedro Barquinha

Pedro Barquinha received his PhD in Nanotechnologies and Nanosciences from Universidade Nova de Lisboa in 2010. He is currently an Associate Professor at the Materials Science Department of FCT-NOVA. He has been working in oxide electronics since 2004, participating in >30 national and international research projects in the area, with academia and industry. His work involves design, deposition and characterization of multicomponent oxide thin films, fabrication and characterization of transistors and their integration in circuits on flexible substrates. He is co-author of >150 peer-reviewed papers (h-index=42, as September 2019), 3 books and 3 book chapters in this area. More recently, he also started to focus on taking oxide electronics towards nanoscale, pursuing low temperature synthesis routes of oxide nanostructures and nanodevice/nanocircuit integration, complemented by device modelling/simulation, targeting multifunctional smart surfaces. In 2016, he got an ERC Starting Grant (TREND) to advance this research topic.

9.5 Dr Luigi Occhipinti

Dr Luigi Occhipinti is Deputy Director and Chief Operating Officer of the Cambridge Graphene Centre. He joined the University of Cambridge in April 2014. Prior to that he was Senior Group Manager and R&D Programs Director at STMicroelectronics where he developed science and innovation for more than 20 years in emerging technology areas for the post-CMOS roadmap, smart systems heterogeneous integration, polymer and printed electronics. He also serves as CEO and Director of Engineering of Cambridge Innovation Technologies Consulting (CITC Ltd), a Cambridge-based medical and healthcare research venture, and as Non-Exec Director of Zinergy UK, another Cambridge-based start-up manufacturing printed flexible energy storage devices. Luigi has authored and co-authored more than 90 peer-review papers, 2 book chapters, 2 international standards and is inventor or co-inventor of 40 patent families. He is co-editor of the Cambridge Elements Series on "Flexible and Large-Area Electronics" published by Cambridge University Press.

9.1 Large-Scale Continuous Manufacture of Nanomaterials for Conductive Inks

Selina Ambrose

Promethean Particles Ltd

Promethean Particles is a UK-based SME that designs and develops inorganic nanomaterial dispersions. The company technology is based on a patented reactor system that allows truly continuous hydrothermal or solvothermal synthesis of nanoparticles (patent WO2005077505). Promethean use small scale reactor systems for rapid prototyping to tune the optimum product for each application and backs this up with pilot-scale production facilities, as well as a multi-ton scale nanoparticle manufacturing plant (capacity more than 1000 tons per year). Our unique, liquid-based production process allows us to tailor the nanoparticles to get the best functionality for an end use application.

To address a market need for high-volume, cost-effective conductive materials, we manufacture copper nanodispersions using our novel continuous-flow process. Furthermore, we will be launching copper inks, based on these nanodispersions, which will be suitable for inkjet and screen printing applications in February of 2020. The scale of our production allows the large volume supply of high-quality products at a price which will enable the market to explore these next-generation materials for new and existing applications.

9.2 Bottom-up chemical approach for engineering thin films of organic electronic materials for field-effect transistors

Aiman Rahmanudin[1], Raymundo Marcial-Hernandez[1], Suresh Garlapati[2], Krishna C. Persaud[2], Michael Turner[1]

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The need to engineer stable thin films and develop sustainable solution processing methods has great technological importance in the performance and progress towards commercialization of organic electronic materials into relevant devices such as organic field-effect transistors (OFETs). Herein, we will highlight the development of two bottom-up chemical approaches that address stable low-voltage OFET chemical sensors and a unique direct aqueous processing method of high performance thin films of polymer semiconductors.

1) OFETs have shown great promise for use as chemical sensors for applications that range from the monitoring of food spoilage to the determination of air quality and the diagnosis of disease.[1] However, for these devices to be truly useful they must deliver reliable, stable low-voltage operation over extended timescales. An important element to address this challenge is the development of a high-capacitance gate dielectric that delivers excellent insulation with robust chemical resistance against the solution processing of organic semiconductors (OSC). We report the development of a bilayer gate dielectric containing a high-*k* fluoropolymer relaxor ferroelectric layer modified at the OSC/dielectric interface with a chemically resistant low-*k* methacrylate-based copolymer buffer layer. Bottom-gate OFET chemical sensors using this bilayer dielectric operate at low-voltage, with exceptional operational stability. They deliver reliable sensing performance over multiple cycles of ammonia exposure (2 to 50 ppm) with an estimated limit-of-detection below 1 ppm. We will briefly mention the use of this polymer gate dielectric as a platform for other OFET gas sensing applications.

2) In conventional organic electronic devices, thin films of polymer semiconductors are solution-processed from toxic chlorinated solvents that are arguably harmful to the environment, while aqueous processing has major advantages as a sustainable and eco-friendly process.[2] A promising method is the use of conjugated polymer nanoparticles (CPNs) as colloidal aqueous inks to process thin films of polymer semiconductors. Typically, CPNs are prepared via emulsification of pre-synthesized polymer semiconductors that are dispersed in a continuous aqueuos phase kept stable as colloid by a surfactant.[3] We proposed a method that combines the synthesis and processability of the CPNs into OFETs through direct aqueous thin film processing of CPNs synthesised via miniemulsion polymerisation. It shortens the route from synthesis to devices, adding more value for a "greener" solution processing method of functional high-performance polymer semiconducting thin films for OFETs.

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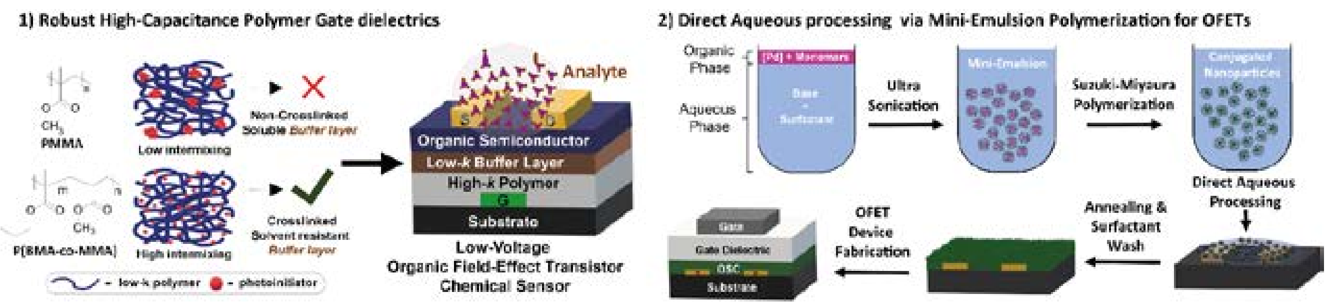

9.3 Innovative approach to large format touch screens through flexible hybrid transparent conductive films

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CHASM Advanced Materials Inc, 480 Neponset St Building 6, Canton, MA 02021, United States

The continuous demand for improvement in functionality, form, and cost-structures of electronics has led to some groundbreaking material innovations and revolutionary manufacturing methods. Indium tin oxide (ITO) was initially one such example, for its unique combination of electrical conductivity and optical transparency becoming the industry's predominant transparent conductive material. However, with new applications and design trends calling for flexibility, stretchability, and large area format, things have been rapidly changing. On flexible substrates ITO suffers well-known drawbacks – susceptibility to cracking when flexed, lower conductivity on plastic compared to glass, and costly to pattern. Yet the need for flexible transparent conductive films (TCF) grows such that by 2022 more than half of the market is anticipated to be comprised of TCFs on flexible substrates.

This has led to the emergence of new materials displacing ITO where it is not viable, for instance the market segment for large format touch screens, which includes electronic white boards and retail displays. Such touch screens require low sheet resistance materials to achieve satisfactory response times. The industry has thus far utilised silver nanowires (AgNW), metal mesh (MM), and copper microwire as alternatives, but each remains suboptimal in terms of cost and/or appearance.

In the case of AgNW, whilst these TCFs offer better transparency and conductivity compared to ITO, their structure requires more expensive circuit patterning than ITO. Metal mesh delivers much lower sheet resistance and flexibility than ITO but the mesh lines can be noticeable and the circuit patterning costs are also high. With microwires, whilst the technology offers good sheet resistance and low cost of patterning, the wires remain the most visible of all the available materials which can be particularly distracting for the user.

Manufacturers and customers desire a better solution without the compromises.

Printed electronic materials can achieve economic circuit fabrication costs, such as conductive polymers (PEDOT) and carbon nanotubes (CNTs). However, neither material is able to provide the necessary optoelectronic performance for large area touch screens.

A new TCF category developed by CHASM Advanced Materials combines existing technologies to create a hybrid solution substantially superior in performance compared to each of these other ITO-alternatives. By combining CNTs with either AgNW or MM, this novel category of CNT hybrid overcomes the limiting factors of the materials deployed by themselves [1]. The hybrid structure (Figure 1) provides conductive redundancy so higher optical transparency can be achieved with low sheet resistance. Whilst the process of creating patterned CNT hybrid TCFs is simple, fast and economical.

CNT hybrid TCFs therefore present an attractive solution to more competitive manufacturing of large format touch screens.

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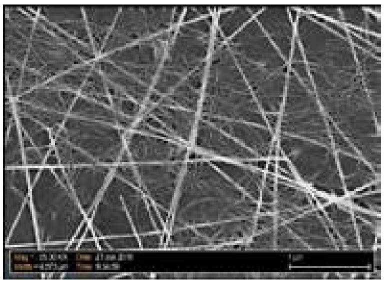

Figure 1. CNT Hybrid Combining CNT and AgNW for Superior Performance.

9.4 Autonomous flexible electronics with zinc-tin oxide thin films and nanostructures

Ana Rovisco[1], Andreia dos Santos[1], Jorge Martins[1], Rita Branquinho[1], Hugo Águas[1], Elvira Fortunato[1], Rodrigo Martins[1], Rui Igreja[1], Pedro Barquinha[1]

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While indium-gallium-zinc oxide (IGZO) thin-film transistors (TFTs) are nowadays assumed as a crucial technology to fabricate active matrix backplanes for high-resolution, low power consumption and even flexible displays, it is imperative to seek for sustainable routes to push the boundaries of oxide electronics. One of the dreams is to conceive a technologic platform enabling seamless integration of autonomous electronic functionalities into everyday objects.

At CENIMAT we are exploring in detail the zinc-tin oxide (ZTO) multicomponent system towards that end. In 2018 we reported for the first time flexible amorphous ZTO TFTs processed at only 180 °C [1]. Controlled hydrogen incorporation during ZTO sputtering and integration with an engineered high-κ multicomponent dielectric were critical to achieve performance metrics similar to IGZO TFTs. Such low-temperature TFTs enable multiple digital and analog circuit blocks operating at 10s of kHz, such as logic gates with rail-to-rail operation or differential amplifiers with gain of 17 dB, even with non-optimized transistor designs (i.e., long channel length, 20 µm, and electrode overlap, 5 µm). Another approach has been exploring ZTO at nanoscale level. In this case we are using hydrothermal synthesis to grow different nanostructures within the ZTO system, such as $ZnSnO_3$ nanowires (NW) or Zn_2SnO_4 NW, nanoparticles (NP), nanocubes (NC) and octahedrons. While in thin film form we are interested in obtaining amorphous structures for large area processing, investigating multiple crystalline phases of the ZTO nanostructures opens up an enormous potential for different applications. Indeed, while the most stable Zn_2SnO_4 phase has been considered as a high-mobility semiconductor material, the metastable $ZnSnO_3$ phase has the potential to greatly improve piezoelectric response over ZnO. To synthesize the desired ZTO nanostructures it was imperative to understand the role of the multiple chemical and physical parameters governing the hydrothermal process. Aspects such as multiple Zn precursors, ratio between Zn-Sn precursors, concentration of the surfactant agent and of the mineralizer, or volume, synthesis duration and process temperature needed to be addressed for this end [2, 3]. Multiple applications are being explored, such as pH sensors, photocatalysis, memristors and energy harvesters. For the later, composite nanogenerators combining piezo and triboelectric effects show output voltage, current, and instantaneous power density of 120 V, 13 µA, and 230 $\mu W \cdot cm^{-2}$, respectively [4].

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9.5 Graphene and two-dimensional materials, from production to applications in sensors and opto-electronics

Luigi Occhipinti
Cambridge Graphene Centre, Department of Engineering, University of Cambridge

This talk will present an overview of the main large-scale production methods of graphene and 2d materials and focus on applications in mechanical, chemical and gas sensors. It will also highlight some of the science and technology roadmaps of graphene and 2d materials developments, in flexible electronics and opto-electronics applications

SESSION 10: WEARABLES FOR HEALTHCARE

10.1 Dr Alison Burdett

Alison has over 30 years of experience in electronic engineering and semiconductor design, particularly in the field of ultra-low power wireless communication for medical applications. She is currently Chief Scientific Officer (CSO) at Sensium Healthcare, responsible for engineering and scientific programmes for the company's digital health products. Dr. Burdett is a Chartered Engineer, a Fellow of the Institute of Engineering and Technology (FIET) and a Senior Member of the IEEE.. She has been an Associate Editor of IEEE Transactions on Biomedical Circuits and Systems (TBioCAS) since 2008, and is Associate Editor in Chief of the IEEE Open Access Journal of Circuits and Systems (OJ-CAS). Alison is a member of the UK Engineering and Physical Sciences Research Council (EPSRC) Strategic Advisory Network, a member of the Wellcome Trust's Programme Advisory Group and a Visiting Researcher at the Institute of Biomedical Engineering, Imperial College. She has 75+ peer-reviewed publications and is a named inventor on 15+ patents.

10.2 Dr Abiodun Komolafe

Dr. Abiodun Komolafe obtained a B.Sc (Hons) degree in Physics in 2007 at the University of Ibadan, Nigeria. Then he obtained a M.Sc in Microelectromechanical systems in 2011 and in 2016, obtained a PhD in printed circuits on fabrics from the University of Southampton. He is experienced in the design and fabrication of e-textiles using screen printing and thin film technologies. He is currently a research fellow in the University of Southampton. He worked on an EPSRC project - Novel manufacturing methods for making functional electronics on textiles using flexible electronic circuits from 2015-2019 and now works in an EU project on wearable multiplexed electrodes for biomedical applications.

10.3 Mr Michael Kasimatis

Michael received his formal training in Chemistry at Durham and developed his interest in functional molecules and materials. He then focused on materials research and the functionalisation of implantable artificial organ scaffolds and received his second degree in Nanotechnology and Regenerative Medicine from University College London. Michael has worked in healthcare, manufacturing, textiles, and informatics in industrial and startup settings, and taught and performed research in Nanotechnology. He is currently doing his PhD in the Guder Research Group investigating wearable sensors, physiological monitoring, and flexible electronic materials. He is the founder of BlakBear, a technology company involved in mass-produced, low-cost sensors, and data analytics in the Agrifood, Healthcare, appliance, and consumer markets.

10.4 Dr Russel Torah

Russel Torah graduated with a BEng(hons) in Electronic Engineering and an MSc in Instrumentation and Transducers, both from the University of Southampton. In 2004 Russel obtained a PhD in Electronics from the University of Southampton. Since 2005 he has been a full-time researcher at the University of Southampton where he is currently a Principal Research Fellow. In 2011 Dr Torah co-founded Smart Fabric Inks Ltd specialising in printed smart fabrics. His research interests are currently focused on smart fabric development but he also has extensive knowledge of energy harvesting, sensors and transducers. Dr Torah has more than 150 publications, 2 patents and an h-index of 27.

10.5 Mr Yasin Cotur

Yasin carries out interdisciplinary projects to apply electronic and analytical tools in biomedicine. He studied BSc in Electrical and Electronics Engineering and MSc in Biomedical Engineering at Bogazici University. He focused on the determination of brain tumour locations from MRI images in the master's thesis. He took part in another academic project to establish an EMG control system on the development of a smart prosthetic hand. He also developed a mobile application for a wireless audiometer device in a start-up company. His PhD in the Guder Research Group at Imperial College is focused on the design of a wearable system for the detection of olfactory recognition events of dogs while they are searching for an odour that they are trained for. Using a paper-based sensor, he has been also developing a prototype for real-time monitoring and analysis of breathing as CTO of Sypras, which is a start-up company based in London.

10.1 Early detection of postoperative patient deterioration through wearable wireless monitoring

Alison Burdett[1],

[1] *Sensium Healthcare, 115 Olympic Avenue, Milton Park, Abingdon, OX14 4SA, UK*

Perioperative complications are unfortunately common following surgical procedures. Postoperative mortality is the third leading cause of death in the USA [1]. The International Surgical Outcomes Study (ISOS) found that 17% of patients undergoing inpatient surgery developed at least one complication [2]. This figure rose to 27% in patients undergoing major surgery. In addition, 2.8% of patients who developed a postoperative complication died before discharge from hospital. Monitoring patients beyond the operating room is important to allow early detection of clinical deterioration and timely intervention [3]. In high dependency wards such as ICU, patients are connected by wires to continuous vital sign monitors to track any changes in physiology that might suggest patient is deteriorating. However on the general surgical wards, continuous monitoring is not practical due to the prohibitive cost and implications for patient mobility and recovery.

Patients admitted to general wards following surgery have their vitals signs measured manually by nursing staff at a frequency determined by local protocols. In the UK, the National Institute for Health and Care Excellence (NICE) recommends monitoring of these vital signs at least every 12 hours for each patient, or more frequently when the patient is believed to be at increased risk of deterioration. However there is a limit to the frequency with which manual observations can be taken practically and affordably by nursing staff, and so patients who deteriorate between manual observation rounds may be undetected for several hours, deteriorating to a point where the patient may need rapid escalation to higher acuity care.

SensiumVitals is an end to end system including a disposable, lightweight (15g), ultra-low power, wireless digital patch with a battery life of five days. It is designed to monitor general care patients' vital signs at two-minute intervals to enable early detection of clinical deterioration. A recent pilot cluster randomized control trial (4) evaluated the use of a wearable wireless patch for patients admitted to two surgical wards. Although the wide confidence intervals (CI) suggest no statistically significant findings, the results were promising; patients in the continuous monitoring group were administered antibiotics sooner after evidence of sepsis, had a shorter average LoS, and were less likely to require readmission to hospital within 30 days of discharge (4).

This talk will outline the user requirements that influenced the design of the current Sensium patch and will highlight further areas for improvement that could potentially be resolved by innovations in large area electronics.

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10.2 Wearable functional e-textiles based on flexible filament circuits

Abiodun Komolafe, Russel Torah, Menglong Li, John Tudor, and Steve Beeby

School of Electronics and Computer Science, University of Southampton, SO17 1BJ, U.K.

The functionalisation of textiles with electronic capabilities presents diverse applications where the electronics provide health monitoring, diagnostic and treatment platforms to the wearer [1]. However, the integration methods for incorporating such electronics into the textile in the research and commercial domains often compromise the natural characteristics and end-of-use recyclability of the textile [2], and more importantly the susceptibility of the wearer where the integrated electronics remain visible to the environment.

This paper introduces a platform technology in the EPSRC funded project - Novel manufacturing methods for functional electronic textiles (FETT) in Figure 1, which combines standard microelectronic circuit fabrication and textile production techniques to hide modular electronics in bespoke pockets within textiles in the form 60 µm thick polyamide filament circuits [3]. The filament circuits are not visible after integration to the wearer or their environment. Unlike other integration methods where the textile is not detachable from the integrated circuits bonded to it mechanically or chemically, these filament circuits are loosely secured within the textile and are easily removable so as to enable end-of-use recycling of the textile and prevent electronic contamination.

The key novelty of the project is the patented vacuum forming packaging of its filaments before integration within the textile filed with application number PCT/GB2019/052906. The filaments are conformally encapsulated with a thermoplastic film which enhances durability of the filaments by situating the electronic layer on the neutral axis. Prototypes are shown to be reliable surviving more than 1500 bending cycles around a 90° bending angle and 50 washing cycles at 60 °C. Example demonstrator applications with this technology include accelerometer and temperature sensing e-textile circuits. Textiles with in-situ processing capability using miniaturised microcontrollers have also been demonstrated with digitally sequenced LED lighting patterns on the fabric.

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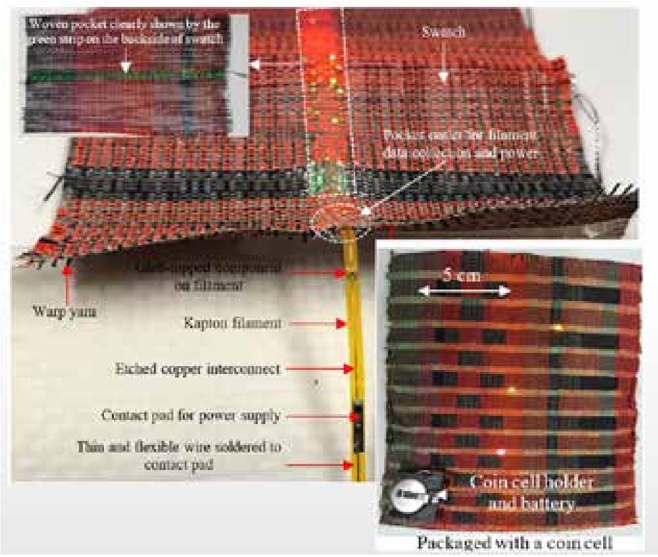

Figure 1. Integration of filament circuits in textiles

10.3 Monolithic solder-on nanoporous Si-Cu contacts for stretchable silicone composite sensors

Michael Kasimatis[1], Estefania Nunez-Bajo[1], Max Grell[1], Yasin Cotur[1], Giandrin Barandun[1], Ji-Seon Kim[2], Firat Güder[1]

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Stretchable devices can conform to curved surfaces, hence they are exceptional as wearable devices for physiological monitoring and rehabilitation.[1–3] Works reported to date have optimized the sensing properties and the manufacturing of stretchable CB-PDMS sensing elements, however, reliable interfacial adhesion of the stretchable sensing element with electronic components, such as wiring, integrated circuits, or other conventional devices, still remains a problem.[4–6] We report a method of creating solderable, mechanically robust, electrical contacts to interface (soft) silicone-based strain sensors with conventional (hard) solid-state electronics using a nanoporous Si-Cu composite.

The Si-based solder-on electrical contact (Cu-pSi) consists of a copper-plated nanoporous Si top surface formed through metal-assisted chemical etching and electroplating, and a smooth Si bottom surface which can be covalently bonded onto silicone-based strain sensors through plasma bonding. Manufacturing methods suitable for large area production and assembly were chosen to enable large scale production of stretchable electronic devices capable of real-world usage.

We extensively investigated the mechanical and electrical properties of the Cu-pSi composite contacts proposed under relevant ranges of mechanical stress for applications in physiological monitoring and rehabilitation. One of the most important features of the Cu-pSi technology is that the contacts do not fail gradually (regardless of whether the devices created are subjected to repeated, increasing or sustained mechanical stress) but instead fail catastrophically. This means that the devices produced using the Cu-pSi technology will either produce a correct signal or do not produce a signal at all; this is especially important for applications in healthcare – e.g., disease diagnostics, rehabilitation monitoring – where wrong signals may lead to a different course of (potentially damaging) medical intervention.

We also produced a series of proof-of-concept devices, including a wearable respiration monitor, leg bang for exercise monitoring, and Squeeze-ball for monitoring rehabilitation of patients with hand injuries or neurological disorders, as well as to improve cardiovascular activity in the elderly through low intensity exertion, to demonstrate the mechanical robustness and versatility of the technology developed, in real-world applications.

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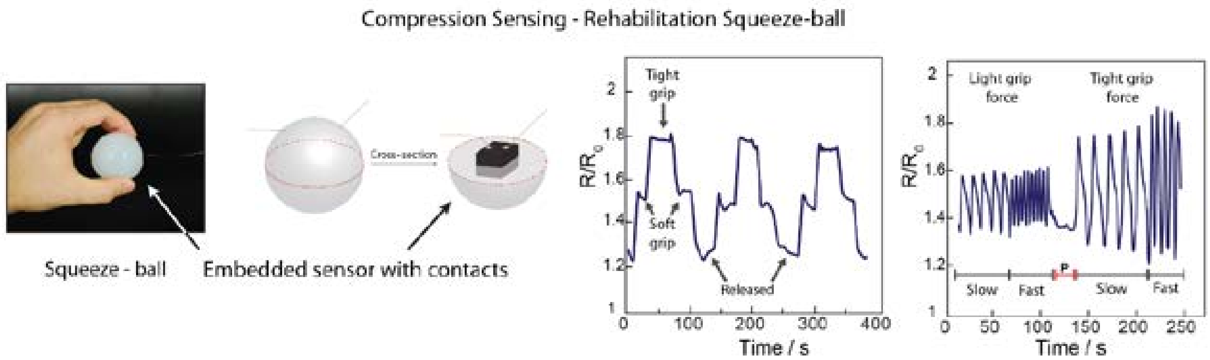

10.4 EU-H2020 project WEARPLEX - Wearable multiplexed biomedical electrodes

Russel Torah[1], Abiodun Komolafe[1], Steve Beeby[1], Milos Kostic[2], Matija Strbac[2], Thierry Keller[3], Nikola Perinka[4], Senentxu Lanceros-Mendez[4], Peter Andersson Ersman[5], Yusuf Mulla[5], Maxim Polomoshnov[6], Luis Pelaez Murciego[7], Strahinja Dosen[7], Erika Spaich[7], Rune Wendelbo[8], Azadeh Motealleh[8], Séverine Chardonnens[9], Katja Junker[9], Jenni Isotalo[10], Roelof Aalpoel[10], Antti Tauriainen[10]

[1] University of Southampton, UK,[2]Tecnalia Serbia, [3]Tecnalia Spain, [4]BCMaterials, Spain, [5]RISE AB, Sweden, [6]Chemnitz University of Technology, Germany; [7]Aalborg University, Denmark; [8]Abalonyx, Norway, [9]IDUN Technologies, Switzerland, [10]Screentec, Finland.

WEARPLEX is a multidisciplinary research and innovation action with the overall aim to integrate printed electronics with flexible and wearable textile-based biomedical multi-pad electrodes. It aims to answer the growing need for user-friendly electrodes for pervasive measurement of electrophysiological signals and application of electrical stimulation. It focuses on the development of the printable electronics and manufacturing processes for stretchable textile based multi-pad electrodes with integrated logic circuits that enable a significant increase in the number of electrode pads (channels) and facilitate the creation of new products in the sectors of medical electronics and life-style. The advanced printed electronics integrated in WEARPLEX electrodes will allow the individual pads to be connected in arbitrary configurations to the output leads of the electrode. Therefore, the pads will be flexibly organized into several virtual electrodes of arbitrary position, shape and size that can be connected to any standard multi-channel recording and stimulation system. In addition, software methods will be developed for automatic calibration of these virtual electrodes, to detect stimulation/recording hotspots and adjust the virtual electrodes accordingly. Therefore, the WEARPLEX project will lead to a new generation of smart electrodes that will be able to adapt simultaneously to the user (wearable and stretchable garment), recording/stimulation scenario (movement type and target muscles) and recording/stimulation system (number of channels). This is a paradigm shift in designing the recording and stimulation systems, as the switching electronics is shifted from the custom-made stimulator/recording device to the smart electrode, leading to a universal solution compatible with any system.

WEARPLEX is funded under the EU Horizon2020 call ICT-02-2018, the work program is over 3 years starting on the 1st of January 2019; this abstract is therefore an opportunity to introduce the project to the community and discuss research directions and present the early results for the project and examples of the Alpha demonstrators from our recent workshop.

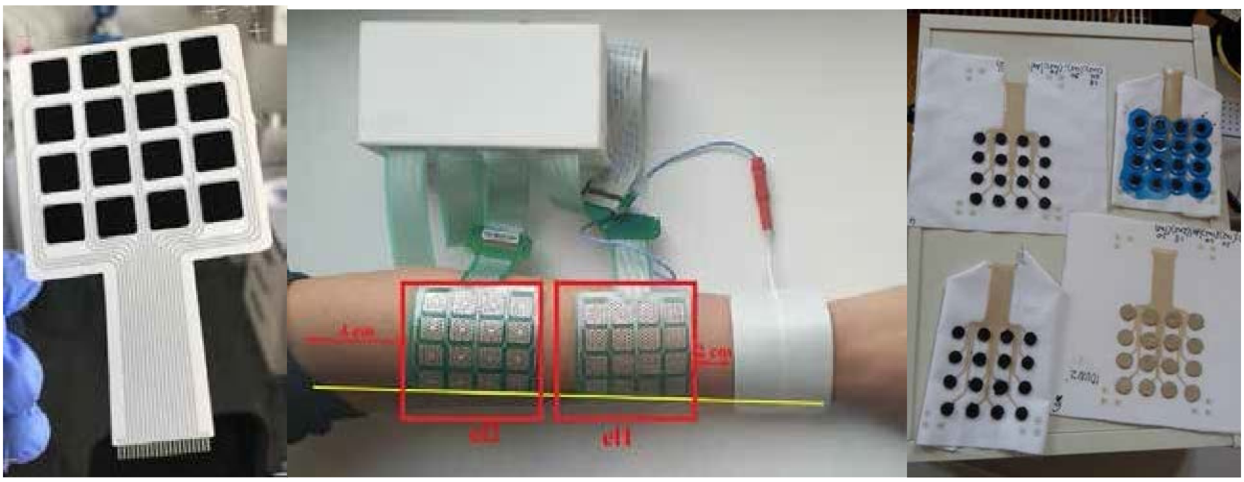

Figure 1. Examples of WEARPLEX printed electrodes for functional electrical stimulation (FES) and electromyography (EMG) recording; printed on thin flexible plastic and textiles.

10.5 Flexible acoustic transducer for monitoring vital signs

Yasin Cotur[1], Michael Kasimatis[1], Matti Kaisti[1], Selin Olenik[1], Firat Guder[1]

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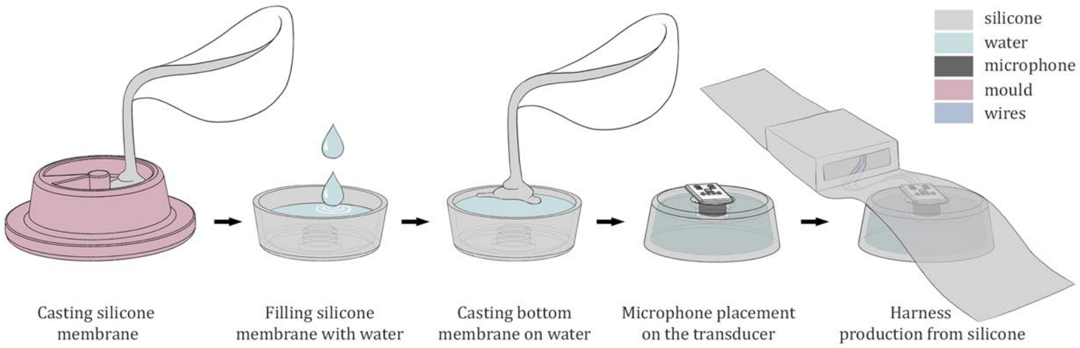
1. Introduction

Measurement of vital signs is challenging with conventional electronic devices that cause rustling noise due to body movement and requires full skin contact. We fabricated a flexible, stretchable, and wearable transducer that provides unobtrusive recording of heart sounds even over clothing. The transducer is composed of a mic and a silicone that encapsulates water (water transducer); silicone conforms to the body well, and heart sounds travel from body water to transducer water with minimal interference eliminating environmental artefacts.

2. Methods

We fabricated the outer region of the transducer from silicone and encapsulated distilled water inside it. The bottom part of the transducer mimics a stethoscope diaphragm which has a bell shape for establishing a good surface contact. The mic was placed on a hollow chamber in the middle of the top surface. The performance of the water transducer was compared to the performance of transducers made of silicone encapsulating air (air transducer), complete silicone (silicone transducer), and a stethoscope. To find the optimum volume of water, two different water transducers with the heights of 15mm and 30mm were also fabricated for comparison.



Three experiments were conducted to study the feasibility of heart sound monitoring of each designed transducer. First, we played an artificial heart sound with 60 beats/min from a speaker and recorded the sound with each transducer. Second, we fabricated a silicone belt including the water transducer and placed it on over a human chest with three layers of clothing to record heart sounds. Third, we tested the transducer directly on a hairy skin of a dog (Labrador Retriever). To determine the similarity between recorded heart sounds with different transducers, we applied Dynamic Time Warping (DTW) to each recording for a quantitative similarity metric.

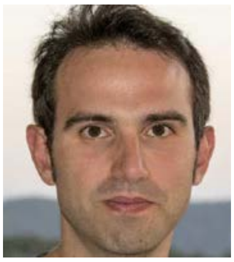
3. Results & Discussion

The analysis on the recordings from artificial data revealed that the water transducer with a height of 15mm outperforms all other devices including a commercial stethoscope in terms of the similarity of the recordings with the original data that was played through the speaker. Tests on human body over clothing showed that the heart sounds recorded with the water transducer have much higher amplitudes than the ones with the stethoscope, which proves that water transducer establishes better contact on the surface. We also managed to obtain heart sound signals on dog experiment although the dog has hairy skin and a panting sound of high volume.

4. Conclusion

In this study, we investigated the performance of a flexible, stretchable and wearable transducer made of silicone encapsulating water, which has a simple, innovative and a low-cost fabrication process. The investigation on recording the heart sounds showed that the water transducer can be reliably used in continuous and unobtrusive health monitoring of humans and animals.

SESSION 11: SENSORS



11.1 Dr Firat Güder

Dr Firat Güder is a senior lecturer in the Department of Bioengineering at Imperial College London. Prior to his appointment at Imperial, he was a research fellow in the group of Prof. George M. Whitesides at Harvard University. He has a PhD in Microsytems Engineering from the University of Freiburg, Germany, and a BSc in Computer Engineering from the University of New Brunswick, Canada. His achievements have been recognized through numerous awards such the UNB Class of 1939 Scholarship, N. Myles Brown Scholarship, Governor Thomas Carleton Scholarship, KU Leuven International Scholarship, Furtwangen University MTM Scholarship, German Research Foundation International Research Fellowship, Tom West Analytical Fellowship and most recently 2018 UNB Young Alumni Achievement Award. Firat and his team work in the interface of material science, electronics, chemistry and biology. His group focuses on the development of new materials, fabrication of low-cost sensors/actuators with the eventual aim of transforming the devices developed into fully functional portable systems for use in healthcare, agricultural and food sciences. In addition to his peer-reviewed papers, he is an inventor of multiple patents and cofounded four startups based on his own research. For more information on Firat and his research activities, please visit www.guderesearch.com.

11.2 Professor Gregory Whiting

Gregory Whiting is an Associate Professor in the Department of Mechanical Engineering at the University of Colorado Boulder (CU). His research is at the intersection of additive manufacturing, novel materials, and functional devices, and is primarily focused on the use of printing as a method to fabricate unconventional electronic components and systems that can be readily customized, mechanically flexible/conformable, large area, widely distributed, biocompatible, and/or controllably transient. These devices can find application in areas including medicine, structural and environmental monitoring, agriculture, robotics, energy generation and storage, assistive technologies, and data security and waste reduction. Prior to joining the University of Colorado in 2017, Greg worked in industrial research, including for Cambridge Display Technology (CDT), the Palo Alto Research Center (PARC), and Google[X] . He received a PhD from the University of Cambridge in 2007 and a BS from the University of California, Berkeley in 2002.

11.3 Dr Daniel Tobjörk

Daniel is a Senior Scientist at CDT currently working in the Biosensors and Gas sensors group to develop gas sensors based on OTFT technology. He holds a MSc in engineering physics from Chalmers University of Technology (Göteborg, Sweden), and a PhD in physics from Åbo Akademi University (Turku, Finland)

11.4 Dr Robert Valentine

Dr Robert Valentine has been working at CPI since 2013 in Electronics focusing on organic semiconductors and development of flexible electronics devices. Robert most recent interest is carbon-based inks and their usage in flexible electronics manufacture, specifically sensing device.

11.5 Mr Pelumi Oluwasanya

Mr Pelumi W. Oluwasanya, MSc, MRes, BSc, MIEEE, MIET, MNSE, is a PhD candidate in the Engineering department. His research interest is mainly in the design, modelling, fabrication and testing of miniaturized/textile-based air quality monitoring sensor devices using new material combinations. He has a MRes in Sensor Technologies and Applications and obtained Engineering degrees from the University of Edinburgh and Olabisi Onabanjo University.

11.1 Near "zero-cost" paper-based electrical gas sensors for measuring food quality

Dr. Firat Güder

Imperial College London

Cellulose paper is a low-cost, flexible and biodegradable material that is ideally suited for the fabrication of near zero-cost sensors using high-volume printing methods. We have recently discovered that the intrinsic properties of cellulose as a highly hygroscopic biopolymer enable measuring gaseous analytes in a fundamentally new way. This new method of sensing gases allows detecting volatiles formed by the degradation of protein rich food products to measure food quality electrically. In this talk, Dr Guder will tell the story of paper-based electrical gas sensors (PEGS), their application in monitoring food spoilage and its future as a commercial solution to reduce food waste.

11.2 Biodegradable printed sensors for monitoring soil conditions

Gregory Whiting[1], Madhur Atreya[1], Gabrielle Marinick[1], Jenna Nielson[1], Sara Khorchidian[1], Yongkun Sui[1], Carol Baumbauer[2], Maggie Payne[2], Ana Claudia Arias[2], Raj Khosla[3]

[1]University of Colorado Boulder, 1111 Engineering Drive, Boulder, CO 80303, USA
[2]University of California Berkeley, 2626 Hearst Avenue, Berkeley, CA 94720, USA
[3]Colorado State University, 307 University Avenue, Fort Collins, CO 80523, USA

Reliable, near real-time, continuous, *in-situ* monitoring of soil conditions at high spatial-density is critical for making effective precision agricultural decisions. Sensor systems that supply appropriate, useful data can improve agricultural management, thereby reducing input (eg. water and fertilizer) and energy use, and potentially improving yields, soil carbon content and farm economics. Large-area and printed electronics provide a compelling approach to fabricate highly distributed sensors in order to address this important need.

This presentation will describe recent progress towards a concept for monitoring soil properties of interest, particularly moisture content and ion concentrations. For this approach sensor nodes fabricated using additive techniques and mostly biodegradable materials are placed directly in contact with soil. These nodes are intended to be read remotely, and to function over the growing season; degrading through microbial activity when no longer needed, thereby more readily enabling high spatial measurement density. The current focus of this research - printed conductors based on composites of biopolymers and soluble metals, capacitive moisture sensors fabricated using these conductors and other biodegradable materials, and potentiometric sensors based on ion-selective electrodes, particularly for nitrate-ion detection - will be discussed.

11.3 OTFT gas sensors for applications in post-harvest monitoring

Dr. Daniel Tobjörk[1]

[1] Cambridge Display Technology Ltd., Unit 12 Cardinal Park, Cardinal Way, Godmanchester, United Kingdom ("CDT")

CDT is a company with significant experience and expertise in creating printed electronics to address a range of fields, including biosensors, image detectors, gas sensors and energy harvesting. In this presentation we will provide an overview of CDT's activity in the field of gas monitoring for the post-harvest industry.

'Smart' agriculture, using technology to inform decision-making in agriculture, is a growing but challenging field for development. High sensitivity requirements and long device operating lifetimes, in challenging conditions have resulted in limited applications, often at significant cost.

CDT has developed a sub-ppm sensor for an important plant growth regulator, 1-MCP, based on an OTFT platform, and demonstrated the ability to discriminate between similar molecules. Data shows extended operation in a low temperature, high humidity environment, common in controlled atmosphere stores where 1-methylcyclopropene (1-MCP) is often used to halt the ripening process. Applications of this platform to another challenging target application, rot detection, will also be presented.

Biography

Daniel is a Senior Scientist at CDT currently working in the Biosensors and Gas sensors group to develop gas sensors based on OTFT technology. He holds a MSc in engineering physics from Chalmers University of Technology (Göteborg, Sweden), and a PhD in physics from Åbo Akademi University (Turku, Finland).

11.4 Fabrication of a printed, flexible temperature and humidity sensor device that is technology enabler for IoT

Rob Valentine[1], David Barwick[1], (Sam) Yun Fu Chan1, Louise Evans[1], Jon Gowdy[1], Phillip Hollis [1], Simon Johnson[1], Paolo Melgari[1], Tim Pease[1], Brian Smith[1], Andrew Stevenson[1], Lee Winchester[1]
[1] CPI, Neville Hamlin Building, Thomas Wright Way, Sedgefield, County Durham, United Kingdom

The Internet of Things (IoT) has been a key driver for the development of sensing devices to monitor environmental conditions for a range of real world applications. The temperature sensor market has an estimated worth of around $20billion in the US alone and it is proposed this market will be worth $40billion by 2022 [1]. Many types of temperature sensors exist from simple thermometers to high temperature resistance detectors (RTDs). At present fully printed temperature sensors make up only a small fraction of this market with estimated sales of $5.3million (US) in 2017 [2]. However, it is forecast that this will grow significantly with a compound annual growth rate of 65% to 2025 leading to a market estimated at over $100million. Temperature sensors can be used in almost every IoT environment, for instance, to measure and monitor the temperature of a package containing a high value, thermally-degradable product. Humidity is another key factor that could affect the integrity of a product.

In this paper, we summarise the manufacture of an Atomic Layer Deposition (ALD) enhanced screen-printed temperature and humidity sensing system. The sensor is integrated with an antenna for data transmission over an NFC protocol to a Bluetooth enabled device, such as a smartphone, running a bespoke application. These sensing devices have been printed on a flexible PET substrate, using commercially available inks for all aspects of the device architecture. ALD is an important technology for organic electronics. Aluminium oxide deposited by ALD has been used to encapsulate the device and differentiate the sensor response to environmental stimuli, allowing for the collection of both temperature and humidity data. The optimal sensor architecture has been fine-tuned using a femtosecond laser tool. This was achieved by laser ablation of the screen-printed sensing material. This offers high precision digital patterning, ablation and singulation processes.

The sensor devices have been tested on a wide range of temperature and humidity conditions of interest for the packaging application market. For a temperature stimulus in the 20-90°C range the response is linear, while there is an exponential change in the relative humidity response between 10-90%.

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Acknowledgement - The authors would like to thank the ERDF (European Regional Development Fund).

11.5 Wearable sensors for personal exposure monitoring

Pelumi W. Oluwasanya*, Tian Carey, Yarjan A. Samad, Luigi G. Occhipinti

Cambridge Graphene Centre, University of Cambridge, 9 JJ Thomson Avenue, Cambridge CB3 0FA, UK

With the growing awareness of the need for clean air also comes the strict requirements of highly sensitive and selective sensors that are robust to different environmental conditions [1]. These requirements have been difficult to meet, especially for miniaturised and non-intrusive sensors. In this work we demonstrate novel sensors suitable for integration in wearables for personal exposure monitoring. We present our recent work on particulate matter detection [2] gas sensing. Multiphysics models for particulate matter sensors and fabricated sensors based on nanomaterial composites [3] on flexible substrates. We show that the sensors are selective to NO_2 in the presence of CO_2 and NH_3. This work opens the frontier for on-clothing air pollution sensors suitable for use in personal exposure monitoring.

**Presenting author*

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[3] T. Wang, D. Huang, Z. Yang, S. Xu, G. He, X. Li, N. Hu, G. Yin, D. He, and L. Zhang, "A Review on Graphene-Based Gas/Vapor Sensors with Unique Properties and Potential Applications," Nano-Micro Letters. 2016.

SESSION 12: ADVANCED MANUFACTURING PROCESSES & EQUIPMENT

12. 1 Professor Duncan Hand

Duncan Hand is Professor Applied Photonics at Heriot-Watt University and leads research into applications of high power lasers in manufacturing, working with a range of industrial partners. His focus is on high precision micro-scale applications, including bonding, micro-machining, cutting, and surface structuring. Applications range from packaging of electronics, manufacturing of microfluidics, through to generation of high friction surfaces for ship engine parts. He also is involved in fibre optic delivery of short pulse, high peak power laser light for applications in manufacturing and surgery.

12.2 Dr James Blakesley

James Blakesley is a Senior Research Scientist in Electronic and Magnetic Materials at the National Physical Laboratory. His team provide contract R&D, measurement services and consultancy to a wide range of industries, particularly photovoltaics, and printed electronics. Current projects include in-situ characterisation of photovoltaics, reliability and degradation of thin-film electronic materials and tools for quality control and industrial inspection. He is active in the international standards community and is currently involved in several standardisation projects, including developing standards for energy rating of emerging photovoltaics and characterisation of printed electronic materials.

12.3 Mr Vikram Turkani

Vikram Turkani is an Applications Engineer at NovaCentrix based in Austin, Texas. He joined NovaCentrix after receiving his M.Sc. degree in Electrical Engineering at Western Michigan University (WMU) in 2018. He worked as a Research Assistant at the Center for the Advancement of Printed Electronics, WMU prior to joining NovaCentrix and has been involved in the field of printed electronics for the last 3 years. He has authored several articles published in peer-reviewed journals/conference proceedings on printed physical and chemical sensors.

12.4 Dr Ivor Guiney

Ivor’s experience is in physics, engineering and semiconductor materials, with focuses on solid state device development, epitaxial growth advancement and novel materials development. He has taken the lead on projects which have developed new combinations of functional materials with a view to linking innovative science with real-world applications. Throughout numerous projects, Ivor has taken charge of material deposition and characterisation for electronic and optoelectronic devices to solve issues endemic to the semiconductor industry.

Ivor has held positions both in the commercial world of capital equipment manufacture and academia as a senior physicist at the University of Cambridge. He also sits on the Institute of Physics Semiconductor Committee.

12.5 Mr Thomas Kolbusch

Thomas Kolbusch is Vice President of Coatema Coating Machinery GmbH, an equipment manufacturing company for coating, printing and laminating solutions located in Dormagen, Germany. He is member of the board of the OE-A (Organic Electronic Association) and of COPT.NRW, a local association in Germany. He served 6 years as the exhibition chair of the LOPEC in Munich. He is conference co-chair of the Flextech conference in the US. He serves on the advisory board of Fraunhofer ITA institute and has been an auditor for the Fraunhofer Eneas institute. He is active in the field of fuel cells, batteries, printed electronics, photovoltaics and medical applications. He organizes the Coatema Coating Symposium and represents Coatema in a number of public funded German and European projects. Thomas studied Business Economics at the Niederrhein University of Applied Sciences and got his degree as business economist in 1997. He started his career at 3M, Germany and has worked for Coatema Coating Machinery in different positions since 1999.

12.1 Picosecond laser microwelding: a novel technique for hermetic joining of transparent materials.

Paulina Morawska[1], R.M. Carter[1], M.J.D. Esser[1], Y.F.Chan[2], P.Melgari[2], R. Douglas[2], D. Karnakis[3], D.P. Hand[1]

[1] *School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, UK*

[2] *Centre for Process Innovation Ltd – National Printable Electronics Centre, The Neville Hamlin Building, Thomas Wright Way, NETPark, Sedgefield, Stockton-on-Tees, UK*

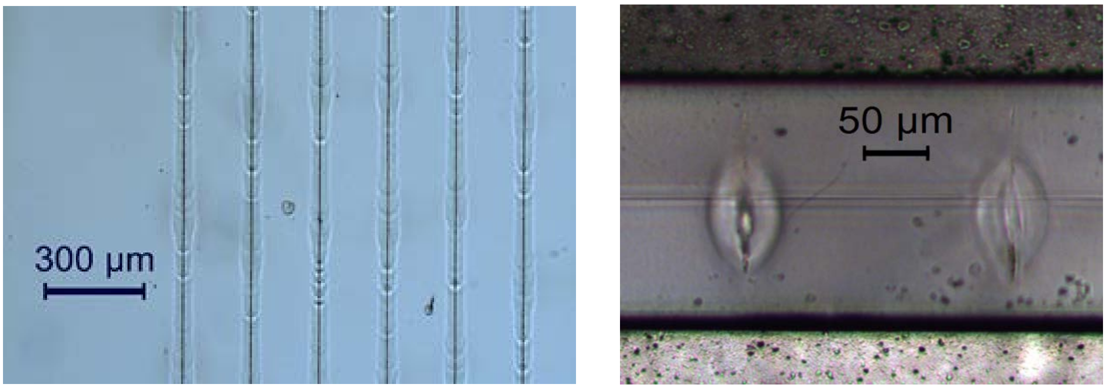
[3] *Oxford Lasers Ltd, Unit 8, Moorbrook Park, Didcot, OX11 7HP, UK*

We have developed a laser welding process for bonding optical materials to other (optical and non-optical) materials using ultra-short laser pulses of only a few picoseconds duration. This process creates very small weld volumes and hence there is minimal total heat input. These ultra-short pulses of laser light have an extremely high peak power which leads to absorption even in a transparent material, but only at the focus of the laser beam where the power density exceeds a few TW/cm^2. This means that a plasma volume only a few microns across can be created at focus, and the associated heat creates a melt volume only a few tens of microns across, without affecting the surrounding material. This allows very thin transparent materials to be welded, for example thin flex glass.

We report application of this process to a wide range of materials, demonstrating the welding of glasses and optical crystals to metals, semiconductors and glasses. In particular, we focus on the welding of thin flex glass to thin flex glass (both 100 µm thick) for hermetic encapsulation of OLEDs in conformable packages. The welding can be combined with conventional laser material removal processes such as laser micro-machining/thin film ablation for more complex packaging challenges.

This work is being carried out as part of an Innovate UK project called UltraWELD, and a prototype commercial laser welding machine is being developed for this process.

We acknowledge financial support from Innovate UK under grant No. 103763, UltraWELD.



(a) (b)

Figure 1. Optical microscope images of the weld features in two 100 µm thick flexible glass components obtained by ultrafast laser microwelding (a) Top view of a series of welds; (b) cross section of the weld seam

12.2 A new tool for high-speed quantitative functional imaging of large-area electronics

James Blakesley, George Koutsourakis, Andrew Thompson, Sebastian Wood, Fernando Castro

National Physical Laboratory, Teddington, United Kingdom

Photocurrent imaging known as laser- or optical- beam induced current (LBIC or OBIC) is a powerful tool for quantifying spatial non-uniformity, defects and quality in a range of semiconductor devices. The method can extract spatially resolved values for quantities such as quantum efficiency, carrier diffusion length and resistance change. It has been applied to a range of technologies including photovoltaics, LEDs, FETs, microelectronics and interconnects, printed electronics, 2D materials and power electronics. The technique works by focussing a modulated laser beam at a point on the device's surface and measuring the corresponding photocurrent before moving to the next point and repeating. In this way, an image of is acquired one pixel at a time. However, it is beset by low speed and poor signal-to-noise ratio, particularly when extended to large areas; acquiring high-resolution images can take many hours. For this reason, the application has generally been limited to research or failure analysis, but it is not widely used as an industrial inspection tool.

We have developed an alternative approach using a digital micromirror array to project patterns of light onto a large surface area instead of a single point [1-4]. Sequences of specially selected patterns are used to encode spatial information about the device under test such that the measured device current contains information about all pixels in an image simultaneously. This approach has several benefits:

1) Noise is reduced, as each pixel in the image is sampled many times;
2) Signal amplitude is boosted as many pixels are measured simultaneously;
3) Compressive sensing theory enables the image to be undersampled, meaning that fewer measurements are required than the number of pixels in the final image;
4) In contrast to photoluminescence and electroluminescence imaging, the technique is quantitative and can be calibrated.

We present a description of the operating principles and show how the system can be used to image defects and monitor quality in large-area electronics and can even be used *in situ* to visualise degradation in real-time. We also describe the challenges of developing this into an industrial metrology tool, including novel mathematical approaches needed for megapixel image reconstruction and high bandwidth instrumentation that we have employed to reduce measurement time from hours to minutes.

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This work was supported by the EMPIR PV-Enerate project. PV-Enerate has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme. It has also received support from the UK Department of Business Energy and Industrial Strategy through the National Measurement System.

12.3 Next generation paper: Cost-effective printed electronics techniques advancing augmented book manufacturability

Radu A. Sporea[1], Brice Le Borgne[1], Georgios Bairaktaris[1], David M. Frohlich[1], Vikram Turkani[2], Rudresh Ghosh[2], Vahid Akhavan[2], Stan Farnsworth[2]

[1] *University of Surrey, Guildford, GU27XH, United Kingdom*

[2] *NovaCentrix, Austin, 78728, United States of America*

The use of paper as a reading medium has not disappeared with the rise in digital reading. In fact, the use of print-based documents goes alongside with the digital devices in many instances such as educational (textbooks and laptops) and leisure (novels and smartphones). The interplay between print and digital media has given rise to the development of a hybrid reading experiences in the form of “augmented books” or “a-books” [1].

The development of a-books aims to add functionality to a physical book though incorporation of electronic components. This functionality connecting to multimedia content such as video, images and websites on a handheld digital device despite its ordinary paper appearance. As a consequence, a-books bring the reader closer to the digital content without compromising the reading experience.

In this work, the development of an augmented book termed as Next Generation Paper (NGP) is demonstrated. It relies on traditional screen-printing processes for functional augmentation and signal routing within the a-book, resulting in a robust, low-cost and lightweight implementation. This effort is the next step in an iterative development of the previously reported work by Sporea et. al [2]. The process of developing the NGP a-book (Fig.1(a)) involves digital content creation by embedding the specific multimedia content into the text/figures using Adobe InDesign software, thereby resulting in a digital book (e-book). The content from the e-book can be conveniently used for printing the physical pages of the book, while the multimedia content is accessible via the electronic augmentation.

The electronics part of the NGP comprises of printed organic photovoltaic (OPV) cells (VTT, Finland) to detect opened page by the user. Communication in terms of Bluetooth® low energy module, microcontroller (ATMEGA 328P-AU) and signal conditioning circuit are housed in the custom designed printed circuit board. NGP uses a Li-Po battery and wireless charging to recharge the battery. These physical electronics are connected using screen printed interconnect traces on polyethylene terephthalate substrate (Fig. 1(b)) alongside the screen-printed capacitive touch sensors (NovaCentrix, USA), a reliable and cost-effective solution for enabling the augmentation.

When the user reads a certain page, the embedded OPVs enable the system to recognize the page number and relay it to a smartphone app. The user can access that page (e-book) on the app and navigate to the multimedia link of interest embedded in the text. Finally, the printed touch sensors on the margin of the book provide variety of functionality to access the multimedia content as the user navigates through the page.

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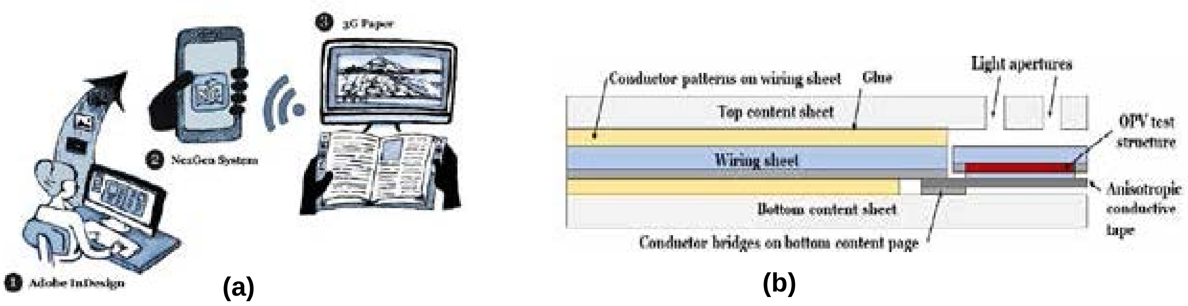

(a) (b)

Figure 1. Augmented book system (a) and instrumented page cross section (b)

12.4 Next Generation Large Area Graphene for Electronics

Ivor Guiney

[1] *Paragraf Ltd., Somersham, Cambridgeshire, UK*

Since its discovery in 2004, Graphene has been postulated for many applications in electronic devices and components. This stems from its unique and excellent material properties including high electron mobility, atomic thinness, high optical transparency and high mechanical strength, to name but a few of its properties. A large number of electronic devices with various remarkable operational characteristics have been proven at small scale in research labs around the world. Recently, focus has turned to scaling up proof of concept devices to larger volumes.

However, there are several well-documented drawbacks to the current approaches of creating graphene. One method of obtaining atomically thin graphene suitable for electronic devices is to exfoliate it from graphite; also known as the "scotch tape method". This results in excellent quality graphene but is limited to very small sizes and flakes. Chemical vapour deposition (CVD) is employed to create large-area sheets of graphene. Significant progress has been made in this sphere in the last several years. However, the most common method of synthesising graphene via CVD is to use a metal catalyst such as copper foil to promote graphene formation. This copper foil has to be etched away, which leads to contamination of the graphene layer or layers; this is problematic for many applications in electronic devices [1]. Sublimation of silicon carbide wafers is sometimes employed, which yields very good quality graphene. However, the cost of the silicon carbide wafers prohibits uptake in many applications.

Paragraf has developed a novel approach to forming graphene directly on semiconductor wafers, without the use of any catalysts, eliminating graphene transfer steps, and using existing equipment and infrastructure in the semiconductor industry. This has allowed for Paragraf to produce electronic devices using graphene, at scale.

In this talk, the various technologies that Paragraf is investigating and developing will be outlined, along with device results from Paragraf's first product, a magnetic (Hall) sensor.

References

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12.5 Silver nanowires application on big scale for flexible displays and flexible electronics

Thomas Kolbusch[1*], Thomas Exlager[1], Dr. Klaus-Peter Crone[1]

[1] *Coatema Coating Machinery GmbH, Roseller Strasse 4, 41539 Dormagen, Germany*

* Presenting and corresponding author, Thomas Kolbusch, tkolbusch@coatema.de

Large area printed and hybrid electronics technology has been developed and scaled up over the past years to a huge extent. In many applications printed sensors, displays and organic photovoltaic (OPV) devices are used quite commonly. The applied manufacturing technology methods are also advancing and become more and more refined

The Author will present equipment and machinery solutions for the R&D, pilot line and production of conductive coatings like Silver nanowires, Pedot:PSS and other replacement of ITO as conductive coating on flexible films.

Cost-efficient production requires coating Technologies, e.g. slot die and specific drying technologies for water-based and solvent-based conductive inks. Here the author will focus on slot die coating and the drying process of conductive formulations on flexible polymer film substrates.

The development from Lab2Fab is shown in some layouts and today's standard of production technology is explained. The replacement of ITO by flexible and bendable nanowires will be the needed revolution for flexible and foldable displays

Posters will be displayed in the exhibition space.

The conference will focus attention on the poster presentations during tea breaks, lunch and at the poster drinks reception on Tuesday 21st January from 17:30, prior to the gala dinner.

The Programme Committee will award a prize to the best poster based on presentation quality, scientific excellence and the impact of the work for academia or industry. The award will be announced at 10am on Wednesday January 22nd following the first keynote talk.

Poster presenters are requested to make sure that their poster is displayed on the appropriate board before lunch on Tuesday 21st January, and removed at the conclusion of the lunch break on Wednesday 22nd January.

POSTER PRESENTATIONS

innoLAE 2020

Poster	Presenter	Institution	Abstract Title
P1	Dr John Hardy	Lancaster University	*Multiphoton fabrication of bioelectronics*
P2	Mr Sagnik Middya	University of Cambridge	*Transparent microelectrode arrays for in-vitro electrophysiology and simultaneous imaging*
P3	Mr Anastasios Polyravas	University of Cambridge	*Using Organic Electrochemical Transistors for Enhanced Electrophysiology Recordings*
P4	Mr Dimitrios Simatos	University of Cambridge	*Stabilizing organic electronics devices for long-term environmental sensing*
P5	Ms Nicola Broughton	CPI	*Challenges and opportunities in reproducible electrochemical ink formulation and processing for multiplexed biosensor design*
P6	Dr Daniel Arnaldo De Cerro	Oxford Lasers Ltd	*Laser selective sintering of laser printed silver inks on polymeric substrates for flexible RFID devices*
P7	Professor Duncan Hand	Heriot-Watt University	*Picosecond laser microwelding of ultra-thin flexible glass for hermetic encapsulation of OLEDs*
P8	Mrs Christina Koutsiaki	Nottingham Trent University	*Excimer Laser Annealing of sol-gel Metal-Oxide thin films*
P9	Mr Douglas Vieira	UNESP	*The effect of UV irradiation on electrical properties of spray-coated ZnO thin films*
P10	Mr Emre Yarali	King Abdullah University of Science and Technology (KAUST)	*Photonic Processing of Metal Oxide Thin Films for Electronic Devices*
P11	Mr João Luis	Durham University	*Tuning the electronic properties of metal oxides by low temperature annealing*
P12	Professor Pedro Barquinha	UNINOVA-CEMOP	*TCAD and XPS studies on the effect of device structure, electrode material and semiconductor composition on the performance of low-temperature IGZO TFTs*
P13	Mr Navid Mohammadian	The University of Manchester	*Low-power High-performance a-IGZO Thin-Film Transistor using OTS Modified Ta2O5 as the gate dielectric*
P14	Ms Gabriel Nogueira	São Paulo State University (UNESP)	*Fabrication of Schottky diode and Electrolyte-Gated Transistor using spray-printed ZnO at low-temperature as the semiconductor material*
P16	Mr Md Nazmul Anam Rafi	Tampere University	*Low voltage p-channel organic TFT on low-cost substrates.*
P17	Mr Panagiotis Mougkogiannis	University of Manchester	*Organic Field Effect Transistors for Low-level Detection of N-Alkyl Amines*
P19	Mr Oliver Read	University of Manchester	*exfoliated 2d Material inks for IJP*
P20	Mr Maykel Klem	São Paulo State University (UNESP)	*Spray-printed molybdenum disulfide electrodes for application in supercapacitors*
P21	Ms Gopika Rajan	University of Exeter, Exeter, Devon, UK	*Graphene based electronic devices on flexible textile fibres*

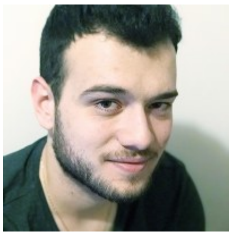
Poster	Presenter	Institution	Abstract Title
P22	Dr Junjie Shi	University of Southampton	*Flexible textile power module based on ferroelectret energy harvester and super capacitor*
P23	Dr Samuel Beddoe	University of Southampton	*Bi2S3 thin film photovoltaics; a study of the impact of morphology on absorber properties*
P24	Ms Lokeshwari Mohan	Imperial College London	*Large-scale deposition of copper (I) thiocyanate hole transport material for use in perovskite solar cells*
P25	Mr Pavlos Giannakou	University of Surrey	*Conformal 3-Dimensional Energy Storage through Inkjet and Water-Transfer Printing*
P26	Ms Sarah-Jane Potts	Swansea University	*Effect of press parameters and ink viscosity on ink separation mechanisms in screen printing*
P27	Ms Josephine Charnley	Quantum Technology Supersensors	*Applications of LAE - Simultaneously addressing healthcare needs & the step change required in climate action*
P29	Mr Georgios Bairaktaris	University of Surrey	*Next-generation paper: a versatile augmented book platform*
P30	Mr Sang Yun Bang	University of Cambridge	*Quantum dot-based colour gamut and rendering for white electroluminescent lighting device*
P31	Dr Neri Alves	São Paulo State University (UNESP)	*Aluminum layer roughness effect on the anodization process and in electrical properties of Al2O3 films*
P32	Ms Huda Ahli	Imperial College London	*The evolution of OSC's performance parameters under mechanical bending*

P1 Dr John Hardy

John Hardy is a 50th Anniversary Senior Lecturer in the Department of Chemistry and Materials Science Institute at Lancaster University. He is a chemist by training with 10 years of interdisciplinary postdoctoral research experience (in biomedical engineering, materials science and pharmacy) in France, Germany, Northern Ireland and the USA. His interdisciplinary group develop stimuli-responsive materials for medical and technical applications. Collaborations with academic and industrial partners are warmly welcomed.

P2 Mr Sagnik Middya

Sagnik Middya obtained his B. Tech in Electronics and Electrical Engineering (with a Biotechnology minor) from the Indian Institute of Technology (IIT), Guwahati, India in 2017. After his graduation he worked for a year at IIT Guwahati as a Junior Research Fellow developing biosensors for point of care diagnosis of diseases (e.g. pancreatitis). He joined the Sensors CDT in 2018 and is pursuing his PhD in the Department of Chemical Engineering and Biotechnology. His present work involves fabricating transparent microelectrode arrays for in-vivo imaging and electrophysiology.



P3 Mr Anastasios Polyravas

Anastasios Polyravas received his B.Sc. and M.Sc. in Electrical Engineering from the University of Thessaloniki, Greece, in 2017. He specialised in the field of Electronic & Computer Engineering. He did his Master thesis on the programming and recording of signals in microprocessors, such as Arduino. As a Ph.D. student, Anastasios is developing and characterising organic electrochemical transistors (OECTs) for brain-computer interfaces (BCIs).

P4 Mr Dimitrios Simatos

Dimitrios holds a diploma in Electrical Engineering and a Msc in Micro and Nano Technologies. Currently, he is a Sensor CDT student in the University of Cambridge, and pursues a PhD in Physics.

P5 Ms Nicola Broughton

Nicola Broughton is a Senior Scientist at CPI working on collaborative and commercial research projects in the field of printable electronics. With a background in cell biology, Nicola worked as an industrial laboratory chemist developing new products and formulations for an aerosol manufacturer. At CPI Nicola has worked to develop functional ink formulations, particularly those containing nanomaterials. She also works to establish coating, printing and curing methods for a number of different applications including LEECs, IoT enabled devices, wearable electronics and sensors.

P6 Dr Daniel Arnaldo del Cerro

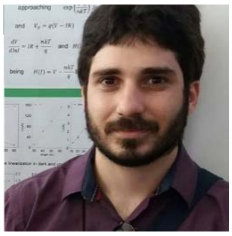
Daniel Arnaldo del Cerro, PhD, is an R&D applications engineer at Oxford Lasers Ltd. His research interests lie in the area of surface texturing with short and ultra-short laser pulses for applications including friction and wear reduction, wetting control, enhancing heat transfer in two-phase phenomena or, lately, laser selective sintering and patterning of thin films for flexible electronics. He has more than 8 years of experience in these areas, gathered during his work in institutions such as the Laser Zentrum Hannover (Germany), the University of Twente (The Netherlands), Aimen Technology Centre (Spain) and his current position at Oxford Lasers (UK).

P7 Professor Duncan Hand

Duncan Hand is Professor Applied Photonics at Heriot-Watt University and leads research into applications of high power lasers in manufacturing, working with a range of industrial partners. His focus is on high precision micro-scale applications, including bonding, micro-machining, cutting, and surface structuring. Applications range from packaging of electronics, manufacturing of microfluidics, through to generation of high friction surfaces for ship engine parts. He also is involved in fibre optic delivery of short pulse, high peak power laser light for applications in manufacturing and surgery.

P8 **Mrs Christina Koutsiaki**

Christina Koutsiaki, PhD Candidate, has received her Bachelor Degree in Physics (2015), in Aristotle University of Thessaloniki. During her postgraduate studies (Master of Nanosciences and Nanotechnologies, Aristotle University of Thessaloniki, 2018), she particularly emphasized in "Large scale fabrication and characterization of flexible OTFTs via printing methods". In her ongoing PhD studies she mainly focuses on the photochemical conversion of solution processed (sol-gel) Metal Oxide precursors via photonic curing.



P9 **Mr Douglas Vieira**

Graduated in physics at the São Paulo State University (UNESP) and currently a master's student of post-graduation in materials science and technology (POSMAT) at the UNESP. I'm member of the Laboratory of Organic Devices and Sensors (LaDSOr), devoting studies about electronic devices, printed electronics and optoelectronics.

P10 **Emre Yarali**

Emre Yarali is a current Ph.D. student at King Abdullah University of Science and Technology (KAUST). He is working on the photonic processing of solution-based metal oxide thin films for transistor applications under the supervision of Prof. Thomas D. Anthopoulos.

P11 **Mr João Luis**

João Sousa Luis is a PhD student in the department of physics in Durham University, funded by the European Regional Development Fund Intensive Industrial Innovation Programme and working in collaboration with PragmatIC.

P12 **Professor Pedro Barquinha**

Pedro Barquinha received his PhD in Nanotechnologies and Nanosciences from Universidade Nova de Lisboa in 2010. He is currently an Associate Professor at the Materials Science Department of FCT-NOVA. He has been working in oxide electronics since 2004, participating in >30 national and international research projects in the area, with academia and industry. His work involves design, deposition and characterization of multicomponent oxide thin films, fabrication and characterization of transistors and their integration in circuits on flexible substrates. He is co-author of >150 peer-reviewed papers (h-index=42, as September 2019), 3 books and 3 book chapters in this area. More recently, he also started to focus on taking oxide electronics towards nanoscale, pursuing low temperature synthesis routes of oxide nanostructures and nanodevice/nanocircuit integration, complemented by device modelling/simulation, targeting multifunctional smart surfaces. In 2016, he got an ERC Starting Grant (TREND) to advance this research topic.

P13 **Mr Navid Mohammadian**

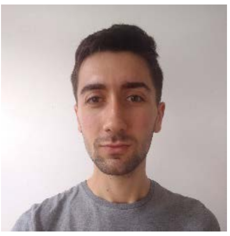
Navid Mohammadian received his BSc and MSc degrees in Electrical and Electronic Engineering from the IA University of Iran in 2012 and 2016, respectively. His main field of study and research focuses on amorphous oxide and polymer semiconductors, as well as high-k metal oxide dielectrics for low-voltage electronic device applications. He started his PhD in 2017 at the University of Manchester in the Department of Electrical and Electronic Engineering and currently he is working on low-voltage complementary metal-oxide-semiconductor (CMOS) under the supervision of Dr Leszek A. Majewski.

P14 **Ms Gabriel Nogueira**

Gabriel Nogueira is a 3nd year Ph.D. student in the School of Technology and Sciences, São Paulo State University (UNESP), supervised by Prof. Dr. Neri Alves. He has a Licentiate degree in physics and a Master's degree in Materials Science. His background is in printed electronics and his research focus is to study and develop electrodes for printed devices.

I, Md Nazmul Anam Rafi, is pursuing my MSc in Electrical Engineering at Tampere University, Finland. Currently, I'm working as a research assistant in the university's Future Electronics Laboratory in Prof. Donald Lupo's team. My main interests in research are in semiconductor technology, RF design, wireless communication technologies, etc.

Panagiotis Mougkogiannis is a Doctoral candidate at the University of Manchester. He is supervised by Prof. Dr Krishna Persaud, with Prof. Dr Michael Turner as a co-supervisor. His current research interests focus on low voltage organic field effect transistors for gas sensing of volatile organic chemicals, and inkjet printing of functional materials. He has a BSc degree in Chemistry and a MSc in advanced technology materials from the University of Patras in Greece.



P19 Mr Oliver Read

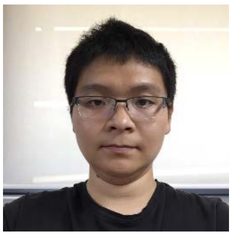
Oliver graduated with a first-class masters degree from the University of Southampton in 2019 and has since undertaken a role as PhD candidate within the Casiraghi Group at The University of Manchester. Research interests include the characterization and synthesis of solution processable 2D-materials.

P20 Mr Maykel Klem

Maykel Klem is a 2nd year Ph.D. student in the School of Technology and Sciences, São Paulo State University (UNESP), supervised by Prof. Dr. Neri Alves. He has a Licentiate degree in physics and a Master's degree in Materials Science. His background is in printed electronics and his research focus is to study and develop printed energy storage devices.

P21 Gopika Rajan

Gopika Rajan has been working with University of Exeter since 2017 as a Postgraduate researcher in the centre of graphene. She is currently working on Wearable Electronics, especially on realization of graphene based e- textiles for sensing and energy harvesting applications.



P22 Dr Junjie Shi

Junjie Shi received the B.Sc. degree from the Nanjing Institute of Technology, China in 2008, and from the University of Southampton, an MSc degree in Microelectromechanical systems in 2012 and a PhD in 2017. I was appointed, in the same year, as a Research Fellow in the Department of Electronics and Computer Science (ECS). My research interest covers a board range of wearable including but not limited to sensors, actuators, memory, and energy harvesting etc. As well as those wearable devices, I am also interested in the fabrication technologies, such as 3D printing, dispenser printing, inkjet printing, micro-fabrications, which enable the conventional and novel devices to be directly fabricated on to textiles.

P23 Dr Samuel Beddoe

Sam Beddoe is a PhD student at the University of Southampton working with Dr Iris Nandhakumar in the Department of Chemistry and in collaboration with Prof Laurie Peter at the University of Bath. He is working on the synthetic chemistry of new and emerging materials and structures for solar photovoltaics and has published on a new synthetic route to the earth abundant solar absorber material Zn_3P_2. Presently he is working on another solar absorber, Bi_2S_3 which he has synthesised by two xanthate routes (aerosol assisted CVD and spin coating), which yield thin films having different morphologies. In his poster he will report on their influence on the performance of photovoltaic devices. Sam is funded by the EPSRC Centre for Doctoral Training in New and Sustainable Photovoltaics.

P24 Ms Lokeshwari Mohan

Lokeshwari is a final year PhD student at the Department of Materials and Centre for Plastic Electronics at Imperial College London. Her research focuses on the large-scale deposition of copper (I) thiocyanate via aerosol assisted chemical vapour deposition to determine intrinsic properties of the material and its performance in solar cell applications. Lokeshwari completed her MEng in Materials Science and Engineering with Industrial Experience at Queen Mary University of London before joining her MRes in Plastic Electronics as a part of the PhD program. Her research during the MRes year focused on the deposition of tin perovskites via aerosol assisted chemical vapour deposition.

P25 Mr Pavlos Giannakou

Pavlos Giannakou received his BEng in Mechanical Engineering from the University of Surrey in 2017. He is currently a PhD candidate under Dr Maxim Shkunov's supervision in Advanced Technology Institute at the University of Surrey in United Kingdom. His current research is focused on printed electronics and energy storage, particularly supercapacitors.

P26 Ms Sarah-Jane Potts

Sarah-Jane currently works as a Scale Up Technology Transfer Fellow at Specific, Swansea University. She is also finishing her EngD in "Advanced manufacture by screen printing" in the Welsh Centre for Printing and Coating (WCPC), through the Materials and Manufacturing Academy (M2A) at Swansea University, sponsored by icmPrint. For her EngD, she assessed the effect of ink rheology, press parameters and post processing on the performance of conductive carbon inks, as well as assessed the ink deposition and separation mechanisms occurring during screen printing with high speed imaging and a custom made rig. She has a Master's Degree (MEng) in Product Design Engineering from Swansea University which she completed in 2015. Her work currently focuses on scaling up printed electronics including solar cells and resistive heaters.

P27 Ms Josephine Charnley

Quantum Technology Supersensors is a specialist materials development SME producing a new generation of 'smart' & 'multi-functional' materials that harness nature's Quantum Technology effects to enable new ways of making electronics for environmental impact and energy reduction whilst reducing weight and costs. Its Award Winning environmentally friendly Quantum Technology Supersensor™ (QTSS™) materials open up new and exciting possibilities for interactive surfaces, touch sensing, strain gauges, friction & shear sensing and single point or multi-touch pressure/force sensors & switches. QTSS™ materials change from insulator to conductor under pressure in proportion to the amount of force applied exhibiting resistance change over many orders of magnitude of over a billion ohms. This provides a uniquely large operating range capability and sensitivities are alterable. Design freedom opens up new possibilities for novel, yet more sustainable product innovation in high growth markets such as Healthcare, Prosthetics, Robotics, IOT, Consumer, Automotive/ Transport, Responsive Environments & Wearables.

P29 Mr Georgios Bairaktaris

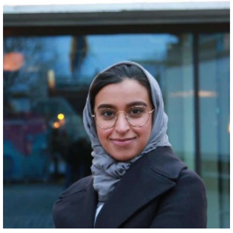
Mr Georgios Bairaktaris is a postgraduate researcher currently in his 1st year of study for his PhD in textile electronics and new user interfaces at the Advanced Technology Institute, University of Surrey. He graduated at the top of his class in Electrical and Electronic Engineering at the University of Surrey and he has been working on the Next Generation Paper project since 2018 as part of his dissertation, progressing the control electronics and the user interfacing in collaboration with industrial partners.

P30 Mr Sang Yun Bang

Sang Yun Bang is currently a Ph.D. student under Professor Jong Min Kim in Electrical Engineering Division at the University of Cambridge. His research is integrating metal oxide thin-film transistors backplane with red-green-blue patterned quantum dot light-emitting diodes using a transfer printer for display application. Prior to this, he received MS degree in Electrical Engineering from New York University and obtained BS degree in Electrical Engineering from the University of Illinois at Urbana-Champaign.

P31 Dr Neri Alves

Neri Alves received the Ph.D. degree in applied sciences from the University of São Paulo, Brazil, in 1992. He is currently senior lecturer at São Paulo State University (UNESP). His current research interests include organic electronic, printed electronics, and sensors.



P32 Ms Huda Ahli

Huda Obtained her BEng in sustainable energy engineering from Queen Mary university of London. In there, she worked on solution processed semi-transparent solar cells for windows applications under the supervision of the late Dr Russell Binions. In 2016 she joined the centre of plastic electronics where she became a member in Dr. Martyn McLachlan’s research group. She is currently in her final year of PhD and her work revolves around investigating organic solar cell’s performance parameter’s evolution during mechanical testing.

P1 Multiphoton fabrication of bioelectronics

John G. Hardy[1], Sara J. Baldock[1], Damian Cummings[2] and Frances Edwards[2]

[1] *Department of Chemistry, Faraday Building, Lancaster University, Lancaster, UK*

[2] *UCL Neuroscience, University College London, London, UK*

Electromagnetic fields affect a variety of tissues (e.g. bone, muscle, nerve and skin) and play important roles in a multitude of biological processes (e.g. nerve sprouting, prenatal development and wound healing), mediated by subcellular level changes, including alterations in protein distribution, gene expression, metal ion content, and action potentials. This has inspired the development of electrically conducting devices for biomedical applications, including: biosensors, drug delivery devices, cardiac/neural electrodes, and tissue scaffolds. It is noteworthy that there are a number of FDA approved devices capable of electrical stimulation in the body, including cardiac pacemakers, bionic eyes, bionic ears and electrodes for deep brain stimulation; all of which are designed for long term implantation. Polymers are ubiquitous in daily life, and conducting polymers (e.g. polyaniline, polypyrrole, poly(3,4-ethylenedioxythiophene)) have shown themselves to be capable of electrically stimulating cells. Furthermore, when implanted in mammals their immunogenicities are similar to FDA-approved polymers such as poly(lactic-co-glycolic acid) (PLGA), supporting their safety in vivo. These preclinical studies suggest that conducting polymer-based biomaterials are promising for clinical translation.

We have an interest in the use of multiphoton fabrication to print conducting biomaterials for use as neural electrodes, characterize their physicochemical and electrical properties, and to validate the efficacy of the bioelectronic devices to interact with brain tissue ex vivo.[1] Clinically approved electrodes are manufactured from inorganic materials (e.g. titanium nitride, platinum, and iridium oxide), however, their mechanical properties are far from those of soft tissues in the central and peripheral nervous system, and such mechanical mismatch leads to local tissue inflammation and their encapsulation in fibrous scar tissue that impedes the successful function of the neural electrode (in some cases this necessitates the application of up to 7V to stimulate the nerve tissue which leads to tissue damage). The development of neural electrodes with biomimetic chemical and mechanical properties is highly attractive as it may facilitate the widespread use of such electronic devices.[1,2] An update on recent progress will be presented.

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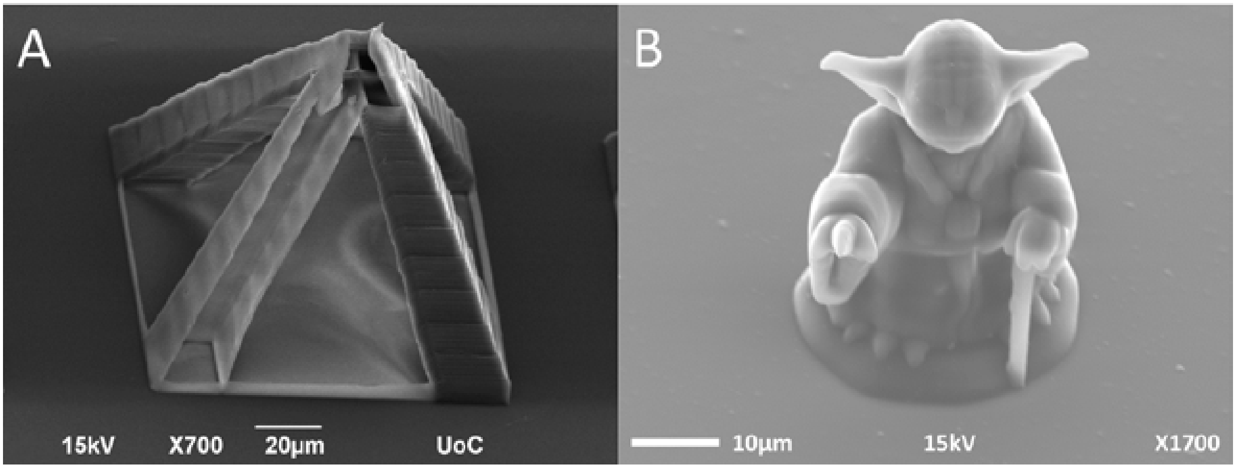

Figure 1. Micron scale structures printed via multiphoton fabrication. A) Pyramid-like structure. B) Yoda.

P2 Transparent microelectrode arrays for *in-vitro* electrophysiology and simultaneous imaging

Sagnik Middya[1], Vincenzo F. Curto[2], Mirranda Robins[1], Alex W. E. Dunn[3], Susanna B. Mierau[3], Gabriele S. Kaminski Schierle[1], George G. Malliaras[2]

[1] Department of Chemical Engineering and Biotechnology, University of Cambridge, UK
[2] Department of Engineering, University of Cambridge, UK
[3] Department of Physiology, Development and Neuroscience, University of Cambridge, UK

Microelectrode arrays (MEAs) are most suitable for collecting electrophysiological data from a vast population of neurons which is often necessary to understand their functional aggregation. MEAs and electrodes in general provide a high temporal resolution in recording the activity of neurons but lack specificity since they only monitor the ion flux across the cell membrane. In another approach to electrophysiology, the exchange of ions and their concentrations inside neurons can be observed by high resolution microscopy. This method has a high spatial resolution and specificity of targeting selective ions and molecules but is limited by the poor time resolution. It can be envisioned that the synergy between MEAs and optical imaging will provide deeper insights into the signalling and communication in neuron populations. Hence, development of optically transparent MEAs have received much attention in recent years. Traditionally, MEAs are made from metals like Au, Pt, Ir, etc. and are optically opaque. Materials like transparent metal oxides and graphene have been utilized to achieve transparency but they show very high impedance in electrolytic media, similar to metallic electrodes. This adversely affects the signal to noise ratio of the recordings. Conducting polymers, on the other hand, exhibit suitable mechanical properties for attachment of neurons and their growth. Au electrodes coated with PEDOT: PSS, one of the most characterised conducting polymers in this regard, has shown superior impedance compared to bare Au electrodes. This is attributed to the large volumetric capacitance of PEDOT: PSS, which is much greater than the planar electric double layer capacitance of metals.

Here we report on the development of transparent MEAs based solely on PEDOT: PSS. The MEAs were fabricated by a standard lithography process. Compared to transparent MEAs reported earlier, the electrodes exhibited a superior impedance of 54.38 KΩ at 1 KHz, which indicated its effectiveness as recording electrodes for electrophysiology. The MEAs also demonstrated minimal photo-excitability or none at all. Since fluorescent lifetime imaging is considered as the preferred imaging modality, the effect of PEDOT: PSS electrodes on the lifetime of the fluorescent dye was also investigated. Finally, the compatibility of the MEAs with optical microscopy and imaging was demonstrated for cortical neurons *in-vitro*.

References (optional)

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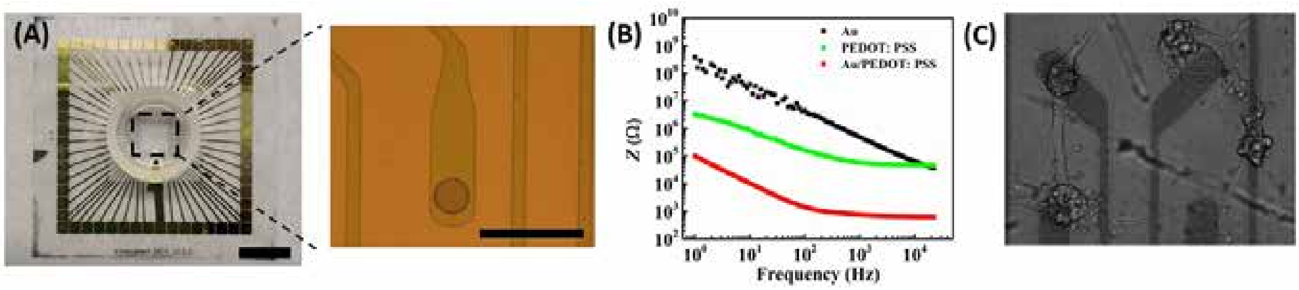

Figure 1. (A) Optical image of the transparent MEA with the magnified view of an electrode. (B) Comparative impedance spectra of Au, PEDOT: PSS and Au/PEDOT: PSS electrodes. (C) Optical image of neurons growing on the transparent PEDOT: PSS electrodes.

P3 Using Organic Electrochemical Transistors for Enhanced Electrophysiology Recordings

Anastasios G Polyravas[1], Vincenzo F Curto[1], George G Malliaras[1]

[1] Electrical Engineering Division, Department of Engineering, University of Cambridge, 9 JJ Thomson Ave, Cambridge CB3 0FA, United Kingdom

Our ability to treat neurological disease is severely limited by the complexity of the nervous system and the quality of the information derived from recording devices. A device that holds great potential for recording high quality electrophysiology signals is the organic electrochemical transistor (OECT). OECTs are transistors in which the output current is regulated by the injection of ions from an electrolyte. They are fabricated from biocompatible materials and have been shown to provide higher signal-to-noise ratio compared to electrodes. Their unique properties pave the way for enhanced performance neural interfaces while minimising the invasiveness of the recording method. We report on how different parameters such as device geometry and bias conditions affect the noise characteristics of OECTs. These results show how to minimise noise and boost signal-to-noise ratio. We further show how these new design rules are applied to reduce the footprint of OECTs and drastically improve their recording capability when used in neural interface applications.

P4 Stabilizing organic electronics devices for long-term environmental sensing

Dimitrios Simatos[1], Mark Nikolka[1], Jerome Charmet[2,3], Tuomas Knowles[1,3], Henning Sirringhaus[1]

[1] *Department of Physics, Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK*

[2] *Institute of Digital Healthcare, WMG, University of Warwick, UK*

[3] *Department of Chemistry, Cambridge University,Lensfield Road, Cambridge CB2 1EW, UK.*

Over the past decades organic electronic devices have been used in versatile flexible electronic applications such as OLED displays, photovoltaics, nonlinear optics, and sensing. Recently, the prospect of integrating disposable, flexible OFET-based sensors with lab on a chip applications has emerged, pushing the need for water-stable, high-mobility organic materials. We used an additives-based approach to passivate water-induced traps[1], making high-performance water-stable OFETs. The OFETs retain their performance after being immersed in different liquids over the course of a month. We also applied the same stabilization technique in WG-OFETs integrated with microfluidics, and explored the additional challenges in stabilizing these devices.

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Acknowledgement - This work was supported by the Engineering and Physical Sciences Research Council [EP/L015889/1].

P5 Challenges and opportunities in reproducible electrochemical ink formulation and processing for multiplexed biosensor design

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1 CPI, Wilton, Redcar, United Kingdom

2 JE Solutions Consultancy, Manchester, United Kingdom

3 Bender Tech, Raleigh, North Carolina, United States of America

Multiplexing of electrochemical sensors provides opportunities for point-of-care biomedical screening and diagnostic applications that require fast results, a simple user experience, and the simultaneous quantification of multiple biomarkers [1]. Sensitive and specific quantification of biomarkers in complex biological fluids requires development of new, highly engineered materials with reproducible and scalable manufacturing processes to achieve their promise of low-cost and widespread adoption.

Here we discuss the use of scalable, conventional printing processes to produce electrodes on a flexible substrate and two approaches to incorporate metal oxide nanomaterials, which have been reported to have excellent electrocatalytic properties [2], into a sensor ink. In addition, we have identified challenges and failure mechanisms regarding process timing and material selection.

We report the use and testing of electrochemical sensor processing techniques for individual and multiplexed sensor designs, including how the electrochemical response to various processing techniques and ink formulations was assessed to identify prospective manufacturing techniques that deliver reproducible and scalable results (Figure 1).

The identification of these challenges and optimization of these processing techniques provides the understanding needed for moving applications in electrochemical sensors from the laboratory to the clinical setting.

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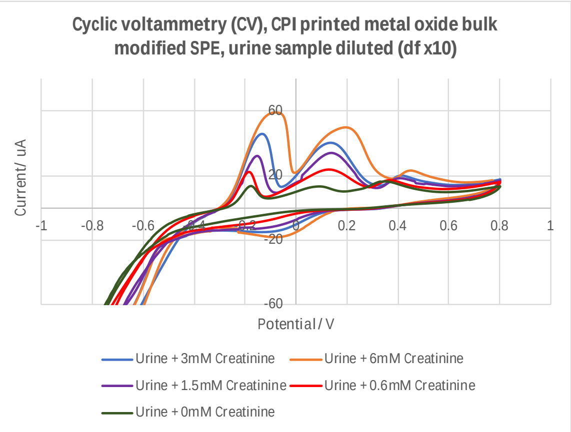

Figure 1. Voltammograms demonstrating a robust and sensitive electrochemical response in real-world biological conditions of bulk processed metal-oxide inks.

P6 Laser selective sintering of laser printed silver inks on polymeric substrates for flexible RFID devices

Daniel Arnaldo del Cerro[1], Simon Tuohy[1], Merijn Giesbers[2], Gari Arutinov[2], Darshana Kariyapperuma[3], Richard Price[3], Catherine Ramsdale[3], Dimitris Karnakis[1]

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[3] PragmatIC Printing Limited, 400 Cambridge Science Park, Cambridge, CB4 0WH, UK

Thin flexible integrated circuits are gaining interest, among others, due to the possibility of bringing cost-effective digital traceability and interactivity to everyday objects, when employing radio-frequency identification (RFID) or near-field communication (NFC) technologies.

Laser micro-processing is a digital technology that can be exploited to increase the accuracy and selectivity of relevant processes related to those technologies, such as printing and sintering of micrometric-sized wide conductive tracks. Being able to selectively sinter printed tracks allows employing cost-effective flexible substrates, which would otherwise degrade when employing traditional non-selective sintering techniques, e.g. oven sintering. This becomes possible thanks to the highly confined exposure of the material to the laser radiation. Particularly when using short pulsed lasers, the undesired heat affected zone can be limited to a few micrometres or less [1]. Highly integrated modern laser sources with advanced CNC and fast optical scanning systems offer also an accuracy in positioning and steering a laser beam in the range of just a few micrometres across large areas, which can typically reach several hundreds of millimetres.

In this work, the combined application of these two laser technologies for creating functional RFID antennas on a flexible polymeric substrate is demonstrated. First, Laser Induced Forward Transfer (LIFT), a digital laser-based printing technique, is applied to transfer silver inks according to a designed antenna pattern onto the polymeric substrate. Selective laser sintering is afterwards employed to process the printed tracks and make them electrically conductive, without damaging the underlying substrate [2]. The electrical resistance of the resulting antennas is afterwards measured, to ensure sufficient conductivity for the circuit to be functional. The laser printed and sintered antennas show a measured sheet resistance below 30mΩ/sq and a resistivity below 10x bulk silver.

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Acknowledgement - This work has been funded by EU project HIPERLAM, grant 723879. All metallic ink materials provided by project partner PV Nanocell Ltd (Israel).

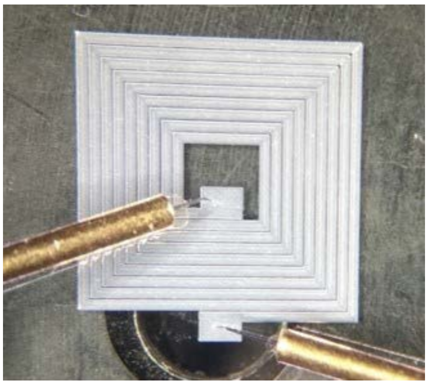

Figure 1. A laser printed and sintered RFID antenna on a two-probe electrical conductivity measurement station.

P7 Picosecond laser microwelding of ultra-thin flexible glass for hermetic encapsulation of OLEDs

Paulina Morawska[1], R.M. Carter[1], M.J.D. Esser[1], Y.F.Chan[2], P.Melgari[2], R. Douglas[2], D. Karnakis[3], D.P. Hand[1]

[1] *School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, UK*
[2] *Centre for Process Innovation Ltd – National Printable Electronics Centre, The Neville Hamlin Building, Thomas Wright Way, NETPark, Sedgefield, Stockton-on-Tees, UK*
[3] *Oxford Lasers Ltd, Unit 8, Moorbrook Park, Didcot, OX11 7HP, UK*

OLEDs are of significant interest in both displays and lighting due to their flexibility and efficiency, however they are highly sensitive to both oxygen and moisture and so must be placed inside a hermetic package. A solution is to encapsulate the OLED between two sheets of thin flex glass, providing both flexibility and hermeticity; however hermeticity can be compromised by the material used (typically a polymer) to bond the glass sheets. A direct weld would be the best solution, hence we have developed a laser process, driven by non-linear absorption within a normally transparent glass, to provide reliable and repeatable welding of thin glass to thin glass.

The glass-glass welding process relies on the very high peak intensity from an ultra-short pulsed (picoseconds or less) 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 [1]. For a successful weld, the laser pulse repetition rate has to be sufficiently high to also provide thermal accumulation, resulting in a localised melt volume surrounding the small plasma. The size of this volume depends on the laser parameters used and can be modified to be smaller than 100 µm. As the laser spot translates across the material, this highly localized melt zone solidifies behind the beam and forms a strong bond (microweld) between the two surfaces.

We report laser microwelding of two 100 µm thick flexible glass sheets using a picosecond laser system (5.9 ps, 400 kHz at 1030 nm). We investigate both hermeticity and strength of the welding seam.

Finally we provide details of a prototype commercial laser welding machine developed for this process and for other optical material welding applications (e.g. glass to metal; Nd:YAG to metal).

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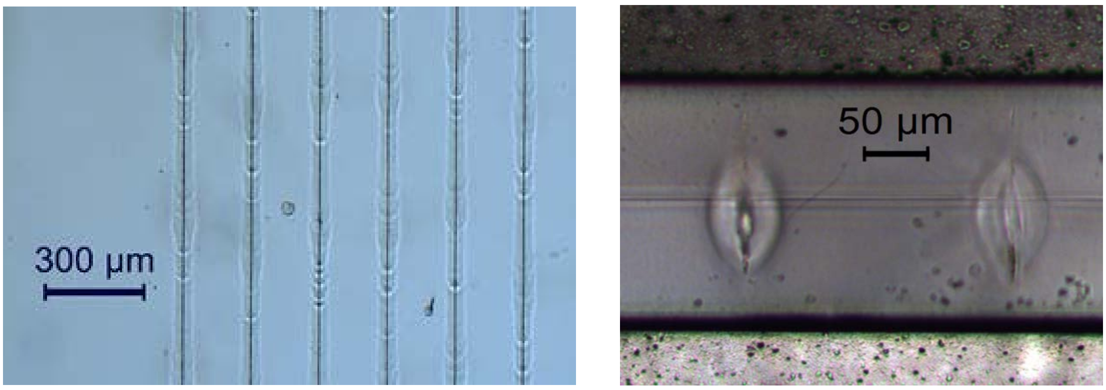

(a) (b)

Figure 1. Optical microscope images of the weld features in two 100 µm thick flexible glass components obtained by ultrafast laser microwelding (a) Top view of a series of welds; (b) cross section of the weld seam

P8 Excimer Laser Annealing of sol-gel Metal-Oxide thin films

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Over the last decade, large area electronics manufacturing has become an emerging yet challenging field of interest, with flexible transparent devices drawing the attention of the scientific community as well as the industrial sector. A major factor to this development has been the transition from conventional vacuum deposition techniques to a novel, solution process-scheme which enabled the realization of a plethora of state-of-the-art applications (sensing technologies, integrated smart systems, wearables, lighting and printed displays) employing large area manufacturing approaches (i.e. roll-to-roll).

Metal oxides (MO) have emerged as promising material candidates in various electronic and optoelectronic applications. In comparison with amorphous silicon and organic semiconductors, metal oxides offer unique advantages such as mechanical stability, high mobility (even in the amorphous phase), wide band gap and the ability to be controllably doped. Thus, they constitute an attractive, highly promising candidates towards delivering trend-of-future applications (such as Internet of Things).

The fabrication of MO *via* 'sol-gel' is considered as one of the currently favourable large-area compatible manufacturing processes, giving rise to the industrialization of top-quality films. Nevertheless, the deposition of MO precursors concomitantly with their subsequent thermal treatment is linked to a major challenge, the mandatory use of high temperature post-deposition treatment, followed by long processing times. This step constitutes a major obstacle, inhibiting the utilization of polymer substrates, thus hindering the introduction of sol-gel MOs in flexible technology. Therefore, Excimer Laser Annealing (ELA) constitutes a propitious alternative of post - deposition treatment, as its unique characteristic of high temperature induction within nanoseconds, enables the successful organometallic precursor transformation into top-quality MO films, while maintaining the substrate intact. This-currently absent-link between the two highly attractive attributes (solution and laser processing) will notably empower the next generation of MO- based flexible electronics.

To respond to this challenge, we employ Spectroscopic Ellipsometry in an extended spectral range, from infrared (IR) to ultraviolet (UV) (0.03 – 6.5 eV) is utilized, in an effort to elucidate the opto-electronic properties of sol-gel In_2O_3 thin films. The IR range (0.03 – 1.5 eV) provides information on the electron transport properties as well as elucidates the presence of defect states within the energy gap as well as more fundamental lattice information i.e. phonon modes. Additionally, the range between 1.5 – 6.5 eV provides important information on the transparency region and the energy gap of the material. The above-mentioned properties are correlated to the ELA processing parameters (laser fluence and number of pulses) in an effort to gain knowledge on the underlying mechanisms that efficiently convert the metalorganic precursor $In(NO_3)_3$ into an In_2O_3 metal oxide thin film and lead to its further densification and crystallisation. This investigation is further accompanied by structural (XRD) and morphological (AFM) examination of the In_2O_3 films. Finally, the MOs are subsequently implemented in n-channel transistors and their performance is evaluated via the transfer and output I-V characteristics.

P9 The effect of UV irradiation on electrical properties of spray-coated ZnO thin films

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Ultraviolet (UV) radiation exposure monitoring is an important public health topic because, at moderate rates, it facilitates the synthesis of vitamin D, prevent rickets and also kill germs. However, at elevate rates, UV radiation becomes dangerous and oftentimes it is associated to the development of diseases such as skin cancer [1]. Then, there is a demand for simple and low-cost UV-sensing materials. In this sense, printed electronics offers the possibility to obtain this materials in a cheap way, compatible to the production in large scale to be used in packaging or even in adornments.

Zinc oxide (ZnO) is a n-type semiconductor with high potential to be used in devices such as thin-film transistors and diodes. It is considerably cheap, non-toxic and wide band gap of about 3.4 eV, which results in a high optical absorbance at UVA wavelengths. Furthermore, solution-processing of this material is an excellent alternative to sophisticated deposition processes like RF sputtering or pulsed-laser deposition, allowing the use of different printing techniques such as spray-coating, that have the great advantage to combine the deposition with the pyrolysis process of precursor solution to obtain highly uniform and homogeneous thin films. We used a zinc acetate dihydrate solution deposited by spray pyrolysis as a precursor to obtain the ZnO films.

In the present work, we studied the effect of UV irradiation on electrical properties of spray-coated ZnO thin films to understand the photoresponse behavior of ZnO in a simply resistive Al/ZnO/Al architecture aiming applying this material in UV-sensor devices. The photocurrent versus irradiance curve of the Al/ZnO/Al sample under UV irradiance was performed. This curve showed that the photocurrent increases with the square of the intensity of light at low values of irradiance. This suggests a complex process of electron/hole pair generation, trapping of the holes and recombination [2] in ZnO volume. But, when the irradiance increases, this behavior changes to almost linear behavior, being the slope close to the unity, which implies the existence of monomolecular recombination [3]. Besides that, the current-voltage proportion given by the power law ($I \propto V^n$) was analyzed too. It was found that in low values of UV irradiance the film ZnO volume is dominated by ohmic conduction mechanism (n~1), but, when the UV irradiance increases, the mechanism changes to a space charge limited current (SCLC) behavior (n~2).

The use of different channel lengths between the electrodes allowed the analysis of the dependence of the dark current and the photocurrent on the device surface area and volume. It was observed that the dark current decreases with the increase of the spacing between electrodes. In contrast, the current under UV irradiation increases proportionally to the channel length. In other words, changes in channel lengths results in changes in the I_{UV}/I_{dk} ratio which is very nice for optoelectronic applications.

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P10 Photonic Processing of Metal Oxide Thin Films for Electronic Devices

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Metal oxides have emerged as strong material candidates in electronic and optoelectronic device applications in research and industry alike, due to their unique properties such as high transparency, high mobility and adjustable carrier concentration via facile doping protocols. This characteristic versatility is the foundation for their widespread applications in a variety of different fields ranging from photonics to electronic circuits.

Although there are various fabrication methods available to obtain high quality metal oxide materials from vacuum processes (e.g. PVD, CVD, or ALD), solution-based manufacturing techniques are highly sought after as they promise higher throughput rates, more flexibility and easier scalability for large-area electronic applications. Metal oxide deposition with solution-processed techniques is typically limited to high temperature annealing steps (>400°C) for long times (hours) to reach the same quality as vacuum-based techniques. This slows down the fabrication process, consumes energy, and brings along a restriction when it comes to the choice of substrates, i.e. excluding all common flexible substrates. Considering these problems, alternative conversion methods to conventional thermal annealing have been studied to overcome these issues. Photonic processing methods such as laser annealing, flash lamp annealing (FLA) and deep UV conversion were suggested to be used in solution-based metal oxide thin film devices [1].

Among these techniques, FLA relies on short pulses (µs to ms) of high intensity white light (broad spectrum of 190-1100 nm) generated by a xenon flash lamp that is directed to the substrate located in close proximity. Under flashing, high temperatures in excess of 1000 °C can easily be reached in a short period of time when an absorbing material is introduced on the substrates' surface. Simultaneously, the substrate itself remains at low temperatures due to the short light exposure time and mismatch of thermal conductivity between substrate and absorber. The rapid nature of photonic processing and its compatibility with a broad range of inexpensive substrate materials makes it an ideal candidate for use in high throughput manufacturing such as roll-to-roll production.

In our study, we employed FLA for the first time to pattern and convert solution-based metal oxide conductor, semiconductor and dielectric layers with the use of photosensitizer elements. Especially the UV spectrum emitted by the high intensity flash light was used for the decomposition of photosensitizers and gave rise to extended metal oxide frameworks. Due to the high conversion rate on a short time scale, it is possible to build fully transparent metal oxide layers for TFT device applications. This approach suggests a new technological process for easy and high throughput rate production of TFTs and other (opto-)electronic devices for large-area electronics.

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P11 Tuning the electronic properties of metal oxides by low temperature annealing

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With the rise of the Internet of Things, the field of electronics has moved away from a one-size-fits-all approach, as in silicon-based transistors on rigid substrates, to application specific devices and technologies [1]. For example, flat panel display technologies employ transparent thin film transistors (TFTs) to minimise the current necessary for the intended luminosity. and with more applications shifting towards flexible devices, material engineering requirements are more stringent.

TFTs are composed of a dielectric, a semiconductor layer and three separate electrodes and ideally, all these need to be transparent to maximize their efficiency in display applications. Metal oxides have surfaced as the most promising candidates for a wide range of applications. They can be readily deposited using standard vapour deposition techniques at room temperature, ideal for flexible electronics applications. Metal oxides have a wide band gap, providing optical transparency in the visible range which is especially attractive for display applications. Depending on composition, metal oxides can either be applied as electrodes, dielectrics or semiconductors. For flexible electronics, metal oxide semiconductors have advantages over amorphous silicon, as they provide higher carrier mobility in the amorphous phase, allowing room temperature deposition [2].

A major challenge with semiconducting metal oxides is the complex defects present in the films, commonly in the form of oxygen vacancies (V_O). These defects create trapping centres for electrons and lead to reduction of the number of charge carriers, resulting in changes in the film electronic properties. In a fully built TFT, this can translate to higher sub-threshold swing and increased hysteresis.

High temperature annealing (>520 ºC) in air atmosphere has been well documented and shown to reduce the number of V_O, however, it has also been demonstrated that excess oxygen can be incorporated in the film during the anneal process, negatively impacting performance. Low temperature annealing (<300 ºC), compatible with flexible substrates, has also been reported to contribute to a reduction of the number of V_O. however limited studies are available on the conditions required and the defect mechanism [3, 4].

The main goal of this work is to understand the effects of low temperature annealing on the electrical properties of metal oxide thin films. We aimed to find the ideal set of annealing conditions, temperature and time, for tuning and optimising the electrical properties for flexible electronics deposited by vapour phase deposition at room temperature. In this study, X-ray reflectivity (XRR) Will be used to determine film thickness, density and surface roughness of both film interfaces. Electrical measurements Will be taken by 4 point probe to obtain parameters such as sheet resistance and resistivity and some Hall-effect Will be used to provide electron hall mobility. The relationship between structural properties and functional electrical behaviour Will be presented.

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P12 TCAD and XPS studies on the effect of device structure, electrode material and semiconductor composition on the performance of low-temperature IGZO TFTs

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The simultaneous transparency, large area uniformity and good electrical performance of indium-gallium-zinc oxide (IGZO) thin-film transistors (TFTs) enables a wide range of applications. Furthermore, the possibility of fabricating them at low-temperature allows to use inexpensive flexible substrates for lightweight and conformal applications. A good example of such applications are medical systems, namely low-cost, robust, lightweight and flexible x-ray panels making use of a TFT-based active matrix array. Given the low thermal budget imposed by flexible substrates and/or other materials of the panel, namely p-type organic semiconductors for integration of CMOS circuitry into the backplane, it is expected that the chosen oxide TFT architecture dictates to a large extent the achievable level of electrical performance and stability.

In line with this, in the present work we investigate the effect of using different oxide TFT architectures (staggered/coplanar, top/bottom-gate) with a fabrication temperature of only 150 °C, employing an organic dielectric (Parylene-C), different IGZO compositions achieved by a co-sputtering route and electrode materials, such as Mo, Mo alloys and Ti. A TCAD simulation tool (Silvaco Atlas) and X-ray photoelectron spectroscopy (XPS) analysis are used to shed light into the physics behind the experimental results obtained for these TFTs. By proper device structure design it is verified that field-effect mobility can be enhanced from 1 to ≈20 $cm^2/(V.s)$ and non-idealities such as negative output resistance and stress effects can be suppressed. TCAD simulation captures multiple deterioration mechanisms associated with the lower performance structures, such as charge-scattering at the semiconductor-dielectric interface or poor carrier injection at source-drain contacts when particular combinations of electrode material/IGZO composition are used, all supported by the XPS interface analysis. The variation on electrical properties observed for different device structures are also correlated to the processing steps seen by the TFT layers (e.g., F incorporation into IGZO/Parylene interface on top-gate coplanar structures due to SF6 plasma etching of source-drain electrodes) [1].

This work clearly shows the importance of combining the knowledge from process engineering, materials science and physical simulation tools to bring low-temperature oxide TFT performance into state-of-the-art levels.

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P13 Low-power High-performance a-IGZO Thin-Film Transistor using OTS Modified Ta_2O_5 as the gate dielectric

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Low-voltage, high-performance thin-film transistors (TFTs) have been getting tremendous attention over recent years due to the increasing demand for low-power, portable electronic devices and sensor arrays. However, reducing the power consumption of TFTs is an extremely challenging task [1]. High-κ dielectric materials are thought to play an essential role in applications where a low-power device operation is needed.

In particular, tantalum pentoxide (Ta_2O_5) is a very promising candidate due to the high dielectric constant in the bulk (κ_{bulk} ~27) and as a thin-film ($\kappa_{thin\text{-}film}$ ~20). These values are at least two times larger than that of Al_2O_3 (κ_{bulk} ~9) and five times larger than that of SiO_2 (κ_{bulk} ~3.9) [2]. As a result, Ta_2O_5 has been abundantly used in electrolytic capacitors, DRAM devices, and recently in solution-processed inorganic semiconductor thin-film transistors as a promising gate dielectric for low-power electronics [3].

In this talk, low-voltage a-IGZO TFTs using solution-deposited, OTS-modified Ta_2O_5 operating at 1 V are presented. The optimised devices display threshold voltages V_{TH} around 0.4 V, subthreshold swings (SS) below 90 mV/dec, current on/off ratios larger than 10^5, and field-effect mobility in excess of 2.3 cm^2/Vs. The morphology and dielectric properties of both pristine and OTS-treated thin Ta_2O_5 films have been studied. It is shown that the proposed approach has a high potential to enable the design of stable, low-voltage organic semiconductor circuitry in a highly reproducible manner.

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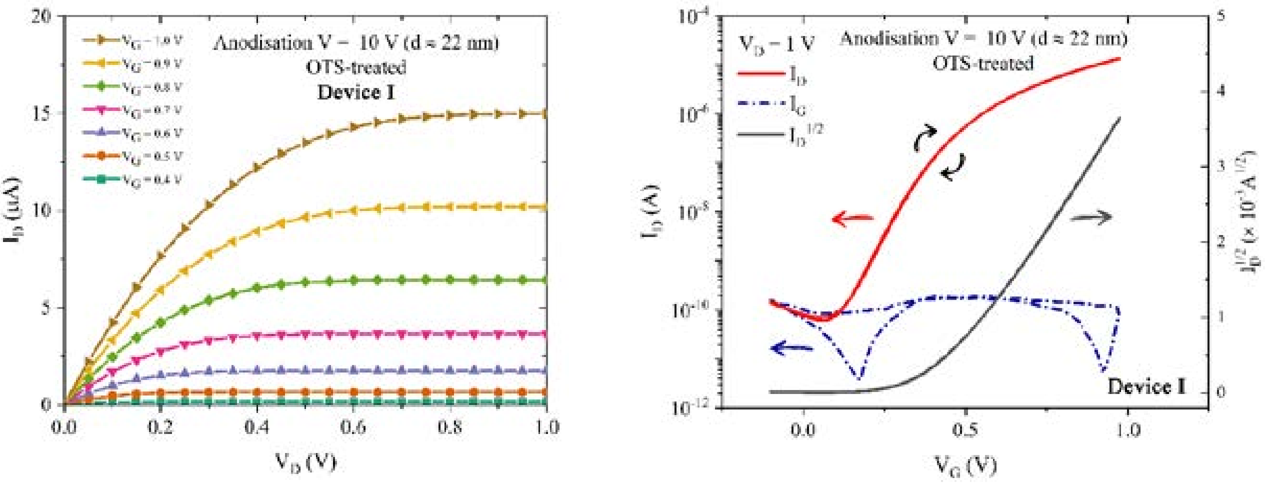

(a) (b)

Figure 1. A typical output (a) and transfer (b) characteristics of low-voltage a-IGZO using OTS-treated Ta_2O_5 as the gate dielectric.

P14 Fabrication of Schottky diode and electrolyte-gated transistor using spray-printed ZnO at low-temperature as the semiconductor material

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Spray-printed technique have attracted interest among others well established printing processes due to their simplicity and low-cost implementation, enabling the ease fabrication of electronics devices. An important fabrication step is the semiconducting layer. Zinc oxide (ZnO) is one of the most successful inorganic semiconductor due to their abundance, low-cost, facility to form nanostructures and large bandgap. Between all the possible application of ZnO as the semiconductor, Schottky Diode (SD) [1] and Electrolyte-Gated Transistor (EGT) [2] are two devices that stands out. However, less attention has been paid to the SDs and the EGTs fabrication using ZnO by spray-printing technique. Here, we deposited the ZnO ink by a low-temperature processes using a low-cost airbrush and manufactured a SD and an EGT using the sprayed ZnO as the semiconducting material.

We formulated suitable ink to spray-coating technique by dispersing AgNW and ZnO nanoparticles (both from Sigma-Aldrich) in ethanol. In our homemade spray-coating system, the airbrush can move in a linear way above the substrate, where we can easily control the thickness by setting the number of layers. To the fabrication of the SD, we made the bottom electrode by printing the AgNW onto glass substrate. Next, the ZnO was sprayed forming the semiconducting layer onto the AgNW electrode. To finish the diode structure, aluminum (Al) electrodes were evaporated on top of ZnO film. After, we fabricated the EGT. We used a glass substrate covered with patterned ITO (from Ossila) to act as the source and drain electrodes. For the active layer, the ZnO ink was sprayed onto these electrodes. To finish the transistor structure, the ion gel film and the top gate electrode were stacked onto the ZnO.

AgNW electrodes showed the sheet resistance and the transparency (550 nm) of 10 Ω/sq and ~98 %, respectively. Figure 1a shows the expected current rectification for the ZnO/AgNW Schottky contact, achieving the rectification ratio of 1.4×10^{3}. Applying the Cheung' method, were calculated an ideality factor (n), series resistance (Rs), and barrier height ($Ø_b$) of 1.58, 1.3×10^{6} Ω, and 1.07 eV, respectively. Figure 1b shows the low-voltage transfer curve for the ZnO transistor. The calculated transistors parameters as Ion/Ioff ratio, turn-on voltage (Von), and mobility (μ), are of 1000, -0.5 V, and 0.33 $cm^2V^{-1}s^{-1}$, respectively. In conclusion, the ZnO was successful applied as the spray-printed semiconductor material in both SD and EGT. The low-cost manufacturing process proposed here has a great potential to large area and flexible electronic devices.

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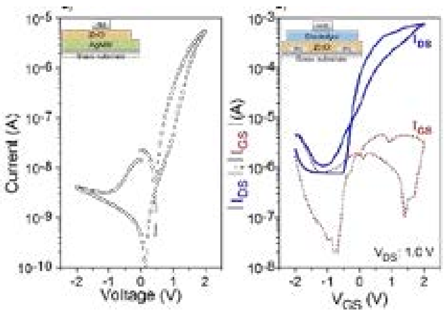

Figure 1. ZnO-based devices: (a) Current vs. Voltage curve for the Schottky diode (SD). (b) Transfer curve for the electrolyte-gated transistor (EGT).

P16 Low voltage p-channel organic TFT on low-cost substrates

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Printed and flexible circuitry has vast potential for novel applications in fields such as sensing and body measurements, due to the simple processes and the possibility of integration of sensor and circuitry using the same production processes. However, there are numerous issues inhibiting the use of such circuitry, including the issue of relatively high voltage operation and the need for low voltage, low power complementary circuitry. Solution-processed n-type metal oxide TFTs operating at low voltage have been reported [1], although work to reduce the processing temperature is still on-going. While high mobility p-type organic materials have been available for some time, the operating voltages are still relatively high. The availability of reliable and low operating p-channel organic FETs will foster the development of fully solution-processed integrated circuits.

In this work, low-voltage organic TFT with dimension characteristics of (W=1000µm and L=60µm), were produced on Cellophane-tape, PET and glass, which are cheap and widely available. A bottom gate top source-drain (S/D) structure was used. The gate was made of 100nm of evaporated aluminium. A 10 nm thick high-k dielectric layer (Al_2O_3) was obtained by electro-chemical anodization of aluminium in a 0.01 M solution of Citric Acid at room temperature, under a current density of 75 µA/cm^2. The S/D electrodes were made of a 100nm layer of evaporated Silver, modified by treatment with a self-absorbed monolayer (SAM) to improve charge injection- We used a commercial (SP400, Merck), organic semiconducting material as active layer. It was deposited by spin coating at 500rpm for 15 seconds and 1200rpm for 120 seconds. Unlike the previously reported operation voltage of 30V using the same material, we demonstrated devices working below the low drain bias voltage of -3 V. On Cellophane tape we achieved an ON/OFF current ratio of 10^4; a turn-on and threshold voltage (V_{th}) of -1.4V. In PET numerous issues are inhibiting a threshold (V_{th}= -1V), but a slightly lower ON/OFF 10^3. The devices produced on glass for comparison also operated at (V_{th}= -1V) with the ON/OFF ratio of 10^4. The hole mobility (3.63 cm^2/V. s) was similar across the three substrates and comparable to the values reported earlier using solution-processed low-k dielectrics, in contrast to common expectations that the field-effect mobility in organics is degraded by contact with a high-k dielectric. The results were independent of substrate, indicating a potential for integration into future smart systems on a variety of different substrate.

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P17 Organic Field Effect Transistors for Low-level Detection of N-Alkyl Amines

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Organic field effect transistors (OFETs) manufactured using printable electronics technologies have been demonstrated to be promising volatile chemical sensors with good sensitivity and selectivity at room temperature (Tate *et al.*, 2017). For the detection of low concentrations of N-alkyl derivatives of ammonia, potential interferences need to be eliminated or compensated for. For example, the response of OFET gas sensors to analytes is affected by humidity and temperature. Here, we investigate the responses of OFET devices to alkyl amines in the presence of ethanol vapour as a potential interferent.

Air stable OFET devices that can operate at low voltages ($V_{GS} = V_{DS} = -3V$) were fabricated using the solution processable organic semiconductor poly(3,6-di(2-thien-5-yl)-2,5-di(2-octyldodecyl)-pyrrolo[3,4-c]pyrrole-1,4-dione)thieno[3,2-b]thiophene) (DPPTTT) as a sensing/conducting layer. Both high-k and low-k dielectrics based on the ferroelectric polymer poly(vinylidene fluoride-trifluoro ethylene-chloro-fluoroethylene) / P(VDF-TrFE-CFE) and the poly(methyl methacrylate) / PMMA cross-linked with benzophenone are used as an insulating/dielectric layer with a bottom gate bottom contact structure.

Gas sensing results show that the sensitivity of the OFET sensor towards propylamine vapour over a concentration range between 3-118 ppb and trimethylamine (5-193 ppb) is 7.3 ± 0.3 and 3.9 ± 0.1 % ppb^{-1} respectively. The presence of ethanol vapour (40-190 ppb) alters the response to recovery rate ratio dramatically for both propylamine and trimethylamine. Sensors were exposed to analytes for varying lengths of time (1-12 min) to determine the optimum response characteristics. Future work will concentrate on enhancing the quality of dielectrics for improving the isolation between gate and ‘’active’’ layer and the accumulation of charge carriers between semiconductors and insulator films.

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P19 Synthesis and characterization of water-based inks of 2D-materials

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Extensive research into the field of advanced materials and most notably 2-dimensional (2D) materials has been undertaken since the isolation of graphene, owing to its exceptional physical properties including high electrical and thermal conductivities, mechanical and chemical stability and high optical transparency [1].

Liquid phase exfoliation (LPE) offers one of the most promising routes to large-scale solution processing of defect-free 2D materials, in which ultrasonic waves are used as the exfoliation method whilst careful choice of solvent is required to stabilise the nanosheets [2]. Typically, layered materials are exfoliated in non-green organic solvents such as N-methyl-pyrrolidone (NMP) or dimethylformamide (DMF) which are expensive, toxic and difficult to remove thereby limiting scalability. Ideally, water should be used as solvent. Owing to graphenes hydrophobic nature, LPE in water can be performed only by using stabilising agents, which assist exfoliation and, at the same time, avoid the re-aggregation of the exfoliated sheets in solution.

In our group we use pyrene derivatives as exfoliating agents to exfoliate graphite and other layered materials in water [3-6]. These molecules have shown to be very effective at exfoliating graphite, owing to their π-π interactions with graphene, whilst maintaining high solubility due to the hydrophilic nature of their functional groups. This method has been used to produce highly concentrated dispersions of mostly few-layer nanoflakes of a large range of different layered materials. The produced dispersions are stable over time and have been used to make several devices by inkjet printing, including photodetectors [5,7], capacitors [8] and transistors [8-9].

In this work we show an extensive characterization study of the lateral size and thickness of graphene nanosheets produced using different pyrene derivatives by Atomic Force Microscopy (AFM). In a previous work on graphene produced by LPE in NMP [10], a correlation between thickness and lateral size was found, which was attributed to the processes happening during sonication. Thus, we aim at comparing this model with the results obtained by LPE in water, when pyrene derivatives are used as stabilizing agents, in order to elucidate if these molecules do also participate in the exfoliation, by affecting the lateral size and thickness distribution of the flakes. This would help getting more insights on the fundamental processes happening during LPE with exfoliating agents, which are largely unknown.

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P20 Spray-printed molybdenum disulfide electrodes for application in supercapacitors

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Among a variety of 2D graphene-like materials, molybdenum disulfide (MoS_2) stands out due to its remarkable physical, electrical, and optical properties [1]. The existence of a direct bandgap in the MoS_2 monolayer offers an attractive possibility of using this material in field-effect transistors and optoelectronic devices. Furthermore, MoS_2 can produce high specific area nanostructures and has reasonably good electrochemical performance, the desirable features for application in energy storage devices [2]. However, the mass production of large-area electrodes based on MoS_2 has been a major hurdle for their practical applications.

Here we present the production of MoS_2 electrodes deposited over stainless steel substrates by spray-coating and its application in supercapacitors. We obtained the MoS_2 by hydrothermal synthesis, using thiourea and sodium molybdate dihydrate as precursors. The material was dispersed in a solution of water and ethanol (30%wt.) assisted by sonication. After 3 h of sonication, we centrifuged the dispersion at 500 rpm over 10 min to remove the undispersed material. The film deposition was carried out by transferring the as-prepared dispersion to an airbrush coupled to a modified 3D printer with in-line displacement. We fabricated a supercapacitor prototype using the spray-printed electrode and a gel-like electrolyte based on Poly (vinyl alcohol) (PVA) and phosphoric acid (H_3PO_4).

SEM images showed flower-like structures for the MoS_2 powder collected from the autoclave, which was transformed into nanoflakes during the dispersion process. Raman spectroscopy showed that the chemical composition of the film did not change after the deposition. The as-prepared supercapacitor prototype exhibited a high specific capacitance of 142 F/g. The device also exhibited good electrochemical behaviour over cyclic voltammetry (C-V) measurements and galvanostatic charge/charge cycles. In conclusion, we have demonstrated the production of large-area MoS_2 electrodes for application in supercapacitors using a scalable method.

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P21 Graphene based electronic devices on flexible textile fibres

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The field of wearable electronics is a fast-growing market expected to be worth 50 billion euros in 2025, over three times the current market. The main challenge facing current wearable devices is that intrusive solid electronic attachments limit the usage of established devices in wearable systems. Integration of electronic functions within fabrics, with production methods fully compatible with textiles, is therefore of current interest, to enhance performance and extend functions of textiles. Graphene, which has outstanding mechanical, optical and electronic properties, has been demonstrated as potential candidate for application in smart textiles which are stretchable and flexible.

We have previously developed a method to coat textile fibres with graphene, making them conductive. In this work we demonstrate different electronic devices on this platform. These include touch sensors and light-emitting devices and humidity and temperature sensors. These devices are durable, flexible, adaptable, and breathable in addition to being quite easily integrated within textiles. This technology can be employed in several sectors including sports, healthcare and military.

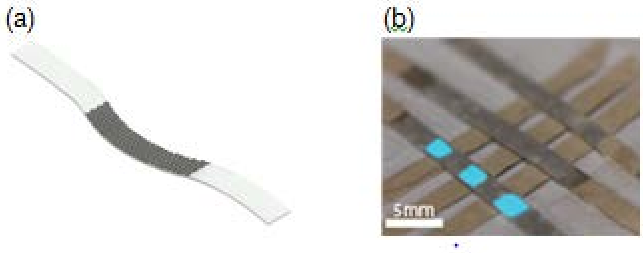

Figure 1.. (a) Graphene coated textile fibre; (b) Array of electroluminescent light emitting device on textile fibres.

P22 Flexible textile power module based on ferroelectret energy harvester and super capacitor

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E-textile devices require an efficient, flexible and durable power supply module, at present, they are typically powered by secondary batteries that neither flexible and require frequent charging. This paper reports an investigation into an alternative power supply: an integrated textile power module for e- textile applications [1]. The textile power module presented here enables biomechanical energy harvesting using a textile based ferroelectret harvester and storing of the energy in a solid-state supercapacitor with both devices being fabricated in the same single piece of woven cotton textile.

Previous attempts to combine a supercapacitor and energy harvester together include the work by Pu et al. [2] who demonstrated a triboelectric nano-generator (TENG) fibre network made with nickel coated polyester straps with a parylene coating, and a fibre supercapacitor formed from reduced graphene and nickel yarns with an acidic gel electrolyte. Dong et al [2] reported a stretchable knitted textile power modules realised by silicon rubber coated stainless steel/polyester fibre networks forming a TENG and a fibre supercapacitor with carbon nanofibers/PEDOT:PSS fibre electrodes and an acidic gel electrolyte. These works use bespoke fibres, acidic electrolytes and triboelectric harvesters that require non-conventional textile materials.

The proposed module was fabricated using a typical woven fabric material, standard processes and inexpensive and non-hazardous materials. The textile ferroelectret was formed from aluminium coated fluorinated ethylene propylene (FEP) film bonded to each side of the cotton textile that was then sealed by an EVA polymer annulus. The textile supercapacitor electrodes were fabricated by spray coated carbon ink and this was followed by impregnation of a gel electrolyte forming a multilayer structure with the carbon electrodes separated by cotton fibres. Both devices were electrically connected by a printed rectifying circuit and encapsulated by a screen printed polyurethane layer (figure 1 (a)). The textile ferroelectret (6 cm × 6 cm) achieved a peak power output of 0.47 $\mu W.cm^{-2}$ for a compressive force of around 350 N (figure 1 (b)). The single layer textile supercapacitor obtained an area capacitance of 5.2 $mF.cm^{-2}$. Tested as a whole, cyclical mechanical input of 350 N at 1 Hz for 40 seconds achieved a voltage across the textile supercapacitor of 50 mV (figure 1 (c)). This work has demonstrated the capability of integrating a full power module on a single piece of cotton.

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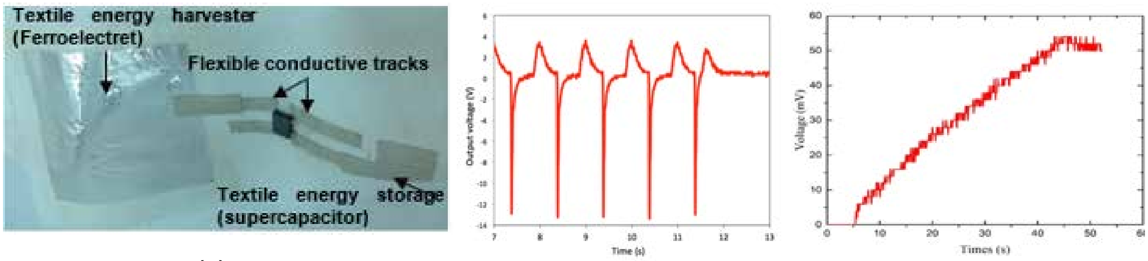

(a) (b) (c)

Figure 1. The textile power module. a) assembled textile power module image; Output voltage of textile based FEP ferroelectret harvester under cyclical 350 N compressive force with 10 MΩ load;) FEP textile ferroelectret harvester charging the textile supercapacitor.

P23 Bi_2S_3 thin film photovoltaics; a study of the impact of morphology on absorber properties

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The increasing demand for low cost, large area photovoltaic technologies requires new materials to be; non-toxic, inexpensive to manufacture and scalable to industrial production. Synthesis of Bi_2S_3 is presently is achieved via thermal decomposition of bismuth ethyl xanthate, which is readily solubilised in a range of organic solvents. Aerosol Assisted Chemical Vapour Deposition (AACVD) and spin coating can be employed economically to synthesize Bi_2S_3, both methods utilising solution-based delivery of the precursor which allows convenient manipulation of film morphology by varying both the solvent system and degradation temperature.

Bismuth sulphide (Bi_2S_3) is an n-type semiconducting material, with a high absorption coefficient (10^5 cm^{-1}), tuneable bandgap of 1.3 – 1.7 eV and an absorption onset at ~900 nm. The potential of Bi_2S_3 as a photovoltaic absorber was first illustrated by preparing photosensitive anodic Bi_2S_3 grown on parent bismuth anodes in Na_2S solution. [1] It was shown that Bi_2S_3 films just 3.9 µm thick exhibit photocurrent quantum yields approaching unity, highlighting the possibility of low-cost manufacture associated with minimal amounts of required material.[2]

The first reports of Bi_2S_3 being employed as an absorber material in photovoltaic devices utilized a chemically deposited Bi_2S_3 thin film absorber as part of a liquid junction solar cell. [1] PCEs of these devices were modest, yet as this is attributed to poor electron mobility, high recombination rates and high doping, careful manipulation of both stoichiometry and morphology has been shown to greatly improve device efficiency. [3]

Examination of Bi_2S_3 morphology variation attained via the two synthetic routes and its effect on a heterojunction device, employing P3HT as the p-type material will be presented. Analysis of these variations has highlighted substantially different nano-structured morphologies associated with the spin coating and AACVD methods. SEM analysis has shown that spin coating produced an interwoven mesh of nano-wires/rods, while AACVD produced nano-platelets, corroborating recent work published by Revaprasadu. N. et al who showed that the solvent mixture, temperature, pre-cursor type and synthetic technique were all crucial on the morphology of Bi_2S_3. [4]

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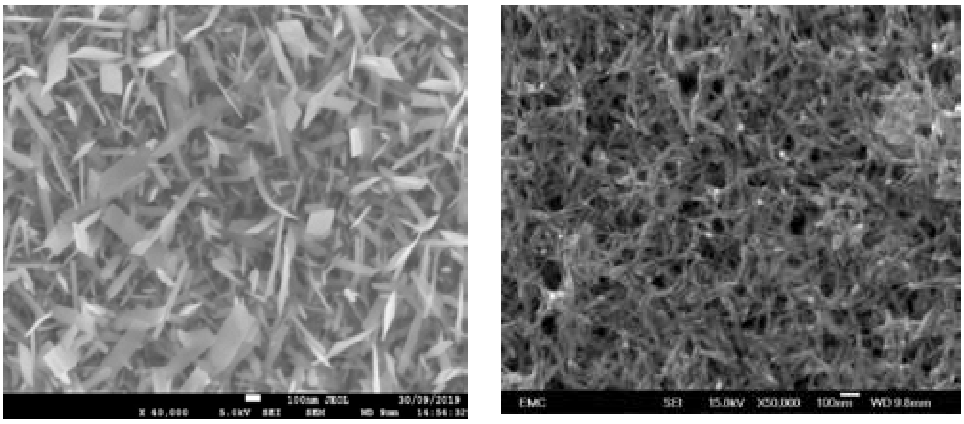

Figure 1. SEM images of as deposited Bi_2S_3 via (a) AACVD and (b) spin coating.

P24 Large-scale deposition of copper (I) thiocyanate hole transport material for use in perovskite solar cells

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Copper (I) thiocyanate (CuSCN) is an optically transparent, wide bandgap (3.4-3.9 eV), p-type semiconductor used in organic and perovskite solar cells. In comparison to other hole transporting materials (HTMs), CuSCN is economically favourable and comparable in performance, with efficiencies for hybrid organic-inorganic metal halide perovskite solar cells exceeding 20% [1].

Current research involves several solution-processable methods such as spin coating, spray coating and doctor blading. This study reports the first ever deposition of CuSCN via aerosol assisted chemical vapour deposition (AACVD). AACVD is a scalable ambient-pressure technique with low processing costs and simple reactor design. An added advantage is the flexibility over material choice due to the process being dependent on the solubility of the precursor, rather than the volatility as in conventional chemical vapour deposition techniques.

The study involves deposition of CuSCN using diethyl sulfide solvent. The deposition temperature, concentration of solution and amount of precursor solution deposited were varied to form a uniform film. CuSCN films produced were further optimised by studying the growth characteristics. CuSCN films deposited via AACVD were compared to films produced by conventional spin coating methods. Scanning electron microscopy (SEM), atomic force microscopy (AFM), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS) and ultraviolet-visible spectroscopy (UV-Vis) were used to determine morphological, structural and optical information.

Using the optimised conditions, AACVD CuSCN was incorporated into a working methylammonium lead iodide perovskite solar cell. Addition of interlayers, different electron transport layers and device architectures were explored to determine structure with highest performance. Studies into the solar cell performance allowed further understanding of the less well-known CuSCN HTM. Solar cells were tested under AM 1.5 and a champion efficiency of 10.44% was achieved, which represents the first ever working solar cell using AACVD CuSCN.

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P25 Conformal 3-Dimensional Energy Storage through Inkjet and Water-Transfer Printing

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The rapid growth of Internet-of-Things (IoT) has stimulated the development of embedded electronics into physical components and daily objects which triggered a tremendous and rapidly grown interest for electronic devices and energy storage systems with advanced and diverse form factors (*i.e.* flexible, wearable and conformal).Typical fabrication methods, such as photolithography and electrode winding/stacking, that are commonly used in conventional electronics and energy storage systems respectively, are difficult to be applied as fabrication strategies towards devices with advanced form factors (*e.g.* three-dimensional (3D), stretchable, conformal). In this study, we demonstrate the fabrication of supercapacitors on 3D objects through inkjet and water-transfer printing (Figure 1). The devices are printed on a water-soluble substrate, which is then placed on the surface of water, and once the substrate is dissolved, the devices are transferred on the 3D object by controlling the level of water. Planar supercapacitors constituted of a silver nanoparticle-based current collector, a nickel (II) oxide (NiO) nanoparticle-based active electrode material and an ultraviolet-cured triacrylate polymer-based solid-state electrolyte, were used as model materials to explore the feasibility of the proposed concept. The conformed supercapacitors showed maximum areal capacitance of 87.2 $mF \cdot cm^{-2}$ at a voltage window of 0 – 1.5 V.This new class of water transferable, inkjet-printed, all-solid-state supercapacitors with advanced conformality, offer new alternative approach towards monolithically-integrated/object-tailored power sources that are needed for complex-shaped devices for IoT and flexible/wearable electronic applications.

Acknowledgement
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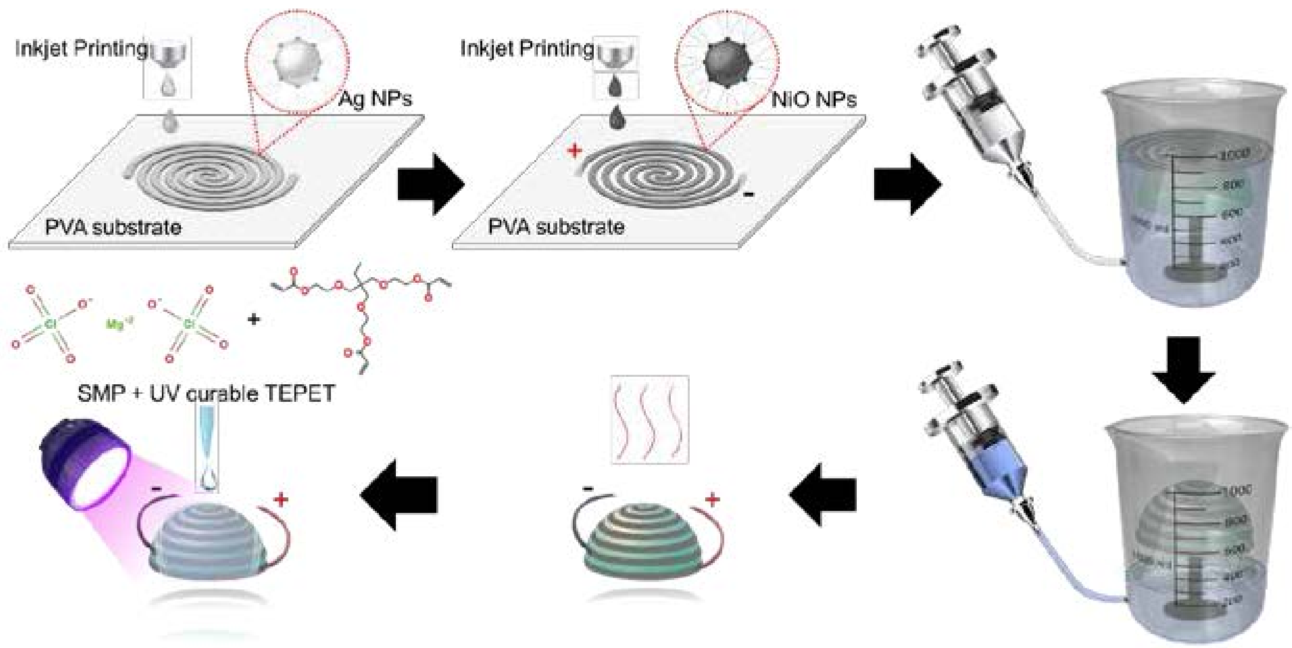

Figure 1. Fabrication process of inkjet and water transferred supercapacitors.

P26 Effect of press parameters and ink viscosity on ink separation mechanisms in screen printing

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A specially designed screen-printing visualisation rig has been developed for ink and process evaluation, which has been used alongside traditional methods such as shear and extensional rheometry. This has been used to provide validation to existing theories of ink transfer mechanisms, as illustrated in Figure 1. Providing sufficient experimental evidence to identify key transfer mechanisms and provide validation for the theory suggested by Messerschmitt (1). Where the four stages of ink deposition, consisting of adhesion, extension, flow and separation were identified. The screen-printing visualiser (SPV) can also be used to assess quantifiable changes in the ink separation mechanism with changes in press parameters and ink rheology. In the case of press parameters, when snap off distance had significant effects on the adhesion to extension stages, for the commercial carbon ink assessed. Reductions in snap distance led to shallower angles between the mesh and substrate. This led to notable increases in the adhesion to extension stages as at these lower angles. Sufficient shear flow for separating the ink was not achieved until a greater distance behind the squeegee than with greater snap distances. When print speed was increased, the filaments forming during the flow to separation stages also showing changes in the necking profile from that typical of a power law fluid to a weakly elastic fluid, as the ink behaved in a more elastic manner at higher speeds due to its viscoelastic profile. Quantifiable changes in the mechanism were also observed when the carbon concentration of the ink was reduced by increasing the solvent content, leading to a gradual reduction in viscosity and elasticity. Typically, less viscous inks containing lower concentrations of carbon produced a clean separation after the extension stage. While inks containing higher carbon, concentrations produced filaments during separation. Inks producing more filaments during separation were found to deposit more ink. In addition to this, further investigations on the SPV could be conducted to assess the effect of ink rheology on other functional inks as well as graphics inks, the effect of using different meshes and substrates with different surface energies. These results could be used to develop boundary conditions for computational models and predictive methods.

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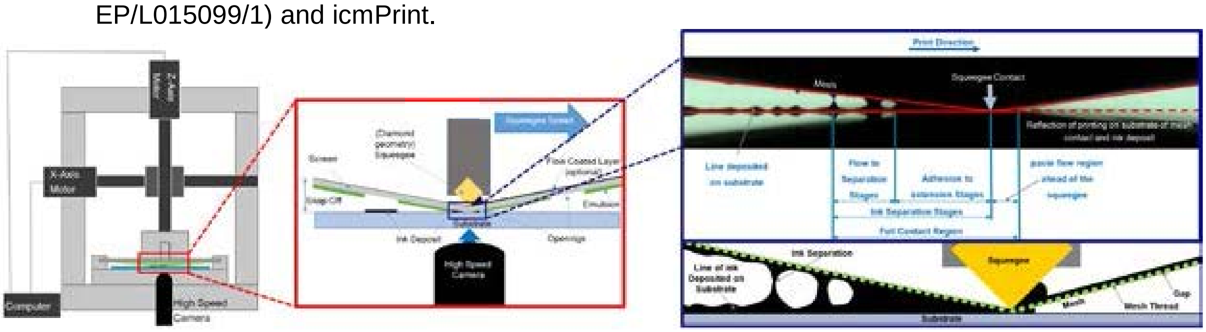

Figure 2. Schematic diagram of the screen-printing visualisation (SPV) rig, with a zoomed in schematic diagram of a cross section through the screen printer and a zoom in showing a labelled high-speed image and diagram quantifying the separation zones.

P27 Applications of LAE – Simultaneously addressing healthcare needs & the step change required in climate action

Josephine Charnley

Quantum Technology Supersensors & Teesside University Healthcare Innovation Centre

SocketSense – Advanced QTSS™ sensor-based design & development of wearable prosthetic socket for amputees.
Limb amputations cause serious physical disabilities that compromise the quality of life of many people around the globe. There are 40 million amputees in the world with an estimated 2.4 million in the EU and approximately 215,000 amputation surgeries performed each year (around 90% are lower limb amputees). Thus, there is a growing demand for efficient prosthetic socket systems due to growing numbers of amputees and lack of an existing solution for the comfortable socket. Development of a new solution for a prosthetic socket by utilizing embedded, wearable printed electronic sensors is presented. The sensors allow real-time data collection allowing prosthetists to monitor the evolution of the performance of a patient's existing socket as well as anatomical changes of the residual limb of amputees. New algorithms will evaluate the biomechanical characteristics so that once the existing socket does not serve the patient a new socket can be produced with minimal need for lengthy clinic visits. The sensor system is based on integration of the Environmentally Friendly and skin safe smart sensing QTSS™ materials with flexible and wearable electronics resulting in lightweight, flexible, printed sensors that in turn are integrated in the prosthetic socket system. Printed electronics and LAE are the key to the manufacturing new electronic components that can resolve current needs in healthcare and enable new innovative products to be created that were first unthinkable due to technical and design freedoms. With new functional and environmentally friendly scientifically advanced materials like QTSS™ inks and QTSS™ gels the step change required in climate action can also be simultaneously addressed by producing more environmental impact reducing solutions.

Quantum Technology Supersensors is a specialist materials development SME producing a new generation of 'smart' & 'multi-functional' materials that harness nature's Quantum Technology effects to enable new ways of making electronics for environmental impact and energy reduction whilst reducing weight and costs.
Its Award Winning environmentally friendly Quantum Technology Supersensor™ (QTSS™) materials open up new and exciting possibilities for interactive surfaces, touch sensing, strain gauges, friction & shear sensing and single point or multi-touch pressure/force sensors & switches. QTSS™ materials change from insulator to conductor under pressure in proportion to the amount of force applied exhibiting resistance change over many orders of magnitude of over a billion ohms. This provides a uniquely large operating range capability and sensitivities are alterable. They are 'smart' as they know 'where' and 'how hard' they are being pressed and can add 3D Force-Touch pressure sensing functionality to most surfaces including recyclable ones. Design freedom opens up new possibilities for novel, yet more sustainable product innovation in high growth markets such as Healthcare, Prosthetics, Robotics, Stretchable & Conformable Electronics, Consumer, Automotive/ Transport, IOT, Responsive Environments, Packaging and Wearables.

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P29 Next-generation paper: a versatile augmented book platform

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We report on fully working prototypes of an augmented travel guide which presents relevant and up-to-date digital content on an internet-connected device in response to user interaction. Our demonstrator continues recent research into routes to conferring books and paper product additional functionality by embedding electrical and electronic components [1-4]. More generally, the current embodiment of the *a-book* platform uses hybrid integration of electronic components for two aspects of its functionality. First, embedded within each page of the book, centimetre-scale flexible organic photovoltaic (OPV) modules made using a roll-to-roll process at VTT [5] create a unique digital code which identifies which page has been exposed to light, as the user reads. Second, a microcontroller system embedded in the hard cover (typical size ~ 20 * 15 cm) detects user interaction by reading the code generated by the OPVs and the state of touch/pressure pads arranged on the periphery of the cover [6].

Recent developments, shown in Figure 1 include the evolution of the “cover electronics” from consumer-off-the-shelf discrete boards into a miniaturized, versatile, general-purpose design including: the microcontroller, Bluetooth LE module, and power management circuitry handling the wireless charging of the included Li-Po battery. Also presented in Figure 1 are the waveforms of the four analog data channels related to the state of illumination of the embedded OPV modules, as the user turns the pages. By comparing to a programmable threshold, these voltages are converted to binary data which uniquely represent each page.

This platform established a new type of interaction combining seamlessly the versatility of internet-connected multimedia devices and the advantages of handling objects in the environment. The manipulated object becomes, in this way, a (remote) control device for interacting with digital content. In the final step of development, we will be working with industrial partners on improving the commercial manufacturability and integration of the components by designing custom cabling and adapting the hard-cover book-making process. User trials are ongoing.

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Figure 1. Augmented book platform: left – evolution and integration of cover electronics; middle – typical page from the a-book *showing the embedded OPV module for page number recognition; right– as pages are turned, the optical sensors embedded in each page generate a unique digital code, read by the cover electronics.*

P30 Quantum dot-based colour gamut and rendering for white electroluminescent lighting device

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Flat panel displays always have been looked around alternative methods for eliminating backlight module and colour filters in order to transform into advanced form factors for the future display application. A major drawback is the structure difficulties, which can be solved using the promising materials. Colloidal quantum dots (c-QDs) has the advantages of colour tunability, high luminescence and sharp emission bandwidth.[1] Especially, unique optical property of tunable bandgap by the quantum size effect plays significant role for electroluminescent mode on various display purpose.[1] This prosperous material will be not only the key for the light emitting layers on the flat panel for the individual colours of red-green-blue (RGB), but also colour rendering techniques to imply on numerous different substrates for flexible lighting module.

In this report, three methods have been introduced for white electroluminescence from various structure of c-QDs. In a perspective of a purely colour-based approach, rendering RGB will produce the white light, and the methods, shown in Figure 1, involve with different RGB structure as light-emitting diodes (LEDs). Adjusting the relative concentrations of RGB QD, a mixture of QDs has spin-coated as a single layer for emission layer. In addition, individual RGB QD layers were stacked in a specific sequence and thickness to tune the colour spectrum for the white light. At the last, the transfer printing technique was used to pixelated on same surface while tuning the emission area of RGB QD.

Furthermore, the work has been supported by the optics in a layered structure, which have been numerically simulated in order to understand the spectrum of the out-coupled light. Here, QDs are located on different positions of the source layers depending on the device structure, and spectral analysis provides useful information for rendering colours on the different form factor of device structure and the display system. Likewise, the report not only shows how to render RGB QDs for the white light emission but also covers how to make more specific colours from RGB QDs.

References

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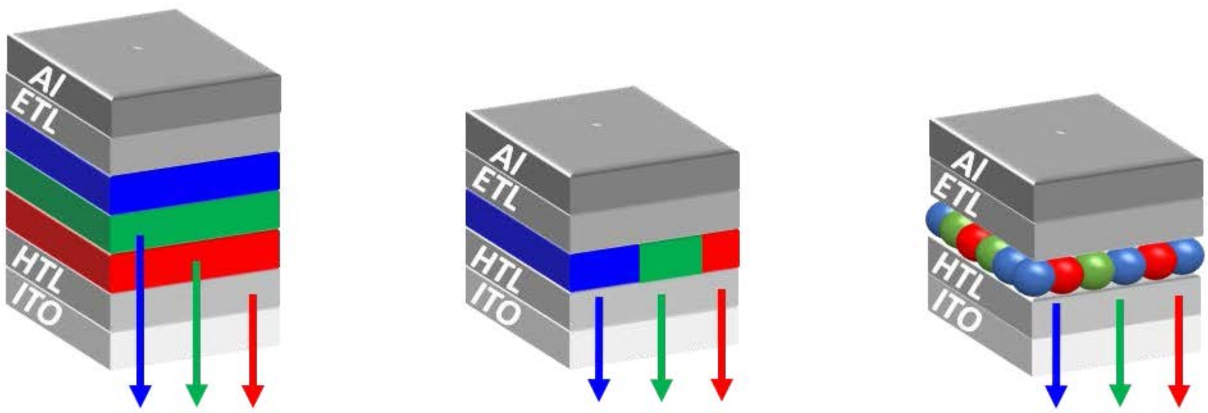

Figure 1. Schematic structure of White QLEDs

P31 Aluminum layer roughness effect on the anodization process and in electrical properties of Al_2O_3 films

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Printed, flexible and large area electronics stand out and is expected to boom in the global market next years. A new generation of gadgets as e-readers, flat panel displays, internet-of-things devices (IoT) and smart packaging are coming. But, to achieve this technological foresight is need to develop new printable materials as dielectric, semiconductors and conductors. Dielectrics are of critical importance, especially for thee transistors development. Several transistor parameters as, for instance, power consumption in off state, operating voltage, current leakage, threshold voltage stability and frequency operation, are influenced by the gate dielectric. The anodized aluminum oxide (Al_2O_3) has been considered a very promising high k dielectric for transistor as well as other devices, in printed electronic. The anodization process is particularly interesting for flexible electronics due to its simplicity, low cost, low temperature, excellent thickness control in nanometric scale and, mainly, for the good compatibility with R2R manufacture process. Also, the anodization process can be applied locally in an aluminum layer previously deposited over the substrate or directly in the aluminum packaging. The roughness of the aluminum surface is an important parameter that can influence the Al_2O_3 electrical properties. In this work 40 nm thickness film of Al_2O_3 was grown on the aluminum foil with four different roughness, changing from nanometers scale to micrometers, in rms, achieved by electropolishing techniques. We observed that the time to reach the final voltage during the grow, by anodization with constant current, is proportional to the roughness RMS value of aluminum foil. This can be explained considering that the real surface area increases with the roughness enlargement. For a smooth surface the curves of voltage versus time in anodization at current constant are straight lines, but deviations of linearity are observed for surfaces very rough. Upper electrodes of PEDOT:PSS were deposited by spray on the top of the Al_2O_3 films, to accomplish the manufacture of a printed capacitor, allowing to perform electrical measurements. Electrical measurements show that imaginary and real capacitance are strongly influenced by the sample roughness. Also was observed that for the roughest samples the humidity influence was strongest. The morphological analyses obtained by AFM and SEM and the electrical measurements during the film grown, and impedance analyses of the capacitor allows us to state that Al_2O_3 films following the roughness of the aluminum foil, like a “sheet spread over a stone bed”. Summarizing, this study show confirms that anodized Al_2O_3 films is very good alternative to obtain a dielectric for printed, flexible or large area electronic devices, but the roughness of the aluminum is an important parameter that has to be considered.

P32 The evolution of OSC's performance parameters under mechanical bending

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Flexible organic solar cells (OSCs) have been gaining a lot of focus lately as they possess the advantages of low cost and light weight [1]. Which make them the most promising photovoltaic devices for wearable electronics and to be used in drones and buildings. However, there is so little known about the evolution of the performance of these cells when they bent or undergo any mechanical testing [2].

In this study we chose to investigate the effect of 3 point flexural bending test on an inverted structure of PBDB-T:ITIC based Organic solar cell fabricated on Polyethylene terephthalate (PET) substrate. to understand the relationship between degree of bending and device performance, 4 different bending radiuses were studied.

The optical, electrical and morphological properties of Indium tin oxide (ITO) coated PET were obtained and compared to the conventional glass ITO substrate to insure its candidacy as an excellent base for cell's fabrication. We then investigated the effects of mechanical bending on device performance. Using Finite Element Analysis (FEA) we simulated the stress distribution on the cell during bending (see Figure 1). With the use of Scanning electron microscope (SEM) and Atomic Force Microscopy (AFM) we were able to study the microstructural changes in the device structure and possible interfacial roughening after mechanical bending. We reported the evolution of the electrical property's changes following the bending test via 4-point probe. To further understand the effects of possible degradation roots, the results were compared to those of incapsulated devices, as flexibility is key, low temperature flexible encapsulating process was used.

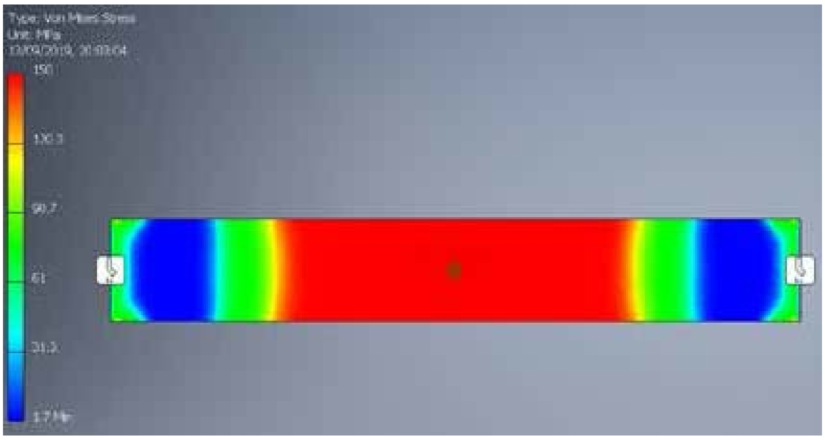

Figure 1. Stress distribution during bending (r= 2.5 cm) on organic solar cell fabricated at the centre of 8 cm long PET substrate.

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