## Topical Symposia
## Room Town & Country B - Session TS3-WeA
## Processes of Materials for Printed and Flexible Film Technologies

**Moderators: Prof. Panos Patsalas**, Aristotle University of Thessaloniki, Greece, **Dr. Demosthenes Koutsogeorgis**, Nottingham Trent University, UK

2:00pm **TS3-WeA-1 Upscalable Nanomanufacturing of Thin-Film Electronics***, **Thomas Anthopoulos**,* King Abdullah University of Science and Technology (KAUST), Division of Physical Sciences and Engineering, Saudi Arabia **INVITED**

Adapting existing manufacturing methods to emerging forms of large-area nanostructured electronics presents major technological and economic challenges. Despite the difficulties, however, a number of new processing concepts have been gaining ground, transforming the broader marketplace and relevant manufacturing infrastructure. In this talk, I will discuss our recent efforts toward scalable manufacturing of emerging forms of large-area nanostructured electronics. I will show how the development of innovative patterning technologies in tandem with engineered nanomaterials, can lead to more sustainable forms of optoelectronics with high-performance characteristics. Particular emphasis will be placed on the development and evolution of adhesion lithography (a-Lith) and self-forming nanogap lithography techniques and their use in an expanding range of applications from ultra-fast optoelectronics to new forms of chemical reactors.

2:40pm **TS3-WeA-3 Plasma Technologies for Sustainable Packaging Materials***, **Glen West**,* Manchester Metropolitan University, U.K.*; T. Cosnahan, C. Struller, N. Copeland,* Bobst Manchester Ltd., UK*; P. Kelly,* Manchester Metropolitan University, U.K.

The sustainability drive in the plastics packaging market has, in recent years, been propelled to public attention and incorporated into corporate strategies. In response, most major market players, from resin producers to brand owners and retailers are aligned to have only fully recyclable packaging by 2025, and to reduce carbon dioxide emissionsfor this 141 MTonne market. Other requirements in development from various regulatory and statutory bodies present an environment of increasing demand on producers throughout the sector. From an equipment manufacturer perspective, these environmental sustainability pledges will require technological development.

The industry is moving away from multi-layer, multi-chemistry structures which were used to adhere various coating layers to each other, as mono-material plastic packets are being targeted due to their recyclability. Substantial research attention is focused on promoting the surface energy of polyolefin materials, including the utilization of plasma in the early converting steps. Plasma techniques are favored within the industry, as they are operator independent processes. The plasma surface treatment of kilometers-long reels of polymer to prepare them for subsequent deposition steps is now understood to be vital to achieve the required interfacial bond strength. This is understood to promote barrier and adhesion performance to parity with historical non-recyclable structures (i.e. <1 cc/m2.day oxygen transmission and > 3 N/15mm adhesive failure).

Within the flexible film packaging market, thin film SiOx and diamond-like-carbon are deposited using plasma enhanced chemical vapor deposition – as these thin films create robust environmental barriers to oxygen and water vapor on plastic packaging for food and medical products, although one drawback of DLC is the use of acetylene which comes with various safety hazards. One of major issues when using plasma is the control of arcs that can damage the polymer web. For successful plasma enhanced chemical vapor deposition, two key parameters required: high enough ionization percentage of large input gas flow, and sufficient energy of deposition. These create the high reaction rates required and the energy for surface reorganization (and reaction) of the deposit on the surface to create a correctly reacted and structured bonding which has the balance of properties of barrier, flexibility and toughness. The plasma technologies for achieving effective surface treatment and consistent barrier film deposition on large areas with sufficient processing speed will be discussed in this paper.

3:00pm **TS3-WeA-4 Transition Metal Nitride Colloids: From PVD Targets to Laser-Ablated Nanoparticles***, N. Pliatsikas, S. Panos, I. Fekas, S. Kassavetis, **Panos Patsalas**,* Aristotle University of Thessaloniki, Greece

Transition metal nitrides (TMN), such as TiN, ZrN, HfN, VN, NbN, TaN, MoN, WN, have been the cornerstone of hard coating industry for several decades. Some of them have been considered as electronic materials of substantial importance, mostly as diffusion barriers in transistors. Recently TMN have been revisited as important plasmonic materials and biomaterials for emerging applications in the printed electronics and biomedical sectors. TMN share unique traits such as refractory character, electronic conductivity, notorious chemical stability, and miscibility among them facilitating the formation of ternary (e.g. $Ti_{1-x}Zr_xN$, $Ti_{1-x}Ta_xN$, and $Ti_{1-x}Sc_xN$, among others) and quaternary (e.g. $Ti_{1-x-y}Zr_xAl_yN$, $Ti_{1-x-y}Ta_xAl_yN$, among others) alloys. TMN collectively cover a wide range of values for their electron conductivity, work function and plasmon resonance spectral location. While they are routinely produced in thin-film form by PVD (mostly sputtering) and CVD/ALD, the formation of colloidal nanoparticles of TMN has been proven exceptionally challenging, especially for the case of ternary TMN. In this work we exploit the knowledge of various sputtering variants (including HIPIMS) to produce thick TMN films to be used as targets for laser ablation in liquids (LAL) to produce TMN colloids and inks. We attempt to correlate the crystal structure and chemistry of the film materials with the LAL conditions (laser wavelength, pulse duration, liquid solvent), and with the traits of nanoparticles by implementing a variety of experimental techniques such as optical transmission spectroscopy, AFM, SEM, XPS, and Raman spectroscopy.

3:20pm **TS3-WeA-5 Fully Inkjet-Printed Gas Sensing Antenna Based on Carbon Nanotubes for Wireless Communication Applications***, **Hsuan-Ling Kao**,* Chang Gung University, Taiwan*; L. Chang,* Ming Chi University of Technology, Taiwan*; Y. Tsai,* Chang Gung University, Taiwan

Sensors have been widely used in wearable electronic devices for various detection such as gas, strain, or temperature. The sensor incorporates wireless transmission to reduce the bulkiness and inconvenience caused by the cable. Wireless sensors that embedded sensing film into wireless communication devices such as resonators or antennas has been proposed to achieve small size, simple fabrication, high energy efficiency, and low cost for real-time remote monitoring. In order to embedding sensing film into wireless devices, the conductivity of sensing film is important. Fully inkjet printing technology promotes the green process using by digital controlled pattern in required location due to the advantages fast fabrication, material saving, low cost, high substrate selectivity, and low annealing temperature, which is one of the green process technologies. Carbon nanotubes (CNTs) have been attention for gas sensing applications owing to their high specific surface area and high structural porosity, which enable fact response, high sensitivity and low operating temperature. Inkjet printing technology can precisely control the density carbon nanotubes by droplet spacing (DS) and multi-pass to provide various resistive-type samples to study gas response. However, the relationship between the density of carbon nanotubes and gas sensing response has not been discussed yet. In this work, various DSs and passes were used to control the density of CNTs by pattern rotation. The sensing film and conductive film were printed by commercially carbon nanotube ink (Nink-1000, Nano Lab.) and nanoparticle silver ink (DGP-40LT-15C, Advanced Nano Products Co., Ltd.), respectively. The gas sensing properties were studied by resistance response to validate its feasibility, repeatability, and reversibility. After optimize the CNTs sensing film, wireless sensing antenna composite was designed and fabricated. The appropriate carbon nanotube sensing film was embedded into the dipole antenna by changing the transmission characteristics of antenna. The CNT films allows the electromagnetic transduction of antenna during gas sensing. The appropriate carbon nanotube sensing film was embedded in the dipole antenna to use microwave characteristics to obtain multi-dimensional values for providing high precision detection, which is also more stable than DC resistance value. In addition, it can also reduce the connection-induced loss and the area required for matching to obtain compact area and low power consumption. The wireless antenna sensor can be used in portable electronic products for its light, thin, and compact size and detection in anytime and anywhere.

3:40pm **TS3-WeA-6 Characterization and Evaluation of PVD-Coatings on Bipolar Plates for PEMFC***, **Julian Kapp**, V. Lukassek, V. Mackert, J. Wartmann, H. Hoster,* ZBT Zentrum für BrennstoffzellenTechnik GmbH, Germany*; R. Cremer, P. Jaschinski,* KCS Europe GmbH, Germany

As a result of the steadily increasing demand for energy and the associated need for the responsible use of global energy resources, efficient and sustainable energy conversion and storage is becoming increasingly important. Promising solutions in this context are new developments in fuel cell technology. Here, the chemical energy of an energy carrier (e.g. hydrogen) is directly converted into electrical energy, resulting in high efficiency.

The development of novel techniques for improvement of Proton Exchange Membrane fuel cell (PEMFC) components has to be addressed. One of those components is the bipolar plate (BPP) which has various functions within the PEMFC, such as cell separation, fuel and oxidant gas distribution, collection and transport of generated electricity as well as water and heat management. Therefore, with respect to all those functions, an ideal BPP has to fulfill a number of material requirements, such as high compressive strength, sufficient electrical and thermal conductivity, along with good electrochemical stability. Although metal-based BBPs meet all necessary requirements, the main weak point of these is their susceptibility to corrosion in acid environment, as during PEMFC operation. While formation of the passive layer prevents further corrosion, it often results in electrode catalyst poisoning and contamination of the membrane. Furthermore, an increase in electrical resistance is a typical behavior induced by a passivation process of the metallic surface.

One goal of this work is the suitable series production of corrosion protection coatings with an excellent electrical conductivity on metallic BPP from a PEMFC. The Physical Vapor Deposition (PVD) processes arc and sputtering are used to generate these layers. When selecting the material for the BPP, attention is paid to inexpensive steel and aluminum alloys. The coating material is completely deposited without precious metals for cost reasons. At the same time, the task is to develop a continuous coating process that meets the demands for large-scale production of BPPs.

The developed coating systems were investigated using material characterization (XPS, SEM/EDX, CLSM and Contact Angle Measurements) and in-situ electrochemical analysis. Interfacial-electrical contact resistance (ICR) of coated BPP samples were measured before and after they were exposed to electrochemical corrosion testing. The ICR values and the corrosion rate were compared to United States Department of Energy (DOE) values. Promising coating systems were finally subjected to in-situ diagnostic studies.

4:00pm **TS3-WeA-7 Towards Large Area Scalable Organic Solar Cells using Solution Processing***, **S. Ravi P. Silva**,* Advanced Technology Institute, University of Surrey, UK **INVITED**

The rise in global energy consumption and demand requires a faster expansion in renewable energies. The world at present is powered from energy generated by burning coal/oil and gas to sustained industry, domestic heating and electricity [1]. The world now needs to change from the fossil fuels and march towards a net carbon zero position, with changes urgently needed to the energy mix, all manufacture, including the electronic device industry as well as powering devices during its operational lifetime.

Electronic devices have evolved into nanoscale architectures that could be powered via mW power management systems. The envisioned future sustainable societies will be intrinsically inter-connected: humans to transport to homes to cities etc. driven by inexpensive nano-scale electronics, most likely in the form of inexpensive flexible devices that are connected to everything – the Internet of Everything (IoE) -.This lends itself to delocalized power sources, that can operate under variable conditions. Plastic electronics are ideally suited to produce such devices with some of the lowest carbon footprints. We will examine next generation designs for sustainable nanodevices and renewable energy harvesting systems to help reduce the impact on the carbon foot-print. This will include energy harvesting systems such as plastic photovoltaics and Triboelectric generators.

Hybrid organic-inorganic halide perovskite solar cells (PSCs) show great potential for future solar, due to their incredible efficiency growth in last decade, which now reached as high as 25.7%, competing with the commercially available Si solar cells. Perovskites benefits from superior light absorption coefficient, long carrier diffusion length, high mobility, low exciton binding energy, and high defect tolerance. The solution processability of perovskite materials to form high-quality polycrystalline thin films provides the possibility of low-cost fabrication of PSCs on both rigid and flexible substrates. This can significantly cut the final price of solar energy harvesting. Roll-to-roll (R2R) production of flexible solar cells can also reduce the cost of transferring and storing and makes it possible to easily deliver the solar cells to less developed regions in the world with higher needs for energy.

[1] Silva, S.R.P. (2021), EDITORIAL: Now is the Time for Energy Materials Research to Save the Planet. Energy Environ. Mater., 4: 497-499. https://doi.org/10.1002/eem2.12233

4:40pm **TS3-WeA-9 Rational Design of Perfluorocarbon-Free Oleophobic Textiles***, **Sadaf Shabanian**,* University of British Columbia, Canada*; K. Golovin,* University of Toronto, Canada

Water- and oil-repellent fabrics have global applications within the textile industry and as technical apparel. Fabric finishes utilizing perfluoro compounds (PFCs) are known to render textiles both water and oil-repellent uniquely. However, PFC-based finishes are not sustainable because they compromise environmental and human health, and garment factories have accordingly begun to phase out PFC usage. This is problematic, as all previous studies on fabric finishes indicate that oil repellency cannot be achieved without perfluorination. Here we develop design parameters for fabricating oil-repellent textile finishes using PFC-free surface chemistries. In this work, we demonstrate that oil repellency is possible using PFC-free finishes by controlling a finish's texture size, porosity, and surface chemistry, based on a design framework rooted in wettability theory. For example, a PFC-free, oil-repellent jacket fabric is fabricated that exhibits oleophobicity towards canola, olive, and castor oil in addition to synthetic sweat. The textile remains non-wetted for liquids with surface tension as low as 23.9 $mN\,m^{-1}$. The equations developed in this work allow for the rational design of oil-repellent textile finishes that do not utilize perfluorinated substances.

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