Topical Symposia

Room Pacific Salon 3 - Session TS4-1-MoM

Thin Film Materials for Flexible Electronics

Moderators: Oleksandr Glushko, Erich Schmid Institute of Materials Science, **Nicholas Glavin**, Air Force Research Laboratory, Materials and Manufacturing Directorate, USA

10:00am **TS4-1-MoM-1 2D Materials Based Epidermal and Implantable Conformable Bioelectronics***, **Nanshu Lu,*** University of Texas at Austin, USA **INVITED**

Bio-tissues are soft, curvilinear and dynamic whereas wafer-based electronics are hard, planar, and fragile. Such mismatch fundamentally impedes their integration with each other. As atomically thin, optically transparent, mechanically robust, and highly functional electronic materials, 2D materials are ideal for conformable bioelectronics. We have invented a cost- and time-effective "wet transfer, dry patterning" process for the freeform manufacture of graphene e-tattoos (GETs) [1-2]. Our GET has a total thickness of less than 500 nm, an optical transparency of ~85%, and a stretchability of more than 40%. Tensile fracture of PMMA-supported graphene has been experimentally investigated and different stages of fracture have been identified [3]. GET can be directly laminated on human skin exactly like a temporary transfer tattoo and can fully conform to the microscopic morphology of the skin surface via just van der Waals forces. Analytical models are developed to guide the GET design for full skin conformability even under skin deformation [4]. As a dry electrode, GET-skin interface impedance is found to be as low as medically used Ag/AgCl gel electrodes. GET has been successfully applied to measure electrocardiogram (ECG), electromyogram (EMG), electroencephalogram (EEG), skin temperature, and skin hydration. When applied around human eyes, imperceptible GET electrooculogram (EOG) sensors can capture eye movement with an angular resolution of 4 degrees, which can be used to wirelessly control a quadcopter in real-time [2]. In addition to noninvasive e-tattoos, we have engineered human eye-inspired soft implantable optoelectronic device using atomically thin MoS_2-graphene heterostructure and strain-releasing, retina conformable designs [5]. The hemispherically curved image sensor array exhibits infrared blindness and successfully acquires pixelated optical signals. We propose the ultrathin hemispherically curved image sensor array as a promising imaging element in the soft retinal implant with minimum mechanical loading to the retina. Optical signals obtained by this curved image array can be converted to electrical stimulations applied to optic nerves to restore visualization.

[1] Ameri et al, Acs Nano 2017, 11 (8), 7634-7641.

[2] Ameri et al, npj 2D Materials and Applications 2018, in revision.

[3] Jang, et al. To be submitted 2017.

[4] Wang, et al. Journal of Applied Mechanics 2017, 84 (11), 111003.

[5] Choi, et al. Nat Commun 2017, 8, 1664.

10:40am **TS4-1-MoM-3 Performance Deterioration Characteristics of Silver-Nanoparticle-Printed Flexible Electric Wirings under Severe Bending Deformation***, **Shoji Kamiya**, H Izumi,* Nagoya Institute of Technology, Japan*; T Sekine,* Yamagata University, Japan*; Y Haga, H Sugiyama,* Nagoya Institute of Technology, Japan*; N Shishido,* Green Electronics Research Institute, Kitakyushu, Japan*; M Koganemaru,* Kagoshima University, Japan

One of the important issues in flexible electronic devices is certainly their mechanical robustness. For further development of devices and wider applications in markets, how to characterize performance deterioration behavior under large scale bending deformation and how such information should be shared among suppliers and users of devices must be established for the sake of quantitative risk management in the actual operation toward the society of so-called IoT or ubiquitous sensor networks.

Mechanical robustness of flexible devices is most commonly demonstrated by bending them to a certain curvature while they are working. However, such a demonstration is mere consolation because no one knows what happens with even a bit of severer curvature. Therefore, in order to appropriately understand their robustness, bending test must be once carried out to the end of possibility, i.e., to folding them in half, while their performance is being evaluated. This is indeed a similar concept to common strength tests of materials, where materials are loaded until breakage to know safety margins of operation conditions.

To examine such a concept on flexible devices, a new type of bending test method was proposed in this study. Silver nano-particle wirings printed on flexible films were selected for the actual experiment, since wirings are utilized as the component most commonly found in any kinds of flexible devices, and tested not only under monotonic but also repeated bending loadings. Depending on the levels of loading, their resistance increased not always gradually but occasionally also suddenly. Such sudden behavior could hardly be deduced with the data obtained under less severe loading conditions and in shorter time of testing.

On the basis of deterioration behavior of performance observed above as an example, a number of new possibilities will be discussed in the presentation to share knowledge for the evaluation of operation risks associated with flexible devices to be distributed as a new type of infrastructures in the next step of society.

11:00am **TS4-1-MoM-4 Characterizing the Mechanical Reliability of Flexible and Stretchable Conductive Inks on Polymeric Substrates***, **Gabriel Cahn,*** Georgia Institute of Technology, USA*; M Wolfe,* DuPont Photovoltaic and Advanced Materials, USA*; J Meth,* DuPont Electronics and Imaging, USA*; S Graham, O Pierron,* Georgia Institute of Technology, USA

Flexible hybrid electronic (FHE) devices are produced through precision printing of electrically conductive inks onto flexible substrates. A fundamental understanding of the inks' conductivity evolution under mechanical strain is required to properly address mechanical reliability of these devices and develop better conductors for mechanically-demanding applications such as wearable devices. This work investigates the behavior of DuPont's 5025 ("flexible") and PE874 ("stretchable") silver conductors under strain and on different polymer substrates (Kapton Polyimide (PI), Polyethylene Terephthalate (PET), and Thermoplastic Polyurethane (TPU)). Both inks are composite materials made of silver flakes embedded at high volume density within an insulating polymer matrix. While contacts between the flakes form electrically conductive pathways within the ink, their evolution under strain due to inhomogeneous deformation and local cracking, and the effect on conductivity has not been explored yet. This works specifically investigates this aspect using an *in situ* optical microscopy technique to measure the resistance evolution during monotonic, stress relaxation and creep loadings. As the applied strain is increased, the resistance of both inks increases as well, but at a much lower rate for PE874. Under stress relaxation, both inks see similar recovery in resistance, the amount of which is a function of the polymer substrate. The local deformation is investigated using digital image correlation to interpret these results and understand the role of polymer matrix and ink/substrate elastic modulus mismatch on ink conductivity.

11:20am **TS4-1-MoM-5 Printed Hybrid Materials for Flexible Electronic and Optoelectronic Devices***, E List-Kratochvil, **Felix Hermerschmidt,*** Humboldt-Universität zu Berlin, Germany **INVITED**

Beyond the use in home and office-based printers, inkjet printing (IJP) has become a popular structuring and selective deposition technique across many industrial sectors. More recently great interest also exists in new industrial areas like in the manufacturing of printed circuit boards (PCBs), solar cells, flexible organic electronic and medical products. In all these cases IJP allows for a flexible (digital), additive, selective and cost-efficient material deposition, which can be used in an in-line production process. Due to these advantages, there is the prospect that up to now used standard processes can be replaced through this low cost innovative material deposition technique. However, using IJP as a production process in manufacturing, beyond the use in research laboratories, still requires rigorous development of cost and performance optimised functional electronic inks and processes, in particular those allowing for the fabrication on low cost flexible substrates polyethylene terephthalate. By this means this important aspect also addresses the trend in industry for high-throughput, roll-to-roll device processing, where the use of common plastic substrates instead of glass poses problems concerning the thermal stability of the substrate and the mechanical stability of the deposited device layers, including the transparent conductive electrode (TCEs) against damages caused by substrate bending during the production and operation lifetime of the flexible devices. In this contribution we report on the design, realisation and characterization of novel low temperature processes for printed metals, active and passive IJP electronic devices on flexible low cost substrates. We will present examples of resistive memories, printed TCEs and related electrode structures for organic light emitting diodes and organic solar cells based on IJP. [1]

[1] F. Hermerschmidt, S. A. Choulis, E. J. W. List-Kratochvil, "Implementing Inkjet-Printed Transparent Conductive Electrodes in Solution-Processed Organic Electronics", Adv. Mater. Technol. (2019) 1800474.

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