Manufacturing Science and Technology
Room: 302 - Session MS+TF-WeA

Overview: Applications and Manufacturing of Devices on Paper and Textiles
Moderator: Liangbing Hu, University of Maryland, College Park, Bridget R. Rogers, Vanderbilt University

2:20pm **MS+TF-WeA1 Challenges and Opportunities in the Production of Cellulose Nanomaterials**, ***Junyong Zhu***, USDA Forest Products Lab **INVITED**

Callulose nanomateruals has attracted great attention in the scienticific community due to its unique optical and mechancial properties along with its renewablility and abundance. However, the production process is very costly using current technologies, which limited its use to high value products. This created a market mismatch, i.e., a very large amount natural cellulose are available. In this presenttaion I will outline the challenges in reducing the cost of cellulose nanomaterials. At the sametime, I provide some opportunities to reduce the cost. I will specifically outline a few process innovation in our laboratory for both cellulose nancrystal and cellulose nanofibril productions

3:00pm **MS+TF-WeA3 Engineering Cellulose Nanomaterial Substrates for Flexible Electronics***, Y. Zhou, C. Fuentes-Hernandez, T. Khan,* Georgia Institute of Technology*, J.-C. Liu, J. Diaz,* Purdue University*, J. Hsu, J. Shim, A. Dindar,* Georgia Institute of Technology*, **Robert Moon**,* US Forest Service-Forest Products Laboratory*, J. Youngblood,* Purdue University*, B.J. Kippelen*, Georgia Institute of Technology **INVITED**

Fabrication of flexible electronics (e.g. solar cells) on recyclable and biodegradable substrates are attractive for the realization of a sustainable technology, but significant advances are required to make the technologies economically viable and, from a life-cycle perspective, environmentally friendly, and consequently scalable. One of the key areas of research for making this a reality is in the design/engineering of suitable substrate materials that can: mechanically and chemically support the given electronics, have sufficient surface features (low roughness, surface chemistry, etc) to facilitate the process of the electronics, have similar thermal expansion characteristics of the electronics to minimize stress at the substrate-device interface, have the desired optical transmittance for device performance or application of product, and facilitate the recovery of the electronic components during the recycling process, to name a few. Our recent work has focused on the development cellulose nanocrystals (CNCs) based substrates for such applications. Cellulose nanomaterials (CNM) are emerging high-value nanoparticles extracted from plants that are abundant, renewable, and sustainable. CNCs are rod-like nanoparticles of about 4-10 nm in diameter and 50-400 nm in length and through solvent casting of aqueous suspensions, transparent substrates suitable for electronic devices can be produced. By adjusting the suspension composition, pH, application of shear (control CNC alignment), drying conditions and heat treatment, have been identified as relevant factors affecting the final film/substrate properties.

This talk will provide a general introduction and review of the current state of art in cellulose nanomaterials, their use as substrate materials for flexible electronics, and summarize our work on the measurement of thermo-mechanical properties of CNC-based substrate materials and the development of efficient polymer solar cells fabricated on optically transparent CNC substrates.

4:20pm **MS+TF-WeA7 Circuits on Cellulose: From Transistors to LEDS, from Displays to Microfluidics on Paper***, **Andrew Steckl***, University of Cincinnati **INVITED**

Organic electronics is a rapidly growing field due to a combination of strong performance from improving materials with the low fabrication cost associated with large area printing technology. Recently, the incorporation into organic electronic technology of natural biomaterials that are renewable and biodegradable is being increasingly investigated with the goal of producing “green” electronics that is environment-friendly.

In this presentation, a review is given on the use of cellulose-based paper as a material in a variety of electronic (and related) applications, including transistors, light emitting diodes, displays, microfluidics. Paper is a very attractive material for many device applications: very low cost, available in almost any size, versatile surface finishes, portable and flexible. From an environmental point of view, paper is a renewable resource and is readily disposable (incineration, biodegradable). Applications of paper-based electronics [1,2] currently being considered or investigated include biochips, sensors, communication circuits, batteries, smart packaging, electronic displays. The potential advantages of paper-based devices are in many cases very compelling. For example, lab-on-chip devices fabricated on paper for bio/medical applications [3] use the capillary properties of paper to operate without the need of external power sources, greatly simplifying the design and reducing the cost. Specific examples of paper-based devices will be discussed, including organic light emitting diodes [4] (OLED) and field effect transistors [5] (OFET) on flexible and transparent paper, medical diagnostic devices utilizing lateral capillary flow on paper.

1. D. Tobjork and R. Osterbacka, “Paper electronics”. *Adv Mater* **23**, 1935, doi:10.1002/adma.201004692 (**2011**).

2. A. J. Steckl, “Circuits on Cellulose”, *IEEE Spectrum* **50** (2) 48, doi:10.1109/MSPEC.2013.6420146 (**2013**).

3. Rolland, J. P. & Mourey, D. A. “Paper as a novel material platform for devices”, *MRS Bulletin* **38**, 299, doi:10.1557/mrs.2013.58 (**2013**).

4. S. Purandare, E. F. Gomez and A. J. Steckl, “High brightness phosphorescent organic light emitting diodes on transparent and flexible cellulose films”, *IOP Nanotechnology*, **25**, 094012, doi 10. 1088/0957-4484/25/9/094012 (March **2014)**.

5. A. Zocco, H. You, J. A. Hagen and A. J. Steckl, “Pentacene organic thin-film transistors on flexible paper and glass substrates”, *IOP Nanotechnology*, **25**, 094005 , doi 10.1088/0957-4484/25/9/094005 (March **2014**).

5:00pm **MS+TF-WeA9 Cellulose Nanostructures for Energy Devices and Flexible Electronics**, *H.L. Zhu, W. Bao, F. Shen, Y. Li, Z. Fang, **Liangbing Hu***, University of Maryland, College Park **INVITED**

I will discuss our recent results and the fundamental science of novel transparent paper with tailored optical and mechanical properties, and applications in flexible electronics, origami devices and solar cells. I will also discuss the fundamental advantages of using mesoporous, soft wood fibers for low-cost Na-ion batteries.

5:40pm **MS+TF-WeA11 Designing Functional Paper for Emerging Electronics and Energy Devices**, ***Hongli Zhu**, L.B. Hu*, University of Maryland, College Park

The natural wood fiber has a hierarchical structure with one regular fiber consisting of numerous smaller fibers, and these small nanofibers can be disintegrated from the microfiber with chemical and mechanical treatment. By integrating electronically conductive material, we apply the low cost and sustainable biomaterial in the electronics and energy storage devices. In the first part, we will introduce a novel transparent paper made of wood fibers that displays both ultrahigh optical transparency (~96%) and ultrahigh haze(~60%), thus delivering an optimal substrate design for solar cell devices. We will also introduce the flexible transparent organic field-effect transistors (OFETs) and organic light emitting diode (OLED) device fabricated on nanopaper. These studies are important for the future development of flexible electronics based on new transparent substrates made from sustainable cellulose instead of plastic. In the second part, we will discuss wood fiber based batteries. The wood fibers are intrinsically porous and soft. Thin film Sn anodes deposited onto wood fibers sustain more than 400 charging/discharging cycles, a new record for Sn anodes in Na-ion batteries. Additionally, dual ion transport pathways within the mesoporous structure of wood cellulose fibers significantly improve the traditionally slow ion transport in Na-ion batteries.

6:00pm **MS+TF-WeA12 Transparent Films of Cellulose Nanocrystals Derived from Waste Cotton T-shirts**, ***Nasim Farahbakhsh**, J.S. Jur, R.A. Venditti*, North Carolina State University

The hierarchical structure of cellulosic materials is a renewable building block for a wide range of novel applications, including electronic devices. In this work we present on the fabrication of the transparent cellulose nanocrystal (CNC) thin films for flexible electronic applications. The CNC platforms were manufactured from waste cotton T-shirts fibers using sulphuric acid at optimum reaction temperature and acid concentration. The derivation of nanocellulose from cotton fibers beneficial due to a high cellulose content (~95%) and high crystalline structure which results in high yield without any intensified purification process. The resultant CNC particles, with an average diameter of 25 nm with average length of 200 nm, are used to produce transparent free-standing films and spun-cast films on silicon. Opportunities related device fabrications are presented.

Authors Index
Bold page numbers indicate the presenter