Thursday Morning, November 12, 2009

Inkjet Technology: Printing, Materials Processing, and Microfluidics Fundamentals Topical Conference
Room: B3 - Session IJ+BI+MN+SE+AS-ThM

Inkjet Technology: Novel and Emerging Applications
Moderator: C. Klapperich, Boston University

8:00am **IJ+BI+MN+SE+AS-ThM1 An Overview of the Use of Ink-jet Technology for Non-traditional and Emerging Applications**, ***D.B. Wallace***, MicroFab Technologies, Inc. **INVITED**

In the last decade ink-jet printing technology has come to be viewed as a precision microdispensing tool. Today, this tool is being used in a wide range of manufacturing and instrument applications. Manufacturing applications include electrical (solders & nanometal conductors) & optical (microlenses & waveguides) interconnects; sensors (polymers & biologicals); medical diagnostic tests (DNA, proteins, cells); drug delivery (microspheres, patches, stents); scaffolds for tissue engineering; nanostructure materials deposition; and MEMS (Micro-Electrical-Mechanical) devices and packaging. Instrument applications using ink-jet technology have received less notice than manufacturing applications, but represent a growing class. Applications include protein identification (peptide mass fingerprinting, ion mass spectrometry tissue imaging) and structure analysis (protein crystallization); laser surgery and machining; medical diagnostic instruments; extreme ultra-violet (EUV) radiation generation; and explosive detector calibration. This paper illustrates some of the manufacturing and instrument applications of ink-jet technology.

8:40am **IJ+BI+MN+SE+AS-ThM3 Inkjet Printing for Bioengineering Applications**, ***T. Boland***, Clemson University **INVITED**

We will present the inkjeting of bioink, which may include active compounds such as drugs and living cells as well as non-active, scaffolding materials to build two- and three-dimensional constructs for medical treatment. The technology faces several limitations that present interesting engineering opportunities. The nature and scope of the problems will be discussed in the context of the fabrication of microvasculature. The current tissue-engineering paradigm is that successfully engineered thick tissues must include vasculature. As biological approaches alone such as VGEF have fallen short of their promises, one may look for an engineering approach to build microvasculature. Layer-by-layer approach for customized fabrication of cell/scaffold constructs have shown some potential in building complex 3D structures. With the advent of cell printing, one may be able to build precise human microvasculature with suitable bioink. Human Microvascular Endothelial Cells (HMEC) and fibrin were studied as bioink for microvasculature construction. Endothelial cells are the only cells to compose the human capillaries and also the major cells of blood vessel intima layer. Fibrin has been already widely recognized as tissue engineering scaffold for vasculature and other cells, including skeleton/smooth muscle cells and chondrocytes. In the study presented here, we precisely fabricated micron-sized fibrin channels using a drop-on-demand polymerization. This printing technique uses aqueous processes that have been shown to induce little, if any, damage to cells. When printing HMEC cells in conjunction with the fibrin, we found the cells aligned themselves inside the channels and proliferated to form confluent linings. Current studies to characterize the biology and functionality of these engineered microvascular structures will be presented. These data suggests that a combined simultaneous cell and scaffold printing can promote HMEC proliferation and microvasculature formation.

9:20am **IJ+BI+MN+SE+AS-ThM5 Inkjet Printing for MEMS Fabrication**, ***J.A. Kubby***, *O. Azucena*, University of California, Santa Cruz, *C.L. Goldsmith*, *D. Scarbrough*, MEMTronics Corporation, *A.S. Mangalam*, Tao of Systems Integration, Inc. **INVITED**

In this presentation we will review the use of inkjet printing to fabricate Micro-Electro-Mechanical Systems (MEMS). We are investigating the use of sintered silver nanoparticle inks for the structural layer and polymers for the sacrificial layer in printed MEMS fabrication. As an example, inkjet printing technology has been used to fabricate microwave transmission lines for an RF MEMS switch on a glass substrate (with MEMTronics Corporation). 50 mm resolution was obtained using 10 pL drop volumes on a Corning 7740 glass substrate. The conductivity of the sintered silver structures were 1/6 that of bulk silver after sintering at a temperature much lower than the melting point of bulk silver. A comparison of the DC resistance of the sintered silver shows that it can match the performance for electroplated and etched copper. Printed coplanar lines demonstrated losses of 1.62 dB/cm at 10 GHZ and 2.65 dB/cm at 20 GHz. We will also discuss printing MEMS hot-wire anemometer sensors for use in aeronautical applications (with Tao of Systems Integration).

10:40am **IJ+BI+MN+SE+AS-ThM9 Formation and Surface Characterisation of a Combinatorial Acrylate Polymer Microarray Produced by an Ink-Jet Printer**, ***A.L. Hook***, *J. Yang*, University of Nottingham, UK, *D.G. Anderson*, *R.S. Langer*, Massachusetts Institute of Technology, *M.C. Davies*, *M.R. Alexander*, University of Nottingham, UK

Polymer microarrays are emerging as a key enabling technology for the discovery of new biomaterials. This platform can readily be screened for properties of interest and for correlating surface chemistry with biological phenomenon. A method for forming polymer microarrays has been developed whereupon a contact printer is used to deposit nanolitre volumes of premixed acrylate monomer and initiator to defined locations of a glass slide with subsequent UV irradiation[1]. This results in polymerisation occurring on the slide, offering a useful high throughput materials discovery platform. The identification of relationships between cell response to these materials and surface properties is facilitated by high throughput analysis of this slide format[2,3]. Here, we have formed these polymer microarrays for the first time using ink-jet printing, to offer flexibility of slide production. Characterisation was achieved using a high throughput surface analysis approach, including the techniques of X-ray photoelectron spectroscopy, time-of-flight secondary ion mass spectroscopy and sessile drop water contact angle measurements[2]. Of particular interest were polymers containing ethylene glycol functionality that were investigated for their switchable properties under biologically relevant conditions.

[1] D. G. Anderson, S. Levenberg, R. Langer, *Nat.Biotechnol.* **2004**, *22*(7), 863.

[2] A. J. Urquhart, D. G. Anderson, M. Taylor, M. R. Alexander, R. Langer, M. C. Davies, *Adv.Mater.* **2007**, *19*(18), 2486.

[3] Y. Mei, S. Gerecht, M. Taylor, A. J. Urquhart, S. R. Bogatyrev, S. W. Cho, M. C. Davies, M. R. Alexander, R. S. Langer, D. G. Anderson, *Adv. Mater.* **2009**, 21(early view), doi:10.1002/adma.200803184.

11:00am **IJ+BI+MN+SE+AS-ThM10 Development of an Inkjet Printed Drug Formulation**, ***N. Scoutaris***, *C.J. Roberts*, *M.R. Alexander*, Nottingham University, UK, *P.R. Gellert*, AstraZeneca, UK

The potential application of ink-jet printing technology as a novel drug formulation technique is examined in this study. Since the inkjet printing technology offers high accuracy of fluids, a success implementation of the project can offer the capability to produce precise amounts of medicines, tailored for each patient.

Felodipine, an antihypertensive drug, was used as an example of an active pharmaceutical ingredient (API), and polyvinyl pirrolidone (PVP) as an excipient. These were dissolved at various ratios in a mixture of ethanol and DMSO (95/5). Using a piezoelectric driven dispenser, picolitre size droplets of the solutions were dispensed onto suitable hydrophobic substrates. The dried products were characterized using AFM, localized nano-thermal analysis and high resolution vibrational spectroscopy (ATR-IR and Raman). Results indicate intimate mixing of the micro-dot API and excipient mixtures. Specifically, ATR-IR confirmed the interaction of felodipine and PVP by means of hydrogen bonding. Nanothermal analysis indicates a single glass transition point which is lowered as the API concentration increases. Finally, confocal Raman microscopy mapping on single droplets allows the visualization of the homogeneous distribution of the drug. These results are a promising first step to ink jet printing of pharmaceuticals.

References

1. Peter A. Melındez, et al., Thermal inkjet application in the preparation of oral dosage forms: Dispensing of prednisolone solutions and polymorphic characterization by solid-state spectroscopic techniques. *Journal of Pharmaceutical Sciences*, 2007. **97**(7): p. 2619 - 2636.

2. Karavas, E., et al., Investigation of the release mechanism of a sparingly water-soluble drug from solid dispersions in hydrophilic carriers based on physical state of drug, particle size distribution and drug-polymer interactions. *European Journal of Pharmaceutics and Biopharmaceutics*, 2007. **66**(3): p. 334-347.

3. Karavas, E., et al., Combining SEM, TEM, and micro-Raman techniques to differentiate between the amorphous molecular level dispersions and nanodispersions of a poorly water-soluble drug within a polymer matrix. *International Journal of Pharmaceutics, 2007.* **340**(1-2): p. 76-83.

11:20am **IJ+BI+MN+SE+AS-ThM11 Fabrication of Plastic Biochips via *in situ* Inkjet Oligonucleotide Array Synthesis**, ***I. Saaem***, *K. Ma, J. Tian*, Duke University

With the foreseeable integration of microfluidics and microarrays, polymers stand to play a critical role. Generally, arrays are constructed on glass, silicon, membranes, or polyacrylamide matrices. The preference of such materials makes the marriage of arrays and microfluidics fraught with challenges such as developing low-cost manufacturing methods and simultaneously scaling rapidly for diverse applications and chip designs. In addition, deposition or synthesis of the requisite biomolecule reliably in defined surface geometries is a challenging task. We try to alleviate these problems by utilizing the steadily maturing art of inkjet printing on polymer substrates. Polymeric, or plastic, biochips have several advantages in cost, durability, the ability to scale to industrial techniques and possibly serve as disposable point-of-care devices. In our studies, we utilized an inkjet based *in situ* oligonucleotide synthesis platform that uses salvaged printheads from commercial printers. The platform utilizes standard four-step phosphoramidite chemistry with some modifications in order to synthesize oligonucleotides on functionalized substrates. A sensitive pressurization system is used to ensure print quality and an on-board vision system enables substrate registration and synthesis monitoring. Using this platform we synthesized oligonucleotides on prepatterned functionalized plastic slides. Such patterned substrates help in proper droplet formation and fluid mixing on the surface while mitigating satellite and irregular drops, which can lead to cumulative synthesis errors. Functional integrity of synthesized oligonucleotides was confirmed by hybridization with complementary strands. Being able to hot emboss microfluidic structures directly onto plastic slides in combination with the ability to generate arbitrary sequences provides diagnostic capabilities as well as the means to harvest pools of cheap oligonucleotides on demand. Importantly, our results show that the combination of technologies presented is a suitable strategy of fabricating plastic biochips at a cost-effective industrial scale.

11:40am **IJ+BI+MN+SE+AS-ThM12 Study on the Effects of Particle Size and Substrate Surface Properties on the Deposition Dynamics of Inkjet-Printed Colloidal Drops for Printable Photovoltaics Fabrication**, *S. Biswas,* ***Y. Sun***, Binghamton University

Using fluorescence microscopy, the inkjet deposition dynamics of monodispersed polystyrene particles in the size range of 0.02 to 1.1 μm have been studied on glass, Ar plasma cleaned glass, and PDMS coated glass substrates. The results show that the substrate properties play an important role in determining the final dried patterns formed by the colloidal particles. Our observations also reveal that particle size and contact angle formed by the solvent in the dispersion determine how close to the contact line the particles can be deposited. It is found that the diameter of the dried deposited features decrease with the increase in hydrophobicity of the substrates, irrespective of particle sizes. On Ar plasma treated glass ($\theta_A = 13°$), the smaller particles (0.02 & 0.2 μm) show larger depositions than the bigger 1.1 μm particles. Similar type of behavior of the dried deposited features are also observed on clean glass samples ($\theta_A = 36°$). In contrast, on PDMS coated glass ($\theta_A = 111°$), the behavior of the contact line diameter with the evaporation of the drop is similar for all types of particles. On an average, the diameters of the dried deposited features on PDMS coated glass substrates are independent of particle sizes. This study can serve as a realistic experimental model system for a number of fundamental queries on how the final deposition microstructure depends on the ink formulation and substrate properties. The knowledge obtained here can be explored further to optimize process parameters for the fabrication of hybrid solar cells with improved morphology and device properties.

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