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

Microfluidic Fundamentals and Inkjet Technology
Moderator: G.E. Mårtensson, Mydata Automation AB

8:00am **IJ+BI+MN-WeM1 The Life and Death of a Drop: Topological Transitions and Singularities in Fluids**, *S. Nagel, **N.C. Keim***, University of Chicago **INVITED**

The exhilarating spray from waves crashing into the shore, the distressing sound of a faucet leaking in the night, and the indispensable role of bubbles dissolving gas into the oceans are but a few examples of the ubiquitous presence and profound importance of drop formation and splashing in our lives. They are also examples of a liquid changing its topology. Although part of our common everyday experience, these transitions are far from understood and reveal delightful and profound surprises upon careful investigation. For example in droplet fission, the fluid forms a neck that becomes vanishingly thin at the point of breakup. This topological transition is thus accompanied by a dynamic singularity in which physical properties such as pressure diverge. Singularities of this sort often organize the overall dynamical evolution of nonlinear systems. I will first discuss the role of singularities in the breakup of drops. I will then discuss the fate of the drop when it falls and eventually splashes against a solid surface.

8:40am **IJ+BI+MN-WeM3 Liquid Fragmentation**, ***E. Villermaux***, Marseille Universite, France **INVITED**

Fragmentation phenomena will be reviewed with a particular emphasis on processes occurring with liquids, those giving rise to drops --in the broad sense, the process of atomization--. Various observations converge to propose a unifying scenario describing the overall transition between a compact macroscopic liquid volume and its subsequent dispersion into stable drops. In liquids, primary instabilities always give birth to more or less corrugated ligaments whose breakup induce the shape of the drop size distribution in the resulting spray. Examples include the fragmentation of jets and liquid sheets, the formation of spume by the wind blowing over a liquid surface, bursting phenomena, impacts and raindrops.

9:20am **IJ+BI+MN-WeM5 Dripping and Jetting: Mechanisms of Droplet Formation in Two- and Three-Phase Flows**, *A.S. Utada*, Harvard University and University of Tokyo, Japan, ***A. Fernandez-Nieves***, Georgia Institute of Technology, *D.A. Weitz*, Harvard University **INVITED**

Drop formation is an ubiquitous process familiar from our daily life. For example, water flowing through a faucet will break into droplets through one of two different mechanisms: discrete droplets will drip from the tap at low flow rates or a continuous jet will flow from the tap at higher flow rates. A qualitatively similar process happens when drop formation occurs within a second immiscible liquid. However, in this case, the presence of surface tension between the two immiscible liquids fundamentally alters the dynamics. We describe the transition between dripping and jetting in a coflowing stream within a microfluidic device and show that this transition can be understood with a general phase diagram [1]. Building on this understanding, we use a modified microfluidic device to generate monodisperse double emulsions from which we use to form novel core-shell structures [2].

[1] A. S. Utada, A. Fernandez-Nieves, H. A. Stone, D. A. Weitz, Phys Rev Lett **99**, 094502 (2007).

[2] A. S. Utada *et al*., Science **308**, 537 (2005).

10:40am **IJ+BI+MN-WeM9 Interplay between Simulation, Theory, and Experiment in Nonstandard Inkjet Printing: From New Devices to Complex Fluids**, ***O.A. Basaran***, Purdue University **INVITED**

During its early days, applications of inkjet printing were restricted almost exclusively to the graphic arts. In the late 1990s, the method found widespread application in DNA arraying. More recently, the applications of inkjet technology have broadened considerably to span areas as diverse as direct printing of electronic circuits and solar cells and drop-by-drop construction of organs and other biological structures. Inkjet printing involves the formation of drops from nozzles and the subsequent impact and deposition of such drops on suitable substrates. Both drop formation and drop impact are prototypical free surface or free boundary problems involving large deformation and breakup of fluid-fluid interfaces. Given the ever decreasing time and length scales inherent to inkjet printing, e.g. micron size drops are formed from an inkjet nozzle in time scales of microseconds, and that inkjet printing is a free boundary problem that involves finite time hydrodynamic singularities, e.g. pressures and velocities blow up in finite time as the drop surface approaches breakup or pinch-off, simulation, theoretical description, and experimental visualization of the dynamics of inkjet drops are challenges to the modeler, the theorist, and the experimentalist alike. Moreover, many of the emerging applications of inkjet printing involve fluids that can be characterized as complex fluids in that their bulk rheologies are non-Newtonian and/or their surface tensions vary in time. Motivated by research being carried out in the PI's group on inkjet printing of drops of complex fluids containing pharmaceutical active ingredients on edible substrates, this talk will focus on how computation, theory, and experiment are being used in concert to advance the state-of-the art in the field. Examples that will be used to highlight the computations will include construction of phase diagrams that help identify regions of the parameter space where high quality drops can be produced and efforts aimed at producing nanoscopic drops from microscopic nozzles. To tie the simulations and theory, the excellent agreement between computed predictions and scaling theories of pinch-off will be demonstrated. The excellent agreement between the simulation results and the experiments will be highlighted by means of photographs obtained with an imaging system that is capable of capturing 100 million frames per second. Since complex fluids cannot be characterized by their shear viscosity alone and drop formation involves predominantly extensional deformations, efforts underway to infer the extensional viscosity of such fluids will also be described.

11:20am **IJ+BI+MN-WeM11 The Microfluidics of NonSpherical Colloidal Particles and Vesicles with Application to Blood Additives**, ***E.S.G. Shaqfeh***, Stanford University **INVITED**

Many dispersions of colloidal particles with application in materials processing, biological assays, or medicine, contain elongated particles (e.g. ellipsoidal disks, rods, etc.) Recently these particles have been used in drug delivery applications because of the inability of leukocytes to easily rid them from the circulation. Moreover such particles are useful at the nanoscale for application in cancer therapies, either for detection of tumor vasculature or for the delivery of anti-cancer agents to tumor endothelial cells. Thus, the study of anisotropic particulate flows with adhesion in microchannels especially in mixtures with vesicle flows (i.e. red blood cells) has taken on a particularly important set of engineering applications. We will review our computer simulations of these processes with a view toward virtual prototyping and engineering these therapies.

Inkjet Technology: Printing, Materials Processing, and Microfluidics Fundamentals Topical Conference
Room: B3 - Session IJ+MN+TF-WeA

Inkjet Printing Technology: Advances and Challenges
Moderator: D.P. Trauernicht, Eastman Kodak Company

2:00pm **IJ+MN+TF-WeA1 Scaling Inkjet Printing to Nano Dimensions**, ***J. Bokor***, University of California, Berkeley **INVITED**

For many applications of inkjet printing, scaling the droplet size, and hence the resolution of printed features to micro and even nanoscale dimensions would be of great benefit. I will describe work on scaling a thermal printhead technology to droplet diameter in the range of one micron (0.5 femtoliter). Prospects for further scaling to nanodimensions will also be discussed.

2:40pm **IJ+MN+TF-WeA3 The Technology and Capabilities of Thermal Inkjet Printing**, ***E.G. Hanson***, Hewlett-Packard Laboratories **INVITED**

Thermal ink jet (TIJ) technology has a wide range of capabilities in the non-contact dispensing and printing of materials. TIJ is best known as an extremely effective and successful method for printing of documents and images on paper, using colored inks, but its applications extend far beyond ink-on-paper.

A TIJ printhead is a MEMS (Micro Electro Mechanical System) device, incorporating electronic devices and micro-machined geometrical features which are fabricated on a silicon wafer. TIJ excels in scalability and nozzle packing density. Over the past 20 years, its performance in terms of ejected ink drops per second per printhead has doubled every 18 months.

TIJ technology is extremely precise, offering volumetric control as low as 1% coefficient of variation for volumes > 0.1 microliter, and placement accuracy as low as 3 micrometers standard deviation. A wide range of materials can be ejected very effectively, including nanoparticle suspensions, pharmaceutical compounds, bioactive molecules, polymers, and adhesives. In addition to aqueous solutions, TIJ can efficiently jet numerous non-aqueous solvents.

TIJ is a drop-on-demand ink jet technique, meaning that ink drops are only ejected from nozzles when needed. In contrast, continuous ink jet technology generates a steady-state stream of ink drops, using additional components downstream of the nozzles to deflect and recirculate those drops which are not needed. Aside from TIJ, there is one other common type of drop-on-demand ink jet: piezoelectric (piezo) ink jet. In both TIJ and piezo devices, ink is ejected from nozzles when needed by applying pressure pulses to fluid-filled chambers upstream of those nozzles. These two ink jet techniques use different pressure pulse generation methods – formation of a vapor bubble inside the chamber in the case of TIJ, and mechanical deflection of a diaphragm in the case of piezo. TIJ uses much smaller chambers and generates much higher peak pressures than piezo, giving advantages in nozzle packing density, low printhead cost, and high tolerance to trapped bubbles. Piezo printheads are larger, higher cost, and more sensitive to trapped bubbles, but they do also offer longer printhead life and a wider fluid space than TIJ.

A large variety of materials deposition and dispensing applications are benefiting from the high precision and versatility of TIJ technology. The base technology of TIJ was primarily developed originally for the large market of printed ink on paper, but now these materials applications are leveraging and extending that technology base.

4:00pm **IJ+MN+TF-WeA7 Recent Advancements in Continuous Inkjet Technology**, *J. Chwalek, E. Furlani, J. Gao, K. Vaeth,* Eastman Kodak Company*, G. Hawkins,* Eastman Kodak Company (retired)*, **J.M. Grace***, Eastman Kodak Company **INVITED**

Recent advancements at Eastman Kodak Company in the ability to precisely control the instabilities in thermally stimulated microjets, coupled with advancements in MEMS technology, computer modeling of complex microfluidic systems, nanopigment ink technology, and ink-substrate interactions, enabled the development and subsequent commercialization of a new continuous inkjet technology. This technology offers extremely high productivity with high image quality and excellent reliability on a wide variety of substrates while maintaining a low total ownership cost. This technology, referred to as KODAK Stream Inkjet Technology (or "Stream"), forms the basis of a technology platform that is highly extensible, allowing participation in markets that rely up on high-speed digital print production. The fundamental physics of droplet generation and control and nanopigment ink chemistry create inherent advantages in areas such as productivity, image quality, and ink latitude. In this presentation, we will describe the principles of operation of Stream 's printhead. These principles include the physics of droplet formation, a discussion of fluid properties relative to jet modulation, wavelength dependencies, thermal modulation schemes, satellite drop formation, and drop control effects.

4:40pm **IJ+MN+TF-WeA9 Innovative Strobe-Based System for Analysis of Drops-in-Flight**, *K. Johnson, Y. Kipman, **G. Bartos***, ImageXpert Inc.

Imaging and measurement of drops-in-flight often relies on the measurement system's ability to drive the print head directly in order to synchronize the strobe for repeatable image capture. In addition, many systems do not have the necessary combination of precise strobe control, camera triggering, and powerful image analysis for full drop-in-flight evaluation.

This paper includes a discussion of a fully integrated machine-vision based system for visualization and measurement of drops-in-flight that can be used with any frequency-based jetting system. The strobe is linked to the firing frequency of the print head, so while it is synchronized, it is independent of the specific print head being used.

The imaging system resolves droplets down to 3 picoliters in volume at the highest zoom level. And an open architecture software package allows for image collection and archiving as well as powerful and flexible image analysis.

This paper will give an overview of the details of this system as well as show some of the system capabilities through several examples of drop-in-flight analysis.

5:00pm **IJ+MN+TF-WeA10 Controlling the Evaporation and Material Deposition Process of Printed Drops by Systematic Substrate Modification**, ***V. Bromberg****, S. Gawande, T. Singler, Y. Sun*, Binghamton University

The evaporation dynamics of an inkjet-printed drop on a solid surface have been investigated experimentally. An inkjet-printed drop will generally evaporate in two modes – a continuous decrease in contact angle with a constant contact area, followed by a shrinking of the contact area at a constant contact angle. This evaporation process determines the internal flow and final deposition pattern of functional material being carried by the drop. In an effort to better understand this process, fluorescent microscopy was used to visualize the flow of colloidal material inside printed water drops. We have systematically examined the effects of substrate wettability in controlling the flow and deposition dynamics. It has been found that critical wettability values (as determined by the contact angle) exist which delineate the evaporation and deposition process into regimes of significantly different final deposit patterns. These critical values have been explored as functions of particle characteristics (volume fraction, surface functionality, size) and ambient conditions (relative humidity). A theory of particle kinetics within the three-phase contact line region has been proposed to explain the existence of these critical wettability parameters. These parameters have been used to suggest effective techniques for controlling the shape and structure of final deposition for inkjet printing functional material.

5:20pm **IJ+MN+TF-WeA11 Droplet Velocity Fluctuations in Thermally Stimulated Continuous Liquid Jets: Assessing the Effects of Nozzle Bore Geometry**, ***J.M. Grace****, G. Farruggia*, Eastman Kodak Company

The break-up of thin liquid jets into droplets, known and studied for over a century, has significant practical applications, including inkjet printing. Whether jets are stimulated in on-demand or continuous modes, noise in the stimulation and break-up process can generate fluctuations in drop velocity. As inkjet technology continues to advance to higher resolution and the requirements for control of drop placement become increasingly more stringent, the fundamental noise characteristics of the break-up process become of increasing interest. In this presentation, we study the spatial jitter of drops to infer the underlying velocity fluctuations in thermally stimulated continuous fluid microjets. We present measurements of jitter for fluids jetted from nozzles having different bore radii and bore lengths. The jitter appears to decrease for decreasing nozzle bore lengths. Analysis based upon observed break-off lengths and the implied initial radial perturbations of the jet is presented as a means to assess whether nozzle bore geometry has a fundamental effect on jitter. In addition, analysis based upon energy delivered to the jet during each drop formation period is presented to assess the importance of thermal coupling between heater and jet.

5:40pm **IJ+MN+TF-WeA12 Novel Dynamic Volume Control in Jetting of Complex Fluids**, ***G.E. Mårtensson***, *W. Holm*, Mydata Automation AB, Sweden

In conventional ink jetting applications, a pressure difference is used to ensure the continuous and prompt filling of the jetting chamber between jetting actuations. The delivery of precise fluid volumes utilizing inkjet-like drop-on-demand jetting technology is primarily controlled by the piezo voltage that actuates the jetting chamber (Gerhauser et al. 1983, SID 83 Digest). The jetting of large volumes, in excess of 1 nL, of complex viscous fluids is complicated by the difficulty of filling the ejection chamber quickly after the previous droplet ejection.

In order to ensure the delivery of fluid to the ejection chamber, a mechanism utilizing a helical viscous pump has been introduced and implemented by the authors. The fluid is fed to the helical pump from a reservoir of fluid stabilized by a regulated reservoir pressure. The flow rate is regulated by the speed of the driving surface of the viscous pump. The ejection mechanism consists of a piezo actuated piston that drives the fluid in the chamber through the nozzle on to the intended surface.

The ejected volume of fluid has been studied with respect to piezo voltage, V_p , pulse time, t_p , of the piezo signal and the angular speed of the helical viscous pump. The ejected volume has been estimated from digital photographs taken of the droplet, as well as via 3D profilometry methods. It has been shown in the experimental jetting setup that the volume of a jetted deposit is only affected to a minor degree, of the order of 5% of the goal volume, by the chosen piezo voltage, V_p , acting on the piston. This is also true for the chosen pulse time, t_p . The form of the ejected fluid droplet is affected by the pulse time, tp, only for relatively small volumes. Through imaging experiments, it has been shown that the speed of the ejected droplet has a nearly linear response to the piezo voltage, V_p .

The effect of the fluid's viscosity, represented by its dynamic shear modulus, G*, and its dependancy on rate of shear, $d\gamma / dt$, on the ejected volume was also studied. The effect on the delivered volume was slight for the range of non-Newtonian fluids available, in spite of a strong shear-thinning behaviour.

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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