Center for Nanoscale Chemical-Electrical-Mechanical-Manufacturing Systems (Nano-CEMMS)

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Abstract: The Center for Nanoscale Chemical-Electrical and Mechanical Systems is a NSF-sponsored Nanoscale Science and Engineering Center (NSEC) that is focused on developing the science and engineering of processes, tools and systems for manufacturing at the nanoscale along with the human resources to enable it. Inaugurated in September of 2003 and renewed in 2008, Nano-CEMMS is a partnership between North Carolina A&T, Northwestern University, Notre Dame University, Stanford, University of California at Irvine and the University of Illinois at Urbana Champaign.

1. Introduction

The *vision* of the Nano-Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS) Center [1] is to make the most basic elements of manufacturing, *transcription* of matter and the *transduction* of its state, a practical reality at the nanoscale. Therefore, its *mission* is to: (a) Explore and develop new methodologies and tools that exploit chemical, mechanical and electronic phenomena and processes for 3-D manufacturing at the nanoscale; (b) Create viable technologies that integrate nanoscale manufacturing methodologies into scalable, robust and cost-effective operational systems for manufacturing devices and structures at larger length scales; and (c) Develop diverse human resources to enhance the scientific research, education, and industrial nanotechnology workforce the country.

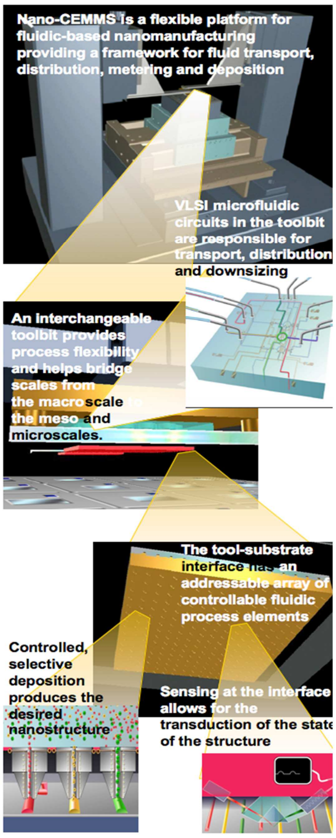

Figure 1: Schematic of the different scales & subsystems in the Nano-CEMMS Platform.

The programs within the Center concentrate on two main areas (a) Research and (b) Education and Outreach. The Center integrates the work of roughly 21 faculty (from 7 disciplines), 4 post-doctoral researchers, 25 graduate students, 17 undergraduate students and 6 staff members into a number of cross-disciplinary research projects with strong components of education and outreach.

2. Research

Nano-CEMMS' strategic research vision is *to explore and exploit fluidic and ionic transport phenomena at the nanoscale to create a fundamentally new manufacturing paradigm to enable nanoscale heterogeneous integration.* If a fundamentally new manufacturing paradigm is possible, then nanoscale fluidics, rich in efficient and tunable transport, is an obvious domain in which to begin. Therefore, the Nano-CEMMs primary strategic goals are to:

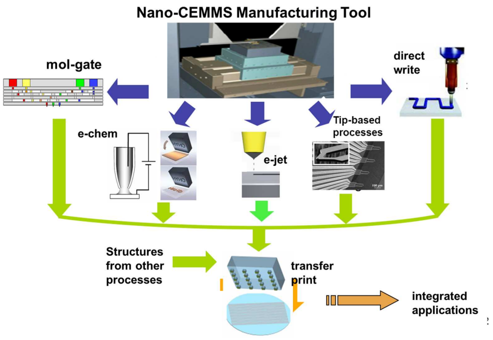

Figure 2 The Nano-CEMMS manufacturing strategy integrates fluidics-based processes with an assembly process to create a manufacturing pathway to heterogeneously integrated products.

Goal 1 – Explore and characterize nanoscale fluidic or ionic transport and phenomena to increase the knowledge of fluid-material-structure-field interactions, for the purpose of creating new approaches to manufacturing at the nanoscale. This goal is addressed by *Thrust 1 – Micro-Nano Fluidics.*

Goal 2 – Develop and extend the basic technology infrastructure required in a manufacturing process (such as sensing, positioning, microfabrication tooling, and micro-nanofluidics) beyond the current state-of-the-art to support fluid and ionics-based manufacturing at the nanoscale. This goal is addressed by *Thrust 2 – Nanoscale Sensing and Positioning and Fabrication.*

Goal 3 – Combine the results of basic exploration of nanoscale fluidic transport and phenomena in a new nanomanufacturing modality and merge these capabilities into an integrated set of processes for nanomanufacturing, addressed by *Thrust 3 – Manufacturing Processes and Systems.*

Goal 4 – Demonstrate how the new manufacturing processes being developed (i) produce new routes to heterogeneous integration in electronics, optoelectronics and microfluidics, with capabilities at the nanoscale; and (ii) create new capacity to support specific testbed applications. This goal is addressed by *Thrust 4 – Applications and Testbeds.*

To integrate these goals, Nano-CEMMS uses a manufacturing platform depicted in Figure 1. Figure 2 shows how the basic scheme underlies a set of processes and assembly mechanisms for heterogeneous integration, enabling broad material coverage, nanoscale resolution capabilities and flexibility in the geometries, from flat to full three-dimensional layouts. The vision of a fluidic and ionic-based nanomanufacturing platform includes developing physical realizations of the manufacturing processes in configurations that enable high throughput, high resolution, flexibility, robustness and high yield, via positioning platforms, embedded sensing, and localized control arrays of process elements and interchangeable toolbits. Research teams within Nano-CEMMS have made significant progress with respect to each of the goals. Since inception the Center has made 38 patent disclosures of which 31 have been filed. Last year alone, researchers in the Center published 128 journal papers and 38 conference papers. For example,

- The Kenis and Shannon team is investigating the basic processes occurring at a solid-liquid interface in the presence of an applied electric field to identify specific parameters that can impact the wettability and surface chemistry of the solid-liquid interface The model system representing the solid-liquid interface is an alkanethiol

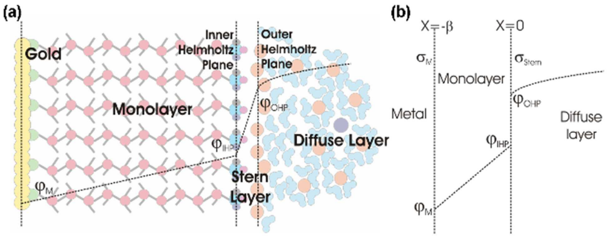

Figure 3: (a) Schematic of double layer structure at the surface of a monolayer modified gold electrode in contact with an aqueous electrolyte solution. (b) Equivalent model representation of the system in (a)

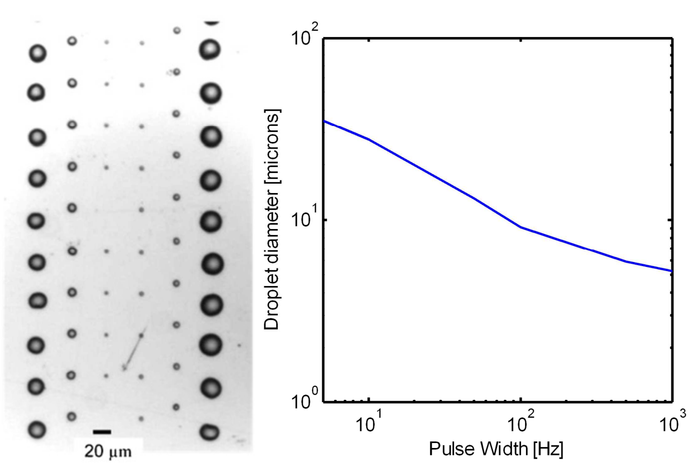

Figure 4: (Left) A coupon of droplets printed with different pulse-widths. (Right)Plot of droplet diameter against pulse width (Hz = 1/ T_d). The slope of the log-log plot is 0.25, which is expected because of the shape of the droplets on the substrate being a compressed semi-ellipsoid.

modified monolayer self-assembled on gold, in contact with an aqueous electrolyte solution. Specific head groups are used to impart the desired surface properties (e.g. hydrophobicity) to the solid liquid interface. This work identifies specific properties of the solid-liquid interface and tracks their evolution as a function of the applied potential using electrochemical impedance spectroscopy with a goal to eventually develop high resolution chemical sensing capabilities. Figure 3 depicts a model system being used in this study. Shannon and Kenis [2] have derived a constitutive expression for the low frequency impedance of the metal-thin film insulator-electrolyte system. Using this, and fitting to measured impedance of the composite system, they have evaluated the surface charge density at the Stern plane (Figure 3b) and other charge transport characteristics of the system, such as the potential of zero field (PZF).

- Alleyne along with Rogers and Ferreira has developed a new mode for electrohydrodynamic jet (e-jet) printing [3], a printing process that has been demonstrated to have deep sub-micron resolution capabilities. Until recently, the e-jet resolutions were high, its printing speed was in the range of 1 to 10 Hz (i.e. droplets/sec.). The group has introduced pulse-modulated e-jet printing and demonstrated printing with droplet deposition cycles of 100Hz to 10kHz. The pulse modulated jets has also allowed the team to independently vary the droplet size and droplet spacing, giving the process a drop-on-demand capability. Figure 4 shows a coupon of e-jet printed droplets with their size controlled by pulse width modulation and spacing by pulse frequency modulation. It also shows that the droplet sizes follow the expected relationship to the pulse width. These capabilities have been implemented into an affordable printer that is currently in evaluative use at industrial and academic research labs.

3. Education and Outreach

The broader mission of the Center involves advancing education in nanoscience and technology, and developing diverse human resources in science and engineering in general, and nanomanufacturing in particular. A solid HRD program infrastructure has been built that supports programs for pre-college, undergraduate, and graduate students, as well as teaching professionals. Since inception, 13 new courses based on Center research have been taught at UIUC and NCA&T, 27 Ph.D, and 27 M.S. students have graduated from the Center. During the past year, 1260 K-12 teachers and 3928 students attended Center programs and used learning modules developed by the Center. Components aimed at increasing diversity are embedded in all facets of the Center. Evaluations of all education and outreach activities are conducted by faculty and staff from the Departments of Education at UIUC and NCA&T. The Center's education program has also leveraged its budgets this year through collaborations with the Illinois State Board of Education for the development and delivery of teacher education programs.

4. Summary

In the seven years since its inception, Nano-CEMMS has developed into a vibrant, interdisciplinary research and education environment. The Center is successfully translating its research into industry with a number of licenses and startups. Manufacturing processes and tools developed by the Center have made their way into industrial laboratories. Scientists and engineers graduating from the Center are making their way into both academia and industry.

7. References

[1] http://www.nano-cemms.illinois.edu/

[2] C. Gupta**,** M. Shannon**,** P. Kenis**;** "Electronic properties of a monolayer-electrolyte interface obtained from mechanistic impedance analysis" *Journal of Physical Chemistry C* vol. 113:21 pp. 9375–9391, February 2009.

[3] Mishra, S., K. L Barton, A. G. Alleyne, P. M. Ferreira and J. A. Rogers, "High-speed and Drop-on-demand Printing with a Pulsed Electrohydrodynamic Jet," J. Micromech. Microeng., 20, 095026, 2010. (DOI:10.1088/0960-1317/20/9/095026).