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. Started up 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.

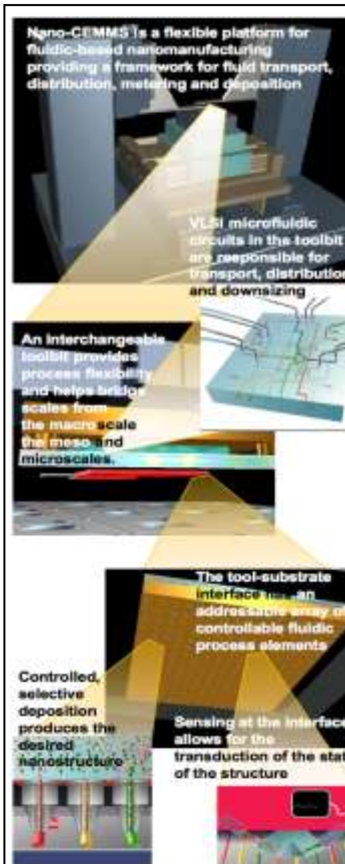

Figure 1: Schematic of the different scales & subsystems in the Nano-CEMMS Platform.

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.

The programs within the Center concentrate on two main areas (a) Research and (b) Education and Outreach. Nano-CEMMS has brought together 30 world class faculty from 9 disciplines, 10 post-doctoral researchers, 41 graduate students, 14 undergraduate students from 7 institutions and 7 staff members with expertise in manufacturing, micro- to nanofabrication, micro- to nanofluidics, photonics, physics, chemistry, systems, education, operational planning and control.

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:

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.*

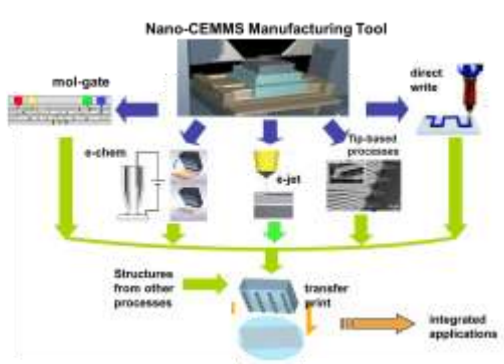

Figure 2 The Nano-CEMMS manufacturing strategy integrates fluidics-based processes with an assembly process to create a manufacturing pathway to heterogeneously integrated products.

Goal 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

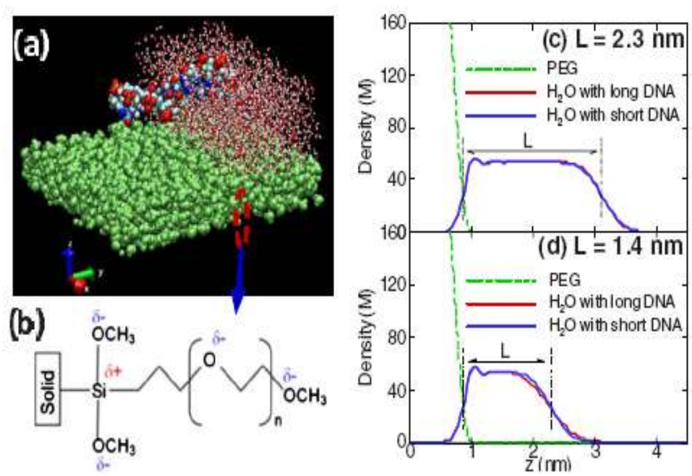

Figure 3: (a) Molecular visualization of ssDNA in water film on PEG-silane grafted surface. The surface lies along the *xy*-plane. The red ball is the oxygen atom, white is the hydrogen atom, blue is the nitrogen atom, cyan is the carbon atom, and tan is the phosphorus atom; (b) Structure of PEG-silane molecule; (c) Density plots of water and PEG for the thick water film; (d) Density plots of water and PEG for the thin water film. For the examples considered here, water density was not significantly influenced by the DNA type.

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. Over the last year these research efforts have resulted in 82 journal papers and 43 conference papers and proceedings. Since the Center's inception, these efforts have also resulted in 54 patent disclosures, of which 36 were filed. For example,

- In the past year, Aluru has used molecular dynamics simulations to investigate the conformation and diffusion of longer and shorter single-strand DNA (ssDNA) as a function of water film thickness (Fig. 3) with applications in surface-based nanomanufacturing techniques [2]. While the conformation of the shorter ssDNA is significantly affected and the diffusion is suppressed with reduction in water film thickness, the conformation and diffusion of the longer DNA is not influenced. Aluru explained these observations by considering the competition between stacking interactions of bases and solvation tendencies in ssDNA. This work suggests an approach to control the surface motion of ssDNA and other long-chain molecules in nanoscale water films using film thickness.
- Cunningham has focused on incorporating a nanostructured SERS active surface into a plastic flow cell connected with flexible tubing. The SERS nanodome surface used in the this study is produced on a flexible plastic substrate by a large-area nanoreplica molding process with peak Raman enhancement factor of 1.37×10^{8} [3].

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 or modified courses based on Center research have been taught at UIUC and NCA&T, 38 Ph.D, and 32 M.S. students have graduated, and 33 REU students have participated in the Center. During the past year, 535 K-12 teachers and 4364 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 collaborated with the

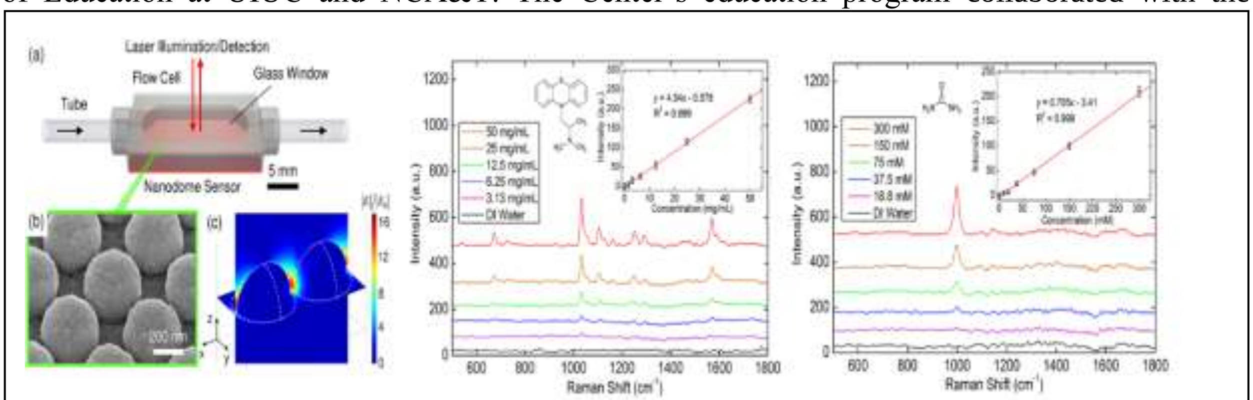

Figure 4: Left - (a) Schematic of the nanodome sensor tubing. (b) SEM image of nanodome surface. (c) 3D FEM simulation of electric field distribution. Middle - SERS spectra for promethazine solution within the sensor tubing (Inset: Raman intensity measured at 1030 cm^{-1} as a function of promethazine concentration). Right - SERS spectra for urea solution within the sensor tubing (Inset: Raman intensity measured at 1000 cm^{-1} as a function of urea concentration).

Illinois State Board of Education for developing and delivering 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.uiuc.edu/

[2] J. Park, N. R. Aluru.; "Water film thickness-dependent conformation and diffusion of single-strand DNA on poly(ethylene glycol)-silane surface" Applied Physics Letters vol. 96:12 p. 123703, 2010.

[3] C. J. Choi, Z. Xu, H. Wu, G. L. Liu, B.T. Cunningham; "Surface-enhanced Raman Nanodomes" Nanotechnology vol. 21:41, October 2010.