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, Nano-CEMMS is a partnership between four institutions: Caltech, North Carolina A&T, Stanford 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.

The programs within the Center concentrate on two main areas (a) Research and (b) Education and Outreach. The Center integrates the work of roughly 25 faculty (from 7 disciplines), 4 post-doctoral researchers, 45 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:

The research goal of the Center is to develop and integrate and integrate the science and engineering to realize a primarily fluidics-based approach to manufacturing at the nanoscale. To develop a scalable, yet economic approach to building and patterning nanostructures the research within the Center concentrates on approaches with the following characteristics:

a. Hybrid combination of the control of top-down approaches with the economy of bottom-up techniques to create high resolution structures with long-range order
b. Gradual access to the nanoscale by bridging through the microscale, exploiting further developing the infrastructure (sensors, instrumentation, actuators, etc.) at this length scale.
c. Use of a primarily liquid-phase approach to transport and processing.
d. Achieve parallelism through the controlled transport in VLSI networks and addressable arrays of controlled gates.

Figure 1 depicts the process paradigm being developed within Nano-CEMMS. To realize an embodiment of such a paradigm requires significant advances in our understanding of micro and nano-fluidics transport and phenomena and its use in the design, analysis, fabrication and

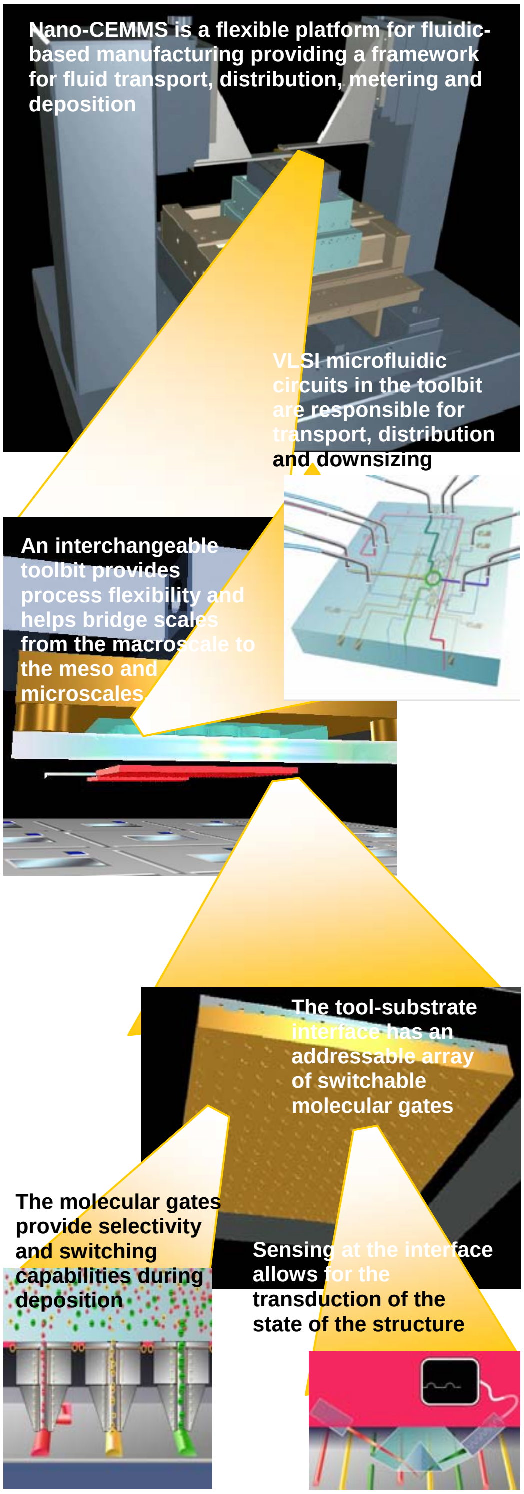

Figure 1: Schematic of the Nano-CEMMS approach to manufacturing at the nanoscale.

operation of VLSI fluidic systems. Advances are also required in our knowledge of fluid-solid interfaces and the manipulation and control of surface properties to effect and control efficient transfer of fluids between solid interfaces. New sensor technologies are required for probing the tool-workpiece interfaces, the structures manufactured, and the internal state of the micro-nano fluidics toolbit. Positioning, manipulation and registration with nanometer resolution and repeatability, high bandwidth, and integration with process controls are of fundamental importance to provide any realization of the above paradigm the flexibility and programmability to address a large range of geometry, size and materials specifications. To address the research challenges that accrue from trying to realize such a paradigm to manufacturing at the nanoscale the research within the Center is organized into four thrust areas, with one cross-cutting effort: (1) The Micro-Nanofluidic Network Toolbit, (2) Process Sensing & Control, (3) The Manufacturing System, and (4) Nano-CEMMS Applications and Testbeds. The cross-cutting activity is computational modeling, an effort that attempts to integrate knowledge and tools that address multiple length scales and domains to realize this manufacturing process.

Two application areas, flexible, large-area electronics (for displays, energy conversion, etc.) and combinatorial chemistry are used thematically to drive and integrate research in process development. These application areas are chosen because both represent significant departures from current technology roadmaps and leverage the capabilities and research directions of the Center.

The basic process model shown in Figure 1 can be adapted to work a number of different materials and process output characteristics (resolution, processing rate, geometries of structures produced, etc.) by exploiting different transport phenomena within the toolbit and at the tool-substrate interface. Each such resulting process is physically realized in the process infrastructure in the form of an interchangeable toolbit. For example, the research in the Center addresses the use of electro-osmotic, electrohyrdodynamic, electrochemical and pressure-driven flows as the basis of different processes for creating nanostructures in a diverse set of materials. Interesting new processes have been developed as a result. For example, Suryavanshi and Yu [2] have developed a very efficient process for pulling out-of-plane nanostructures (see Figure 2) while Hsu, Ferreira and Fang [3] have developed an all solid-state process for direct patterning of metallic nanostructures with 50 nm resolution (See Figure 3)

While the above processes lead to the creating of structures, progress in micro-transfer printing allows the integration of these structures to be integrated into different substrates and the co-assembly of such structures. Innovative extensions, for example, from Rogers and Huang Labs [4] allow for the integration on silicon on stretchable substrates (see Figure 4).

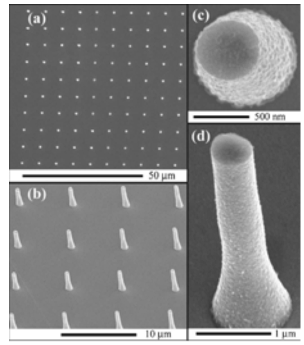

Figure 2: SEM images of freestanding Cu nano wires built electrochemically [1]

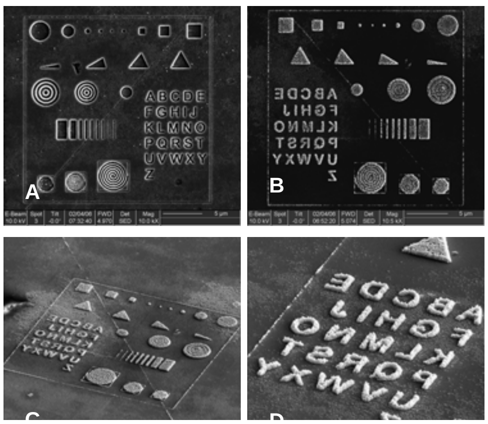

Figure 3. An example of silver patterning using the Solid-StateSuperionic Stamping (S^4) process.(a) A FIB patterned Ag_2S stamp. (b-d) The stamping results on a 250 nm thick evaporated silver film

Besides the new and novel processes, research in the Center leads to important results in sensing, positioning and fabrication approaches. For example, the Choquette group has developed a VCSEL integrated with a 2-dimensional photonic crystal compatible with micro-fluidic circuits in the nano-CEMMS toolbits. The system is capable of extremely sensitive species sensing as very pronounced shifts in the emission mode of the VCSEL are observed with the passage of different chemical species. Figure 5 shows a schematic of the system along with experimental results. The Cunningham laboratory has developed a method for simultaneously integrating label-free photonic crystal biosensor technology into microfluidic channels by a single step replica molding process [5]. The Ferreira Lab has developed and demonstrated novel parallel-kinematic schemes for high-bandwidth nanopositioning and contouring [6].

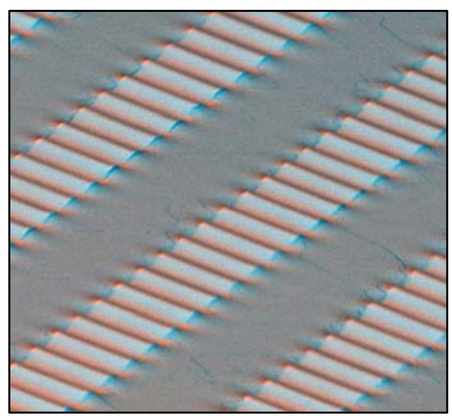

Figure 4: A colorized scanning electron micrograph of 'wavy' single crystal silicon ribbons on a rubber substrate. In this configuration, the silicon, a brittle material, can be reversibly stretched and compressed through large levels of strain. This approach has the potential to lead to new, stretchable forms of electronics. This work, published in *Science* on January 13, 2006, has been featured in many places in the popular press.

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. Each program includes components aimed at increasing diversity 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 UNC Greensboro.

New courses based on Center research are being taught at UIUC and NCAT in the area of nanoscale manufacturing. A dynamic graduate student group meets regularly and organizes internal seminars. The Center is planning its third REU program for 16 students from seven universities. REU supplements have allowed the Center to provide professional development experiences for REU students. Through Grants from Motorola and the State of Illinois, the HRD program has tripled its capacity to train teachers and supply classroom materials. Two-day fall workshops and two-week summer institutes are held for middle and high school teachers and student teachers.

The Center continues to develop hands-on learning modules that can be assembled in different configurations for varying audiences of adults and students. Nano-CEMMS presents these learning modules in multiple sessions for summer camps at UIUC and NCAT, all geared to pre-college students who are interested in math, science, and engineering. The Diversity Programs Coordinator and HRD staff members present monthly programs at Chicago schools that serve underrepresented minorities and women. Presentations are made regularly for a wide range of audiences at schools, museums, scout events, and professional meetings. The Center held its 3rd Annual Industrial Board Meeting in March. It was attended by 30 representatives from industry and government laboratories.

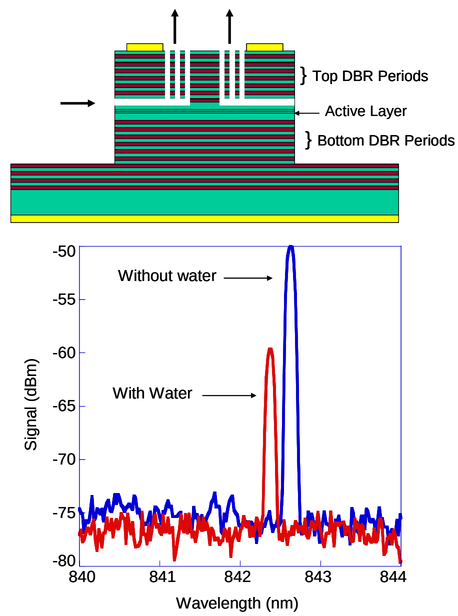

Figure 5 Schematic of VCSEL with integrated photonic crystal (above).Experimental evidence of frequency shift in emission

4. Summary:

In the three years since its inception, Nano-CEMMS has developed into a vibrant, interdisciplinary research and education environment. Tangible results of this integrated environment are evident from its ability to leverage funds from other agencies and industry. The productivity of the environment is visible in the number of publications (around 80) with more than half published with two or more Center researchers. Four disclosures and two patents were published and around 8 graduate degrees are expected to be granted this year.

7. References:

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

[2] A. P. Suryavanshi and Min-Feng Yu, “Probe-based electrochemical fabrication of freestanding Cu nanowire array”, Applied Physics Letters, 88, 083103(2006).

[3] Keng Hsu, Placid M. Ferreira and Nicholas Fang, "Direct Nanopatterning with Solid Ionic Stamping", in IMECE 2006, Session SYST-2-4 "Nanotechnology: Processing Techniques I", Nov 8, Chicago, IL 2006.

[4] D.Y. Khang, H. Jiang, Y. Huang and J.A. Rogers, “A Stretchable Form of Single Crystal Silicon for High Performance Electronics on Rubber Substrates,” Science 311, 208-212 (2006). (Also selected for publication in Virtual Journal of Nanoscale Science & Technology).

[5] C. J. Choi and B. T. Cunningham, “Photonic crystal biosensor with integrated liquid handling and fabrication method”, *submitted patent disclosure* (2006).

[6] Yao, Q., P. M. Ferreira, and D. Mukhopadhyay, “Development of a Novel Piezo-driven Parallel-kinematics Single Crystal Silicon Micropositioning XY Stage,” *Proceedings of the SPIE Symposium, Microtechnologies for the New Millenium 2005*, Sevilla, Spain, May 9-11, 2005.