NANOSCALE CHEMICAL-ELECTRICAL-MECHANICAL-MANUFACTURING SYSTEMS

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The *vision* of the Nano-Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS) Center is to make the most basic elements of manufacturing, *transcription* of matter and the *transduction* of its state, a practical reality at the nanoscale. Our goals are to be able to build a manufacturing tool that can, in reasonable time scales, build 3-D structures from the nano- to micro- to macro- length scales, simultaneously handle liquids and solids, and utilize multiple types of raw materials. Furthermore, we also plan on developing the technologies that enable the industrial production and use of this tool. The *legacy* of this center will be to create the first nanoscale assembly line for manufacturing.

The *missions* of the nano-CEMMS NSEC are 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 and 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 for our nation.

RESEARCH:

The Center has been functional for about a year and brings together 33 faculty members and 46 graduate students from the three institutions working in interdisciplinary research teams to realize an approach to manufacturing at the nanoscale by using and controlling transport in large scale addressable arrays in a manufacturing tool. Figure 1 schematically depicts how the Nano-CEMMs platform is realized for a deposition

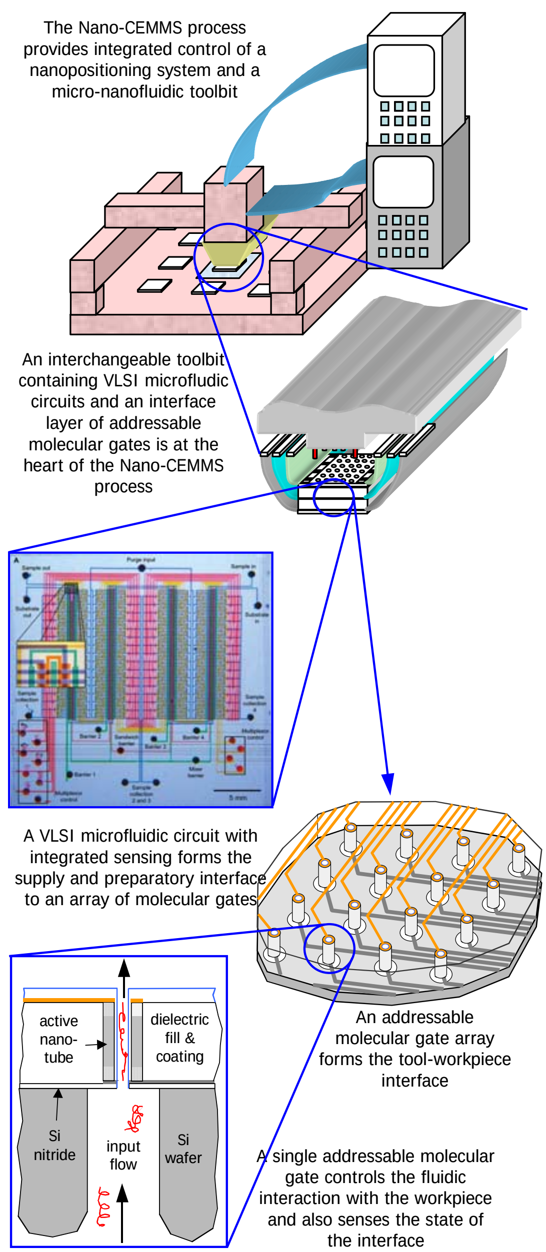

Figure 1: A schematic depiction of the Nano-CEMMs Platform and its components

process. Following an initial meeting of researchers, the Center's research has been organized into 4 groups: (1) The Micro-Nanofluidic Network Toolbit, (2) Process Sensing & Control, (3) The Manufacturing System, and (4) Nano-CEMMS Applications & Testbeds.

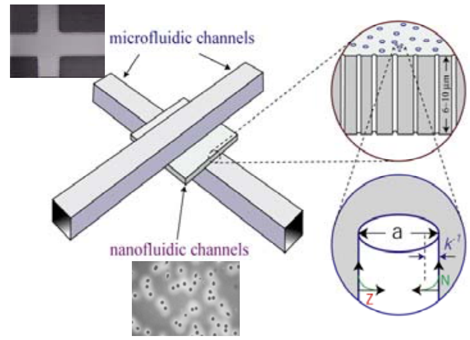

Figure 2. Schematic and photographs of two micro-channels bridged by a molecular gate of nanofluidic pores on the order of the Debye length in diameter. [Kuo, 2001].

The Micro-Nanofluidic Network Toolbit: Currently around 40% of the Center's research efforts are dedicated to exploring, characterization and engineering of processes and phenomena that will allow for the economic, flexible, and robust construction of toolbits for the Nano-CEMMS platform. With eight interdisciplinary projects in this group, issues in modeling of mass transport through nano-pores, modeling and fabrication of switchable molecular gates, surface chemistry modification for controlling fluid-toolbit interaction and fluid delivery, design of new materials and devices for VLSI microfluidic circuits are being addressed. For example, an important component in the toolbit is the *molecular gate* [Kuo, 2001] that can be digitally controlled to deliver attoliters ($10^{-21}\ m^3$) of material. Work is underway by researchers to pattern and control arrays of such devices. Figure 2 schematically depicts an ensemble of gates bridging two microfluidic channels. Figure 3 shows results of research into patterning regular arrays of single addressable nanopores. Another important capability Nano-CEMMS is building upon is the development of VLSI microfluidic networks that include thousands of pneumatic valves to address hundreds of individually addressable chambers [Thorsen, 2002]. Researchers in Nano-CEMMS (Quake, Kenis and Rogers) have been able to build microfluidic supply networks to the toolbit interface. Figure 4 is an example of a microfluidic subsystem built by the Kenis group for combinatorial chemistry applications of the Nano-CEMMS toolbit.

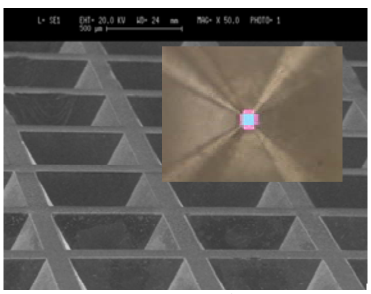

Figure 3: Wells patterned for the Nano-CEMMS toolbit with individual molecular gates at the bottom (Adesida, Shannon)

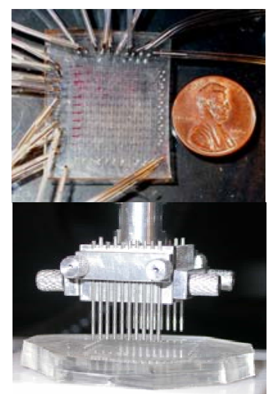

Figure 4: Micro-fluidic arrays for the Nano-CEMMs toolbits along with fluidic interfaces

Process Sensing & Control: This group of projects is responsible for integrating optical, electrical and chemical sensing within the Nano-CEMMS toolbit and between the toolbit-workpiece interface Currently, issues with sensing within the nano-fluidic system as well as at the tool-workpiece interface are being addressed. Near –field optical sensing of position of the toolbit relative to the substrate (workpiece) is also being addressed. For example, Choquette and coworkers have developed 64 × 32 arrays of individual vertical-cavity surface-emitting lasers (VCSELs) with integrated resonant-cavity photodetectors (RCPDs) [Geib, 1998]. Work is also underway to integrate photonic crystal vertical cavity lasers [Danner, 2003] (see Figure 5) within the toolbit. The chemical processes effort in this research addresses different chemical species, and tries to understand how

Figure 5 Top view images of photonic crystal VCSELs, including single and multiple element arrays. Nanometer scale holes in a periodic pattern are designed to engineer the microcavity laser optical properties.

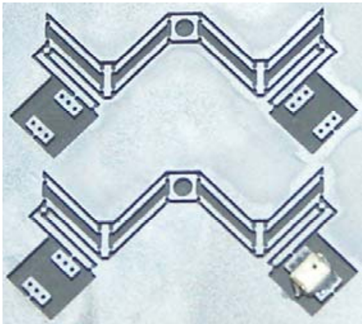

Figure 6: MEMS scale stages being developed for the nano-CEMMS toolbit.

confinement within the small spaces of the molecular gates affects the kinetics of reactions between species within them. Work by researchers in the Center also addresses the measuring of conductance changes as different molecules pass through the gates. This will be used for detecting different chemical species and gaining an understanding of transport of different species through nanopores.

The Manufacturing System: To successfully process materials at the nanoscale, the Nano-CEMMS toolbit requires a manufacturing system that exploits its capabilities, while controlling its position relative to the substrate/workpiece. The focus here is on determining the operation of the toolbit and its interaction with the workpiece; routing of fluids, chemicals, and electrical signals in large arrays; the integration of macroscale, microscale, and nanoscale components into a system; and the manufacturing technologies and processes that are needed for commercialization of the Nano-CEMMS technology. The *goal* of this research program is to *develop the manufacturing system as a whole* by addressing problems that arise in *Metrology & Nanopositioning*, *Process Planning & Operational Control*, *System Integration*, and *Processes & Manufacturing Technologies*. Researchers in this group are, for example, developing high-bandwidth nano-positioning systems. Figure 6 shows two stages within an array of XY MEMS-scale stages for integration within the toolbit. Figure 7 shows the results of software routing of different fluids in a micro-fluidic network. Other research involves integration of sensing and controls and the prototyping of an integrated manufacturing platform.

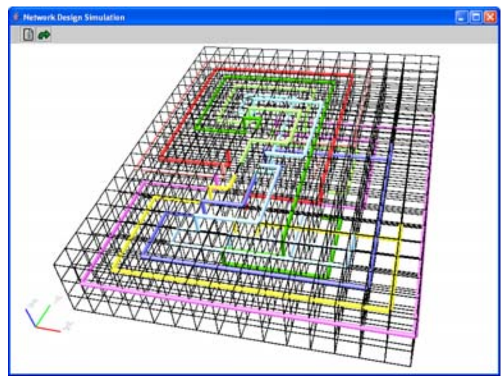

Figure 7: Software for route planning of different fluids in the microfluidic network of the Nano-CEMMS toolbit.

Nano-CEMMS Test beds and Applications: This program of research is used to drive the goals and development in the three other research programs with specifications that originate from viable applications of the envisioned Nano-CEMMS tool. Two test beds: *The Next Generation Technology for Combinatorial Chemistry* and *Organic Optoelectronics* are being addressed by the Center's research. In both cases, processing is expected to benefit greatly from improvements in the miniaturization and the high density of the devices embedded in the tool. Further, enhanced capabilities in sensing and positioning are expected to contribute to making Nano-CEMMS a viable processing technique for such applications. Figure 4 shows a combi-chem chip developed by the Kenis laboratory for the Nano-CEMMS testbed.

HUMAN RESOURCE DEVELOPMENT

Human Resource Development (HRD) is a *core program* that is directed towards the mission of Nano-CEMMS. All HRD activities have four key components, *Diversity, Education, Knowledge Transfer,* and *Assessment and Evaluation*. The overarching goal of the HRD program is to develop a diverse U.S. workforce of educators, scientists, engineers, and practitioners to advance nanomanufacturing technology in the U.S. and beyond. *Every participant* in the Nano-CEMMS Center, including faculty, graduate students, post-doctoral, and research fellows, *is expected to contribute at least 15% of their total committed time* to the Center's human resource programs. UIUC and NCA&T


Figure 8: Participants in the Nano-CEMMS Summer Teacher's Workshop work together in Professor Choquette's Photonics Device Research Laboratory.

work closely to merge the HRD efforts on both campuses. Nano-CEMMS partners with College of Education faculty at UIUC and UNC Greensboro to assist with program assessment and evaluation, combining their expertise with the best practices of other NSF centers.

The Center provides a wide range of HRD activities, specifically targeted *to increase the diversity of the students involved, to increase K-12 and undergraduate educational opportunities, and to provide graduate students with teaching experience in an emerging field.* The HRD activities include: (i) Nano-CEMMS summer camps for nanotechnology; (ii) teacher workshops aimed for middle and high schools; (iii) REU and graduate fellowships; (iv) *courses* and *hands-on laboratories* in nanomanufacturing for *undergraduates* and *community college students*; (v) extensive Knowledge Transfer activities, including weekly and annual symposia, a monthly graduate student group meeting, internships with industry, and an Affiliates Council; (vi) participation in major conferences and (vii) a website/collaboratory that links researchers, educators, K-12 & college students, and the public. Nano-CEMMS has several programs targeted to recruit, mentor, train, and provide educational opportunities for students from underrepresented groups. These include: (i) monthly sessions and structured campus visits for underrepresented high school students who are interested in engineering and science; (ii) a peer recruiting program for high school students; (iii) a summer program that provides undergraduate students from underrepresented populations an opportunity to explore graduate school and careers in research and (iv) a program that brings promising graduate school prospects from diverse cultures to the campus for a two-day visit. In addition, the Center actively recruits faculty in nanomanufacturing, provided they add to the diversity of the College of Engineering.

Collaboration with Industry: Industry response to the creation of this Center has been rewarding and exciting – to date 21 companies, covering key application and technology areas, have signed up as members of the Center's Industrial Advisory Board. Seventeen of these companies attended the first meeting in February of 2004. Participation continues to be strong and the Center has put forth a proposal for the development of an affiliates program. In addition, many of the companies have developed direct relationships with faculty and students within the Center.

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