NANOSCALE CHEMICAL-ELECTRICAL-MECHANICAL-MANUFACTURING SYSTEMS

NSF NSEC Grant 0328162

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Partner Institutions: *California Institute of Technology* and *North Carolina A&T University*

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:

We propose to bring together researchers, from the three partner institutions, with expertise in manufacturing, micro- to nanofabrication, micro- to nanofluidics, nanoelectronics, chemistry, computations, systems, operational planning and control, and combinatorial optimization to form teams to advance nanomanufacturing.

To achieve the vision of nano-CEMMS, a host of *fundamental questions* must be addressed and investigated in order to able to build and use the nanomanufacturing tool. To address these questions, the Center's research is focused into four main groups: (1) The Micro-Nanofluidic Network Toolbit, (2) Process Sensing & Control, (3) The Manufacturing System, and (4) Nano-CEMMS Applications & Testbeds.

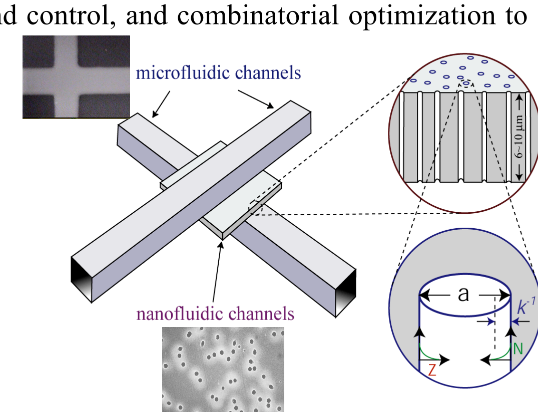

Figure 1. Schematic and photographs of two micro-channels bridged by a molecular gate of nanofluidic pores on the order of the Debye length in diameter. [Kuo, 2001].

The Micro-Nanofluidic Network Toolbit: This group's objective is to access the nanoscale by creating a toolbit that sequentially takes fluids down from the macro- to micro- to the nanoscale. This raises fundamental issues in *Macro-Micro Interconnect, Micro-Nano Interconnect, Tool-Workpiece Interface,* and *Micro-Nanofluidic Modeling Computations*. This work is expected to build on capabilities that already reside within the research team. An important component is the *molecular gate* [Kuo, 2001] that can digitally deliver and control attoliters (10^{-21} m^3) of material*,* akin to transistors delivering and controlling electrons, but with *increased* functionality because molecules can undergo chemical reactions. Molecular gates can control multiple reactants to make new molecules from basic constituents. Figure 1 schematically depicts an ensemble of gates bridging two microfluidic channels. Another important capability, Nano-CEMMS will build upon, is the development of VLSI microfluidic networks that include thousands of pneumatic valves to address hundreds of individually addressable chambers [Thorsen, 2001]. The Nano-CEMMS program will integrate such switchable, VLSI fluid circuits to supply large arrays of instrumented, individually addressable molecular gates at the tool-workpiece interface. To aid the exploration and understanding of electrokinetic flows in nanopores (of the molecular gates), advanced computational modeling tools and techniques will be developed. For example, modeling, understanding and exploiting the large velocity-slip, often observed near channel walls can contribute to very efficient electrokinetic pumping at the nanoscale.

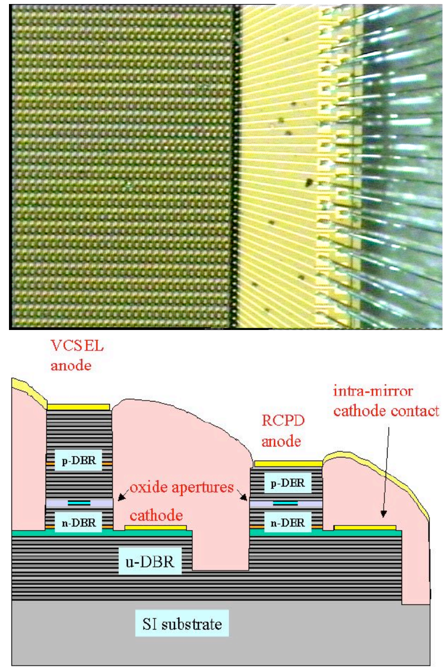

Figure 2. Top: Part of a 64 × 32 array of VCSELs with each one RCP Detector. Each set of two dots is a laser-detector element.

Process Sensing & Control: This research program's objectives are to control the operation of the micro-nanofluidic network toolbit, integrate nanoelectronic and photonic sensing into the toolbit, and to study the molecular interactions. It is organized into 3 teams: *Sensing, Chemical Processes, Coordination and Control Optimization.* Optical/optoelectronic sensing in confined spaces, both in the Nano-CEMMS toolbit and that the tool-workpiece interface is expected to pose significant challenges leading to research that, while addressing fundamental issues, will provide Nano-CEMMS the ability to perform near-field detection of molecules, track fluid movement in micro-and nanochannels, and sense 3-D nanometer scale displacements. For example, Choquette and coworkers have developed 64 × 32 arrays of individual vertical-cavity surface-emitting lasers (VCSELs) with integrated resonant-cavity photodetectors (RCPDs) as shown in Fig. 2 [Geib, 1998]. These matrix addressable laser-detector arrays will enable a variety of sensing capabilities mentioned above. The chemical processes effort in this research program will lead to the ability to detect chemical species at the molecular gates, study the effects of chemical functionalization of their surfaces on affinity for, and flow of, different chemical species, and understand how confinement within the small spaces of these gates affects the kinetics of reactions between species within them. The control efforts here will focus on issues such as addressing, multiplexing and efficient encoding of the state of very large sized arrays (10^8 to 10^{12}) for actuating and sensing,

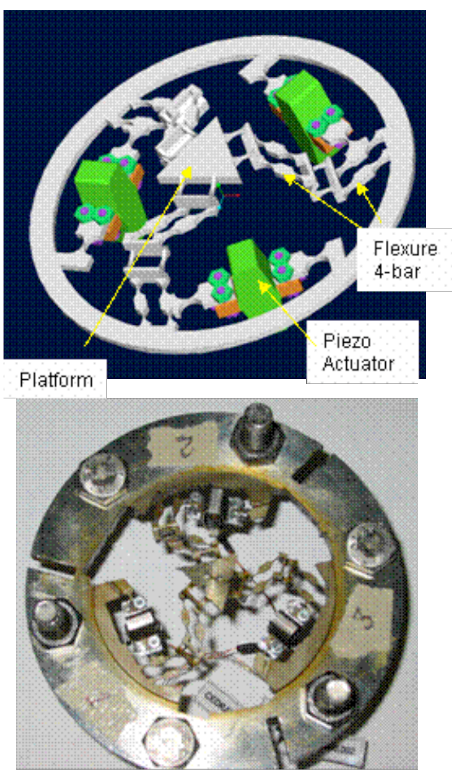

Figure 3: Model and prototype of a high-bandwidth parallel-kinematic spatial translator built by Ferreira and Stori at UIUC

The Manufacturing System: To successfully process materials at the nanoscale, the nano-CEMMS toolbit will require a manufacturing system that exploits its capabilities, while controlling its position. 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*. This program of research will address issues ranging from the nano-metrology (spatial calibration and self calibration) and positioning (high-bandwidth, high-resolution nano-positioning of rigid and flexible structure, see Figure 3, for example) to integration of motion with nanofluidic switching and chemical processing, to task planning issues (compilation of process requirements to coordinated routing of fluids through the system, switching of valves and gates and indexing of tool position), to optimization in the planning and execution 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. In particular two test beds are planned: *The Next Generation Technology for Combinatorial Chemistry* and *Organic Optoelectronics*. In both cases, processing is expected to benefit greatly from improvements in the miniaturization and 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.

HUMAN RESOURCE DEVELOPMENT

Human Resource Development (HRD) is a *core program* that is directed towards the mission of nano-CEMMS with four components, *Diversity, Education, Knowledge Transfer,* and *Assessment and Evaluation* of all HRD activities. 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 nano-CEMMS, including faculty, graduate students, post-doctoral, and research fellows, *is expected to contribute at least 15% of their total committed time* to the Diversity, Education, and Knowledge Transfer activities of the Center. The nano-CEMMS plans to partner with faculty in the College of Education to assist with program assessment and evaluation, combining their expertise with the best practices of other NSF centers.

The nano-CEMMS will provide 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 so that they can help advance their academic development.* The HRD activities include: (i) nano-CEMMS summer camps for nanotechnology; (ii) teacher workshops aimed for middle and high schools; (iii) REU opportunities and fellowships, graduate fellowships; (iv) *courses* and *hands-on laboratories* to *undergraduates* and *community college students* in nanomanufacturing; (v) extensive Knowledge Transfer activities including weekly and Annual Symposia, internships with industry, and an Affiliates Council; and (vi) a web-based Collaboratory to link researchers, educators, K-12 & college students, and the public together, as well as serving as the nano-CEMMS interactive website. To increase the diversity of our students and faculty, nano-CEMMS has extensive plans to recruit, mentor, train, and provide educational opportunities for students from underrepresented groups, and the Dean at UIUC has promised two faculty lines 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 15 companies, covering key application and technology areas the Center will address, have indicated their interest in supporting and working with the Center through activities ranging from scientific exchanges, lectures, and internships. A core group of these firms are also committed to joining the Center’s Industrial Advisory Board that will play an active role in developing, guiding, and assessing the Center’s research & education programs and overall progress. The firms range from new ventures with cutting-edge technology to major technology leaders such as Motorola and end-users such as Kennametal.

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