Nanoscale Science & Engineering Center for Integrated Nanopatterning and Detection Technologies

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The NU-NSEC brings together recognized leaders with diverse expertise from Northwestern University (NU), University of Chicago (UC), University of Illinois/Urbana-Champaign (UIUC), Argonne National Laboratories (ANL), as well as educational partners from the Museum of Science and Industry, Chicago, and Harold Washington College. Housed in NU's $34 million Center for Nanofabrication and Molecular Self-Assembly, one of the first joint federally and privately funded facilities of its kind in the country, NU-NSEC members represent a broad spectrum of disciplines (medicine, biomedical engineering, chemistry, mechanical engineering, materials science, chemical engineering, and electrical and computer engineering), and address opportunities that are too complex and multifaceted for individuals or small groups of researchers to attempt on their own. By facilitating synergistic science and engineering research in the emerging areas of nanopatterning and nanoscale detection technologies, the NU-NSEC is making contributions to cross-disciplinary research and advancing pre-college education, workforce training, and public understanding of nanoscale science and engineering.

Center research is focused on the development of state-of-the-art nanopatterning technologies that are compatible with soft materials and can be used for the development of powerful new detection systems. These studies will provide the fundamental knowledge base for the rational design of chemical and biological sensors with significant advantages (sensitivity, selectivity, and cost) over conventional systems that derive from the physical and chemical properties of small structures. The development of patterning technologies that provide access to the 1-100 nm length scale represents one of the greatest and perhaps most important challenges to the field of nanotechnology. While such technologies could significantly impact a variety of disciplines, they will have an enormous impact in the detection arena.

Center research is organized into three synergistic research groups (SRGs), including:

The Nanopatterning SRG, which focuses on developing state-of-the-art sub-100 nm patterning capabilities for a large variety of molecules, substrates, and environments. The group also develops the molecular surface chemistry that controls the assembly of target molecules and nanostructure signaling systems on integrated devices.

The Optical Nanoarray Sensor SRG, which focuses on nanoparticle-based optical technology as a route to ultra-sensitive and selective nanoscale molecular detection.

The E-chip SRG, which focuses on developing chip-based sensor technology that uses electrical or electrochemical methods to signal target-driven nanostructure assembly. Part of this effort focuses on developing rugged sample processing systems.

The Center also supports seed projects in new and emerging areas.

Significant Accomplishments

Some of the significant accomplishments realized at the Center since its inception are listed below.

(1) A 3D nano-manipulator that enables welding of a carbon nanotube (CNT) to an AFM tip was developed (Fig.1). CNT tips are expected to offer a means of improving the resolution of DPN.[1]

Figure 1: *3-D nanomanipulator mounted in a TEM holder.*

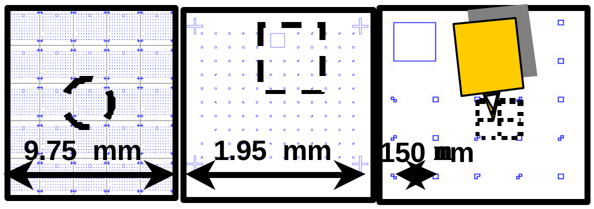

***Figure 2**: Multiscale "roadmap" for DPN alignment registration. Micron scale patterning of alignment markers (left) is performed with traditional lithography; nanometer-scale registration (right) is achieved using AFM imaging within an optically detectable subregion.*

(2) A new method of increasing the alignment registration capabilities of DPN was invented. The method involves the micro-fabrication of a "road-map" on gold-coated silicon wafers, which are typically used for DPN studies (Fig. 2).

(3) DPN systems with multiple, independently addressable pens were realized.[2] A new fabrication process based on silicon was demonstrated and is currently under development. A prototype arrayed DPN device is shown in Figure 3. Designs for one-dimensional and two-dimensional arrays for spotting DNA and proteins were completed.

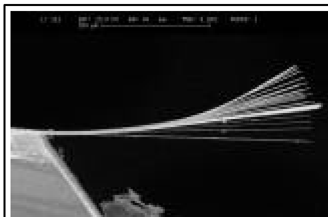

***Figure 3:** Scanning electron micrograph of an array of thermally-actuated probes.*

(4) Progress towards extending the flexibility and compatibility of feedback-controlled lithography (FCL) for nanopatterning of soft materials under ambient conditions was made. As a preliminary step, it was shown that the resolution of a well-known method of tip-induced oxidative silicon patterning that uses conductive AFM can be improved when performed on atomically flat monohydride Si(111) surfaces.

(5) A method of templating the immobilization of proteins in nanoscale arrays[3] was developed. In addition, selective adhesion of cells to nanoscale patches of Retronectin, a recombinant fibronectin fragment, was demonstrated (Figure 4). Ongoing work is aimed at preparing substrates having combinatorial arrays wherein the sizes and distributions of the circular features (the patterned monolayers) are varied. This project provides a clear example of the importance of nanoscale patterning for biological applications and may lead to design rules for constructing substrates for cell adhesion.

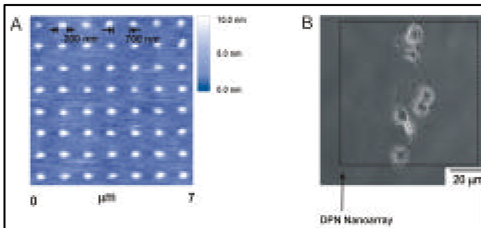

***Figure 4:** (a) Retronectin dots assembled on a MHA template.(b) Cells adhering to retronectin nanodots.*

(6) A photoinduced method for converting large quantities of silver nanospheres into triangular nanoprisms was developed.[4] The photo-process has been characterized by time-dependent ultraviolet-visible spectroscopy and transmission electron microscopy, allowing for the observation of several key intermediates in and characteristics of the conversion process. This light-driven process results in a colloid with surprisingly uniform size and shape and distinctive optical properties (Figure 5) that directly relate to particle size, shape, and composition.

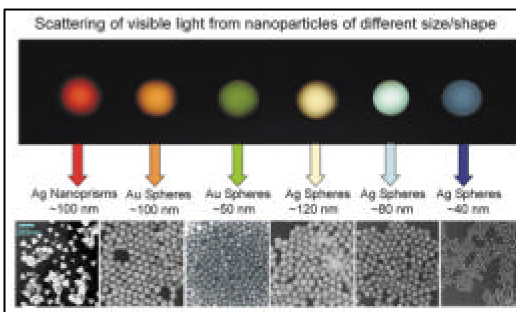

***Figure 5**: Dependence of nanoparticle scattering on size, shape and composition.*

(7) Progress has been made in developing a platform for combinatorial studies of the sensitivity of nanoparticle-based bio-molecule detection to the geometry of a nanoscale electrode gap.[5]

A combinatorial electrode chip with multiple electrodes and various submicrometer spacings was developed (Figure 6). The gap is functionalized with probe DNA. In the case of DNA hybridization of probe and target gene strands, the surface chemistry causes gold nanospheres to form a continuous electrical path between the two electrodes.

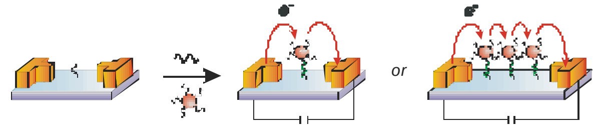

Figure 6: *Conductivity-based DNA detection with nanoparticle indicators*

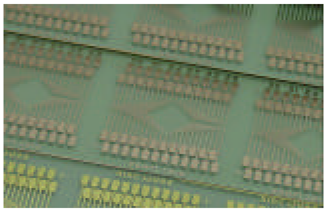

Figure 7: *Micrograph of a chip for electronic detection of DNA hybridization.*

(8) A state-of-the-art, high-sensitivity LIF detection system was designed and installed in the NU Institute for Nanotechnology in collaboration with ACLARA BioSciences. The system is being used to monitor the results of electrophoretic separations within microfluidic devices and enables separations research to be performed under realistic device-like conditions. Results of a benchmark separation, *i.e.* that of a 100-bp DNA ladder separated in under 2 minutes on a plastic chip, is illustrated in Fig. 7.

NSEC Outreach

In addition to innovative research, the NU-NSEC seeks to restructure teaching and learning at all levels to include nanoscale science concepts and to nurture the scientists, technicians, and teachers of tomorrow. Since its inception in September 2001, the NU-NSEC has initiated the following educational outreach programs:

Figure 8*: 2002 RET participant, Jennifer Cleary injecting DNA sample into HPLC.*

(1) Two summer research programs for undergraduates - the Research Experience for Undergraduates (REU) and the Minority Internships in Nanotechnology (MIN) programs were launched. (2) The Research Experience for Teachers (RET) program was initiated, which provides hands-on nanoscale research during the first summer (Fig.8), and guidance and support to develop teaching units introducing nanotechnology in high school classrooms during the second summer. (3) A "Nanostructures Module" is under development by NU-NSEC researchers, high school teachers, and administrators to supplement curriculum in pre-college classrooms. (4) The Center is collaborating with the Museum of Science and Industry, to develop a conceptual design plan for a nanotechnology exhibit, which ultimately will introduce millions of museum visitors each year to nanotechnology. (5) The Small Business Evaluation and Entrepreneurs (SBEE) Program was initiated in partnership with Northwestern's Kellogg Graduate School of Management to create a streamlined way to initiate start-up companies based upon NSEC developments. (6) A nanotechnology website for children and nanotechnology presentations are under development.

References

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