Nanomanufacturing and Processing—Research, Education, Infrastructure, Security, Resource

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The National Science Foundation-European Community (NSF-EC) Workshop on Nanomanufacturing and Processing was held at the Caribe Hilton Hotel in San Juan, Puerto Rico from January 5-7, 2002. Some 50 participants including 34 U.S. researchers, and 9 EC and 7 NSF Directors participated in this Workshop. The program included several keynote and individual presentations addressing the state-of-the-art in nanoscience and technology and status of various programs supported by NSF in this area. The goal of the Workshop was to join the forces of the NSF with the EC program agencies to catalyze progress in research and education in the emerging field of nanomanufacturing and processing. A memorandum of understanding (MOU) was signed by these two organizations. It is envisioned that this collaboration will provide a critical thrust for new scientific developments and engineering applications that will have a mutually beneficial impact for both the U.S. and European research partners. Nanomanufacturing encompasses all processes aimed toward building of nanoscale structures, features, devices, and systems in 1D, 2D, and 3D. Nanomanufacturing include both bottom-up and top-down processes. Typical examples of the bottom-up processes include contact printing, imprinting, spinodal wetting/dewetting, laser trapping/tweezer, assembly and joining (self- and directed-assembly), template growth, electrostatic (coatings, fibers), colloidal aggregation, and 2-photon confocal processing. Typical examples of the top-down processes include lithography (e-beam, ion beam, scanning probe, optical near field), thin film deposition and growth, laser beam processing, mechanical (machining, grinding, lapping, polishing), and electro-chemical material removal processes. Advances in nanomanufacturing are anticipated to result in rapid progress in nanomaterials technology; information technology nanodevices including ‘‘nanosemiconductors,’’ molecular electronics, and spintronics; nanobiotechnology-diagnostics, implants, therapeutic delivery; safety and security aspects including sensors, adsorbents/filters/decontamination; and NEMS/nanorobots.

The objectives of the Workshop were to develop (1) Research milestones in (a) nanomaterials and nanomanufacturing; (b) prototyping, scale-up, and integration issues in nanomanufacturing, (c) measurement and metrology, and (d) theory, modeling, and simulation; (2) Security issues; (3) Resources—equipment, human and funding; (4) NSF-EC Collaboration-cooperative research programs and educational exchanges, sharing of nanomanufacturing research facilities and (5) Interactions in general with the community-at-large. In the following, these objectives are elaborated in some detail.

1 Research Milestones

(a) Materials & Manufacturing: Nanocomposites—deformation mechanisms governed by interface between matrix and nanophase; Nanofluidics—fluid/surface interactions, fluid properties (e.g. for imprinting); Synthesis and processing of nanoparticles and nanofibers; Nanoprinted ‘‘breadboards’’ or standard substrates; and Materials for nanofabrication by printing/imprinting (e.g., lubricants, surfactants) and Adaptive Surfaces (e.g., biomimetic, programmable, bioactive); Bi- and Multi-stable molecular systems (towards molecular machines, nanorobots); Improved energy efficiency for transportation, manufacturing, and devices (e.g., fuel cells, photovoltaics); Self-assembly by competing interactions (e.g., block co-polymers-kinetics and thermodynamics governed).

(b) Manufacturing: Prototyping, Scale-up, and Integration: Develop fabrication technologies for hierarchical assembly—consolidation and forming of nanostructures into macroscopic objects—integration of nanoparticle and nanomaterial synthesis with subsequent manufacturing steps for product realization; Develop patterning and deposition technologies (e.g., stamping/printing) as an approach to sustainable, user-friendly, affordable, high throughput, large area fabrication of a wider range of materials; Fabrication/synthesis of building blocks, (dots, wires, tubes, particles, fibers) from a greater range of materials, with better control of size, shape, and their polydispersity; Substrate and building block surface modification for directed self-assembly; Prototype device; fabrication to demonstrate nanoscale functionality; Integration of traditional and new manufacturing processes; Improve resolution and control of rapid prototyping processes (e.g., EBL); Scale-down of lab/fab on a chip type device and Control of surface/interface composition/structure to minimize defects and enable subsequent processing (e.g., nanoscale planarization, polishing); Removal and repair of defects in nanofabricated structures; Three dimensional assembly; Interconnect nanostructured devices (with microcircuits); and Manipulation of material components in multi-step fabrication (e.g., rapid setup).

(c) Measurements and Metrology: Develop experimental and analytical tools with a broader range of capabilities (chemical analysis, sub-surface properties, charge transport, spectroscopy); New tools to characterize surface and sub-surface defects; Calibration and standardization; and Reproducible (re)positioning with nm accuracy and Develop analytical tools *in situ*, real time, variable temperature, pressure, electrical and magnetic fields; Improve spatial resolution to 0.1 nm.

(d) Theory, modeling, and simulations: Theory of nanocontact mechanics; Develop structure-property relationships for nanomaterials and nanostructures; New design tools for nanomanufacturing; and Process modeling in restricted spatial domains where boundary effects will become pervasive and Develop structure-property-processing-performance relationships for nanomaterials and nanostructures; Develop models that couple the various spatial and time scales; Develop models that incorporate coupled physical/chemical phenomena, including non-equilibrium phenomena (e.g., transport, growth); Develop potentials that are appropriate for nanostructure interactions, utilizing *ab initio* approaches to benchmark their accuracy; Explore statistical mechanics approaches to thermodynamic properties and phase diagrams and Create new design paradigms for nanomanufacturing.

2 Security Issues

International security issues including protection of the public from sabotage activity, chemical and biological threats, nanosensors—fast-response, high surface area, portable, low power, (e.g., molecular recognition); Selectively permeable mem branes (passive systems for filtering); Mass producible, affordable, environmentally safe and benign products and processes; Adsorbents/Filters/ Decontamination; Lightweight/High Strength Low Cost Structures for mechanical, thermal, etc., protection (e.g., smart, ‘‘intelligent,’’ materials and systems); and Nanostructured coatings for ocular protection and Fast-response, high surface area sensor arrays and actuators for smart/defensive nanosystems—real-time integrated sensing and chemical/ biological response/activity; and Lightweight/High Strength Low Cost

Structures from Nanomaterials for mechanical, thermal etc. protection (e.g., smart, ‘‘intelligent,’’ materials and systems).

3 Resources

(a) Equipment and Facilities; Establish no-cost access to national research facilities (e.g. national labs); Enhance funding of major research equipment; Funding for replacing and upgrading instruments—Nanoscale measurement instruments are developing rapidly and must be replaced every couple of years and Development of new machines and instrumentation; Integrated/combinatorial/hybrid equipment and ‘‘next generation’’ fab labs for nanomanufacturing (along the line of NNUN); Networks and Centers—increase the number of geographically distributed centers; integrate with existing centers.

(b) Human Resources: Mentoring of young and mid-career faculty; Support for interdisciplinary teaching and release time for the creation of educational tools (e.g., textbooks, websites, monographs); Support K-12 educational efforts in nanomanufacturing; Provide funds for technicians to operate the more sophisticated machines for 3-5 years and Create dedicated graduate fellowships for nanomanufacturing and Learn interdisciplinary ‘‘subject’’ language, and promote interdisciplinary skills, grow knowledge-base with the subject; Identify and build basic skill sets to apply to undergraduate and graduate students; Train skilled technicians; and Support interdisciplinary graduate programs in Nanoscience/Nanotechnology.

(c) Funding Distribution: higher emphasis on infrastructure (Research & Education and Technology Transfer) and Additional funds to encourage multi-PI, interdisciplinary projects.

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