Nanomanufacturing

National Science and Technology Council
Committee on Technology
Interagency Working Group on Manufacturing Research and Development
Public Forum: March 3, 2005

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A New Epoch in Manufacturing

1900-1960	Capital-Resources-Labor
1960-1990	Engineering Productivity and Scientific Discovery
1990-Present	Knowledge-People-Innovation
Future ???	New products and enterprises enabled by Nanomanufacturing R&D

Nanomanufacturing as part of that New Epoch

- Nanomanufacturing: activities and systems to produce, control, modify, manipulate, or assemble nanometer scale elements (< 100 nm) to deliver a product or system that exploit nanoscale properties.
- Scale-up
  - Producibility
  - Predictability
  - Productivity
- Up-scaling Integration
  - Across scales: nano-structures → functional devices → system architectures → products & services
  - Of materials & geometries
  - Across energetic domains: mechanical, electromagnetic, thermal, biological, chemical

Evolution of Nanomanufacturing

- **First generation ~ 2001:** Passive nanostructures such as nano-structured coatings, nanoparticles and nanostructured metals, polymers and ceramics.
- **Second generation ~ now:** Active nanostructures illustrated by transistors, amplifiers, targeted drugs and chemicals, actuators and adaptive structures.
- **Third Generation ~ 2010**: 3-D nanosystems and systems of nanosystems using various assembling techniques, networking at the nanoscale and new architectures.
- **Fourth Generation ~2015:** Heterogeneous molecular nanosystems where each molecule has a specific structure and role.

NNI History

The National Nanotechnology Initiative (NNI) was established in 2000.

- 22 federal agencies participate -- 11 having R&D budgets
- The Program component areas are as follows:
  - Fundamental nanoscale phenomena and processes
  - Nanomaterials
  - Nanoscale devices and systems
  - Instrumentation research, metrology, and standards for nanotechnology
  - **Nanomanufacturing**
  - Major research facilities and instrumentation acquisition
  - Societal dimensions

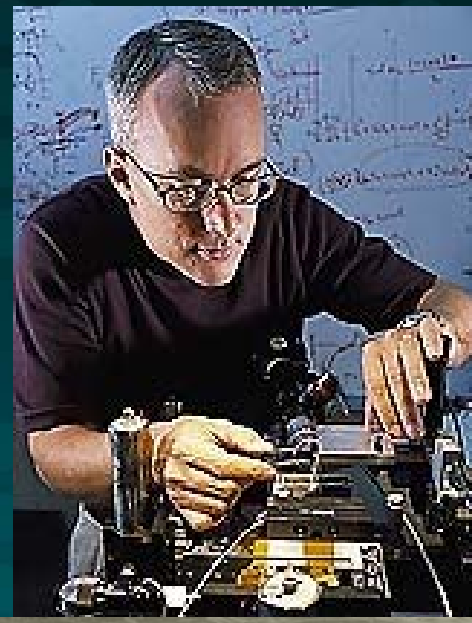
Key Need/Challenge Areas

- Infrastructure Development and Standards
- Design, Manufacturing Processes and Systems, and Instrumentation
- Workforce, Societal Impact and Environmental Health and Safety

Key Research Challenges/Gaps

Infrastructure Development and Standards

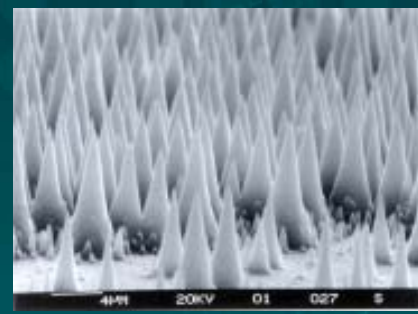
- **Access to shared infrastructure**
  - National labs with state-of-the-art nanomanufacturing and metrology tools.
  - Cyberinfrastructure to support data driven tools and enterprises.
- **Standards development**
  - Performance models and data for equipment and nanoscale devices/systems.
  - New traceable standards.
- **R&D contributions needed:**
  - Advanced instrumentation and metrology.
  - Performance metrics, standards, and test methods.

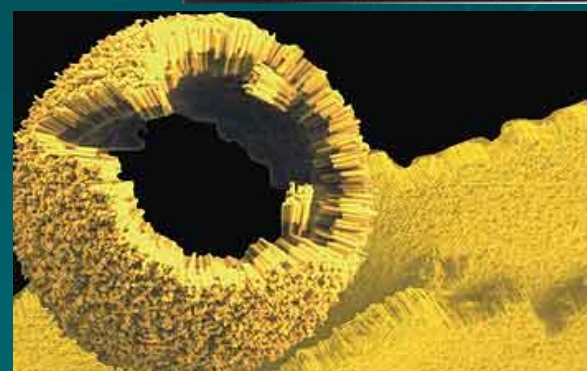


Key Research Challenges/Gaps

Design, Manufacturing Processes and Systems, and Instrumentation

- ***Scalable Manufacturing Processes:***
  - Directed and self-assembly approaches.
  - Patterning and templating beyond 2D / 2D+ to true 3-dimensional structures.
  - Ultra-precision positioning.
  - Manufacturing processes to produce structures that are repeatable and exhibit engineering properties beyond placing nano-elements in close proximity.
- **R&D contributions needed:**
  - New processes or hybrid systems that break down current limitations and support scalability.
  - Sensing, actuation and control.
  - New ways to “see” at the nanoscale.
  - Biomimetic systems design and biotechnology-based processing.





Key Research Challenges/Gaps

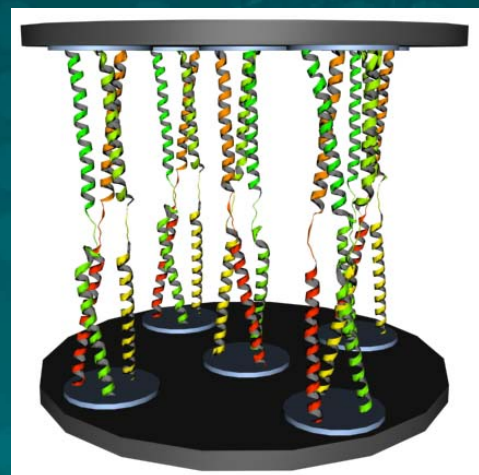
Design, Manufacturing Processes and Systems, and Instrumentation

- **Virtual Design and Manufacturing**
  - Power of emerging virtual environment technologies and computational capabilities.
  - Tools that allow designers to dynamically cross size scales.
  - Reduce the uncertainty regarding nano-element position.
  - Controlled interaction and manipulation nanoelements will require new methods.
- **R&D contributions needed:**
  - Correlate virtual and physical environment.
  - Real-time imaging of nanomanufacturing processes.
  - Architectures for multi-scale design-manufacture models and functions.
  - Intuitive interface to explore phenomenon at the nanoscale of manufacture and metrology.

Key Research Challenges/Gaps

Design, Manufacturing Processes and Systems, and Instrumentation

- **Integration of nanoscale devices and systems**
  - Exploit functionality of nanoscale elements at device and system level.
  - Enable new methods that are not reliant on compatibility of processes.
    - Additional materials available to designer.
    - New methods to assemble components that were manufactured by incompatible processes.
  - Packaging.
- **R&D contributions needed:**
  - Interconnect design and realization.
  - Modular nanoscale building blocks.



Key Research Challenges/Gaps

Workforce, Societal Impact and Environmental Health & Safety

- Workforce and Societal Impact
  - Workforce to support a US nanomanufacturing industry.
  - Opportunity for developing new skills.
  - What will a nanomanufacturing industry be like?
- R&D and Education contributions needed:
  - Strong foundation in science, technology, engineering and math
  - Lifelong learning and training beyond high school.
  - Ethical, legal and societal implications of a nanomanufacturing industry.

Key Research Challenges/Gaps

Workforce, Societal Impact and Environmental Health & Safety

- Environmental Health & Safety
  - Accelerate efforts to adequately prepare the nanoscale manufacturing community and society.
- R&D and Education contributions needed:
  - New nanotech products for cleaning up environment.
  - Recycle/Reuse/Remediation processes
  - Environmentally benign manufacturing

Participating Agencies

- DoD
  - Centers and Infrastructure
  - Research focus - security, surveillance, and construction of materials used in defense technology, and battle field medical applications of nano biotechnology, Defense University Research Initiative on NanoTechnology (DURINT)
- DOE
  - Nanoscale Science Research Centers, User Facilities
  - Research focus - optical devices, nanometer-sized sensors, advanced computer architectures, ultra dense memories, and quantum-information science and technology
- DOEd
  - K-12 education, Workforce training, and public awareness of nanotechnology and nanomanufacturing
- NASA
  - Sensors, Structural Materials, & Nanoelectronics and Computing.

Participating Agencies

- NIH
  - Research focus - medically related nanotechnology, tissue engineering, injectable nanoparticles, Bio-medicine, probes and instruments, anti-rejections materials, controlled release, nano-fiber technology targeted delivery system for anti-cancer drugs.
- NIST
  - Advanced Measurement Laboratory
  - Metrology, instrumentation, and standards.
- NSF
  - Centers and infrastructure
  - Research and educational
- USDA
  - Food safety, agricultural education, crop protection, microfluidics, BioNEMS, BioSensors, Bioselective surfaces
- US Food and Drug Administration (FDA)
  - Regulates a wide range of products which may utilize nanotechnology or contain nanomaterials.

Next Steps for Federal Role

Promote R&D to provide:

- Infrastructure Development and Standards
- Design, Manufacturing Processes and Systems, and Instrumentation
- Workforce, Societal Impact and Environmental Health and Safety

Expected Impacts / Benefits

- Enhance the performance of existing products with tools, processes and systems that make US companies leaders in scalability, productivity, produceability of nanomanufactured products.
- Provide the advanced tools and systems that go beyond enhancing existing products, but to create entirely new nanomanufacturing enterprises with a new knowledge enabled workforce.
- Assure the US lead in nanoscale science and engineering with a nanomanufacturing base, as a national resource for defense, space exploration, heath, security, education and other National priorities

Conclusion

- The changing global competitive environment poses great challenges for the U.S. manufacturing sector and the selection of federal research priorities.
- Nanomanufacturing will provide the technical foundation needed for advancing our manufacturing sector while promoting an exciting new industry that will provide economic success under US technological leadership.
- We look forward to your input on development and refinement of nanomanufacturing technical needs to meet these challenges.