NSF Nanomanufacturing Programs

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National Science Foundation

Arlington, VA

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Nanomanufacturing @ NSF

NM

- $100-150K/yr
- 3-years
- 1-investigator
- *Fundamentals*
- TRL 1

SNM

- $250-375K/yr
- 4-years
- Inter-disciplinary; Industry
- *Address scalability*
- TRL 1-2

NSECs / NERCs

- $4M/yr
- 5 to 10-years
- Multi-institution; Industry; Labs
- *Systems approach*
- TRL 1-3

EFRI: 2-DARE

- $2M/yr
- 4-years
- Team
- *Fundamentals*
- TRL 1

SBIR/STTR

- $150K/6 mts + $750K/2 yrs
- 2-3-years
- Small business
- *Commercialization*
- TRL 4-7

Nano IMIs

- $15-20M/yr + matching
- 5-years + sustain
- PPP
- *Overcome "valley of death"*
- TRL 4-7

NM Program

Objective

Study the principles for the manufacturing of nano-scale materials, structures, devices … *complex nano-enabled engineered systems*

Phenomenological

Conduct *fundamental research* in novel nano-scale processes

Leverage *advances in understanding* of nano-scale phenomena

Promote *design and integration* of nanostructures to higher-order systems

Practical

Encourage *systems approach* to scale-up

Address *manufacturability issues* – quality, efficiency, yield, scalability, reliability, safety and affordability

Advance *instrumentation, metrology and standards*

Validation

Base research on *computation, modeling and simulation*

Qualification

Use of *process sensing, monitoring, and control*

Activities that advance NM fundamentals

SNM Program

Objective

Research to *overcome the key scientific and technological barriers* that prevent the production of useful nanomaterials, nanostructures, devices and systems at an *industrially relevant scale*, reliably, and at low cost and within *environmental, health and safety guidelines*

- MUST: Address scale-up – *large area, continuous ..*
- STRONGLY ENCOURAGED: Multi-disciplinary collaboration – *ENG, MPS*
- ENCOURAGED: Industrial collaboration – *tangible*
- MUST: Address NM value chain – *building-blocks → systems*
- ENCOURAGED: Design principles for production systems – *platforms; metrology, instrumentation, standards; process control methodologies; quality and yield assessment*

Activities that address manufacturability

Motivation Factors

What we are interested in …

- Research to *overcome fundamental knowledge barriers* that prevent manufacture of useful nano-enabled products in high volumes and at low cost
- Proposed manufacturing processes must have *potential for scale-up*
- *New fundamentals with nano-scale justification having far-reaching impact*
- *Nanomanufacturing knowledge base having wider applicability*

What we are not ..

- Materials Research – New nanomaterials and nanostructure syntheses, bulk processing, extensive characterizations, testing and analyses
- Device Physics – Studies and analyses at device-level

Research Areas

Materials and Structures
C-based: CNT, Graphene, Bucky-tape, CNT Fibers, Cellulosic
Nanostructures: Nanoporous, Aerogels, Membranes, Electrodes, Arrays, Gratings
Semiconductors: Organic, Amorphous Si, Compound
Metals and Ceramics: Ag, Au, Cu, Pt, Ti, Oxides, Sulfides, Borides
1D: Nanowires, Nanopillars, Nanotubes, Nanofibers, Nonwovens
2D Atomic Layer: MoS_2, BN, TMDs
Nanoparticles: Magnetic, Semiconductor, Dielectric, QDs, Core-shell, Janus, Hierarchical
Complex: Metamaterials
Structural: Nanocomposites
Functional: Catalysts
Thin-films: Langmuir-Blodgett Films

Research Areas

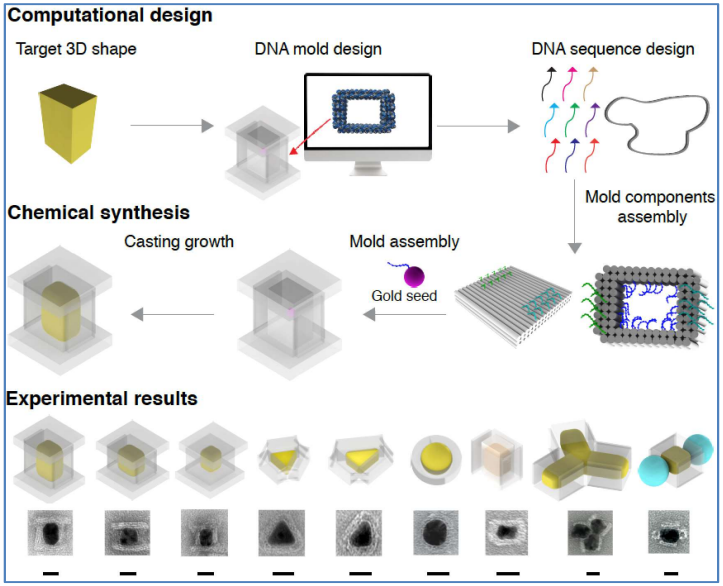
Processes and Methods
Chemical/Thermal: Combustion, Plasma, Hydrothermal, Thermal Drawing, Etching
Vapor-based: CVD, PVD, PECVD, Laser CVD, ALD, MLD
Self-assembly: Spontaneous, Directed, Templated, Molecular
Patterning/Printing: Direct-write, AFM, DPN, Photolithography, NIL
Templated patterning: Block Copolymers (BCPs)
Solution-based: Wet-coating, Die-casting, Film And Laminate Casting, Slot-coating, Colloids
Fluidics: Electrospray, Electrophoresis, Electrospinning, Electroetching, Microfluidics
Directed Energy: Laser Beam, E-beam, Ion-beam
Bio-inspired: DNA, Virus, Protein Templates for Patterning and 3D Nanostructure
Mechanical: Exfoliation, Nanomachining
High-throughput: Roll-to-Roll, Microreactor, Large Area, Massively Parallel
System-level: In-line Metrology, Process Control, System Integration, Nano-positioning
3D Nanomanufacturing: micro-SLA, 3D Printing, Holographic Lithography, MacEtch

Research Areas

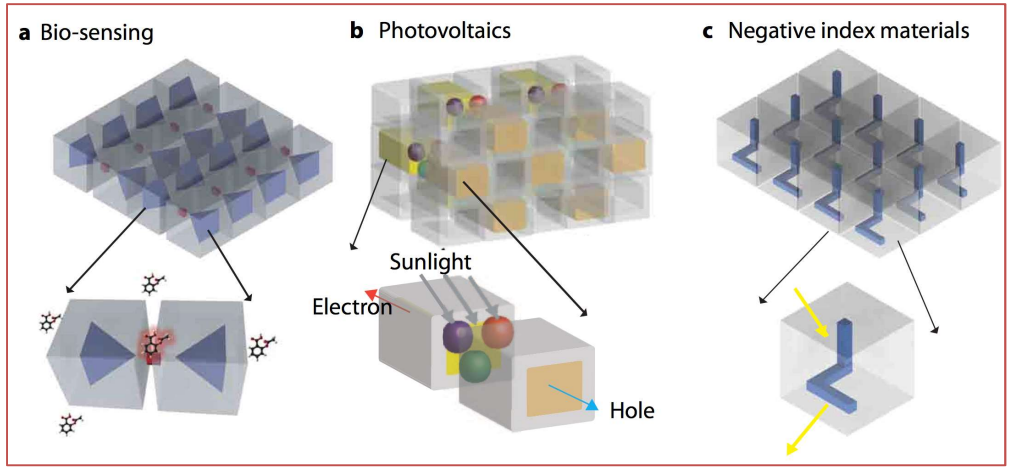
Applications
Energy: Storage, Conversion, Batteries, Capacitors, Supercapacitors, PVs, Solar Cells, Fuel Cells
Environmental: Water Purification, Analytical Separation, Wastewater Treatment
Electronics: ICs, Flexible, Storage Memory, 3D Devices, Thin-Film Devices, EM-Shielding
Optoelectronics/Photonics: Imaging, Waveguides, Displays, Lighting
Magnetics: Motors
Sensors: Biological, Chemical, Multiplexed
Structural: High-Strength, Light-Weighting, Packaging
Biomedical: Implants, Tissue Scaffolds, Diagnostics, Therapeutics
Probes: Resistivity, Cellular Electrophysiology, Neural Electrical Signal
Patterning: Templates, Masks, Photoresists
Chemical: Oxidation Catalysis, Gas Storage
Sheets and Ropes: Fibers, Cables, Filters, Textiles, Paper

Examples of NM Research

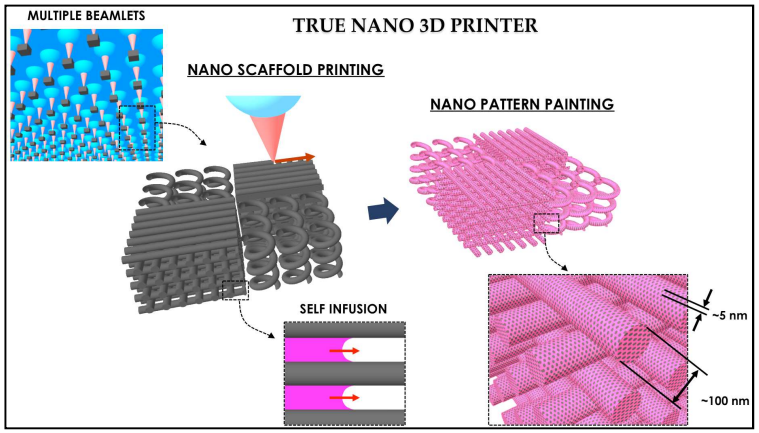
Casting Inorganic Nanostructure Arrays with 3D DNA Crystal Molds *PI: Peng Yin, Harvard*

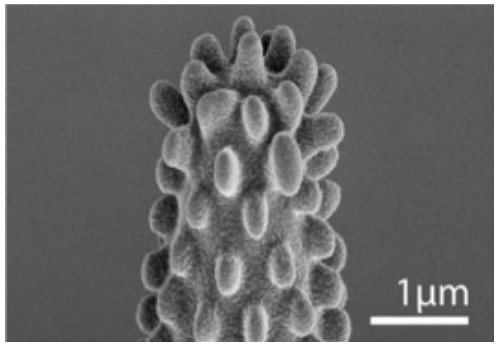


Casting growth: sub-25 nm digital fabrication of 3D metal nanoparticles at sub-5 nm resolution

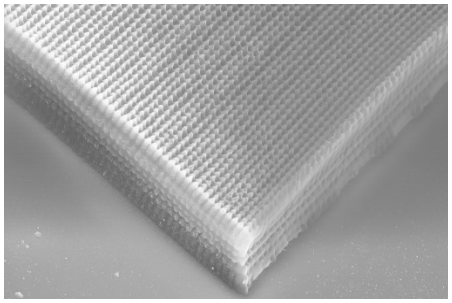


Ultrafast Laser Directed 3D Nanofabrication *PI: Costas Grigoropoulos, UC-Berkeley*





Multi-scale 3D biomimetic structure

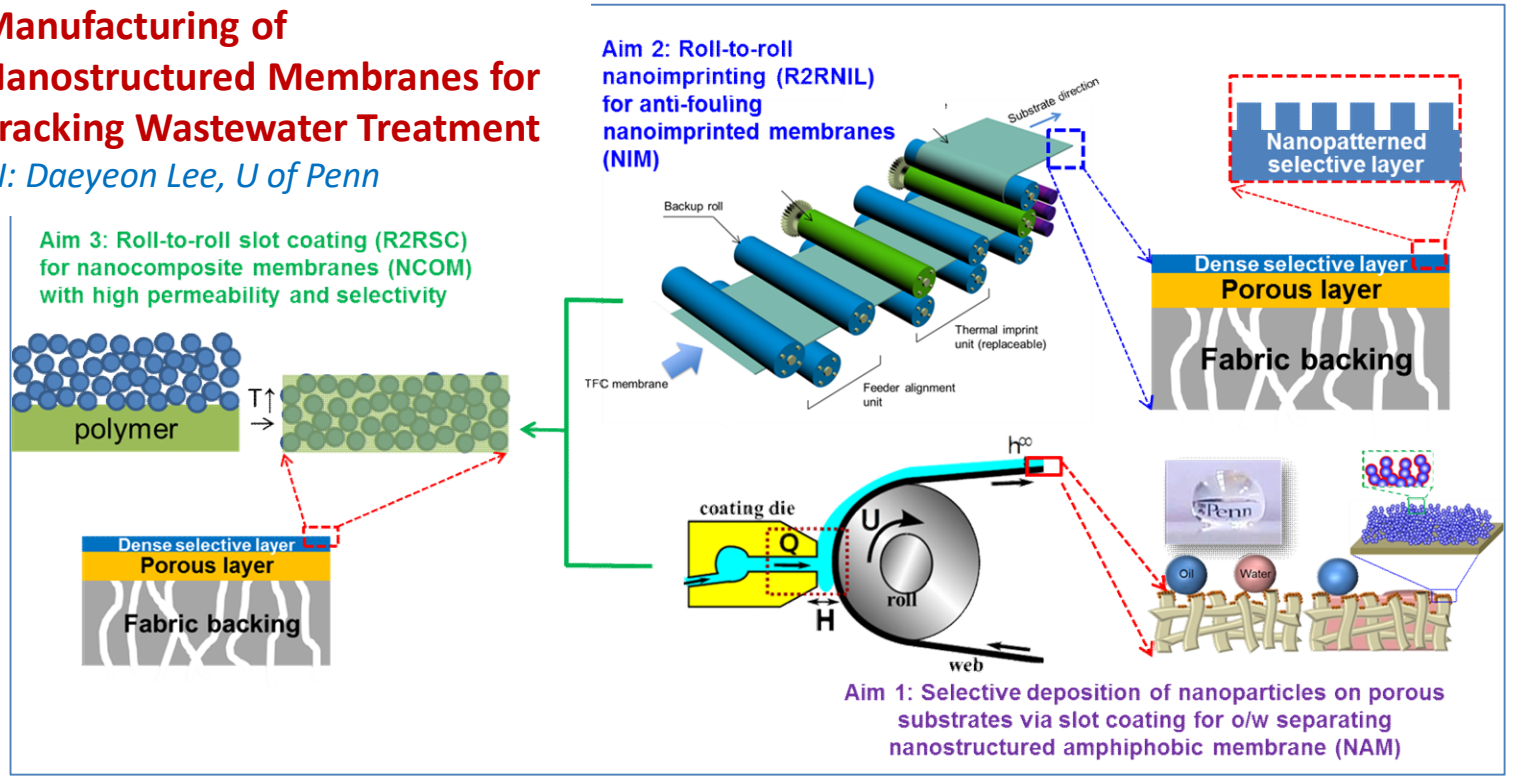


Wood-pile photonic crystal of 400 nm periodicity by two-photon polymerization

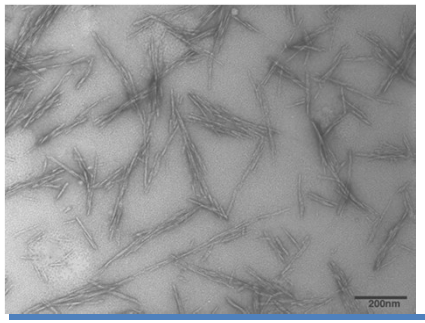
Examples of SNM Research

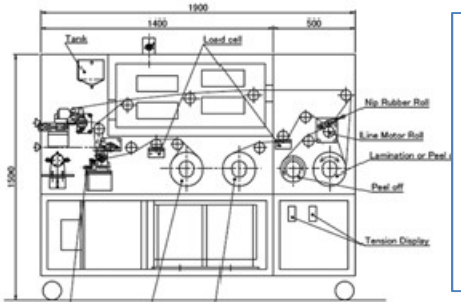
Manufacturing of Nanostructured Membranes for Fracking Wastewater Treatment

PI: Daeyeon Lee, U of Penn



R2R Manufacturing of Cellulosic Nanomaterial (CN) Films & Laminates *PI: Jeffrey Youngblood, Purdue*





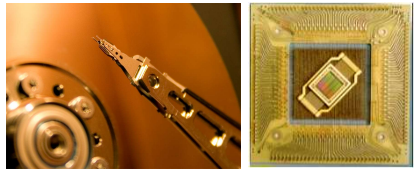
- Solvent-less CN modification
- Real-time in-line measurement and feedback
- Integrated multi-scale modelling

Future Trends

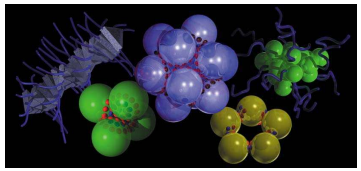
Nanotechnology Roadmap

- *Increased complexity, new functions, more capabilities in less space*

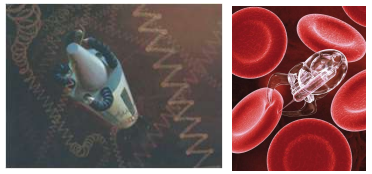
Passive Nanostructures
2000-2005



Active Nanostructures
2005-2010



3D Nanosystems
2010-2015



Molecular Nanosystems
2015-2020

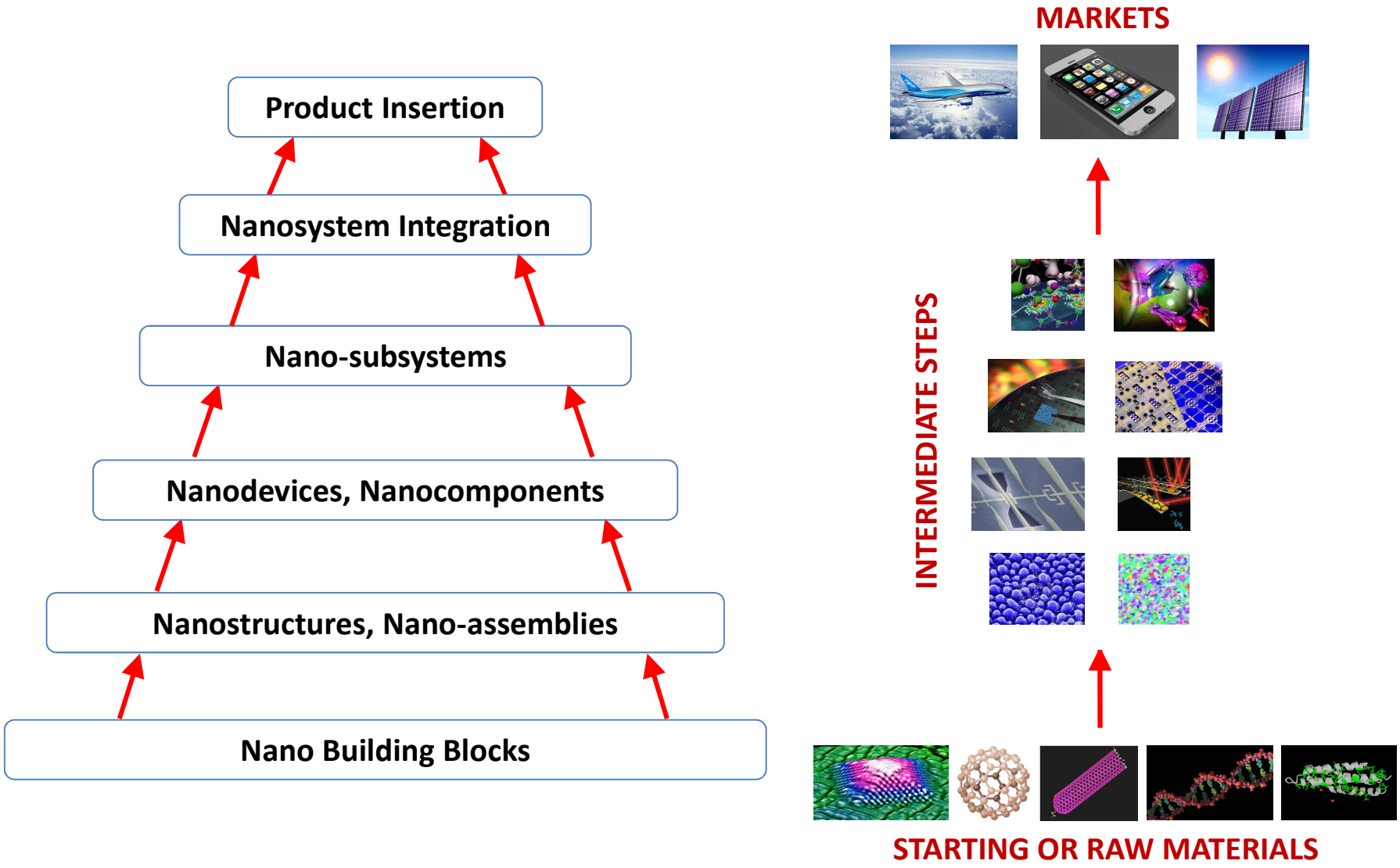
Complex Systems

- Heterogeneous, multi-functional, multi-component, multi-scale systems
- Systems having one or more of following attributes:
  - *adaptive, responsive to external stimuli, biomimetic, intelligence and smarts, autonomous, …*

Nanomodular Materials and Systems by Design

- 3D assemblies and integration, hierarchy and functionality, materials and systems architecture, interfaces for modular assembly, simulations and predictive models

Nanomanufacturing Value Chain



Manufacturing Challenges

Desired Outcomes

- Product quality and durability
- Process repeatability and reliability
- Production scalability and affordability
- Yield and production efficiency
- Desired device and system performance and functionality

Appropriate Metrics

- Precision of placement
- Feature size and resolution
- Overlay registration
- Nanostructures:
  - *Density,*
  - *Complexity,*
  - *Rate of forming*

APM-My 2 cents

Challenges

- *What structures, devices, systems, products are of interest?*
  - *Structural, Functional, Multi-functional*
  - *Scale, complexity, heterogeneity*
- *What will be the manufacturing tools?*
  - ***Integrated nanosystems***
  - *Precision, control*
- *What will be the production rates?*
  - *Build rate*