The U.S. National Nanotechnology Initiative and Commercializing Nanotechnology through U.S. Small Business Research Innovation Research Programs.

T. James Rudd
National Science Foundation
U. S.A

The Fourth U.S.- Korea Forum on Nanotechnology
Honolulu, HI, U.S.A.
April 26-27th, 2007

Update on the U.S. National Nanotechnology Initiative

NATIONAL NANOTECHNOLOGY INITIATIVE

The National Nanotechnology Initiative: Vision and Goals

- **The vision of the NNI: a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry**

- **Four goals for nanoscale science, engineering, and technology, as described in the NNI's Supplement to the President's FY 2007 budget and Strategic Plan:**
  - Maintain a world-class research and development program
  - Facilitate technology transfer
  - Develop educational resources, a skilled workforce, and the supporting research infrastructure and tools
  - Support responsible development of nanotechnology

- **Similar language is used to describe the purpose of the NSET SC in the five-year charter of June 2005**

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Broad Brush View of NNI Operations

- **Management** → **EOP + Agencies**
  - Establishment of nanotechnology as high priority R&D area
  - Budget creation and funding allocation to agencies
  - Negotiations with Congress
- **Coordination** → **NSET Subcommittee**
  - Coordinates development of strategic plan for NNI
  - Providing mechanisms for interagency communication and coordination on nanotechnology R&D
- **Reporting** → **NNCO**
  - Publishes reports on behalf of the NSET and the NNI for use by Congress, academia, industry, and the public
  - Serves as public point of contact for NNI

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Growth of Participants in the NNI

- Six agencies developed 2001 NNI proposal
- Now have 26 NSET Subcommittee member agencies

OSTP
OMB
NIH
NIST
NASA
DOD
DOE
NSF

DOS
DOTr
IC
DOT
USDA
EPA
DOJ

FDA
NRC
DHS
DOC TA

USDA FS
DOC BIS
USPTO
ITC
CPSC
NIOSH

USGS
DOL
DOEd

2001: Six Agencies

2002: Seven New Agencies

2003-4: Four New Agencies

2005: Six New Agencies

2006: Three New Agencies

NNI budget information

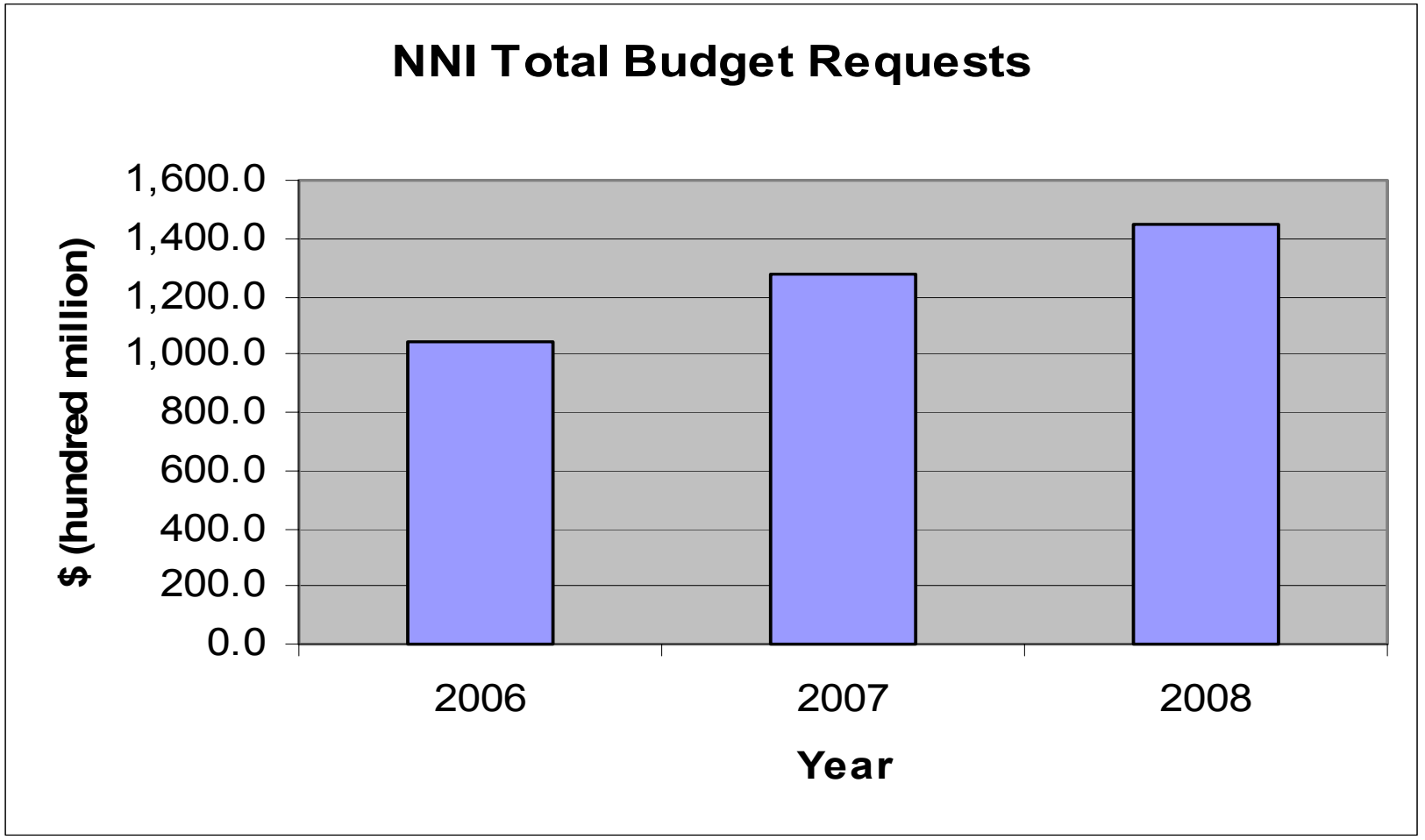
- **Federal NNI expenditures are estimated at roughly $1.4 billion/year. From the FY 2008 budget request:**

	2006 Actual	2007 Estimate	2008 Proposed	Dollar Change: 2007 to 2008	Percent Change: 2007 to 2008
NSF	359.7	373.1	389.9	16.8	4.5%
DOD	423.9	417.2	374.7	-42.5	-10.2%
DOE	231.0	293.3	331.5	38.2	13.0%
SC	*204.9*	*293.3*	*331.5*	*38.2*	*13.0%*
EERE	*26.1*	*36.4*	*45.9*	*9.5*	*26.1%*
HHS	195.4	174.8	207.5	32.7	18.7%
NIH	*191.6*	*170.2*	*202.9*	*32.7*	*19.2%*
NIOSH	3.8	*4.6*	*4.6*	*0.0*	*0.0%*
DOC	77.9	89.3	96.6	7.3	8.2%
NASA	50.0	25.0	24.0	-1.0	-4.0%
EPA	4.5	8.6	10.2	1.6	18.5%
USDA	6.2	6.5	7.6	1.2	17.8%
CSREES	*3.9*	*3.9*	*3.0*	*-0.9*	*-23.1%*
FS	*2.3*	*2.6*	*4.6*	*2.1*	*80.4%*
DOJ	0.3	1.4	0.9	-0.5	-35.7%
DHS	1.5	2.0	1.0	-1.0	-50.0%
DOT	0.9	0.9	0.9	0.0	0.0%
TOTAL	1,351.2	1,392.1	1,444.8	52.7	3.8%

The amounts included as 2007 Estimates in these tables reflect the 2007 Budget levels, with the exception of the numbers for the Departments of Defense and Homeland Security, which are the enacted levels.

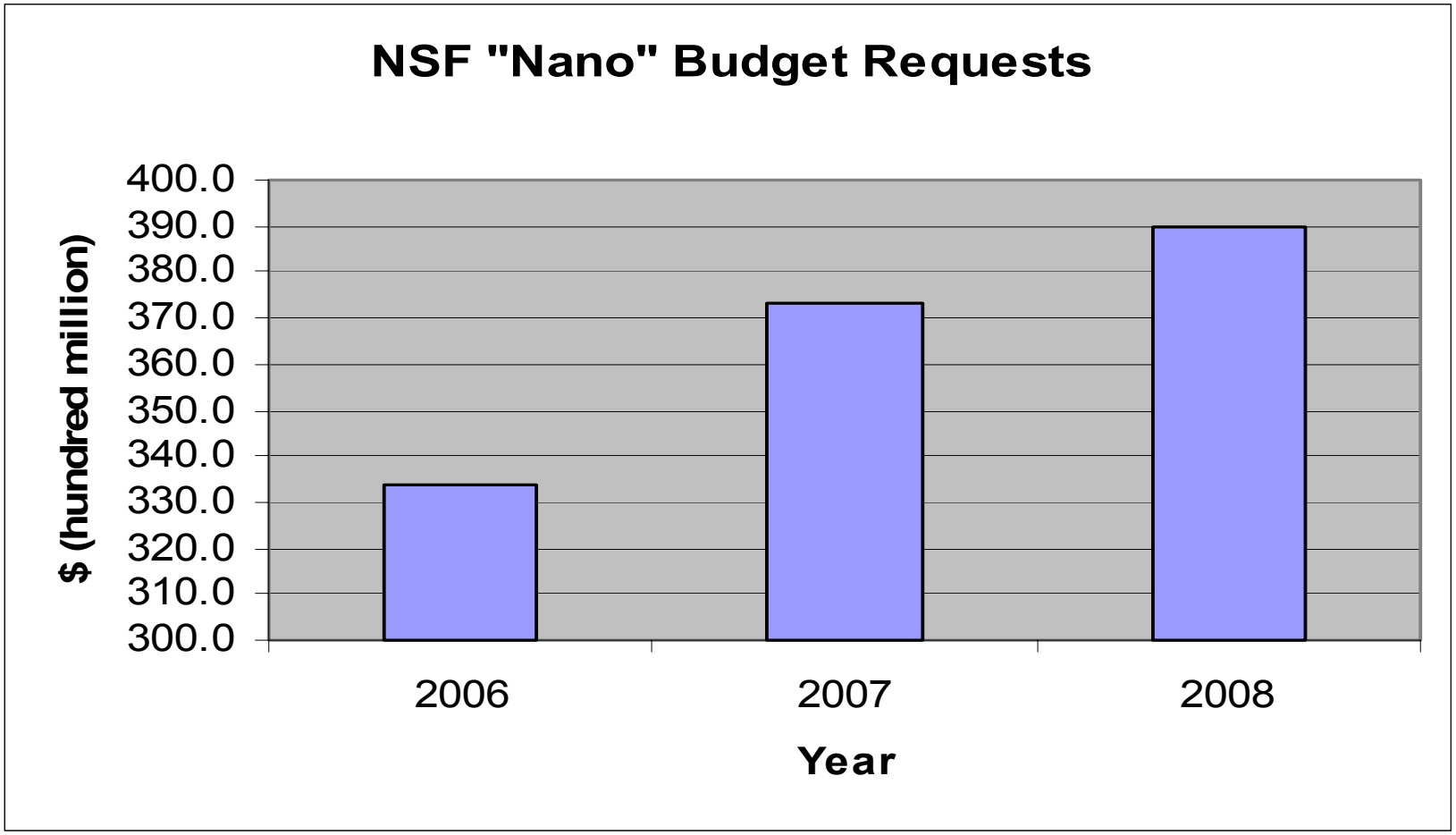
NNI budget information

- NNI expenditures have grown from ~$1 billion in 2006 to a requested ~$1.4 billion in 2008:



NNI budget information

- NSF nanoscale S&T budgets have grown from ~$330 million in 2006 to a requested ~$390 million in 2008:



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Areas of investment (Program Component Areas)

- 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 (EHS, ELSI, Education)

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Interagency activities facilitated by NSET (with NNCO implementation and contributions)

- Consolidated reporting on nanoscale science, engineering, and technology efforts across the federal complex
- Cross-cutting workshops, publications, strategic planning, and information exchange among both research and regulatory bodies
- Coordinated interactions with state and regional efforts, international bodies, industry, and others
- Joint development of tools, methodologies, and facilities, such as the Nanotechnology Characterization Laboratory established by the National Cancer Institute of NIH in collaboration with NIST and FDA
- Joint grant solicitations, such as an annual call regarding environmental and human health effects of manufactured nanomaterials led by EPA and involving NSF, NIEHS, and NIOSH

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A sampling of NSET Subcommittee publications

Supplement to the President's FY 2007 Budget

Environmental, Health, and Safety Research Needs

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NSET Subcommittee working groups

- Promote effective interagency communication, coordination, and joint programs
- Enable efficient operation of the Subcommittee
- Four working groups now established
  - Nanotechnology Environmental and Health Implications (NEHI)
  - Nanotechnology Innovation and Liaison With Industry (NILI)
  - Global Issues in Nanotechnology (GIN)
  - Nanotechnology Public Engagement Group (NPEG)
- Additional informal task forces and subgroups as needed

Recent and upcoming NSET activities

- **Environmental, Health, and Safety issues:**
  - House Committee on Science hearings (11/05 and 9/06)
  - publication of EHS Research Needs report (9/06)
  - subsequent Public Meeting (1/4/07; written input by 1/31/07)
  - NSET is working to establish priorities among the research needs identified in the recently-published document, to establish more detailed reporting of activities relevant to EHS of nanomaterials (with OMB), and to identify gaps. Results will be provided in a follow-up report.

Recent and upcoming NSET activities

- **Industry interactions:**
  - Presentations at business-oriented conferences and ongoing discussions with industry representatives such as the NanoBusiness Alliance (meeting with NSET 1/30/07)
  - Consultative Boards on Advancing Nanotechnology (CBANs) serve as a mechanism to facilitate input from industry
  - Existing CBANs with the chemical, electronics, and industrial research communities continue to provide valuable input and have led to joint efforts (e.g., nanoelectronics support at NSF)
  - Additional CBAN groups being established as warranted; expect chartering of a Forest Products Industry CBAN shortly

Recent and upcoming NSET activities

- **International activities:**
  - Organization for Economic Cooperation and Development (OECD): Two Working Parties developed, one dealing with environmental, health, and safety issues of nanotechnology and the other more policy-oriented. Substantial U.S. involvement via NSET; workshop scheduled in Amsterdam, The Netherlands (2/07)
  - International Organization for Standardization (ISO): NSET has, through the American National Standards Institute (ANSI), supported U.S. representation in ISO Technical Committee 229 on Nanotechnologies. Dr. Clayton Teague, Director of the National Nanotechnology Coordination Office, heads the U.S. delegation. The U.S. hosts the working group on EHS aspects within ISO TC-229. Other working groups address terminology and nomenclature, and measurement and characterization.

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Recent and upcoming NSET activities

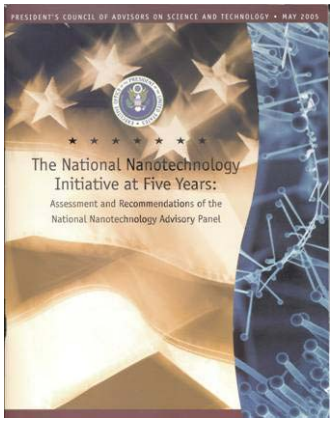
- **Public and other broad interactions and engagement:**
  - Media information session and roundtable at Lawrence Berkeley National Laboratory (3/06)
  - Public Participation workshop in Arlington, VA (5/06)
  - Public Meeting for input on Environmental Health and Safety Research Needs for Engineered Nanoscale Materials in Arlington, VA (1/07)
  - Workshop on Ethical Aspects of Nanotechnology, organized in Tempe, AZ with NSET support and participation (1/07)
  - International Workshop on Public Outreach, to be held in Leuven, Belgium with NSET involvement in organization (5/07)
  - Planning for web dialogues as another mechanism for public engagement

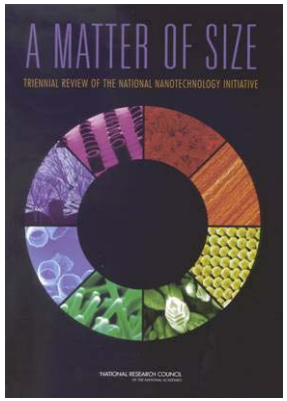
Recent and upcoming NSET activities

- **Other major efforts**
  - Completion of the NNI Supplement to the President's FY 2008 Budget (the "annual report" of the NNI) – data collection and text development in progress
  - Revision of the NNI Strategic Plan, as required by legislation (due December 2007)
  - Development of a compilation of major research targets that provide examples of specific technical achievements that nanotechnology research has the potential to enable or contribute towards

External reviews of the NNI

- PCAST is designated as the National Nanotechnology Advisory Panel and is called upon to assess the NNI every two years; their first report was issued 5/05





- The National Research Council of the National Academies is to provide a triennial review of the NNI; their first such report was published late in 2006 and the next is due 6/08

- NSET has made efforts to address the recommendations of the PCAST report and is evaluating those of the recent NRC review

OVERVIEW OF NSF

Industrial Innovation Partnership Division

SBIR/STTR Program

The SBIR/STTR Program

Small Business Innovation Development Act of 1982

Congress designated 4 major goals

- Stimulate technological innovation in the private sector
- Use small business to meet federal R&D needs
- Foster and encourage participation by minorities and disadvantaged persons in technological innovation
- Increase private-sector commercialization innovations derived from federal R&D

SBIR / STTR Participating Agencies

TOTAL ~ $2.2 B
FY 2006

- DOD SBIR/STTR
- HHS SBIR/STTR
- NASA SBIR/STTR
- DOE SBIR/STTR
- NSF SBIR/STTR ~$104M
- DHS SBIR
- USDA SBIR
- DOC SBIR
- ED SBIR
- EPA SBIR
- DOT SBIR

NSF SBIR/STTR Innovation Model

Unique to NSF

Phase IIB Third-Party Investment + 1:2 NSF Matching

MATCH MAKER

Private Sector or Non-SBIR Investment

PHASE I
Feasibility Research
$100k/6 mos

PHASE II
Research towards Prototype
$500k/24 mos

PHASE III
Product Development to Commercial Market

Federal Investment

Taxes

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Market Driven Solicitation Topics

- Advanced Materials and Manufacturing
- Biotechnology
- Electronics
- Information Technologies

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Electronics – Sub-topics

- Sensors
- IC Design
- MEMS
- Energy/Power management
- Semiconductor materials
- Nano-electronics, -magnetics
- Semiconductor manufacturing
- Micro-electronics packaging
- Wireless technologies
- Photonics
- Robotics
- Instrumentation
- Organic electronics

OPPORTUNITIES IN NANOTECHNOLOGY

- Small Businesses are playing an important role in the development and commercialization of nanotechnologies

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Industry Liaison in Support of Technology Transfer and Commercialization

- Chemical Industry
- Semiconductor/Electronics Industry
- Industrial Research Institute
- SBIR/STTR programs

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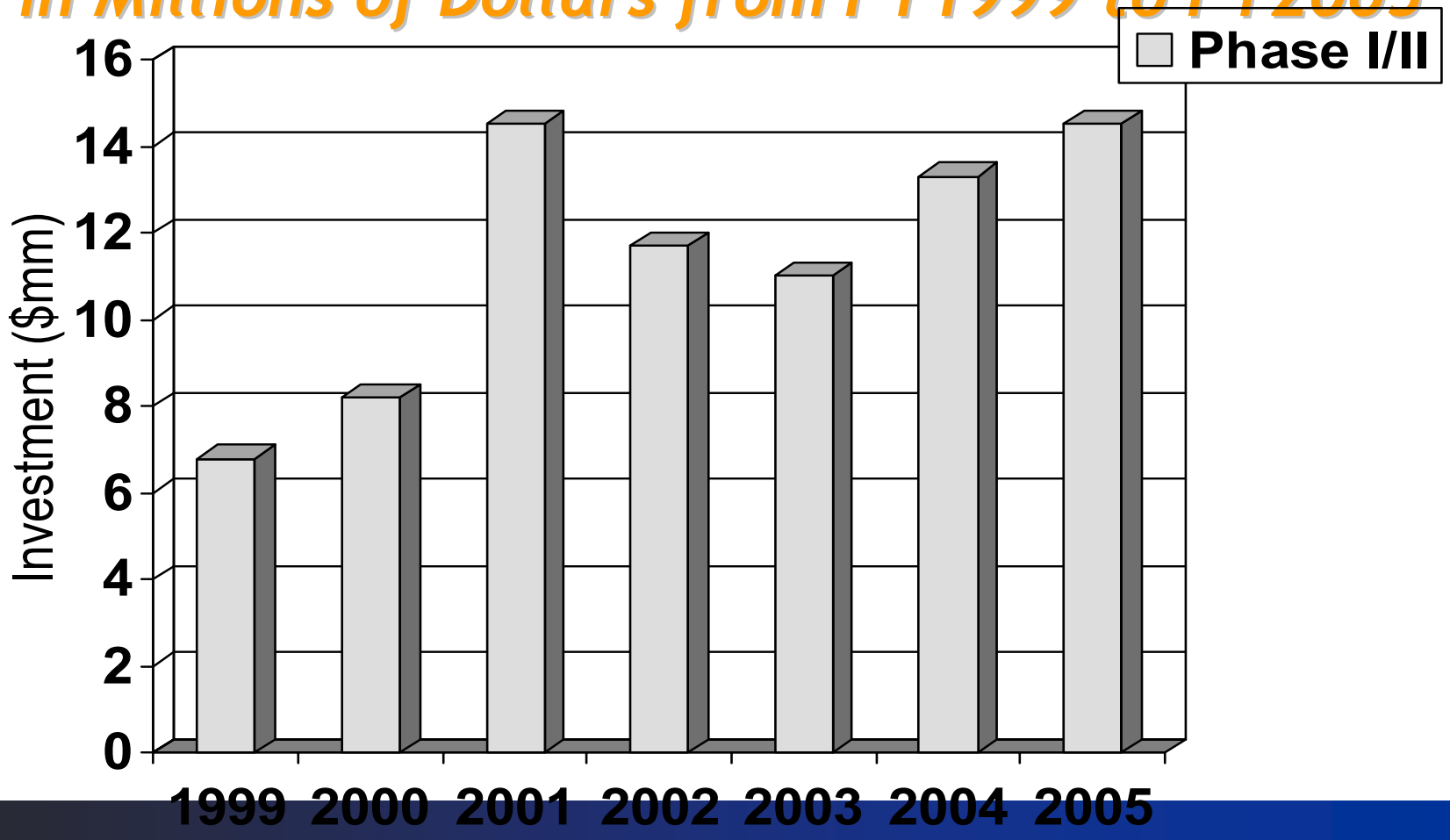
Nanotechnology Thrusts in SBIR/STTR at NSF

- Synthesis and Processing - techniques for synthesis, fabrication, and processing of nanostructures
- Materials, Devices, Systems, and Architectures - techniques for processing and converting molecules and nanoprecursors into functional nanostructures; nanostructured materials, nanocomponents and nanodevices
- Nanomanufacturing - techniques for synthesis and scale-up of structures, devices and systems employing nanostructured materials and processes with nanoscale control

NSF SBIR/STTR Grants in NANOTECHNOLOGY in Millions of Dollars from FY1999 to FY2005

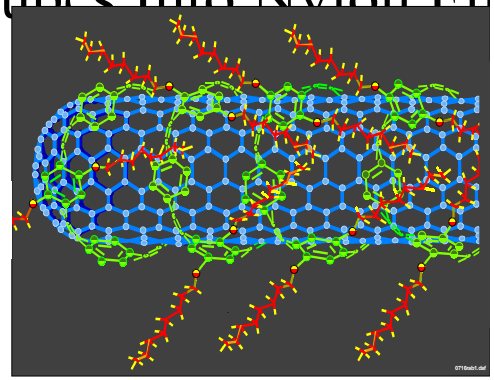


Major Product Areas Funded

- Nanoparticle composites
- Nanofilter membranes
- Nanocrystalline coatings
- Nanobiomaterials
- Nanoelectronics
- Nanophotonics
- Nanomagnetics
- Nanomanufacturing

Nanoparticle composites

Incorporation of Carbon Nanotubes Into Nylon Filaments



Technical Objective

- Formulate Synthesis For Making Functionalized Polymer That Wraps SWNT
- Develop Viable Functional Groups
- Develop Methods For Making Composites
- Determine Mechanical, Electrical and Thermal Properties

Goals

- To Incorporate SWNTs Into Nylon Filaments
- To Make Very Strong, Light Weight Structural Materials Using This Polymer Composite
- To Make Electrically and Thermally Conductive Composites For Use In EMI Shielding And As Adhesives

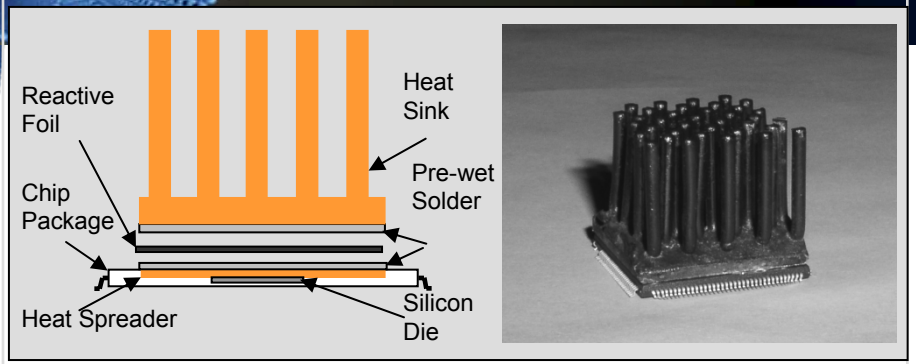
Commercialization Strategy

- Patent Application
  U.S. Provisional Application Serial No. 60/497,896.
  U.S Patent Application Serial No. 10/927,628.
- Have Interested Corporation (Henkel) But Still Need to Demonstrate Method Produces Desired Properties in Composites

Reactive Nanotechnologies

Tim Weihs & Jai Subramanian

Reactive Mounting of Heat Sinks



Technical Objectives

1. Select configuration for mounting heat sinks to dies/spreaders.
2. **Optimize configuration for best thermal performance and ease of commercial insertion.**
3. **Characterize configuration to demonstrate reliability and repeatability.**

Goals

Heat sink to die/spreader optimization and characterization.

- Determine optimal configuration for heat sink mounting. (April 2004)
- Optimize thermal performance of above configuration. (October 2004)
- Optimize and characterize performance of heat sink to silicon joints. (April 2005)
- Gather long term reliability data and complete characterization efforts. (October 2005)

Commercialization Strategy

- **Market strategy: engage end-users and partner with established companies in the adjacent markets: solders, adhesives, etc.**
- **Reach broader market by:**
  - Leveraging performance and reliability data results from the grant work.
  - Leveraging capabilities in shaping foils, ignition methods and foil-solder pre-forms
  - Aligning closely with market enablers like sub-con. assemblers and thermal management solution providers.

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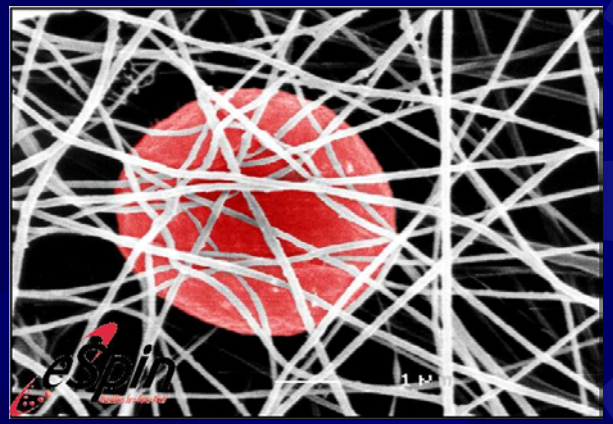
Nanofilter membranes

eSpin

High Efficiency Nanofilter Media

- Technology:
  - Nanofiber from Solution
  - Spinning technology
  - Web manufacture
- SBIR Follow-On Funding:
  - FleetGuard Diesel Filter
  - State of Tennessee



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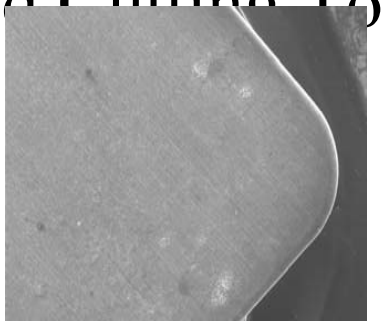
Nanocrystalline coatings

Vista Engineering Inc.
Raymond G. Thompson
DMI-0349769

Nanocrystalline Diamond Coated Cutting Tools



Technical Objectives

Batch Process
Intrinsic Film Adhesion
Robust Process Parameters

Goals

Product to Market 2005
Venture Capital 2004 – 2005
Win in Growing Market -
$300M in 2010

Commercialization Strategy

High-end
High Productivity
Partner with Tool Manufacturer
Automotive Applications

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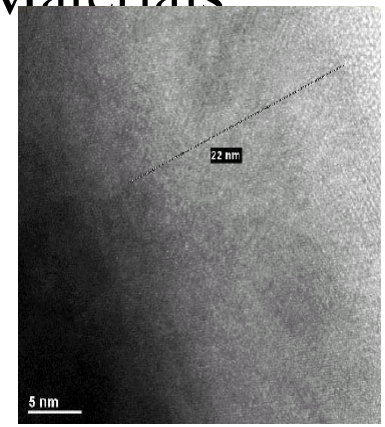
ALD NanoSolutions, Inc.
Dr. Karen J. Buechler
DMI-0422220

STTR Phase II: Novel Nanocoated Ferromagnetic Materials

γ-Al_2O_3 growing epitaxially to iron particle surface



Technical Objectives:

- Develop Atomic Layer Deposition (ALD) chemistry for placing conformal, pinhole-free, and nanothick alumina films on individual primary particles
- Produce Kilograms of nanocoated fine iron powders using a scaleable fluidized bed process
- Characterize the product: film thickness, composition, crystallinity, particle size distribution, surface area, oxidation resistance, magnetic moment

Goals:

- Use Particle-ALD™ to Deposit Nanothick Films on Fine Particles
- Develop Pilot Scale Production Capabilities for Particle-ALD™
- Develop Link to Consumer Products for Nanocoated Fine particles through use of Strategic Partners

Commercialization Strategy:

- Work with Strategic Partners to Design materials for the Aerospace, Elecronic, and Automotive Industries
- Using Facilities proven during Phase II, provide materials for Consumer Product Development
- License or Manufacture coated particles designed through Phase II to Strategic Partners as needs dictate

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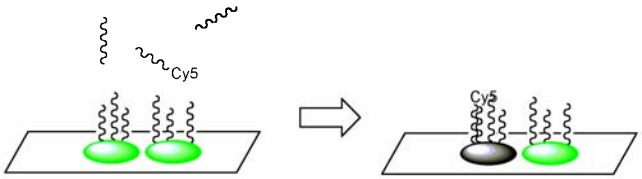
Nanobiomaterials

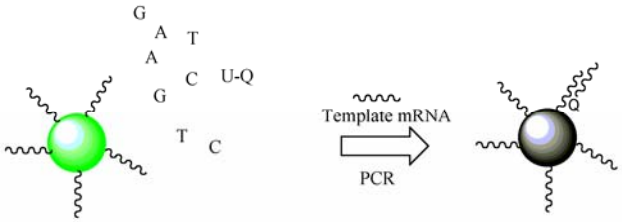
Nomadics, Inc
Lawrence F. Hancock and Joongho Moon
215 First St., Suite 104,
Cambridge, MA 02142
617-441-8871,lhancock@nomadics.com

Fluorescent Polymer Nanoparticles

Gene Expression Reagents



q-RT PCR Reagents



Technical Objectives

- **Optimize PPE Nanoparticles**
- **Demonstrate PPE Fluorescence Quenching Enhancement**
- **Gene Expression & q-PCR Reagents**
  - Define Specifications and Performance
  - Compare Specs. And Performance with Competitors
  - SOP's and QA/QC Procedures
  - Protocols
  - Beta Test
  - Draft Instructions/Application Notes

Goals

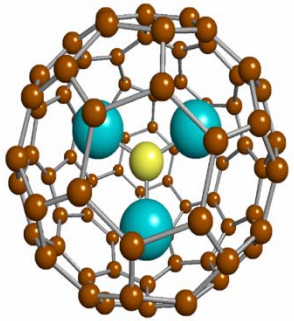
- Develop and Launch
  - **Gene Expression Reagents**
  - **q-RT PCR Reagents**

"Improved Photostability"
"Enhanced Sensitivity"
"Wide Dynamic Range"

Commercialization Strategy

- Direct integration of PPE nanoparticles into widely practiced experiments on existing bioanalytical instrument platforms.
- Introduction of PPE-based labels and nucleotide conjugates in application-specific reagent kits.
- License and/or partner with established reagent suppliers and equipment

"Nuclear-Magnetic Resonance (NMR) Properties of Carbon Nanomaterials for Medical Applications"



Goals

- Increase production efficiency by 10X
- Enhance water solubility while maintaining low apparent molecular weight
- Develop high field strength MRI contrast agents

Technical Objectives

- Enhance Production Efficiency for $Gd_3N@C80$ and other Trimetaspheres
- Optimize and Finalize functionalization of Gd3N@C80
- Optimize and functionalize $Er_3N@C80$, $Ho_3N@C80$, and $Tb_3N@C80$

Commercialization Strategy

- Competitive advantage-25X more sensitive than current MRI agents
- Establish wide customer base sales through emerging and established pharmaceutical companies
- Ability to produce "site-directed" contrast agents

Dr. Stuart Farquharson

Nanomaterial for Microchip Sensors

Goal

Build a microchip chemical analyzer that simultaneously separates chemical species and provides surface-enhanced Raman activity to allow < 5-min analysis of < mL samples at ppm concentrations.

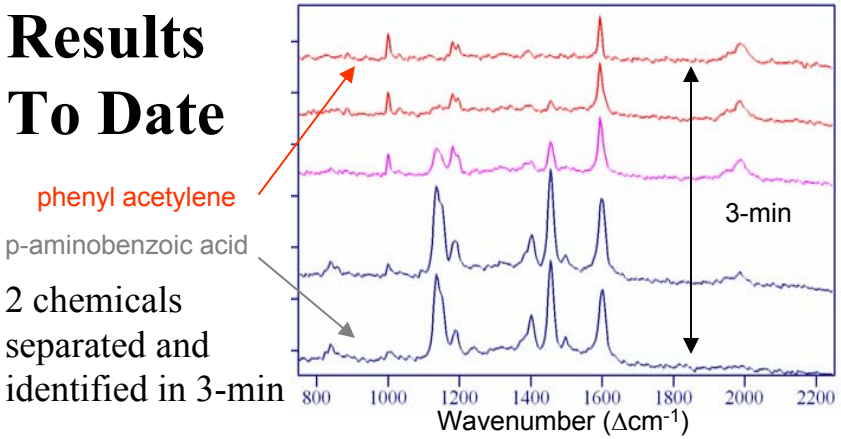
Technical Objectives

- Develop Separation Chemistry
- Design & Build SERS Microchip
- Build Analyzer (fluid delivery)
- Test Analyzer (figures of merit)
- Product Design with Customers

Commercialization Strategy

- Protect with patents
  (two submitted 10/02, third in 01/03)
- Develop applications with strategic partners (pharmaceutical, medical, clinical, biotech)
- Leverage exclusive use against investment

Results To Date



2 chemicals separated and identified in 3-min

Applied Spectroscopy, 57, 479 (2003)

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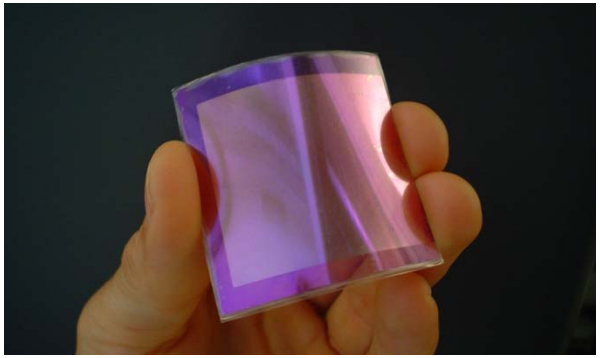
Nanoelectronics

Nanocomposite Solar Cells



Goal:

• Develop high performance, low cost lightweight flexible solar cells

Approach:

• Innovative solar cell design that combines precisely engineered inorganic semiconductor nanocrystals with a light-weight, flexible host-matrix

Technical Objectives:

• Develop optically and electronicly enhanced nanocrystals
• Develop new Device Components
• Develop Advanced Device Architectures

Commercialization Strategy:

• Nanosys focuses on nanotechnology element in the end product
• Partner with industry leaders to jointly develop and manufacture nano-enabled component into end product.
• Our partner provides marketing resources and access to end customers

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Photovoltaics : Nanoparticle co- sensitizers for increased efficiency

Ka

process produces mm, flexible solar cells

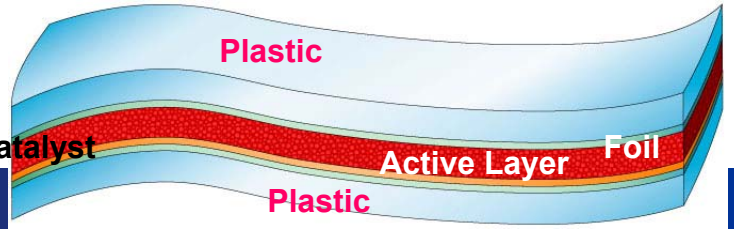
Polymer photovoltaic products in a variety of form factors for commercial, industrial, military and consumer applications

- **Uses photoactive dyes & conducting polymers**
- **High-speed manufacturing processes**
- **Low temperature environment**
- **Uses low cost materials**
- **Highly scaleable**

- **Mass customization from a single source**
- **World solar PV market: CAGR > 35%**
- **20+ patents pending**

Schematic of Dye Sensitized Titania Cell

Total thickness 0.01 inch



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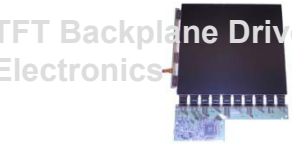
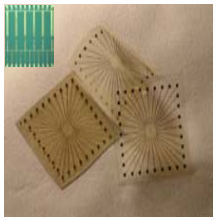
Thin Film Transistors: Silicon Nanowires

High Performance, large area nano-structured macro-electronics substrate technology

TFT Backplane Drivers – Integrated Edge Electronics





Beam-Steering Antennas

- **Eliminates high-temperature steps required for semiconductor deposition**
- **Dramatically reduces manufacturing cost, time and complexity**
- **Deposition on virtually any substrate material possible**

A variety of application areas:

- **Portable & large-area flat panel displays**
- **Low-cost RFID and smart cards**
- **Electronically steerable phased-array RF antennas**

RFID Tags

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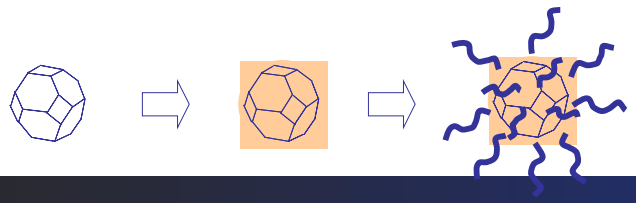
Nanophotonics

Continuous Flow Reactor & Size-Selection Scheme for Use in High Throughput Manufacture of Si Nanoparticles

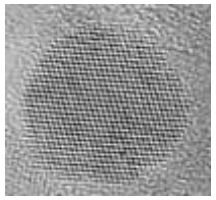
Goals:

- Si nanomanufacturing system
- Process parameters
- 5 grams/hour



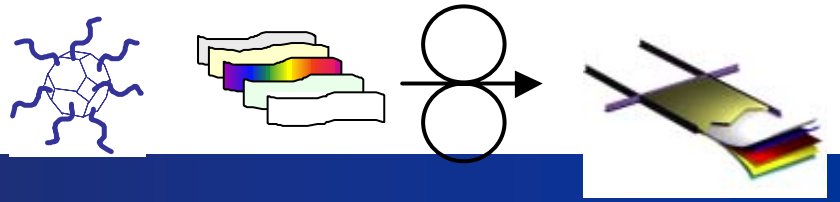
Technical Objectives:

- High quantum yields
- Tunable emission
- Defect-free particles



Commercialization Strategy:

- IP portfolio
- Cell phones, exit lighting (short term)
- Solid-State Lighting

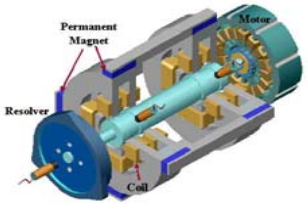


NATIONAL
NANOTECHNOLOGY
INITIATIVE

Nanomagnetics

Nano-magnetic materials

Nanocrystalline FeCo for EMI Suppression



Technical Objectives

- Production of nano-sized FeCo and their consolidation to near net shapes
- Magnetic Characterization and EMI testing
- Fabrication of magnetic bearings and their testing
- Fabrication of materials for inductors and their testing

Goals

- Scale up the production and the consolidation process
- Tailor materials for EMI suppression up to 1 GHz
- Optimize material properties for enhanced bearing performance in flywheel energy storage and artificial implants
- Low loss magnetic cores and inductors

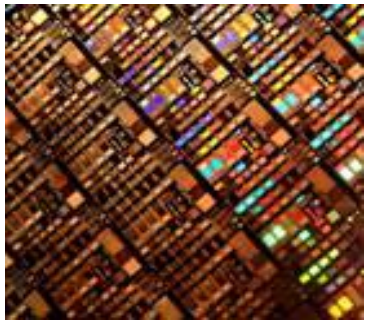
Commercialization Strategy

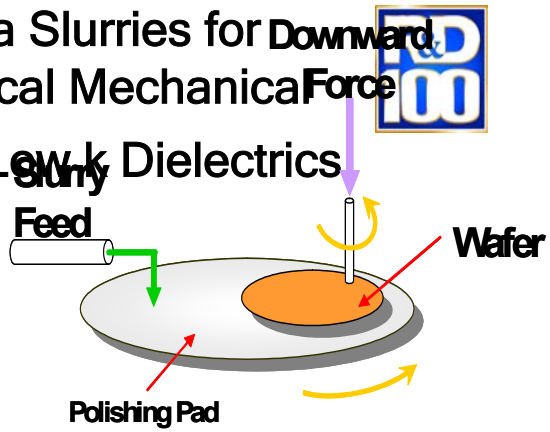
- Strategic Alliances
- Worldwide licensing for a fixed fee
- Spin off a separate business unit

NATIONAL
NANOTECHNOLOGY
INITIATIVE

Nanomanufacturing

Nanoporous Silica Slurries for Enhanced Chemical Mechanical Planarization of Low-k Dielectrics





Goals

MARKET OPPORTUNITY	SINMAT's GOAL
•New Materials (Cu/Low K, Cu /Ultra Low K)	•Low Stress Soft Layer Polishing
•Need New Solutions - Ultra Low K	•Nanoporous Particles
•Increasing CMP Costs	•Integration

Technical Objectives

- Low Defectivity Polishing (Ta)
- Large scale Synthesis
  - Nanoporous Silica
- Formulate CMP slurries
- Test and Benchmark CMP results
  - Initial Tests Complete

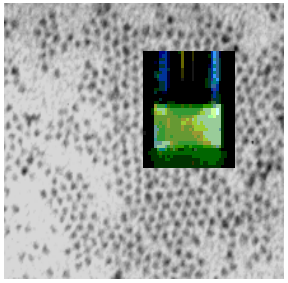
Commercialization Strategy

- Protect Intellectual Property
- Complete and implement staged fund raising strategy
- Execute R&D and marketing alliances with select, major industry partners

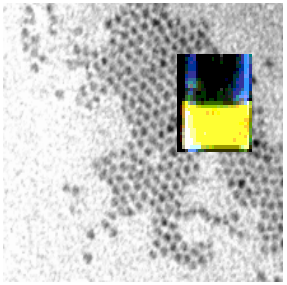
NATIONAL NANOTECHNOLOGY INSTITUTE

Semiconductor Nanocrystal (Quantum Dot) Manufacturing

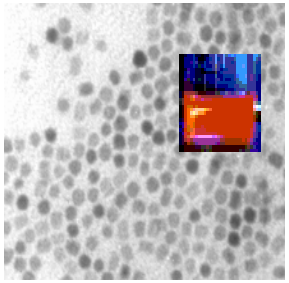
A New Scale-Up Technology for Industrial Production of High-Quality Semiconductor Nanocrystals



2.5 nm CdSe



3.5 nm CdSe



5.5 nm CdSe

Goals:

NN-Labs will offer customers colloidal semiconductor nanocrystals with the:

- Highest Quality: stable, surface flexibility, narrow size distribution
- Lowest Price: affordable
- Broadest Range: II-IV, III-V, and IV-VI semiconductor nanocrystals

Technical Objectives

- Develop large-scale synthetic protocols for type II-IV, III-V, IV-VI semiconductor nanocrystals
- Stabilize these nanocrystals with dendron ligands
- Establish industrial standards
- Assemble Auto CB Synthesizer™

Commercialization strategy

- Focus on electronic and biological applications
- Patent and license the synthesis protocol
- Advertise: Commercial ads and conference exhibits
- Secure financial support from VC and strategic partners

Summary

- Reviewed the U. S. National Nanotechnology Initiative program as of Spring 2007.
- Described the NSF SBIR/STTR program for early stage technology commercialization.
- Highlighted NSF funded SBIR/STTR companies involved in nanotechnology commercialization.

NSF SBIR/STTR Home Page

www.nsf.gov/eng/iip/sbir

Thank You.

James Rudd

tjrudd@nsf.gov