Nanotechnology in the SBIR/STTR Programs at NSF

T. James Rudd
Industrial Innovation and Partnerships
Engineering Directorate
National Science Foundation

Nanoscale Science and Engineering

Grantees Conference

December 4th, 2008

Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) Program at the National Science Foundation

Topics Supported at NSF - SBIR

- Electronics, Components and Engineering Systems
- Nanotechnology, Advanced Materials & Manufacturing
- Biotechnology and Chemical Technology
- Software and Services
- Special Topics
  - Security Technologies
  - Environmental Technologies

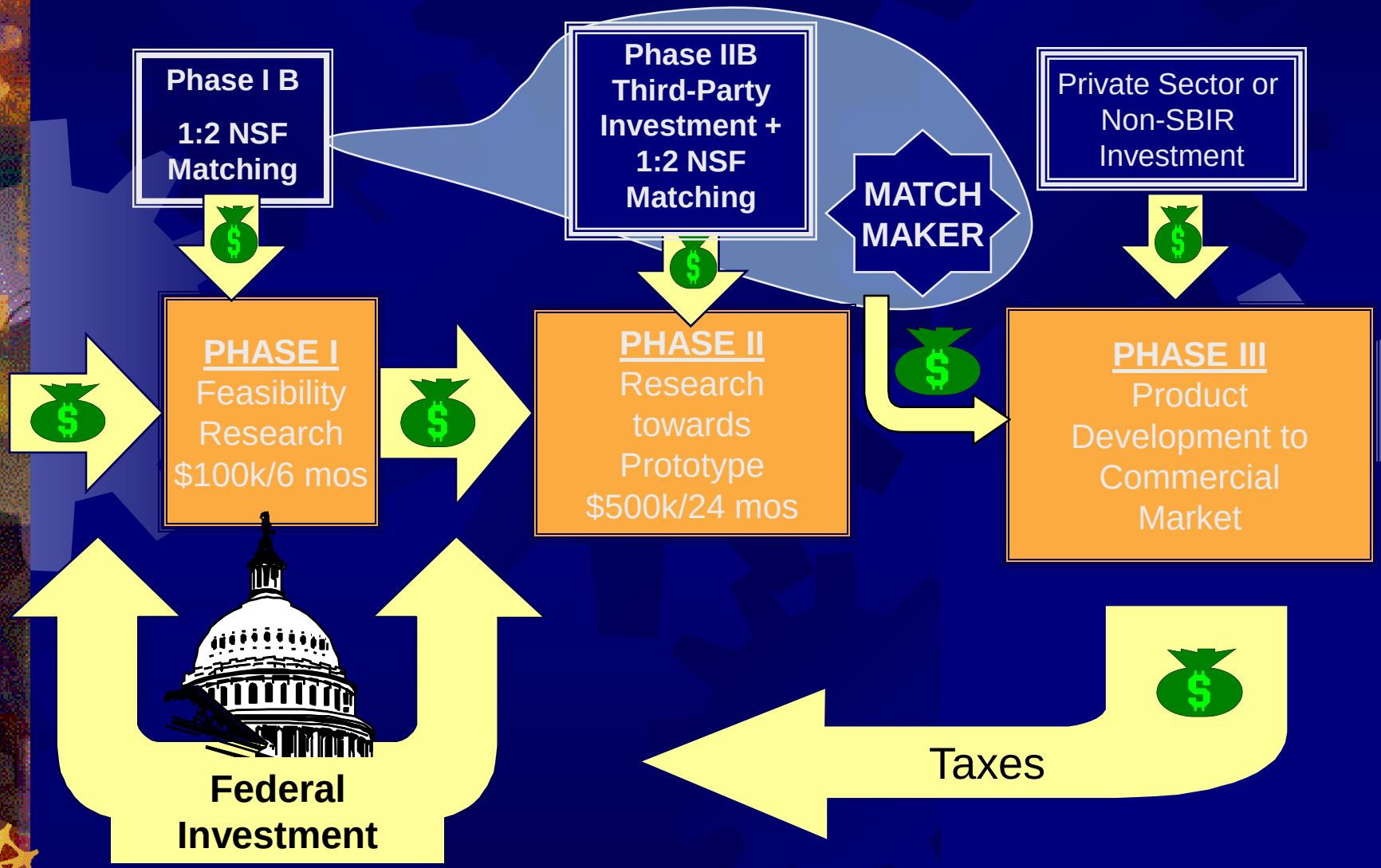
Currently Expecting Proposals (Solicitation: NSF 08-548)

- Proposals due December 4, 2008
  - SBIR Topics
    - Biotech & Chemical Technologies (BC)
    - Electronics , Components & Engineering Systems (EL)
    - Software & Services (SS)

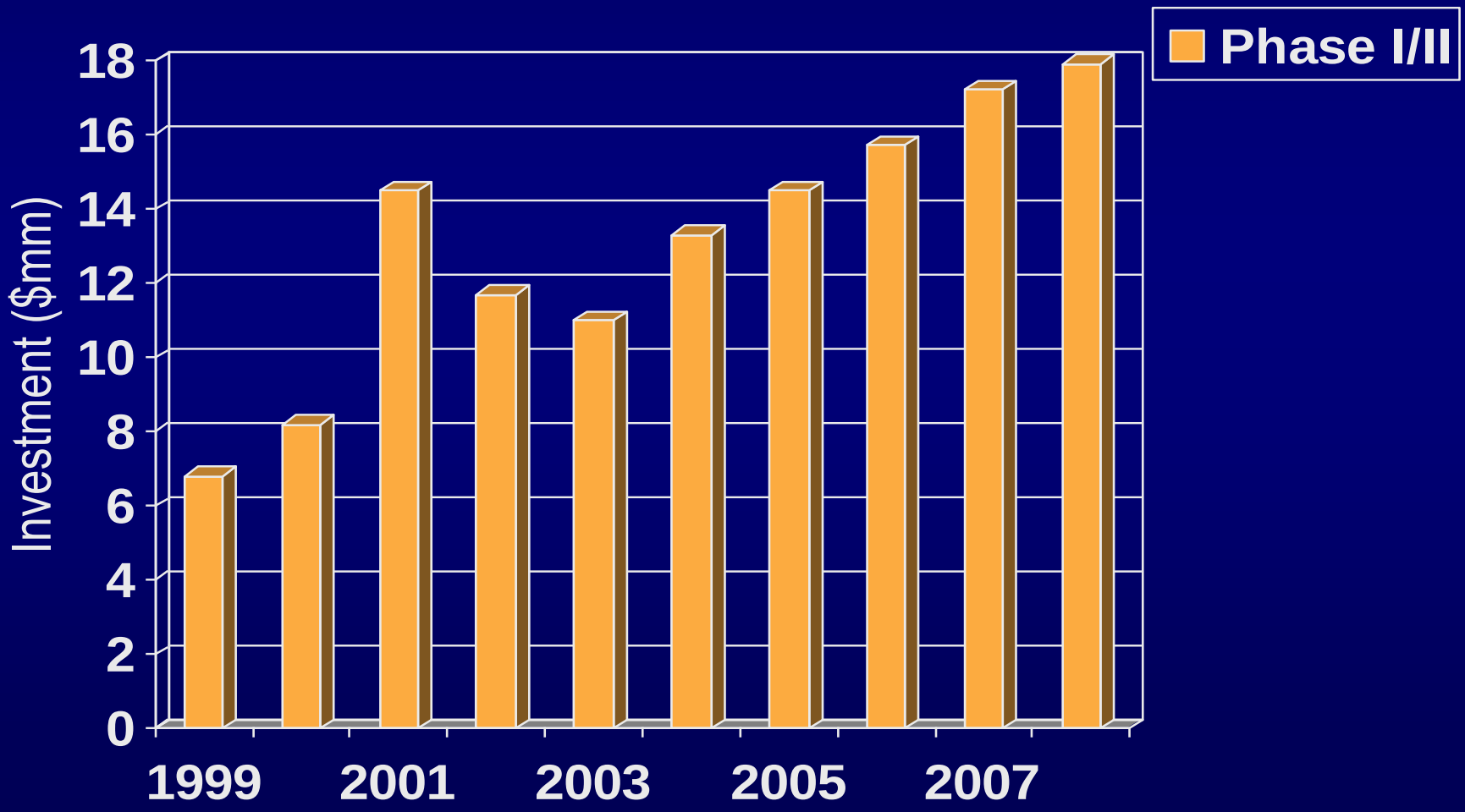
Nanotechnology Thrusts in SBIR/STTR at NSF

- **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 Innovation Model



NSF SBIR/STTR Grants in NANOTECHNOLOGY in Millions of Dollars from FY1999 to FY2008



Major Product Areas Funded

- Nanoparticle composites
- Nanofilter membranes
- Nanocrystalline coatings
- Nanobiomaterials
- Nanoelectronics
- Nanomagnetics
- Nanotechnology for batteries
- Nanomanufacturing

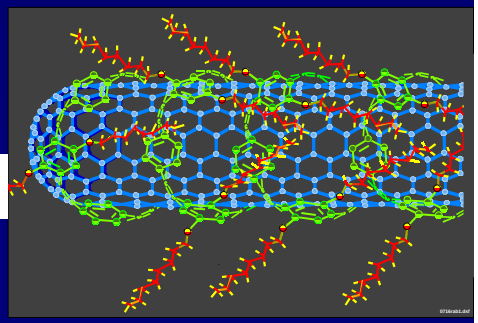
Examples of Nano Applications

- Selected examples of nanotechnology applications funded by SBIR/STTR since 2005

Nanoparticle composites

Carbon Nanotube Reinforcement
Eltron Research, Inc

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

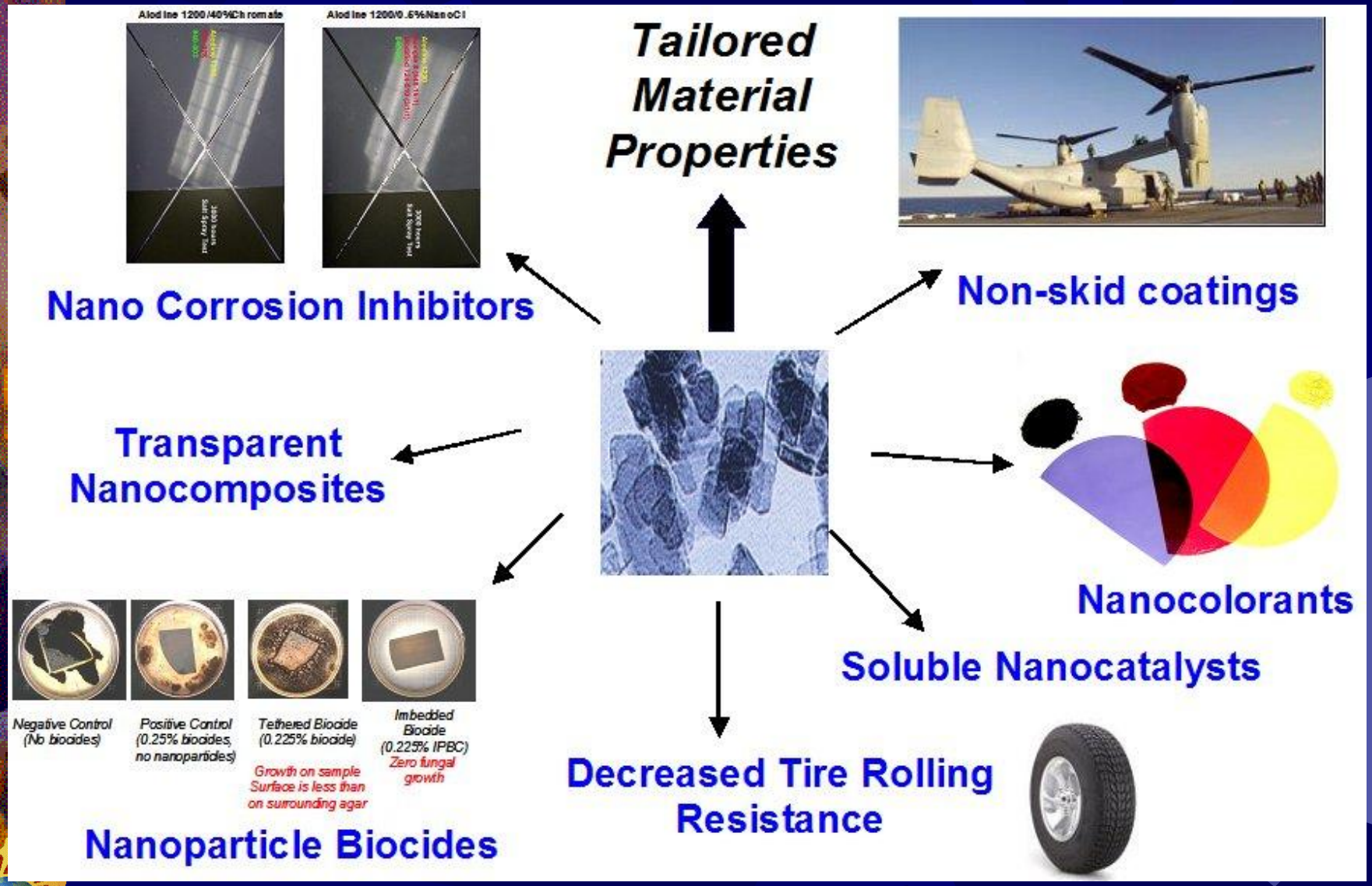
- To Incorporate SWNTs Into Nylon Filaments
- To Make Very Strong, Light Weight Structural Materials Using This Polymer Composite
- To Make Electrically and Thermally Conductive Composites For Use In EMI Shielding And As Adhesives

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

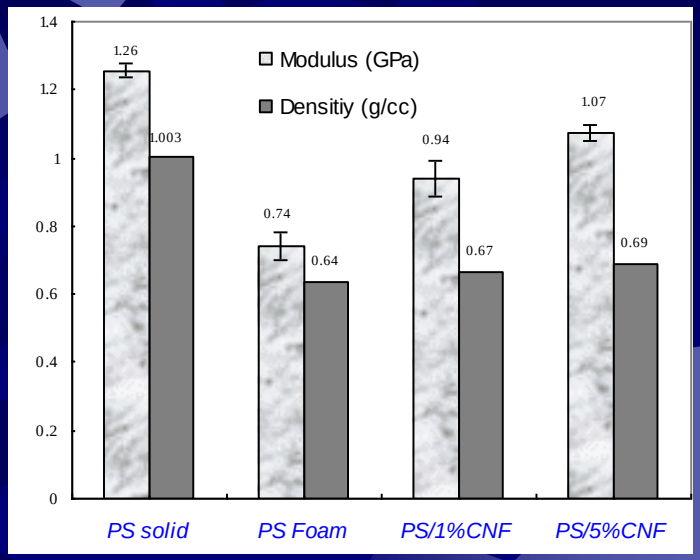
Nanoparticle Technology Platform

TDA Research, Inc

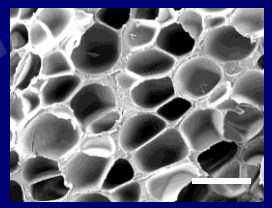


Polymer Nanocomposite Foams

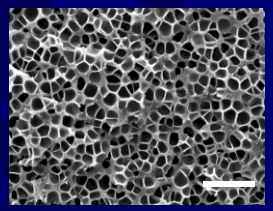
Nanomaterial Innovation, LLC



- **Nanoparticle Material Innovations**
  - Improvements in mechanical strength without losing toughness/impact strength
  - Cell morphology control agent, Gas diffusing barrier, Infrared attenuation agent, Carrier for benign co-blowing agents



Nanoparticle added

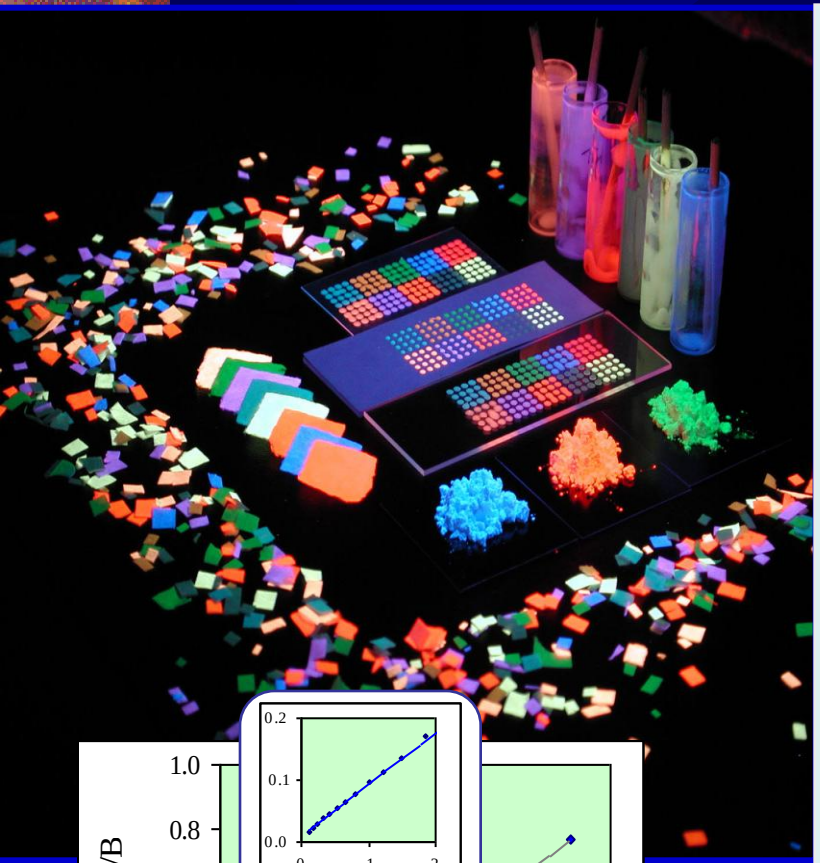


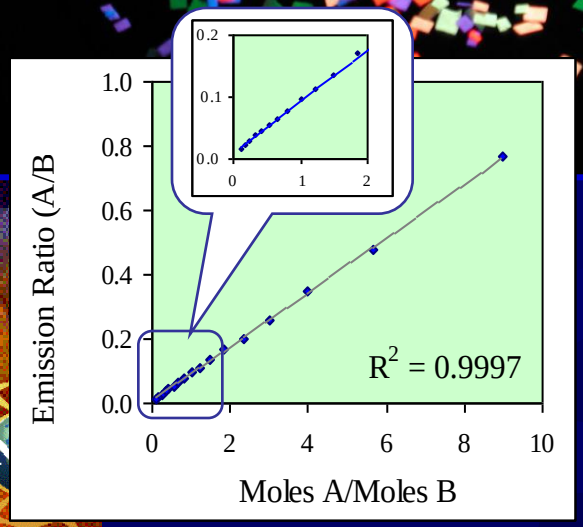
scale bar 20 μm

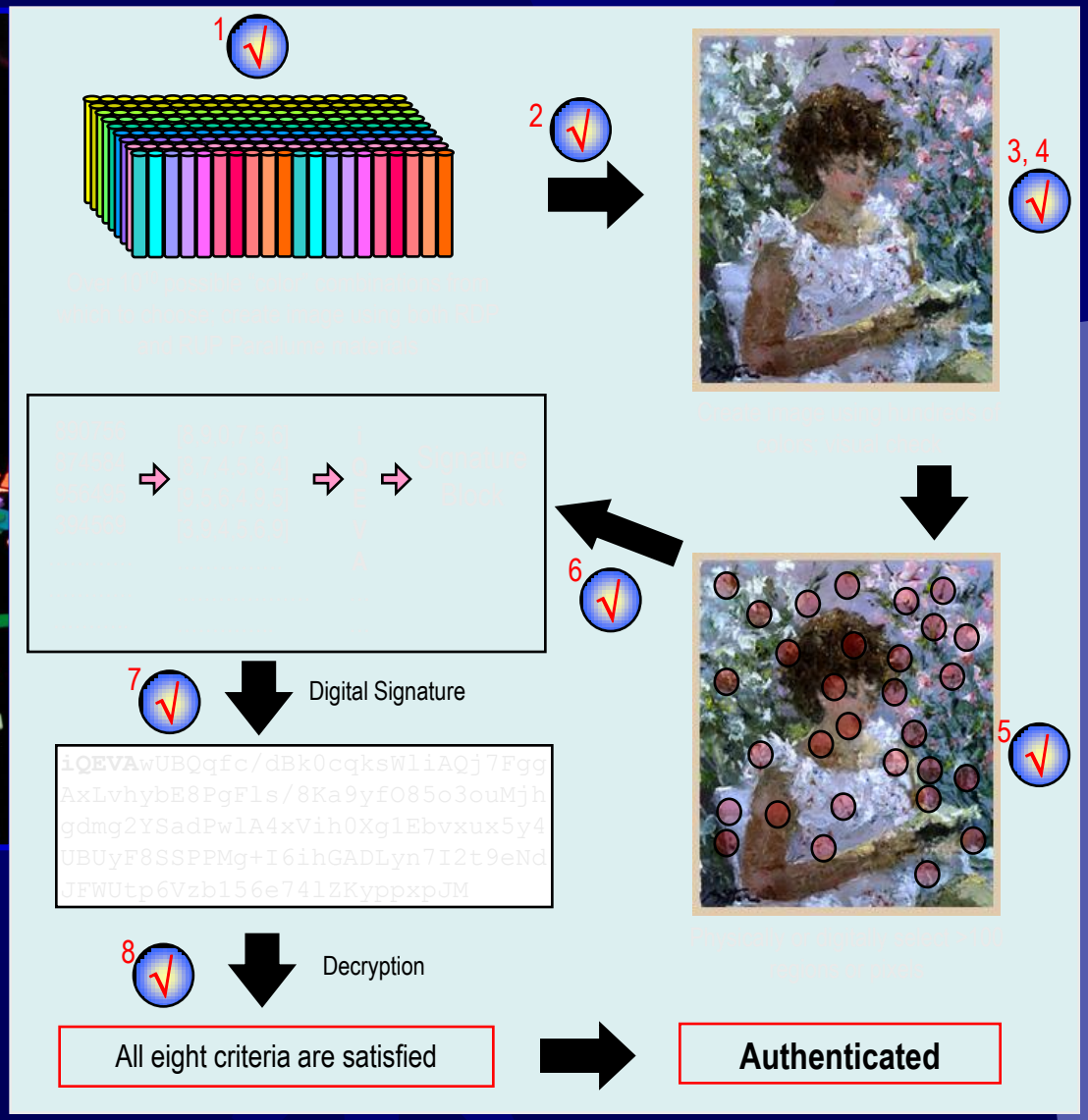
- **Blowing Agent Innovations**
  - Traditional chloroflurometh**ane** blowing agents has been prohibited globally because of their high ozone depletion effect.
  - Among the potential replacements, CO_2 is the most favorable, because it is nontoxic, environmentally benign and it is inexpensive.

Universal Nanoparticle Taggants:

Parallel Synthesis Technologies, Inc







Nanocomposite Foil for Bonding

Reactive Nanotechnologies, Inc

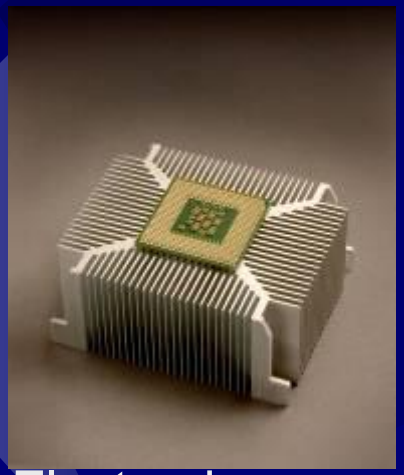
Joining Configuration

NanoBond® Joining of Electronic Components

- Enables direct solder attach between silicon and thermal management components without exposing them to reflow temperatures
- High thermal conductivity: 4-8X improvement over current commercial solutions
- Lower residual stress
- Bond dissimilar materials

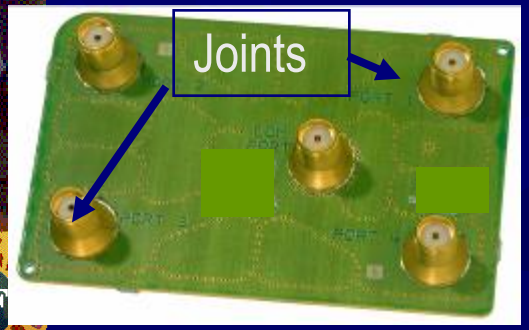
Product Portfolio RNT Nanobonding

MicroElectronics:
Thermal Management

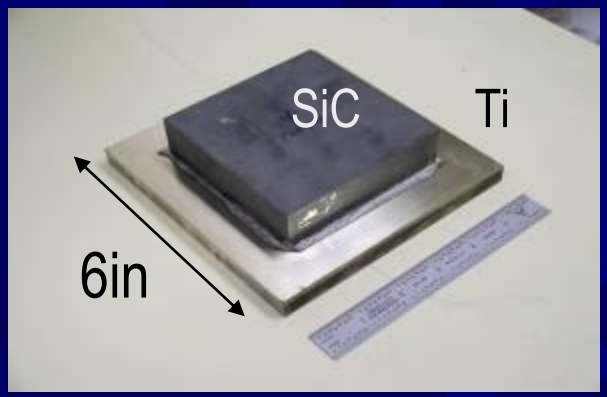


Semiconductor Materials: Target Mounting

MicroElectronics:
Component Mounting



Ceramic-Metal Joining:
Armor



Energetics:
Propellant Ignition

Nanofilter membranes

Water Purification Technology for the Removal of Chemical & Biological Contaminants

Crystal Clear Technologies, Inc.

Lisa M. Farmen

IMPACT

- Industrial: Removes metal contaminants without generating a waste stream.
- Societal: Technology can purify enough water for one person for a year for $1.00

LINEAGE:

- Funding from Siemens for field test
- Validation samples at Dow Water
- MOU with CDI for OEM manufacturing
- Sandia Nat'l. Labs – filter testing
- CRADA – NUS, NRL, UO
- Licensing with Ga Tech/NUS
- ONAMI Gap Grant $225K

NOVELTY

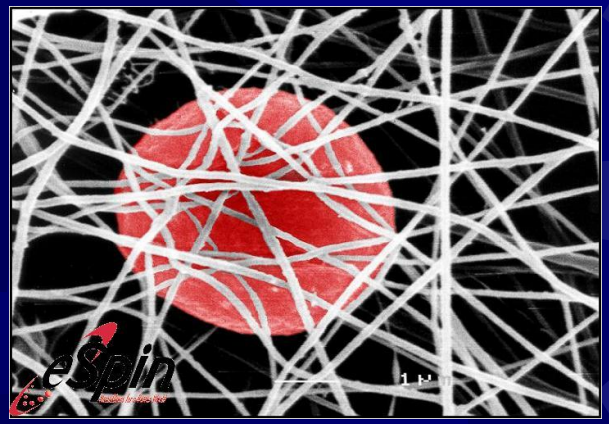
NMX™ nano-coated filter media can be recharged, with a "double sticky tape" ligand and accumulate numerous layers of metal before the media exhausts.

COMPANY MISSION

To commercialize low cost water purification products at a cost affordable to the majority of the world's population.

High Efficiency Nanofilter Media
eSpin, Inc

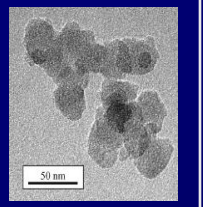
- Technology:
  - Nanofiber from Solution
  - Spinning technology
  - Web manufacture
- SBIR Follow-On Funding:
  - FleetGuard Diesel Filter
  - State of Tennessee



Catalytic Filter for Diesel Exhaust Purification
Aspen Products Group, Inc.

Motivation

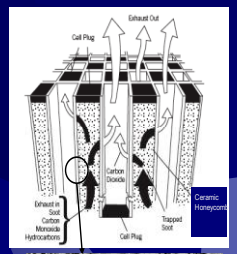
- Particulates (PM) emitted from diesel engines pose significant health hazards
  - lung cancer
  - cardiovascular disease
  - asthma
- 2007 EPA regulations - 0.01 g PM /bhp-hr

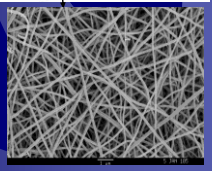


- Conventional diesel particulate filters (DPF) are expensive, reduce engine fuel economy and require frequent maintenance

Approach

- Wall flow filter coated with nanofibers that catalyze soot oxidation
- Filtered PM is continuously oxidized by oxygen present in exhaust at typical exhaust temperatures
- Benefits:
  - increased PM capture efficiency
  - reduced filtration system cost
  - reduced operating cost





Lineage

- SBIR programs focused on catalyzed filter development

Company Mission

- APG develops materials and processes that enable the use of conventional fuels in more fuel-efficient and environmentally-friendly ways
  - exhaust aftertreatment
  - hydrogen generation for fuel cells
  - catalytic heating
  - gas purification

Nanocrystalline coatings

Diamond: Nature's perfect material

- Hardest substance on Earth
- Best thermal conductor
- Hydrophobic
- Low coefficient of thermal expansion
- Chemically inert
- Electrically insulating
- Extremely strong

- ***Low coefficient of friction***
- ***Smooth as-deposited***
- ***Fracture toughness***
- ***3-5 nm grains***
- ***Micromachinable***

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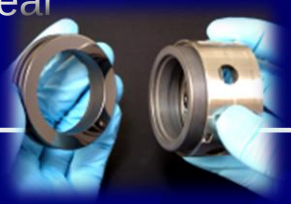
Ultrananocrystalline Diamond as Wear Resistant and Protective Coating for Mechanical Shaft Seal Applications

Advanced Diamond Technologies, Inc.

Impact

- John Crane offers largest product line with UNCD®
- Advanced Diamond Technologies, Inc. (ADT) selling UNCD seals to direct users (www.diamondseals.com)
- Reduced energy consumption, wear



Novelty

- Reduction in seal face friction by 75%
- Multiples of decrease in wear from SiC in accelerated wear testing with hot-water (250F, 150 psig).
- Smooth diamond suitable for use with conventional mating ring

Lineage

- UNCD resulted from 10+ years of R&D at DOE's Argonne National Laboratory (ANL)
- Advanced Diamond Technologies, Inc. spun out of ANL in 2003, and is exclusive commercial source of UNCD.
- Other products in market or development include UNCD wafers, AFM probes, supported by NSF SBIR programs

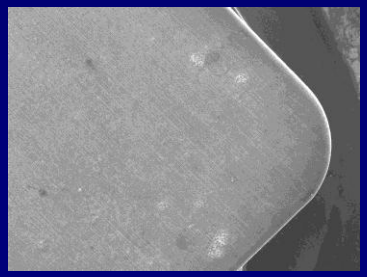
Company Mission

- TEAM: ADT (prime), ANL, John Crane NA
- Product-oriented company focused on thin, smooth diamond
- *We solve hard problems*™

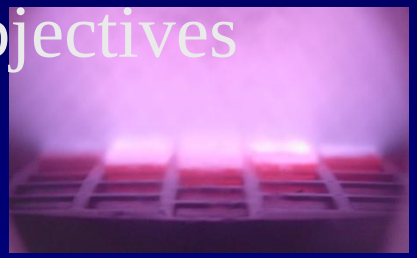
ADVANCED DIAMOND TECHNOLOGIES, INC.

Nanocrystalline Diamond Coated Cutting Tools

Vista Engineering Inc.



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

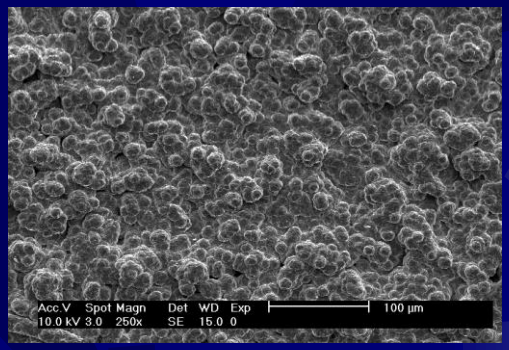
Commercialization Strategy

High-end
High Productivity
Partner with Tool Manufacturer
Automotive Applications

Nanocomposite Temperature-Adaptive Solid Lubricant Coating for Cutting Tools

Nanomech, Inc

- Novel composite coating for cutting tools comprising:
  - NanoTuff™ hard coating made of cubic boron nitride and titanium nitride (cBN-TiN)
  - Nanoparticles-based temperature adaptive solid lubricant coating made of zinc oxide and molybdenum disulphide (ZnO, MoS_2)
- Solid lubricant is temperature-adaptive and self-replenishing
  - Lubricant resides in reservoirs created by micro-structured surface of the NanoTuff™ hard coating



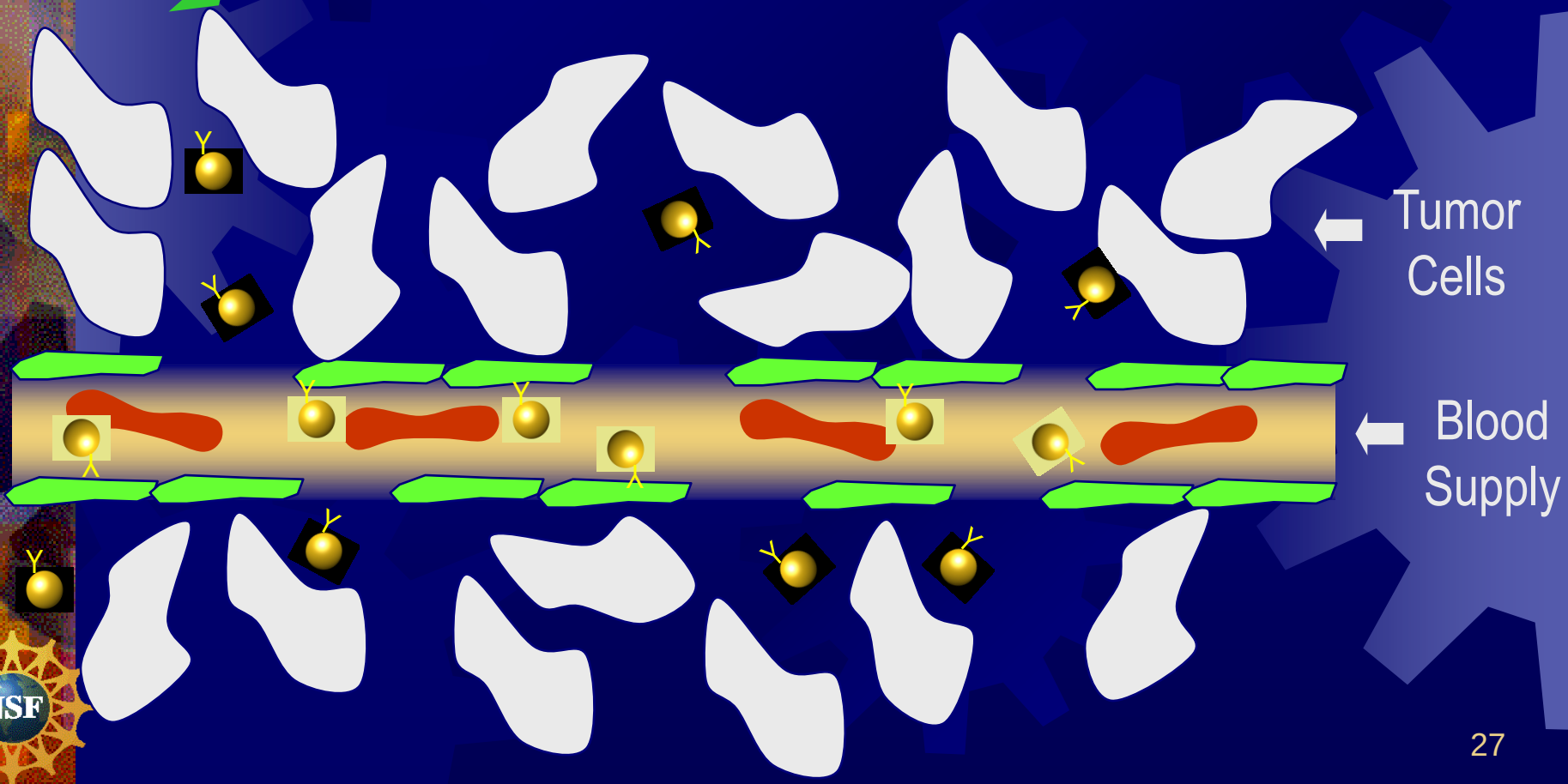
- Target applications:
  - Hard turning – manufacturers want to move from grinding of hardened steels to hard turning, thus lowering costs and increasing productivity
  - Dry machining – growing need to reduce or eliminate use of cutting fluids due to cost and environmental impact of fluids

Nanobiomaterials

Targeted Drug Delivery

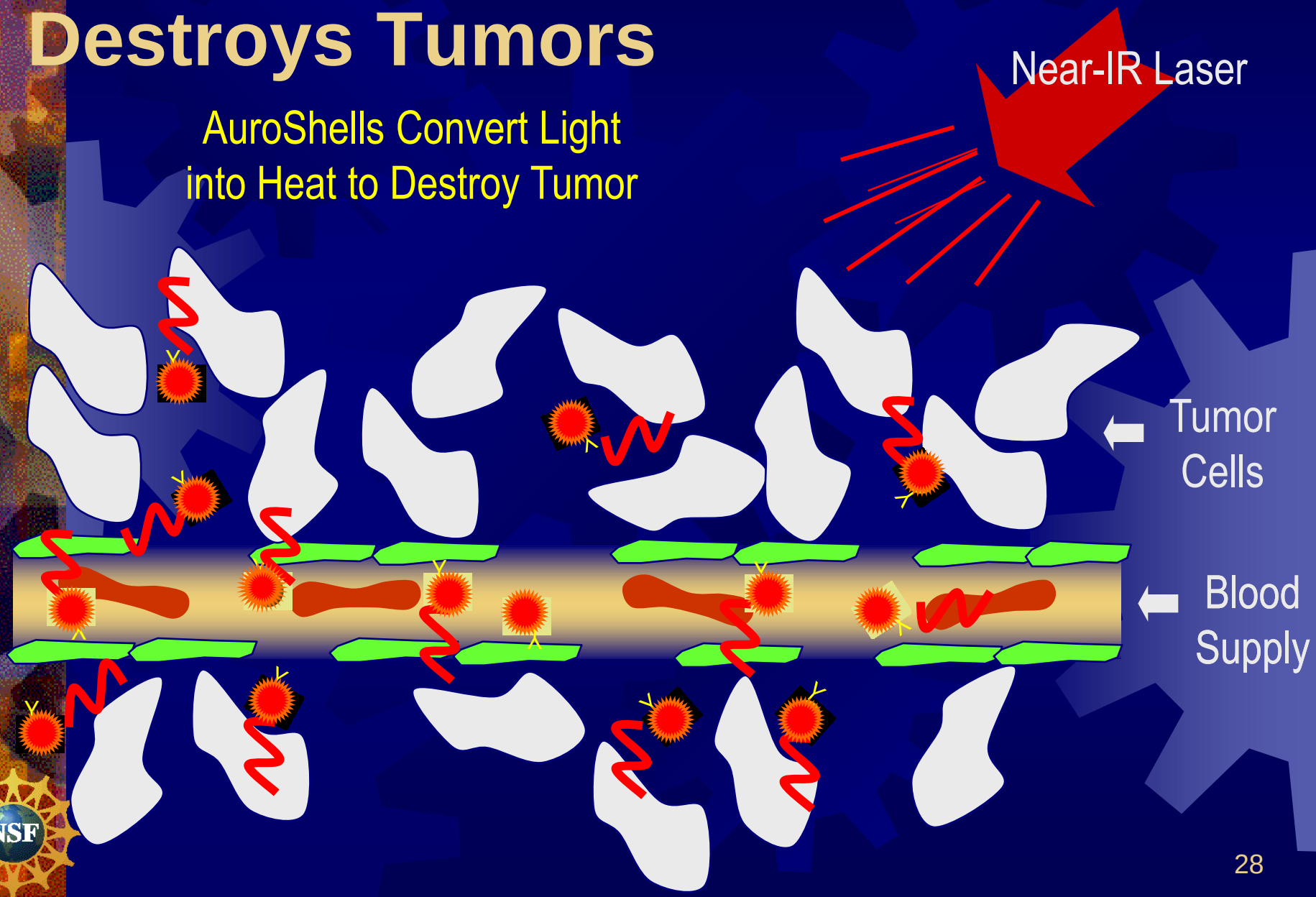
Nanospectra Biosciences, Inc

AuroShells Injected into Blood Will Exit Through Holes and Lodge in Tumor, Target Vasculature Receptors



AuroLase™ Therapy Thermally Destroys Tumors

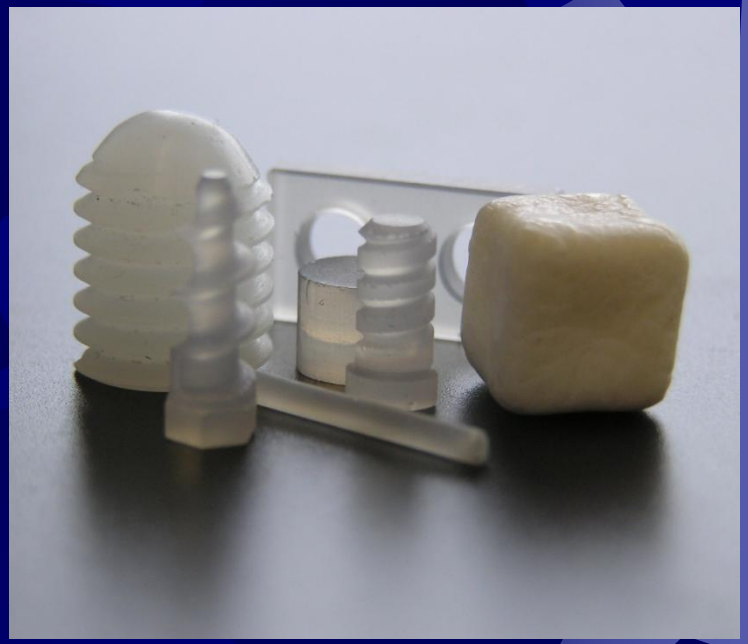
AuroShells Convert Light into Heat to Destroy Tumor



Synthetic Bone Material -NanOss™

Angstrom Medica

- Structural Medical Devices
  - Osteoconductive
  - Remodels into Bone Over Time
- Injectable Cement
  - Endothermic, Rapid-setting
  - Structural, Weight-bearing
- Bioactive Coatings
  - Micron Thicknesses
  - Can Act as a Carrier



Proprietary and Confidential

Nanocomposite Coating on Coronary Stents

Principal Investigator: Robert Hoerr, M.D., Ph.D.

Impact

- Provides an enabling tool for the drug eluting medical device industry
  - Accelerates product development through engineered drug release
    - Speeds translation of basic research findings into new therapeutics

Novelty

- ElectroNanospray™ technology creates superior medical device coatings with improved drug release and biocompatibility
- Single-step process, high degree of control enables high throughput testing of drugs and biologic agents for drug eluting stents
- Applicable for a wide variety of devices, tissue implants and drug formulation

Lineage

University of Minnesota IP. Co-founders included present executive team, inventors, University of Minnesota and Minnesota Research Fund

Partnering with other universities and small businesses to add value with new materials and patents

CharFac

Polymer Science

Stentome, LLC

Company Mission

Value Nanocopoeia will use its ElectroNanospray technology platform to improve delivery of therapeutic devices and materials.

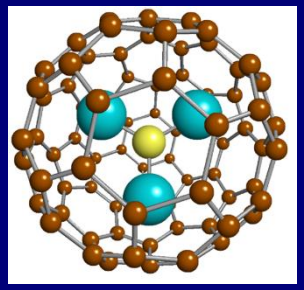
Team Multi-disciplinary technical and business focused team (10 FTE)

Exit Strategy Acquisition by Medical Device Industry Leader

Nanomaterial Contrast Agents for MRI

Luna Innovations, Inc

"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

Nanomaterial for SERS Microchip for drug monitoring.

REAL-TIME ANALYZERS
Providing Chemical Information When & Where You Need It

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

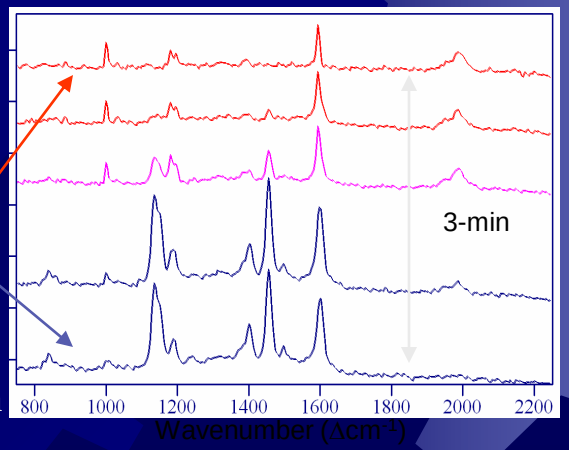
- Protect with patents
  (two submitted 10/02, third in 01/03)
- Develop applications with strategic partners (pharmaceutical, medical, clinical, biotech)
- Leverage exclusive use against investment

Results To Date

phenyl acetylene

p-aminobenzoic acid

2 chemicals separated and identified in 3-min



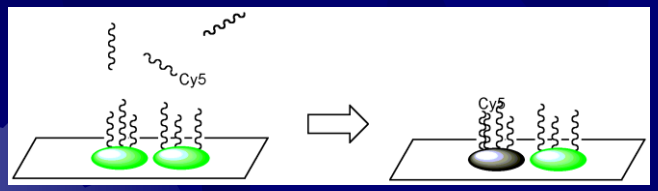
Applied Spectroscopy, 57, 479 (2003)

NOMADICS Life Sciences
215 First St., Suite 104,
Cambridge, MA 02142

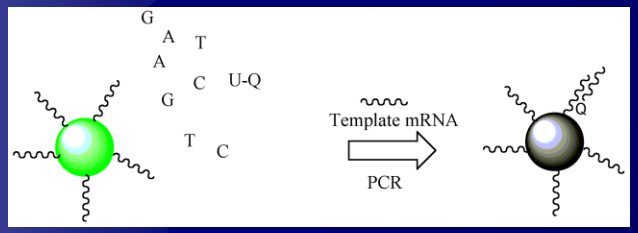
Fluoroescent Polymer Nanoparticles for Gene Sequencing

Fluorescent Polymer Nanoparticles

Gene Expression Reagents



q-RT PCR Reagents



Goals

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

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

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

Commercialization Strategy

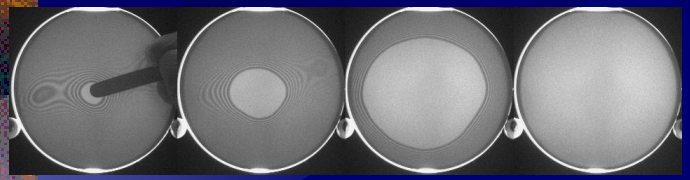
- Direct integration of PPE nanoparticles into widely practiced experiments on existing bioanalytical instrument platforms.
- Introduction of PPE-based labels and nucleotide conjugates in application-specific reagent kits.
- License and/or partner with established reagent suppliers and equipment

Nanoelectronics

Ge-Free Strained Silicon

Belford Research, Inc

Ge-Free Strained Silicon Via dTCE Bonding



Differential TCE Bonding

Technical Objectives

- Design and build plasma bonder
- Define and control surface energy
- Homo- and Hetero- differential bonding
- Strain-Si layer formation

Goals

- Uniaxial Compensated Strained-Si Layer
- Biaxial Strained Layer Formation
- Stabilized Strain-layer

Commercialization Strategy

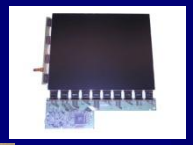
- License the Technology
- Strategic Partnership in Process
- Produce Small Specialized Runs In-House

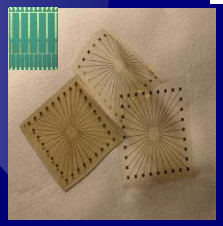
Thin Film Transistors: Silicon Nanowires

Nanosys, Inc

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

TFT Backplane Drivers – Integrated Edge Electronics





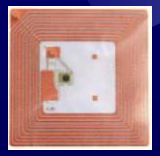
Beam-Steering Antennas

- **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**

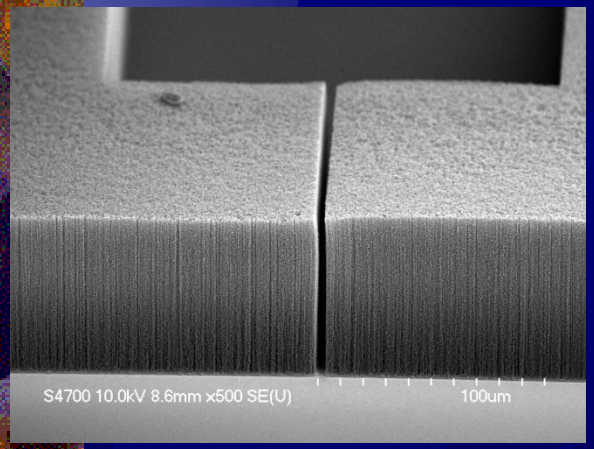
RFID Tags

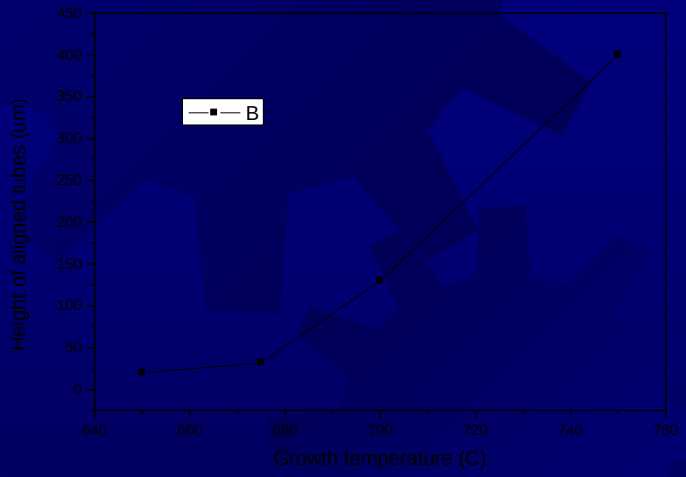


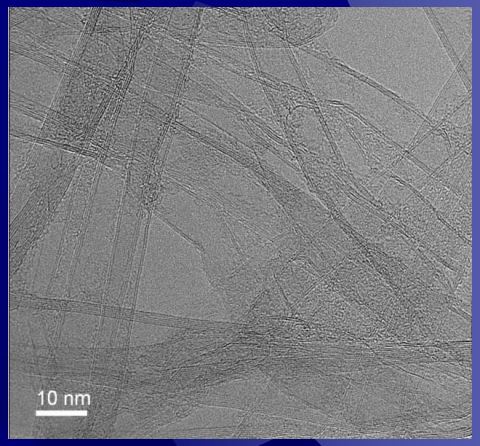
CARBON NANOTUBE FOR THERMAL TRANSFER

Molecular Nanosystems

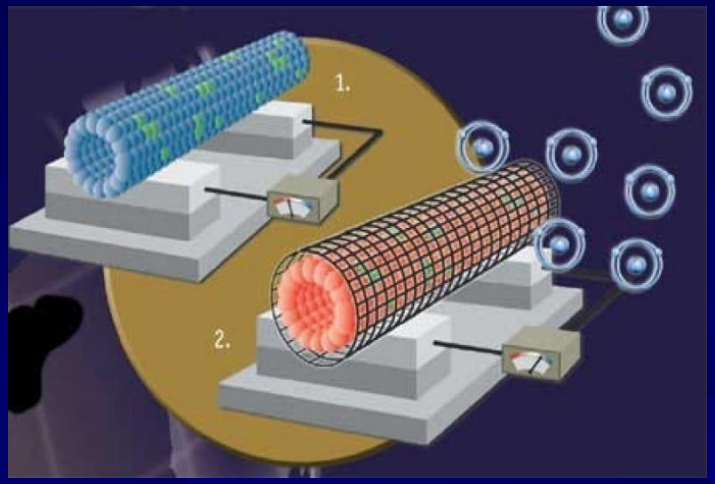
- Project goal: Development of nanotube pad for microelectronics cooling interface
- Technology: CVD-based site-selective synthesis of carbon nanotubes
  - :



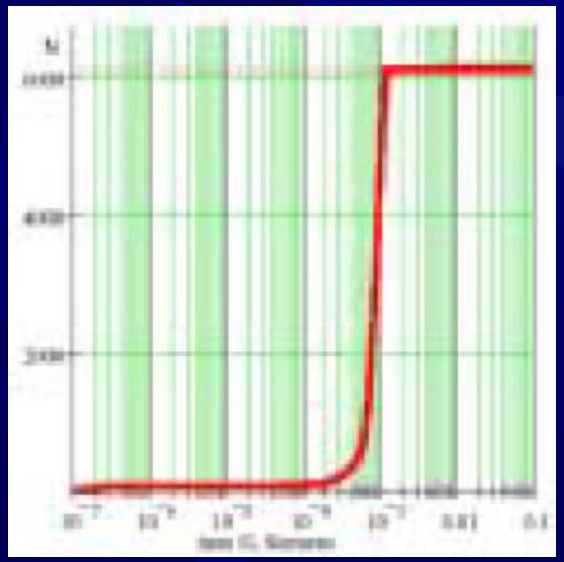




+ One new patent application filed



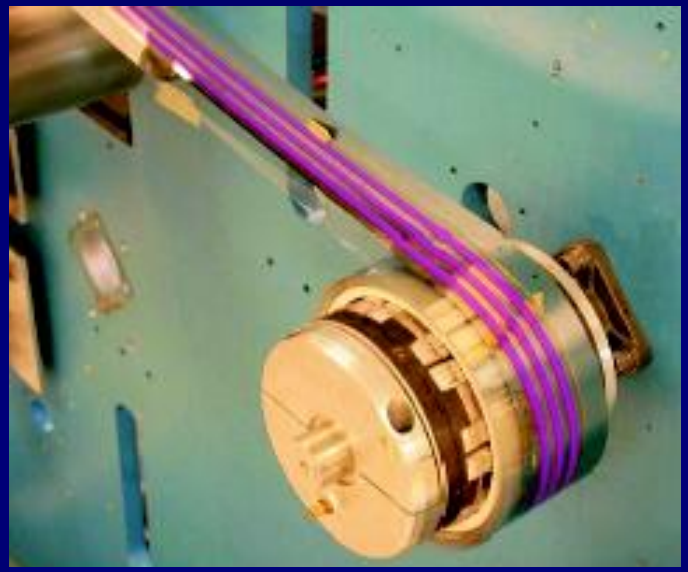
nanōmix



Photovoltaics : Nanoparticle co-sensitizers for increased efficiency.

Konarka, Inc

From Light to Power



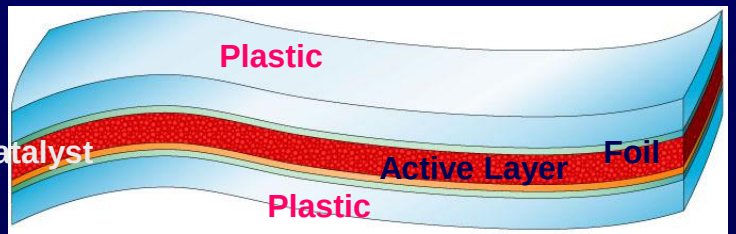
Polymer photovoltaic products in a variety of form factors for commercial, industrial, military and consumer applications

- **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

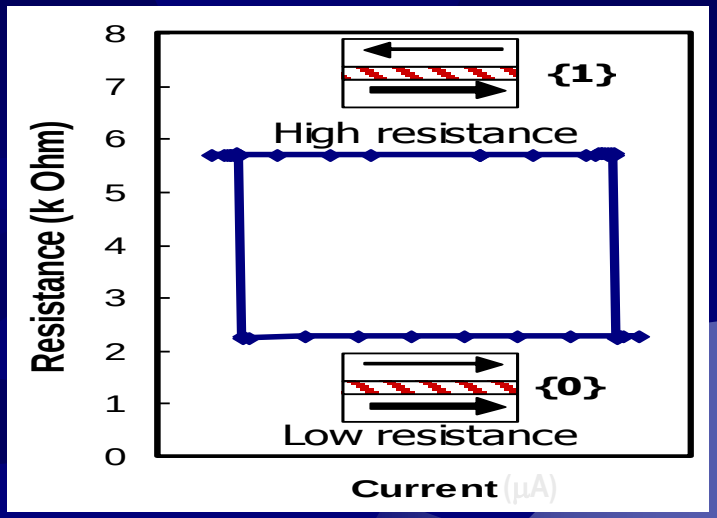


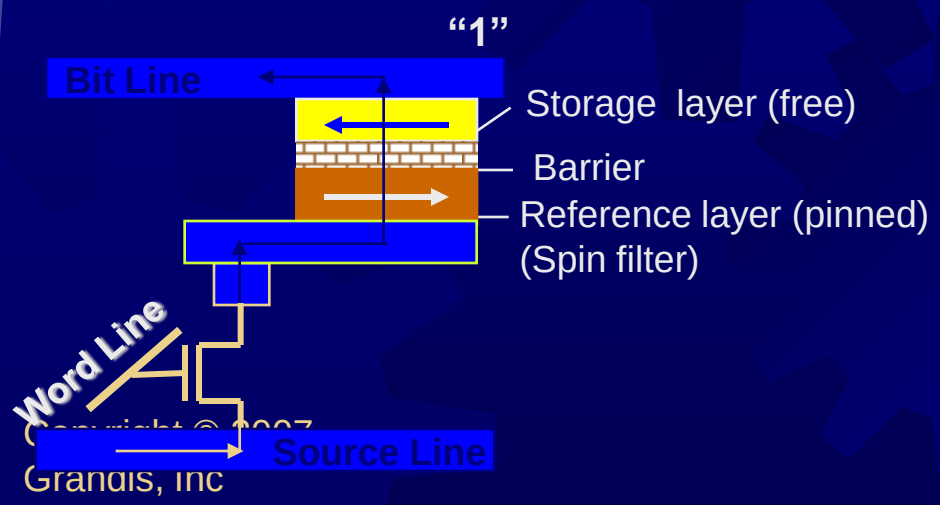
Nanomagnetics

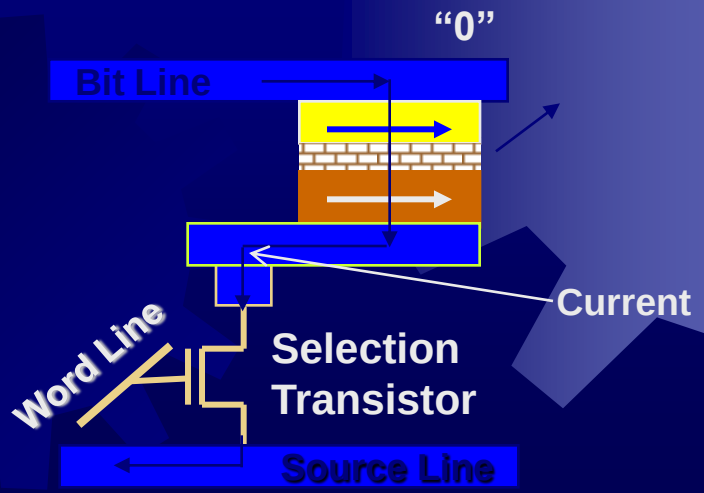
Spintronics Non-volatile Memory

Grandis, Inc

- **Spin Transfer Torque RAM (STT-RAM)**
  - Fast: less than 10ns read/write
  - Non-volatile memory: >10 year lifetime
  - Scalable: beyond 65nm
  - Low Power
  - Multiple bits per cell capable
  - Compatible with semiconductor processes
- **SBIR PHASE II Grant**
  - Allows Grandis to continue materials research to enable an advanced demo chip to accelerate commercialization.







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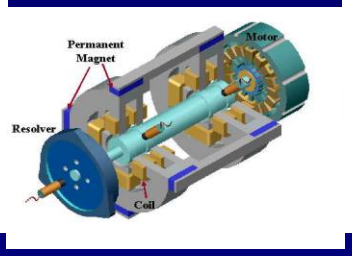
Grandis, Inc

Nano-magnetic materials

Materials Modification, Inc

Nanocrystalline FeCo for EMI Suppression



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

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

Commercialization Strategy

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

Nanotechnology for batteries

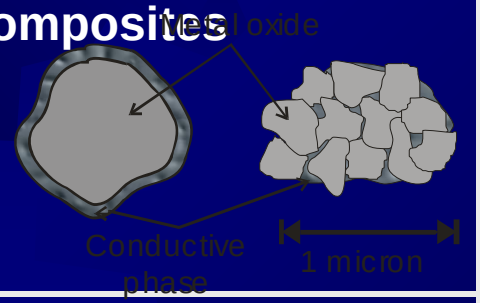
- Grants related to battery technology

T/J Technologies, Inc.

Lithium Ion Batteries

Technology:

High Rate, High Capacity Anodes for Rechargeable Li Batteries Based on Metal Oxide Nano Composites



Outside Investment

NASA Contract: $2,200,000
Acquired by A123 Company

Goals:

- Reduce irreversible capacity to <15%
- >300 mAh/g reversible capacity
- >10C at 80% rated capacity and 80% DOD
- Achieve projected material costs of <$10/kg

Commercialization Strategy:

- System payoff:
  30-50% reduction in large format lithium-ion battery size
- Develop a cost-competitive battery suitable for HEV, UPS, military and aerospace applications
- Strategic Partnerships for joint development of new materials:
  materials production and battery manufacturing

Lithium Reservoir Nanocarbons for Lithium Ion Batteries
Applied Sciences, Inc

IMPACT

- Enables Long-Range HEVs and EVs
- Supports Alternative Energy Use
- Reduces Emissions
- Reduces Dependence Upon Foreign Oil
- Creates Domestic Manufacturing Jobs

NOVELTY

- High Capacity Anodes for Li-Ion Battery
- Safe Performing Battery

LINEAGE

- Technology
  - Carbon Nanofiber – GM, ASI, PPI
  - Anode – ASI, PPI, GM, Others
- Funding Source
  - NSF → GM → Ohio Fund → A123
  - M Secured

COMPANY MISSION

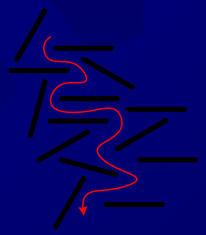
- High Performance Li-Ion Battery → Chevy Volt
- Insertion in 2011 at 30 k lb/yr
- $8 M investment for 400 k lb/yr demand in 2013
- Revenues of $26 M by 2013
- ROI > 45% in 2013

Nanomanufacturing

Supercritical Fluid Processing of Polymer/Clay Nanocomposites

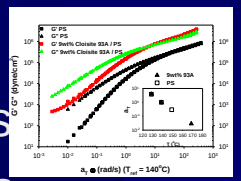
nanoScience Engineering Corporation
Steve Horsch

Impact

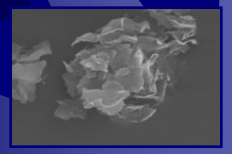


- Create jobs
- Create wealth for investors
- Increase shelf-life of perishables
- Introduce high performance nanocomposites in products

Novelty



- Green, economical process
- Highly dispersed nanofillers
- Improved mechanical, thermal properties
- Improved barrier properties



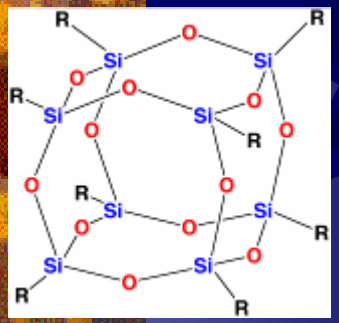
Lineage

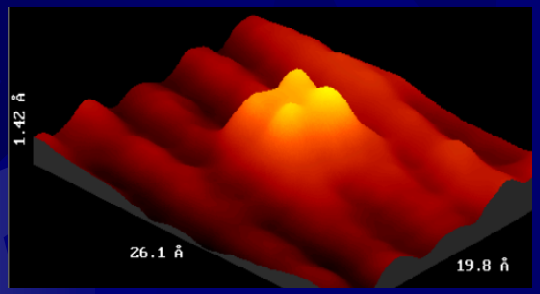
- Joint Development Agreements
- Raised $500,000 venture capital/investors
- Collaboration with WSU/Clemson

Company Mission

- Value: Highly dispersed nanofillers at a competitive price
- Team: Experienced entrepreneurs and Research Scientists
- Exit Strategy: IPO, Strategic Partnership, or Sale

Hybrid Plastics, Inc
POSS® Nanotechnology





1nm POSS® on silicon wafer

POSS® is the only "nano" that is amenable to top-down electronics grade manufacturing.

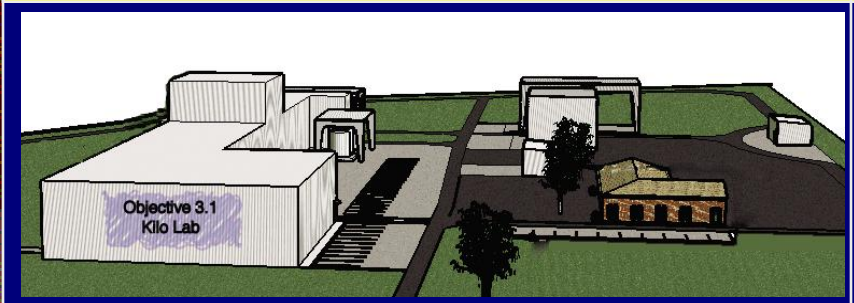
POSS® Dielectrics

POSS® Photoresists

Nanostructured® Lead-free Solders

NeuShield® & POSS® Shield

Hybrid Plastics Commitment



Facility Expansion for Electronic Grade POSS

- 14000 sqft expansion of existing production facility
- Represents $1.5M for POSS® in microelectronics

Benefits

- Affordable OEM Pb-Free Solder Solution
- Affordable Retrofit Solution POSS® Shield
- Turnkey insertion into OEM & Retrofit processes.
- Intellectual property portfolio
- 2005 Presidential Determination for POSS®

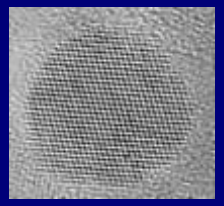
Silicon Nanoparticles Manufaturing

Innovalight, Inc

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

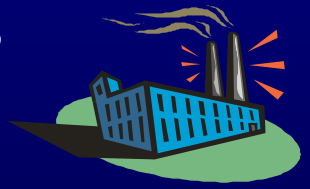
Technical Objectives:

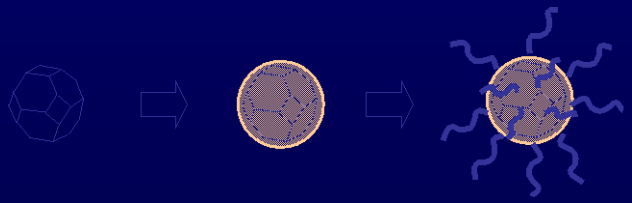
- High quantum yields
- Tunable emission
- Defect-free particles



Goals:

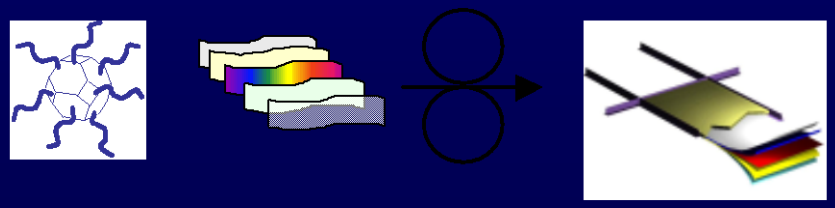
- Si nanomanufacturing system
- Process parameters
- 5 grams/hour





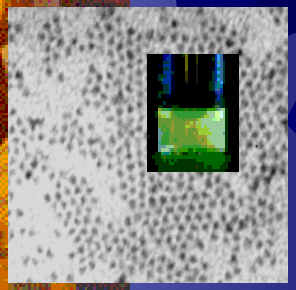
Commercialization Strategy:

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

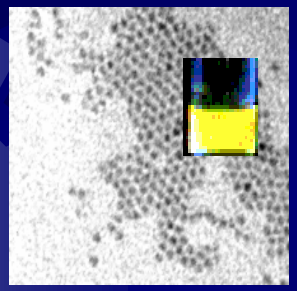


Quantum Dot Manufacturing
NN- Labs

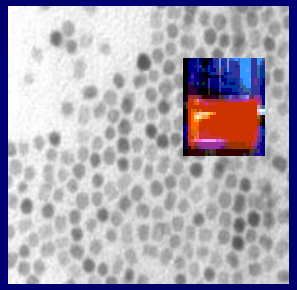
A New Scale-Up Technology for Industrial Production of High-Quality Semiconductor Nanocrystals



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

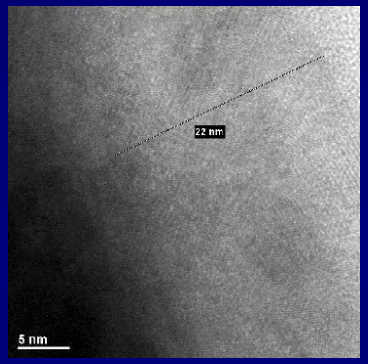
- Focus on electronic and biological applications
- Patent and license the synthesis protocol
- Advertise: Commercial ads and conference exhibits
- Secure financial support from VC and strategic partners

Atomic Layer Deposition

ALD NanoSolutions, Inc.

STTR Phase II: Novel Nanocoated Ferromagnetic Materials

γ-Al_2O_3 growing epitaxially to iron particle surface



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

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

Commercialization Strategy:

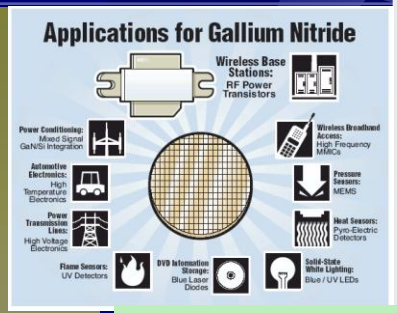
- Work with Strategic Partners to Design materials for the Aerospace, Elecronic, and Automotive Industries
- Using Facilities proven during Phase II, provide materials for Consumer Product Development
- License or Manufacture coated particles designed through Phase II to Strategic Partners as needs dictate

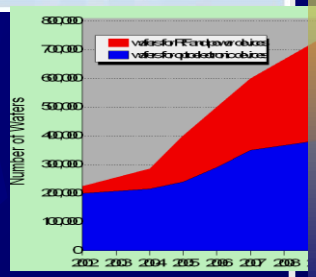
Gentle Atomic Level Chemical Mechanical Smoothening (CMS) of Gallium Nitride Substrates

Sinmat, inc

Impact

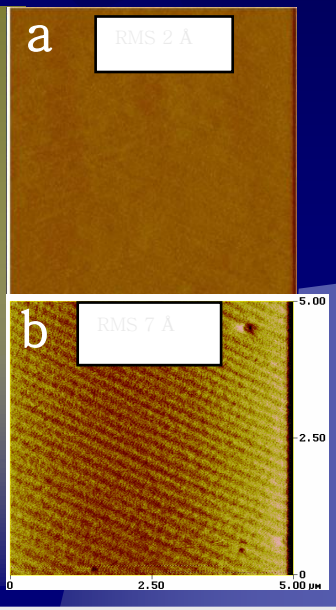
- Increasing demand for WBG devices for RF, power & opto-electronic applications
- GaN components sales > $7.2 Billion by 2009
- Great potential for energy saving devices
- Creation of new hi-tech R&D and manufacturing jobs





Novelty

- Novel polishing process (chemistry, particles, etc.) for bulk GaN & GaN films on various substrates
- Atomic level polishing
- High removal rate
- Uniform, low defect polish over large area: high yield/low cost
- Scalable > 2" substrates
- Good reproducibility



Lineage

- Idea conceived and developed at Sinmat Inc.
- Patent applications in preparation
- Selective results have been published
- Collaborations with University of Florida (UF) for film deposition, device fabrication, testing and data analysis
- Several companies interested in Sinmat's process, and supplying substrates for evaluation of GaN polishing process

Sinmat Inc.'s Mission & Goals

- Establish a leadership position in providing value-driven semiconductor solutions to industry on planarization technologies
- Establish strategic industrial partnerships for R&D, marketing, sales, & services
- Build up Intellectual Property portfolio (5 licensed patents & several pending applications)
- Teams: Sinmat scientists (9 PhDs); UF (Profs. Pearton & Abernathy); Advisors & Consultants

End of examples

- Please see MatchMaker CD for more details of these SBIR/STTR grants.
- Important new opportunity for STTR grants.

Multi-Functional Materials

Upcoming Proposal Opportunity (Solicitation: NSF 08- 608)

http://www.nsf.gov/pubs/2008/nsf08608/nsf08608.htm

- Letter of Intent due **January 14, 2009**; Full proposals due **February 25, 2009**
- Multi-Functional Materials includes four broad subtopics
  - **Bio-inspired Materials and Systems (BMS)**
  - **Materials for Sustainability (MS)**
  - **Nanostructured Materials (NM)**
  - **Smart Materials and Structures (SMS)**

Summary

- SBIR/STTR grants are a key part of the technology transfer between universities and industry for commercializing nanotechnology.
- In FY 08 the NSF SBIR/STTR program made 85 nano-related grants to small companies totaling close to $18 MM.
- Across the whole Federal government SBIR/STTR programs accounted for $80 MM in nano-related grants (FY 07).

NSF SBIR/STTR Home Page

www.nsf.gov/eng/iip/sbir

Thank You

James Rudd

tjrudd@nsf.gov