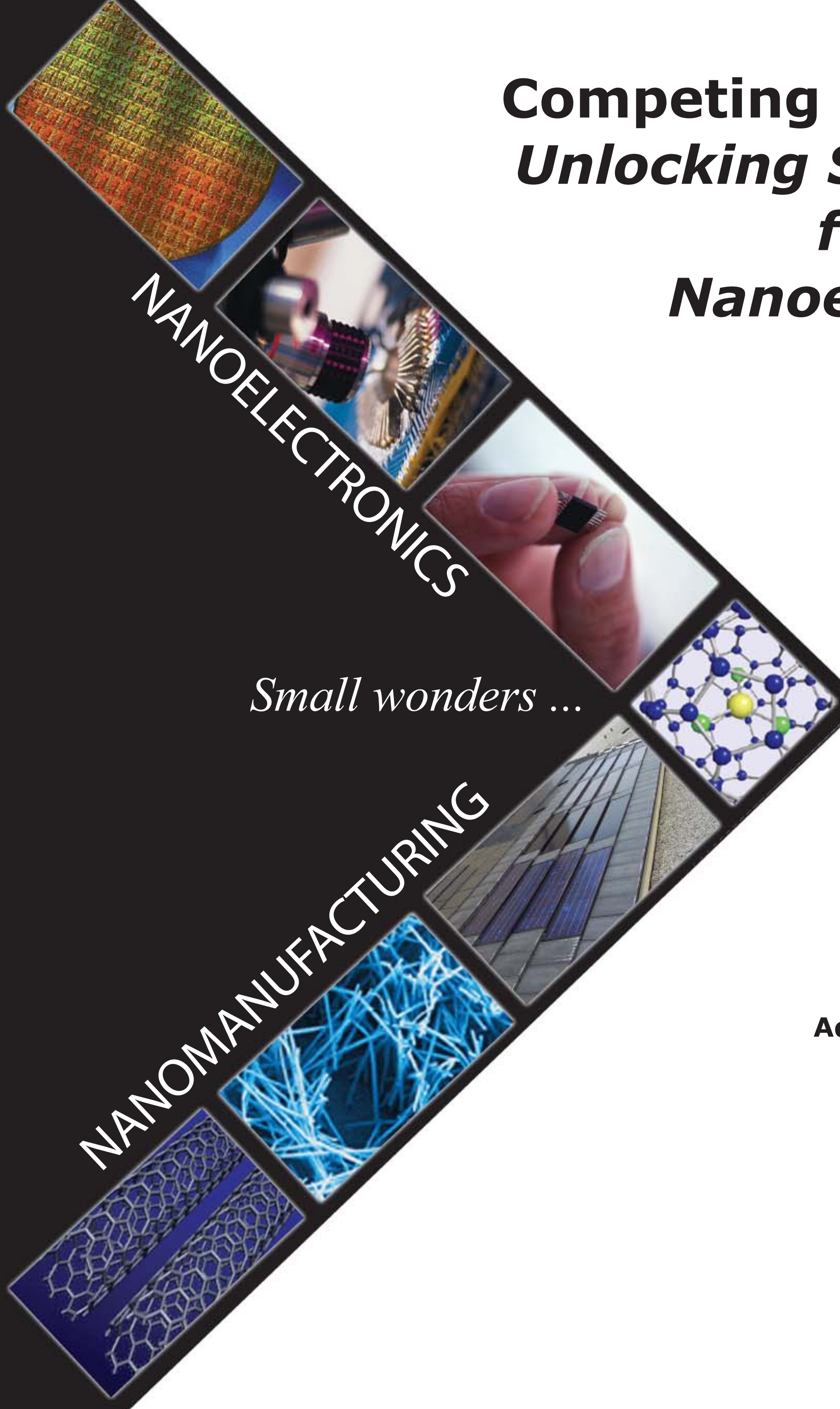
ADVANCED TECHNOLOGY PROGRAM

Competing for the Future:
Unlocking Small Wonders for Tomorrow's Nanoelectronic Uses



Small wonders ... big challenges!

Marc G. Stanley, Director
Advanced Technology Program
NIST

October 2006

National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce

Competing for the Future:
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Acknowledgement

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Competing for the Future:
Unlocking Small Wonders for Tomorrow's Nanoelectronic Uses

"Nanotechnology touches upon a broad array of disciplines, including chemistry, biology, physics, computational science, and engineering. Like information technology, nanotechnology has the potential to impact virtually every industry, from aerospace and energy to healthcare and agriculture."

The National Nanotechnology Initiative at Five Years:
Assessment and Recommendations of the
National Nanotechnology Advisory Panel
May 2005

It has been suggested that by 2025 at least half of the companies comprising today's Dow Jones Index will be replaced by nanotechnology companies. In a recent report, Lux Research forecast the worldwide market for nanotech products and services to reach $2.6 trillion by 2014. If this happens, it will represent approximately 15% of global manufacturing output.[1]

Nanoelectronics is defined as advanced electronic and optical systems that depend upon innovations in nanotechnology. The field of nanoelectronics embraces a range of technologies, all ultimately for the purpose of creating and improving the functionality, cost, and performance of tomorrow's electronic systems. This report examines the historical role the Advanced Technology Program (ATP) has played in fueling innovation and American competitiveness in areas of nanotechnology that will lead to totally new-to-the-world electronic and optical products.

NIST, ATP and Nanotechnology

For more than a century, the National Institute of Standards and Technology (NIST) has helped to lay the foundation for the innovation, economic growth, and quality of life that Americans have come to expect. NIST technology, measurements, and standards help U.S. industry invent and manufacture superior products reliably, provide critical services, ensure a fair marketplace for consumers and businesses, and promote acceptance of U.S. products in foreign markets.

Researchers in NIST's seven major laboratories are developing measurements, standards, and data crucial to private industry's development of products for nanotechnology markets. NIST's work also aids federal agencies' efforts to exploit nanotechnology to further their missions, such as national security and environmental protection. In addition, NIST has launched the new state-of-the-art Center for Nanoscale Science and Technology to help U.S. companies, universities, and government agencies overcome obstacles to cost-effective manufacturing of nanoscale products.[2] NIST's accomplishments in nanotechnology are captured in a recent NIST Special Publication.[3]

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1 Sizing Nanotechnology's Value Chain, Lux Research Report, October 2004.
2 http://physics.nist.gov/Divisions/Div841/Gp3/cnst_home.html.
3 *Accomplishments in Nanotechnology,* NIST Special Publication: 1052, August 2006.

The nanotechnology projects funded by ATP are poised to impact the way in which tomorrow's electronic and optical products are conceived, perform, and ultimately deliver economic security, quality of life, and social benefits to American citizens.

The Advanced Technology Program (ATP), one of the three external programs within NIST, has contributed to developments in nanoelectronics since 1999 when the first nanotechnology awards began. ATP has the mission of helping U.S. companies bridge the gap between the research lab and the marketplace by encouraging them to pursue the development of high-risk enabling technologies that otherwise would not be developed or that would be developed too slowly to take advantage of market opportunities. ATP's early stage partnerships and investments with the private sector accelerate the development of innovative technologies deemed too technically risky or too far from commercial viability to be considered by private sector funding sources. ATP-funded projects promise significant commercial payoffs and widespread economic benefits for the nation in the longer term. Through a competitive peer review process, ATP has issued awards based on rigorous technical and economic criteria:

- Scientific and technological merit: innovation, high technical risk and feasibility, and quality of R&D plan, and
- Potential for broad-based economic benefit: national economic benefits, need for ATP funding, and pathway to economic benefits.

ATP has funded **25 nanotechnology awards** across nine states for nanoelectronic applications. These awards represent **$224.1 million of total industry-based R&D**, of which $114.6 million has come from ATP and $109.5 million as cost share from industry. ATP's first awards in nanotechnology became active in Fiscal Year (FY) 1999 and addressed technology barriers in semiconductor manufacturing and energy. Since then, the number of nanotechnology awards has steadily grown as opportunities emerge. **Figure 1** presents the profile of ATP nanotechnology awards for nanoelectronics underway during any one year, from FY 1999 to the present. For example, 18 of the 25 awards were active and underway in FY 2005.

Figure 1
Yearly Representation of Active ATP Nanotechnology Awards for Nanoelectronic Uses

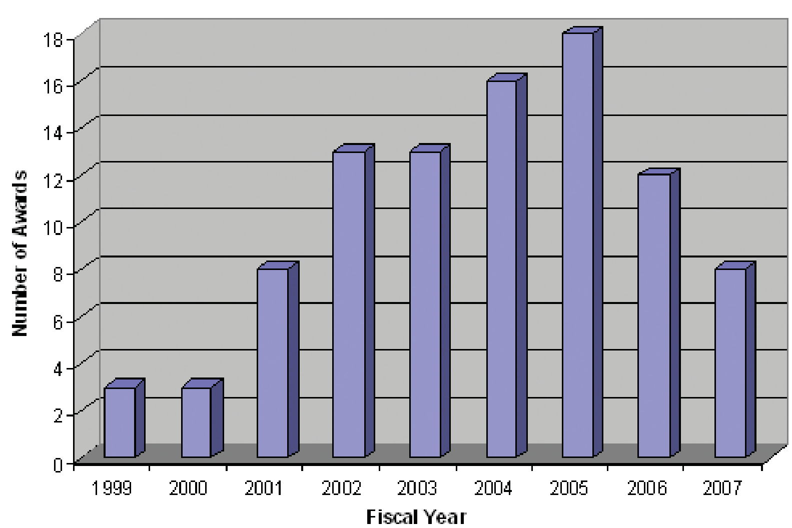

Table 1 summarizes ATP's nanotechnology funding for projects that impact nanoelectronics. It shows the distribution of awards among award type, participant type and size[4], and presents project lead information by company size. Of the 25 awards funded, 13 have been single applicants and 12 as JVs. Within these awarded projects, a total of **90 entities** have participated as recipients and subcontractors. Of these, **nearly 80% of all participants have been small entrepreneurs, mid-sized companies, or universities**. Furthermore, *all* single applicant awards and *over half* of the joint-venture (JV) awards for nanoelectronics have been led by small- or medium-sized companies. This large percentage involvement by small- to medium-sized businesses, and universities, speaks to the newness and opportunities of nanotechnology, and the role these enterprises play in creating game-changing, disruptive technologies. *Appendix A* shows all companies, universities, or other entities that have participated in ATP awards in nanotechnology for tomorrow's electronics.

Table 1 - ATP Nanotechnology for Nanoelectronics Awards and Funding ($ millions)

Total R&D Funded	**$224.1**		**Total Participants** [5]	**90**
ATP share	$114.6		Small Company	43
Industry share	$109.5		Medium Company	7
			Large Company	16
Total Awards	**25**		Not-for-Profit Organization	1
Single Applicant	13		University	22
Joint Venture	12		Federal Laboratory	1
Single Applicant by Lead	**13 awards**		**Joint Venture by Lead**	**12 awards**
Small Company	13		Small Company	5
Medium Company	0		Medium Company	2
Large Company	0		Large Company	4
			Not-for-Profit Organization	1

In the nanotechnology awards reported, universities as subcontractors or JV partners are playing an essential and expansive role in translating laboratory research into viable commercial technologies. Universities participate, on average, in nearly each award ATP has funded in this area. Also, ATP JVs are being effectively used to foster partnerships between universities as scientific experts, small entrepreneurs as suppliers, and large firms as developers of complex technological systems. ATP nanotechnology JV awards for nanoelectronics represent the cutting edge in technology innovation and in the business model used by international systems developers to remain competitive within the global marketplace. ATP's awards in this area are helping position American small businesses to become best-of-the-breed global suppliers.

[4] ATP defines a "company" as a for-profit business that is independently owned and operated and is organized for profit. A "small company" is a business with fewer than 500 employees. A "large company" is any business, including any parent company plus related subsidiaries, having annual revenues that places it within the Fortune 500 listing of companies for the year the award is issued. A "medium company" is a business that falls in between a small and large company.

[5] Participants represent all organizations, including subcontractors, and may include multiple instances of involvement by the same organization.

Table 2 shows the funding distribution among states, based on the location of the lead company for the award. The funding distribution shown does not reflect the final funding received by each state because projects distribute funds to several partners and subcontractors that may be located in other states, including those not shown here. *Appendix A* does identify states that are associated with each ATP award participant and the nature of their participation.

Table 2
ATP Nanotechnology for Nanoelectronics Awards and Funding Among States

State	AWARDS			FUNDING*		
	Total	Single Company	Joint Venture	Total R&D, $M	ATP Share, $M	Company Share, $M
California	8	5	3	$62.69	$32.63	$30.06
Connecticut	1	1	0	$0.90	$0.44	$0.46
Kansas	1	1	0	$2.31	$2.00	$0.31
Maryland	1	1	0	$3.38	$1.97	$1.41
Massachusetts	1	1	0	$3.41	$2.00	$1.41
Michigan	2	0	2	$30.99	$15.11	$15.88
New Mexico	1	1	0	$3.84	$2.00	$1.84
New York	3	1	2	$16.90	$8.22	$8.68
North Carolina	2	1	1	$9.35	$5.38	$3.97
Texas	5	1	4	$90.31	$44.80	$45.51

* Funding amounts are a reflection of the state of residence of each award lead company.

Expanding Frontiers and Delivering Benefits: Innovations in Nanotechnology

The New York State Office of Science Technology and Academic Research (NYSTAR) reported earlier this year (2006) that the State University at Albany's Center for Advanced Technology in Nanomaterials and Nanoelectronics has generated $1.1 billion in economic impact against a New York State investment of $7 million.

Albany Business Review, February 27, 2006

Today, across the globe, a race is underway as scientists and engineers seek to unlock the secrets and possibilities of nanotechnology. [6] The ability to understand and control matter at dimensions from 1 to 100 nanometers, where unique phenomena arise, will unlock innovation and enable novel applications. The nanotechnology innovations made possible by ATP funding will aid America's economic security in tomorrow's information, health, and energy economies.

Table 3 shows five application areas that emerge as the most likely early-on beneficiaries of the nanotechnology innovations that have been developed by ATP funded project teams. Because of the enabling nature of the awards ATP funds, spill-over benefits to other application areas are expected to accrue as the technology is successfully diffused within the marketplace. Thus, application areas beyond those identified below are likely to emerge from the awards ATP has funded in these areas.

Table 3
Early-on Application Areas of ATP Funded Projects in Nanoelectronics

Application Area	Number of Awards	Funding		
		Total R&D, $M	ATP Share, $M	Company Share, $M
Alternative Energy	5	$18.38	$9.93	$8.44
Bioelectronics	3	$16.74	$9.60	$7.14
Materials Discovery	2	$16.56	$8.56	$8.00
Mixed-function Electronic Systems	7	$73.32	$36.21	$37.11
Semiconductor Nanomanufacturing	8	$99.09	$50.26	$48.83

Nanoelectronics, like nanotechnology, is already positioned to be a major engine of change that drives economies well beyond the 21st Century. Many of ATP's nanotechnology awards for nanoelectronics directly involve innovations in metrology, materials, manufacturing, or device technologies that directly impact semiconductor nanomanufacturing and electronic systems application areas.

[6] A nanometer is one-billionth of a meter (10xE-9 m). Novel and differentiating properties and functions of nanomaterials and nanoscale devices arise at this critical length scale of matter (http://www.nano.gov/html/facts/whatIsNano.html).

- ***Semiconductor nanomanufacturing*** investments set the stage for tomorrow's integrated circuits, the infrastructure upon which they depend, and the nanoelectronics products that they enable.
- ***Mixed-function electronic systems*** benefit from nanotechnology innovations in magnetic, optical, or electronic technologies. When merged with advanced semiconductor electronics, giving rise to broader utility of nanoelectronics in tomorrow's economy takes place.

Nanoelectronics offer solutions to the demands for ever increasing data rates. It enables a shift to optical communications within and between IC chips. New low-cost ultra-high bandwidth optical communications, made possible by nanomanufacturing photonic crystals, will greatly improve the performance of computers and the internet. Other advancements include nanomaterials for solid-state lighting; precise deposition reactors for ultra-high density magnetic memory; and precisely controlled growth of nanomaterials for medical imaging systems, lamps and displays. These innovations will be possible because of ATP funding that benefits mixed-function electronic systems.

Three other nanoelectronics application areas expected to find early benefits from ATP funded projects include bioelectronics, fundamental materials discovery, and alternative energy generation.

New nanoscale devices and manufacturing processes are allowing manufacturers to utilize spintronics-based memory in conventional integrated circuits, allowing the increased use of magnetic memory for non-volatile, low power, and fast computer memory.

- ***Bioelectronics***, an interdisciplinary research field that has recently emerged, will impact a range of industries. It seeks to exploit the growing technical ability to integrate biomolecules with electronics to develop a broad range of functional devices.[7] Bioelectronics includes elements of chemistry, biology, physics, electronics, nanotechnology, and materials science.
- ***Materials discovery*** is the process of creating wholly new materials, including electronic materials or nanomaterials, as a result of nanoscale metrology innovations being coupled with advanced electronic systems.
- ***Alternative energy***, in particular renewable energy such as fuel cells, photovoltaics, and energy storage systems, all are poised to benefit from breakthroughs in nano-materials, devices and manufacturing.

To be commercially successful, nanoelectronics, like other applications of nanotechnology, demands a broad range of innovations. The federal government first acted on the potential for the broad-based impact of nanotechnology in FY 2001 through the establishment of the National Nanotechnology Initiative (NNI). The NNI identifies a number of essential investment areas in nanotechnology innovation.[8] Four NNI innovation areas are applicable to the awards ATP funded:

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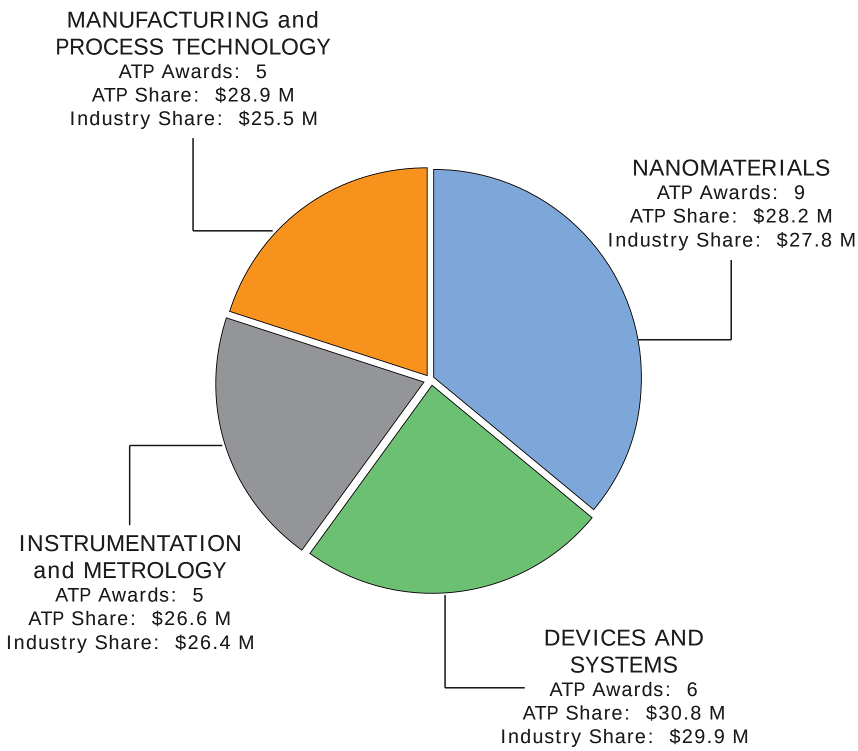
[7] http://www.sric-bi.com/Explorer/NGT-BE.shtml.

[8] The National Nanotechnology Initiative – Supplement to the President's 2006 Budget, National Science, Engineering, and Technology Subcommittee, Committee on Technology, National Science and Technology Council, March 2005.

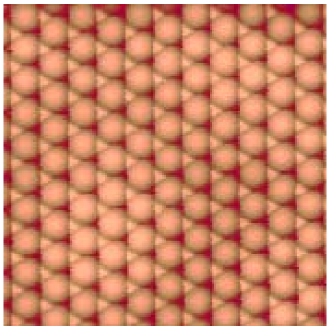
- New nanoscale ***devices and systems*** built upon diverse nanotechnology innovations with improved performance or new functionality.
- Cutting edge ***instrumentation and metrology*** capable of resolution, precision and throughputs that match industry's exacting demands.
- New ***manufacturing and process technologies*** that allow for precisely controlled fabrication of nanometer structures that perform and behave within design tolerances.
- New ***nanomaterials*** that capture uniquely new properties and functionality as a result of their controlled composition and nanometer-scale structure.

Figure 2 presents a breakdown of ATP's nanotechnology awards with application to nanoelectronics, using the four NNI innovation areas outlined above. New nanomaterials innovations dominate the portfolio, accounting for 36% of ATP's awards impacting nanoelectronics. This observation underscores the enabling nature of new materials innovations that has historically driven new technology innovation.

Figure 2
ATP Funded Nanotechnology Innovation for Nanoelectronics Applications



The following sections present examples of ATP-funded projects in each of these four NNI innovation areas, and provide a glimpse into the technologies that have been developed and the potential economic security, quality of life, and societal benefits to America's citizens that are likely as a result of ATP funding. *Appendix B* also presents all 25 ATP nanotechnology awards for nanoelectronics categorized by NNI innovation and early-on application areas.



DEVICES AND SYSTEMS

ATP has invested **$30.8 million** in nanoscale devices and systems R&D, with **$29.9 million industry cost share** across **six projects**.

Innovations in nano-scale devices and systems are poised to provide new types of electronic, photonic, and other devices and systems across a wide range of applications. Biotechnology and healthcare, and telecommunications and integrated circuits are a few of the application areas most likely to benefit from innovative nano-scale devices and systems.

An ATP funded award in nanoscale devices and systems that is well positioned to create substantial broad-based benefits for U.S. industry was recently completed by Luxtera, Inc.[9]

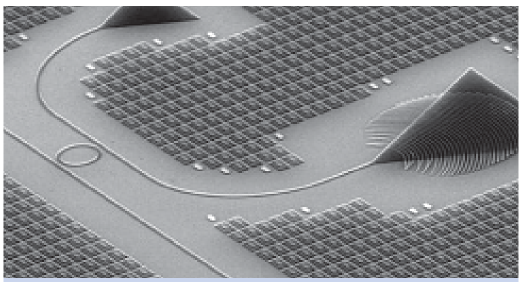


Image: Electron microscope image of a vertical optical coupler within a npIC (image courtesy of Luxtera, Inc.)

Nanophotonic Integrated Circuits for Telecommunications and Computing

Luxtera Inc.

Project: Design, fabricate, and demonstrate the performance of nanophotonic circuits integrated on semiconductor wafers using standard semiconductor processing equipment.

Optical switching systems now used to send telephone calls and internet data over fiber-optic communication lines fill large racks and are costly to buy and operate. In its ATP project, Luxtera, Inc. drastically shrank these systems down to just a few microchips by designing, fabricating, and demonstrating the performance of nanophotonic circuits integrated on to semiconductor wafers using standard semiconductor processing equipment.

"The potential impact on the industry of combining photonic and electronic elements on a single CMOS die is substantial," said Lawrence Gasman, president of CIR, a leading technology forecasting company. "Many applications, including those in the cost sensitive consumer markets, will benefit from the improvements in cost, power consumption and size."

The nanophotonic Integrated Circuit (npIC) technology represents a new industry segment offering substantial product cost and performance advantages in telecom and microprocessor applications. The Luxtera advance will enable microprocessors to communicate with each other at ultra-high speeds, reducing the need for memory cache and increasing the efficiency of multiprocessor applications. According to a recent article in *Forbes* magazine, "teaching silicon new photonic tricks promises a huge boost in getting data out of a computer." [10] The article notes that Luxtera's growing fan club includes Michael Fister, formerly with Intel and now chief executive of Cadence Design Systems,

9 http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-4973.

10 "Ride the Light," by Elizabeth Corcoran, Forbes.com, 4/11/2005, http://www.forbes.com/business/free_forbes/2005/0411/068.html.

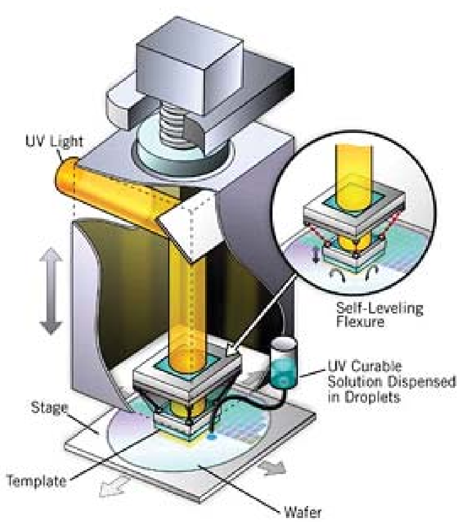
the leading maker of chip-design software tools. "There's good reason to be intrigued with this technology, and Luxtera is definitely worth watching," Fister states.

In an August 2006 press release, Luxtera announced the industry's first single-chip npIC device implemented in a standard CMOS process. The technology integrates high-performance optics and mainstream electronics on a single die, bringing fiber connectivity directly to the chip. According to the company, "Additional digital logic can be integrated into the same chip with optical devices, further reducing overall solution size, power consumption and cost."

Luxtera reports it is currently sampling prototype devices for preliminary testing by strategic development partners, and plans to have a commercial product line based on this underlying technology by early 2007. Initial product offerings are expected to be multi-port transceivers for communications, storage, and computing applications. The company believes CMOS photonics technology will enable the widespread adoption of 10G interconnects, which today are very expensive to deploy, by driving the cost of 10G optical ports to well below $100.

Total economic benefits to original equipment manufacturers, chipmakers, telecom service providers, businesses, and consumers are projected to be substantial.

Further examples of ATP funding of high technical risk R&D in nanoscale devices and systems are shown below.



Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond

Participants: Molecular Imprints Inc.; Motorola Inc.- Motorola Labs; Photonics Inc.; KLA-Tencor Corporation; and University of Texas at Austin

Design and demonstrate technology for step and flash imprint lithography (S-FIL), a novel method of transferring integrated circuit patterns to the surface of a semiconductor wafer by molding of three-dimensional features potentially as small as 20 nanometers or less.

Image: Schematic representation of MII nanoimprint lithography tool (image courtesy of Molecular Imprints, Inc.).

Molecular Imprints Wins EE Times' Ace Award For "Most Promising New Technology", March 15, 2005

Molecular Imprints, Inc. (MII) won the EE Times' Annual Creativity in Electronics (ACE) Award for "Most Promising New Technology", beating out IBM, Intel, and two others for this award. MII's technology, called Step and Flash Imprint Lithography (S-FIL™), was chosen for this award, which goes to a compelling electronic component or enabling technology that is outstanding in its technical design, potential for market impact, and demonstrated leadership in its area.

The Seamless Detection and Treatment of Cancer with Near-Infrared Absorbing Nanoshells

Participant: Nanospectra Biosciences, Inc.

Develop an integrated approach to the diagnosis and treatment of cancer allowing more accurate detection and contemporaneous, minimally invasive treatment using near-infrared absorbing nanoparticles.

Image: Simulated representation of a near-infrared absorbing nanoshell (courtesy of Nanospectra Biosciences, Inc.).

Deposition Source for Producing Super Lattice, Multilayer Thin Films to Enable Perpendicular Magnetic Recording

Participant: Intevac, Inc.

Develop a high-throughput thin-film deposition source capable of rapidly depositing precisely defined multilayer thin films to enable commercial production of magnetic super lattice films for the next generation of high-capacity disk storage devices.

Image: The Intevac 200 Lean (courtesy of Intevac, Inc.

Intevac Delivers a Revolution in Data Storage

In their ATP project, Intevac, Inc. developed a revolutionary magnetic disk sputtering system tool for manufacturing next generation magnetic data storage known as perpendicular magnetic recording. New perpendicular media recording technology delivers smaller form factor magnetic hard disk drives that meet ever-increasing demands of consumer products, and achieve the productivity and costs requirements for future hard disk manufacturing.

The ATP-funded R&D has given rise to a new Intevac tool named *200 Lean*. The *200 Lean* is Intevac's latest-generation disk sputtering system with capabilities to address advanced longitudinal and perpendicular media processing on the same platform.

According to Intevac in their June 12, 2006 press release, the company reports, "we project that Intevac would deliver between 34 and 39 *200 Leans* for revenue during calendar 2006."

Photo by Barry Gardner

INSTRUMENTATION AND METROLOGY

ATP has invested **$26.6 million** in nanotechnology instrumentation and metrology R&D, with **$26.4 million industry cost share** across **five projects**.

U.S. manufacturers require a wide range of tools for inspecting and measuring their output for quality and performance. Metrology is essential for development and improvement of new materials, processes, and tools for manufacturing; all essential for successful commercialization of nanomanufacturing.

"Metrology is a key enabler for all manufacturing and it is especially important to nanotechnology. It has been predicted that within the next 10 years, at least half of the newly designed advanced materials and manufacturing processes will be built at the nanoscale. Measurement science (metrology) and advanced instrumentation are essential for nanomanufacturing"[11]

An ATP funded award in nanotechnology instrumentation and metrology that is well positioned to create substantial broad-based benefits for U.S. industry was completed by Micro Magnetics, Inc. [12]

Spintronics-Based High-Resolution, Non-Invasive, and Ultrafast Metrology for the Semiconductor Industry

Participant: Micro Magnetics, Inc.

Project: Develop a nanoscale magnetic tunnel junction current-sensing system for integrated circuit inspection that will help maintain the U.S. lead in semiconductors by providing vastly improved metrology for in-process inspection.

Micro Magnetics develops, produces and markets novel technologies employing advances in magnetic sensing technology based on spintronics–a revolutionary new field created by the convergence of magnetics, electronics and nanotechnology. These technologies aim to provide the semiconductor and manufacturing industries with more efficient, cheaper products based on the introduction of technologies enabled by high-performance miniaturized magnetic sensors and devices.

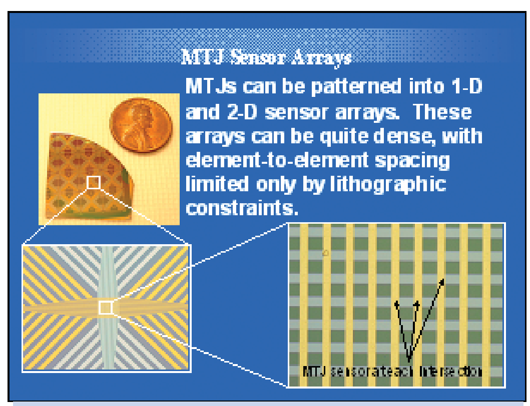


Image: Micro Magnetics MTJ sensor array (courtesy of Micro Magnetics, Inc.)

Recently, Micro Magnetics announced a series of new product offerings based on the ATP technology, featuring low-field sensors with 180% magnetoresistance. These sensors feature magnetic tunnel junction devices that incorporate cutting-edge magnesium oxide barrier technology. This capability represents a six-fold increase in sensitivity and voltage response from their current SpinTJ products and will enable a new generation of low-field sensing applications.

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11 http://www.mel.nist.gov/proj/nm.htm.

12 http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-5866.

Micro Magnetics is the first company worldwide to offer low-field sensors with magnetoresistance values in excess of 100%, an important milestone in magnetic sensing. The smallest dimension of the MTJ sensor is only about 10 nanometers, with field sensitivity of 5 nanotesla, active areas as small as 1x2 micrometers, and an operating temperature as high as 100^{o} C.

The ATP funded R&D is being driven by opportunities in semiconductor nanomanufacturing, specifically semiconductor fault isolation and failure analysis.

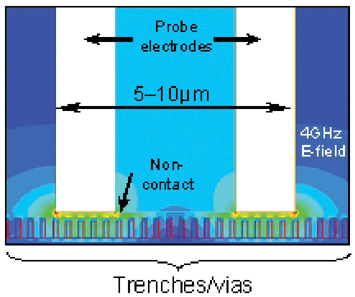
Micro Magnetics' Circuit Scan 1000 is a magnetic imaging tool which uses the tiny magnetic fields emitted by all of the currents inside any chip to understand the inner workings of the circuitry– without the need to process or even touch the device at all. Using mathematical algorithms which convert the magnetic field data into a map of current density, this system allows the user to see a map of all of the current flowing on every level of the device, down to the single microamp level. Because current is the lifeblood of an integrated circuit, this map can be invaluable to engineers and technicians attempting to understand the nature of the problem.

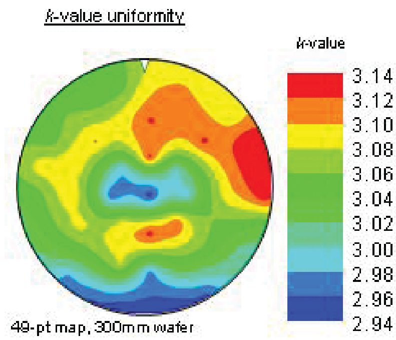
Spill-over applications of the ATP funded MTJ sensor technology are also being pursued by Micro Magnetics, Inc. in the following areas:

- ***Bio-sensing and Biomagnetic Applications:*** Micro Magnetics' micrometer-size magnetic tunnel junction sensors have demonstrated the capability to detect single magnetic nanoparticles, which makes them_ideal for use in the emerging applications area of "lab-on-a-chip" detectors.

- ***Detection of Magnetic Media and Inks:*** The magnetic sensors will be utilized in many of today's most vibrant industrial segments such as Hard-disk drives, Digital and analog video, audio tapes, flight data recorders, and floppy disks.

Further examples of ATP funding of high technical risk R&D in instrumentation and metrology are shown below.





Advanced Technology for Non-destructive, Localized, Dielectric Metrology of Future Generation Integrated Circuits

Participant: Neocera, Inc.

Develop technology for making non-destructive, quantitative measurements of dielectric constants at length scales (about 100 nanometers) and microwave frequencies (1-10 gigahertz) appropriate to ICs. Potential impacts include:

- Accelerate process development and enhance manufacturing yield for ICs,
- Decrease time to market of future ICs, and
- Create cost savings for IC manufacturing.

Probe simulation and wafer level k-value uniformity profile (images courtesy of Neocera, Inc.)

High-Speed AFM-Based Platform for Quantitative Nanomechanical Measurements

Participants: Dow Chemical Company; and Veeco Instruments, Inc.

Develop an atomic force microscopy based platform for high-speed, high-bandwidth quantitative nanomechanical measurements which provides structure-property understanding at the nanoscale in order to accelerate discovery, design, and commercialization of nanomaterials.

Potential Impacts of this technology include:

- Unprecedented mechanical property resolution at interfaces for new product development and predictive material models;
- Development of nanocomposites that can save fuel costs by lowering the overall weight of automobiles;
- Reduce yield loss in sub-65 nm semiconductor manufacturing; and
- Increase the speed of critical characterization for nanoscience research.

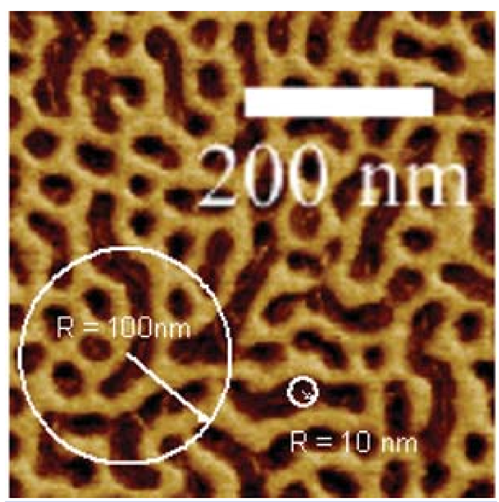
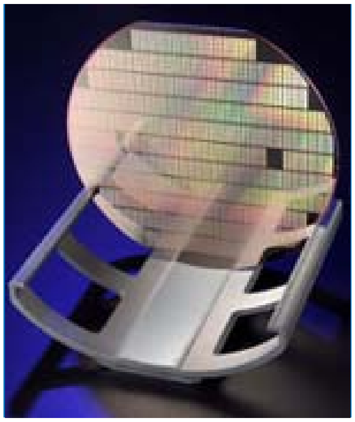


Image: The dimensions of a current nanoindentation tip (R = 100 nm) and proposed tip (R=10 nm) superimposed on a developmental copolymer film (imaged courtesy of Dow Chemical Co.)



MANUFACTURING AND PROCESS TECHNOLOGIES

ATP has invested **$28.9 million** in nanotechnology manufacturing and process technologies R&D, with **$25.5 million industry cost share** across **five projects**.

Manufacturing at the nanoscale level can be achieved by either scaling down current process technologies or by molecular level self-assembly process technologies. R&D for implementing these two approaches include pattern generation in 2-dimensional and 3-dimensional structures, atomically precise manufacturing processes, tools for defect identification and reduction, and new processes to fabricate nanoscale structures. New manufacturing technologies should also be friendly to the environment, i.e. reduce the use of hazardous chemicals and emission of pollutants, and conserve natural resources.

An ATP funded award in nanotechnology manufacturing and process technology that is well positioned to create substantial broad-based benefits for U.S. industry was recently completed by Uncopiers, Inc. [13]

ACIM "Point*Suns": Concentrating Energy through Silent Sound and Clean Water

Participant: Uncopiers, Inc.

Project: Design and build an energy-efficient, chemical-free nanoparticle detector and wafer cleaner to enable the semiconductor industry to clean and inspect next-generation wafers reliably and profitably. Locating a nanoparticle on a wafer is equivalent to finding a specific grain of sand on a baseball field.

Image: Nanocavitation bubbles at work using silent sound and clean water: here it is shown removing ink from paper (courtesy of Uncopiers, Inc.)

Uncopiers, Inc., a start-up company located in Manhattan, Kansas, is developing a new technology, called PointSuns™, ideally suited for nanotechnology pursuits. It is a unique way of concentrating energy at nanometer length scales without any collateral energy dispersal, dissipation, or damage. Using only silent sound and clean water, PointSuns™ are created through controlled acoustic nano-cavitation. They are capable of pin-pointedly interacting up to several hundred MeV of energy per cubic-nanometer of matter. This new capability allows one to accomplish tasks sometimes considered beyond the reach of prevailing technological practices.

The ATP funded R&D is being used to overcome critical issues in semiconductor nanomanufacturing:

- ***Semiconductor wafer cleaning:*** Uncopiers has developed an entirely chemical free method of removing sub-micrometer particulates from semiconductor wafers. Only water and silent sound are used to dislodge attached nanoparticles from the wafer surface, rendering the wafer clean for further processing. The water effluent itself can be refiltered, reprocessed and reused, thus conserving

13 http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-4403.

a precious resource. Because no chemicals are used, the cleaned wafer can be rinsed and dried in the same setting on a common footprint. Wafer cleaning is the most frequently used process step in IC manufacturing.

- ***Detection and elimination of nanoparticles in liquids:*** Controlled cavitation can be used to detect the presence of nanoparticles in liquids. Presently available methods of particle detection fail to detect sub-100nm individual particles in liquids. Detection of nanoparticles in liquids paves the way for ultrapurification of liquids critical in IC manufacturing.

Spill-over applications of the ATP funded PointSuns™ technology are also being pursued by Uncopiers, Inc. in the following areas:

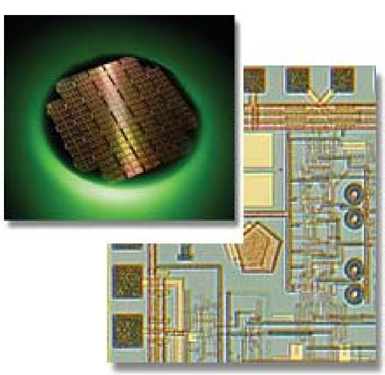
- ***Adhesion testing of thin films:*** In another application, PointSuns™ can be used to characterize and fashion thin films on substrates. Adhesion integrity of monolayer thin coatings can be conclusively and quantitatively inferred using this new technology.

- ***Removal of ink from paper in non-destructive way:*** The ATP PointSuns™ technology can be used to completely remove the photocopier ink from paper without hurting the underlying paper in an effort to reuse-recycle paper.

Further examples of ATP funding of high technical risk R&D in manufacturing and process technology are shown below.

Rapid and Comprehensive Development of Advanced Dielectric Materials for Wireless Applications

Participant: Intematix Corporation



Develop novel advanced dielectric materials using high-throughput synthesis and diagnostic tools to enable path-breaking improvements in the next generation of wireless telecommunications components.

Image: Typical semiconductor wafer and circuit pattern.

Small Times, 2005

Intermatix was named one of five finalists for **2005 Best Product of the Year** by ***Small Times*** magazine. Using its ultra-rapid materials development and proprietary tools and processes, Intermatix discovers materials in a fraction of the time typical for conventional methods.

Image: Optical image of an ion source for mass spectrometers built with automated microassembly (courtesy of Zyvex Corp.)

Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era

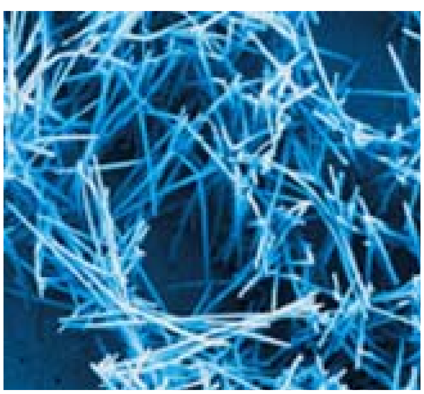
Participants: Zyvex Corporation; and Honeywell International, Inc.

Development of low-cost, computer controlled, microscale assemblers that operates in parallel to assemble three-dimensional microscale components, with extension of this technology to nanoscale assemblers for the commercialization of nanotechnology.

Building upon the ATP funded technology, a number of application areas are being pursued by Zyvex Corp.

- ***Microsensors:*** Recent commercialization efforts have focused on miniature optical systems (electron, ion and photon) for micro-instrumentation and sensing applications such as miniature mass spectrometers (MMS) and miniature scanning electron microscopes. The automated microassembly technology, developed under the ATP project, has enabled the creation of these types of systems in an economically viable way.
- ***Biological Tissue Manipulation and Testing:*** The scaled MEMS grippers have potential application in biological tissue manipulation and testing (e.g. collagen fibers) in biomedical research.
- ***Micromanipulation:*** Microgrippers will have applications in TEM sample preparation for semiconductor companies, and for manipulation of components in disk drive assembly.
- ***Assemblers for nanomanufacturing***
- ***Atomically precise manufacturing***

NANOMATERIALS



ATP has invested **$28.2 million** in nanomaterials R&D, with **$27.8 million industry cost share** across **nine projects**.

At the nanoscale, the physical, chemical, electrical and biological properties of materials differ in often unexpected and sometimes valuable ways from the behavior of bulk matter. Assembling materials with molecular precision create material ensembles with new properties and enable new applications. As a result of imaging, measuring, modeling, and manipulating matter at the nano-scale regime, scientific breakthroughs are being realized that will lead to entirely new approaches and solutions to problems in virtually all areas of technology and the economy.

An example of an ATP funded joint-venture award in nanomaterials that is well positioned to create substantial broad-based benefits for U.S. economy is being led by Cree, Inc. [14]

[14] http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-7011.

Low Cost, High Efficiency LED Lamp

Participants: Cree, Inc., and Nanocrystal Lighting Corp.

Project: Demonstrate a white light-emitting diode (LED) lamp package with an integrated chip approach that would more than quadruple the brightness and double the efficiency of existing LED systems and significantly reduce the cost per lumen.

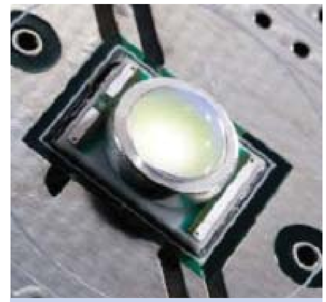


Image: Cree 7090 XLamp™ (courtesy of Cree, Inc.)

Current lighting technologies are very inefficient, wasting energy that could translate to reduction in spending by individuals and businesses. Specifically, incandescent and halogen lamps consume 42 percent of the total energy used for lighting in the United States while producing only 16 percent of the nation's electrically powered lighting.

A technology that will radically improve this situation is solid-state light-emitting diodes (LEDs) – very small light bulbs illuminated by the movement of electrons in semiconductor materials. LEDs are compact and durable and are often used in traffic lights, small liquid crystal displays, and indicators in cars and electronics.

But while the energy efficiency of white LEDs today exceeds that of incandescent lamps, the overall brightness and cost of high flux LED lamps need to be improved before the technology can penetrate the general illumination market. Cree, Inc., and its joint venture partner Nanocrystal Lighting Corporation, are demonstrating novel integrated white LED lamps that are significantly brighter and more efficient than existing LED lamps, as well as lower in cost per lumen of light output. The companies combined high-efficiency blue LEDs with phosphor and other nanomaterials that convert blue light to white light and significantly reduce energy consumption.

The U.S. Department of Energy estimates, widespread adoption of LED-based lighting would greatly reduce U.S. energy consumption, potentially saving around $10 billion annually by 2011, while also reducing annual carbon emissions by 5-10 million metric tons. The project is expected to generate jobs in the nanotechnology and semiconductor industries in the United States.

In August 2006, Cree announced the release of a new LED power chip that incorporates some of the key innovations developed under the ATP-funded research. The new LEDs are twice the brightness of Cree's current power chips, and are designed for general lighting applications, such as home and office lighting, auto headlamps, streetlights, and garage and warehouse low bay lighting.

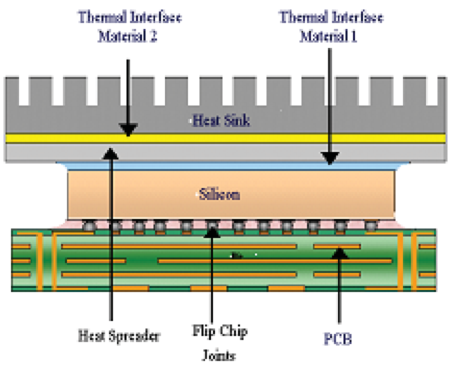
Significant breakthroughs are still needed in both materials and packaging fabrication technology to improve light extraction while controlling costs and improving the stability of novel encapsulation materials. The ATP JV brought together two companies with complementary expertise: Cree, a leading maker of LEDs, and Nanocrystal Lighting, a startup formed to commercialize new nano-photonic materials.

Although the current progress in the Power LED technology base is significant, not all the technical goals of the ongoing ATP project have been achieved given that the award is still underway. These potential new breakthroughs could further reduce the future price of white solid-state lighting by up to 50 percent, which together with higher efficiency and longer lifetimes, could lead to significantly greater reach in home and medical lighting applications, backlighting for computers and television, and mobile appliances and projectors, among others. The worldwide market for solid-state lighting could be worth as much as $40 billion.

Further examples of ATP funding of high technical risk R&D in nanoelectronic materials are shown below.

Nanoengineered Thermal Interfaces Enabling Next Generation Microelectronics

Participants: General Electric Company, University of Binghamton (Binghamton, NY), and Cabot Corporation (formerly Superior MicroPowders, LLC)

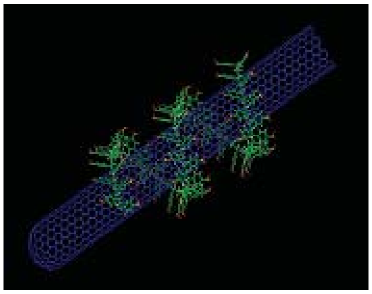


Develop and demonstrate the performance of novel materials, for use as interfaces between computer chips and heat sinks, that conduct heat 10 times better than today's interface materials

Image: Schematic representation of the use of thermal interface materials in a flip-chip application (courtesy of General Electric Co.)

"Free Standing", Single-Wall Carbon-Nanotube Fuel Cell Electrode

Participants: Carbon Nanotechnologies, Inc.; Motorola; and Johnson Matthey Fuel Cells, Inc.



Developing novel, free-standing single-wall carbon nanotube electrode assemblies containing an immobilized noble-metal catalyst for PEM fuel cells.

Image: Model-derived representation of a single-wall carbon-nanotube (courtesy of Carbon Nanotechnologies, Inc.)

Major Patent Milestone

In early 2005, ATP recipient Carbon Nanotechnologies, Inc. (CNI), Houston, TX, announced it had reached a major milestone with 30 issued or allowed patents related to the innovative use of small diameter carbon nanotubes. CNI is a manufacturer and producer of single-wall and other small-diameter carbon nanotubes, thought by many to represent a transforming technology to produce and deliver superior products.

Summary

Funding for science and technology development programs is typically directed to universities for basic or applied research, or companies for low technical risk product development. Federal funding for basic research is addressing fundamental barriers in nanotechnology and opening up many new opportunities for nanotechnology innovation by U.S. companies. Significant challenges remain in funding translational research in nanotechnology to speed the development of path-breaking technologies that have the potential to create substantial economic benefits.

A funding gap exists for early stage technology development where technical risks remain high and the timeline to success is long. Investments made by the Advanced Technology Program in nanotechnology have helped to bridge this funding gap, facilitated the development of nanoelectronics by U.S. companies and their university partners, and brought to the global marketplace early-on benefits in a number of nanoelectronics application areas.

The commercialization of new, innovative ideas in nanotechnology, made possible by ATP funding, is expected to expand in the years to come. As this occurs, tremendous national benefits, in the form of economic security, quality of life, and societal benefits to American citizens, are expected.

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Organization	Project Number	Project Title	Participation Type	State	Start Date	End Date
Small-size Companies						
Abeam Technologies	2004-1E-6814	Development and Demonstration of a Multiple, High-Current-Density Shaped E-Beam Column With Independent Vector Beam Placement	Subcontractor	California	10/1/2004	9/30/2006
Accurel, Inc.	2004-1E-6814	Development and Demonstration of a Multiple, High-Current-Density Shaped E-Beam Column With Independent Vector Beam Placement	Subcontractor	California	10/1/2004	9/30/2006
Advanced Research Corporation	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	Minnesota	11/1/2001	10/31/2006
Ansoft Corporation	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	Pennsylvania	11/1/2001	10/31/2006
Cabot Corporation (formerly Superior MicroPowders, LLC)	2002-1E-5139	Nanoengineered Thermal Interfaces Enabling Next Generation Microelectronics	Joint-Venture - Partner	New Mexico	11/1/2002	10/31/2005
Cabot Corporation (formerly Superior MicroPowders, LLC)	1998-03-0002	Preparation and Fundamental Evaluation of Catalytic Materials for Energy Applications	Single Applicant	New Mexico	11/1/1998	10/31/2001
Carbon Nanotechnologies, Inc.	2004-1C-6962	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Joint-Venture - Lead	Texas	10/1/2004	9/30/2007
Consultant	2000-1B-4243	Advanced Wafer Inspection for Next-Generation Lithography	Subcontractor	Pennsylvania	11/1/2000	10/31/2004
Consultant	2001-3E-4601	Heat Assisted Magnetic Recording	Subcontractor	California	11/1/2001	10/31/2006

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Small-size Companies (cont.)						
Consultant	2001-3E-4601	Heat Assisted Magnetic Recording	Subcontractor	Minnesota	11/1/2001	10/31/2006
Corning Tropel Corporation (formerly Tropel Corporation)	2000-1B-4243	Advanced Wafer Inspection for Next-Generation Lithography	Joint-Venture - Partner	New York	11/1/2000	10/31/2004
Dendritech, Inc.	1998-06-0052	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Subcontractor	Michigan	4/1/1999	9/30/2002
Energy Beam Sciences, Inc.	2004-1E-6814	Development and Demonstration of a Multiple, High-Current-Density Shaped E-Beam Column With Independent Vector Beam Placement	Subcontractor	Massachusetts	10/1/2004	9/30/2006
Euxine Technologies	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	Colorado	11/1/2001	10/31/2006
HIMARC Simulations	2002-3E-5853	Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond	Subcontractor	California	5/1/2004	4/30/2007
Intematix Corporation	2001-2C-4478	Rapid and Comprehensive Development of Advanced Dielectric Materials for Wireless Appplications	Single Applicant	California	10/1/2001	1/31/2004
InterScience, Inc.	2000-1B-4287	Digital Holographic Inspection of Semiconductor Devices	Joint-Venture - Partner	New York	11/1/2000	5/9/2006
Intevac, Inc.	2000-1B-4201	Deposition Source for Producing Super Lattice, Multilayer Thin Films to Enable Perpendicular Magnetic Recording	Single Applicant	California	11/1/2000	10/31/2003

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Small-size Companies (cont.)						
JME, Inc.	1998-03-0027	Asymmetric Supercapacitor Based Upon Nanostructured Active Materials	Subcontractor	Ohio	3/1/1999	2/28/2002
Light Age, Inc.	2000-1B-4287	Digital Holographic Inspection of Semiconductor Devices	Joint-Venture - Partner	New Jersey	11/1/2000	5/9/2006
Luxtera, Inc.	2002-1E-4973	Nanophotonic Integrated Circuits for Telecommunications and Computing	Single Applicant	California	11/1/2002	10/31/2004
MEMS Optical, Inc.	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	Alabama	11/1/2001	10/31/2006
Micro Magnetics, Inc.	2002-3E-5866	Spintronics-Based High-Resolution, Non-Invasive, and Ultrafast Metrology for the Semiconductor Industry	Single Applicant	Massachusetts	10/1/2003	9/30/2006
Micro Star Technologies	2004-1E-6249	High-Speed AFM-Based Platform for Quantitative Nanomechanical Measurements	Subcontractor	Texas	12/1/2004	9/30/2007
Microcell Corporation	2001-2C-4429	Fabrication of Fuel Cells from Microcell Fibers	Single Applicant	North Carolina	11/1/2001	10/31/2004
Molecular Imprints, Inc.	2002-3E-5853	Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond	Joint-Venture - Lead	Texas	5/1/2004	4/30/2007
Molecular Nanosystems, Inc.	2002-1C-5223	Template Synthesis Platform for Nanostructured Materials	Joint-Venture - Partner	California	11/1/2002	12/31/2005

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Small-size Companies (cont.)						
Molecular Probe (formerly Quantum Dot Corporation)	2004-1B-7002	Quantum Dots for Biomedical and Consumer Applications	Single Applicant	California	12/1/2004	6/30/2008
MRS, Inc.	2004-1E-6814	Development and Demonstration of a Multiple, High-Current-Density Shaped E-Beam Column With Independent Vector Beam Placement	Subcontractor	California	10/1/2004	9/30/2006
Multibeam Systems, Inc.	2004-1E-6814	Development and Demonstration of a Multiple, High-Current-Density Shaped E-Beam Column With Independent Vector Beam Placement	Single Applicant	California	10/1/2004	9/30/2006
Nanocrystal Lighting Corp.	2004-1E-7011	Low Cost, High Efficiency Chip Scale LED Lamp	Joint-Venture - Partner	New York	11/1/2004	10/31/2007
Nanospectra Biosciences, Inc.	2004-1B-6963	The Seamless Detection and Treatment of Cancer With Near-Infrared Absorbing Nanoshells	Single Applicant	Texas	10/1/2004	6/30/2007
Neocera, Inc.	2001-5E-4850	Advanced Technology for Non-destructive, Localized, Dielectric Metrology of Future Generation Integrated Circuits	Single Applicant	Maryland	6/1/2002	5/31/2004
nLine Corporation	2000-1B-4287	Digital Holographic Inspection of Semiconductor Devices	Joint-Venture - Lead	Texas	11/1/2000	5/9/2006
PixelVision, Inc.	2000-1B-4287	Digital Holographic Inspection of Semiconductor Devices	Joint-Venture - Partner	Oregon	11/1/2000	5/9/2006
Plug Power, Inc.	2002-3E-5836	Low Cost Fuel Cell System Technologies Development	Single Applicant	New York	12/1/2003	5/30/2006

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Organization	Project Number	Project Title	Participation Type	State	Start Date	End Date
Small-size Companies (cont.)						
Quantum Dot Corporation	2000-1A-4106	Blood "Fingerprinting": A First Step Toward Personalized Medicine	Joint-Venture - Partner	California	1/1/2001	6/30/2005
Standard MEMS, Inc.	2001-2E-4469	Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era	Joint-Venture - Partner	Massachusetts	10/1/2001	12/16/2006
SurroMed, Inc.	2000-1A-4106	Blood "Fingerprinting": A First Step Toward Personalized Medicine	Joint-Venture - Lead	California	1/1/2001	6/30/2005
The Technological Group, Inc.	2004-1C-6962	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Subcontractor	Texas	10/1/2004	9/30/2007
Uncopiers, Inc.	2001-1E-4403	ACIM "Point*Suns": Concentrating Energy Through Silent Sound and Clean Water	Single Applicant	Kansas	9/1/2001	8/31/2004
US Nanocorp, Inc.	1998-03-0027	Asymmetric Supercapacitor Based Upon Nanostructured Active Materials	Single Applicant	Connecticut	3/1/1999	2/28/2002
Zyvex Corporation	2001-2E-4469	Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era	Joint-Venture - Lead	Texas	10/1/2001	12/16/2006
Medium-size Companies						
Cree, Inc	2004-1E-7011	Low Cost, High Efficiency Chip Scale LED Lamp	Joint-Venture - Lead	North Carolina	11/1/2004	10/31/2007
KLA-Tencor Corporation	2000-1B-4243	Advanced Wafer Inspection for Next-Generation Lithography	Joint-Venture - Lead	California	11/1/2000	10/31/2004

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Medium-size Companies (cont.)						
KLA-Tencor Corporation	2002-3E-5853	Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond	Joint-Venture - Partner	California	5/1/2004	4/30/2007
Photronics, Inc.	2002-3E-5853	Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond	Joint-Venture - Partner	Connecticut	5/1/2004	4/30/2007
Sarnoff Corporation	2000-1B-4287	Digital Holographic Inspection of Semiconductor Devices	Joint-Venture - Partner	New Jersey	11/1/2000	5/9/2006
TIAX	2004-1E-7011	Low Cost, High Efficiency Chip Scale LED Lamp	Subcontractor	Massachusetts	11/1/2004	10/31/2007
Veeco Instruments, Inc.	2004-1E-6249	High-Speed AFM-Based Platform for Quantitative Nanomechanical Measurements	Joint-Venture - Partner	California	12/1/2004	9/30/2007
Large-size Companies						
Celanese Ventures, GmbH	2004-1C-6962	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Subcontractor	New Jersey	10/1/2004	9/30/2007
Corning IntelliSense Corporation	2002-1C-5223	Template Synthesis Platform for Nanostructured Materials	Subcontractor	Massachusetts	11/1/2002	12/31/2005
Dow Chemical Company	1998-06-0052	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Joint-Venture - Lead	Michigan	4/1/1999	9/30/2002
Dow Chemical Company	2004-1E-6249	High-Speed AFM-Based Platform for Quantitative Nanomechanical Measurements	Joint-Venture - Lead	Michigan	12/1/2004	9/30/2007

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Large-size Companies (cont.)						
Eveready Battery Company	1998-03-0027	Asymmetric Supercapacitor Based Upon Nanostructured Active Materials	Joint-Venture - Partner (Participant Type at Project Start)	Ohio	3/1/1999	2/28/2002
General Electric Company	2002-1C-5223	Template Synthesis Platform for Nanostructured Materials	Joint-Venture - Lead	New York	11/1/2002	12/31/2005
General Electric Company	2002-1E-5139	Nanoengineered Thermal Interfaces Enabling Next Generation Microelectronics	Joint-Venture - Lead	New York	11/1/2002	10/31/2005
Honeywell International, Inc.	2001-2E-4469	Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era	Joint-Venture - Partner	Washington	10/1/2001	12/16/2006
IBM, Almaden Research Center	1998-06-0052	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Joint-Venture - Lead	California	4/1/1999	9/30/2002
Johnson Matthey Fuel Cells, Inc.	2004-1C-6962	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Joint-Venture - Partner	Pennsylvania	10/1/2004	9/30/2007
Kellogg Brown & Root, Inc. (Halliburton)	2004-1C-6962	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Subcontractor	Texas	10/1/2004	9/30/2007
Kelly Services	2004-1C-6962	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Subcontractor	Texas	10/1/2004	9/30/2007
Motorola, Inc.	2004-1C-6962	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Joint-Venture - Partner	Arizona	10/1/2004	9/30/2007

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Large-size Companies (cont.)						
Motorola, Inc. Motorola Labs	2002-3E-5853	Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond	Joint-Venture - Partner	Arizona	5/1/2004	4/30/2007
Motorola, Inc., Semiconductor Product Services	2002-1E-4973	Nanophotonic Integrated Circuits for Telecommunications and Computing	Subcontractor	Texas	11/1/2002	10/31/2004
Seagate Technology, LLC	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	California	11/1/2001	10/31/2006
Federal Laboratory						
Oak Ridge National Laboratory	2000-1B-4287	Digital Holographic Inspection of Semiconductor Devices	Subcontractor	Tennessee	11/1/2000	5/9/2006
Non-Profit Organization						
Information Storage Industry Consortium (formerly National Storage Industry Consortium)	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Lead	California	11/1/2001	10/31/2006
Universities						
Carnegie Mellon University	2000-1B-4243	Advanced Wafer Inspection for Next-Generation Lithography	Joint-Venture - Partner	Pennsylvania	11/1/2000	10/31/2004
Carnegie Mellon University	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	Pennsylvania	11/1/2001	10/31/2006
Florida Atlantic University (Florida Atlantic Research Corporation)	1998-03-0027	Asymmetric Supercapacitor Based Upon Nanostructured Active Materials	Subcontractor	Florida	3/1/1999	2/28/2002

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Organization	Project Number	Project Title	Participation Type	State	Start Date	End Date
Universities (cont.)						
North Carolina State University	2001-2C-4429	Fabrication of Fuel Cells from Microcell Fibers	Subcontractor	North Carolina	11/1/2001	10/31/2004
Purdue University	2002-1E-5139	Nanoengineered Thermal Interfaces Enabling Next Generation Microelectronics	Subcontractor	Indiana	11/1/2002	10/31/2005
Rensselaer Polytechnic Institute	2001-2E-4469	Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era	Subcontractor	New York	10/1/2001	12/16/2006
Stanford University	1998-06-0052	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Subcontractor	California	4/1/1999	9/30/2002
State University of New York (SUNY) at Binghamton	2002-1E-5139	Nanoengineered Thermal Interfaces Enabling Next Generation Microelectronics	Joint-Venture - Partner	New York	11/1/2002	10/31/2005
Texas A&M University	2004-1B-6963	The Seamless Detection and Treatment of Cancer With Near-Infrared Absorbing Nanoshells	Subcontractor	Texas	10/1/2004	6/30/2007
University of Arizona (Arizona Board of Regents)	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	Arizona	11/1/2001	10/31/2006
University of Albany, Albany NanoTech	2002-3E-5836	Low Cost Fuel Cell System Technologies Development	Subcontractor	New York	12/1/2003	5/30/2006
University of California at Santa Barbara	2004-1E-6249	High-Speed AFM-Based Platform for Quantitative Nanomechanical Measurements	Subcontractor	California	12/1/2004	9/30/2007

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Organization	Project Number	Project Title	Participation Type	State	Start Date	End Date
Universities (cont.)						
University of Colorado	2002-1E-5139	Nanoengineered Thermal Interfaces Enabling Next Generation Microelectronics	Subcontractor	Colorado	11/1/2002	10/31/2005
University of Maryland	1998-06-0052	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Subcontractor	Maryland	4/1/1999	9/30/2002
University of Maryland	2001-5E-4850	Advanced Technology for Non-destructive, Localized, Dielectric Metrology of Future Generation Integrated Circuits	Subcontractor	Maryland	6/1/2002	5/31/2004
University of Maryland	2001-5E-4850	Advanced Technology for Non-destructive, Localized, Dielectric Metrology of Future Generation Integrated Circuits	Subcontractor	Maryland	6/1/2002	5/31/2004
University of Maryland	2002-1C-5223	Template Synthesis Platform for Nanostructured Materials	Subcontractor	Maryland	11/1/2002	12/31/2005
University of Minnesota	2001-3E-4601	Heat Assisted Magnetic Recording	Joint-Venture - Partner	Minnesota	11/1/2001	10/31/2006
University of Northern Texas	2001-2E-4469	Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era	Subcontractor	Texas	10/1/2001	12/16/2006
University of Texas at Austin	2002-3E-5853	Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond	Joint-Venture - Partner	Texas	5/1/2004	4/30/2007
University of Texas at Dallas	2001-2E-4469	Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era	Subcontractor	Texas	10/1/2001	12/16/2006

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Appendix A

Participants in ATP Nanotechnology Awards for Nanoelectronic Applications

Organization	Project Number	Project Title	Participation Type	State	Start Date	End Date
Universities (cont.)						
Washington State University	1998-06-0052	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Subcontractor	Washington	4/1/1999	9/30/2002

Appendix B

Advanced Technology Program Nanotechnology Awards for Nanoelectronic Applications by Innovation and Early-on Application Areas

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Nanotechnology Awards for Nanoelectronics by Innovation and Early-on Application Areas

Appendix B

Project Number	Lead Organization	Title	Award Type	Start Date	End Date	ATP Share, $ (est.)	Industry Share, $ (est.)
Nanotechnology Innovation Areas							
Devices and Systems							
2000-1B-4201	Intevac, Inc.	Deposition Source for Producing Super Lattice, Multilayer Thin Films to Enable Perpendicular Magnetic Recording	Single Applicant	11/1/2000	10/31/2003	$1,554,114	$1,554,114
2002-1E-4973	Luxtera, Inc.	Nanophotonic Integrated Circuits for Telecommunications and Computing	Single Applicant	11/1/2002	10/31/2004	$1,999,960	$2,193,728
2002-3E-5853	Molecular Imprints, Inc.	Nano-Imprint Lithography Infrastructure for Low Cost Replication at the 65 nm Node and Beyond	Joint-Venture	5/1/2004	4/30/2007	$17,623,118	$19,167,367
2004-1E-6814	Multibeam Systems Inc.,	Development and Demonstration of a Multiple, High-Current-Density Shaped E-Beam Column With Independent Vector Beam Placement	Single Applicant	10/1/2004	9/30/2006	$1,999,180	$708,300
2004-1B-6963	Nanospectra Biosciences, Inc.	The Seamless Detection and Treatment of Cancer With Near-Infrared Absorbing Nanoshells	Single Applicant	10/1/2004	6/30/2007	$2,000,000	$551,351
2000-1A-4106	SurroMed, Inc.	Blood "Fingerprinting": A First Step Toward Personalized Medicine	Joint-Venture	1/1/2001	6/30/2005	$5,595,485	$5,708,524
Instrumentation and Metrology							
2004-1E-6249	Dow Chemical Company	High-Speed AFM-Based Platform for Quantitative Nanomechanical Measurements	Joint-Venture	12/1/2004	9/30/2007	$6,560,714	$6,828,495
2000-1B-4243	KLA-Tencor Corporation	Advanced Wafer Inspection for Next-Generation Lithography	Joint-Venture	11/1/2000	10/31/2004	$6,716,870	$7,002,847
2002-3E-5866	Micro Magnetics, Inc.	Spintronics-Based High-Resolution, Non-Invasive, and Ultrafast Metrology for the Semiconductor Industry	Single Applicant	10/1/2003	9/30/2006	$2,000,000	$1,406,744

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Nanotechnology Awards for Nanoelectronics by Innovation and Early-on Application Areas

Appendix B

Project Number	Lead Organization	Title	Award Type	Start Date	End Date	ATP Share, $ (est.)	Industry Share, $ (est.)
Instrumentation and Metrology (cont.)							
2001-5E-4850	Neocera, Inc.	Advanced Technology for Non-destructive, Localized, Dielectric Metrology of Future Generation Integrated Circuits	Single Applicant	6/1/2002	5/31/2004	$1,968,348	$1,410,453
2000-1B-4287	nLine Corporation	Digital Holographic Inspection of Semiconductor Devices	Joint-Venture	11/1/2000	5/9/2006	$9,395,604	$9,779,101
Manufacturing and Process Technologies							
2001-3E-4601	Information Storage Industry Consortium (formerly National Storage Industry Con)	Heat Assisted Magnetic Recording	Joint-Venture	11/1/2001	10/31/2006	$10,760,830	$10,838,696
2001-2C-4478	Intematix Corporation	Rapid and Comprehensive Development of Advanced Dielectric Materials for Wireless Applications	Single Applicant	10/1/2001	1/31/2004	$2,000,000	$1,169,688
2004-1B-7002	Quantum Dot Corporation	Quantum Dots for Biomedical and Consumer Applications	Single Applicant	12/1/2004	6/30/2008	$2,000,000	$888,524
2001-1E-4403	Uncopiers, Inc.	ACIM "Point*Suns": Concentrating Energy Through Silent Sound and Clean Water	Single Applicant	9/1/2001	8/31/2004	$2,000,000	$310,730
2001-2E-4469	Zyvex Corporation	Assemblers for Nanotechnology Applications and Manufacturing: Enabling the Nanotechnology Era	Joint-Venture	10/1/2001	12/16/2006	$12,170,000	$12,245,945
Nanomaterials							
1998-03-0002	Cabot Superior MicroPowders (formerly Superior MicroPowders)	Preparation and Fundamental Evaluation of Catalytic Materials for Energy Applications	Single Applicant	11/1/1998	10/31/2001	$2,000,000	$1,842,811
2004-1C-6962	Carbon Nanotechnologies, Inc.	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Joint-Venture	10/1/2004	9/30/2007	$3,616,054	$3,763,653
2004-1E-7011	Cree, Inc	Low Cost, High Efficiency Chip Scale LED Lamp	Joint-Venture	11/1/2004	10/31/2007	$3,383,865	$3,567,330

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Project Number	Lead Organization	Title	Award Type	Start Date	End Date	ATP Share, $ (est.)	Industry Share, $ (est.)
Nanomaterials (cont.)							
1998-06-0052	Dow Chemical Company	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Joint-Venture	4/1/1999	9/30/2002	$8,556,629	$9,049,142
2002-1C-5223	General Electric Company	Template Synthesis Platform for Nanostructured Materials	Joint-Venture	11/1/2002	12/31/2005	$2,833,996	$2,949,672
2002-1E-5139	General Electric Company	Nanoengineered Thermal Interfaces Enabling Next Generation Microelectronics	Joint-Venture	11/1/2002	10/31/2005	$3,506,139	$3,761,381
2001-2C-4429	Microcell Corporation	Fabrication of Fuel Cells from Microcell Fibers	Single Applicant	11/1/2001	10/31/2004	$1,997,923	$404,033
2002-3E-5836	Plug Power Inc.	Low Cost Fuel Cell System Technologies Development	Single Applicant	12/1/2003	5/30/2006	$1,879,586	$1,973,957
1998-03-0027	US Nanocorp, Inc.	Asymmetric Supercapacitor Based Upon Nanostructured Active Materials	Single Applicant	3/1/1999	2/28/2002	$441,000	$459,000
Early-on Application Areas							
Alternative Energy							
1998-03-0002	Cabot Superior MicroPowders (formerly Superior MicroPowders)	Preparation and Fundamental Evaluation of Catalytic Materials for Energy Applications	Single Applicant	11/1/1998	10/31/2001	$2,000,000	$1,842,811
2004-1C-6962	Carbon Nanotechnologies, Inc.	"Free Standing" Single-Wall Carbon-Nanotube Fuel Cell Electrode	Joint-Venture	10/1/2004	9/30/2007	$3,616,054	$3,763,653
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2002-3E-5836	Plug Power Inc.	Low Cost Fuel Cell System Technologies Development	Single Applicant	12/1/2003	5/30/2006	$1,879,586	$1,973,957

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Project Number	Lead Organization	Title	Award Type	Start Date	End Date	ATP Share, $ (est.)	Industry Share, $ (est.)
Alternative Energy (cont.)							
1998-03-0027	US Nanocorp, Inc.	Asymmetric Supercapacitor Based Upon Nanostructured Active Materials	Single Applicant	3/1/1999	2/28/2002	$441,000	$459,000
Bioelectronics							
2004-1B-6963	Nanospectra Biosciences, Inc.	The Seamless Detection and Treatment of Cancer With Near-Infrared Absorbing Nanoshells	Single Applicant	10/1/2004	6/30/2007	$2,000,000	$551,351
2004-1B-7002	Quantum Dot Corporation	Quantum Dots for Biomedical and Consumer Applications	Single Applicant	12/1/2004	6/30/2008	$2,000,000	$888,524
2000-1A-4106	SurroMed, Inc.	Blood "Fingerprinting": A First Step Toward Personalized Medicine	Joint-Venture	1/1/2001	6/30/2005	$5,595,485	$5,708,524
Materials Discovery							
2004-1E-6249	Dow Chemical Company	High-Speed AFM-Based Platform for Quantitative Nanomechanical Measurements	Joint-Venture	12/1/2004	9/30/2007	$6,560,714	$6,828,495
2001-2C-4478	Intematix Corporation	Rapid and Comprehensive Development of Advanced Dielectric Materials for Wireless Appplications	Single Applicant	10/1/2001	1/31/2004	$2,000,000	$1,169,688
Mixed-function Electronic Systems							
2004-1E-7011	Cree, Inc	Low Cost, High Efficiency Chip Scale LED Lamp	Joint-Venture	11/1/2004	10/31/2007	$3,383,865	$3,567,330
2002-1C-5223	General Electric Company	Template Synthesis Platform for Nanostructured Materials	Joint-Venture	11/1/2002	12/31/2005	$2,833,996	$2,949,672
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Mixed-function Electronic Systems (cont.)							
2000-1B-4201	Intevac, Inc.	Deposition Source for Producing Super Lattice, Multilayer Thin Films to Enable Perpendicular Magnetic Recording	Single Applicant	11/1/2000	10/31/2003	$1,554,114	$1,554,114
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Semiconductor Nanomanufacturing							
1998-06-0052	Dow Chemical Company	Ultra-Low Dielectric Constant Materials for Integrated Circuit Interconnects	Joint-Venture	4/1/1999	9/30/2002	$8,556,629	$9,049,142
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2004-1E-6814	Multibeam Systems Inc.,	Development and Demonstration of a Multiple, High-Current-Density Shaped E-Beam Column With Independent Vector Beam Placement	Single Applicant	10/1/2004	9/30/2006	$1,999,180	$708,300
2001-5E-4850	Neocera, Inc.	Advanced Technology for Non-destructive, Localized, Dielectric Metrology of Future Generation Integrated Circuits	Single Applicant	6/1/2002	5/31/2004	$1,968,348	$1,410,453
2000-1B-4287	nLine Corporation	Digital Holographic Inspection of Semiconductor Devices	Joint-Venture	11/1/2000	5/9/2006	$9,395,604	$9,779,101

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Semiconductor Nanomanufacturing (cont.)							
2001-1E-4403	Uncopiers, Inc.	ACIM "Point*Suns": Concentrating Energy Through Silent Sound and Clean Water	Single Applicant	9/1/2001	8/31/2004	$2,000,000	$310,730

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For further information on these and other ATP funded projects, visit the ATP website at *www.atp.nist.gov*.