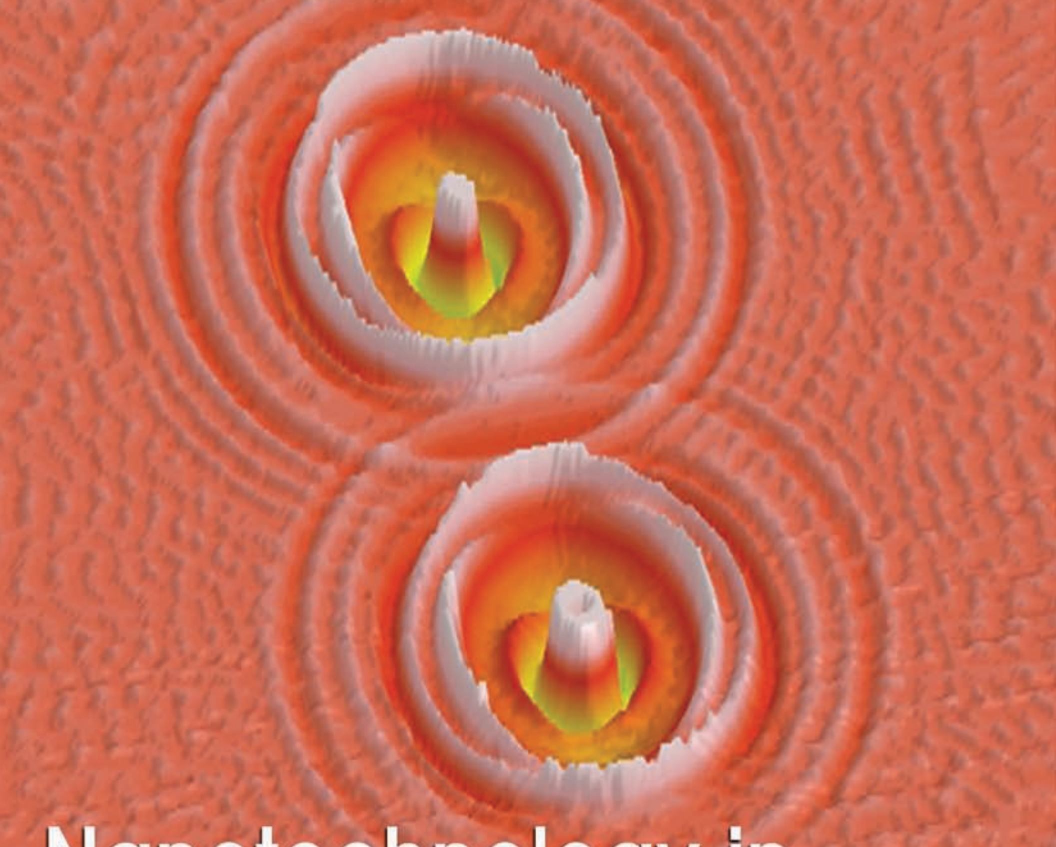

Nanotechnology in Society & Manufacturing

American Institute of Physics Corporate Associates 2006 Meeting Report

November 12-14, 2006
San Francisco, CA

Held in conjunction with the
Nano-Manufacturing Topical Conference
at the AVS International Symposium

2006
Industrial
Physics
Forum
for Corporate and
Academic Leaders

MISSION STATEMENT OF THE AIP CORPORATE ASSOCIATES

To serve the industrial physics community by improving the effectiveness of people and organizations in advancing corporate goals through the use of physics.

2006
AIP INDUSTRIAL PHYSICS FORUM REPORT

Nanotechnology in Society and Manufacturing

AVS International Symposium
November 12-14, 2006, San Francisco, California

We are entering a brave new world in the 21st century, where makeup “defies” one’s advancing years, “self-cleaning” windows shed dirt when it rains, wound dressings have built-in antibiotic and anti-inflammatory properties, composite building materials are stronger than ever before, and high-tech fabrics are being created for bulletproof vests, making them more flexible, yet stronger, with electrically conductive properties. On the horizon is toothpaste that automatically coats, protects, even rebuilds tooth enamel; electronics devices far smaller than even the tiniest CMOS technology; and perhaps, one day in the distant future, tiny robots capable of performing minor surgical procedures within the human body.

The key enabling factor in much of this is nanotechnology, the theme of the 2006 Industrial Physics Forum (IPF), sponsored by the American Institute of Physics Corporate Associates and held in conjunction with the AVS International Symposium in San Francisco, California. “Nanotechnology” is a broad term that describes any area of scientific research dealing with objects measured in nanometers—the same size scale as individual atoms and molecules. At that scale, quantum effects hold sway, so materials have very different chemical and physical properties than they exhibit at larger scales—which in turn can lead to exciting and innovative new applications.

Some of those emerging applications are potentially very lucrative, and capable of revolutionizing our lives in unexpected ways. Nanotechnology has become big business, with private corporations pouring funds into nanotech-related research. The National Science Foundation (NSF) estimates that nanotechnology could become a $1 trillion/year industry by 2015. The federal government is also investing heavily in nanotech R&D, most notably through the National Nanotechnology Initiative. Its growing prevalence has also sparked an ongoing debate—and many studies—about potential risks, societal impacts, and the need for well-established policies concerning nanotechnology. But the real excitement of nanotechnology can still be found at the cutting edge of research.

The 2006 IPF program highlighted the latest breakthroughs and prevailing issues across the broad spectrum of the nanotechnology enterprise. These include exciting new applications for nanoparticles, such as their use in cancer diagnosis and treatment; an update on the challenges ahead for large-scale nano-manufacturing; recent progress on building nanoelectronic devices; and how nanotechnology can make cars more efficient, and help with environmental remediation.

THEME SESSION:

EXAMPLES OF NANOTECHNOLOGY MANUFACTURING

This session examined new technologies that have already been (or shortly will be) enabled through the use of nanostructures that are actually on manufacturing lines.

Mark Bünger, an analyst with Lux Research, kicked off the conference by taking a look at the "Economics of Matter"—namely, identifying the most successful business strategies for making money off of the continuing explosion of research advances in nanotechnology. Bünger notes that the nanotechnology arena has shifted from being primarily an R&D enterprise dominated by scientists (such as the late Richard Smalley and Eric Drexler), to one that is increasingly dominated by big business. Not only did President Bush specify nanotechnology as one of the top three areas for scientific research in his 2006 State of the Union address; so have the CEOs of powerful major corporations like GE, GM, and Procter & Gamble.

We are already seeing the first smattering of nano-products in the marketplace, but to keep their fingers on the pulse of innovation, corporate giants look not just to the cutting-edge research being done in academic circles, but also to exciting innovations under development at local start-ups. There's a distinct trend towards forming useful outside partnerships—a practice Bünger dubs "open innovation." But it can be challenging for potential investors to determine which of the plethora of nanotech start-ups are likely to make the best potential business partners.

Lux Research has a new report surveying 136 such start-ups and rating them according to how they scored (ranging from 1 to 25, for a total of 100 points) in four basic criteria: the scientific "pipeline," i.e., how active and robust an R&D program they have, evidenced by things like patents and publications; whether they have a product that is commercially viable; how well they have been able to navigate the minefield of legal and regulatory considerations; and how well they perform on standard measures of operations and finance. It is the first quantitative measure developed to help identify the best potential companies for "open innovation" partnerships.

Photovoltaics is a major research focus for Paul Alivisatos, a professor of physics at the University of California, Berkeley. Such devices perform quite well in a laboratory setting, but the cost per unit and overall efficiency just don't scale up to sufficient performance levels to make them useful for anything more than select niche energy applications. The US consumes between 1 and 3 Terawatts of energy every day. There is no solar technology currently in existence that can generate energy at that enormous scale while still being affordable and efficient.

Colloidal nanocrystals might hold the key. Alivisatos pointed out that there have been many significant advances in our ability not only to grow colloidal inorganic nanocrystals, but also to control their size, shape, and even branching, as well as their topology (they must be hollow and nested to achieve the desired properties). Like most nanoscale materials, many of their unique properties are size dependent, but colloidal nanocrystals are also quite stable and can be processed in solution, just like polymers. Alivisatos thinks this makes them an attractive candidate for solar cell components.

He is working on a project that seeks to turn solar energy into a usable transport fuel by converting photon energy into the energy found in the chemical bonds in gasoline. The project requires going beyond current solar cell technology that converts sunlight into electricity and seeks to store the energy of light in a transportable fuel. The challenge is that it is very difficult to control a material's properties and behavior at the nanoscale to a suitable level of precision. If such challenges can be met, nanoscale solar fuel technology could combine very high efficiency with good scalability, making it a highly desirable energy source.

Alivisatos is also exploring the possibility of inorganic colloidal nanocrystals in biological labeling applications. Specifically, the Berkeley group measured the light scattering of coupled pairs of Au nanocrystals in DNA cutting experiments, and found that the intensity goes up right before the cutting, then drops rapidly afterwards, because the enzyme used as a cutting tool bends the DNA slightly right before cutting it. This produces very different light scattering patterns, thereby providing a unique "signature." Alivisatos calls his technique a "plasmon ruler," and believes it could offer advantages over the use of fluorescent dyes, since it can make measurements over a larger length scale: between 1 and 70 nanometers, compared to between 1 and 10 nanometers using conventional techniques.

Nanotechnology is undeniably promising, but it cannot realize its full potential unless we find ways to scale up nanomanufacturing to make commercial quantities available at an affordable cost, according Richard Siegel of Rensselaer Polytechnic Institute (RPI). Also a co-founder of Nanophase Technologies, Siegel described how nanoparticles have moved from the lab to the marketplace over the last 17 years, starting with metal oxide nanoparticles manufactured via a gas-condensation physical process. Nanophase, for example, produces commercial quantities of nanoparticles and dispersions that are used in sunscreens and other health care products, polishing media for microelectronics, and nanoscale fillers for plastics. But fundamental research is ongoing at RPI's NSF-funded Center for Directed Assembly of Nanostructures to create materials with enhanced mechanical, electrical, optical and bioactive properties, which should lead to even more applications.

The automotive industry is interested in a variety of nanotechnologies, particularly those that could help produce vehicles with higher energy efficiencies, according to Mark Verbrugge, director of the materials and processes laboratory at GM Research and Development Center. He discussed recent work on new nanocomposites for structural materials for body subsystems of vehicles, as well as new electronic materials for efficient energy storage and transfer.

The latter category includes nanomaterials for improved batteries, thermoelectric devices, and hydrogen storage media for fuel-cell applications—all of which could prove highly valuable to developing advanced propulsion subsystems for vehicles. For instance, decreasing particle size in the catalysts used in a fuel cell stack increases the surface area for reaction, thereby reducing voltage losses. Similarly, smaller particles for supercapacitors in hybrid vehicles not only increase the surface area for energy storage processes, they decrease diffusion resistance in batteries. Nano-derived materials can also provide additional control over the thermoelectric conductivity of these energy-efficient technologies.

The development of nanoscale dendrimers for targeted drug delivery to kill cancer cells was the focus of James Baker of the University of Michigan's Nanotech Institute for Medicine and Biological Sciences. He described his research group's proof-of-principle success in creating what he calls "molecular velcro": synthetic nanoparticles called dendrimers that are built up spherically layer by layer. They have proven highly effective as a targeted drug delivery mechanism to fight certain types of cancers.

Baker and his colleagues created a "Trojan horse" that tricks cancer cells into absorbing the lethal drug while leaving healthy cells intact. Specifically, it exploits a peculiar feature of some cancer cells: they over-express their folate receptors, since they need lots of folic acid. The U-Michigan nanoparticles are designed to bind to the folate receptors, making it far more likely they will penetrate past the cell's natural protective barrier and release the therapeutic drug into the cell to kill it. Experimental tests on lab mice showed that the targeted drug delivery was far more effective in killing cancer cells and diminishing tumors than the free-form injection of the same drug, with far fewer side effects.

Ultimately, Baker would like to develop a therapeutic "smart cancer sensor," consisting of a single nanoparticle. It would target the affected site, bind to, and penetrate, cancer cells, and emit a telltale "signature" so doctors can tell where the cancer is located. It would also be able to measure the changes in the targeted cancer cells and select the appropriate therapeutic agent(s) based on those changes, then release the appropriate agent to kill the cancers.

The past decade has seen an explosive growth worldwide in the physical, chemical and biological synthesis of a wide range of nanoscale building blocks with unique properties in laboratory settings. There are already some being manufactured as well as several emerging applications and heavy investment in nanotech start-up companies.

BEYOND CMOS: EMERGING MATERIALS AND DEVICES

Electronic devices are already at the nanometer size scale; this session explored needs and options that might extend the recent decades of rapid improvements in information technology devices.

Ever since 1965, “Moore’s Law” has defined the semiconductor industry, leading to ever-faster processing speeds and transistor densities on silicon chips. The result has been more functionality at lower costs. In fact, transistor costs are still decreasing between 30 percent - 35 percent per year. “Moore’s Law is alive and well,” according to Intel’s C. Michael Garner, who opened the session with an overview of the semiconductor industry’s “road map” for the next 15 years.

There are three major challenging areas if the industry is to continue to extend CMOS devices in keeping with Moore’s Law: (1) new processes; (2) new materials; and (3) new lithography techniques. Of these, the second seems the most paramount: “This is the decade of new materials,” said Garner, while cautioning that the introduction of any new material brings its own challenges in the form of compatibility issues and the need for new process chemistries, among potential obstacles. He outlined some of the most promising recent advances, including strained silicon materials, novel transistor structures (such as Intel’s Trigate transistor currently under development), and the development of a high-dielectric metal gate that can reduce leakage by a factor of more than 10, leading to cooler devices.

As the industry moves into what Garner terms “extreme CMOS,” there is a corresponding need for superior performance and increased chip densities while controlling critical materials properties, and improving thermal management. This will require nanoscale control of both catalyst and growth kinetics. Beyond CMOS, only silicon nanowires and carbon nanotubes hold reasonable promise as replacement technologies but Garner admits that to date, they cannot meet the semiconductor industry’s stringent performance criteria, which include scalability, energy efficiency, room temperature operation, and heterogeneous integration of any alternative technologies comparable to the integration levels that characterize conventional silicon platforms.

Jeffrey Welser of Semiconductor Research Corporation extended this discussion, focusing on the potential of semiconductor nanoelectronics as a replacement for conventional CMOS technology. Broadly speaking, he emphasized that there should be a strong university research component, in collaboration with industry, in order to continue the rapid pace of technology development, as well as a broadening of the spectrum of the kinds of research being undertaken. This is the only way to bring about the critical paradigm shift needed to usher in an entirely new technology, which is what happened to the computer industry in 1980.

Welser believes that an alternative to CMOS is perfectly feasible, and the stage is set for a similar revolution if scientists can find something other than electronic charge to represent a “bit” of data. A few of the more radical possibilities include molecular electronics, so-called “spintronics” (which exploits the electron spin of atoms), and quantum computing. However, he agreed with Garner that the technologies with the most short-term potential are nanowires and carbon nanotubes, because it may be possible to integrate them directly onto a standard CMOS device, although there are still serious obstacles to overcome in order to achieve such integration. Power and variability will continue to be the semiconductor industry’s top principal concerns. “We will always be forced to trade off between speed and density,” he said.

Perhaps the most promising R&D in nanoelectronics is not the more showy or exciting, but the more mundane and workmanlike. That’s the opinion of Intel’s Michael Mayberry, who compared the buzz over the potential for carbon nanotubes (CNTs) to revolutionize nanoelectronics with the pronounced lack of buzz over what he considers to be a more promising approach: developing nanomaterials that can be grown in place (via techniques like pattern-assisted self-assembly) on an existing substrate. He believes that approach is much more likely to be easily integrated in future devices, which many of the session’s speakers felt would probably be a hybrid CMOS/nano device—at least initially.

It is well known in nanotechnology circles that there are serious scale-up problems when it comes to manufacturing ICs out of CNTs. Yet somehow those grim realities have not done much to crush the excitement over CNTs’ potential. Take the example of copper nanowires, a promising component for future nanoelectronic devices. The manufacturing process consists of three steps: surface preparation, deposit, and patterning. In contrast, CNTs require a much more complicated process. Achieving purity and exact alignment are the most difficult of those steps. It can be done in carefully controlled laboratory conditions at the small scale, but the techniques are not nearly robust enough to scale up to the industrial levels needed to make CNTs truly viable for nanoelectronics in the near future. For that reason, Mayberry contends that the IT industry will tend to favor those applications with the fewest alignment requirements.

Any improvements to existing CMOS devices, or entirely new replacement technologies, will require innovative new metrology methods to measure and monitor structural, chemical and electrical properties of such devices, according to Eric Vogel of the University of Texas at Dallas. He described the metrology challenges associated with some of most promising emerging devices and materials. For example, the industry is moving towards high-K gate dielectrics. By 2010, he estimates that the physical length of such gates will be 18 nm. In order to test or measure properties at those size scales, inline nondestructive microscopy resolution will need to be 0.16—which is only achievable by moving to atomic force microscopy. Similarly, gate thickness will be only 1.2 nm, beyond the current capabilities of standard physical and electrical metrology techniques. Further in the future, it will become necessary to characterize materials in three dimensions with angstrom-scale resolution.

Dawn Bonnell of the University of Pennsylvania closed the session by presenting some possible new metrological methods to measure nanoscale properties. One approach would be to combine different kinds of probes to yield new information at atomic dimensions, such as scanning impedance microscopy and nano-impedance spectroscopy. In this way, researchers would glean information from multiple signals, not just about surface details, but also about qualities like dielectric constant polarizability. This could be a particularly useful approach if the industry ends up assembling multiple types of nanostructures as components of an integrated device.

Bonnell also discussed the possibility of using biological compounds for microelectronics and optoelectronics, among other engineering functions, linking proteins, particles and wires to construct functional devices. As a means to this end, she sees great promise in manipulating nanoscale structures through ferroelectric lithography. There are already a variety of techniques for patterning ferroelectric substrates: electron-beam lithography, for example, or scanning probe microscopy. Ferroelectric nanolithography would move beyond older techniques, manipulating electronic structure to control site-specific reactivity. By developing such novel methods, she foresees a day when oxide substrates, silver nanoparticles, and biological molecules will co-exist on a complex, integrated nanodevice.

New processes, new materials, and new lithography techniques are helping extend the limits of conventional CMOS technology over the next decade, but there are also promising alternative technologies being pursued that, if successful, could one day supplement or replace it, revolutionizing the computer industry once again.

POLICY SESSION:
NANOTECHNOLOGY AND SOCIETY

This session explored environmental, safety, health and economic issues from industrial and regulatory perspectives.

Andrew Maynard of the Woodrow Wilson Institute addressed the issue of managing potential risk and protecting human health and the environment in the age of nanotechnology. He believes that we need to develop a nanotechnology oversight policy built on a firm scientific basis, to best protect ourselves from any potentially harmful impacts of nanotechnology without unnecessarily impeding further developments in this booming field.

Maynard insists that any approach to nanotechnology oversight must be discussed within the context of specific applications, because of the sheer complexity and scope of the field. However, he believes there are nonetheless some general principles that can be extrapolated. He suggested setting initial boundaries for oversight along two basic criteria: (1) nanomaterials capable of entering or interacting with the body in potentially harmful ways; and (2) nanomaterials which exhibit biological activity that is dependent on its nanostructure. These two criteria incorporate such things as nanoparticles (aerosols, powders, suspensions and slurries), and also agglomerates or aggregates of nanoparticles that may (or may not) retain their unique small-scale structural properties even when grouped.

Research into potential health and environmental risks of nanotechnology is still in the early stages, but there is some compelling preliminary experimental evidence that nanoparticles of titanium oxide and barium sulfate—which are normally quite chemically inert—can cause inflammation of the lungs in rats. There's also been some consumer concern about the use of nanoparticles in sunscreens and make-up, addressing the issue of whether it is possible for tiny nanoparticles to penetrate the protective dermis of the skin. Experiments suggest that the skin is a very effective barrier, but a recent experiment involving quantum dots suggests that altering the surface chemistry of the dots in very specific ways can increase the chances of penetration. So the size of nanoparticles is not the only feature that matters when it comes to assessing potential health risks: their structure, surface area, surface reactivity, and other properties influence both their behavior and impact.

Michele Ostraat of DuPont also addressed potential health risks of nanotechnology. DuPont, Procter & Gamble, Dow, and Intel are founding members of the Nanoparticle Occupational Safety and Health Consortium (NOSH), launched in 2004. Today there are more than 16 companies and organizations worldwide participating in the consortium. Its purpose is to begin filling in the "knowledge gaps" concerning occupational safety and health associated with aerosol (airborne) nanoparticles via a collective effort, with an eye towards establishing workplace exposure monitoring and protocols.

There are numerous stated goals and "deliverables," most notably the performance of aerosol chamber experiments on silicon dioxide nanoparticles to determine factors such as the rate of particle diffusion and coagulation and the life cycle of the nanoparticles to determine when they no longer pose a risk. That aspect of characterizing the aerosol behavior of a well-understood nanoparticle over time is nearing completion. The consortium is also working to develop instrumentation and protocols to better assess the barrier effectiveness of filter media used to safeguard workers from both charged and uncharged aerosol nanoparticles.

More challenging is the planned development of a portable air sampler device capable of detecting and measuring the presence of aerosol nanoparticles in the atmosphere. Such a device would need to be low cost, simple to operate, handheld (easily portable), and robust. For example, it must function not just in a controlled laboratory environment to detect carefully engineered nanoparticles, but also in the "real world," which most likely has a strong "background" of pre-existing airborne nanoparticles that will make reliable detection and measurement much more challenging.

Concerns about environmental and health risks aside, nanoparticles can help with environmental remediation by cleaning up soil and groundwater contamination. Weixian Zhang of Lehigh University talked about his work with zero-valent iron nanoparticle technology, which is proving quite popular for remediation and treatment applications: everything from chlorinated organic solvents and organochlorine pesticides, to PCBs, perchlorate and hexavalent chromium. Such nanoparticles are small enough to be injected at the contaminated site and can be easily dispersed across large surface areas. They react quickly with contaminants to transform them into less harmful compounds. Recent advances have made these nanoparticles much more cost-effective for large-scale applications.

Ann Johnson of the University of South Carolina further explored the various ethical issues related to the emergence of nanoscience and nanotechnology, citing the need to engage the public in such discussions to enable them to make more informed decisions about using nanotech products, without falling victim to undue fear or panic. Communication is needed because there is often a sharp distinction between a scientist's notion of what constitutes a "safe" product, and that of the average non-scientist; she suggested identifying common areas for these two disparate groups.

Johnson noted how attitudes towards social responsibility have shifted in the scientific community. Ethical questions tend to be tied to applications of scientific research, such as the development of the atomic bomb in the 1940s. In those days, many scientists—with a few notable exceptions—believed they were not ethically accountable for the applications of their fundamental research, since how society chose to use the knowledge they created was beyond their control. Ethics was considered the realm of philosophy, not science.

Today, most scientists understand that even the most fundamental research does not occur in a societal vacuum and any research with a "nano" prefix is undertaken with eventual real-world applications in mind. Ergo, Johnson maintains that the scientific community must "create space for ethical discussions," and that these discussions must be both public, and take place on a national scale. "Science should not be undertaken behind closed doors," she said.

Having appropriate oversight frameworks in place will be essential to the sustained development of nanotechnology, particularly to address potentially new risks presented by engineered nanomaterials. It is important to strike the right balance. Too little oversight could be as damaging to fledgling nanotechnologies as too much oversight. Nanotechnology also has promise for addressing environmental hazards created by other technologies.

FRONTIERS IN PHYSICS

This perennially popular session addressed the most exciting research going on today, regardless of field.

Nearly 50 years ago, physicist Richard Feynman recognized that biology is teeming with examples of "writing" information on a very small scale. The human body contains billions of living cells, which store all the information needed to coordinate all the functions of a complex organism. Cells are nature's nanomachines, and there is a great deal of R&D currently devoted to engineering nanosystems that mimic nature's genius.

We can create rudimentary nanoscale electronic devices, but they need to be much more robust and self-replicating if we are ever to realize their full potential, according to Michael Roukes, a professor of physics at Caltech, who kicked off the Frontiers in Physics session with an overview of nanosystems of the future. First and foremost is a fusion of technologies, melding techniques from surface biochemistry and microfluidics with sensor technologies from nanoelectronics, nanomechanics and nanophotonics. We must also develop more robust methods for large-scale integration of nanobiotechnology.

"Nature's systems-nanotechnology still far outstrips what is engineerable today," Roukes admitted, and pointed to the profoundly robust and adaptive human immune system as an example. Our immune system provides what is essentially single-molecule sensitivity to invading pathogens: when pathogens are detected, information is conveyed by chemical "messengers," triggering an immune response to kill the interloper. For Roukes, the living cell is a tiny integrated circuit/microprocessor, and single molecules can be viewed as living information "quanta."

His goal is to exploit the cell's incredible sensitivity to detecting invading pathogens to create nanoscale biosensors (BioNEMS). The first step is being able to embed nanoscale biosensor arrays into microfluidic systems to form chip-based electronic "laboratories" for cell biology. Roukes believes in the inherent promise of cell-level nanosystems, particularly the potential for early disease detection, drug discovery and other basic research in medicine and biology that would be possible if we had such a single-molecule sensor. "Ultimately, active nanobiotechnology will enable a detailed real-time window into the complexity of cellular processes," he said.

Wim Leemans, who heads the Lasers, Optical Accelerator Systems Integrated Studies (LOASIS) program at Lawrence Berkeley National Laboratory, gave an overview and a few recent achievements in the area of laser-plasma wakefield accelerators—a tabletop version of the gigantic particle accelerators found at Fermilab, among other locations. In the simplest incarnation of the machine, an intense laser pulse is sent through a gas to ionize it and form a plasma of dissociated electrons and ions. The radiation pressure of the laser pushes the plasma electrons aside, creating a "wake." The change in electron density can result in fields that accelerate particles thousands of times more strongly than in conventional machines, allowing the electrons to reach very high energies over relatively short distances.

Leemans' group has achieved high-quality 1 GeV electron beams in a plasma channel based structure similar to an optical fiber (called a plasma capillary discharge waveguide), and are now experimenting with the generation of intense terahertz and X-ray radiation. The compactness of such accelerators would allow higher energies for the frontiers of fundamental physics; it may also enable more practical applications in medical clinics, as well as scientific laboratories. Other potential applications include drivers for future light sources.

MIT's Marin Soljačić presented his proposed scheme for wireless non-radiative energy transfer. It is still in the theoretical stages, but it might one day be possible to recharge laptop computers, cell phones, and other indispensable electronic gadgets wirelessly, without having to lug around so many different kinds of chargers.

Physicists know it is possible to transmit energy wirelessly, but over long distances, the waves dissipate too quickly for efficient transfer. In order for a cell phone to be able to recharge itself, one would need to transfer energy wirelessly with minimal energy loss. Soljačić's key insight is that the close-range induction that happens inside your basic transformer could potentially transfer energy over short and mid-range distances—sufficient to recharge a cell phone or laptop across the room from a charger. A power transmitter would fill the space with a "non-radiative" EM field, and the energy would only be detected by gadgets designed to "resonate" with that field. Most of the energy not picked up by a receiver would be reabsorbed by the emitter.

Soljačić envisions a day when wireless energy could power not just industrial applications or electric vehicles, but also freely roaming nanorobots, or macroscale robotic factory workers.

Long relegated to the outskirts of theoretical physics—and the pages of science-fiction novels—black holes and neutron stars have now been directly observed in abundance by astronomers, according to Roger Blandford, director of the Kavli Institute of Particle Astrophysics and Cosmology at Stanford University. The study of such exotic objects is pushing basic physics exploration into extreme environments that are currently unattainable in earth-based laboratories.

Blandford reviewed the basics of both types of object. Neutron stars are radio pulsars, and as such make for excellent time-keeping devices for testing general relativity and high energy astrophysics. Among their other fascinating properties, they spin rapidly (near kHz frequencies) and support very strong magnetic fields, and when they explode they create powerful gamma ray bursts with timescales of mere milliseconds. Black holes, on contrast, are believed to be the remnants of massive dead stars that gravitationally collapsed, and possess so-called “event horizons”—a point of no return—that outgoing matter and radiation cannot cross. Most galaxies have massive black holes at their centers, including our own Milky Way galaxy. And sometimes two black holes will merge, creating a burst of radiation that can be detected by astronomical instruments.

From individual cells (nature’s nanomachines), and laboratory tabletops, to large exotic objects found at the furthest reaches of the cosmos, the Frontiers in Physics session aptly demonstrated that cutting-edge physics research at all size scales has the potential to revolutionize both fundamental science and practical applications.

2007 CORPORATE ASSOCIATES

3M Company
The Abdus Salam International Centre For Theoretical Physics
The Aerospace Corporation
Agilent Laboratories
Battelle Energy Alliance
Corning Incorporated
Cryogenic Control Systems, Inc.
The Dow Chemical Company
Energy Conversion Devices, Inc.
ExxonMobil Research and Engineering Company
ExxonMobil Upstream Research Company
Ford Motor Company
General Atomics
General Electric Corporate R&D
General Motors R&D Center
Hewlett-Packard Company
Hitachi, Ltd.
HRL Laboratories, LLC
IBM Thomas Watson Research Center
Janis Research Company, Inc.
Jobin Yvon Horiba
Johns Hopkins University/Applied Physics Laboratory
Lake Shore Cryotronics, Inc.
Lucent Technologies, Bell Laboratories
MIT Lincoln Laboratory
National Institute for Standards & Technology
Palo Alto Research Center (PARC)
Philips Research
Quantum Design, Inc.
Sarnoff Corporation
Schlumberger-Doll Research
Shell E&P Technology Company
Springer Verlag, New York, Inc.
Texas Instruments, Inc.
Thomas Jefferson National Accelerator Facility
UOP, LLC
Xerox Wilson Center for Research & Technology

To find out more about AIP's Corporate Associates Program, contact the office of the Executive Director (301) 209-3131 ◆ E-mail: assoc@aip.org

Additional copies of this report can be obtained, free of charge, by contacting the AIP Industrial Outreach (301) 209-3159 ◆ E-mail: assoc@aip.org.

Announcing the 2007 Industrial Physics Forum...

Industrial Physics Forum

for Corporate and Academic Leaders

To be held in conjunction with the

AVS International Symposium

The theme will address The Energy Challenge.

OCTOBER 14-16, 2007

SEATTLE, WASHINGTON

AMERICAN INSTITUTE OF PHYSICS

One Physics Ellipse
College Park, MD 20740

Go to: www.aip.org/ipf to view the full meeting report
and for information on future meetings.