Nano-Manufacturing Topical Conference
Room 2018 - Session NM+IPF-MoM

Examples of Nanotechnology Manufacturing

Moderator: J. Randall, Zyvex Corporation

8:00am **NM+IPF-MoM1 The Economics of Matter: Nanotechnology & Scale of Manufacturing***, J. Wolfe,* Lux Capital **INVITED**

My venture partners invest in, write about, and live in the realm of mesoscale physics, or, by its more popular nomenclature, nanotechnology. Once poorly understood as an ill-defined amalgamation of disparate, atomic-level sciences, nanotechnology is now a young media darling whose time has come. Sophisticated investors and corporate executives grasp that this is no passing fad. Five years ago, we saw salient advances in materials science being neglected as the herds stampeded toward enterprise hardware and software and optical networking. We were convinced that Nicholas Negroponte would have it wrong, and that soon enough people would be trading in their bits for atoms. When our research arm, Lux Research, released its first annual "Nanotech Report" in 2001, 98 percent of Fortune 1000 executives were unable to define "nanotechnology." Today, nanotechnology has become a presidential priority, has taken center stage on CNBC, and has even surfaced as a subject of activist chatter and environmental concern. Just as plastics revolutionized the structural properties of matter - entering into industries as various as communications, electronics, food and beverage, and entertainment - now, nanoscale advances offer the ability to control the structural and functional properties of matter. This includes electric, thermal, magnetic, and optical properties, which are applicable to every industry imaginable.

8:40am **NM+IPF-MoM3 Colloidal Nanocrystals of Complex Shape: Synthesis, Properties, Applications***, A.P. Alivisatos,* Lawrence Berkeley National Laboratory and University of California, Berkeley **INVITED**

Over the last decade, there have been significant advances in the ability to prepare colloidal inorganic nanocrystals with controlled size, shape, and even interconnection (branching) and topology (hollow and nested). These materials exhibit strongly size dependent properties, but they also share many of the characteristics of inorganic solids, in terms of stability and range of properties. They can be processed in solution like polymers. They thus make attractive candidates for incorporation into a wide range of technologies, from biological labels to components in solar cells and catalysts.

9:20am **NM+IPF-MoM5 Manufacturing Nanoparticles for Applications in Society***, R.W. Siegel,* Rensselaer Polytechnic Institute **INVITED**

The past decade has seen an explosive growth worldwide in the physical, chemical, and biological synthesis and study of a wide range of nanoscale building blocks with unique properties in laboratory settings. However, before these nanoscale building blocks can significantly impact society through a wide range of novel applications, the manufacture of them needs to be scaled up to commercially viable quantities at an affordable cost. This talk will describe how one such type of nanoscale building blocks, nanoparticles, has moved from the laboratory to the marketplace, and milligrams to tons, over the past 17 years. We began making metal oxide nanoparticles via a gas-condensation physical process at Argonne National Laboratory in 1985 and in 1989 founded a company, Nanophase Technologies Corporation, to scale up production and eventually market products. Since that time, a publicly held (since 1997) business has been developed that produces commercial quantities of a variety of nanoparticles and dispersions that have found applications that benefit society in sunscreens and other health care products, polishing media for microelectronics, and nanoscale fillers for a number of plastics, among others. Nevertheless, fundamental research continues with these commercially available nanoparticles that could expand the horizons of their application space in society. Some examples from this research in our own laboratories in the National Science Foundation funded Center for Directed Assembly of Nanostructures at Rensselaer to create materials that possess enhanced mechanical, electrical, optical, and bioactive properties, and multifunctional combinations thereof, will also be presented.

10:20am **NM+IPF-MoM8 Nanotechnology and High-Efficiency Automobiles***, M.W. Verbrugge,* General Motors Research and Development Center **INVITED**

We overview a variety of nanotechnologies and associated opportunities relevant to automotive applications. A significant challenge for the automotive industry is to produce vehicles of higher energy efficiency while continuing to improve vehicle functionality. One can divide the vehicle system into body and powertrain subsystems. This talk overviews recent developments and open questions associated with (1) structural materials for body subsystems and (2) electronic materials for energy storage and transfer. Emphasis is given to nanocomposites and surface analysis methods within the context of structural subsystems. Batteries, thermoelectric devices, and hydrogen storage media are addressed in relation to advanced propulsion subsystems.

11:00am **NM+IPF-MoM10 DNA-linked Dendrimer Nanoparticle Systems for Cancer Diagnosis and Treatment***, J.R. Baker, Jr.,* University of Michigan **INVITED**

Dendritic polymer architecture allows for the development of new therapeutics that directly target cancer cells and largely bypass healthy cells. Clusters of these polymers can be combined into more complex structures with several different subunits, each with its own function, be it targeting, imaging or therapeutics. This technology can be expanded by developing single-function dendrimer modules linked by complimentary oligonucleotides. Thus, producing multifunctional therapeutics that can be customized to a specific patient's needs.

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Beyond CMOS: Emerging Materials and Devices
Moderator: C.M. Garner, Intel Corporation

2:00pm **NM+MS+IPF-MoA1 Technology Challenges: The Next 15 Years***, P. Gargini, C.M. Garner,* Intel Corporation **INVITED**

The semiconductor industry continues to introduce new technologies at the pace dictated by Moore's Law. The International Technology Roadmap for Semiconductors (ITRS) projects that devices can be manufactured with conventional process technology through at least 2020 even though there are significant challenges, but further extensions to extreme CMOS may require new 1D device materials. When extreme CMOS technology has reached the limits of scaling, new devices with potentially new architecture will be needed to provide continued performance improvements. For technologies beyond CMOS, research is proceeding on a number of new alternate "state" devices that would require radical materials with a silicon base. The introduction of new alternate state devices may require the introduction of new interconnect technologies and materials with nm control of properties. The challenges to driving to extreme CMOS and the options for alternate state devices will be discussed. For more information on the International Technology Roadmap for Semiconductors (ITRS): http://public.itrs.net

2:40pm **NM+MS+IPF-MoA3 Beyond CMOS - The Semiconductor Industry's Nanoelectronics Research Initiative***, H. Coufal,* ***J. Welser,*** Nanoelectronics Research Corporation **INVITED**

The tremendously powerful scaling of transistors, that has enabled Moore's Law for the past forty years, can not continue forever. Some of the reasons, such as the atomistic nature of matter, are obvious. Others are less obvious and will be briefly reviewed before some of the potential alternatives to charge based logic will be analyzed. Such an analysis had the semiconductor industry initiate a Nanoelectronics Research Initiative. The current status of this program will be reviewed.

3:20pm **NM+MS+IPF-MoA5 Nano Manufacturing Challenges***,* ***M. Mayberry,*** Intel **INVITED**

Not all "nano" is created equal. Nanostructures formed through tops down construction are widely used in the creation of electronics and have shipped in volume for several years. Nanomaterials that are formed through bottoms-up synthesis or self-assembly are at a comparably early stage in research and development. Combining the two approaches has considerable promise but also significant hurdles to overcome. To illustrate we will discuss three potential applications for nanomaterials and some of the challenges to successful implementation in manufacturing. First consider the problem of forming nanostructures as the size of the features begins to approach molecular dimensions. A 20nm wide structure would only consist of 10 resist molecules side by side if the resist molecule were 2nm in size. That introduces significant granularity which up to now has not been a key concern. This problem could be addressed by designing self-assembly molecules with the proper combination of sensitivity to illumination, chemical properties, and physical size. A second potential application is the formation of dielectrics between metal lines for interconnects. An ideal dielectric is an insulator, strong enough to withstand forces generated with temperature cycling, a barrier to migration of materials, and for performance reasons has a low dielectric constant. These could in principle be met through design of the right building blocks but there are complications with integration in the overall process flow. Finally nanodevices formed through self-assembly (ex. nanotubes) could in principle allow formation of very small devices but the challenge of precision formation, placement, and again integration are daunting. These challenges are not insurmountable but need to be addressed through the right research and development so that the promise of nanomaterials can be achieved.

4:00pm **NM+MS+IPF-MoA7 Metrology for Emerging Devices and Materials***,* ***E. Vogel,*** University of Texas at Dallas **INVITED**

Traditional scaling of the CMOS Field-Effect-Transistor (FET) has been the basis of the semiconductor industry for 30 years. The 15 year horizon of the International Technology Roadmap for Semiconductors (ITRS) is reaching a point which +IBw-challenges the most optimistic projections for the continued scaling of CMOS (for example, MOSFET channel lengths of roughly 9 nm).+IB0- As silicon CMOS technology approaches its limits, new device structures and computational paradigms will be required to replace and augment standard CMOS devices for ULSI circuits. These possible emerging technologies span the realm from transistors made from silicon nanowires to devices made from nanoscale molecules. One theme that pervades these seemingly disparate emerging technologies is that the electronic properties of these nanodevices are extremely susceptible to small perturbations in structural and material properties such as dimension, structure, roughness, and defects. The extreme sensitivity of the electronic properties of these devices to their nanoscale physical properties defines a significant need for precise metrology. This talk will provide an overview of emerging devices and materials, and, through example, an overview of the characterization needs for these technologies.

4:40pm **NM+MS+IPF-MoA9 Linking Proteins, Particles and Wires to make Functional Devices: Metrology, Materials and Properties***,* ***D.A. Bonnell,*** The University of Pennsylvania **INVITED**

Two issues that are critical, and projected to be limiting, to next generation device technology are metrology at the nanoscale and integration of diverse materials into manufactured devices. The first half of this talk will summarize advances in local measurements of properties and demonstrate new techniques that probe electronic structure and properties in nanostructures and molecular wires. These approaches will be illustrated on 3-terminal configurations that exhibit transistor or memory behavior. Opportunities for exciting advances on the horizon will be presented. The second half of the talk will present strategies for integrating a combination of metal and/or oxide nanoparticles, organic and/or biological molecules on oxide or polymeric substrates in device configurations. The processing approach, Ferroelectric Nano Lithography, induces variations in local electronic structure in substrates to direct assembly of nanostructures with diverse properties into complex patterns, thus overcoming one of the limitations of self assembly. The approach has been used to produce a molecular opto electronic switch.

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Nanotechnology and Society

Moderator: J. Murday, Naval Research Laboratory

8:40am **NM+IPF-TuM3 Nanotechnology Oversight - Managing Potential Risk in an Uncertain World*, A.D. Maynard,*** Woodrow Wilson International Center for Scholars **INVITED**

Nanotechnology has been described as a transformative technology, an enabling technology and the next technological revolution. Even accounting for a certain level of hype, a heady combination of investment, rapid scientific progress and exponentially increasing commercialization, point towards nanotechnology having a fundamental impact on society over the coming decades. However, enthusiasm over the rate of progress is increasingly being tempered by concerns over possible downsides of the technology. Real and perceived adverse consequences in areas such as asbestos, nuclear power and genetically modified organisms have engendered skepticism over the ability of scientists, industry and governments to ensure the safety of new technologies. As nanotechnology moves towards widespread commercialization, not only is the debate over preventing adverse consequences occurring at an unusually early stage in the development cycle; it is also expanding beyond traditional science-based risk management to incorporate public perception, trust and acceptance. Having appropriate oversight frameworks in place will be essential to the sustained development of nanotechnologies. These will need to address potentially new risks presented by engineered nanomaterials, and be responsive to the rapidity with which nanotechnologies are being discovered, developed and used. Existing oversight frameworks may be sufficiently robust to address new technologies with little modification, although some commentators suggest that this is unlikely. Either way, too little oversight could be as damaging to fledgling nanotechnologies as too much oversight.

9:20am **NM+IPF-TuM5 Nanoparticle Occupational Safety and Health Consortium*, M.L. Ostraat,*** DuPont Engineering Research and Technology*; K.A. Swain,* DuPont Central Research and Development*; J.J. Krajewski,* DuPont Engineering Research and Technology **INVITED**

The Nanoparticle Occupational Safety and Health (NOSH) consortium of international industrial, government and non-governmental organizations has focused research upon obtaining information on occupational safety and health associated with aerosol nanoparticles and workplace exposure monitoring and protocols. The technical goals of the consortium include 1) generating well-characterized aerosols of solid nanoparticles and measuring aerosol behavior as a function of time; 2) developing an air sampling method that can be used to conduct worker exposure assessments in workplace settings; and 3) measuring barrier efficiency of filter media to specific engineered aerosol nanoparticles. To accomplish these objectives, multiple aerosol synthesis and characterization systems have been designed to generate well-characterized aerosol nanoparticles of various chemistries < 100 nm. These aerosol nanoparticles are transported to aerosol chambers to examine aerosol behavior as a function of time, including rate of dispersion, aggregation, and particle loss for charged and uncharged aerosol nanoparticles. These aerosol nanoparticle studies form the basis for the development of a portable aerosol nanoparticle monitoring instrument which will be field tested in a wide variety of workplace environments. Through this effort, the consortium has developed instrumentation and protocols required to assess barrier effectiveness of filter media to charged and uncharged aerosol nanoparticles as a function of particle chemistry, particle size distribution, and number concentration. Work continues on identifying appropriate filter media that can be used as effective barriers for aerosol nanoparticles and establishing a knowledge base on determining specifications for using those filter media given a set of known properties about a specific nanoparticle aerosol.

10:40am **NM+IPF-TuM9 Nanotech for Environment Renaissance - Soil and Groundwater Cleanup using Reactive Nanoparticles*, W.-X. Zhang,*** Lehigh University **INVITED**

Zero-valent iron nanoparticle technology is quickly becoming a popular choice for remediation and treatment of a wide variety of common environmental contaminants in soil and groundwater. Over the three years, there are more than 30 completed and ongoing applications in North America and Europe. Nanoparticles have small sizes for effective in situ injection and dispersion and large surface areas and high surface reactivity for rapid contaminant transformation. Recent innovation in the technology and increasing supplies of nanoparticles have substantially reduced the cost of this technology for large scale applications. In this lecture, fundamental principles on nanoparticle synthesis and characterization will be highlighted. Applications of the iron nanoparticles for treatment of chlorinated organic solvents, organochlorine pesticides, PCBs, perchlorate, and hexavalent chromium will be presented. In addition, key issues related to field applications such as cost, fate/transport, and potential environmental impact will be discussed.

11:20am **NM+IPF-TuM11 Ethics between Nanoscience and Nanotechnology: Making Space for a Discussion*, A. Johnson,*** University of South Carolina **INVITED**

Much of the work in the ethical implications of science and technology is rooted in a concern over the potential and already occurring societal effects of research and the products of research. But science and technology can have profoundly different underlying assumptions about their societal interactions. Technology, or perhaps more specifically engineering, has developed a robust space for ethical discussion - a fact which underlies the recent re-orientation of engineering curriculum in the US (ABET 2000) to provide curricular support for ethics in engineering education. The ethical landscape of technology is rooted in the fact engineers unquestioning acknowledge that they produce goods for society and that those goods often have societally-transforming effects (both for good and for bad). Science has no such assumption (though individuals' beliefs may obviously differ). Many scientists believe that science can be important without any societal implications - science can be simply about knowing the unknown, without that knowledge having any societal effect. Some scientists, in their pursuit of disinterestedness, have explicitly denied the societal interactions of their work. Science, ideally in their minds, stands outside society. This strongly limits the space for ethical discussion. This position is one which has its own long history, but can be detected in Rowland's "Plea for Pure Science" to Vannevar Bush's (ironically, an engineer!) Endless Frontier to the efforts of Cold War nuclear physicists to distinguish bomb design from basic research to the Science Wars debate of the 1990s. Rather than simply cursing this position, I will address the question here of how this effects today's work at the border of science and technology, by presenting a case study on the way that researchers in nanotechnology, a field with explicit societally-transformative goals, is struggling with the pure-applied/science-technology distinction once again.

Industrial Physics Forum
Room 2020 - Session IPF-TuA

Frontiers in Physics

Moderator: M.T. Bernius, The Dow Chemical Company

2:00pm **IPF-TuA1 Future Nanosystems: Towards Systems Biology of the Individual Cell*, M. Roukes,*** California Institute of Technology **INVITED**

Nanoscience now enables creation of ultrasmall electronic devices that offer unprecedented opportunities for sensing. Transitioning these devices from the realm of one-of-a-kind “feats” into robust, reproducible nanosystems useful for medical and biological research is a monumental challenge. Only the very first steps have been taken towards this end, even though such efforts are absolutely crucial for realizing the promise of "active" nanotechnology. At least two essential elements must be in place to realize the vast applications potential that awaits. First, an unfamiliar fusion of technologies is required, one that melds techniques from surface biochemistry and microfluidics with sensor technologies from nanoelectronics, nanomechanics, and nanophotonics. Second, robust methods for large-scale nanobiotechnological integration are required, and these must engender identifiable routes to production en masse. This disciplined assemblage of disparate technologies is crucial, whether for fundmental discovery work in medicine and the life sciences, or for the development of future clinical products. The requisite methodology is probably more familiar to the commercial sector than to academia. Despite impressive recent achievements in what I term "unit" nanoscience (which focuses upon individual phenomena and novel structures), nature's systems-nanotechnology still far outstrips what is engineerable today. For example, the mammalian acquired immune response represents a profoundly adaptive system that provides essentially single-molecule sensitivity to pathogens. In this light, harnessing cellular systems within hybrid devices appears to have immense potential for early disease detection, drug discovery, and fundamental medical and biological research. Today’s micro- and nanoscale technologies can provide the requisite tools for such applications. We are managing some awkward first steps toward these ends, embedding nanoscale biosensor arrays into microfluidic systems to form chip-based electronic "laboratories" for cell biology. When fully realized, this approach will permit simultaneous observation and control of multiple intra- and inter-cellular interactions. This, in turn, will reverse-engineering of biochemical networks through the techniques of systems biology, but at the level of the individual cell. There is an inevitability about such pursuits; they are increasingly being carried out by laboratories worldwide. Ultimately, active nanobiotechnology will enable a detailed real-time window into the complexity of cellular processes.

2:40pm **IPF-TuA3 Accelerating in the Future with Laser-Plasma Accelerators*, W. Leemans,*** Lawrence Berkeley National Laboratory **INVITED**

More than twenty five years ago, a new method was proposed for the acceleration of electrons to high energies using lasers. The simplest implementation of a so-called laser wakefield accelerator involves sending an intense laser pulse 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 density modulation, or 'wake.' This changing electron density can result in fields that accelerate particles thousands of times more strongly than in conventional machines, accelerating electrons to high energies in short distances. The compactness of these accelerators would allow higher energies for the frontiers of fundamental physics and make clinical and laboratory applications of accelerators practical. In work that brings the promise of laser-driven particle accelerators dramatically closer to reality, we have produced high-quality GeV electron beams in a plasma channel based accelerating structure akin to an optical fiber of only a few centimeters long. Recent progress will be presented, including the generation of intense THz and x-ray radiation. Applications for such accelerators as drivers for future light sources and high energy physics particle colliders will be described, including a discussion on the challenges in laser technology to drive these accelerators.

3:20pm **IPF-TuA5 Wireless "Non-Radiative" Energy Transfer*, M. Soljačić,*** Massachusetts Institute of Technology **INVITED**

The emerging vast acceptance of autonomous electronic devices (e.g. radios, cell-phones, laptops, robots), which are currently being powered by on-site conversion of chemical energy, justifies revisiting the old dream of the pioneers of electrical applications (e.g. Tesla, Edison): transporting electrical energy wirelessly; where for optimal practicality, the energy transfer should be independent of the details of the geometry of the space in which the scheme is being used (e.g. of the exact position of the device with respect to the source, and whether there exists a direct line-of-sight between the device and the source.) Of course it is well known that freely-radiative modes satisfy this requirement (making them very suitable for information transfer), but they are not suitable for powering remote devices, since most of the power ends up being wasted into empty space. In our work, we investigate whether, and to what extent, the unique physical phenomenon of long lifetime resonant electro-magnetic states can, with long-tailed (non-radiative) modes, be used for efficient energy transfer. Intuitively, if both the device and the source are resonant states of the same frequency with long lifetimes, they should be able to exchange energy very efficiently, while interaction with other environmental off-resonant objects could be negligible. Of course, intricacies of the real world make this simple picture significantly more complex. Nevertheless, via detailed theoretical, and numerical analyses of typical real-world model-situations and realistic material parameters, we establish that such a non-radiative scheme could indeed be practical for middle-range wireless energy transfer (i.e. within a room, or a factory pavilion). Important novel applications are thus enabled.

4:00pm **IPF-TuA7 Neutron Stars and Black Holes*, R. Blandford,*** Stanford University **INVITED**

No longer a creation of the theoretical physicists' imagination, neutron stars and black holes have been found in abundance in the observed universe and have allowed astrophysicists to push our exploration of basic physics into extreme environments unattainable in the laboratory. Neutron stars exist as radio pulsars that are splendid clocks for testing general relativity and high energy astrophysics. They can spin with almost kHz frequencies and support 100GT magnetic fields. They can be gravitational machines for transforming the rest mass energy of accreting gas into X-rays and can explode to create gamma ray outbursts with millisecond timescales. Black Holes are gravitational collapsed objects that possess event horizons that outgoing matter and radiation cannot cross. They come in two sizes. Star-sized holes are observed when they have binary companions that evolve to supply them with gaseous fuel which can spiral inward towards the event horizon through an "accretion disk". Stellar holes may be formed during special supernova explosions accompanied by gamma ray bursts. Holes as massive as millions to billions of suns reside in the nuclei of most normal galaxies, including our own. When they are supplied with gas they can easily outshine their host galaxies and are then called quasars. When black holes merge, they can create burst of gravitational radiation which may be detectable.

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