AVS 50th Anniversary Plenary Session
Room 310 - Session AP-MoA

Where Next for Nanotechnology?

Moderator: R.J. Colton, Naval Research Laboratory

2:00pm **AP-MoA1 Nanotechnology: A Policy Perspective*, S. Hays,*** National Science and Technology Council **INVITED**

Nanotechnology research and development is a top priority of the current Administration. Scientific and technological breakthroughs in the ability to measure, manipulate and understand matter on the atomic and molecular scale are enabling the development of novel structures, systems, and devices. Realizing the full potential of the discoveries requires multidisciplinary efforts among researchers as well as truly interdisciplinary work by those who can bridge the "languages" and cultures of biology, physics, chemistry and engineering. The National Nanotechnology Initiative is a coordinated multi-agency federal research program that supports not only fundamental and applied research but also development of necessary tools and infrastructure, education and workforce development, and the study of societal issues. The future of nanotechnology rests in particular on advances in instrumentation and materials processing capabilities, two areas that are central to the interests of the AVS and the expertise of its members.

2:40pm **AP-MoA3 Nanotechnology: Future Challenges and Opportunities*, E. Hu,*** University of California, Santa Barbara **INVITED**

The launching of the National Nanotechnology Initiative nearly 4 years ago has captured the scientific and popular imagination and has catalyzed tremendous scientific discovery at an international level. Working with building blocks at the nanometer scale (molecules, nanoclusters, quantum dots, etc.), nanoscale science and engineering promises to alter not only what complex systems we can make, but also how we can make or manufacture systems. Substantial advancements have been made in (1) designing new instrumentation to image and characterize structures at the nanoscale, in (2) computational power and architectures that will allow modeling and simulation of nanostructure properties and performance, in (3) integrating diverse nanoscale building blocks (e.g. biological and electronic materials), and in (4) assembling modest-level nanosystems. The next 'giant steps' in the realization of multifunctional, manufacturable, higher-complexity nanosystems will require substantial improvements in all the areas mentioned above. Complex assembly of new materials will require designing in redundancy and repair into the processes. As more biological/molecular-electronic composite systems are utilized, we will need much a better understanding of information transfer and coherence across biological-electronic material interfaces. The richness of the work done thus far in creating a new Nanotechnology reveals a multitude of outstanding challenges and at the same time opens many avenues for further exploration and applications.

3:20pm **AP-MoA5 Self-Assembly Processing for Nanomanufacturing*, M. Tirrell,*** University of California, Santa Barbara **INVITED**

Self-assembly is a route to processing of chemical products that relies on information content built into the process precursors. The bonding mechanisms of self-assembled products are weaker than the electronic bonds of molecules; the complexity built into self-assembled products is at the level of supermolecular structure. Self-assembly processes may be spontaneous or directed by the influence of templates or fields. Self-assembly occurs frequently in biology but translating that bioinspiration to controllable chemical processing presents many interesting problems. A challenge for chemical engineers is to develop the practical routes to technologically important self-assembly processes. Applications will be to biomaterials, porous materials, molecular electronics and many other areas. Hurdles that must be overcome include the precision synthesis of precursors, mastering the kinetics and dynamics of such processes, scale-up, and the characterization and control of self-assembly products and processes. Prospects for success and current efforts in these areas will be discussed.

4:00pm **AP-MoA7 Nanotechnology: Constructing a Computer from Molecular Components*, J.M. Tour,*** Rice University **INVITED**

Research efforts directed toward constructing a molecular computer will be described in the context of recent developments in nanotechnology. Routes will be outlined from the synthesis of the basic building blocks such as wires and alligator clips, to the assembly of the processing functional blocks. Specific achievements include: (1) isolation of single molecules in alkane thiolate self-assembled monolayers and addressing them with an STM probe, (2) single molecule conductance measurements using a mechanically controllable break junction, (3) 30 nm bundles, approximately 1000 molecules, of precisely tailored molecular structures showing negative differential resistance with peak-to-valley responses far exceeding those for solid state devices, (4) dynamic random access memories (DRAMs) constructed from 1000 molecule units that possess 15 minute information hold times at room temperature, (5) demonstration of single-molecule switching events and (6) initial assemblies and programming of molecular CPUs in a Nanocell configuration that show room temperature electronic memory for days.

4:40pm **AP-MoA9 Massively Parallel Assembly*, J.N. Randall,*** *G.D. Skidmore, M. Ellis, A. Geisberger, K. Tsui, M. Nolan, R. Saini, C. Baur, K. Bray, M. Chiew, R. Folaron, R. Gupta, J. Hochberg, J.F. Liu, R. Stallcup, P.G. Yu,* Zyvex Corp. **INVITED**

Assembly is generally considered a low-tech, tedious, and expensive undertaking that must be dealt with to manufacture useful systems. Monolithic integration and system-on-a-chip efforts minimize the required assembly, but even the IC industry is economically driven to separate memory and logic chips that are assembled into systems. Where assembly has been automated, the results are expensive primarily because the assembly is serial. This talk will update the ongoing efforts to take assembly manufacturing through the same transition made when Kilby and Noyce revolutionized electronics by going parallel and providing a path for downscaling. We are developing technology for the parallel assembly of Microsystems supported by a NIST-ATP award.@footnote 1@ This technology involves both Micro-Electro Mechanical Systems (MEMS) and high precision robotic stages. By using novel MEMS components that we refer to as "Silicon Snap Connectors" and MEMS grippers, we can do automated, parallel, pick-and-place assembly that achieves higher precision assembly than the precision of the robot that did the pick and place. This is made possible through a self-centering mechanism in the connectors and the sub-micron CD control of the MEMS components. Videos of various microscale automated assembly construction projects will be shown. While the assembly being demonstrated so far is being done with MEMS components and is only modestly parallel, the general strategy for parallel assembly is not restricted to MEMS parts and, as the parts are downscaled, the level of parallelism can grow exponentially. The paper will close with some recent developments towards both massively parallel and nanoscale assembly. @FootnoteText@ @footnote 1@ NIST ATP Award #70NANB1H3021

AVS 50th Anniversary Plenary Session
Room 310 - Session AP-TuM

Information

Moderator: M. Grunze, Universität Heidelberg, Germany

8:20am **AP-TuM1 Light Optical Nanoscopy in Cellular Biophysics***, **C. Cremer**, U. Spoeri, A.V. Failla, B. Albrecht, Ch. Wagner, A. Schweitzer, L. Hildenbrand, I. Upmann, J. Rauch, G. Kreth, N. Kepper, Ch. Engelbrecht,* Univ. of Heidelberg, Germany*; A. Rapp,* Inst. for Molecular Biotech., Germany*; M. Hausmann,* Univ. of Freiburg, Germany*; D. Toomre,* Yale Univ.*; S. Martin, A. Pombo,* Medical Res. Council, UK*; T. Cremer,* Univ. of Munich, Germany **INVITED**

For many studies in cellular biophysics, it is highly desirable to develop optical methods for the analysis of specific biological nanostructures in the interior of three-dimensionally conserved cells. Here, important structural parameters to be considered are topology, i.e. mutual positions and distances of constituting subunits, as well as information about the size of such objects. In the low energy range, this has become possible by development of novel methods of far-field light fluorescence microscopy. Spectral Precision Distance Microscopy [SPDM] is based on labelling of neighbouring objects with different spectral signatures, spectrally selective registration, high precision position monitoring, and careful calibration of chromatic aberrations, cross talk etc. In combination with confocal laser scanning microscopy, SPDM allowed the measurement of spatial positions and mutual distances ("topology") of DNA sequences in specific human nuclear gene domains down to the 30 - 50-nanometer range. Theoretical considerations supported by "Virtual Microscopy" computer simulations indicated that using "Point Spread Function (PSF) Engineering" approaches with a suitably modified PSF, even at the fluorescence photon count number typical for single molecule fluorescence emission, a topological resolution limit down to the few-nanometer range with a precision in the subnanometer range might become feasible. For example, Spatially Modulated Illumination [SMI] far field light microscopy provides a PSF with the required properties; presently, experimental distance measurements in the direction of the optical axis down to the few nanometer scale, with a precision in the one-nanometer range (about 1/500 of the exciting wavelength) have been realized. Furthermore, SMI-approaches have been used to measure the diameter of individual fluorescent targets down to a few tens of nanometer, corresponding to about 1/16 of the exciting wavelength used.

9:00am **AP-TuM3 Biological Applications of Micro and Nanoscale Devices***, **H.G. Craighead**,* Cornell University **INVITED**

Micro and nanoscale technologies are providing new possibilities for investigating life processes at the sub-cellular and molecular level. Electrical and optical probes can be constructed to enable increasingly fine scale resolution of the dynamic processes taking place in living systems. Similar approaches are allowing for analysis of increasingly small amount of biochemicals with the ultimate limit of single molecule analysis being seriously considered. Methods of fabricating micro and nanoscale interfaces with controlled structure and chemical composition are also providing vehicles for exploring the response of living cells to their environment. These same technologies may be exploited for a new biotechnology, making greater utility of active biomolecules combined with electronic and optical devices. This talk will explore some of the activity in the development of these new biological tools and approaches.

9:40am **AP-TuM5 Atomic-scale Device Fabrication in Silicon***, **M.Y. Simmons**,* University of New South Wales, Australia **INVITED**

Over the past three decades the driving force behind the expansion of the microelectronics industry has been the ability to pack ever more features onto a silicon chip, achieved by continually miniaturising the size of the individual components. However, after 2015 there is no known technological route to reduce device sizes below 10nm. We demonstrate a radical new technology for atomic-scale (0.1nm) device fabrication in silicon using a combination of scanning tunnelling microscopy and atomic precision crystal growth. In particular we focus on the ability to place individual phosphorus atoms in silicon at precise locations and encapsulate them in epitaxial silicon with minimal diffusion and segregation of the dopants. We present results demonstrating the power of this approach both towards the controlled fabrication of atomic-scale devices in silicon, and towards the construction of a solid-state silicon based quantum computer.

10:20am **AP-TuM7 Nanometer Computing***, **S.C. Goldstein**,* Carnegie Mellon University **INVITED**

The continuation of the remarkable exponential increases in processing power over the recent past faces imminent challenges due in part rising cost of design and manufacturing and the physics of deep-submicron semiconductor devices. A promising solution to these problems is offered by an alternative to CMOS-based computing, chemically assembled electronic nanotechnology (CAEN). In this talk we discuss the challenges and opportunities posed by CAEN-based computing. We briefly describe recent work in CAEN from the prospective of a computer architecture. The challenges arise from the set of assembly primitives inherent in bottom-up manufacturing. These primitives all but eliminate the ability to create arbitrary connections between devices. The manufacturing methods also imply defect densities which are significantly higher than today's. We show how molecular devices and post-manufacturing reconfiguration can overcome both these obstacles.

11:00am **AP-TuM9 Electronic Materials in the 21st Century: Is the Future Different from the Past?***, **H.L. Stormer**,* Columbia University and Bell Labs, Lucent Technologies **INVITED**

The 20 century may well go into history books of technology as the century of the silicon chip. Silicon and its siblings, the III-V semiconductors, are unquestionably dominating electronics and photonics as we know them. These are just a handful of elements from the periodic table. Why these? What makes them so successful? Are there things they cannot do? Could we overcome such limitations by reaching out to other elements? Which ones and why? Nobody has good answers to these technologically and economically extraordinary important questions. But we can speculate.

AVS 50th Anniversary Plenary Session
Room 310 - Session AP-WeM

Surfaces, Processing, and Materials

Moderator: J.H. Weaver, University of Illinois at Urbana-Champaign

8:20am **AP-WeM1 Controlling Surface Reactions*, G. Ertl,*** Fritz-Haber-Institut der Max-Planck-Gesellschaft, Germany **INVITED**

Reactions at solid surfaces determine the mechanisms of heterogeneous catalysis and form hence the basis of numerous technologically important processes. Studies with well-defined surfaces enable detailed insights into the underlying elementary steps and their control down to atomic length and femtosecond time scales. Nonlinear kinetics coupled to adsorbate diffusion may give rise to phenomena of spatio-temporal self-organisation which may be affected by various feedback strategies. In this way not only options for improving catalytic activity, but also models for structure formation in living systems are established.

9:00am **AP-WeM3 Continuity in Plasma Processing: Yesterday's Accomplishments, Today's Innovations and Tomorrow's Challenges@footnote 1@*, M.J. Kushner,*** University of Illinois, Urbana-Champaign **INVITED**

Plasma processing has provided impressive capabilities for converting either inert or weakly reactive materials into activated species which produce light, modify or create materials or activate other processes. The impact of plasma processing for modification of high technology materials owes its success, in part, to a legacy of research on what at first look seems like unrelated topics, such as lighting, lasers and upper atmospheric physics. These projects created a continuity of knowledgebases of experimental and computational techniques and fundametal data which have provided the foundation for today's advances in plasma based technologies. For example, advanced microdischarge plasma sources such as plasma display panels can trace their origins to dielectric barrier discharges for ozonizers. This legacy of "continuity," leveraging knowledge bases to move forward plasma based technologies, provides insights to how plasmas will impact future high technology applications in microelectronics fabrication, sensors, biotechnology, lighting, and materials processing. That continuity and expectations for future developments in the field will be discussed. @FootnoteText@ @footnote 1@ Work supported by the National Science Foundation, Semiconductor Research Corporation, 3M Inc. and AFOSR.

9:40am **AP-WeM5 The Promise of Solid State Lighting: Status, Trends, and Remaining Challenges*, M.G. Craford,*** Lumileds Lighting **INVITED**

LED technology developments over the past decade have enabled the use of LEDs in a variety of colored and white lighting applications. With further improvement LEDs appear to have the potential to become an important technology for large area general illumination. White LEDs with outputs of more tha 100 lumens are already available commercially. LEDs are expected to save energy, be environmentally friendly, and provide a variety of other features, including long lifetime, compact size, and programmable color control, which enable design options for new approaches to lighting. In this presentation the LED technology status and trends will be described and LEDs will be compared to conventional lighting technologies. Developments that will need to occur for LEDs to be a viable contender for large area general illumination will be discussed.

10:20am **AP-WeM7 Epitaxial Ferromagnetic Heterostructures Based on Semiconductors: Towards a New Spin-Based Electronics*, M. Tanaka,*** University of Tokyo, Japan **INVITED**

Creating a new spin-based electronics (often called "spin-electronics" or "spintronics") is one of the hot topics in the current solid-state physics and electronics research. In order to utilize the spin degree of freedom in solids, particularly in semiconductors the current electronics is based on, we need to fabricate appropriate materials, understand the spin-dependent phenomena, and control the spins. In this talk, I will review the recent developments of epitaxial ferromagnetic heterostructures based on semiconductors towards spintronics. This includes the semiconductor materials and heterostructures having high ferromagnetic transition temperature (III-V based alloy magnetic semiconductors, Mn-delta-doped magnetic semiconductors, and related heterostructures), spin-dependent transport and tunneling, spin-dependent bandgap engineering, their device applications (tunneling magnetoresistance devices and three-terminal devices). Future issues and prospects will be also discussed. @FootnoteText@ The author thanks the collaborations and discussions with S. Sugahara, A.M. Nazmul and Y. Higo, S. Ohya, and T. Matsuno. The work at the Univ. of Tokyo was partially supported by PRESTO of JST, IT Program of MEXT, Toray Science Foundation.

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