Discussion Framework

Session 1: An industrial perspective on difficult problems of future nanofabrication technologies

Background: Panelists are asked to briefly present their vision for future nanofabrication technologies. Specifically, they are asked to select one potential 'breakthrough' technology and identify the major research and development issues that need addressing before implementation of that technology can be deployed for high-volume manufacturing.

Questions

1) What do you see as limiting challenges in top-down fabrication of future electronics systems? How can they be addressed?
2) What do you see as limiting challenges facing the application of bottom-up (additive) fabrication technologies? How can they be addressed?
3) The semiconductor industry has accumulated unique tools and expertise that could be useful in biotechnologies. What are the viable pathways for deployment of the expertise and infrastructure of the semiconductor industry in the bio-nanofabrication domain?
4) What are the opportunities to enhance environmentally friendly semiconductor manufacturing?
5) For a prototypical roadmap for SemiSynBio nanofabrication, please discuss specific goals and a timeline. For example,
    a. What are the major research and development issues to be addressed in order to achieve performance matching today's semiconductor IC fabrication technologies?
    b. What issues need to be addressed with respect to statistical variability in sub-20 nm nanofabrication?
    c. What are the materials, tool, process and metrology issues that need to be addressed?
    d. What is the present status of modeling and simulation capabilities for the device and/or constituent materials? And what are the gaps need to be addressed.
6) What new expertise and infrastructure must be developed, which synergistically leverages existing nanofabrication methods, to enable 'breakthrough' technologies?
7) What strategic knowledge gaps must be addressed to make timely and informed decisions regarding future nanofabrication technologies?
8) What is your 5/10- and 20-year vision of bio-nanofabrication?

Session 2: Bio-molecular nanopatterning: Controlling sub-20nm structures

Background: A grand challenge in the fields of chemistry and materials science is the ability to construct materials with high-precision control over the three-dimensional (3D) placement of each component in order to tailor properties for a given application. A near-term challenge for bio-molecular nanofabrication is defect density reduction, which could be one of the parameters tracked by the roadmap. The focus of this session will be on scaling and patterning with biomolecular elements for sub-20nm 3D fabrication. Sample topics include: deposition of biological parts, nucleation and growth of large arrays, controlled placement of diverse materials, registration and alignment, etc. Biomolecules, such as DNA, RNA, or proteins can provide a programmable mechanism for the development of a wide variety of structures and shapes.

Questions

1) To what extent can a biopolymer-mediated assembly process be programmed to fabricate the different elements of complex 3D structures? For example,
    a. Feature shape and size
    b. Placement
    c. 3D assembly of components with various properties/functions
    d. Release of cargo (metal or semiconductor particles, CNT etc.)
2) What are the possible limiting characteristics of biopolymer-mediated fabrication at
    a. nanoscale - e.g. line edge roughness, critical dimension, number of distinct materials
    b. microscale - for example, in fabricating a memory array, what would be the maximum size of the array and the number of defects?
    c. macroscale – Is parallel manufacturing within the whole wafer size possible?
3) Is there potential for programmed DNA-guided assembly for future interconnected systems?
    a. Conventional, e.g. sub 10-nm metal lines or electrical insulators
    b. Emerging fields, e.g. plasmonic, photonic
    c. System assembly – Can functional systems or sub-systems can be assembled with DNA-guided fabrication processes?
4) Will the cost of DNA and biopolymer synthesis be a limiting factor of practical applications of DNA fabrication technologies?
5) What research/knowledge is needed to enable functional DNA-guided 2D/3D fabrication and assembly?
6) For bio-molecular nano-patterning, what are the most difficult pattern transfer challenges?
7) Does bio-molecular nano-patterning offer novel adaptive or defect healing opportunities?
8) What is your 5/10- and 20-year vision of bio-molecular nanopatterning?

Session 3: Biological Nanofabrication and Cellular Factories

Background: New methods need to be developed for sustainable high-volume production of 2D and 3D parts for sub-20nm fabrication, such as sustainable processing methods using DNA or other biopolymers. Biological systems possess the amazing adaptive capability of self-healing, self-repair and/or fault-tolerance. Engineered microorganisms (bacteria, viruses etc.) can also be used to produce a range of important chemicals, materials and structures for semiconductor processes as well as to self-assemble, pattern, organize, or repair organic polymers, inorganic materials, biopolymer materials, functional circuits and/or electronic components.

Questions

1) What are the envisioned limiting characteristics of bio-guided fabrication at the:
    a. nanoscale - e.g. line edge roughness, critical dimension?
    b. microscale – e.g. placement, number of defects?
    c. macroscale – Is parallel manufacturing within the whole wafer size possible?
2) How can an understanding of the ‘cellular factories’, operating with high yields and low energy, be used to guide substantial improvements in the processes now employed in the semiconductor manufacturing?

e.g. microbial production of nanostructures

3) Can cells be 're-programmed' for electrical connectivity? Can we learn and adopt the self-healing, self-repair and fault-tolerance nature of biological systems for the design and fabrication of electronic circuits?

4) Can engineered microorganisms (e.g. virus/cell/protein cage-mediated synthesis of materials) be used to produce various important chemicals and materials for semiconductor processes, which have the desired chemical composition, size and crystalline structure?

5) What kinds of new tools might be needed for implementation of bio-nanofabrication in high-volume IC manufacturing?

6) What is your 5/10- and 20-year vision for biologically inspired semiconductor nanofabrication?

Session 4: Biomaterials for Electronics

Background: A new materials base may be needed for future electronic hardware. While most of today's electronics use silicon, this may not be a sustainable approach, if, for example, billions of sensor nodes are realized as a part of the Internet-of-Things. Many sensor nodes have short lives and are disposable. We need to be thinking about more sustainable materials, for example carbon-based systems that can be recycled or reused. The potential role for alternative materials (polymers, paper etc.) also needs to be explored. It may also be possible to utilize silicon formed by natural bio-silica systems like diatoms and glass sponges. The focus of this session is on emerging biological compounds or structures that have interesting optical/electronic/magnetic/mechanical properties.

Questions

1) What is the potential role for alternative materials and technologies (e.g. nanowires, polymers, liquid metals, inkjet printing, 3D printing, etc.) in semiconductor nanofabrication or flexible electronics?
2) To what extent can the materials base for the implementation of the future electronic components and systems support sustainability through recycling, bio-degradability etc.?
3) What is the feasibility of fast, long-range charge transport in the biomaterials?
4) What is the potential for scaling and on-chip integration of 'bio-batteries' such as biofuel cells or bio-supercapacitors?
5) What is the potential for insertion of semiconductor/electronic "parts" directly inside cells, or, to use these components to externally control/influence cell behavior? How do we power these within-cell semiconductor/electronic parts? What potential functionalities could these within-cell semiconductor/electronic parts achieve?
6) What other complementary approaches, e.g., biomimetic, could mimic human brain function?
7) What is your 5/10- and 20-year vision of biomaterials for electronics?