

# Research Needs Document: Nanomanufacturing Materials and Processes

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## Background

This document is prepared to accompany the Call-for-Research in the research program of Nanomanufacturing Materials and Processes (NMP). The research needs in this area are very broad. We present here selected areas of high priorities as identified by our sponsor members.

There is no doubt that nanomanufacturing is getting increasingly difficult. Feature sizes are already approaching 10 nm or less in production; accordingly, research must be directed towards 5-nm node generation and beyond. For lithography, EUV is close to production so opportunities exist for a major paradigm shift. Metrology and defect detection are critical and their effectiveness must be improved in order to ensure that capable solutions exist in a timely and cost-effective manner. For unit processes, new materials are sought after for logic and memory devices. These material options must be paired with manufacturable deposition and patterning techniques. In addition, functional diversification calls for a wide range of other devices, such as required by analog applications and the Internet of Things. For interconnects, the reduced size (thickness and linewidth) introduces additional scattering and at the same time, reliability problems increase. Interlayer dielectrics also have increasing difficulty in further reducing the dielectric constant. In generally manufacturing methods and process materials which reduce device and interconnect variability are required.

In semiconductor manufacturing, it is a universal industry goal for all materials and processes to be used efficiently, and in a manner that is protective of human health and the environment. This is not only necessary to comply with government rules, but to avoid corrective measures which are expensive and disruptive. With continuing introduction of new materials and nanomaterials, we have to address their environmental effects for a sustainable industry.

For an overview, we divide nanomanufacturing into five major groups: (1) patterning, (2) front-end processes (FEP), (3) back-end processes (BEP), (4) common areas that are applicable to the first three, and (5) ESH (Environment, Safety, and Health). It should be noted that the boundary between FEP and BEP is not clearly defined in the industry, due to the increasing kinds of devices fabricated between the semiconductor substrate and the first metal level. Here we simply put FEP as processes for devices of all kinds, including memories, passives, TFT, sensors, etc., and BEP as those for interconnects and interlayer dielectrics.

## Research Needs

The research needs for nanomanufacturing are obviously very wide. In this call, due to limited resources, we have gone through some discussions and identified what our members have considered to be the most critical items for university research. The list of topics within these five groups are shown as follows:

### (1) Patterning

- 1a) Resist, patterning, and mechanistic insight for EUV lithography.
- 1b) Directed self-assembly (DSA) using block copolymers (BCPs).
- 1c) Self-aligned patterning processes.
- 1d) Alternative non-traditional patterning (other than DSA or spacer-based multi-pass patterning).
- 1e) Etch-free feature patterning.
- 1f) Exposure-free patterning (example; dip pen lithography).
- 1g) Pattern transfer, including new material combinations.

### (2) Front-End Processes

- 2a) Emerging materials for devices (2-D crystals, complex oxides, C-based, novel dielectrics/conductors):  
Chemistry and synthesis.
- 2b) Novel deposition techniques for highly bottom-up or conformal 2-D/3-D thin films.
- 2c) Interface/surface physics (SiGe, Ge, Ge-Sn, III/V, contacts, 1-D/2-D materials).
- 2d) Hybrid materials with tunable properties.
- 2e) Material-enabled novel functions.

- 2f) Material-enabled low-variability processes.
- 2g) Materials and processes enabling functional diversification on CMOS platform (MEMS, sensors, photonics...).

### **(3) Back-End Processes**

- 3a) Cu-based conductor optimization, cap, and barrier layers.
- 3b) Low-k dielectrics and processing.
- 3c) Reliability (electromigration, TDDB ...).
- 3d) Interconnect contacts and interfaces.
- 3e) Alternate/novel concepts for low-resistance interconnects (beyond-Cu) and low-capacitance dielectrics.

### **(4) Common areas**

- 4a) Atomic-layer deposition (ALD), area-selective ALD, and atomic-layer etch (ALE).
- 4b) Area-selective deposition.
- 4c) 3-D imaging (3-D STEM, atom probe...) and functional imaging (STEM with EELS/EDS, high-resolution strain mapping...). Metrology and analytic techniques.
- 4d) Modeling/understanding of critical unit processes (examples: Generation, annihilation, movement and propagation of the imperfections in SiGe epitaxial growth).
- 4e) Variability of processes/modules and defects.
- 4f) Fundamental material and process understandings for small (sub-5 nm) features including the development of new analytical techniques to measure intrinsic parameters such as magnetism, spin and electronic states.
- 4g) Design for manufacturing (DFM).
- 4h) 3-D heterogeneous integration.
- 4i) Liquid-phase defect understanding and detection (models elucidating how defects form in liquid solutions; sensors that allow for increased sensitivity of liquid-phase defectivity detection...).

### **(5) ESH**

- 5a) ESH aspects of chemicals used in lithography.
- 5b) Treatment of fab process wastewaters and emissions.
- 5c) Energetic compounds and prevention of uncontrolled reactions.
- 5d) Nanomaterial/nanoparticle occupational safety and health, and environmental discharges.
- 5e) ESH enablement of toxic elements (such as III-V materials) and related processes.
- 5f) Development of ESH-preferable material and process alternatives (e.g. sustainable materials and green chemistries).
- 5g) Chemical behavior characterization and predictive modeling for relevant semiconductor chemicals, materials, and processes.

When submitting the white papers, researchers are asked to indicate the topics (in number) what their research topic can best fit in.

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