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 ~10 nm in production; accordingly~~,~~ research must be directed at enabling dense and regularly placed smaller feature patterns. For lithography, EUV is in production yet challenges exist to insure sustainable patterning scalability. Metrology and defect detection are critical, and their effectiveness must be improved 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 that can render thermally, mechanically, chemically, and electrically stable structures. 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 experience increasing difficulty in further reducing the dielectric constant. Manufacturing methods and process materials which reduce device and interconnect variability are required.

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
(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, TFTs, 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 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

a. Resist, patterning, and mechanistic insight for EUV lithography with focus on:
    i. High numerical aperture (NA) resist concepts beyond chemically amplified resist:
        1. High absorbance materials (resists and underlayers).
        2. Pattern transfer of <20nm thick films including post-exposure treatments.
        3. Design and understanding of new contrast mechanisms for high NA EUV.
        4. Nanoscale metrology.
    ii. EUV mask novel material and patterning:
        1. High-k (darker) materials for thin absorber binary mask (<50nm).
        2. Hard-mask pattern transfer for aggressive resolution and 2D structure fidelity.
        3. Damascene patterning process.
    iii. Positive tone metal containing resist or other resist concepts.
    iv. Mechanistic study on propagation of secondary electrons from each film, PR, under layer and various inorganic films.
    v. Mask 3D effect on anamorphic high NA systems.
b. Directed self-assembly (DSA) advances for:

        i. Block copolymer alignment defect improvement through new block copolymer and brush synthesis.
        ii. Multi-pitch using single block copolymer.
        iii. Implementing vertical orientation.
        iv. Regular and dense placement of molecular precursor seeds for low-dimensional devices.
        v. Selective infiltration schemes for block co-polymer.
        vi. Selective etch for new DSA polymers.
        vii. High-chi BCP development for sub-20nm DSA.
    c. Self-aligned patterning processes.
    d. Etch-free feature patterning (i.e., guided or controlled deposition).
        i. Direct Write of Templated ASD of Hardmask.
    e. Patterning for sensitive materials.

(2) Front-End Processes

a. Emerging materials for devices: Chemistry and synthesis.
    i. TMD, FE and AFE uniform growth over many microns.
    ii. Complex oxides: semiconductors P and N type, dielectrics/conductors and multi-ferroics.
b. Interface/surface physics:
    i. Ge-based devices.
    ii. 1-D/2-D channel materials.
    iii. 2-D/3-D materials.
    iv. 2-D/3-D contacts.
    v. Novel channel materials.
c. Hybrid materials with tunable properties.
d. Materials and processes enabling functional diversification on CMOS platform (RF and mm-wave devices, MEMS, sensors, photonics…).
e. Methods to create fluid transport in features that are <200nm in diameter and > 1 micron deep.

(3) Back-End Processes

a. Novel ultra-low resistance interconnect materials and concepts:
    i. 2D materials for ultra-thin barrier liner materials.
    ii. Alternative metals.
b. Low-k dielectrics and processing.
c. Interconnect contacts and interfaces with defect mitigation.
d. High mobility BEOL compatible p-type semiconductor thin films.
e. Ultrahigh-k, low leakage dielectrics with high breakdown voltage.

(4) Common areas

a. High-throughput and low-defectivity Atomic-layer deposition (ALD) and area-selective ALD.
b. Atomic-layer etch (ALE).
c. Molecular Layer Deposition (MLD).
d. Novel/alternative area selective deposition techniques:
    i. Small molecule inhibitors (SMIs).
    ii. Inherently selective deposition (CVD, ALD).
    iii. Selective metal deposition on semiconductor for FEOL and BEOL.
e. Metrology and analytic techniques.
f. Modeling/understanding/detection/process control of critical unit processes:
    i. Methods to apply machine learning to accelerate materials discovery.
    ii. Modeling defects in ferroelectric and anti-ferroelectric materials.
    iii. Models to improve selectivity mechanism.
g. Materials and processes that enable 3-D monolithic heterogeneous integration.
h. AI machine learning to improve process control for yield improvement and/or manufacturing cost reduction (intra-process and inter-process).

i. Understanding and measuring the physical and chemical behavior of liquids in highly confined spaces, e.g. <20nm wide trenches.
j. Supercritical CO2 for surface modification and structural integrity in FE and BE applications.
k. Gas phase, non-reactive ion based methods to selectively etch Si based materials (SiOCN, SiO2, Si3N4, Si) at temperatures below 300°C.
l. corrosion inhibitor wet etch and CMP chemistry on metals beyond Cu:
    i. better atomic-scale control and understanding of corrosion inhibitors.
    ii. improvements in binding efficiency and selectivity between metals.
m. Plasma surface interactions of low-energy ions.

(5) **ESH** (Environment, Safety, and Health)

The Research Needs document can be obtained under a separate call announcement. ESH Call

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