Pathways for implementation of block copolymer lithography in nanomanufacturing

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Previously we have explored and developed the integration of self-assembling block co-polymers with traditional lithographic practices to advance and augment their performance. Our approach is to use lithographic tools such as electron beam (EB) and extreme ultra violet (EUV) lithography to create chemically patterned surfaces, and to take advantage of interfacial interactions between the surface and an overlying block copolymer film to direct the assembly of the copolymer domains into architectures that are useful as templates for device fabrication (see Figure 1). We have demonstrated that 1) directed assembly enables fabrication at length scales not possible with current materials and processes, 2) retains the essential attributes of existing manufacturing practices, and 3) may offer sub 1 nm dimensional control and line edge roughness. Here, in comparing the assembled structures to the lithographically defined chemical pattern, we demonstrate that the density structures (or resolution) may be increased by a factor of two or more (see Figure 1) without sacrificing pattern quality.

Technological hurdles remain, however, in practical implementation of block copolymer lithography to take advantage of the advantages described above. One promising strategy is to direct the assembly of block copolymer templates on lithographically-defined chemical pre-patterns created by EB lithography. The block copolymer acts as a ‘smart resist’, improving quality and resolution beyond the limits of the tool itself. The block copolymer is then used as a soft mask to fabricate a master template, and nanoimprint lithography (NIL) provides the means for massively parallel pattern replication. At the required density of features for most applications, however, even with resolution enhancement (see Figure 1) significant coasts and risks are posed by very long EB write times. Here we demonstrate a new technique called molecular transfer printing (MTP) that allows us to create, transfer, and easily replicate chemical patterns using block copolymers (see Figure 2). In MTP, inks or molecules to be transferred in the process are mixed with block copolymers and deposited as films on a substrate. The inks are compatible with only one block of the copolymer, and after directed or self-assembly of the blend material, the inks are sequestered into domains of nanometer scale dimensions into useful patterns such as parallel lines. A second, “replica” substrate is then placed in contact with the surface of the block copolymer film, or deposited, for example, by evaporation and subsequently handled using wafer bonding techniques. By designing the ink molecules to react, adsorb, or otherwise interact with the second substrate, inks are transferred to the second substrate in the exact pattern of block copolymer domains present at the surface of the block copolymer film. Block copolymer templates are readily reassembled on both master and replica surfaces. Master templates and daughter templates may be reused tens or hundreds of times just like masks in optical lithography or masters in nanoimprint lithography. Moreover, with each passage from master to daughter, MTP tends to improve pattern quality and resolution and reject defects. We anticipate that NIL and MTP may be synergistic in that MTP may be enabling for NIL template fabrication, and tools developed for NIL may be enabling for contacting surfaces in the MTP process.

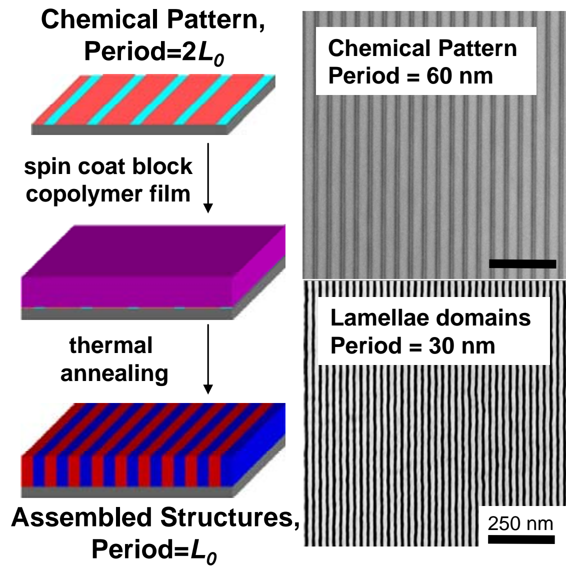

Figure 1. Schematic and demonstration (15 nm resolution) of density multiplication of features on chemically patterned surfaces by directed assembly.

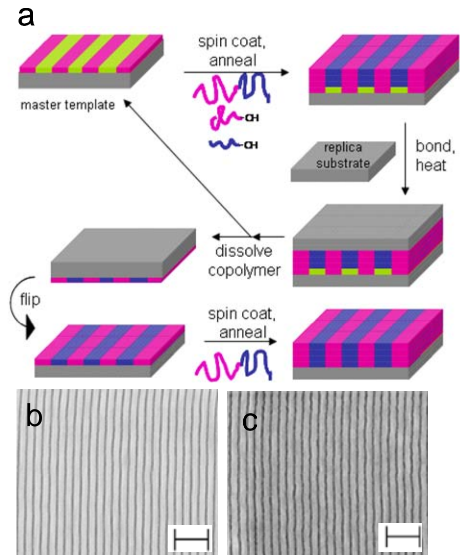

Figure 2. a) Molecular transfer printing schematic. A blend of diblock copolymer and OH-functionalized oligomer inks are assembled on the master template. The replica substrate is attached to the assembled film and heated to react the inks with the replica substrate. The diblock copolymer is dissolved, resulting in regeneration of the master template and release of the replica substrate with a chemical pattern attached. The MTP process concludes with the directed assembly of block copolymer on the replica substrate. b) SEM of master template with a 47.5 nm period after 20 regeneration cycles. c) SEM of assembled block copolymer on 21st replica substrate. Scale bar is 200 nm.