Cross-sectional analysis of resist structures derived from the directed assembly of block copolymers

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Directed assembly presents opportunities to enhance or augment the capabilities of the lithographic process. Compelling motivation for directing the assembly of block copolymers, or block copolymer mixed with solvents, homopolymers, or other diluents, is that the intrinsic properties of these self-assembling systems may lead to improved control over the shape, size, and size uniformity of patterned features, and to improved overall resolution of the lithographic process itself. Over the past several years, significant progress has been made in demonstrating that directed assembly of block copolymers may be able to meet many of the essential attributes of manufacturing, including pattern perfection, registration, and the ability to create patterns of geometric complexity at sub-lithographic dimensions. One outcome of this success is that directed assembly is now included as potential lithography solution in the 2007 ITRS Roadmap.

The patterned features from the directed assembly of copolymer films refer to domains comprised of one block that remain as an etch mask after removal of the other block. Here we are focused on: 1) systems in which the domains of the block copolymer film are directed to assemble using lithographically defined chemically pre-patterned substrates, and 2) patterned structures with high aspect ratios that result from domains that span the thickness of the film, for example from etch selective lamellar- and cylindrical-like domains oriented perpendicular to the substrate. Figure 1 shows a schematic of our strategy integrate block copolymers with advanced lithographic tools. Of particular interest is how the shapes and dimensions of the assembled domains, with and without multiplication of the feature density compared to the lithographically defined chemical pre-pattern, depend on characteristics of the pre-pattern. With respect to perpendicular lamellar domains, for example, critical parameters include the width of the pre-patterned lines and the interfacial interactions (chemistry) of the patterned regions and the blocks of the copolymer. Three significant technological advances were accomplished in pursuing the questions outlined above: 1) the ability to fabricate chemical pre-patterns with well-defined dimensions and geometries, and controlled chemistry, 2) techniques to prepare and image cross-sections of assembled block copolymer films, and 3) predictive models of the material systems based on Monte Carlo simulations of a coarse-grained representation of the block copolymer.

Figure 2 shows quantitative comparisons of the cross sectional scanning electron micrographs and the results of the molecular simulations for representative samples in our study. The block copolymer films were equilibrated in the presence of differing chemical pre-patterns as shown in the schematics. Figure 2A, Figure 2B, and Figure 2D depict perpendicular lamellae-like structures assembled on 1:1 domain: pre-pattern features with relatively strong interfacial interactions, 2:1 domain:pre-pattern features with relatively strong interfacial interactions, and 2:1 domain:pre-pattern features with alternating strong and weak interfacial interactions, respectively. The conditions resulting in structures well-suited for pattern transfer correspond to Figures 2A and 2B. Figure 2C shows one of many non-bulk-like, non-lamellar morphologies that were identified and formed on chemical pre-patterns with differing dimensions and chemistry.

The results of our fundamental study will help determine the inherent constraints that must be met with respect to the properties of the chemical pre-patterns to produce technologically useful block copolymer assemblies for the creation of soft etch mask templates.

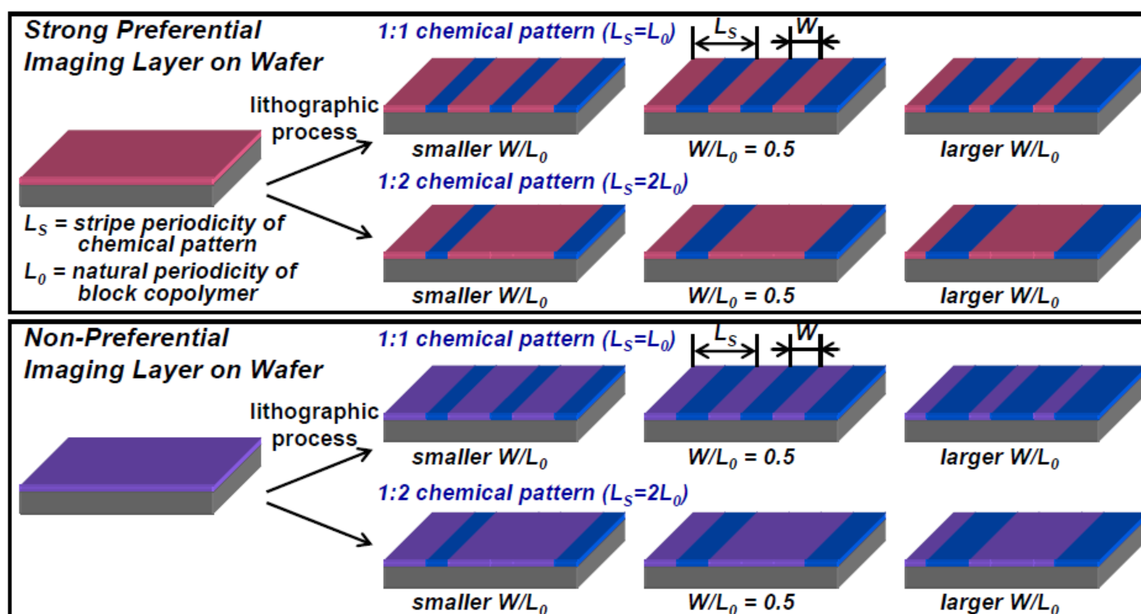

Figure 1. Schematics of lithographic process using block copolymer on chemical pre-patterns. Chemical pre-patterns can be fabricated with having different widths of wetting stripes and interpolated stripes on strong preferential or non-preferential background interactions.

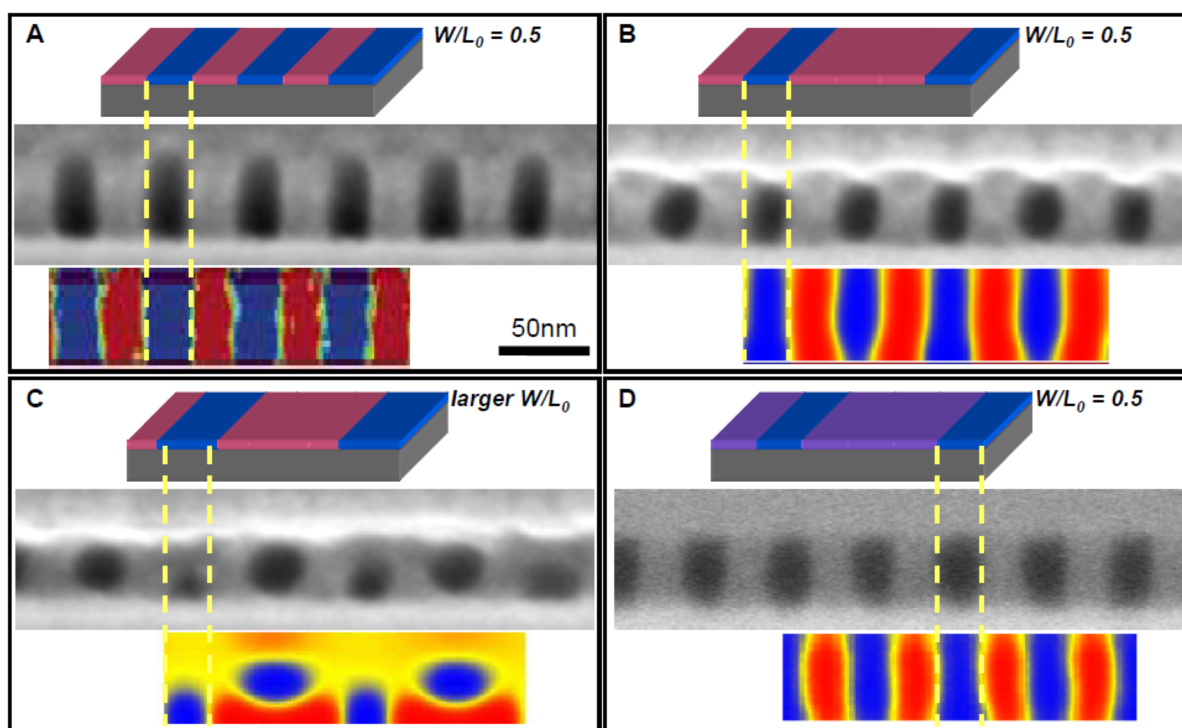

Figure 2. Cross sectional SEM images and simulated composition profiles of lamellar-forming PS-PMMA thin films on chemical stripe pre-pattern using strong preferential imaging layer with L_S = L_0 (W/L_0 = 0.5) (A), L_S = 2L_0 (W/L_0 = 0.5) (B), L_S = 2L_0 (larger W/L_0) (C), and L_S = 2L_0 (W/L_0 = 0.5) with non-preferential imaging layer (D). Yellow dashed lines indicate the patterned stripes.