Development of "Reverse phase" PMMA-b-PS block copolymers as Self-Assembled Hard-Masks for Reactive Ion Etching

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Abstract
Higher density recording media containing bit-patterned, nanostructured materials is of great interest for magnetic data storage. One method of achieving this nanostructuring is the use of block copolymers as a hard mask or template through which to transfer a pattern onto a magnetic layer. These polymers contain immiscible components such as poly(methylmethacrylate) (PMMA) and polystyrene (PS). For appropriate PMMA:PS ratios nanophase separation gives pillars of the minority component (see Figure 1). Previous work has focused on PS-b-PMMA polymers. We report here on a potentially shorter route using PMMA-b-PS, which was deposited on the surface of silicon and Ta substrates. The majority phase (PMMA) was then removed through acetic acid washing to leave nanopillars of the minority (PS) component. These were then exposed to reactive ion etching (RIE) to remove any PMMA residue and ion beam etching (IBE) to transfer the pattern to the substrate below. These techniques were applied to samples containing CoPt and Ru seed layers to determine the affects of the surface pattern transfer on the overall magnetic behavior of the material.

Experimental Methods
During the initial phase of this investigation substrates of H-terminated Si and sputtered Ta films were prepared by spin-coating 1%(wt/vol) solutions of PMMA-b-PS onto the surface followed by processing shown in Figure 2 (right). Other samples were: Si/Ta 5nm/Ru 50nm/CoPt 20nm/Ta 5nm (cap). Reactive ion etching of initial Si and Ta samples used only O2 while the magnetic samples employed a mixture of RIE with O2 and CF4 plus 5.5 min of ion beam etching. Structural characterization of all samples was carried out using both scanning electron and atomic force microscopy. (SEM and AFM data available in Figures 3-5). Magnetic characterization of the multilayers was using an alternating gradient magnetometer is shown in Figure 6.

Conclusions and Future Work
Early samples with reverse phase PMMA-b-PS copolymer on Si and Ta substrates exhibited PS nanopillars. Although they did not have good ordering the size distribution of the structures ranges from 20 to 40 nm which is comparable to that produced with the normal phase (PS-b-PMMA) copolymers. Hysteresis and coercivity results for the Ta capped magnetic multilayers were very encouraging showing a transition from sheet film to isolated magnetic dots. Future work will focus on improving the size and ordering of the polystyrene features by better tuning sample preparation conditions.

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Figure 1: Different block copolymers produce different structures. PS-b-PMMA (A) produces perpendicular holes while PMMA-b-PS (B) the “reverse phase” produces perpendicular free-standing cylinders.

Figure 2: Flow charts showing (left) previous and (right) new processing sequence.

Figure 3: AFM height (A) and phase images (B) of PMMA-b-PS on H-terminated Si after thermal annealing. Image size is 1μm. Brighter features indicate areas containing PMMA.

Figure 4: SEM images of PMMA-b-PS on H-terminated Si; A) annealed, UV irradiated and washed with acetic acid; B) after RIE with O2 for 5s. Higher contrast features here indicate the presence of the PS structures.

Figure 5: SEM images (magnification 100,000X) of Ta capped multilayer samples etched under different conditions. A) after 3s RIE, B) after 5s RIE. Both samples were ion beam etched for 5.5min.

Figure 6: Magnetic hysteresis loops obtained for multilayer samples capped with 5nm of Ta and patterned with PMMA-b-PS. Ta-1: RIE 3s then IBE, Ta-2: RIE 5s then IBE, Ta-3: IBE only. Ta-2 shows the highest coercivity of the three samples.