Single-digit nanofabrication: ultrahigh density sub-10 nm TiO_2 features via the self-aligned double patterning process

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Bit patterned media (BPM) for magnetic recording is a way to increase density beyond what is possible with continuous granular media. Using lithography, bits are patterned to create densely packed grains with defined placement and periodicity. Storage densities above 5 Tb in^{-2} are targeted with a combination of heat assisted magnetic recording and bit patterned media.

One of the biggest challenges for BPM is the fabrication process. A route to high density BPM fabrication combines lithographically directed self-assembly (DSA) block copolymer (BCP) [1], self-aligned double patterning and nanoimprinting lithography [2-4].

Here we study the self-aligned double patterning process for creating nanoimprint masks at 7.5 nm half-pitch and below *(Figure 1)* with a focus on the mandrel and spacer creation *(Figure 1c-f)*. Starting with block copolymer defined lines below15 nm half-pitch block copolymer, we transfer the pattern using cryogenic etching of carbon layer to define the mandrel. Subsequently the patterned is trimmed using a room temperature isotropic etching process.

With the goal of achieving a dense spacer with good mechanical stability, we study 3 different materials, SiO_2, Al_2O_3, and TiO_2. Thermal and plasma processes are investigated using spectroscopic ellipsometry and SEM. We find that depending on the precursor reactivity, some plasma processes are incompatible with the carbon such that it is etched by the plasma oxidation steps during deposition. Ultimately we demonstrate 7.5 nm half-pitch features can be patterned with a proper combination of etching and deposition processes. Figure 2a shows an example of the doubled patterned features at 15 nm pitch using a thermal TiO_2 thin film conformably deposited on the carbon structures After the carbon lines are removed, standing vertical TiO_2 lines with critical dimension below 6 nm are pictured in *Figure 2.b*.

[1] Griffiths, R. A.; Williams, A.; Oakland, C.; Roberts, J.; Vijayaraghavan, A.; Thomson, T. J. Phys. D: Appl. Phys. (2013), 46, 503001.
[2] Chang Hong Bak, *et al.*, Polymer, Volume 60, (2015)
[3] T. R. Albrecht, *et al.*, IEEE Trans. Magn., vol. 51, no. 5, (2015), Art. ID 0800342.
[4] G.S. Doerk, *et al.*, Nanotechnology, 26 (2015) 085304/1-085304/9.

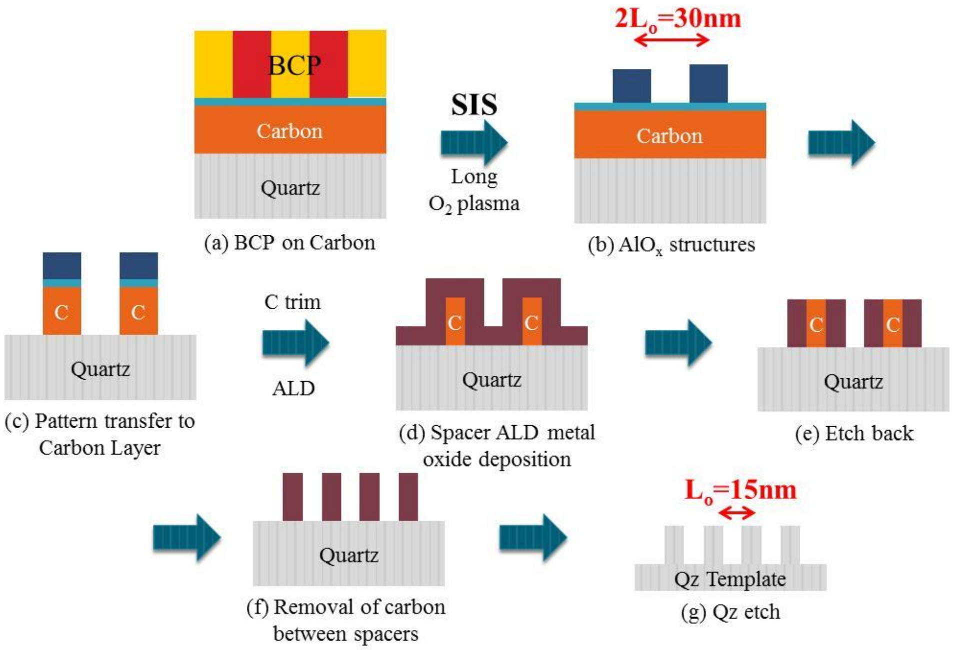

Figure 1: line doubling process: a) Initial PS-b-PMMA BCP pattern; b) AlO_x infiltration of BCP and polymer etching; c) pattern transfer to sacrificial Carbon layer; d) sacrificial carbon layer trimming and thermal TiO_2 spacer deposition; e) spacer anisotropic etch back; f) removal of sacrificial carbon between spacers; g) pattern transfer from spacers to substrate.

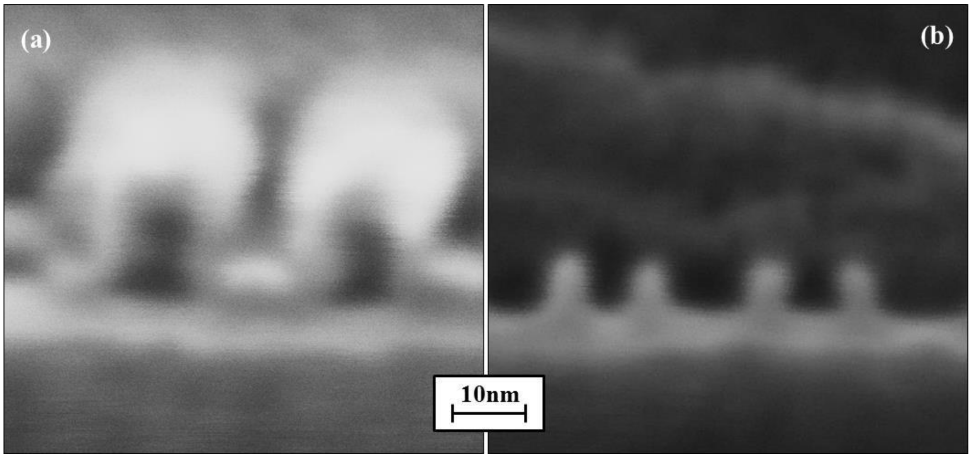

Figure 2: SEM Images comparing the results before and after Carbon structure remove: a) 200˚C thermal TiO_2-coated template after 80 ALD cycles; b) 6nm spacer lines created using an etch beck with CF_4 ICP and complete remove of the carbon template by O_2 plasma.

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