Self-Limiting Low-Energy Glow Discharge Process for Close-Packed Non-Circular Pattern Generation

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We describe a low energy glow discharge process using Oxford 100 Plus reactive-ion etching system that enables non-circular device patterns, such as squares or hexagons, to be formed using precursor arrays of uniform circular openings in poly(methyl methacrylate), PMMA, defined using electron beam lithography. The proposed patterning technique, which is similar to self-limited ion milling (SLIM) reported earlier by our group [1], is of particular interest for bit-patterned magnetic recording medium fabrication, where square magnetic bits result in improved recording system performance.

Periodic close packed non-circular device patterns with sub-100nm critical dimensions are challenging to achieve with e-beam lithography due to proximity effects, especially if high spatial resolution corners are required. The new approach for defining closely packed squares and hexagons uses a simple-to-generate by e-beam lithography precursor pattern in (PMMA) resist followed by low-energy glow discharge processing. The resulting patterns made of graphitized PMMA can then be used, for example, as templates for electrochemical deposition.

In a SLIM process, a PMMA resist is patterned using e-beam lithography as shown in Figure 1a-b and then ion milled using a Veeco RF ion source at a base pressure of 4 x 10-6 Torr and a gas pressure of 0.4mTorr, with a beam energy of 500eV, and a discharge power of 50W. The resulting structures are shown in Figure 1c-d, where the initial circular openings have transformed into a lattice of squares and hexagons, respectively. Significantly, the resulting pattern morphology breaks down at the edges of the pattern as illustrated in the insert in Figure 1b, where the circular structure continues to expand away from the array.

The described above self-limiting ion-milling was demonstrated to extend to substantially higher process pressures where we have used a commercial low-energy glow discharge system (Oxford RIE 100+) with Ar as a process gas at a 10mTorr pressure to achieve similar results. Resulting square patterns were used as templates to electrochemically deposit dense arrays of square Ni device structures (see Figure 2) as a basic proof-of-concept process for bit-patterned medium fabrication (actual bit-patterned media require high-anisotropy alloys or multilayers that are currently under development). The new process is expected to be scalable into the deep sub-100nm scale as the thickness of the graphitized PMMA layer and the milling rates can be effectively controlled by the process parameters. Significantly, in addition to applications in patterned medium, the proposed technology can potentially be applied in various other areas of nanotechnology including fabrication of high density semiconductor memories, infrared filters[2], filtration membranes[3], etc.

1. Parekh, V.A., et al., *Close-packed noncircular nanodevice pattern generation by self-limiting ion-mill process*. Nano Letters, 2007. **7**(10): p. 3246-3248.
2. Qiang, R., et al., *Effects of manufacturing artifacts on infrared filter performance*. Microwave and Optical Technology Letters, 2006. **48**(9): p. 1749-1754.
3. Han, K.P., et al., *Fabrication and characterization of polymeric microfiltration membranes using aperture array lithography*. Journal of Membrane Science, 2005. **249**(1-2): p. 193-206.

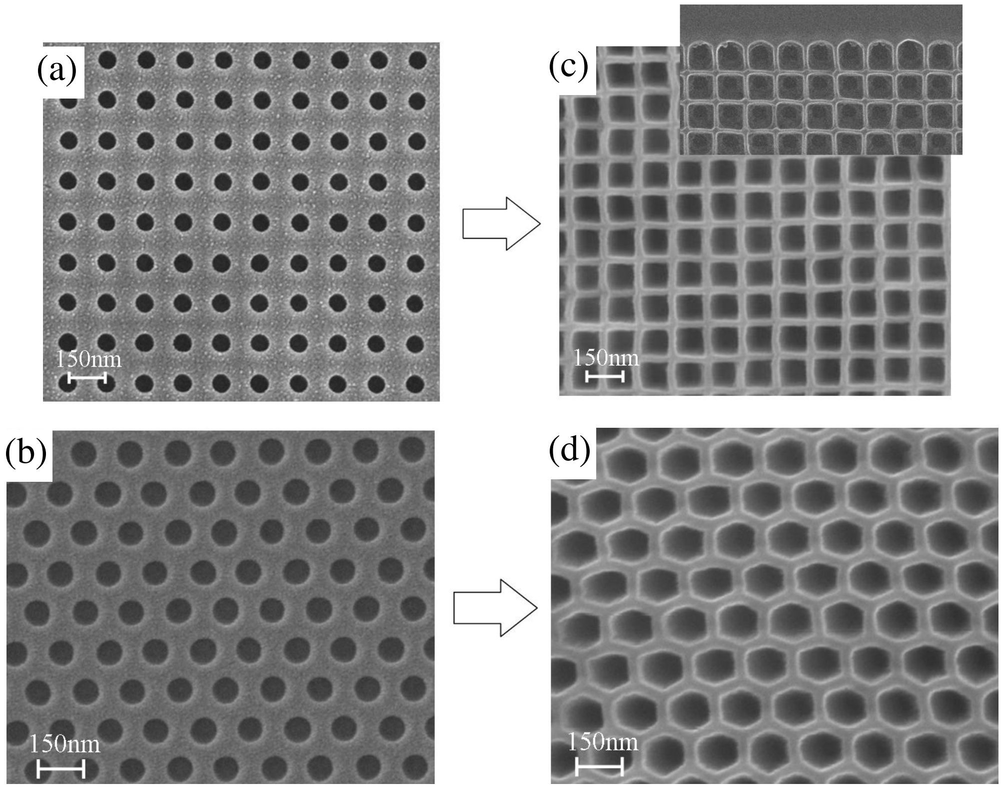

Figure 1. SEM images of ~75nm openings on (a) square and (b) hexagonal grids formed in PMMA using e-beam lithography; Top views of 105nm (c) square and (d) openings on a 150nm pitch after 12 min of self-limiting Ar+ ion milling at a beam energy of 500eV. The insert shows the edge of the pattern where the self-limiting process fails.

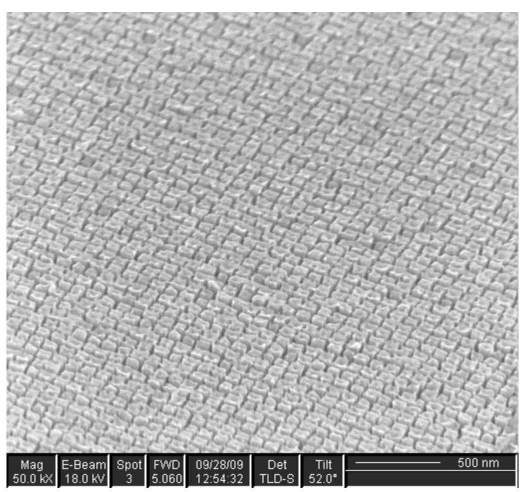

Figure 2. An SEM image of a dense array of 75nm Ni structures electrochemically deposited into a square patterned formed by a low-energy glow discharge process.