Geometrical Limitations for Ar Ion Beam Etching

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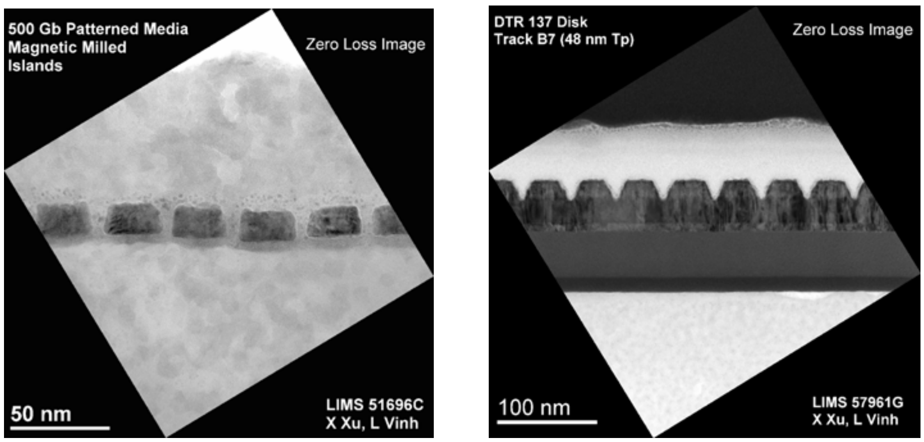
Fabrication of nanometer-scale structures with vertical sidewalls is critical for the performance of descrete track and bit patterned media magnetic recording devices [1], [2]. Most magnetic materials, however, do not easily form volatile reaction products eliminating dry etching as a fabrication technique. Consequently ion beam etching stands as a more suitable technique to pattern these materials. Being a physical process, ion milling is limited by geometry of the structures to be patterned and by the kinetic energy of the incident beam. This paper will present the geometrical limitations that occur when patterning structures with an Ar ion beam.

For this work, electron beam lithography and nano-imprinting were used to generate the carbon patterns on top of magnetic films. The carbon hard mask was patterned into line/space gratings at 68, 56, and 48nm pitch, and circular dot arrays (square lattice) at 35nm pitch. The thickness of the hard mask was 20nm. All samples were ion milled with a 250V Ar beam.

TEM analysis of final etched magnetic structures shows significant differences in sidewall angle depending on the initial hard mask shape and dimensions. Figure 1 shows a comparison of 48nm pitch line/space patterns with 18nm grooves to the 35nm pitch dot arrays with groove minimum at 15nm. The line patterns have an average wall angle of 68 deg, while the dot patterns have and average wall angle of 85 deg. TEM imaging was also done on identical line/space samples that were etched 10nm and 20nm deep. The images, seen in Figure 2, show that as the etch front goes deeper into the sample, the sidewall angle is reduced. At 10nm etch depth, the wall angle is on average 74 deg, compared to 68 deg at 20nm deep.

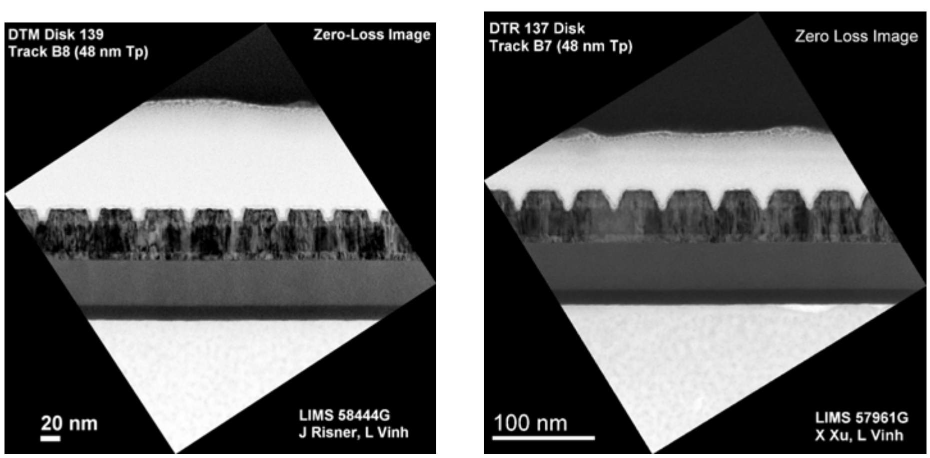
Due to the lack of volatile reaction products, redeposition remains one of the main challenges in Ar ion beam etching [3]. Material being removed in the ion etch process will either escape into the free space above the hard mask or collide with the sidewall. Sidewall collisions will have a certain probability of sticking which resembles that of a collection *cross section*. For this case the incoming Ar ion energy is fixed by the 250V grid. The sidewall redeposition is therefore a geometrical problem. This description supports the observations. The line/space patterns, with less solid angle for ejected material to escape into, will have more redeposition than the circular dot arrays, hence the shallower sidewall angle. By etching deeper into the magnetic media, there is less chance for the removed material to escape which is consistent with the results in Figure 2. The etched feature sidewall angle can be improved by increasing the incoming beam energy, to lessen sidewall redeposition, and reducing the thickness of the hard mask.

[1] Shaw JM, Russek SE, Thomson T, Donahue JM, Terris BD, Hellwig O, Dobisz E, Schneider ML, Physical Review B, Vol 78, Issue 2, Jul 2008
[2] Moneck MT, Zhu JG, Che XD, Tang YS, Lee HJ, Zhang SY, Moon KS, Takahashi N, IEEE Trans Mag, 43, 6, 2127-2129, June 2007
[3] Michael E. Walsh, Yaowu Hao, C. A. Ross, and Henry I. Smith J. Vac. Sci. Technol. B, Vol. 18, No. 6, Nov/Dec 2000



a) dots with 15nm wide gaps b) lines with 18nm wide grooves

Figure 1. TEM images of a) ion beam etched magnetic dots with a wall angle of 85 deg, and b) etched magnetic lines with a wall angle of 62 deg



a) etched grooves, 10nm deep b) etched grooves, 20nm deep

Figure 2. TEM images of line patterns with 18nm wide grooves etched a) 10nm deep with 74 deg wall angle and b) 20nm deep with 62 deg walls