# Ion beam etching of sub-30nm scale Magnetic Tunnel Junction for minimizing sidewall leakage path

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## 1. Introduction

Spin transfer-torque (STT) magnetic tunnel junctions (MTJs) with perpendicular magnetic anisotropy (PMA) are promising candidates for future non-volatile random access memories, due to their fast switching speeds, unlimited endurance and scalable switching currents.[1-3] Chlorine compound[4] and methanol[5] based reactive ion etching[6-7] have been used with Ta hard masks for the fabrication of sub 50 nm MTJ pillars[8]. Although they showed good etching characteristics, the after-corrosion and oxidation issues exists and at sub 30 nm scales the effects could become amplified. Also, the use of the hard mask adds to the layer thickness requiring that the pattern defining polymer resist layer become thicker to endure longer etching times, which reduces pattern scalability at sub 30 nm range.

Here, we have utilized the multi-step ion beam etching (IBE) method and negative electron-beam resist hard mask9 process to overcome the corrosion and oxidation problems during etching.

## 2. Experiment

The PMA MTJ layers, deposited by UHV sputtering, uses TiN (500) / Ta (30) / Ru (100) / Co-Pd multilayer (52) (thickness in angstroms) as the bottom electrode and the free layer, CoFeB (11) / MgO (8) / CoFeB (12) as the (001) oriented MgO tunnel barrier layer, and CoFeTb (300) / Ru (100) / Ti (50) as the pinned layer and top electrode. Arrays of 30~40 nm dot patterns 500 nm apart were defined by 80 kV electron beam lithography (NanoBeam, nB3) in negative-tone electron beam resist (NER) AR-N 7520 (Propylene glycol monomethyl ether acetate compound) with a thickness of 90~100 nm. The IBE etching was performed using the NER as the hard mask layer. For the IBE process, the beam supply voltage (BSV) was 400 V and the acceleration supply voltage (ASV) was 100 V. The incident angle of the Ar ion beam was controllable by tilting the rotating sample stage to set values. After IBE, the samples were cut and the MTJ pillar dimensions were analyzed by scanning electron microscopy (SEM). For electrical test samples, after the MTJ pillar formation, SiNxwas deposited using low temperature (100$^{o}$C) chemical vapor deposition as passivation layer. Then chemical-mechanical polishing (CMP) was performed to expose the top of the MTJ. Finally the top electrodes were defined by optical lithography followed by Cr/Au deposition and liftoff. The magneto-resistance (MR) characteristics of the MTJs were measured in air with perpendicular magnetic-fields swept between –2000 and 2000 Oe, at a sample bias voltage of 50mV.

## 3. Results and Discussion

The IBE etch rate should be high enough so that the NER can withstand the complete process without being removed. The IBE rate of the NER used was~3 nm/min at the given power and since the total etching thickness was 76 nm (including slight over etching of the top surface of the bottom electrodes to remove the shadowing induced incomplete etching around the bottom of the MTJ) the etching time should not be more than 30 min considering that the 30 nm NER pillar can be produced at ~ 90 nm thickness. Therefore, the MTJ etching rate should be above 2.6 nm/min. We chose as the primary etching angle 45o so as to minimize there deposition layer thickness while having a modest etch rate of ~4nm/min and a secondary low angle etching at 30o, with an etch rate of 2.2nm/min and the lowest redeposition layer thickness. By performing multiple steps of the primary and secondary etching we were able to fabricate a 30nm MTJ pillar with significant reduction in the redeposition layer thickness.

The 8-step IBE process performed for 18 min resulted in a 28 nm diameter MTJ pillar 55 nm tall, with almost vertical side profiles. The average resistance of the 28 nm MTJs was 1 kΩ, which was a considerable improvement to previous results using the single IBE process which gave an average resistance of 4 *Ω*. Also the average TMR ratio of 12 % for the multi-step IBE was far improved from 2 % TMR measured for the single step etching. When the IBE process was performed at 700 V BSV, many more such steps were observed in the MR curves. This suggests that by reducing the IBE process energy, it may be possible to further reduce etching damage that may prevent multi domain formation.

## 4. Summary

We have demonstrated the fabrication of sub 30 nm MTJ pillars with PMA characteristics. The multi-step IBE process performed at $45^{o}$ and $30^{o}$, using NER resulted in almost vertical side profiles. There deposition on the sidewalls of the NER prevented lateral etching of the resist hard mask allowing vertical MTJ side profile formation without any reduction in the lithographically defined resist lateral dimensions. For the 28nm STT-MTJ pillars, the measured TMR ratio was 13 % with resistance of 1 k*Ω*, which was due to remaining redeposition layers less than 0.1 nm thick. With further optimization in multi-step IBE conditions, it will be possible to fabricate fully operating sub 30 nm perpendicular STT-MTJ structures for application to future non-volatile memories.

## References

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