Nanofabrication of Magnetic Tunnel Junction Pillars Targeting Nano-Oscillator Applications

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Abstract

Magnetic Tunnel Junctions are Spintronic devices constituted by two ferromagnetic layers separated by a nanometric insulating barrier. The theoretical predictions of giant Tunnel Magnetoresistance (TMR) values in fully crystalline Fe(001)/MgO(001)/Fe(001) structures [1] were soon followed by its experimental verification [2,3]. Such giant TMR effect arises from the conservation of the coherence of the electron wave function during tunneling across crystalline MgO and from the smaller decay rate of the spin up states in the barrier when compared to that of spin down states (spin filtering effect) [4]. In state of the art CoFeB-MgO MTJs, TMR ratios of up to 600% have been reported [5]. In the low resistance x area (RA) range, which is the most important for applications, TMR values of 138% have been demonstrated in MTJs with RA~2.4 $\Omega\mu m^2$ (in unpatterned MTJs) [6].

These results promptly widened the prospect of fabricating novel magnetic devices that operate using spin transfer torque (STT) mechanisms. This effect consists in the transfer of the moment of magnetic spins from a polarized electrical current to the ferromagnetic layers, thus allowing the manipulation of the magnetization of nano-magnets by means of local currents in opposition to magnetic fields. Two of the best positioned STT applications to reach the commercialization in the short term are RF emitters resulting from persistent magnetic dynamics driven by DC currents and non-volatile magnetic random access memories.

In order to achieve high quality STT devices the downscaling of MTJs until dimensions below 100 nm is necessary. In this presentation we will describe our nanofabrication process which is mainly based in e-beam lithography and ion milling steps. Several problems arise from the miniaturization of the MTJs being one of the most prominent the material re-deposition on the sidewalls of the nanopillars during the ion beam etching. This re-deposition inflates the final device critical dimension. More importantly, it causes the electrical shunting across the barrier which decreases the TMR. To remove the material re-deposition a low angle milling is usually used after the normal milling definition. However, low angle millings create damages in the device edges, generate shadowing effects that prevent the formation of vertical sidewalls and decrease the process uniformity due to clamps used at wafer edges. The edge damage can be minimized by using a low beam energy milling. However, the divergence of the beam increases for lower beam energies and thus a compromise must be found. Another problem related to the nanofabrication process consists in conferring mechanical stability to the devices while keeping the nanopillars open on top. This structure enables the microfabrication of the remaining components of the device that allow the reading/writing of the MTJ. To achieve this structure a dielectric material is deposited after the nanopillar definition and afterwards opened on the top of the pillars. In order to open the MTJs, processes based on lift-off and chemical-mechanical processes (CMP) have been used. Despite the simplicity of the lift-off process, the yield of the open nanopillars is relatively low and it has a process time that can go up to two weeks. Moreover, the process is intrinsically worse for smaller nanopillars. As for the CMP process, it is a very fast process that opens more easily the smaller pillars. However, there are a lot of residues arising from the planarization and a good uniformity is difficult to achieve.

Here, we also propose the use of an ion beam planarization step after the nanopillar definition. This process is faster than the lift off and cleaner that CMP and intrinsically better for the smaller pillar sizes. Using the described process we were able to achieve MTJs with RA below 1.5 $\Omega\mu m^2$ and TMR up to 130%. We will also give a general overview of the different devices fabricated, such as the double barrier MTJs, magnetic vortexes and MTJs with perpendicular magnetic anisotropy.

References

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