Sub-10nm thermally stable Perpendicular Shape Anisotropy magnetic memory

Abstract. A new concept of thermally stable and electrically switchable Spin Transfer Torque Magnetic Random Access Memory (STT-MRAM) scalable to diameter down to 4nm was proposed and demonstrated. By dramatically increasing the thickness of the storage layer, a bulk magnetic anisotropy perpendicular to the plane of the layers can be induced which dramatically improves the memory properties, in particular its retention down to 4nm diameter with no penalty on the write current.

Among the various technologies of non-volatile memories, STT-MRAM gathers a unique combination of assets: non-volatility, write speed (3-30ns), density (4Gbit demonstrated by Hynix/Toshiba), low consumption (a few tens of fJ/write), and very importantly an extremely long write endurance (>10^{13}cycles). Conventional STT-MRAM are based on out-of-plane magnetized magnetic tunnel junctions (MTJs) in which the storage layer magnetization is pulled out-of-plane thanks to a perpendicular anisotropy originating from the interface between the oxide barrier and the magnetic electrodes. This phenomenon was discovered at SPINTEC in 2002 and reviewed in Rev. Mod. Phys. 89, 025008 (2017). In conventional STT-MRAM, this interfacial anisotropy is large enough to insure thermal stability of the storage layer magnetization down to diameter of the order of 20nm. To increase the STT-MRAM downsize scalability, a novel type of MRAM with much thicker storage was developed at SPINTEC. By drastically increasing the thickness of the storage layer to values comparable to its diameter, a perpendicular shape anisotropy (PSA) is induced in the storage layer which comes on top of the previously mentioned interfacial anisotropy with no penalty on the switching current. As a result, the perpendicular anisotropy is greatly reinforced enabling to maintain magnetic thermal stability (i.e. good memory retention) down to 4nm diameter. The name PSA-STT-MRAM was coined to designate this memory.

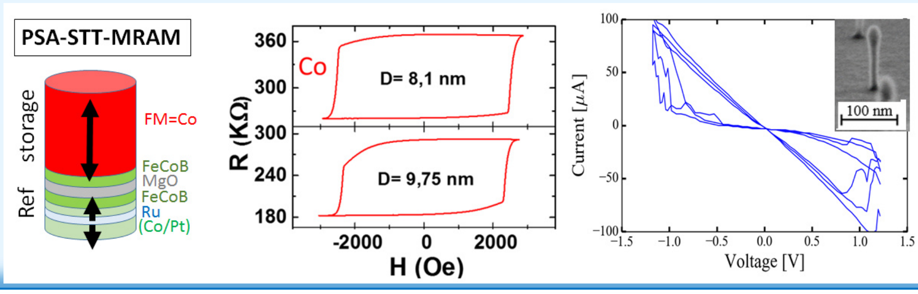

Illustration of the PSA-STT-MRAM concept. R(H) loops showing large coercitivity at 300K even for pillars 8.1nm in diameter. Illustration of spin transfer torque switching in a pillar 12nm

In addition to their excellent and tunable thermal stability at sub-10nm diameter, PSA-STT-MRAM have additional advantages: bulk and interfacial properties of the storage layer can be separately optimized. For instance, low Gilbert damping material can be used in the bulk of the storage layer to reduce the write current without compromising on the tunnel magnetoresistance amplitude. Furthermore, because the storage layer is thick, the thermal variation of its magnetic properties is much closer to that of the corresponding bulk material and therefore much less temperature dependent than when very thin storage layer are used. As a result, PSA-STT-MRAM can more easily be designed to operate on a wide range of temperature than conventional STT-MRAM which is very important for automotive and industrial applications or to fulfill solder reflow compliance.

Team(s): N. Perrissin, S. Lequeux, N. Strelkov, A.Chavent, L.Tillé, L. Vila, L. Buda-Prejbeanu, S. Auffret, R.C. Sousa, I.L. Prejbeanu, B. Dieny

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Further reading: *A highly thermally stable sub-20 nm magnetic random-access memory based on perpendicular shape anisotropy*, N. Perrissin, S. Lequeux, N. Strelkov, A.Chavent, L. Vila, L. Buda-Prejbeanu, S. Auffret, R.C. Sousa, I.L. Prejbeanu, B. Dieny. Nanoscale,10, 12187-12195(2018). DOI: 10.1039/C8NR01365A

bernard.dieny@cea.fr