MATERIAL DEVELOPMENTS AND NANOSECOND-SCALE SWITCHING PROCESS IN PERPENDICULARLY MAGNETIZED STT-MRAM CELLS

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Spin transfer torque (STT)-based magnetic random access memory (MRAM) with perpendicular magnetization are seen as possible new memory elements thanks to their non-volatility, scalability, high endurance and low power requirement. The core of an STT-MRAM stack is a magnetic tunnel junction (MTJ) composed of FeCoB/MgO/FeCoB. One of the FeCoB layer is pinned to a high anisotropy synthetic ferrimagnet to create a fixed reference layer (RL) system while the second FeCoB acts as a free layer (FL). In this perpendicular technology, the requirements for the free layer (FL) include a high anisotropy and a low damping. In addition, reference layers (RLs) have to be insensitive to magnetic fields and spin-torques and are usually constructed in a synthetic ferrimagnet configuration to avoid the generation of stray fields that would destabilize the free layer.

I. MATERIAL RESEARCH

Historically, the FL is capped with amorphous Ta and more recently capped with a second MgO layer to benefit from a second interface anisotropy in the so-called 'dual MgO' configuration. We have studied the influence of the Ta spacer deposition condition on the thermal robustness, anisotropy and damping of the single and dual MgO free layers embedded in a state of the art perpendicular MTJ stack and we benchmark it to optimized single MgO FL devices. Controlling interface quality around the spacer of the free layer is a key requirement to maintain perpendicular anisotropy up to 400°C annealing. The key degradation mechanism is the diffusion of the spacer material that starts as soon as the annealing temperature triggers the crystallization of the FeCoB of the free layer. This crystallization can be postponed almost until the BEOL annealing conditions by increasing the Boron content in the FeCoB parts of the free layer. If interdiffusion occurs, the nature of the spacer material then also influences the damping. Altogether, we will explain how we can obtain a damping factor as low as 0.0035 in a dual MgO free layer and demonstrate it by vector network analyzer ferromagnetic resonance (Fig. 1). Complementary material optimizations concern the coupling of the different functional blocks within the reference layer [1-3] and the proper choice of buffer layers [4] to promote the right texture and the corresponding high perpendicular anisotropy. Altogether, we demonstrate a fully stable double MgO free layer structure up to 90 minutes of annealing at 400°C.

II. STT SWITCHING AT THE NS SCALE

We have then studied the nanosecond-scale STT switching in devices. We first looked at samples in which the fixed system comprises a hard synthetic antiferromagnet coupled to a FeCoB spin-polarizing layer through weak ferrocoupler [4]. The electrical signatures of the reversal indicate non-uniform magnetization reversal with the presence of a domain wall in junctions of various sizes. In the antiparallel to parallel switching, the reversal proceeds within 3-4 nanoseconds. A nucleation phase is followed by an irreversible flow of a wall through the sample at an average velocity of 40 m/s. Conversely, the P to AP transition has a complex dynamics with dynamical back-hopping that worsen at larger applied voltages. We attribute this back hopping to the instability of the nominally fixed layers [4].

We then studied samples in which the fixed system is harder and consequently free of dynamical

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back-hopping [5]. When the field and the spin-torque concur to both favor the P to AP transition, the reversal yields monotonic resistance ramps that can be interpreted as a domain wall propagation through the device; smaller cells switch faster, and proportionally to their diameter. At the largest sizes, transient domain wall pinning can occasionally occur. When the field hinders the P to AP transition triggered by the spin-torque, the P to AP switching is preceded by repetitive switching attempts, during which the resistance transiently increases until successful reversal occurs. At 50 nm, the P to AP switching proceeds reproducibly in 3 ns, with a monotonic featureless increase of the device resistance.

In the reverse transition (AP to P), the variability of reversal is not restricted to stochastic variations of incubation delays before the reversal: several reversal paths are possible even in the smallest junctions. Besides, the non-uniform nature of the magnetic response seems still present at the nanoscale, with sometimes electrical signatures of strong disorder during the AP to P reversal. The AP to P transition is preceded by a strong instability of the AP states in devices larger than 100 nm, indicative of fluctuations likely at the pillar edge. The switching asymmetry is related to the non uniformities of the stray field emanating from the reference layers of the tunnel junction, which affects the zones in which nucleation is favored.

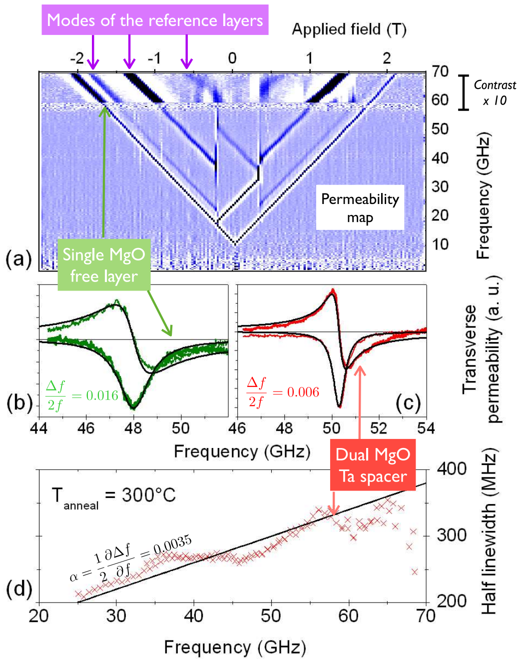

Figure 1: Examples of dynamical properties. (a) Permeability versus out-of-plane field and frequency for an MTJ with a single MgO free layer. The apparent vertical bars are the eigenmode frequency jumps at the different switching fields of the MTJ. (b) Real and imaginary parts of the experimental (symbols) and modeled (lines) permeability for an out-of-plane field of 1.54 T for the same MTJ. The model is for an effective damping that includes the contribution of the inhomogeneity. (c) Same but for a dual MgO free layer based on a Ta spacer (d) Cross symbols: FMR half frequency linewidth versus FMR frequency for a dual MgO free layer based on a Ta spacer. The line is a guide to the eye corresponding to a Gilbert damping of 0.0035.

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