A Novel STT-MRAM Design with Field Assisted Synthetic Anti-Ferromagnet Free Layer

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I. ABSTRACT

Spin Transfer Torque Magnetic Random Access Memory (STT-MRAM) is one of the next generation of new nonvolatile memory, which has the most industrial prospects and followed lots of new ideas. Recently, one published paper reported that under a small electric bias voltage induced by Ionic liquid gating, the synthetic anti-ferromagnetic (SAF) multilayer system can be changed from an antiferromagnetic (AFM) coupling state to a ferromagnetic (FM) coupling state [1]. Base on this phenomenon, we propose a new type of STT-MRAM which critical write current can reduced by an assisting electric field. Micro magnetic simulation will be used to study the switching behavior of the magnetization of the synthetic anti-ferromagnetic (SAF) free layer under the impact of the electric field.

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II. INTRODUCTION

In the past decade, STT-MRAM has been at the core of spintronic memory research and development [2-5], and electric-field (E-field) assisted switching has gained attention since it could drastically reduce writing energy than spin transfer torque (STT) and thus reduces the size of access transistors, resulting in higher bit density [6]. And recent studies focus on E-field regulation of (AFM) has gained increasing attention as well. Nevertheless, since the alternative spins at the AFM/FM interface are strongly pinned by AFM layer, these E-field control processes are usually confined at a low temperature [7,8] or require an magnetic-field assistance [9]. To overcome these difficulties, Yang *et al.* [1] studied the room temperature RKKY interlayer interaction in the synthetic antiferromagnetic (SAF) multilayer only under the impact of electric field as a practical way to manipulate the AFM coupling within the SAF structure. In this sense, this E-field controlled SAF layer at room temperature can be treated as a free layer in a traditional magnetic tunneling junctions (MTJs), therefor we design a new kind of SAF-MRAM which will has strong potential benefits on enhancing the bit density or depressing the energy consumption.

III. MICROMAGNETIC SIMULATION

We use Object Oriented Micromagnetic Framework（OOMMF) [10] to simulate the spin dynamic process in a simplified spin valve structure (FM|NM|FM) with tunable Ruderman–Kittel–Kasuya–Yosida (RKKY) interaction [11]. With changing the sign of the RKKY interaction, the spin valve can reproduce the behavior of the transformation between the antiferromagnetic coupling state and the ferromagnetic coupling state. Thus the spin valve can be treated as a SAF free layer, and switched by injecting spin polarization charge current.

Technically, all the spins are governed by the Landau-Lifshitz-Gilbert (LLG) [12] equation, which reads:

$$\frac{d\boldsymbol{m}}{dt} = -|\gamma|\boldsymbol{m}\times\boldsymbol{H}_{eff} + \alpha\left(\boldsymbol{m}\times\frac{d\boldsymbol{m}}{dt}\right) + |\gamma|\beta\epsilon\left(\boldsymbol{m}\times\boldsymbol{m}_p\times\boldsymbol{m}\right) - |\gamma|\beta\epsilon'\left(\boldsymbol{m}\times\boldsymbol{m}_p\right) \quad (1)$$

where $\boldsymbol{m}$ is the direction of magnetizations, γ the gyromagnetic ratio, α the damping constant, $\beta = |\frac{\hbar}{e\mu_0}|\frac{J}{tM_s}$ with J the injected charge current density, t the free layer thickness, M_s the saturation magnetization, and $\epsilon = \frac{P\Lambda^2}{(\Lambda^2+1)+(\Lambda^2-1)(\boldsymbol{m}\cdot\boldsymbol{m}_p)}$ determine the in-plane STT induced by J with spin polarization P along $\boldsymbol{m}_p$ direction, Λ is the anisotropy effect of STT. The additional RKKY interaction

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is included by introduced an extra energy term:

$$E_{RKKY} = \sum_i \sum_j \frac{\sigma\left[1-\widehat{m}_i\cdot\widehat{m}_j\right]+\sigma_2\left[1-(\widehat{m}_i\cdot\widehat{m}_j)^2\right]}{\Delta_{ij}}$$

(2)

where σ and σ_2 , respectively, are the bilinear and biquadratic surface exchange coefficients (RKKY) between the two surfaces of the two FM layers in the spin valve, $\widehat{m}_i$ and $\widehat{m}_j$ are the magnetization directions at cells i and j , and Δ_{ij} is the discretization cell size in the direction from cell i towards cell j. One should note that if σ is negative, then the surfaces will be AFM coupled and for simple we keep $\sigma_2 = 0$ all the time.

IV. RESULTS

Within the above frame, the phase diagram of the magnetic state thus can be obtained as the function of injecting current and RKKY interaction, the results are shown in Fig. 1, in which, we can conclude that, when the RKKY interaction is negative, we need a pretty large charge current to switch the SAF structure, however, if the RKKY tuned by E-field to a positive value, the switching process only need a weak charge current. In this sense, this E-field controlled SAF-FM transformation could be advantageous is STT-MRAM devices.

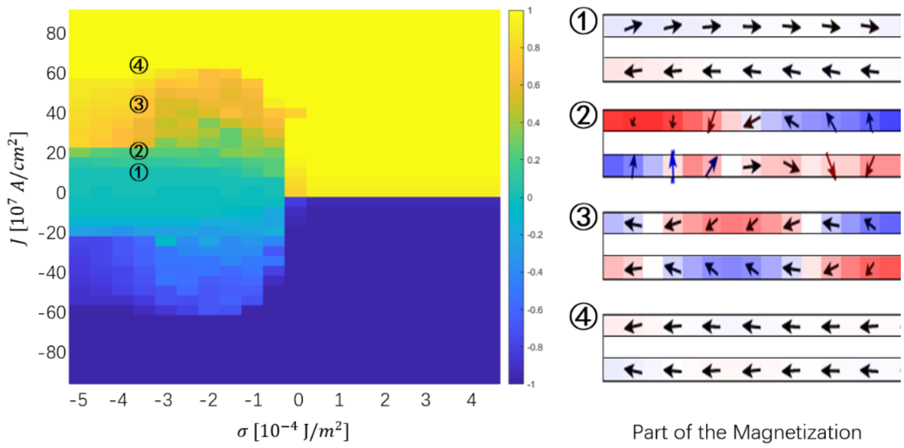

Fig. 1 The phase diagram of the magnetic state of the spin valve. The color represents the average magnetization along in plane direction, thus both blue and yellow stand for FM state with different direction and zero is then SAF state. And in detail we also show the magnetizations texture of part of the devices for the corresponding marked points.

REFERENCES

1) Qu Yang *et al. Nature Communications* 9:991 (2018).
2) Q. J. Yap *et al. Journal of Applied Physics* 116, 043902 (2014).
3) Jian-Gang Zhu, Patent No. US 8675456 B2 (2014).
4) Jian-Gang Zhu, Patent No. US 2008/0180827 A1 (2008).
5) Jian-Gang Zhu, Patent No. US 2009/0237987 A1 (2009).
6) C. Grezes *et al. Appl. Phys. Lett.* 108(1), 012403 (2016).
7) Y. Wang *et al. Adv. Mater.* 27, 3196–3201 (2015)
8) V. Laukhin *et al. Phys. Rev. Lett.* 97, 227201 (2006).
9) M. Liu *et al. Adv. Funct. Mater.* 21, 2593–2598 (2011).
10) M. J. Donahue and D. G. Porter, ``OOMMF User's Guide, Version 1.0," NISTIR 6376, National Institute of Standards and Technology, Gaithersburg, MD (Sept 1999).
11) M. A. Ruderman and C. Kittel. *Phys. Rev.*, 96:99-102 (1954).
12) A. V. Khvalkovskiy *et al. Phys. Rev. Lett.,* 102(6):067206 (2009).