Tuning the Voltage Controlled Magnetic Anisotropy in CoFeB/MgO Magnetic Tunnel Junctions

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BACKGROUND

Magnetic tunnel junctions (MTJ) are promising candidates for next generation nonvolatile memory and logic applications. In MTJs with perpendicular anisotropy (pMTJ), the voltage controlled magnetic anisotropy (VCMA) effect has been demonstrated and has drawn a lot of attention for its potential application of ultra-low energy switching. The VCMA coefficient, which describes the effectiveness of electric field in modulating the interfacial perpendicular magnetic anisotropy (PMA) in the magnetic layer, still sits below 300 fJ/Vm and leaves much to be desired for further application. Much effort has been focused on enhancing VCMA, and the results are mixed.

I. INTRODUCTION

A. Origin of iPMA at CoFeB/MgO interface

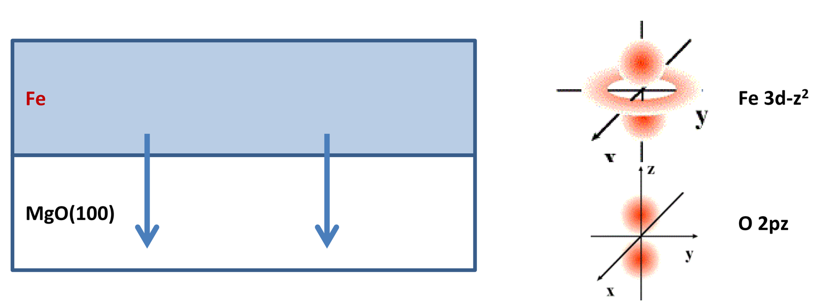
Band specific coefficient (~ 0.2 for Co)

Spin-orbital coupling constant

$$\Delta U_{PMA} = -\frac{G}{H}\frac{\xi}{4\mu_B}\left(m_{orb}^{\perp} - m_{orb}^{//}\right)$$

out-of-plane/ in-plane orbital moments

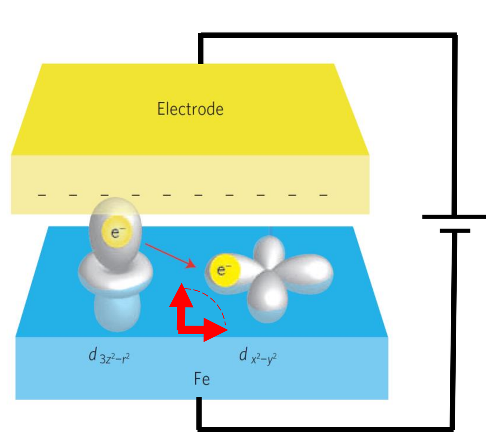
Bruno, *Phys. Rev. B* 39, 865-868 (1989)
Weller et al, *Phys. Rev. Lett.* 75, 3752-3755 (1995)



Hybrid of Fe 3d with O $2p_z$ at interface $m_l(001)>m_l(100)$ via SOC induces PMA

Niranjan et. al. Appl. Phys. Lett. 96, 222504 (2010)
Shimabukuro et. al. *Physica E* 42, 1014-1017 (2010)
Yang et. al. Phys. Rev. B 84, 054401(2011)

B. Voltage controlled magnetic anisotropy

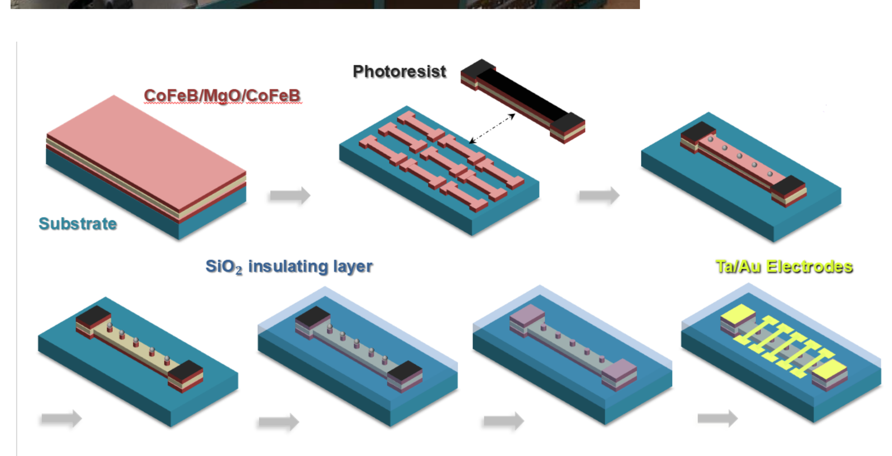


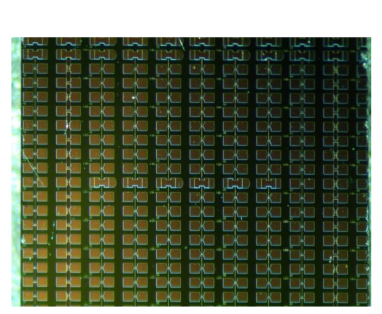
Because of spin orbital coupling at the interface, charge transfer through different orbitals caused by an applied voltage changes the magnetic anisotropy

Nature Nanotechnology **4**, 158 - 161 (2009)

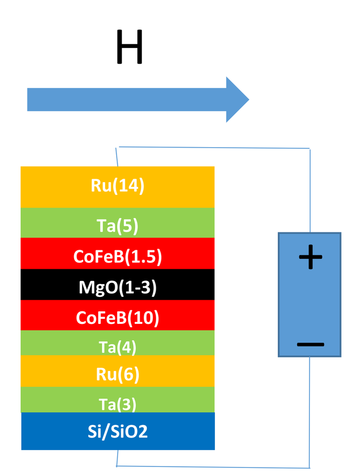
II. FABRICATION

- Magnetron Sputtering
- Metallic layers grown by DC sputtering at 2mTorr
- MgO barrier grown by RF sputtering at 0.6-1 mTorr
- Standard photolithography



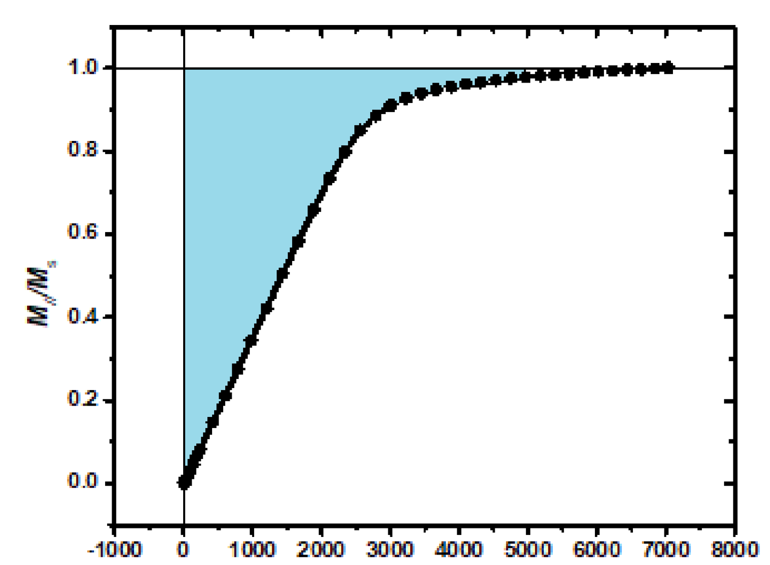


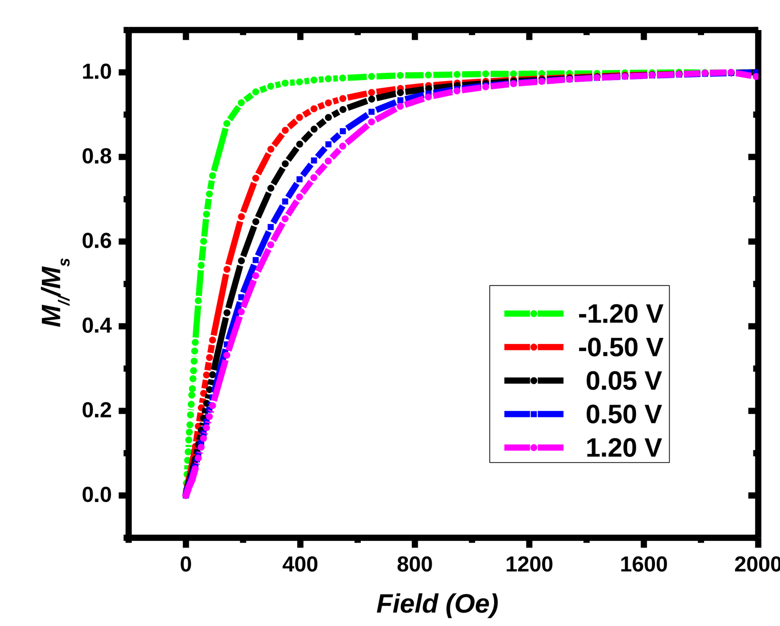
III. MEASUREMENT



Measuring resistance within a range of magnetic field strength gives the in plane component of the saturation magnetization.

$$\frac{M_{in\,plane}}{M_s} = \frac{R_{90}-R(\theta)}{R(\theta)}\,\frac{R_p}{R_{90}-R_p}$$

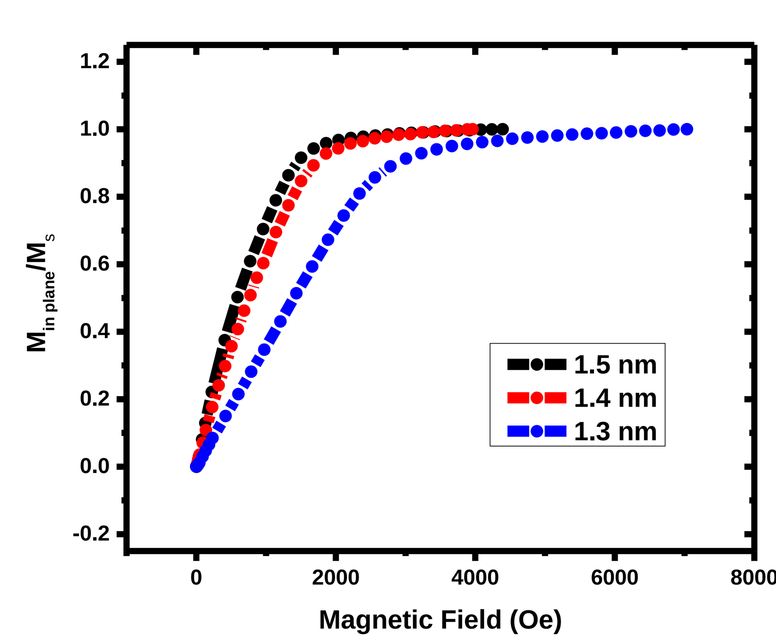


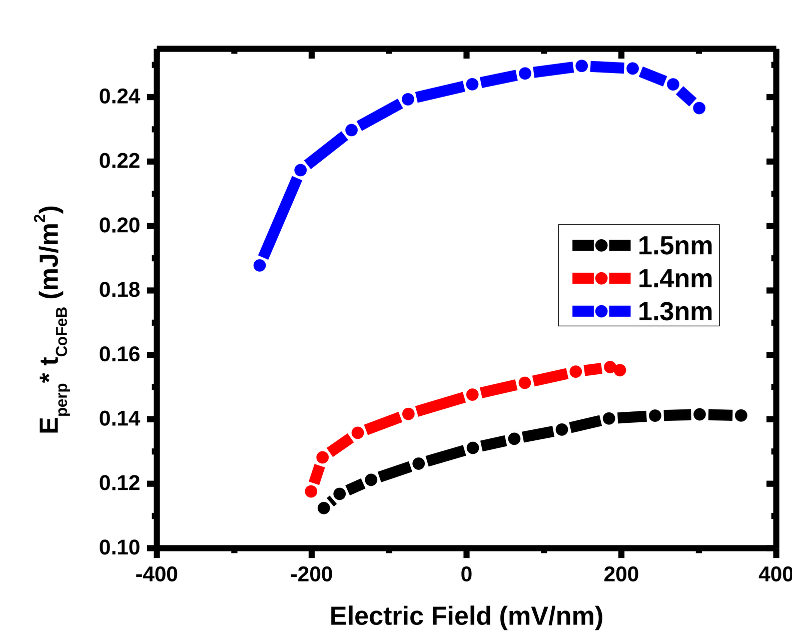


$$W = \int_0^M H\,dM \;\frac{erg}{cm^3}$$

IV. RESULTS AND DISCUSSION

A. Different CoFeB Thickness



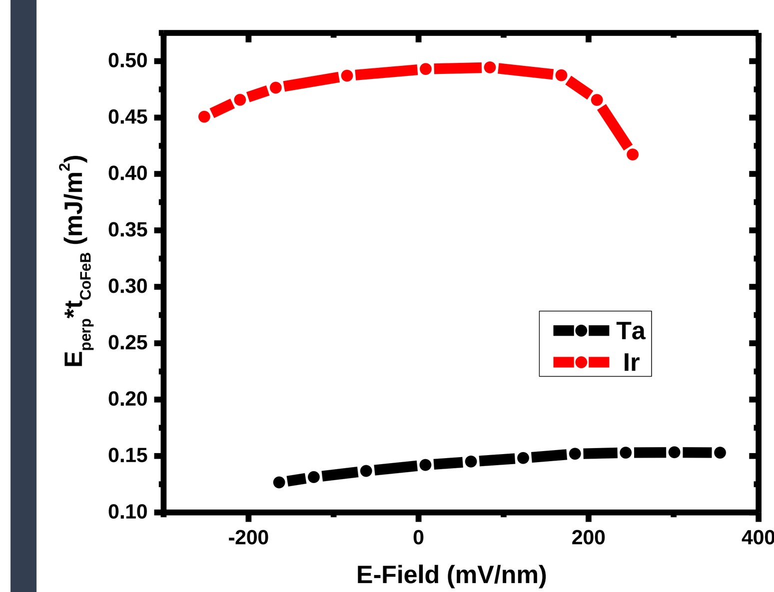


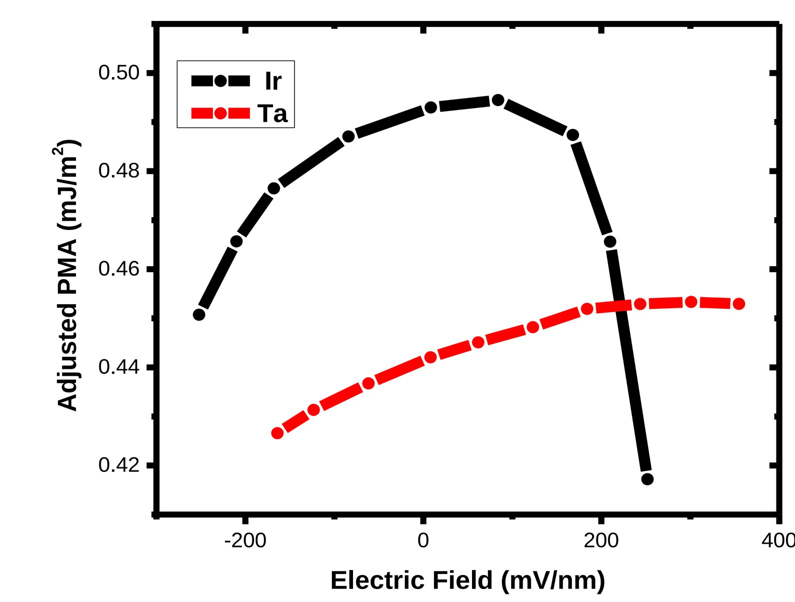
Co/Fe/B thickness	1.3 nm	1.4 nm	1.5 nm
PMA (mJ/m²)	0.244	0.148	0.131

Co/Fe/B thickness	1.3 nm	1.4 nm	1.5 nm
VCMA Coefficient (fJ/Vm)	51.4	71.8	59.8

IV. RESULTS AND DISCUSSION

B. Different Underlayer (Ta and Ir)





Different PMA-electric field behavior for different underlayer!

V. CONCLUSION

★ Variation in CoFeB thickness can modulate VCMA coefficient at CoFeB/MgO interface

★ Large enhancement of PMA using iridium as underlayer with dramatically different PMA-Electric Field dependence

VI. NEXT STEPS

★ Insertion of heavy metals between CoFeB and MgO for their strong spin orbital coupling

★ Exploration of the nonlinear relationship between PMA and electric field under different annealing conditions

ACKNOWLEDGMENTS

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