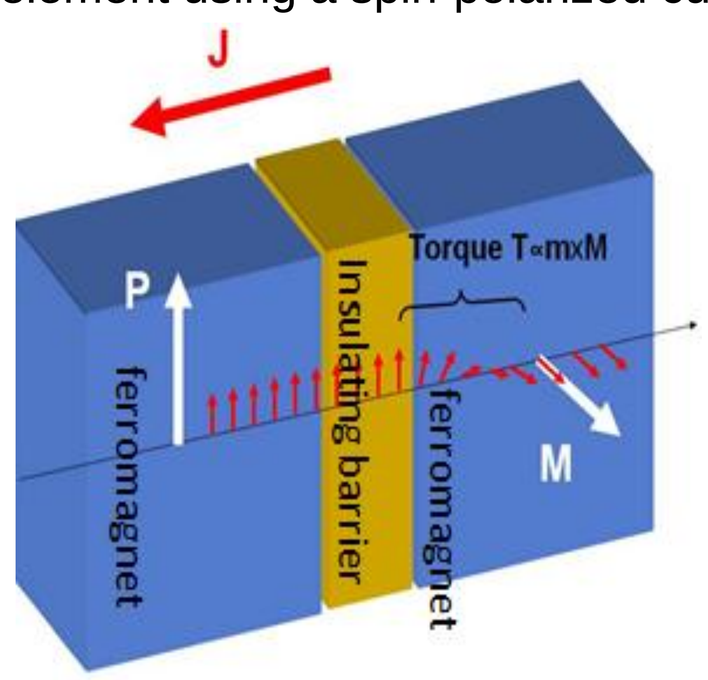
Prospective Material Exploration for Spin-torque transfer Magneto-resistive random access memory

Manli Ding[1], Yishen Cui[1], Jiwei Lu[1], Tim Mewes[2], Joseph Poon[1]

[1]University of Virginia, Department of Physics; [2] University of Alabama, Department of Physics and Astronomy, MINT center

Introduction: Spin-transfer torque

Spin-transfer torque (STT) is a writing technology in which data is written by reorienting the magnetization of a thin magnetic layer in a tunnel magnetoresistance (TMR) element using a spin-polarized current.



TMR element contains two magnetic layers sandwiching an ultra-thin insulating barrier.

The switching current density threshold required for current magnetization reversal is,

$$J_c = \frac{2e\alpha M_s t_F (H_k \pm 2\pi M_s)}{\hbar \eta}$$

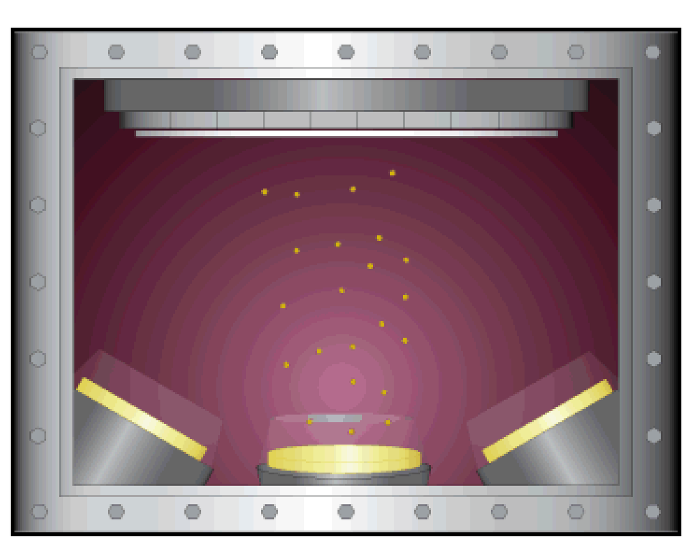
Where M_S and t_F are the magnetization and thickness of the storage layer, α is the damping constant, H_k is the anisotropy field, η is the spin-transfer efficiency having a function of current polarization and the relative angle between two magnetic layers. '+/-' refers to easy in-plane/perpendicular material.

High thermal stability is required for industrial application, where M_s is the saturation magnetization, H_k is anisotropy field, T is the annealing temperature;

$$\Delta = \frac{\mu_0 M_s H_K V}{2k_B T}$$

RF/DC Sputtering system;

Sputtering is a progress whereby atoms are ejected from a solid state target due to bombardment of the target by energetic particles.

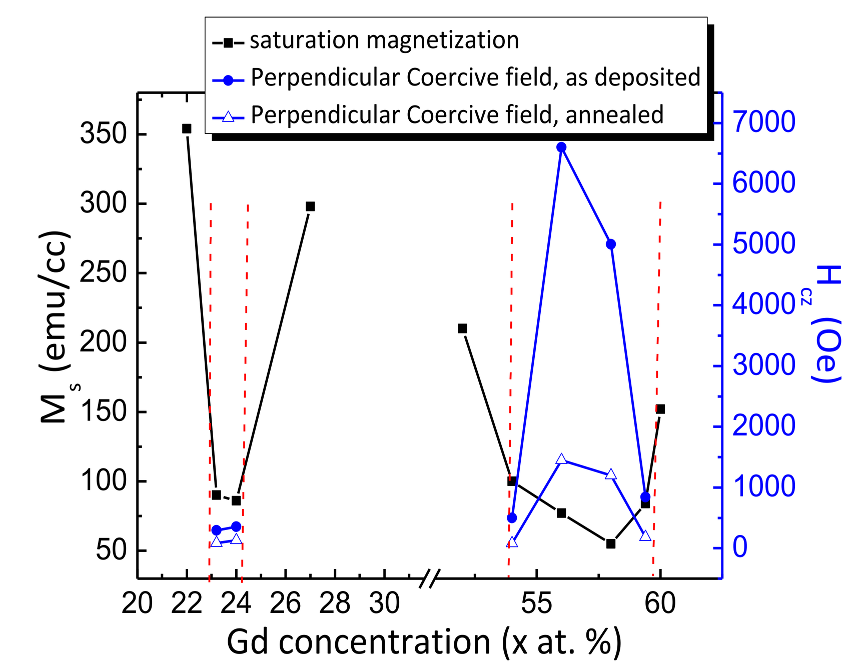


Motivation

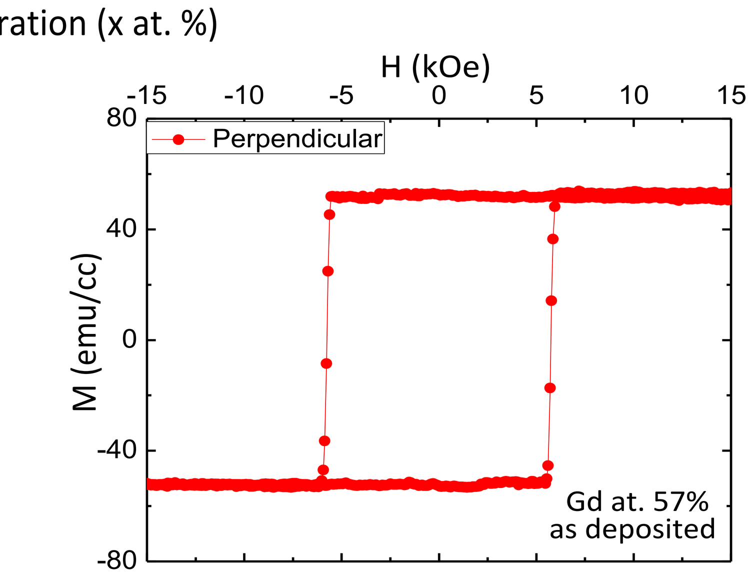
The intrinsic current density can be reduced by using materials with low Ms, α and high spin transfer efficiency.

Material with perpendicular anisotropy is favored to reduce switching current.

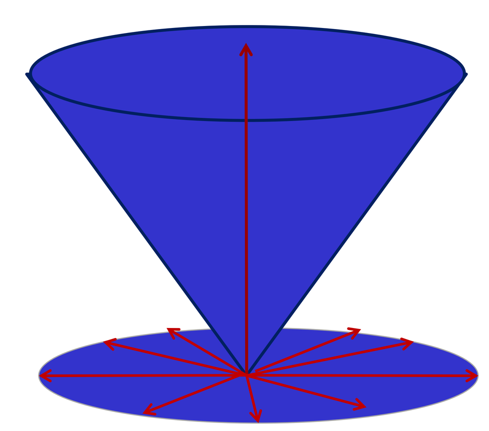
Rare-earth(Gd) sublattice couples antiferromagnetically with the Fe(Co) ferromagnetic sublattice. Perpendicular anisotropy exists near the compensation point, where magnetization is small.

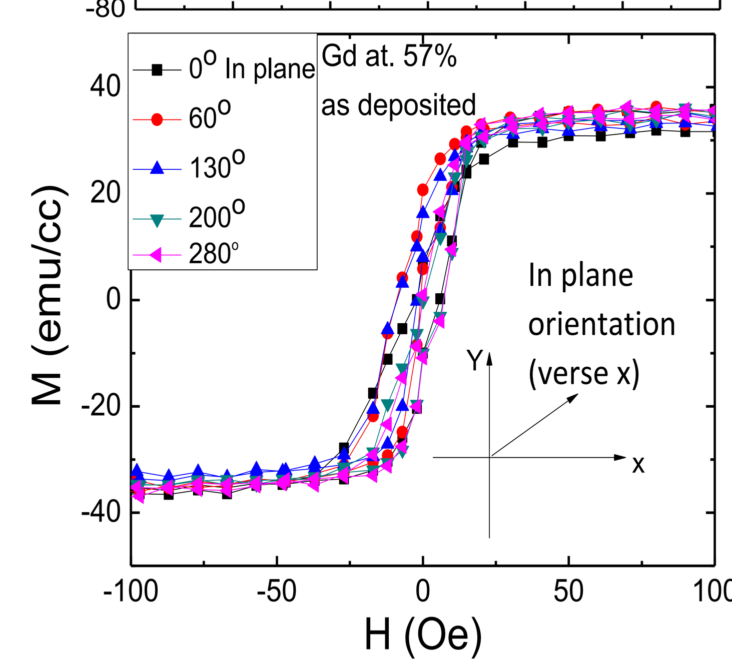


GdFeCo films maintain PMA at the high annealing up to 200°C .

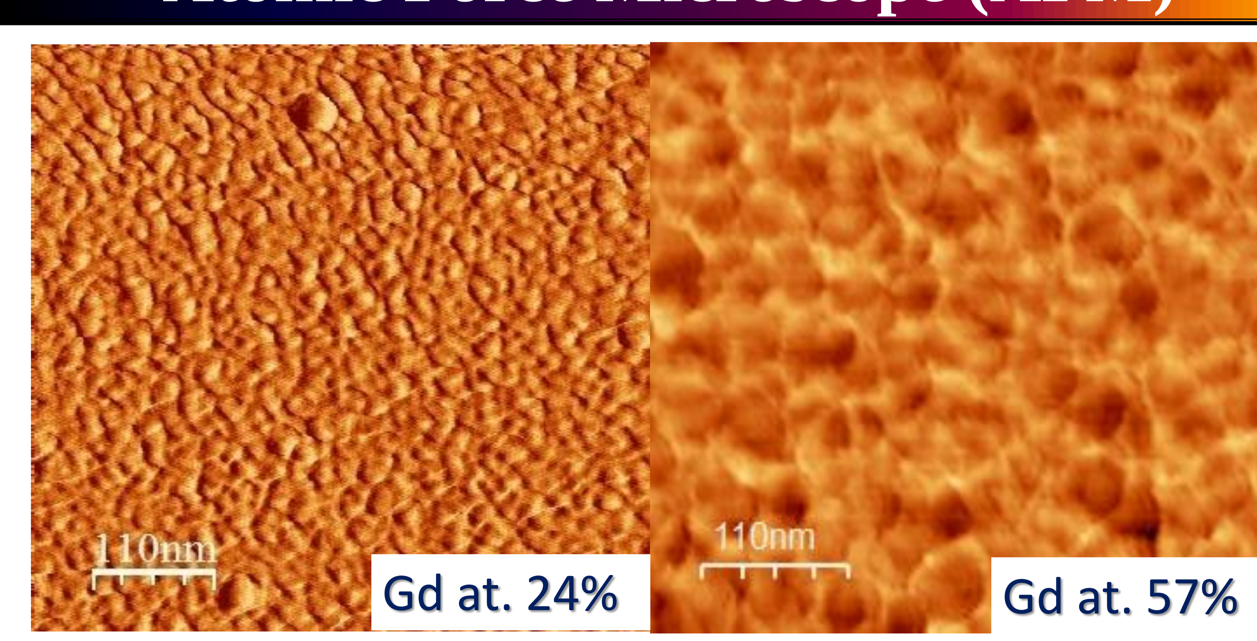


Suggestive of "cone magnetization".





Atomic Force Microscope (AFM)

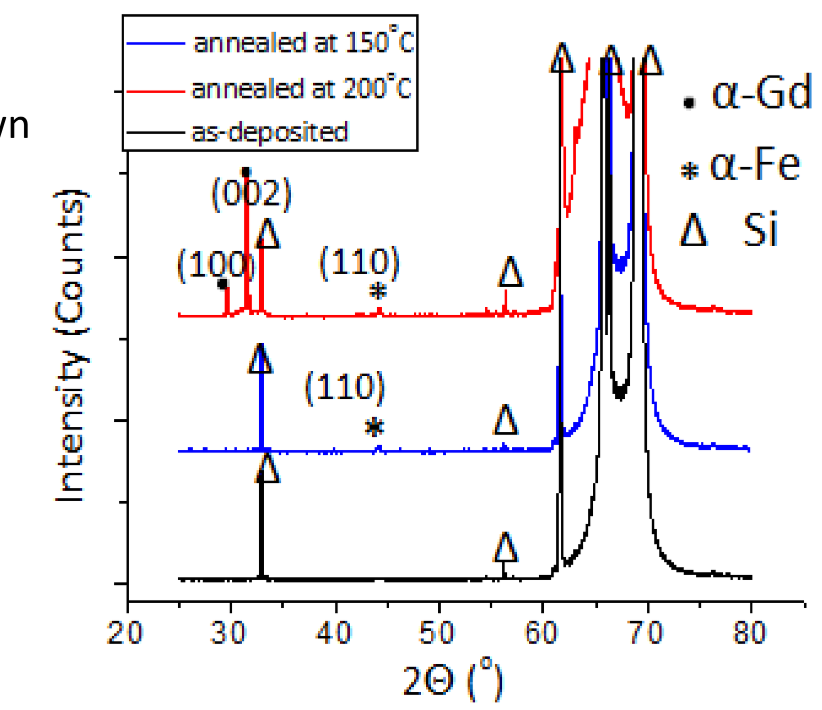


From AFM top views, "column" microstructures exist, which may be the origin of perpendicular anisotropies in two compensation regions.

Thermal stability

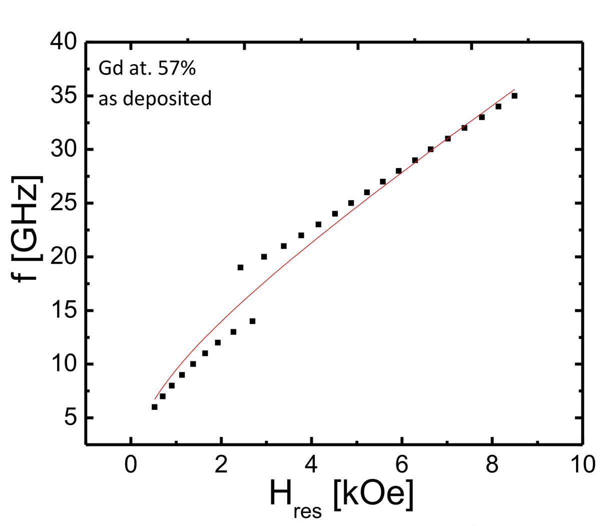
The Crystallization process of GdFeCo alloys can be characterized by a two-reaction stage.
a. α-Fe and α-Gd precipitate near 150°C;
b. Primary crystalline structure forms at ~ 250°C;

GdFeCo grown On Si/SiO2 exhibits amorphous State;



Ferromagnetic Resonance(FMR)

Gd is in the L=0 state. No spin-orbit coupling, Gd alloys are favored to have low damping constant.

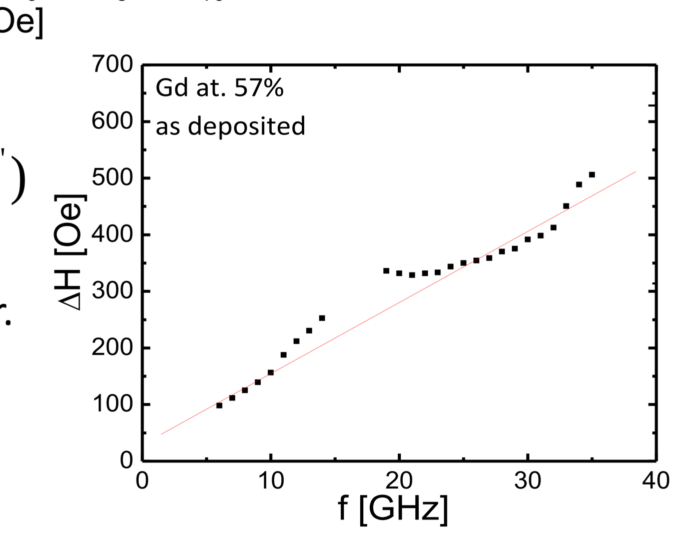


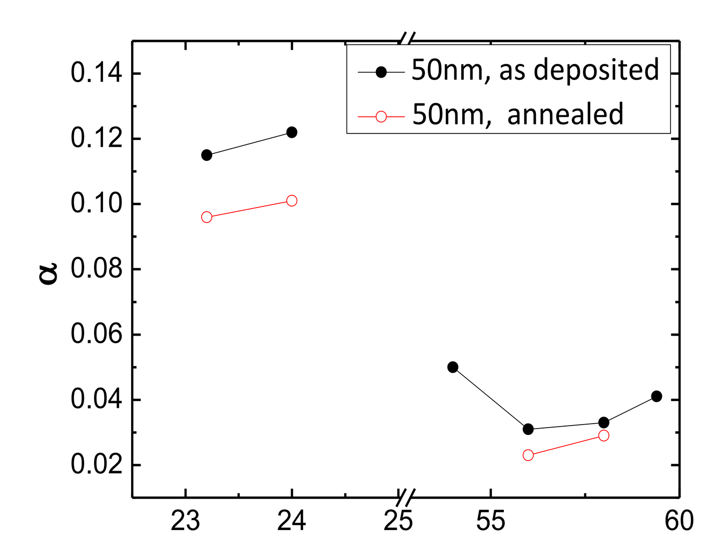
$$f^2 = \gamma'^2 H_{res}(H_{res} + 4\pi M_{eff})$$

where M_{eff} is effective magnetization, ϒ is gyromagnetic ratio.

$$\Delta H_G = 2\alpha f / (\sqrt{3}\gamma')$$

Where α is Gilbert damping parameter.



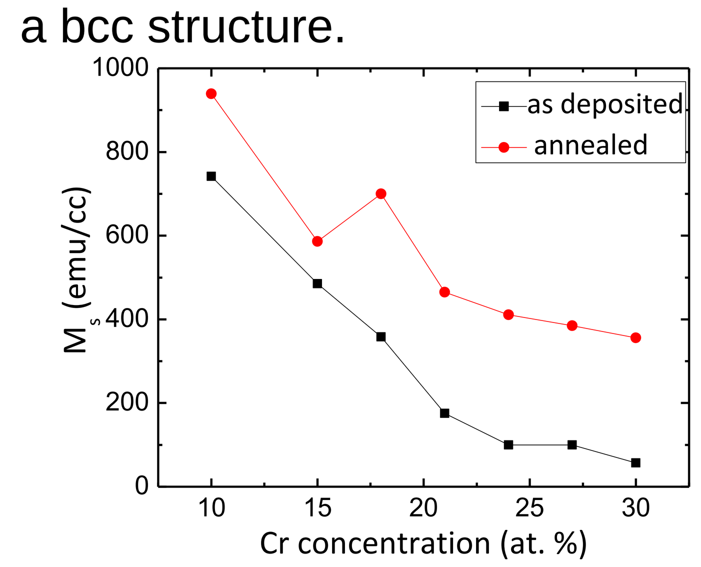


a minimum of α ~ 0.03, which is much lower than that reported earlier.

Easy In-plane material

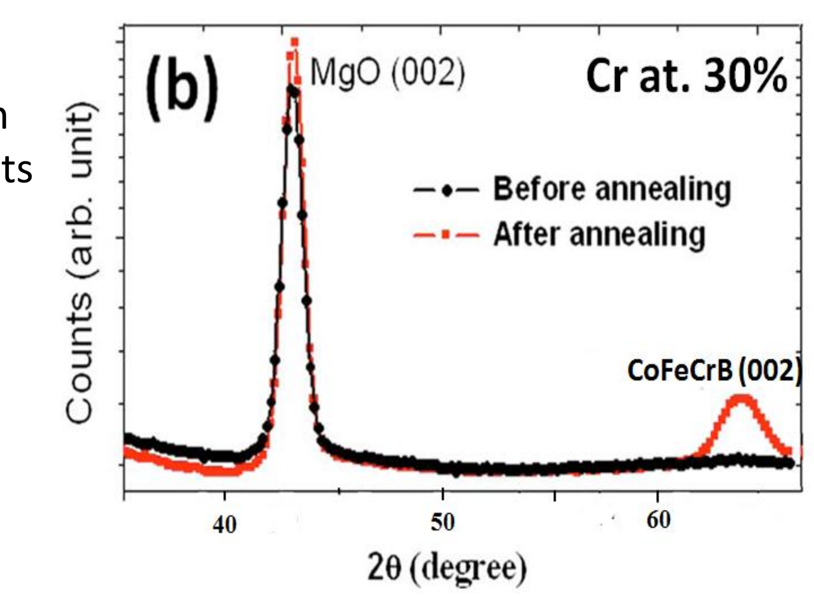
High TMR has been reported with crystalline MgO barrier, which originates from the fact that the electrons in high spin-polarized Δ_1 band in (001) direction of bcc ferromagnetic electrodes (CoFeB generally) can tunnel through the MgO (001) barrier more easily than the electrons in other bands (Δ_2 and Δ_5). TMR refers to the speed of writing/reading data into the memory.

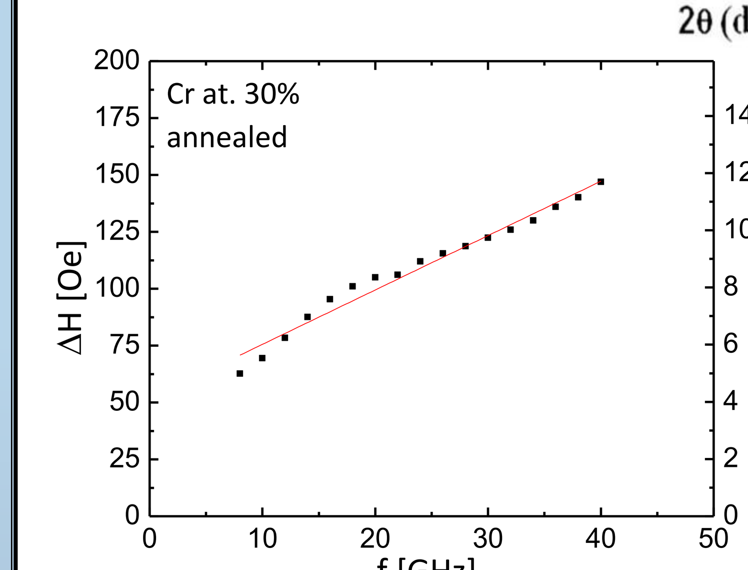
To reduce M_s, we substitute Cr for Co-Fe-B because Cr metal is antiferromagnetic, and exhibits a bcc structure.



CoFeB : M_s ~1000 (emu/cc);
CoFeCrB : M_s ~ 350 (emu/cc);

CoFeCrB grown On MgO exhibits amorphous State, then crystallized into Bcc.





CoFeB : α ~ 0.01;
CoFeCrB: α ~ 0.006;

With the substitution of Cr, the switching current density reduces to ¼ of that in CoFeB films.

ACKNOWLEDGMENTS

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