Perpendicular Magnetic Multilayers for Advanced Memory Application

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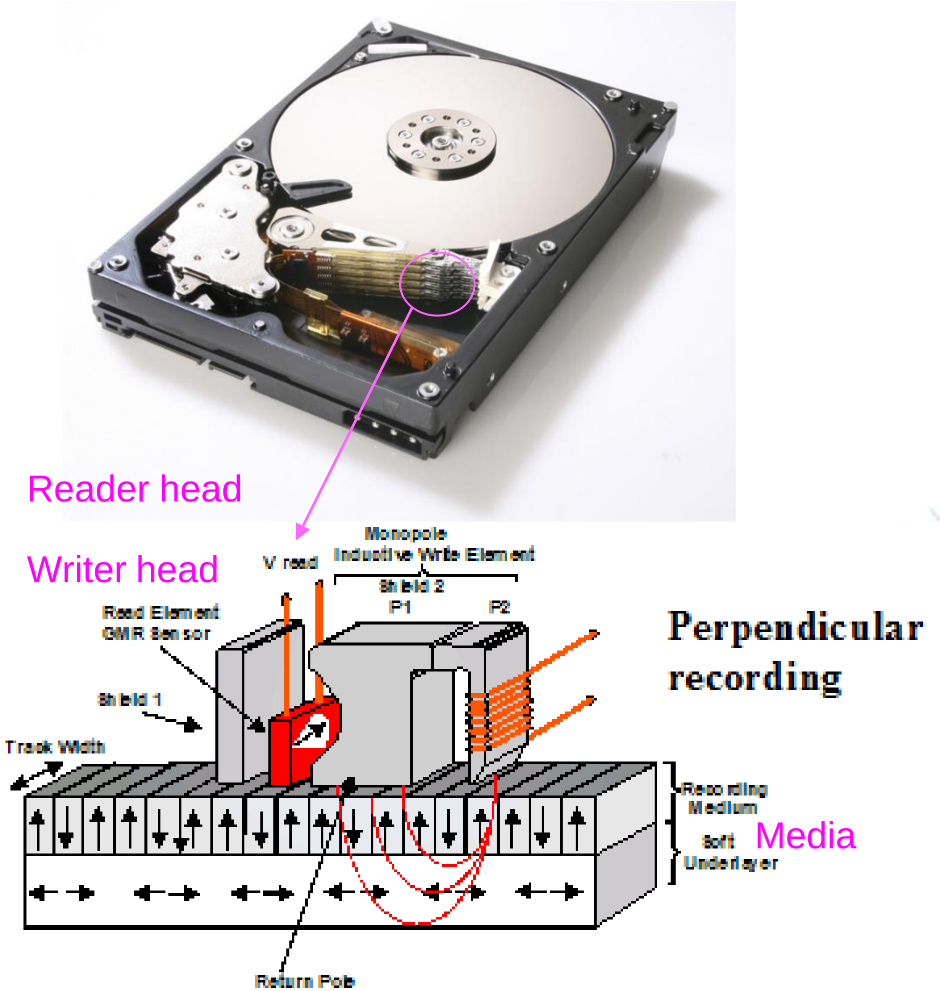
Outline

- **Magnetic thin film and Spintronics**
  - Magnetic thin film is used for data storage and memory applications
  - PMA (Perpendicular magnetic anisotropy) is fundamental building block for memory devices.
- **Tunneling magneto resistance (TMR) for both storage and memory applications**
  - High MR ratio with MgO coherent tunneling is required for both applications
  - Perpendicular magnetic properties of pinned and free layer are also essential for advanced storage/memory
- **High anisotropy PMA pinned layer**
  - [Co/Pt] multilayer
  - [Co/Pt]/Ru/[Co/Pt] SAF structure PMA
  - Thermal Stability
- **Integrated STT-MRAM stack PMA and its performance**

Magnetic thin film for data storage



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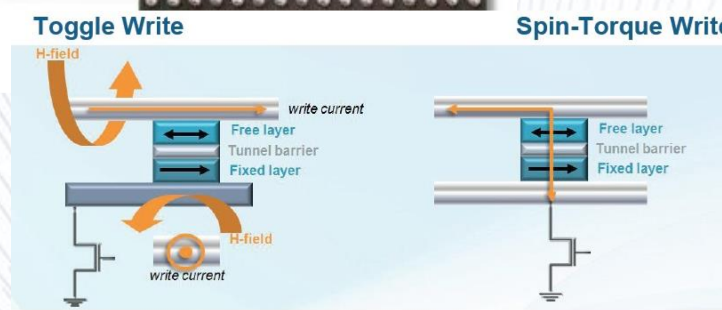
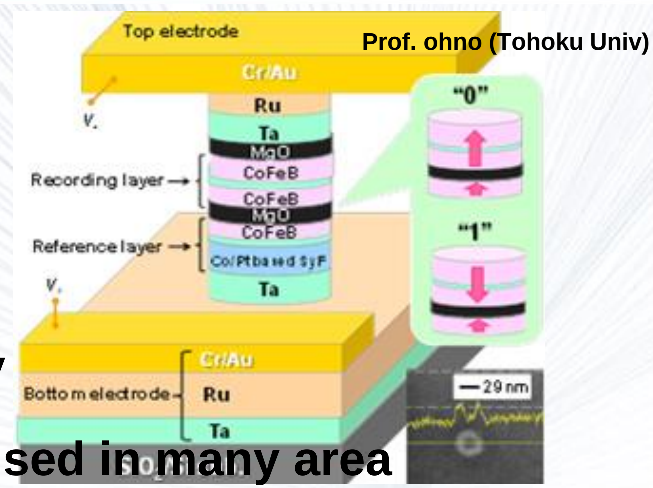
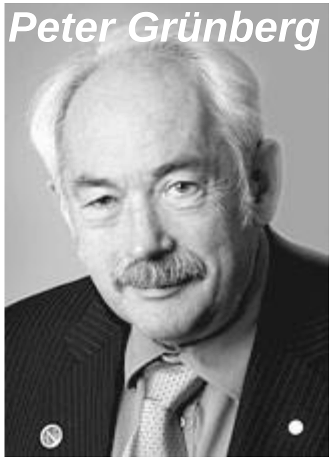
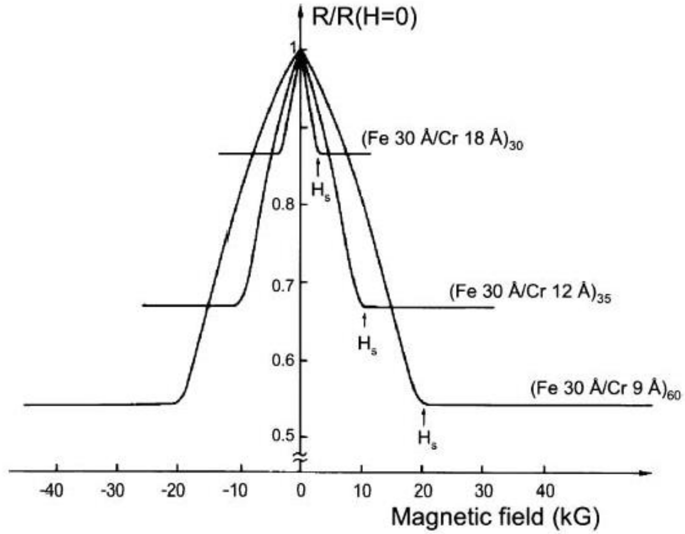




- Magnetic thin film is used for storage industry
- Perpendicular magnetic anisotropy (PMA) is used in many area

Magnetic thin film (GMR) Nobel Prize in Physics 2007

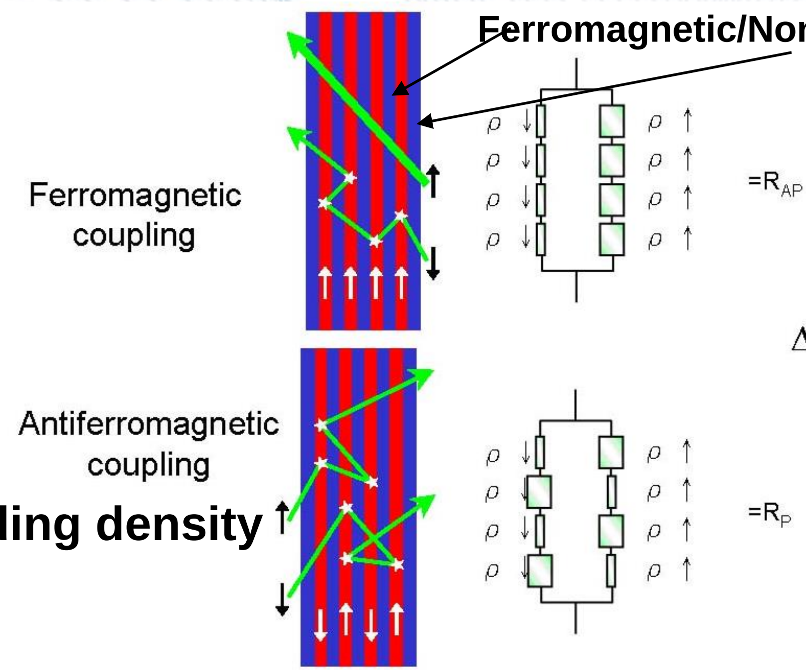




<u>For the discovery of Giant Magneto-Resistance.</u>

Independently discovered by Albert Fert and Peter Grünberg in Fe/Cr multilayers in 1988

- Phys. Rev. Lett. **61**, 2472 (1988)
- Phys. Rev. B **39**, 4828 (1989)

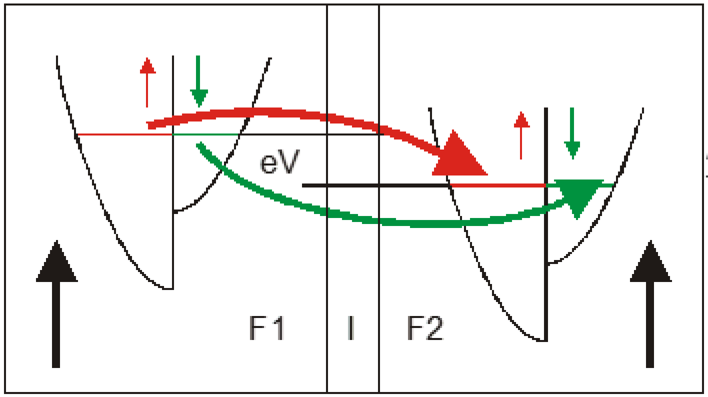


$$\Delta R = \frac{R_{AP} - R_P}{R_P}$$

- ➢ **Remarkable enhancement of recording density**
- ➢ **Spintronices & nanotechnology**

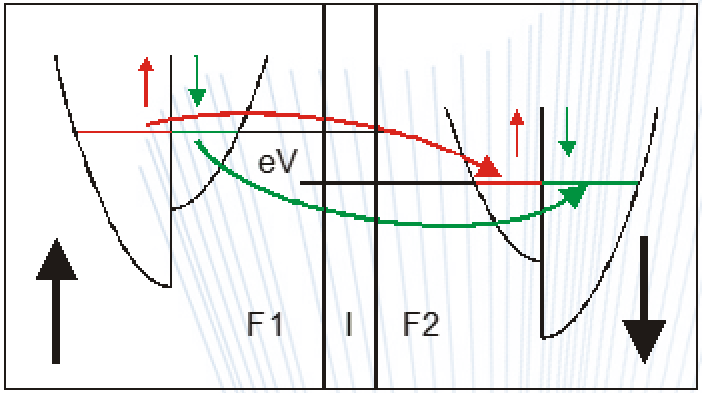
Tunneling Magnetoresistance (TMR)

Low resistance (Parallel state)



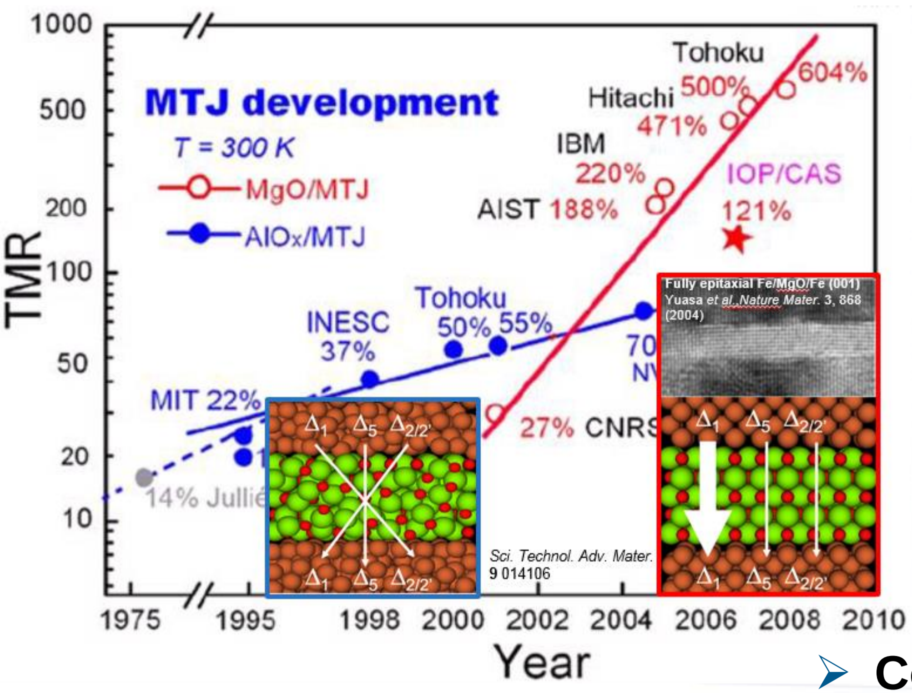
$$TMR = \frac{2P_1P_2}{1-P_1P_2}$$

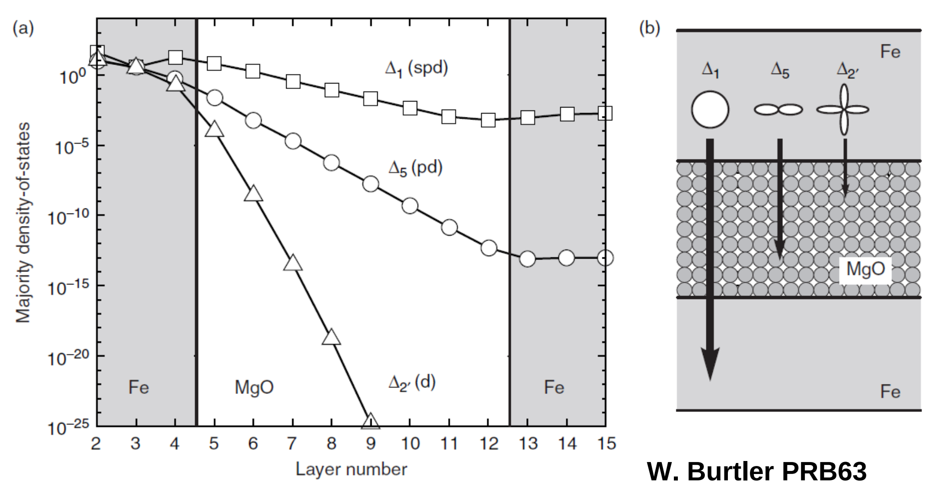
High resistance (Antiparallel state)



P is the polarization, the difference over the sum in up-vs-down electrons at the Fermi Energy

Julliere, Phys. Lett. A 54, 225 (1975)
Moodera et al. Phys. Rev. Lett. 74, 3273 (1995)

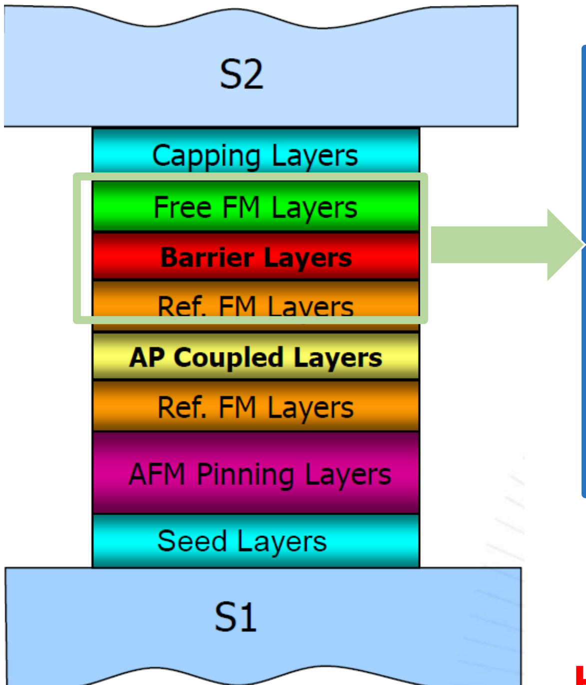




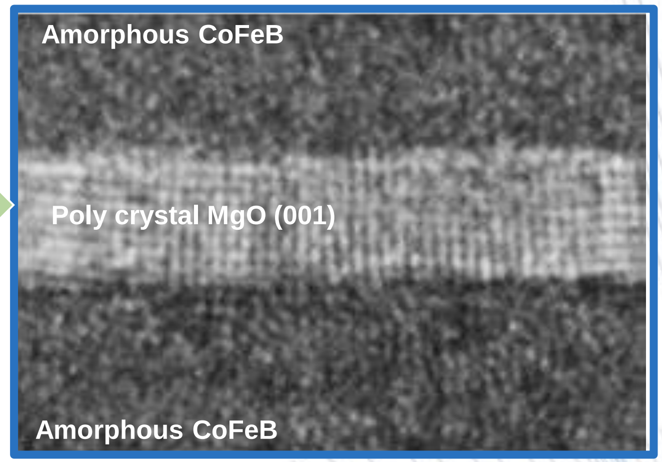
W. Burtler PRB63

- Coherent tunneling with MgO barrier

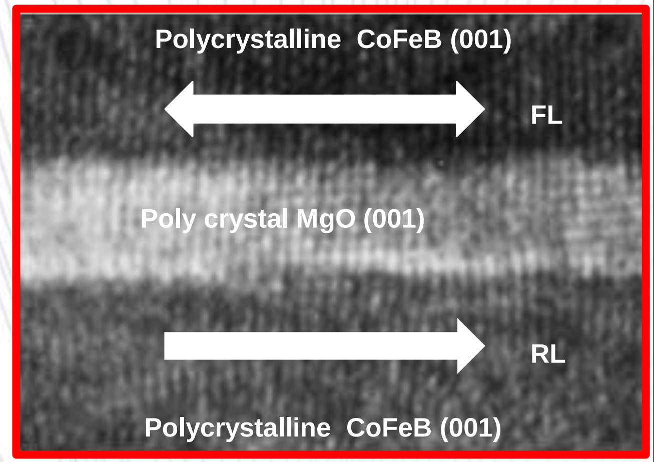
MgO barrier Reader sensor with CoFeB/MgO/CoFeB



Pre-anneal



Post-anneal



APL 86, 092502 (2005)

Anelva & AIST

<u>High signal can be achieved from</u>

Highly spin polarized magnetic interfaces

Spin-filter effects in tunnel barrier

- **1100% (4.2K) TMR at CoFeB/MgO/CoFeB MTJ**

Perpendicular TMR with CoFeB/MgO interface

nature materials LETTERS
PUBLISHED ONLINE: 11 JULY 2010 | DOI: 10.1038/NMAT2804

A perpendicular-anisotropy CoFeB–MgO magnetic tunnel junction

S. Ikeda[1,2]★, K. Miura[1,2,3], H. Yamamoto[1,2,3], K. Mizunuma[2], H. D. Gan[1], M. Endo[2], S. Kanai[2], J. Hayakawa[3], F. Matsukura[1,2] and H. Ohno[1,2]★

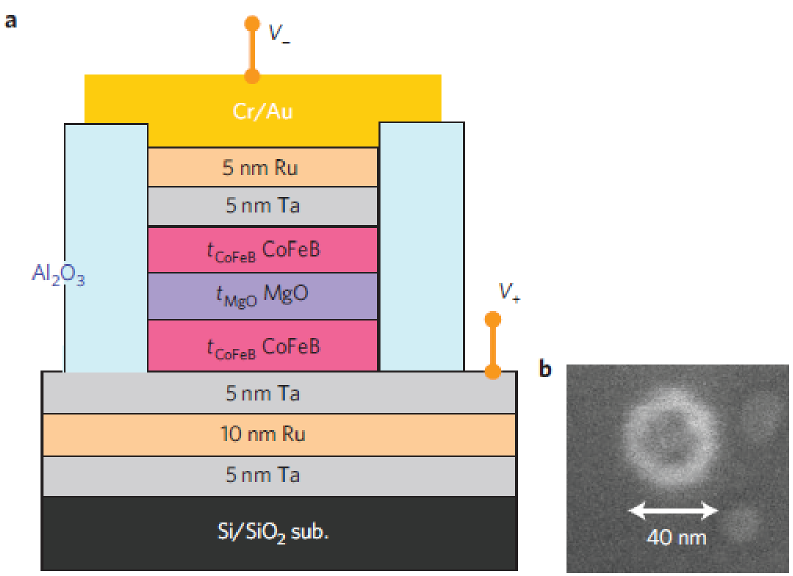


Figure 1 | MTJ structure. a, Schematic of an MTJ device for TMR and CIMS measurements. **b**, Top view of an MTJ pillar taken by scanning electron microscope.

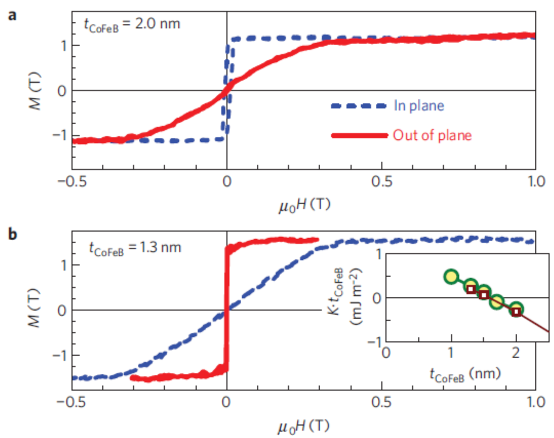
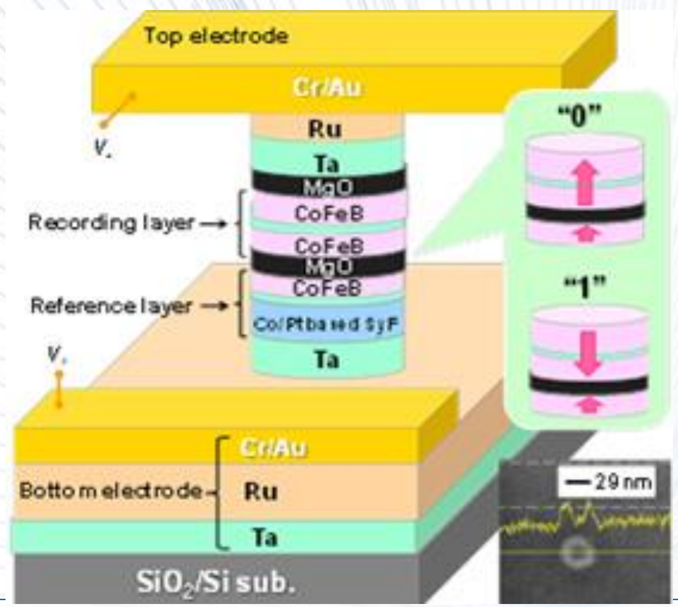


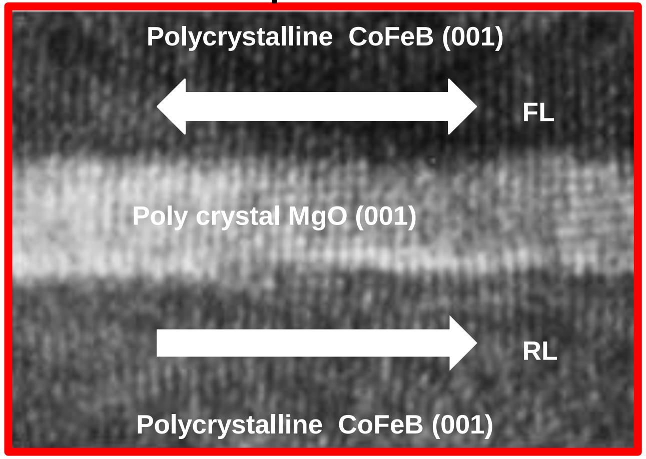
Figure 2 | In-plane and out-of-plane magnetization curves for CoFeB/MgO. a, t_{CoFeB} = 2.0 nm. **b**, t_{CoFeB} = 1.3 nm. Inset: t_{CoFeB} dependence of the product of K and t_{CoFeB}, where the intercept to the vertical axis and the slope of the linear extrapolation of the data correspond to K_i and $K_b - M_S^2/2\mu_0$. Circles and squares are obtained from magnetization and FMR measurements, respectively.



(Prof Ohno, Tohoku Univ)

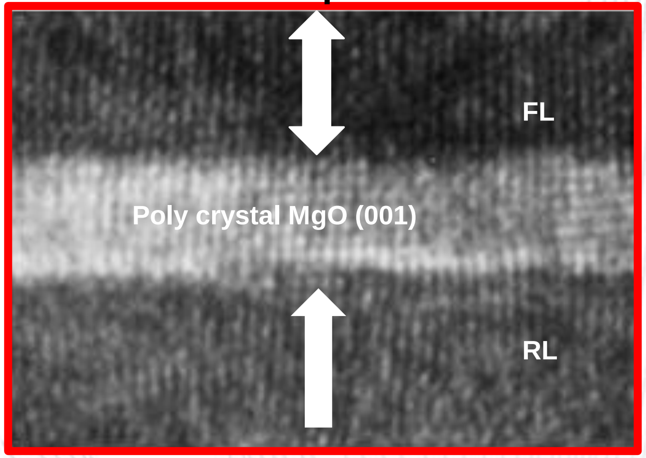
Perpen magnetization anisotropy (PMA)-material

In-plane



How to make?

Out of-plane



Perpendicularly magnetized films

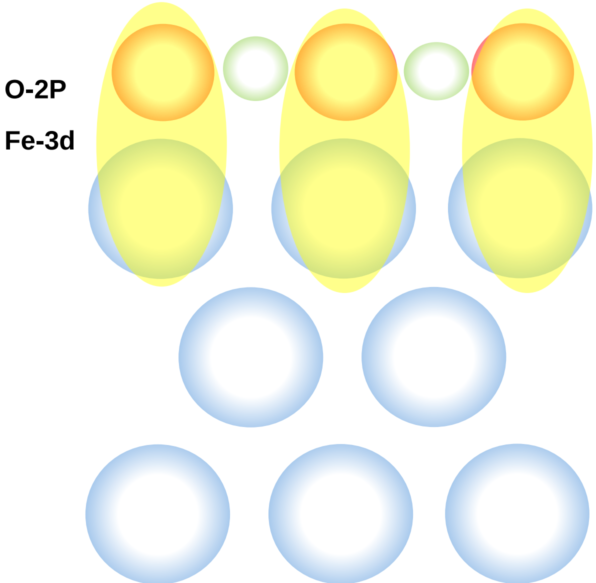
- ➢*L*1_0 ordered alloy films such as FePt, FePd, _Require high Tem deposition (Bulk PMA_high damping & poor band/lattice matching with MgO)
- ➢RE-TM amorphous alloy films such as TbFeCo (Thermally not stable at high Tem >200C)
- ➢Metallic mutlilayers or ultrathin films such as **Ni/Co**, **Co/Pt, CoFeB/MgO**, (Interface PMA)

Perpendicularly magnetized films property

- ➢ High Magnetic anisotropy (high Hk) → Thermally stable
- ➢ Negative shape anisotropy → Easy magnetization switching

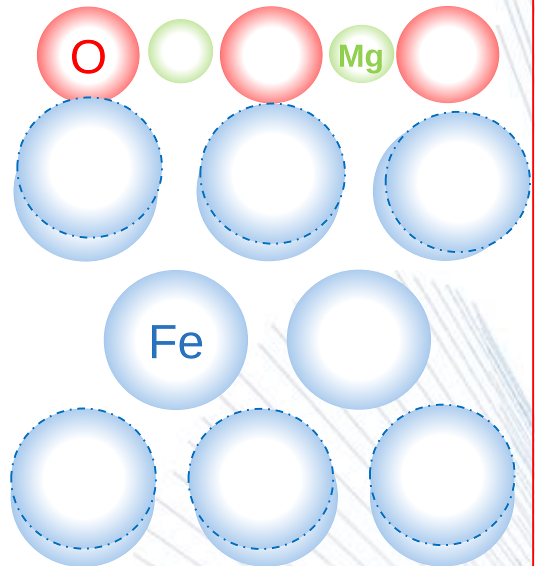
Interfacial Perpendicular anisotropy (i-PMA)

(A)



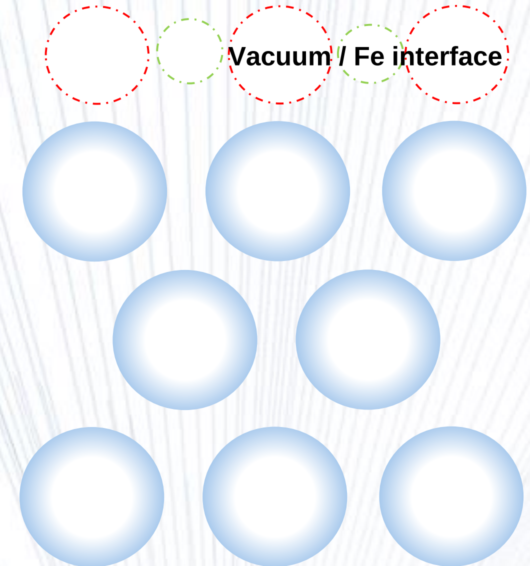
- Fe-O hybridization of atomic orbital

(B)



- Elastic stress due to lattice distortion

(C)



- Interface asymmetry due to Crystal symmetry breaking

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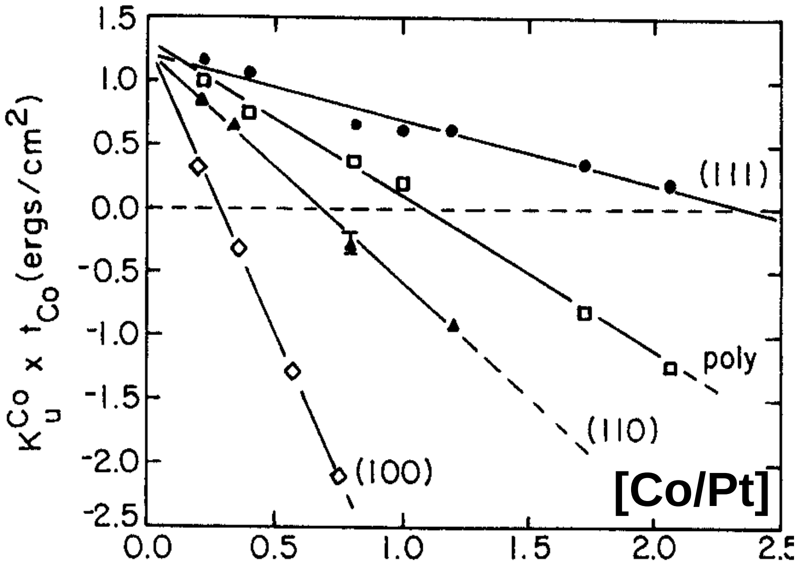
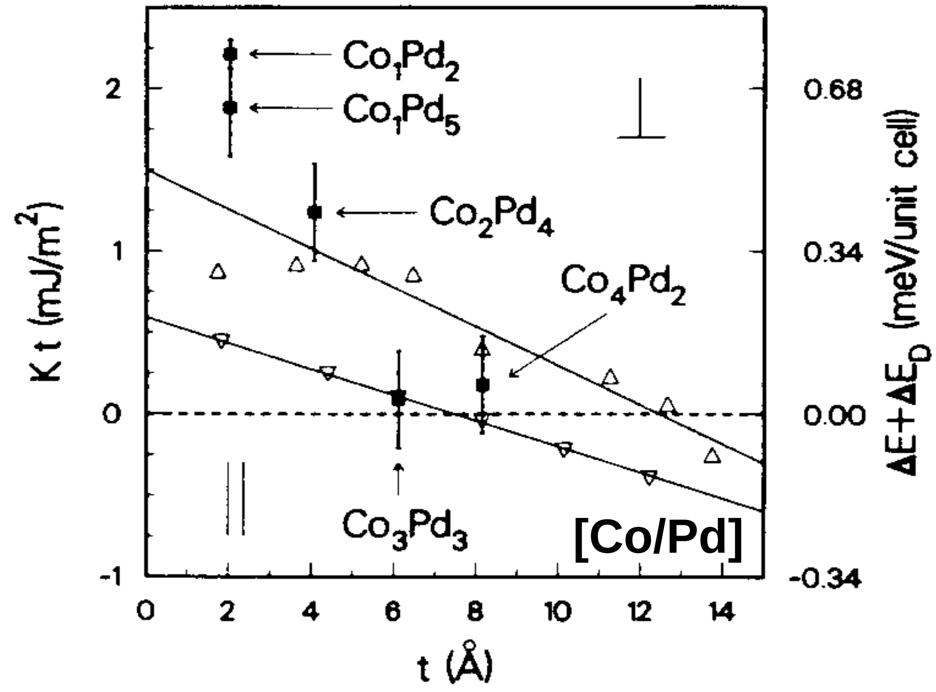
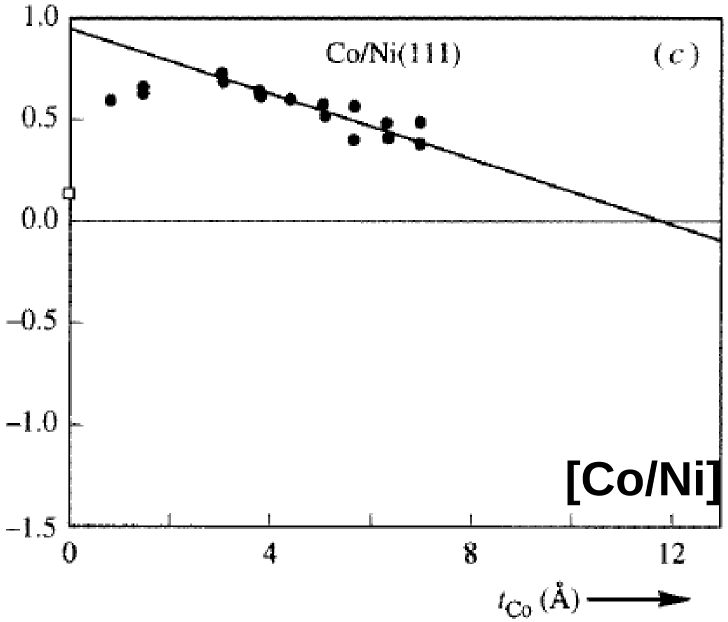
Interface Perpendicular anisotropy system







- [Co/Ni], [Co/Pd], [Co/Pt] from many papers
- Interface driven perpendicular system

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Perpendicular Multilayers

Co/Pt Perpendicular Multilayers

Struc	Thk(A)	Repeat
Ta	40	1
Pt	Y	N
Co	X	
Pt	20	1
Ta	20	1

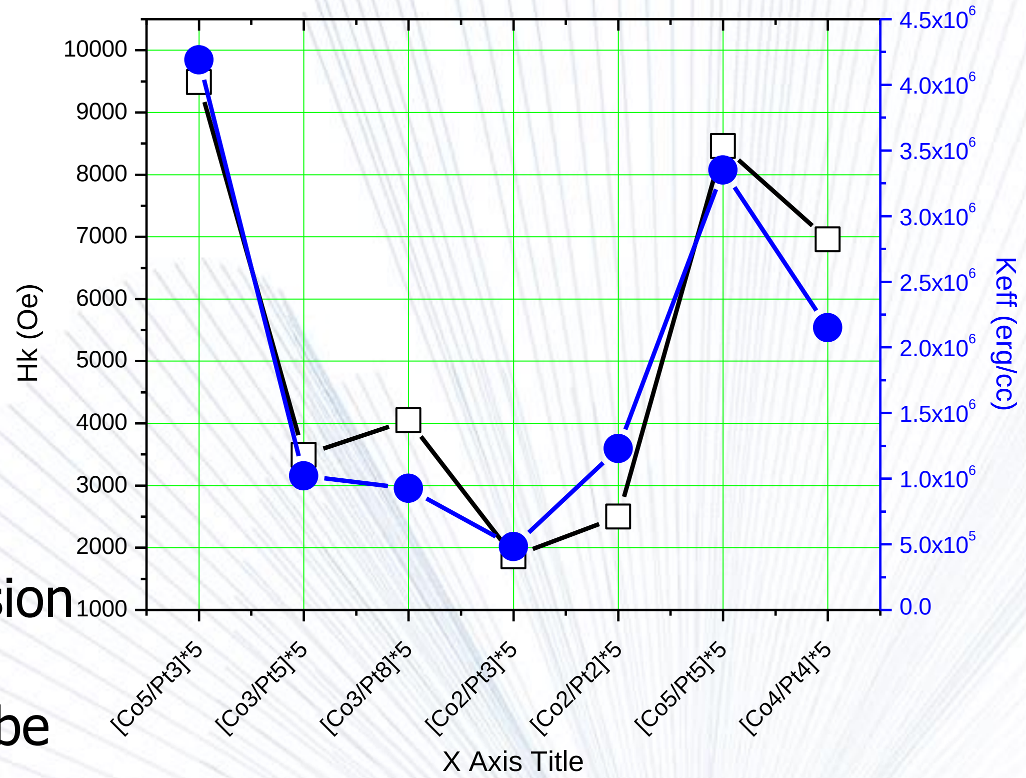
- Strain-induced PMA at the interface-[Co/Pt] system
- Alloying Pt atom become polarized by Co atom in their vicinity
- Keff (erg/cc) was calculated to evaluate PMA
- Optimized x, y, N is crucial for narrow switching distribution
- If Co too thin→superpara, too thick→in-plane or multi-domain thus, optimization of Co thickness is needed.

$$K_{eff}(erg/cc) = \frac{H_k M}{2}$$

Perpendicular Multilayers

Co/Pt Perpendicular Multilayers

- Pt/Co Interface- Source of PMA
- Co/Pt - Flat Interface and Uniform Coverage
- Hk Determined by Co & Pt Ratio
- Thicker Co Buffer Prevent Pt Diffusion
- If Pt is too thin, then Co cannot be separated



Perpendicular Multilayers

PRB 71, 224403 (2005)

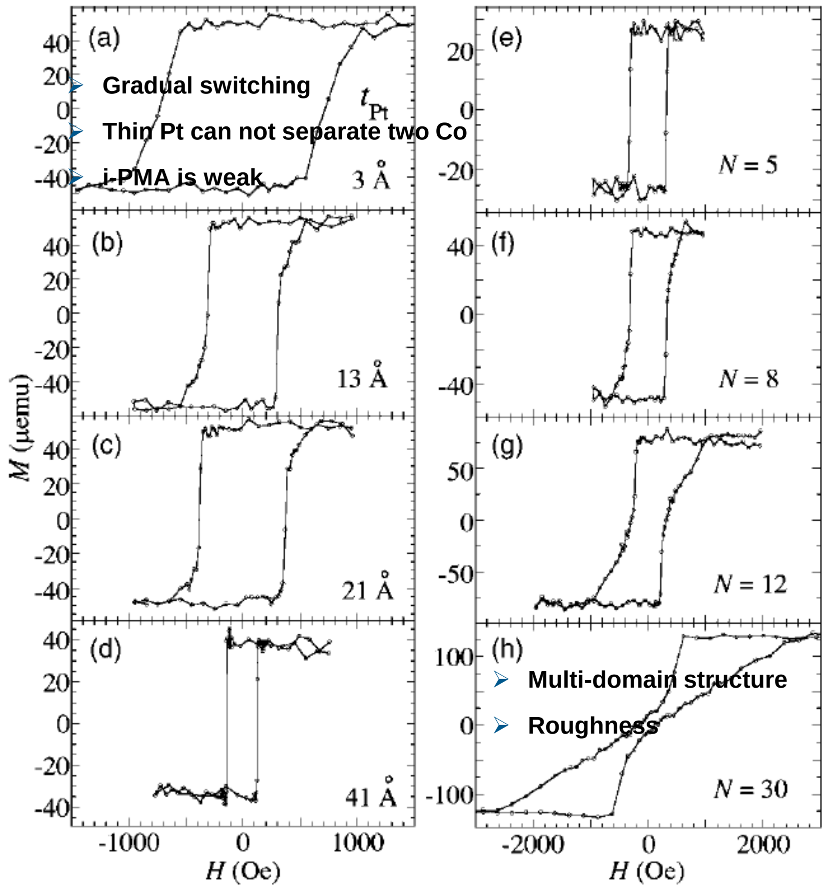


FIG. 1. Room temperature hysteresis loops of [Co(4 Å)/Pt(t_{Pt})]$_8$ multilayers with Pt layer thicknesses (t_{Pt}) of (a) 3 Å, (b) 13 Å, (c) 21 Å, (d) 41 Å, and of [Co(4 Å)/Pt(11 Å)]$_N$ multilayers with (e) N=5, (f) N=8, (g) N=12, and (h) N=30.

JAP 103, 07A917 (2008)

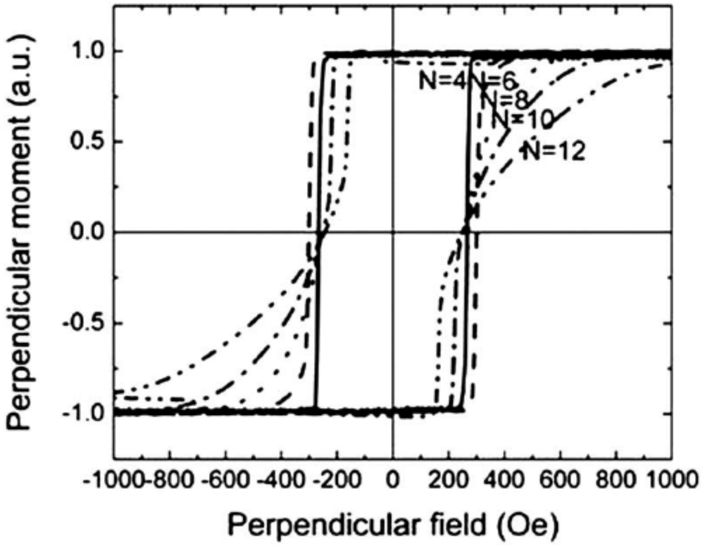
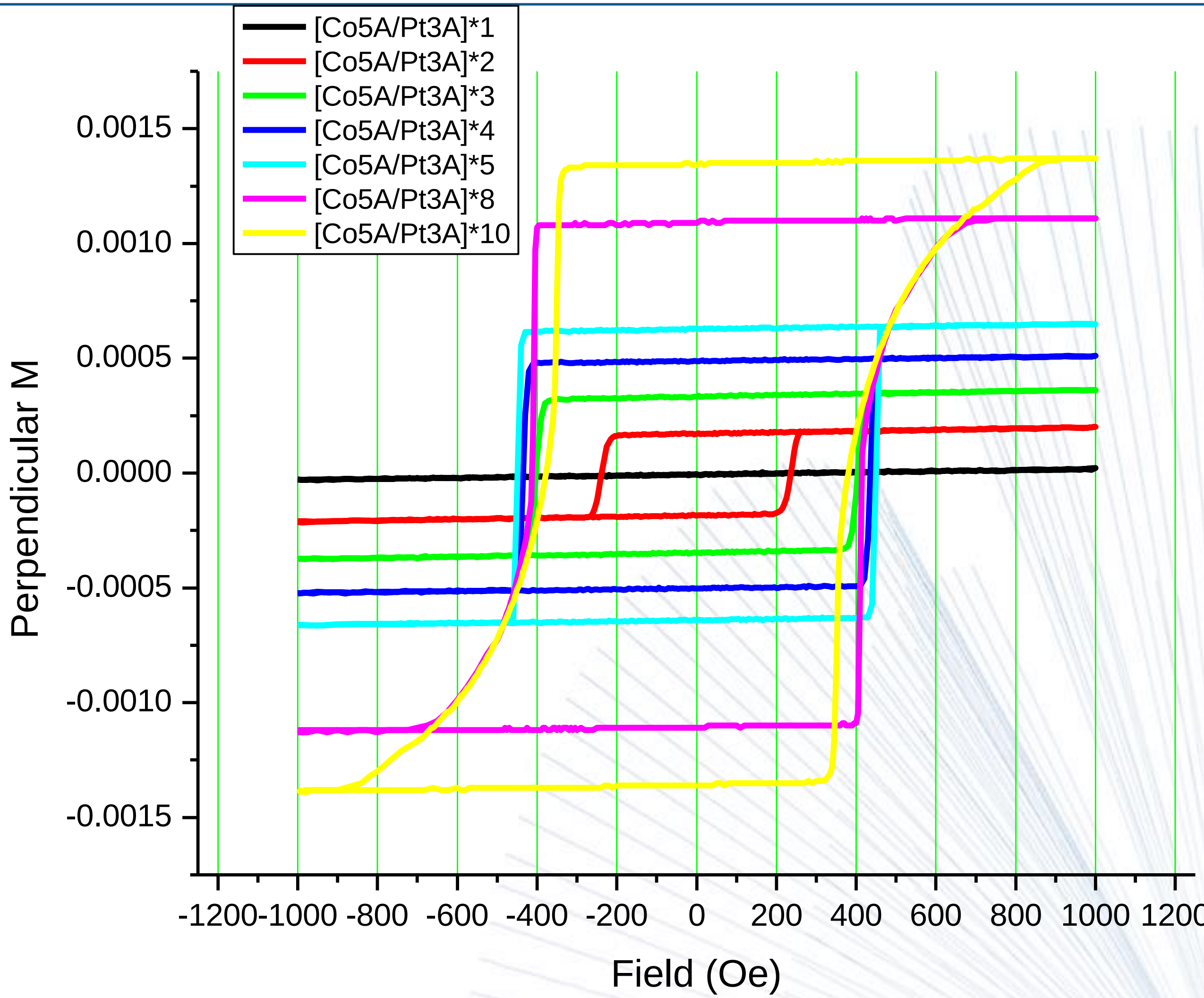


FIG. 3. Perpendicular hysteresis loops of Co/Pt multilayer films with different numbers of repeats, N at the film stack of Si/Ta 30 Å/Pt 50 Å/(Co 6 Å/Pt 18 Å)×N/Pt 32 Å.

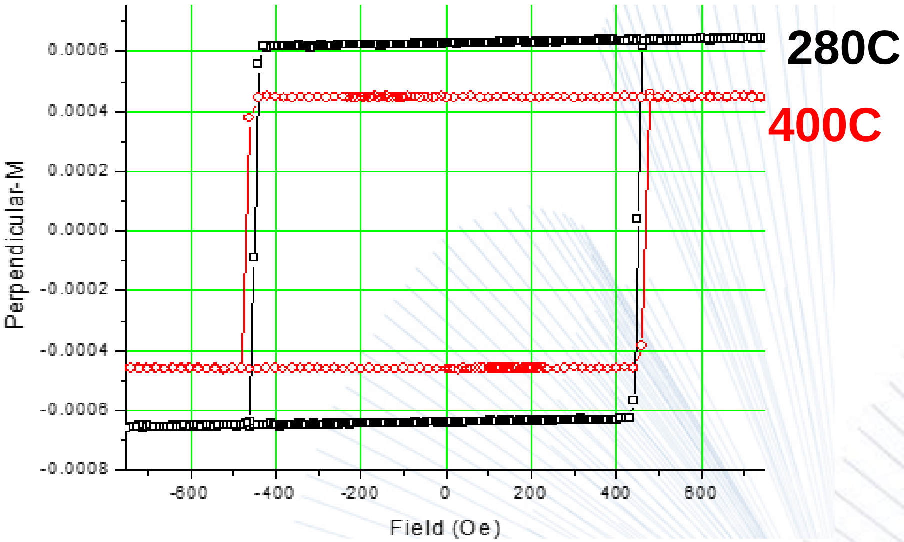
- **As N increases, Hc increases with rectangular shape**
- **And then Hc decreases with unfavorable shearing of loop**
  - ✓ **Increase of roughness can be a reason?**

Perpendicular Multilayers

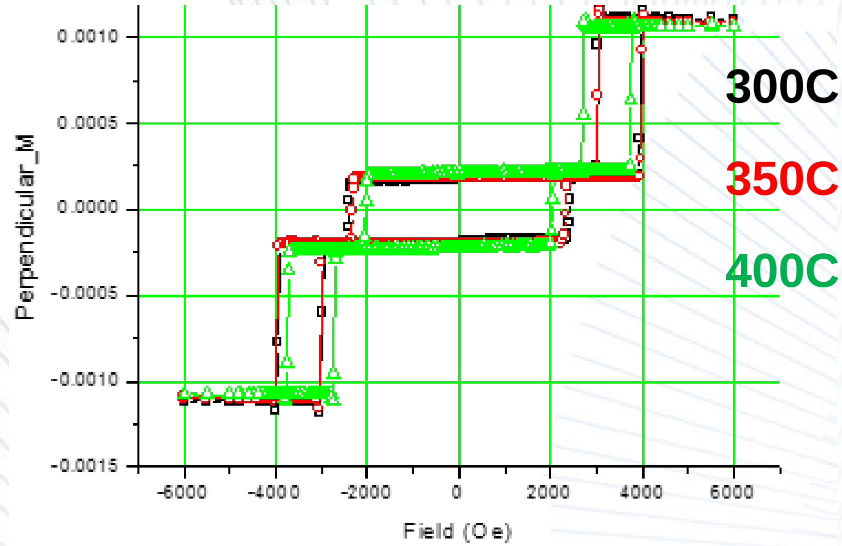


➢Hc Increases with Repeat and Saturate.
If N Larger than 8, Multi-Domain Behavior

Perpendicular Multilayers



Co/Pt Multilayer Hc Stable to 400C



(Co/Pt) SAF Structure Stable upto 400C

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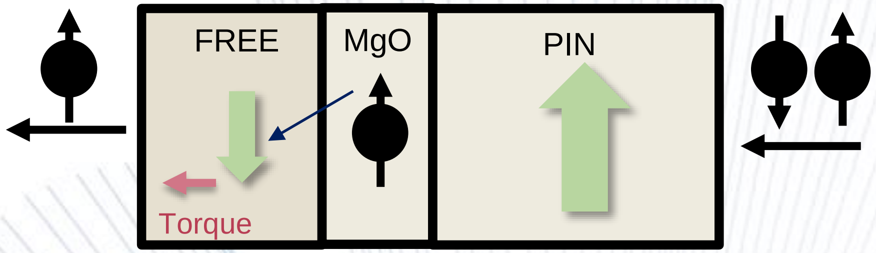
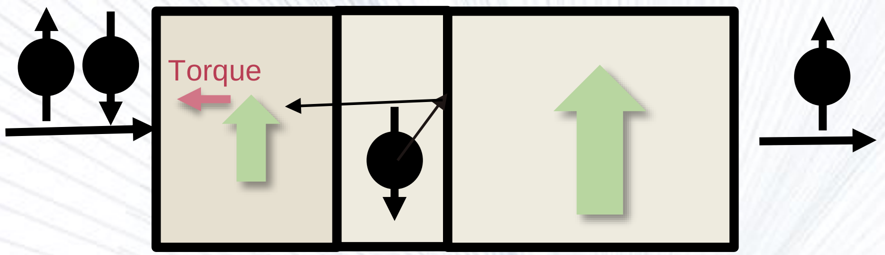
Spin torque Switching for PMA TMR Stack

- Bottom Pin MTJ with CoFeB Electrode
- SAF Co/Pt High Hc Pinned Layer Stray Field Balancing
- PMA Free Layer Maximized with double MgO capping
- STT-Magnetization reversal by switching current

a) STT-switching R(AP)→R(P)

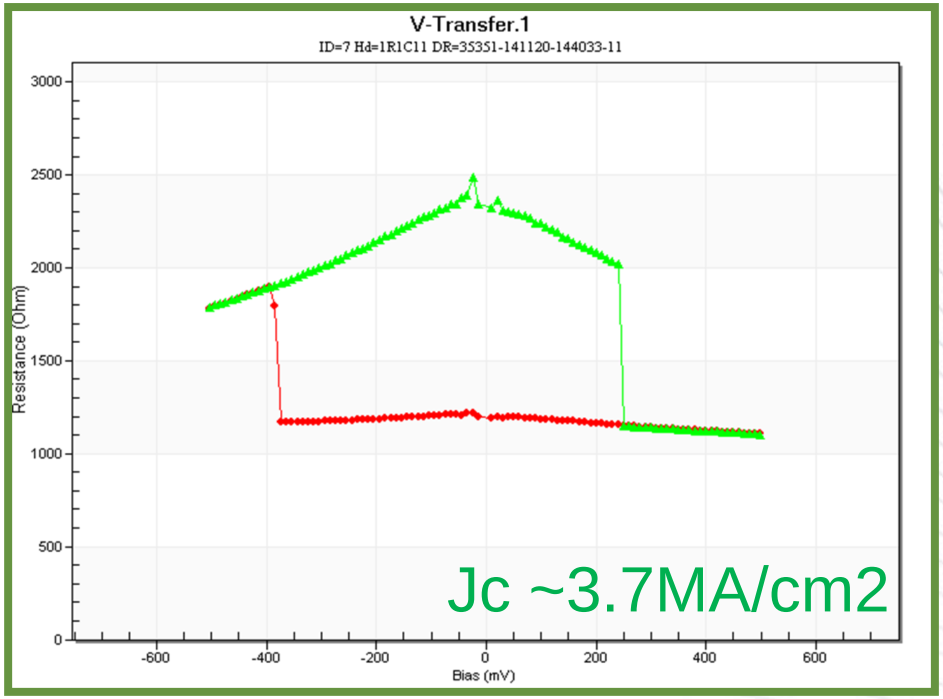


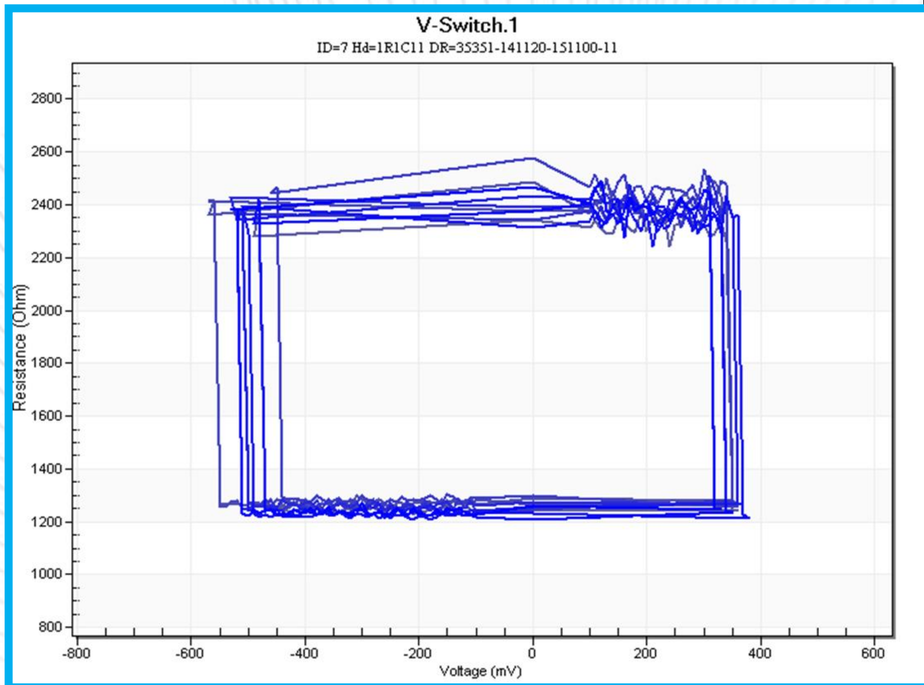
b) STT-switching R(P)→R(AP)



PMA TMR Stack and Spin Torque Switching

- **Successfully Demonstrate PMA Spin Torque Switching**
- **Repeatable Switching is Demonstrated**





Summary

Demonstrated Robust pMA TMR Pinned Layer Magnetic Properties Stable Upto 400C

Demonstrated Repeatable Switching by voltage

Thank You