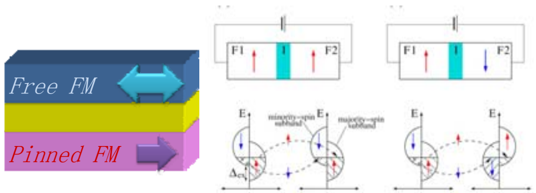
Material Development for Magnetic tunnel junctions in Spin Transfer Torque Random Access Memory (STT-RAM)

Yishen Cui[1], Manli Ding[1], Wei Chen[1], Nam Dao[2], Jiwei Lu[2], Joseph Poon[1], Stuart A. Wolf[1,2]
[1]Department of Physics, University of Virginia
[2] Materials Science & Engineering, University of Virginia

Background:

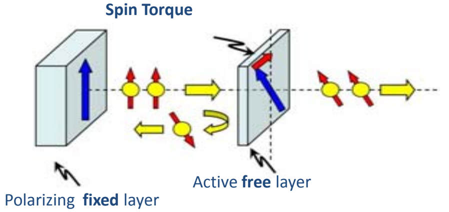
Magnetic Tunnel Junction (MTJ)



[Zutic, et al., RMP. **76**, 323 (2004)]

Low resistance High resistance

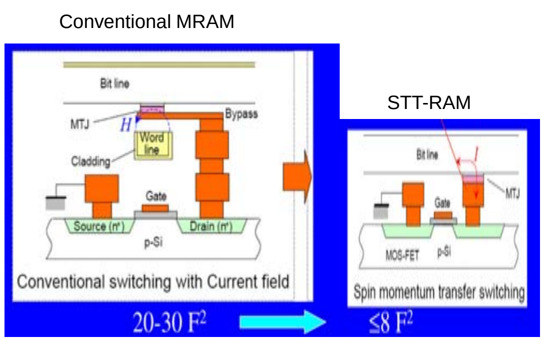
Spin Transfer Torque



[J.C. Slonczewski J. Magn. Magn Mater. **159** L1 (1996)]

- While going through the FM fixed layer, electron spins are polarized towards the layer magnetization by *s-d* exchange interaction.
- Spin transfer torque appears in ultra thin free layer, originated from the Momentum Conservation Law.

Advantages of STT-RAM



• Excellent write selectivity • Simpler Architecture • Highly scalable

Challenges

- **To reduce critical current density, the threshold for free layer switching;**
- **To maintain a high thermal stability.**

In-plane Anisotropy Material--CoFeCrB

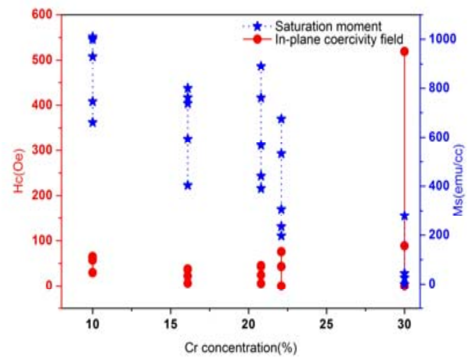
Critical current density (in-plane case)—

$$J_c = \frac{2e\alpha M_s t_F \left(H + H_K + 2\pi M_s\right)}{\hbar\eta}$$

Advantages of CoFeCrB:

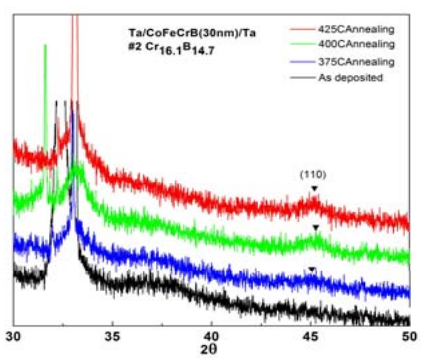
- Low saturation moment M_s to keep a low critical current density;
- High coercivity field to retain a high thermal stability;
- BCC structure leading to high spin polarization efficiency when integrated in MgO-based MTJ.

Magnetic properties:



- Reduced Ms with high Cr content → possibly due to a weaker FM or even AF coupling effect between Cr and Co, Fe;
- Increased Hc → higher Cr addition might cause more lattice distortion or larger crystallized grain size.

Structural properties(BCC)

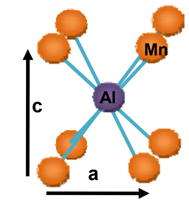


Perpendicular Magnetic Anisotropy (PMA) Material-- MnAl

Critical current density (perpendicular case)— $J_c \sim (H + H_K - 2\pi M_s)$

Advantages of P-MTJ

→ Smaller J_c with perpendicular STT
→ Higher packing density (no elongated cell shape needed)

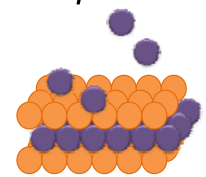


Magnetic τ phase MnAl

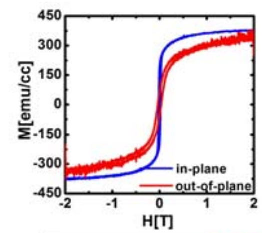
- Only strong magnetic phase: metastable τ phase ($L1_0$);
- High saturation moment & uniaxial anisotropy.

A novel way to preserve the chemical ordering and build MnAl τ phase..

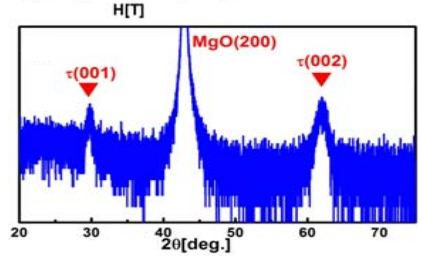
- Alternating Al/Mn quasi-monolayer deposition;
- Template effect from MgO(100) lattice;
- Bias Target Ion Beam Deposition (Low Energy Source).



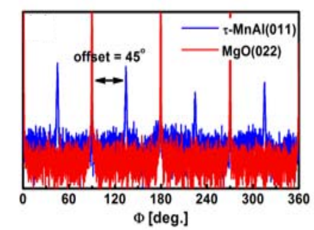
Magnetic & Structure Properties-[Al/Mn(5.7Å)]$_{18}$ (~10nm)

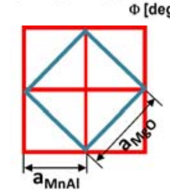


- ❖ High Magnetization close to bulk value!
- ❖ Anisotropy mainly in-plane.



Close lattice match with MgO(100):



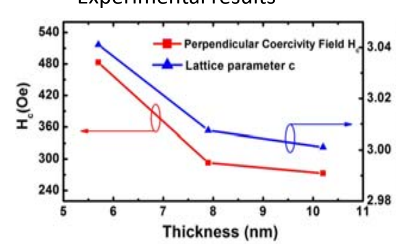


$a_{MgO}/\sqrt{2}$=2.97 Å

a_{MnAl}=3.02Å (also denoted as ã)

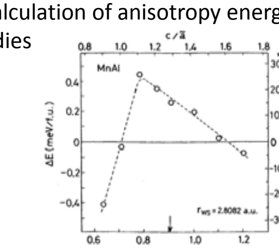
PMA variation with thickness -[Al/Mn(5.7Å)]$_N$,N=10,14,18

- Experimental results



❖ structure close B2 cubic (c/ã~1);
❖ c/ã increases with thickness reduces.

- Calculation of anisotropy energy in previous studies



[A. Sakuma, Journal of the Physical Society of Japan, **63**, 1422(1994)]

❖ PMA disappears when c/ã decreases below 1.