Spin Transfer Torque Reversal in Perpendicular Anisotropy Spin Valves

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NSF Award # DMR-1008654

CMRR Research Review, May 4-5, 2011

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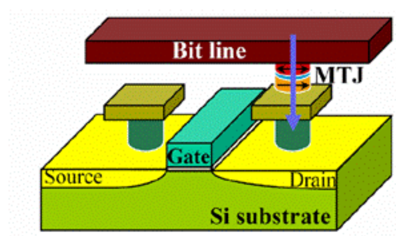
STT-MRAM



- Spin Valves as Memory Elements
- Promising technology for implementing high-density memory in CMOS logic circuits
  - High Density (compared to SRAM, embedded DRAM)
  - Compatible with CMOS logic process
  - Low Power Consumption (no quiescent power)
- **Replace SRAM, DRAM, Flash**

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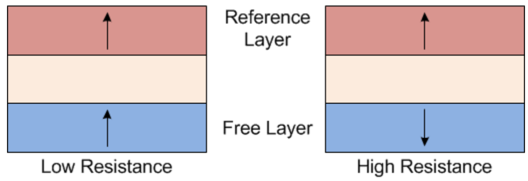
Overview of PMA



Orientation an Analog for Logic Value

- Advantage of PMA materials for STT-MRAM

$$I_{C0} = \left(\frac{2e}{\hbar}\right) \frac{2\alpha}{\eta(\theta)p} E_B$$

- **Scaling** to small size (reducing V) introduces problems due to increasing J_C
  - Also J for driving transistor

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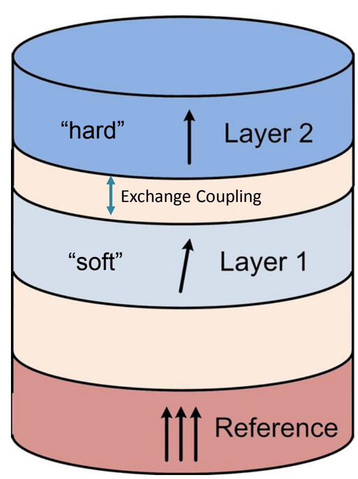
Summary of Work

- Reduce I_C for a given E_B in a device
  - Use bi-layer hard/soft FM coupled structure as free element
- Computational / analytical (simulation based) approach to this problem



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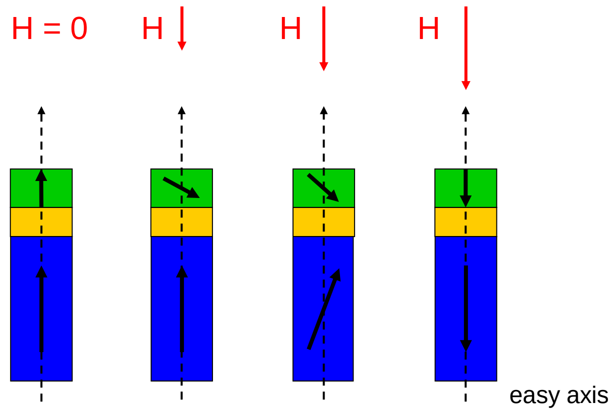
Similar, Existing Problem

H_c reduction in switching of magnetic media



Incoherent reversal lowers the coercive field faster than the energy barrier

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Approach

1. Development of macrospin simulator program "Spinsim GSL"
   - Public/Free, soon to be published on CMRR site
2. Use program to explore parameter space; find reduction in I_C (in I / J_{exch} parameter space)
3. Compare result with 'reference model', consisting of a single free layer with similar E_B
4. Gain understanding of underlying physics governing the results

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Macrospin Simulation

- Integration of LLG equation to resolve macrospin behavior

$$\frac{\delta \boldsymbol{m}}{\delta t} = -\gamma \boldsymbol{m} \times \boldsymbol{H}_{eff} - \alpha \boldsymbol{m} \times \frac{\delta \boldsymbol{m}}{\delta t} + \frac{\gamma}{\mu_0 M_S} \boldsymbol{N}$$

Effective field composed of

1. Anisotropy field
2. Self demagnetizing field
3. Mutual dipolar field
4. Effective field due to FM coupling

Spin Transfer Torque term:

$$\boldsymbol{N}_{st} = \eta(\theta) \frac{\hbar}{2e} \frac{J}{d} \boldsymbol{m} \times [\boldsymbol{m} \times \boldsymbol{M}]$$

M = fixed layer magnetization

$\eta(\theta)$ = STT efficiency [next slide]

LLG eqn. modified for STT - J.C. Slonczewski MMM 159 (1996); N. Smith cond-mat/0406486
STT term – Xiao, Zangwill, M.D. Stiles PRB 72,014446 (2005)

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STT Efficiency Functions

- For metallic junctions, using Symmetric Slonczewski Approx[1,2]

$$\eta(\theta) = \frac{q}{A + B cos(\theta)}$$

- For tunnel junction, using sin() approximation[3]

$$\eta(\theta) = \eta_0$$

(1) J.C. Slonczewski MMM 159, L1 (1996)
(2) J.C. Slonczewski MMM 247, 324 (2002)
(3) J.C. Slonczewski, J.Z. Sun, MMM 310, 2 (2007)

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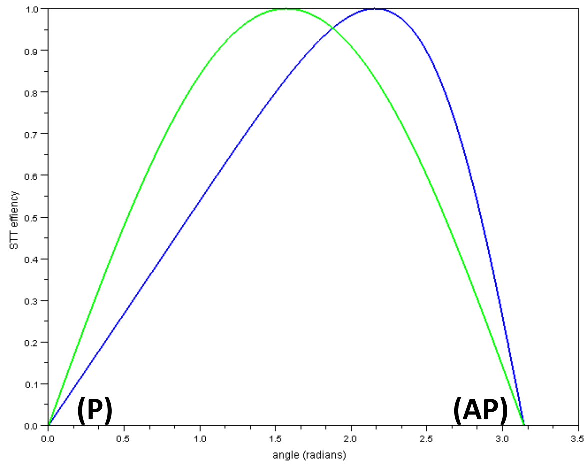
STT Efficiency Functions (2)



BLUE – Symmetric Slonczewski
GREEN – MTJ Approx.

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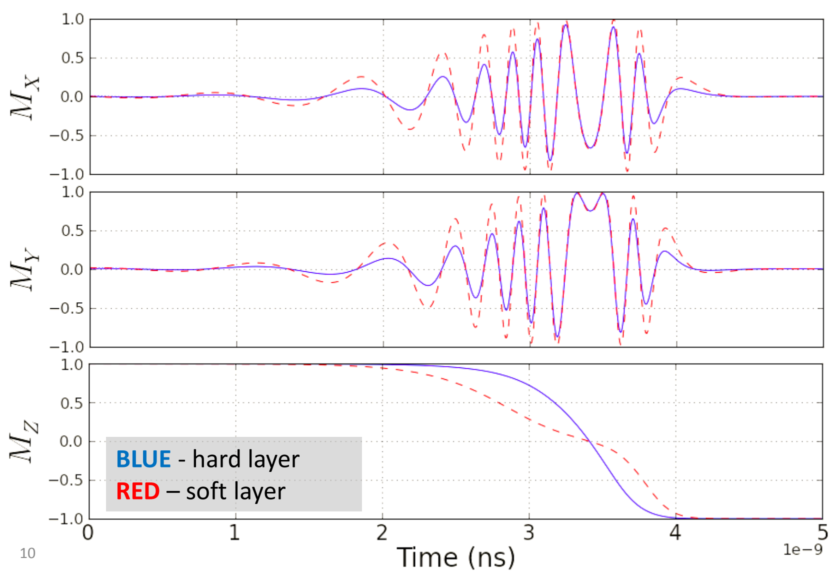
Incoherent Reversal



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Results

- **Significant reduction** in I_C when compared with reference model having similar E_B
- Greater benefit (for worst case) when considering switching at **short timescales**

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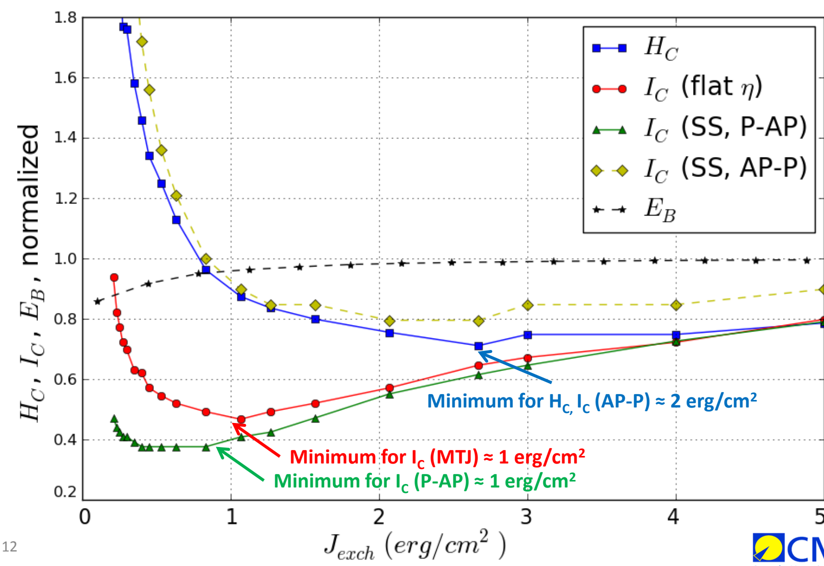
Effect of Coupling on I_{C0}, E_B



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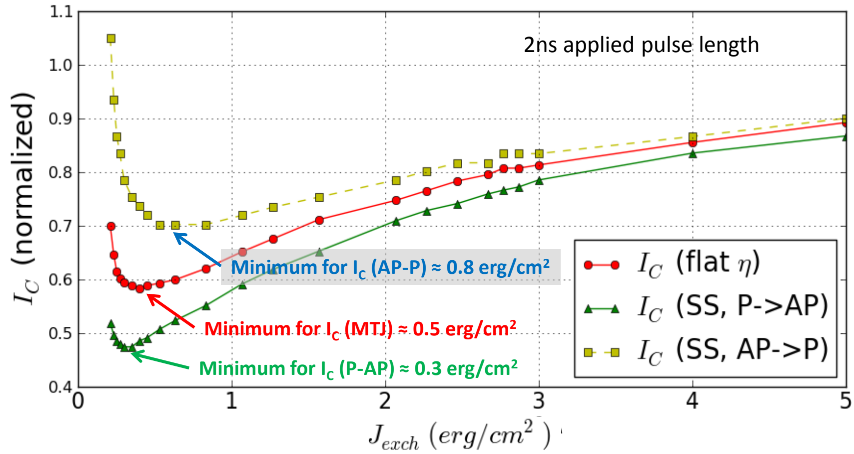
I_C vs J_{exch} for Short Time Scales



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Another Benefit – Pathway to Reduced Damping

$$I_{C0} = \left(\frac{2e}{\hbar}\right)\frac{2\alpha}{\eta(\theta)p}E_B$$

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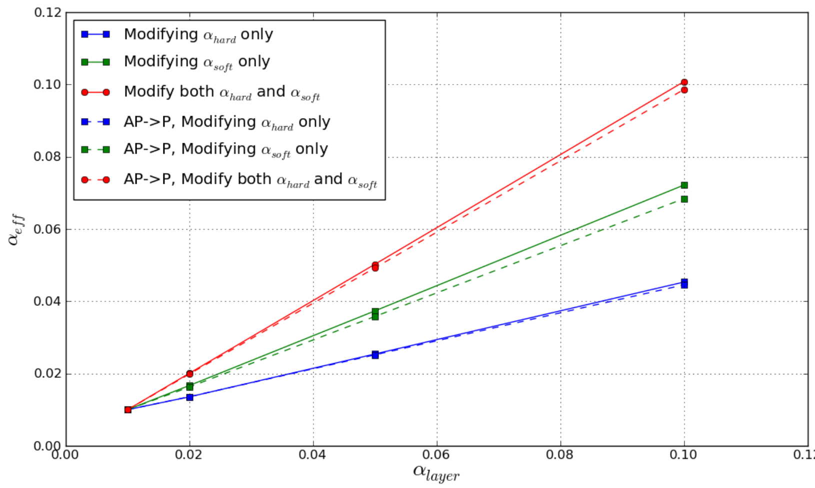
Computing α_{eff} for Bi-Layer Structure



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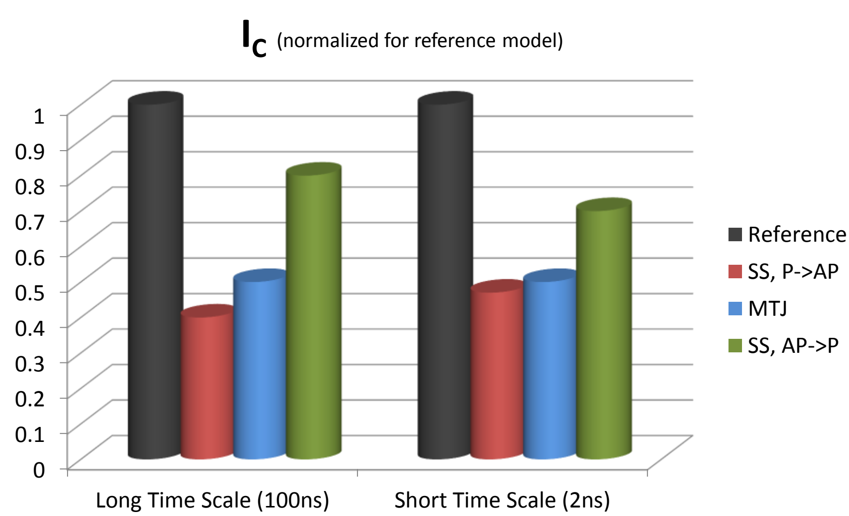
Summary of Results



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Acknowledgments

- **Eric Fullerton** & Fullerton Group (UCSD – CMRR)
- **Marko Lubarda**, under V. Lomakin & E. E. Fullerton (UCSD – ECE & CMRR)
  - Energy Barrier Modeling; Co-Author
- **Christel Berthelot** & **Stephane Mangin** (Université Nancy)
  - Macrospin simulator code development
- **Stephanie Moyerman** (UCSD)
  - Mentoring, Spinsim GSL development and research guidance
- **NSF Award # DMR-1008654**

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