Spin Transfer Torque Reversal in Perpendicular Anisotropy Spin Valves

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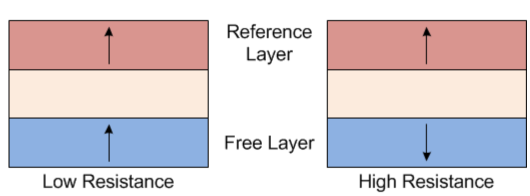
Overview of Spin Valves

- Use magnetization of magnetic element to store information
- One fixed layer, one free layer
  - Parallel -> low resistance
  - Perpendicular -> high resistance
  - With MTJ (using tunneling magnetoresistance) difference can be > 100%.
- Apply small current to sense resistance (read) and large current to switch orientation (write)



Orientation an Analog for Logic Value

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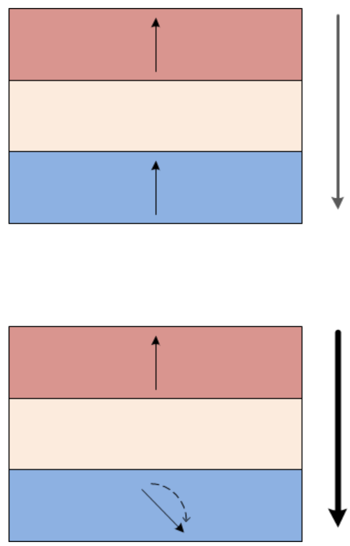
Spin Valves Operation



Small current –
read value stored

Large current –
change orientation

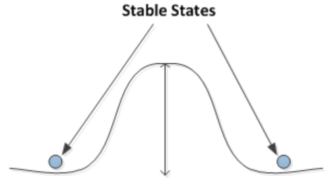
STT-MRAM

- Magnetic RAM, using spin valves as data storage 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**

Thermal Stability and I_C

- To maintain **thermal stability** (avoid having random bit-flips due to thermal noise) $\mathbf{E_B}$ must be greater than ~$45k_BT$
- This puts a floor on I_C (due to $E_B - I_C$ relationship)

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



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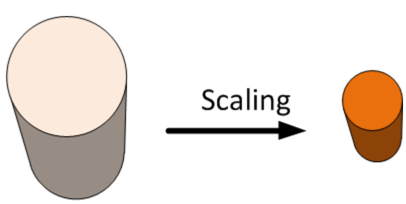
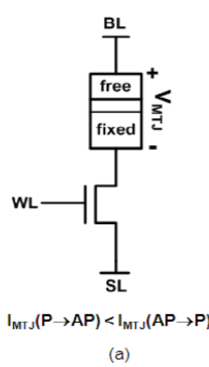
Schematic Illustration of Scaling



Decrease A, keep I_C same → J_C Increases



Lin, Kang, Wang, Lee et al. 2009

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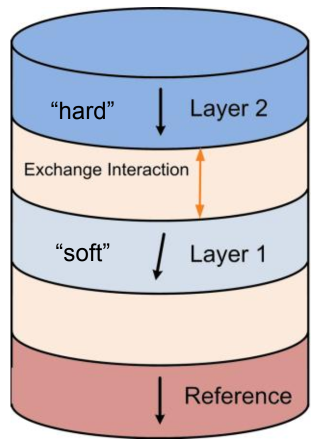
Focus of Project

- Reduce I_C for a given E_B in a device
- Use bi-layer coupled structure as free element
  - Hard (high E_B) layer coupled to soft (low E_B) layer
  - Coupling allows soft layer to "pull" hard layer



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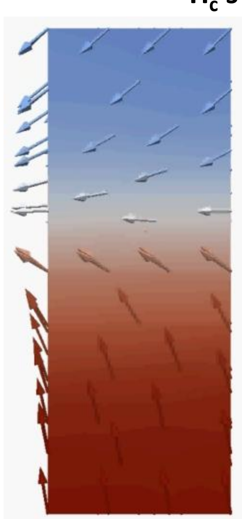
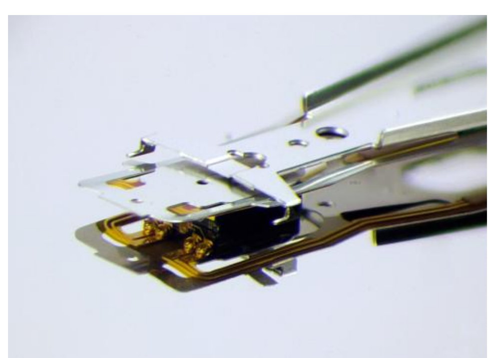
Similar, Existing Problem

H_c switching in magnetic media



M. Lubarda, UCSD 2010



Andrew Hazelden 2010

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Approach

1. Development of macrospin time-domain simulator program "Spinsim GSL"
2. Use program to explore parameter space; find reduction in I_C:E_B (tune K, J_{exch})
3. Compare with 'reference model' consisting of a single free layer, with same E_B
4. Explore parameter space to better understand underlying physics governing the results

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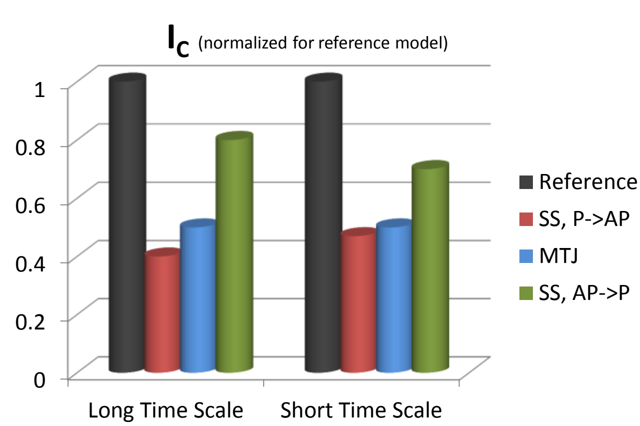
Results

- **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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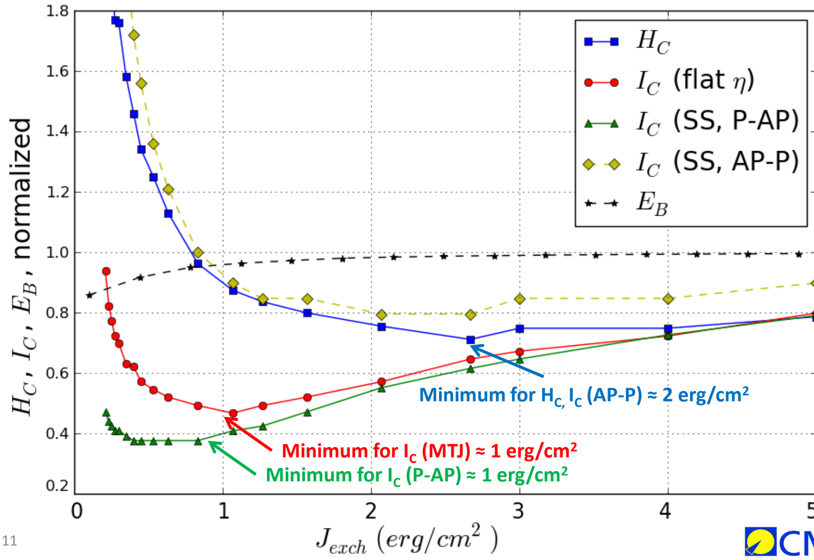
Effect of Coupling on $I_{C,}$ E_B



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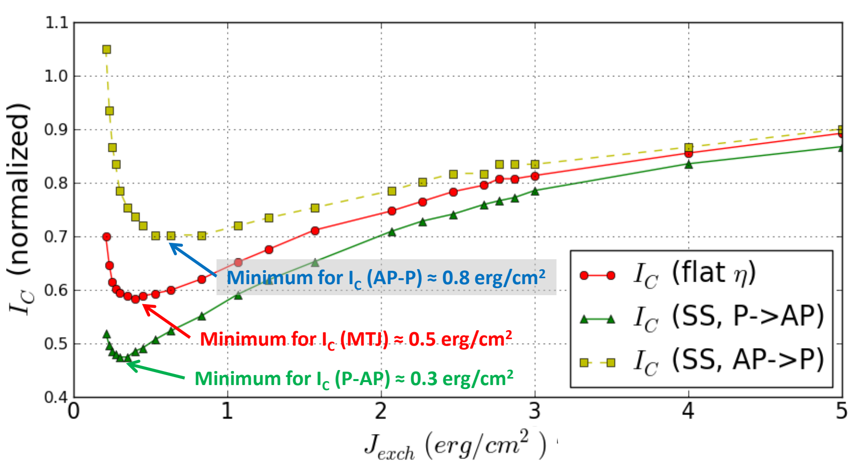
I_C vs J_{exch} for Short Time Scales



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Another Benefit – Reduced Damping

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

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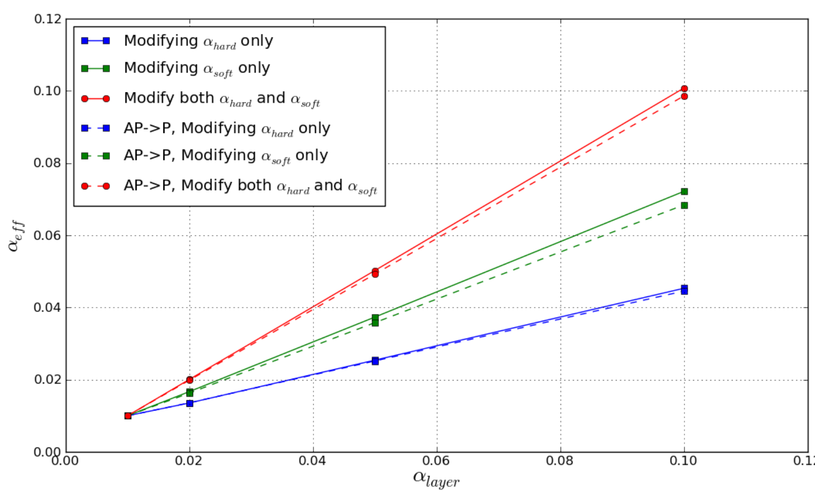
Computing α_{eff} for Bi-Layer Structure



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Conclusion

- Significant reduction in I_C for perpendicular anisotropy spin valves, without reducing E_B
  - Use of hard-soft composite structure for free layer
  - Reduction both due to incoherent switching and reduction in damping
- Encouraging for scaling and wide-spread adoption of STT-MRAM technology

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UCSD

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