Spin Torque Devices: A Technology Simulation

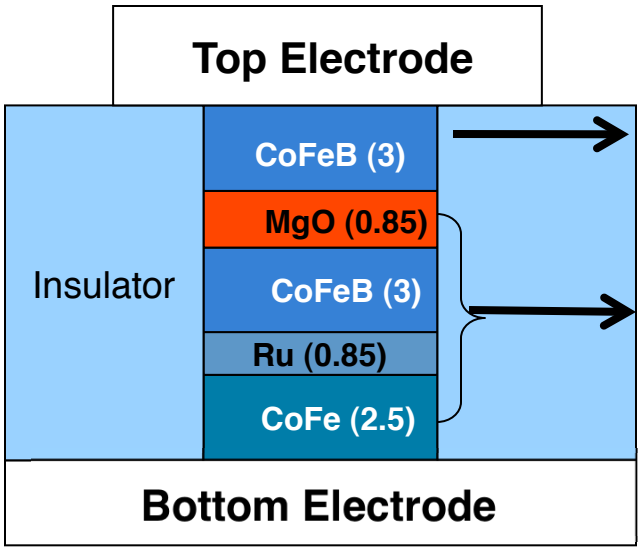
Sayeef Salahuddin

Laboratory for Emerging and Exploratory Devices (LEED)

EECS, UC Berkeley

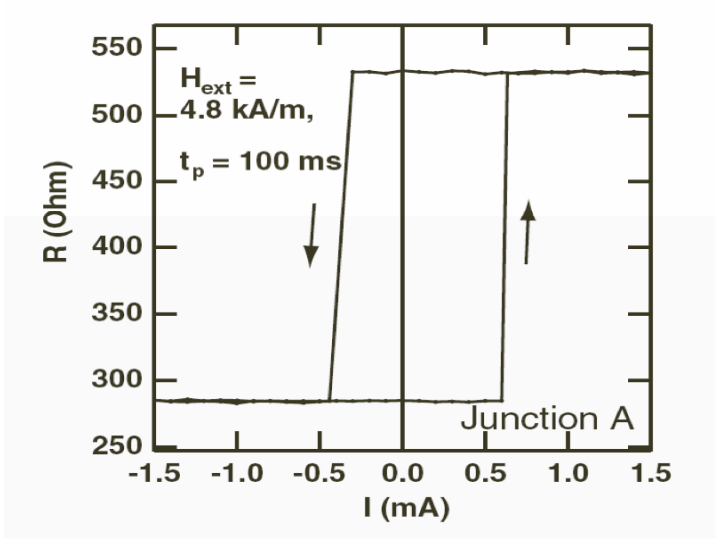
sayeef@eecs.berkeley.edu

Spin Transfer Torque Devices

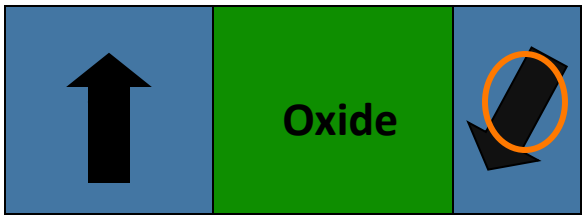


Soft layer

Pinned layer

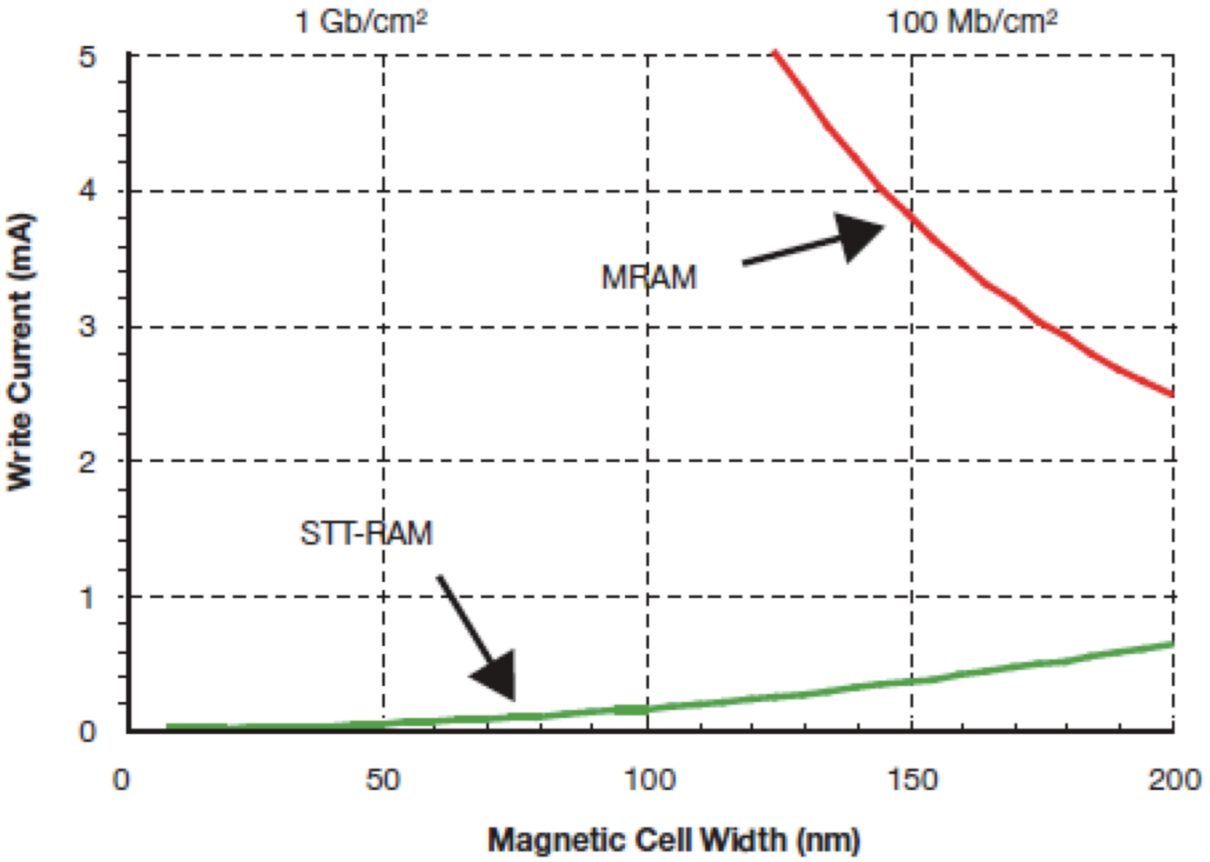


Kubota et. al., JJAP, 44, 40, 1237,2005



Pinned layer **Soft layer**

Why STT Devices?

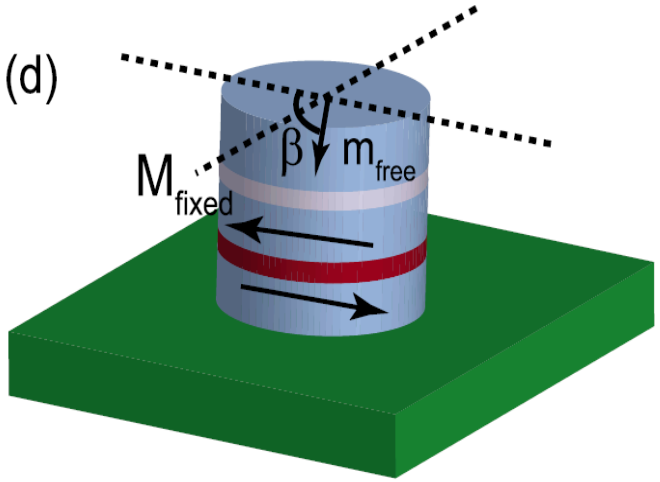


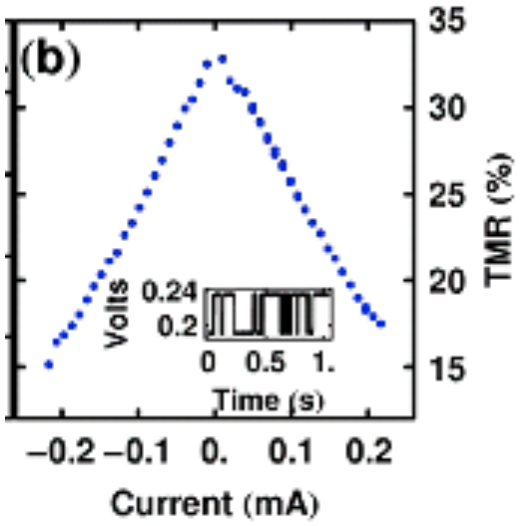
A. D. Smith and Y. Huai, Future Fab International, Issue 23

Why STT Devices?

	SRAM	DRAM	Flash (NOR)	Flash (NAND)	FeRAM	MRAM	PRAM	STT-RAM
Non-volatile	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Cell size (F^2)	50–120	6–10	10	5	15–34	16–40	6–12	6–20
Read time (ns)	1–100	30	10	50	20–80	3–20	20–50	2–20
Write/Erase time (ns)	1–100	50 / 50	1 µs / 10 ms	1 ms / 0.1 ms	50 / 50	3–20	50 / 120	2–20
Endurance	10^{16}	10^{16}	10^5	10^5	10^{12}	$>10^{15}$	10^{10}	$>10^{15}$
Write power	Low	Low	Very high	Very high	Low	High	Low	Low
Other power consumption	Current leakage	Refresh current	None	None	None	None	None	None
High voltage required	No	2 V	6–8 V	16–20 V	2–3 V	3 V	1.5–3 V	0.15 V
	Existing products						Prototype	

Key challenges for device simulation





Fuchs et. al. , PRL 96, 186603, 2006

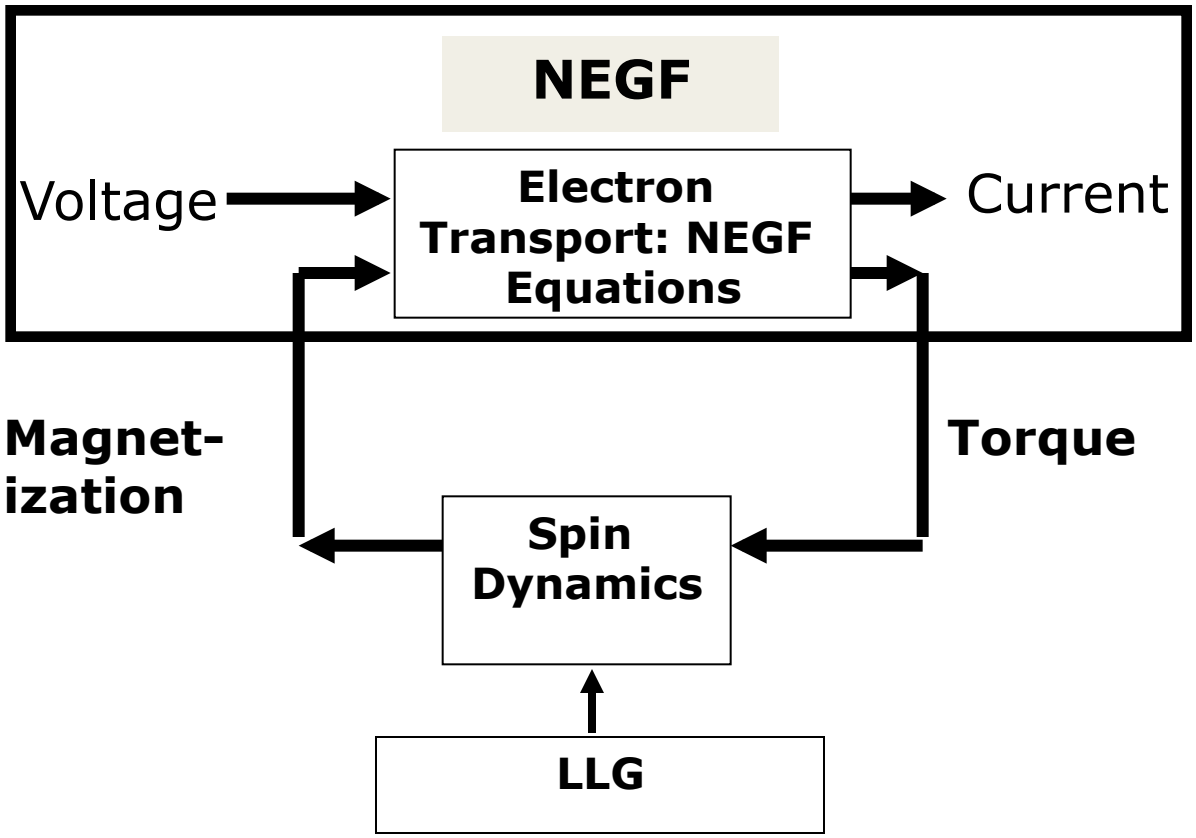
Can we explain the

(i)Amplitude of the switching current

(ii)TMR

With the same set of device parameters?

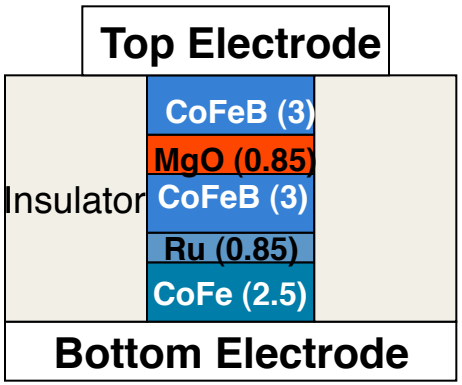
Self Consistent solution of the transport and magnetization dynamics



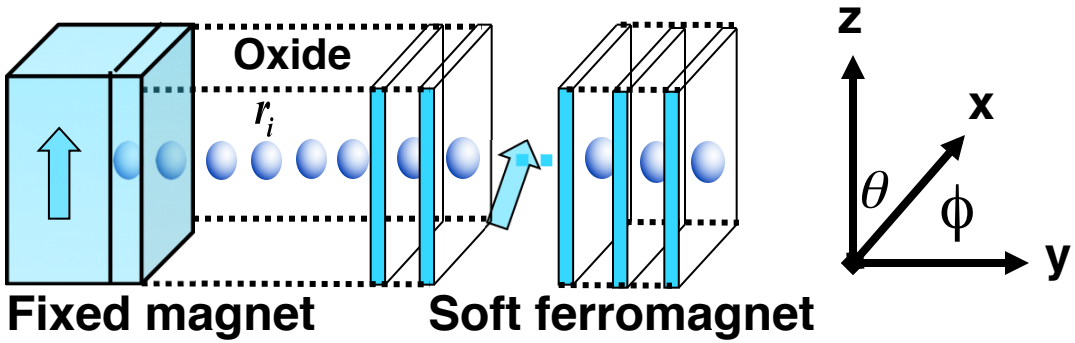
S. Salahuddin and S. Datta:
IEDM (2006)

NEGF Modeling of Spin Torque Devices

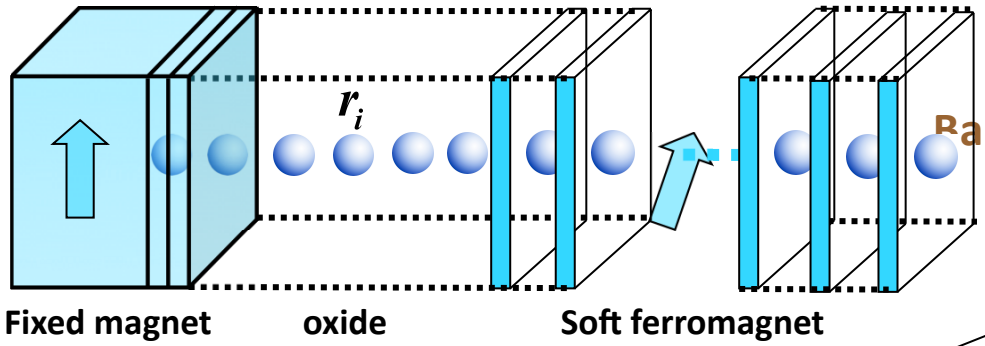
Experimental Device



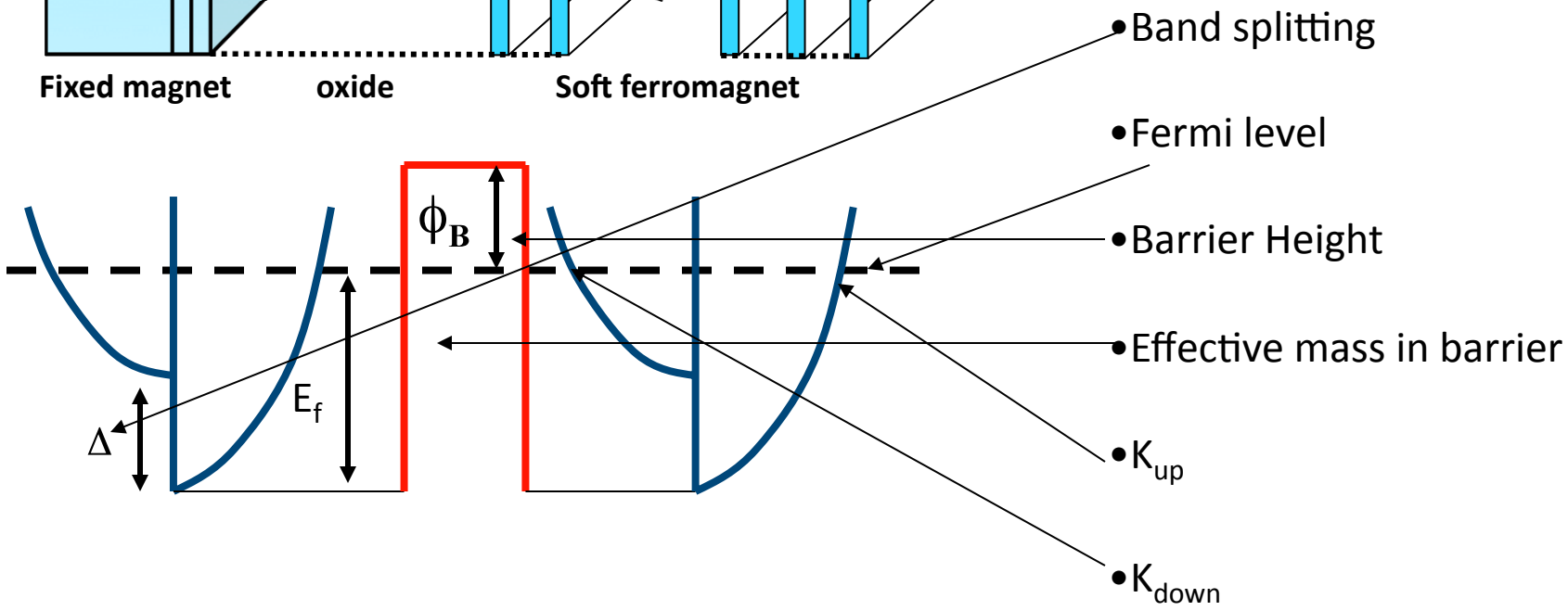
Simplified structure for simulation



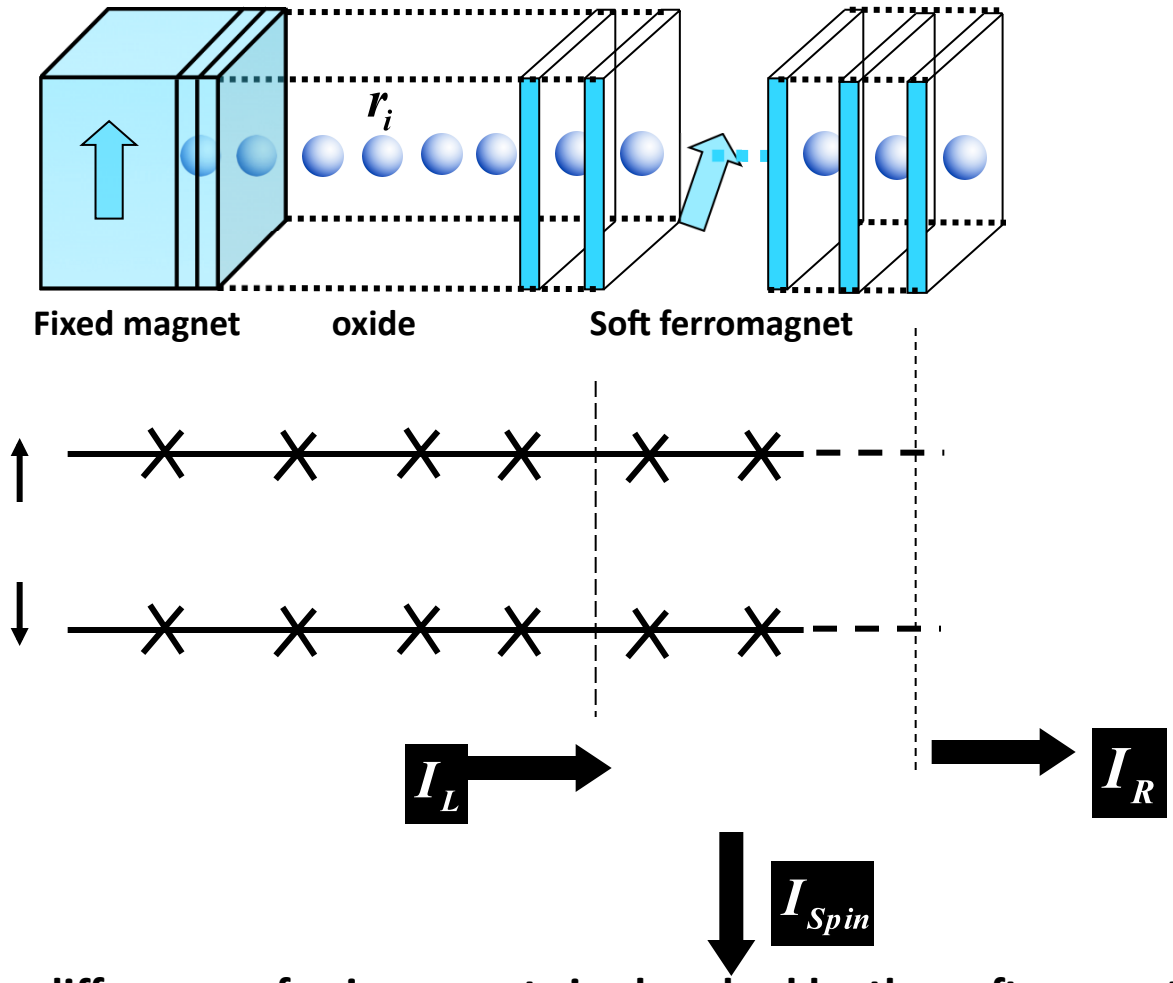
Effective mass treatment of the transport



Band structure dependent parameters

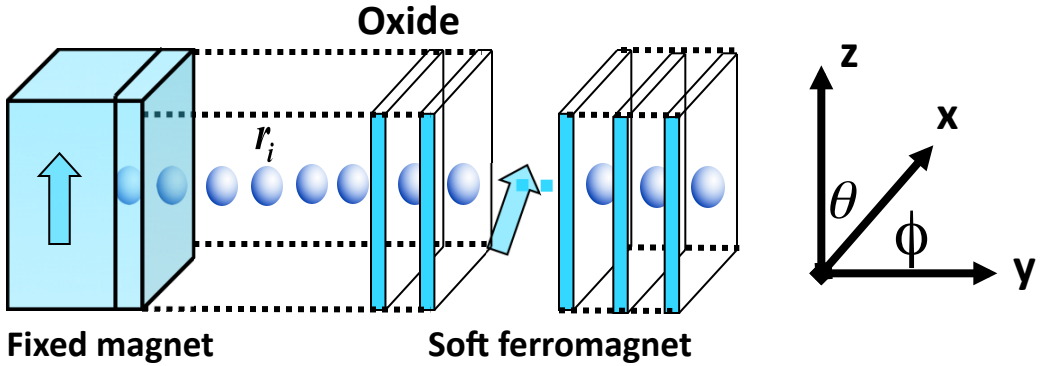


Torque from conservation of angular momentum

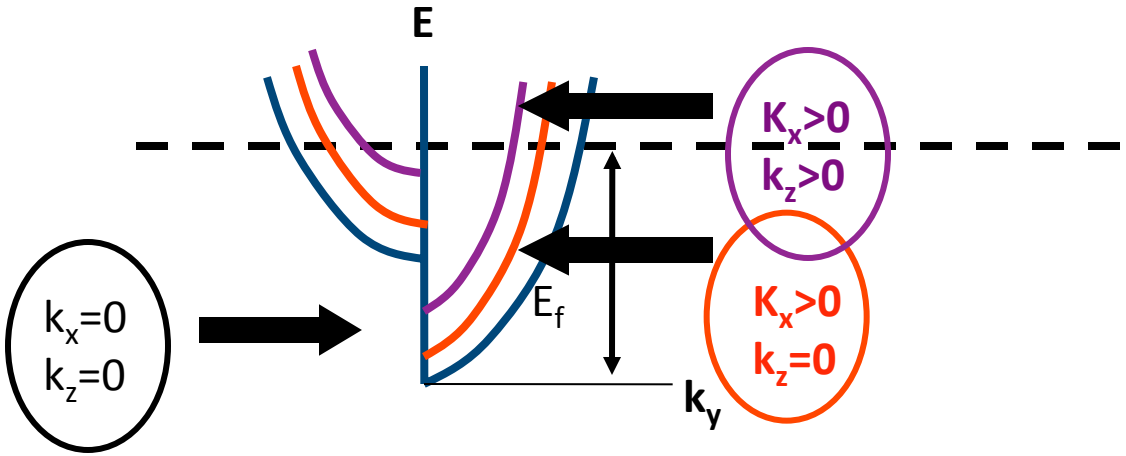


The difference of spin currents is absorbed by the soft magnet

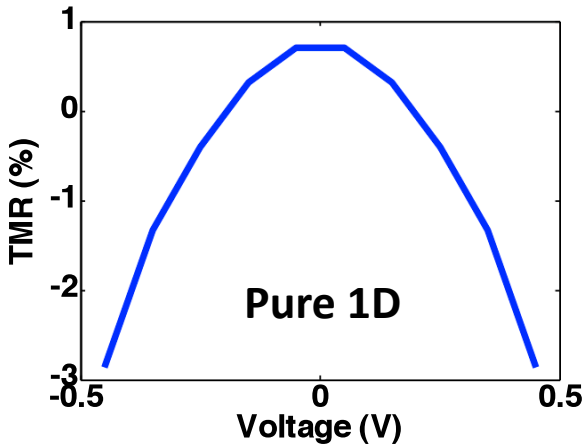
Summation over the transverse modes

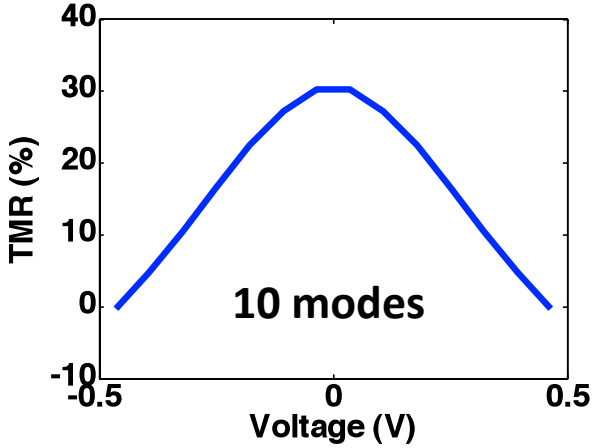


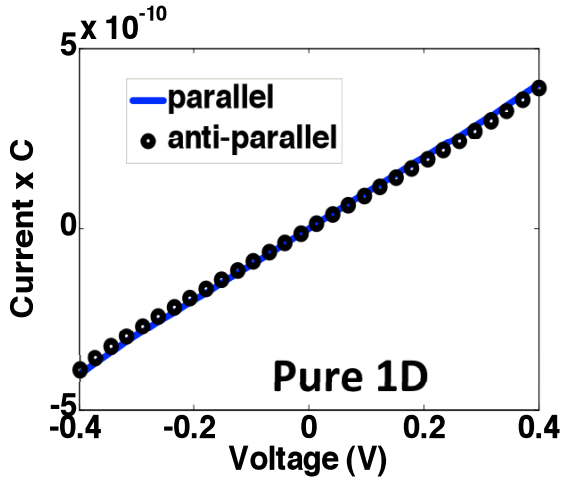
Cross section is typically larger than 50 nm X 50 nm

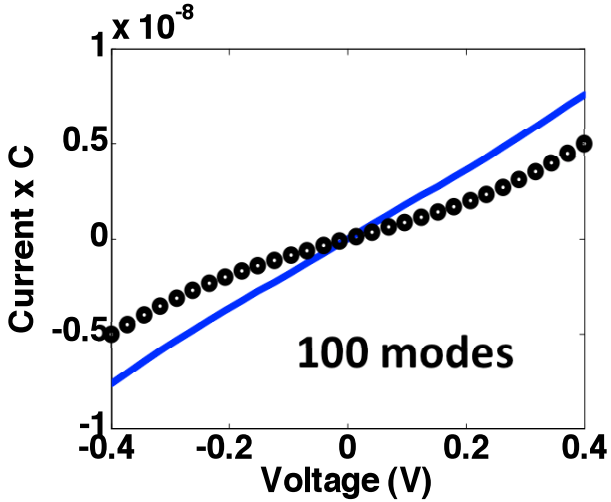


Effect of the transverse modes



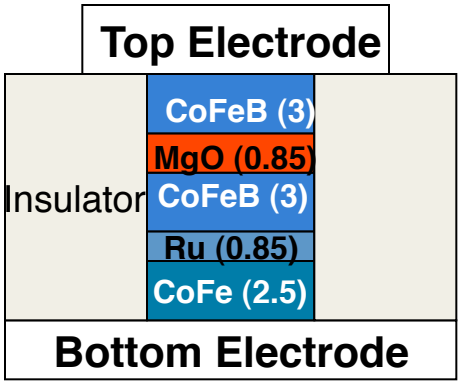


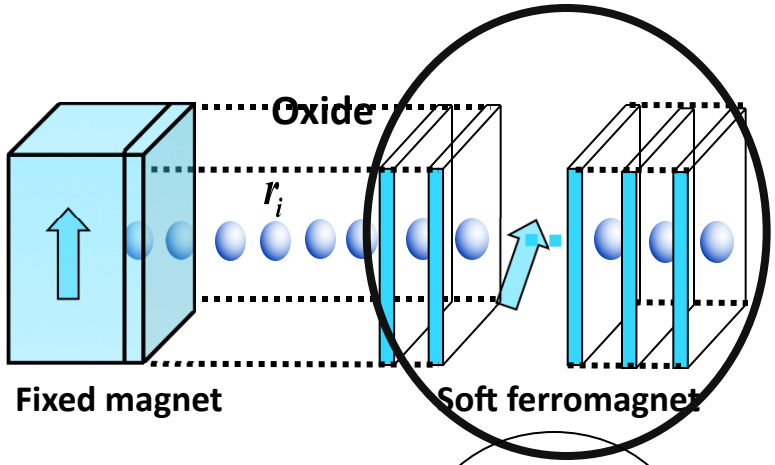


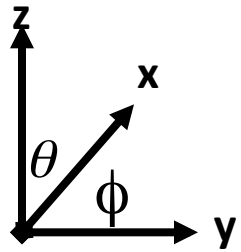


Summation of transverse modes is very important

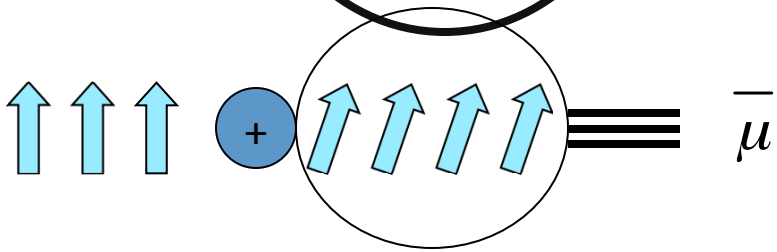
Physics of Spin Torque







Non Equilibrium distribution for the right magnet



Torque

Torque felt by the **s** electrons $\overline{\mu} \times \overline{H}_{s \leftarrow d} = \overline{m_d} \times \overline{H}_{d \leftarrow s}$ Torque felt by the **d** electrons

Calculated from NEGF Calculations

Known from band splitting

Magnetization of The magnet

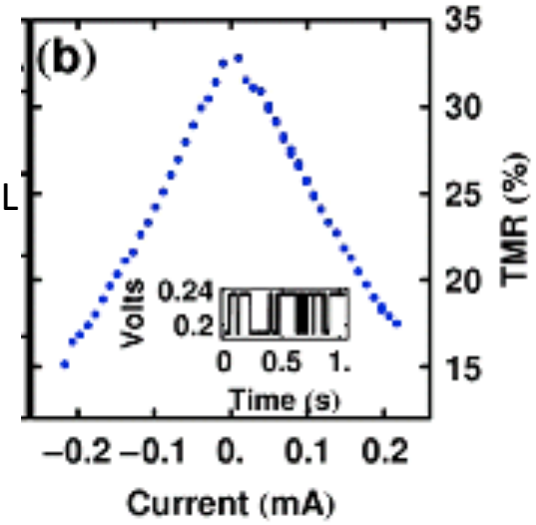
Can be calculated from the other three

$$\overline{T} = \overline{\mu} \times \overline{H}_d$$

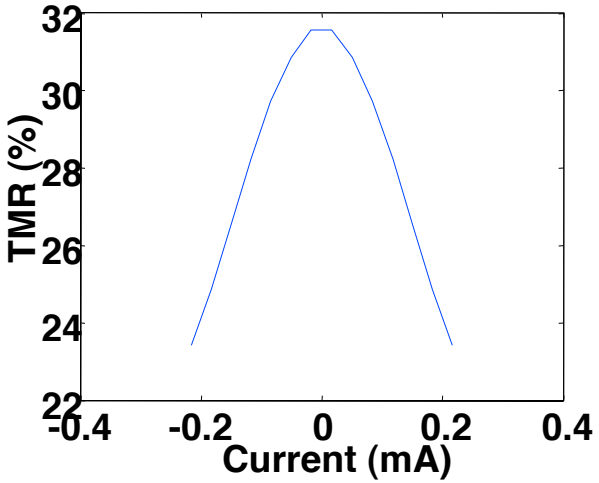
Experimental Benchmark

Experiment

Fuchs et. al. , PRL 96, 186603, 2006



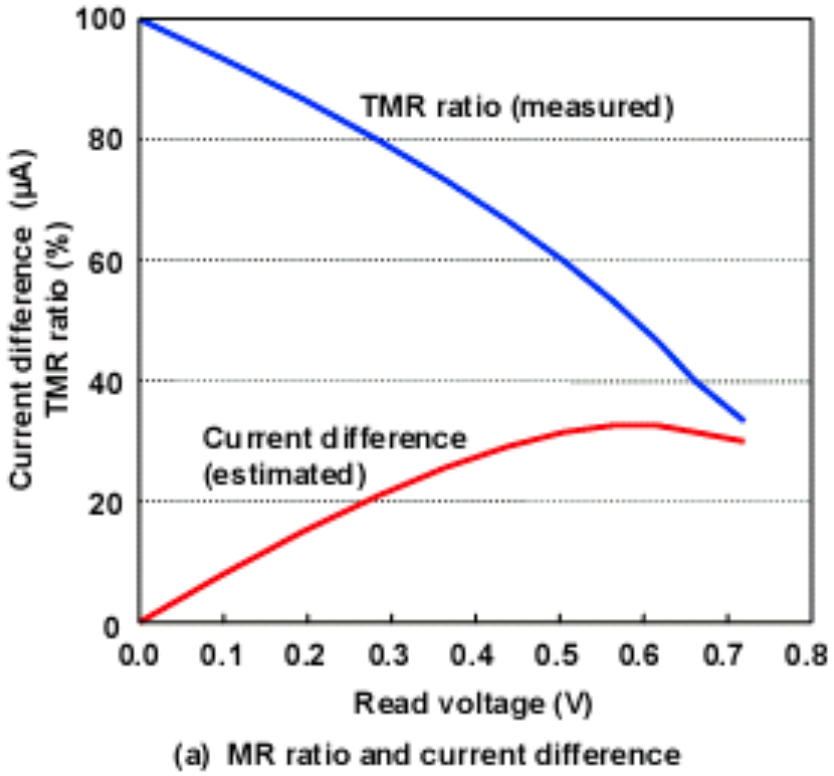
Theory



E_f=2.2 V, Δ=1.35 V, ϕ_B=0.7V, Lc=0.8 nm, $m_{up}=m_{dn}=m_0$ and $m^*=0.2m_0$.

Experimental Benchmark

Experiment



(a) MR ratio and current difference

T. Kawahara et. al., ISSCC, 2007

Theory: Salahuddin group and Datta Group