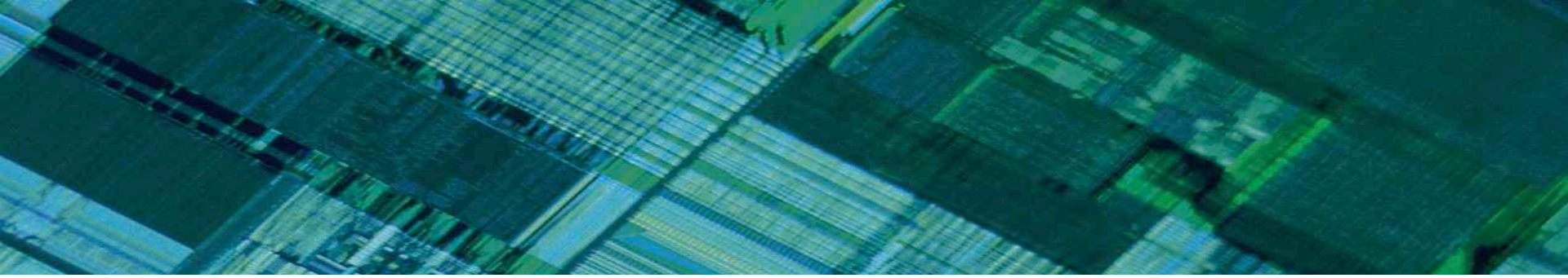


Spin Transfer Technologies

An Allied Minds Company

Orthogonal Spin Transfer (OST)

A Better Approach

Flash Memory Summit
August 2014

Company Background

History

- Formed in 2007 by Allied Minds and NYU to commercialize Orthogonal Spin Transfer (OST) MRAM research led by Professor Andrew Kent
- In 2012, raised $36 million financing from Allied Minds and Invesco and opened Silicon Valley headquarters

Technology

- OST-MRAM is a disruptive innovation in the field of spin transfer MRAM devices and offers advantages over other MRAM
- Higher speed, lower cost, lower power consumption, higher reliability, and enhanced lithographic scalability

Opportunity

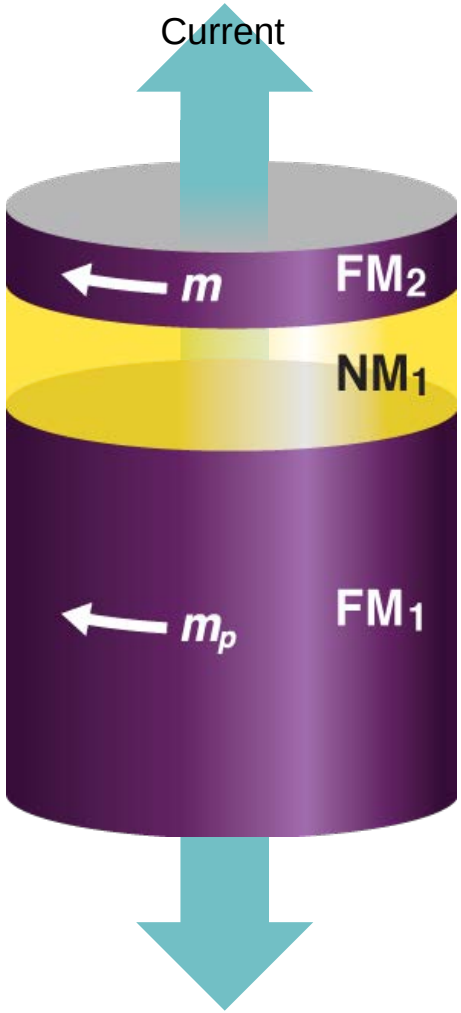
- Served Market Opportunity of $150 Billion in 2015
- Targeted as a replacement for DRAM, SRAM or flash memory
- Markets in storage systems, mobile devices, computing, microcontrollers and SOCs in standalone or embedded configurations

Magnetic Tunnel Junction with Collinear Spin Filter

Magnetic data…'left' or 'right'

Reading - permanent reference direction at low current

Writing - 'collinear spin filter' generates polarization field at high current



"Free" Layer

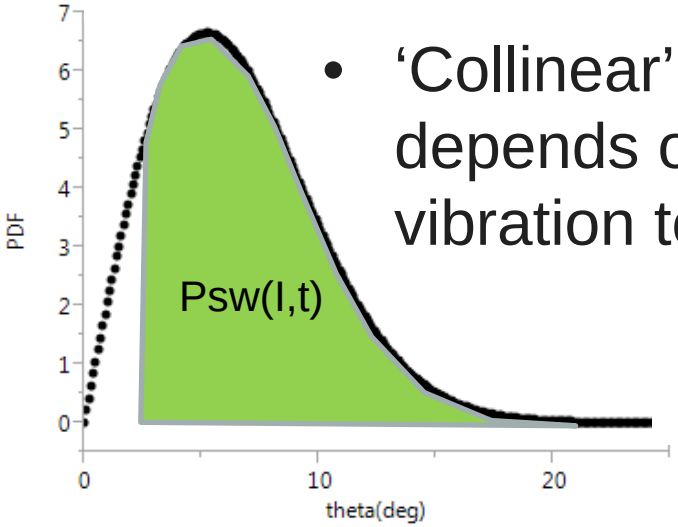
Tunnel Barrier

"Reference" Layer

Not to scale

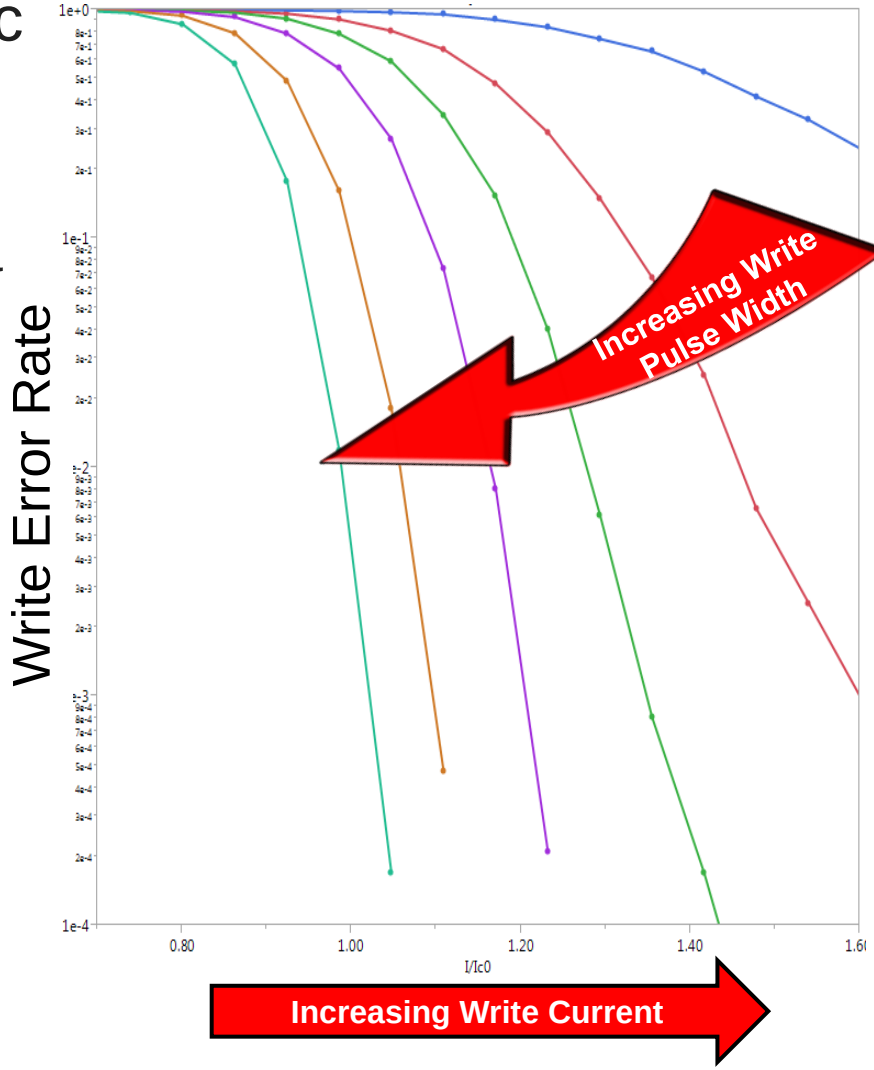
Getting the ‘write’ started

- Torque on the magnetic storage requires a perpendicular component – just like a compass



- ‘Collinear’ switching depends on thermal vibration to get started

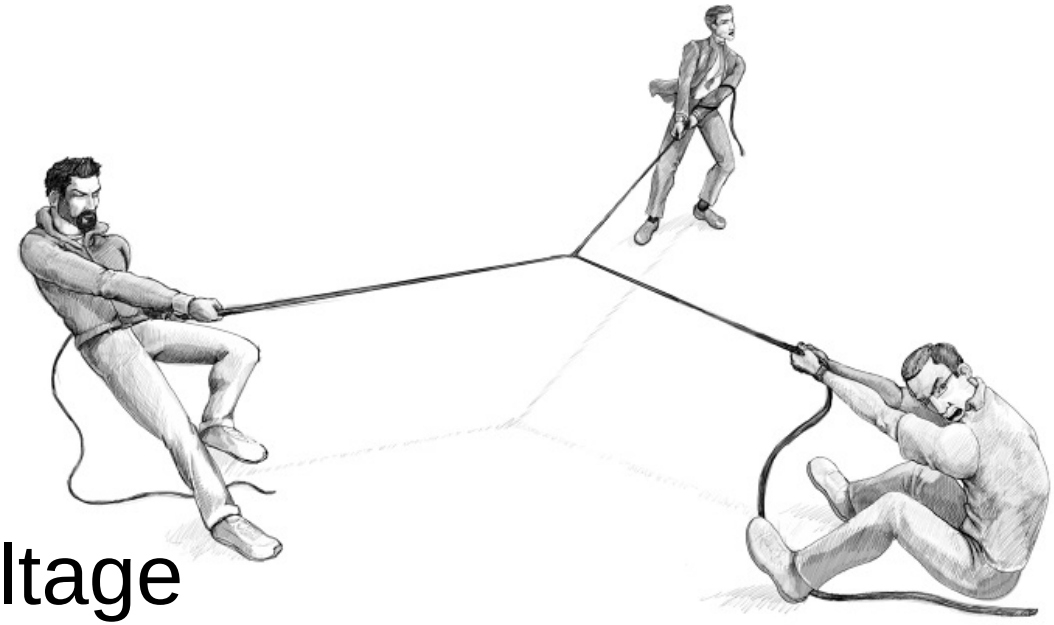
Boltzmann thermal distribution of initial angle



Collinear Spin Transfer – In a Performance Box

Write Error Rate (WER)

→Cost, i.e. ECC



Write Voltage

→Power and Endurance

Write Pulse Width

→Performance and Power

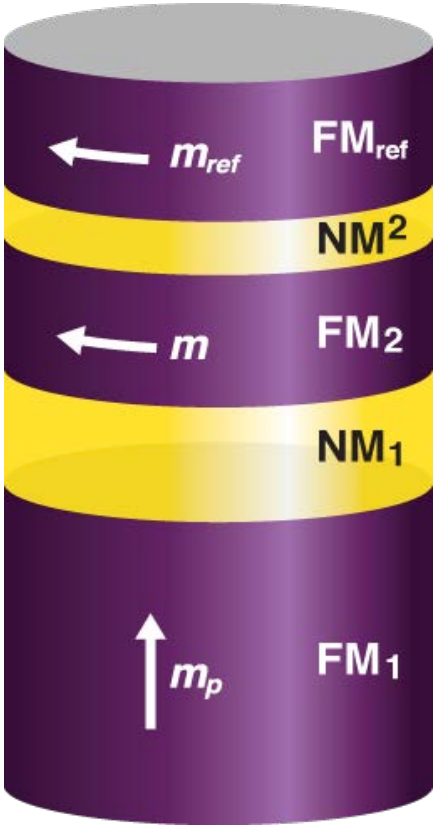
Magnetic Tunnel Junction with Orthogonal Spin Filter

Reading - reference @ low current
Writing - ‘collinear spin filter’ @ high current

Magnetic data…’left’ or ‘right’

Writing - ‘orthogonal spin filter’ @ high current

Strong perpendicular component to ‘spin polarization field’ ***instantaneously*** starts switching of magnetic data in free layer



“Reference” Layer

Tunnel Barrier

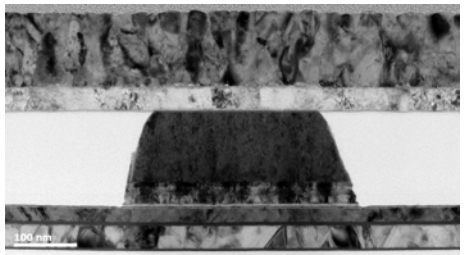
“Free” Layer

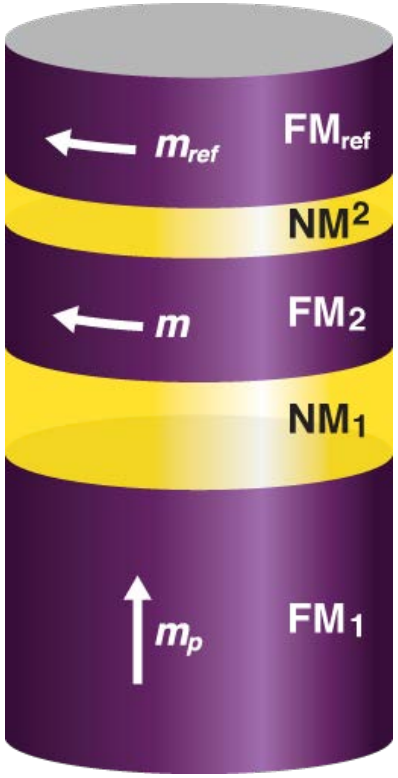
Orthogonal Spin Polarization Filter

Not to scale

OST Technology
Benefits And Advantages

Technology	Benefit	Advantage
Deterministic Write Onset & Shorter Write Pulse	Faster Write Cycle	10-30x $T_{WriteCycle}$ reduction <2ns writing High Speed RAM Application
	Lower Write Energy	10-30x power reduction
	Less Oxide Stress	>>10x write endurance advantage
	Less Peak Current to Switch With Low Error Rate	Smaller CMOS cell transistor → Lower cost per bit
	Lower Write Error Rate per Write Time	Scales to smaller lithography with higher speed and lower write energy




m_{ref}
FM_{ref}
NM^2
m
FM_2
NM_1
m_p
FM_1

Product Benefits of OST

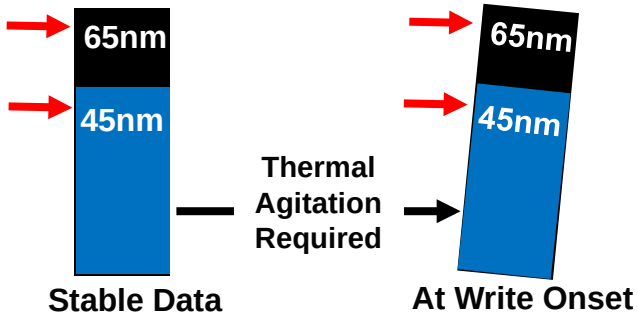
Tech Feature	Product Benefit	OST Comparison to Collinear-ST
Shorter write pulse	Faster write cycle	10-50x $t_{WriteCycle}$ reduction <1ns writing High speed RAM application
	Lower write energy	10-50x power reduction
	Less oxide stress	>>10x write endurance advantage
	Less total charge to switch MTJ	Smaller CMOS switching transistor → smaller cost per bit
Deterministic write onset	Higher intrinsic bit stability	Scale to smaller lithography at high stability

Collinear STT-MRAM vs. OST-MRAM

Spin Polarized Current Switching Analogy

Collinear Spin Transfer Torque (STT)

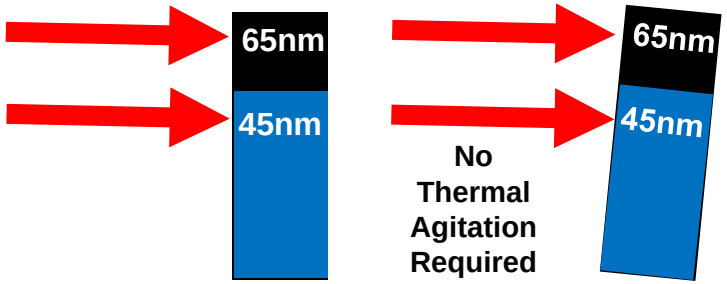
Parallel (collinear) orientation of polarizing & free magnetic vectors



Stochastic Onset of Switching

Orthogonal Spin Transfer (OST)

Orthogonal orientation of polarizing & free magnetic vectors



Deterministic Onset of Switching

	STT	OST
Switching Onset Delay	Stochastic	Deterministic
Energy Required to Switch	Longer Write Pulse	Shorter Write Pulse
Scalability	Less Scalable	More Scalable

Path to MRAM

Spin Transfer Technologies
An Allied Minds Company

2003 NYU files OST patent

2007 Spin Transfer Technologies formed by NYU & Allied Minds to incubate OST

2012 Spin Transfer Technologies transitions to commercial development

LATE 1980's | 1995-1997 | .. | 2001-2003 | .. | 2007-2008 | 2012

Giant Magneto-resistance (GMR) discovered by Fert/Grunberg (Nobel Prize 2007)

Slonsczewski postulates 'spin transfer' physics for writing data in MTJ, sub-100nm feature necessary

GMR-based heads become dominant in HDDs

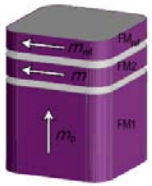
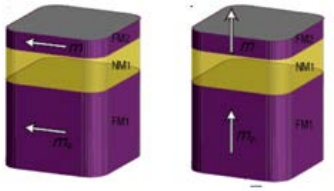
First commercial MRAM introduced – 'field' based, low density, roadmap ends at 130nm

TMR-based heads become dominant in HDDs

First commercial spin-transfer based MRAM introduced to market – 90nm Collinear

Rest of Industry

Among MRAM approaches, STT's OST-MRAM is uniquely advantaged

Comparisons	OST-MRAM	Other spin-torque MRAM
Configuration	Orthogonal orientation of pinned magnetic vector versus free magnetic layer (patent protected) 	Parallel orientation of pinned and free magnetic vectors 
Switching Process	✓ Deterministic	✗ Stochastic
Switch Time	✓ No delay in onset	✗ Incubation delay in onset
Switch Time Variability	✓ Reliable, short switch times	✗ Variability in switching time
Current	✓ Switching at low currents allows smaller transistors	✗ Large current to induce quicker switching
Switching Energy	✓ Low switch energy in proportion to reduced switching time	✗ Average switch energy set by slowest switching bits
Scalability	✓ Scalable to small dimensions	✗ Scalability barriers at larger feature size