Alternative Memories II: MRAM, FeRAM etc

MRAM Memory Cell Structure
What is DRAM?

- (Relatively) fast reads and (relatively) fast writes
- Unlimited number of writes
- Volatile - loses data storage without power
- Dynamic - loses data without periodic refresh
- Could be fabricated using similar materials and (relatively) similar silicon based process technologies as leading edge processors (Small-cheap)
Advantage/disadvantage of Alternatives:

- (Relatively) slower reads and (on some) really slow writes
- (Some) limited number of writes
- Non-Volatile - keeps data storage without power
- May require new materials and (relatively) different process technologies as leading edge processors
MRAM: Basic Features I

- Non Volatile (no need for refresh!)
- High Density
- Non Destructive Read
- Low Voltage, Low Power
- Read Speed = Write Speed, < 50ns
- Unlimited R/W Endurance
- Immune to soft error
- Material Compatibility with CMOS Logic & DRAM?
Magnetoresistance I

- Change in electrical resistance with applied magnetic field

- The resistance against the flow of electrons depend on polarization of electrons and availability of spin-up or spin-down states
Magnetoresistance II

GMR: Giant Magnetoresistance

Ferromagnet 1

Non Magnetic Material

10 Å

Ferromagnet 2

TMR: Tunneling Magnetoresistance

Ferromagnet 1

Insulating layer (oxide)

10 Å

Ferromagnet 2

X-Men: Professor Charles Xavier.
“Telepath who resists Magneto”
MRAM Cell Structure

Wordline: Current flow out of the page

MTJ: Magnetic Tunnel Junction stack

Differences in resistance = “0” or “1”
MRAM Reference Circuit

Reference Cell uses Parallel/Serial combination of MTJ’s in two memory states to generate “mid resistance” reference between those two states.

\[ R_{\text{ref}} = \frac{1}{2} \times (R_{\text{min}} + R_{\text{max}}) \]
MRAM Segment I

Word Line

common source

Reference Circuit

Current Conveyor and Differential Amp

Word Line

BL14 - BL15

R_{\text{max}} - R_{\text{min}}
MRAM Segment II

- Word Line
  - BL14
  - BL15

- Reference Circuit
  - Common source
  - $R_{\text{max}}$
  - $R_{\text{min}}$

- Current Conveyor and Differential Amp
Motorola 1 MBit MRAM Chip

512K Core

Digit Line Row Select

512K Core
FeRAM Cell

- Tetra/Pentavalent Atom
- Di/Monovalent Metal Atoms
- Oxygen Atoms

PZT (PbO, ZrO₂, TiO₂) Lead-Zirconate-Titanate unit cell

Applied Electric Field Moves Center Atom
- Ferroelectric material can be polarized into two stable states. States can be maintained without power.
FeRAM Circuit Structure

1T1C: DRAM-like

2T2C: Built-in reference
FeRAM: Basic Features

- Non Volatile (no need for refresh!)
- High(?) Density
- Destructive Read
- Lowest Voltage & Power
- Fast Read, Fast Write (compared to flash)
- Limited R/W Endurance
- Chips being sampled commercially
  (3/7/2003, Hynix 0.25um, 4 and 8 Mbit, 100 billion R/W cycles, 90ns data access)
Summary

- Alternatives to DRAM actively explored
- Alternatives depend on new materials
- FeRAM closer to commercialization, marketed as flash replacement: (fast write, higher R/W cycle tolerance)

- Density of MRAM and FeRAM not yet approaching DRAM/Flash levels
- Alternative-alternatives exist: PCM/OUM, Fe polymer, RRAM.