Magnetic Random Access Memory (MRAM)

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Computer System

TLB   CPU

SRAM  

L1 Cache

SRAM  

L2 Cache

DRAM  

Main Memory

Disk Drive  

Archival Memory  Non-Volatile Memory

Volatile Memory
Static RAM (SRAM)

Cache Memory

6-Transistor CMOS SRAM

Fast:
- Access time: < 1 ns
- = $10^{-9}$ second

Expensive:
- $100 / \text{MByte}$

Low Density:
- >120 $F^2$

$F$ -- minimum fabrication feature size

Field Effect Transistor (FET)

$n$-channel FET

MOSFET:
- Metal-Oxide-semiconductor-FET
How a FET Works: Transistor On

Active condition:

\[ V_{GS} > V_T \]

\[ V_{GG} > V_T \]

i.e.

Drain current will be a function of gate voltage.

\[ i_D \]

Transistor On

http://www.pbs.org/transistor/science/info/transmodern.html

How a FET Works: Transistor Off

Cutoff condition:

\[ V_{GS} < V_T \]

\[ V_T \] threshold voltage

\[ V_D = V_{DD} \]

Zero Drain current.

\[ V_{DD} \]
A Modern CMOS Process

- Gate Oxide
- Trench
- TiSi2
- AlCu
- SIO2

Dynamic RAM

Main Computer Memory
- Individual access time 60 ns
- 10 F²
- $4 /MByte
- All “1”s need to be refreshed every 1 ms.
Rotational Latency

- Average latency: 3 – 6 ms
- Wait until desired sector passes under head
- Worst case: a complete rotation
  - 7,500 rpm = 8 ms
  - 15,000 rpm = 4 ms

Inexpensive: $0.001/1MByte

Hard Disk Drives

- 18-316  Introduction to Data Storage
- 18-517  Data Storage Systems Design

Magnetic Force Microscopy Image of A Disk Surface
Can one change the disk drive into a high speed memory chip?

If one can, one can put the entire computer system on a single chip:
Magnetic RAM: Historical Perspective

Control Data Corp.
1Kbits Ferrite Core Memory
1965

Motorola
4Mbits MRAM Chip
Magnetic tunnel junction
2003

Honeywell
16Kbits MRAM Chip
AMR Technology 1994

Remember Magnet!
Magnetic moment can maintain its direction without power!
Memory Element

Magnetic Tunnel Junction (MTJ)

- CoFe/Al₂O₃ (7-20Å)/Co
- Magnetic electrode
- Tunnel barrier
- Magnetic electrode

State “0”

State “1”

Resistance (kΩ)

Data Bits

Memory Array

Memory Array

“L” “L” “H” “L”

“H”

“L”

“L”

“L”

“H”

“L”

“L”
Detailed Structure

Only the magnetic moment of a storage layer is switched back and forth.

Writing Bits
**X-Point Addressing**

- **Half-select elements**
- **Y-Component Field (Hk)**
- **X-Component Field (Hk)**

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**MRAM Cell**

- **Bit Cell**
- **MTJ**
- **Bit Line**
- **Word Line**
- **Digit Line**
- **Ground line**
MRAM: Dream Memory?

Advantages of MRAM:

- **Nonvolatile** (No power needed to maintain memory states)
- **SRAM Speed** (~ 1 nanosecond)
- **DRAM Density** (~ 20 F²)
- **Endurance** (Infinitely rewritable)

MRAM has the potential to be an universal memory to replace SRAM, DRAM, FLASH, and disk drives in some applications to become the

**Universal Solid-State Memory!**
A Potential Game Changer

If MRAM replaces SRAM, DRAM or even disk drives:

- Instant on systems: No booting from disk drive
- Minimum stand-by power (Turn it off!)
- Enable computer system to be integrated on a single chip!

Applications
System on Chip (SoC)

Example:

- RF Module
- Data Processing
- Memory

MRAM: Dream Memory?

Present MRAM Technology Shortfalls:

- Relatively high power dissipation (high current)
- Down-size scaling not clear (thermal magnetic stability)
X-Point Addressing

99.999% of power is dissipated as \( FR \) on the write lines!

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Magnetic Cladding

(18-303 Electromagnetics)

- The main power consumption arises from the ohmic dissipation, \( FR \), in word/digital lines.
Thermally Activated Reversal

\[ H_x = 0.8 H_x^0 \]

\[ \tau_{\text{rise}} = 0.3 \text{ ns} \]

The Potential Universal Memory

<table>
<thead>
<tr>
<th>Speed</th>
<th>DRAM</th>
<th>Disk Drive</th>
<th>FLASH</th>
<th>MRAM</th>
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<tr>
<td>Density</td>
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<td>Cyclability</td>
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<td>Cost</td>
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<tr>
<td>Non-volatility</td>
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<tr>
<td>Power consumption</td>
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Conclusions

**MRAM:** The enabling technology for computer systems on a single chip!

*Only Continued Innovation Will Ensure Future Competitiveness of MRAM*

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Data Storage Systems Track

- **18-220** Fundamentals of E.E.
- **18-303** Eng. Electromagnetics
- **18-316** Intro. to Data Storage Tech.
- **18-396** Signal & Sys.
- **18-716** Advanced Appl. Magn.
- **18-817** Data Storage Sys. Design
Building a Virtual Disk Drive using MATLAB/SIMULINK

Data Storage Systems Design

18-315  Fall 2004
Introduction to Optical Communication Systems

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Course Objective:
Provide a basic understanding of present optical communication systems and components, as well as future engineering challenges.
Bandwidth Explosion

Source: Agilent Technologies

Data Rate Capacity (bits/second)

Year

Voice-centric Network Doubles every 4.7 years

Doubles every 9 months

Data-centric Network (Optical)

Telephone

Coax

World wide web

Video on demand

O.S.

DWDM

WDM

Fiber

Facts

A single optical fiber is capable of transmitting $2 \times 10^{12}$ bits of data per second, which is equivalent to

- simultaneously carry more than 30,000,000 phone conversations, or
- 200,000 users download (upload) information at 10 Mbits/second data rate at same time, or
- download all 380 CDs (each with 1 hour long music) in 1 second, or
- download 30 DVD movies in 1 second.

Present dense wavelength division multiplexing (DWDM) technology is realizing the full potential of a single optical fiber!

A optical fiber cable may contain up to 200 fibers.
**Fiber-Optical Long-Haul Routes**

Source: KMI

**Metro Optical Network**

Source: Nortel Networks
e.g. 10 Gbits Ethernet

The optical wireless solution consists of a mesh network of short optical links that extend the fiber loop wirelessly to buildings outside the established fiber network.
This course is designed to:

- prepare students with up-to-date education ready for the optical communication and network industry.
- Provide students sufficient background knowledge for further career development in optical communication systems and networks.
- Stimulate students’ ability for innovation.
- Train students’ problem analyzing and problem solving abilities.
“A road to a world with no borders, no boundaries, no flags, no countries, where the heart is the only passport you carry.”  — Carlos Santana