Nanotechnology, Information Storage, and Applied Physics

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Limits in information storage systems and IC fabrication technology are being approached these are real but are not fundamental in the sense of insurmountable laws of nature.

Information storage today is an application of nanotechnology.

Further advances in nanotechnology will bring unprecedented storage capacity that will fundamentally change the way we think about information.

The integration of information storage and information processing will create a new paradigm to take us beyond CMOS technology.
“….cyberinfrastructure refers to infrastructure based upon distributed computer, information and communication technology. If infrastructure is required for an industrial economy, then we could say that cyberinfrastructure is required for a knowledge economy….. The base technologies underlying cyberinfrastructure are the integrated electro-optical components of computation, storage, and communication that continue to advance in raw capacity at exponential rates.”
The Need for Storage

- New stored information grew about 30% a year between 1999 and 2002.

- Information flows through electronic channels -- telephone, radio, TV, and the Internet -- contained almost 18 exabytes (exabyte=10^{18} bytes) of new information in 2002, three and a half times more than is recorded in storage media. Ninety eight percent of this total is the information sent and received in telephone calls - including both voice and data on both fixed lines and wireless.

- The World Wide Web contains about 170 terabytes of information on its surface; in volume this is seventeen times the size of the Library of Congress print collections.

Inside a disk drive

Seagate Barracuda ATA II

Disk
Head

Courtesy Read-Rite
State-of-the-art industrial demo 170 Gbit/inch²

Pico-slider dimensions

- 0.30 mm
- 1.00 mm
- 1.25 mm

Slider body

- Read sensor width 90 nm
- Writer width 125 nm
At 170 Gbits/inch$^2$
194 k tracks/inch
876 k bits/inch

Fly height ~10 nm
Bit width ~130 nm
Bit length ~29 nm

This is nanotechnology...
Nanotechnology

**Nano;** 1 - 100 nm the length scale at which groups of atoms begin to define their properties in aggregate

**Technology;** the *deterministic* manipulation of objects and materials rather than in an “average” sense.
Magnetic Hard Disk Drives

![Graph showing Gbits/sq. in. vs. Year]

- **Longitudinal demos**
- **Perpendicular demos**
- **Products**

- **Historical demos**: 40 %/yr
- **1999 demos**: 190 %/yr
- **Recent demos**: avg: 25 %/yr
- **Recent products**: 40 %/yr
- **Products 1998-2002**: 100 %/yr
- **INSIC goal**

**Courtesy: J. Bain**
Technology goal today 1 Tbit/in²

What does that mean?

At 1 Tbit/in² you can save a picture of every man, women and child on earth on a disk the size of a Compact Disk.

Libraries of information

750 byte
30 x 30 pixel
8 bit grayscale .jpeg image

Courtesy: T. Rausch
How long can physical limits on scaling be avoided?

90 nm lithography

Gordon Moore ISSCC 2003
Cost of Production

- $30 M/tool today
- $250 M/tool in ten years
- $1 B/tool in twenty years!

Extreme Ultraviolet Lithography (EUV)

Gordon Moore ISSCC 2003
Human Cytomegalovirus (CMV):

- 200,000 base pairs
- Nucleocapsid ~ 100 nm diameter

Information storage density $4 \times 10^5$ bits per $\pi (50 \times 10^{-9})^2 \ m^2$

or about $3 \times 10^{16}$ bits/inch$^2$

A factor of $10^5$ times today’s state-of-the-art

or equivalent to > 30 years of development
Relative Sizes

**CD**
- 1.6 µm
- 0.83 µm minimum

**DVD**
- 0.74 µm
- 0.4 µm minimum

Genetic material of virus
DNA Structure Defined at the Nanoscale

- A:T Base Pair: 11.1 Å
  - 51°
  - 50°
- G:C Base Pair: 10.8 Å
  - 54°
  - 56°

Dimensions:
- 0.34 nm
- 2.0 nm
Can we learn too much from nature?

Bald Eagle in flight  F-15 Eagle in flight

Heavier than air flight is possible.....
Competing with Viruses

- **Virus**
- **50 Tbits/inch²**

**Graphical Elements**
- **Gbits/inch²** axis ranging from $10^2$ to $10^8$
- **Year** axis ranging from 2000 to 2050
- **Lines** indicating different categories:
  - **Demo**
  - **Product**

**Data Points**
- **1999 demos**
- **Recent products**
- **Recent demos**
- **Products 1998-2002**

**Growth Rates**
- **40%/yr**
- **100%/yr avg:** 25%/yr
- **190%/yr**
Areal Density

FePt

3 nm diameter

Areal density
71 Tbits/inch²
Nanoparticle Arrays (Size)
S. Majetich

7.0 ± 0.8 nm
9.2 ± 0.7 nm

**Capacity**

- **Limit capacity to 1 Terabyte (8 Terabits)**
  - Implies an area of 0.16 inch$^2$ (1 cm$^2$ media)
- **For 1 msec rotational latency**
  - 1 kHz vibration or 60,000 rpm

\[ r = 0.564 \text{ cm} \]
\[ v = \omega r = 2\pi \times 1000 \times 0.564 = 35 \text{ m/sec} \]

*Data rate: 10 Gbits/sec*
Writing by Spin Injection (Spintronics)

Nonmagnetic metal tip

storage layer

thicker layer

Metal substrate

Courtesy J. Zhu
Two chips; green represents a CMOS IC that includes a nanofabric or reconfiguration layer, red is a probe layer also fabricated through a CMOS process. These are bonded together.
18-321 Analysis and Design of Analog Circuits
18-300 Fundamentals of Electromagnetics
18-310 Fundamentals of Semiconductor Devices
18-401 Electromechanics
18-410 Physical Sensors, Transducers, and Instrumentation
18-493 Electroacoustics
18-412 Semiconductor Devices II
18-517 Data Storage Systems Design
18-712 Optoelectronics for Networks
18-713 Optical Networks
18-716 Advanced Applied Magnetism
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