FIRST HARD DISK DRIVE – RAMAC

Magnetic recording on rotating disk

First Hard Disk Drive product
5 MB on 50 24” dia disks
Hard Disk Drive Innovation

1956 -- RAMAC
• 5 megabytes (MB)
• Fifty 24” disks, 1200 RPM

Made possible by magnetic, semiconductor and mechanical scaling

1981 -- 3380 system
• 1.2 gigabytes (GB)
• Nine 14” disks, 3600 RPM

1991 -- 2.5” Travelstar
• 60 MB (120 GB today)
• Two 2.5” disks

2005 -- “Mikey,” smallest Microdrive
• 8 GB
• One 1” disk
Historical Areal Density Trend

- 1st Thin Film Head
- 1st MR Head
- 1st GMR Head
- 100% CGR
- 60% CGR
- 25% CGR

Future Areal Density Progress

- Perpendicular Recording

IBM RAMAC (First Hard Disk Drive)

- Lab demos
- Products

Production Year

Areal Density Megabits/in²

10⁶ 10⁵ 10⁴ 10³ 10² 10¹ 10⁻¹ 10⁻² 10⁻³

60 70 80 90 100 110
Scaling means that everything shrinks and the system still works
- Requires vastly improved processes
- Higher mechanical precision

Signal-to-noise ratio drops when things are scaled smaller
- Requires new sensors and materials
- Improve signal processing
**Typical Components in a Modern Disk Drive**

- **Electronic Card**
  - Provides data interface to disk controller
  - Control operation of disk drive (spindle, actuator, position servo)
  - Encodes written data and decodes read back data
  - Provide read/write signals to heads via flex cable

- **Disk Enclosure**
  - Stores written information

- **Spindle Motor & Disk Clamp**
  - Holds and spins disks

- **Load/Unload Ramp**
  - Parks head off media during non-use

- **Disk(s)**
  - Stores written information

- **Actuator**
  - Positions the heads

- **Actuator Voice Coil Magnets**

- **Flex Cable**
  - Provides electrical connection from suspension to electronic card

- **Suspension**
  - Holds suspended heads, provides electrical connections from head to flex cable

- **Filter**
  - Cleans air

- **Disk(s)**
  - Stores written information

- **Head(s)**
  - Writes and reads data

- **Disk Enclosure**

- **Electronic Card**

- **Filter**
  - Cleans air

- **Electronic Card**

- **Disk Enclosure**
Current Longitudinal Magnetic Recording Method

- **Disk**
  - Ultra smooth surface
  - Thin magnetic coating
  - Protective overcoat
  - Surface lubricant

- **Inductive Write Element**
  - Soft magnetic poles
  - Copper write coil
  - Alternate coil current to write magnetic transitions

- **Resistive Read Element**
  - GMR sensor to detect magnetic transitions

- Disk rotates under a slider that has an integrated read/write head at its trailing end
- Very close slider-to-disk surface proximity critical for high resolution recording
- Information is stored in magnetic transitions written onto the disk’s thin magnetic coating
- The magnetization is in the plane of the disk surface
Changing Horses: Perpendicular Recording Technology

Growth of Recording Densities
(Gigabits/square-inch vs. Year-of-Introduction)

Simple scaling allowed for increasing areal density for many years at 30% CGR

In 1990’s rate of increase greatly accelerated to 60-100% CGR

“Superparamagnetic” effect now poses a significant challenge
New technologies required

Areal Density (Gb/in²)
Perpendicular/Longitudinal Technologies Compared

**Longitudinal**
- Lower Pole
- Upper Pole
- Field from Narrow Gap
- Hard Recording Layer

**Perpendicular**
- Return Pole
- Main Pole
- Soft Magnetic Underlayer

- Disk material can be thicker, which makes small grains more resilient to superparamagnetic effect
- Soft underlayer allows head to provide stronger field to make it possible to write on media with higher stability
- Adjacent perpendicular bits stabilize one another
Perpendicular Magnetic Recording

Video:
Hitachi’s 230 Gbits/in² Perpendicular Achievement

- March 2005 laboratory spin-stand demonstration of 233 Gb/in²
  - 965,000 bits/inch x 242,000 tracks/inch = 233 Gbits/inch²

- Requires major changes in Media, Head, and R/W electronics
  - Employed single pole and trailing shield write heads and CoPtCr-oxide media with SUL

MFM image of transitions in media

This areal density will enable 20 GB 1-inch Microdrive or 1 terabyte 3.5-inch desktop drive
Perpendicular Recording Possibilities

- **First products near 150 Gbits/inch² (2005 – 2006)**
  - Enables 160 GB mobile drive and 15 GB Microdrive

- **Perpendicular magnetic recording will be ubiquitous by 2008**

  - Enables 1 TB desktop drive and 20 GB Microdrive

- **Theory shows that perpendicular can be extended to about 500 Gbits/inch²**
  - Enables ½ TB 2.5-inch drive and 40 GB Microdrive

- **Extensions to perpendicular recording -- patterned media and thermally assisted recording -- enable data densities well in excess of 1 Tbit/inch²**
  - Enables multi-TB mobile drives and >100 GB Microdrive
    - Entire HDTV video libraries in a compact set top box
    - Thousands of hours of music and multiple movies in a mobile phone
Patterned Media -- Very Small Bits

- Individual magnetic islands can be created on the disk
- Each island would represent a single bit of information

Patterned media will extend magnetic recording to > 1 Tb/in²

1000 Gb/in² = 1Tb/in²
- 5 TB 3.5-inch drive
- 1.2 TB 2.5-inch drive
- 80 GB 1-inch drive
Patterned Media Challenges

- Must use lithography with feature resolution ~ 20 nm
- Most viable approach may be nano-imprint lithography
- Major changes required in drive architecture
  - Bit aspect ratio ~1: head design, servo
  - Bit locations determined by disk: write synchronization
  - HDI on non-homogeneous surface
Thermally-Assisted Recording

- Employ temperature dependence of media coercivity to meet simultaneous demands of
  - low coercivity for writing, and
  - high coercivity for stable storage

- Requires small spot heating source with <10 ns response time aligned to write head

- Likely to be used in combination with patterned media

- Combination of temperature-assist and patterned media could extend areal density beyond 10 Tb/in²
Thermally-Assisted Recording Challenges

- Requires integration of efficient, very small spot optics with conventional magnetic recording head
- Media must be heated and cooled several 100 °C in less than 10 ns
- Must develop new high-Ku media with low noise and proper thermal properties
- Must maintain HDI reliability

May be possible to make alloys with steep \( \frac{dH}{dT} \) at modest \( T_c \)

FePt 100Å/FeRh 300Å/MgO/SiN

Largest gains only come with very small heating spot and high Ku materials

![Graph showing areal density advantage vs. exposure time]

- Assume \( \frac{T_c}{T_H} = 0.6 \)
- \( \frac{E_B(H,T)}{k_BT} = 45 \)

Integrated optics and novel near-field optical apertures required
Why do I want all this storage?

I will record all relevant information I see & hear ....

- Every picture I’ve ever taken
- Every song I want to hear
- Every movie I want to save
- Every TV show I want to see
- Every street I want to walk on
- Every newspaper I want to read
- Every sports event I want to recall
- Every medical record I’ve ever had
- Every memory of my life