# B38DF
# Computer Architecture and Embedded Systems

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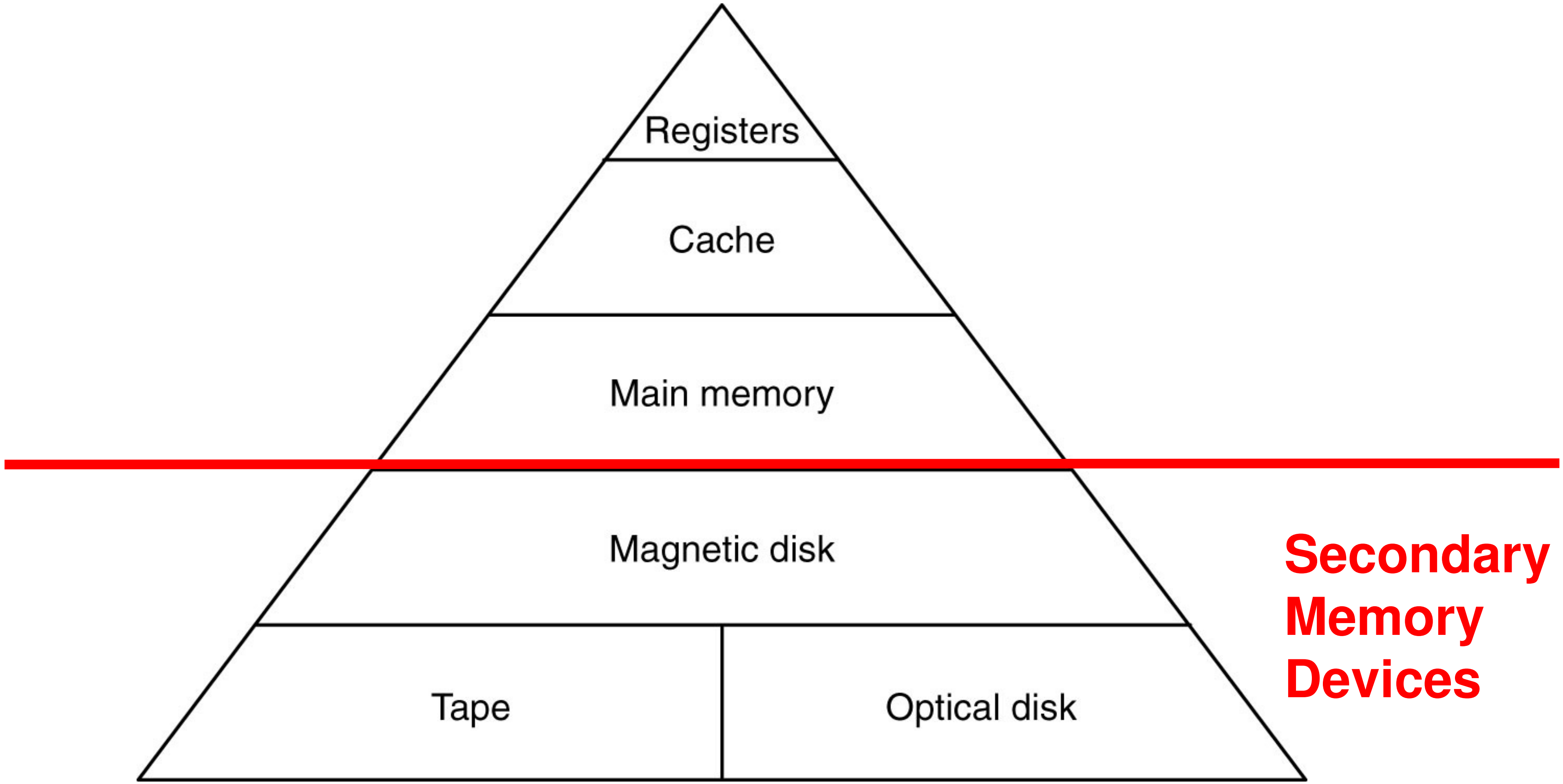
Based on the slides prepared by Dr. Mustafa Suphi Erden

# Recall of Primary Memory

- Computer programs must be in the main memory (random access memory – RAM)
- Main memory (primary memory/internal memory) is the only large storage area that the processor can access directly
  - Usually **too small** to store all the needed programs
  - **Volatile** storage device that loses its contents when power is turned off
- Secondary memory/storage devices → **Large and permanent**

# Memory Hierarchy

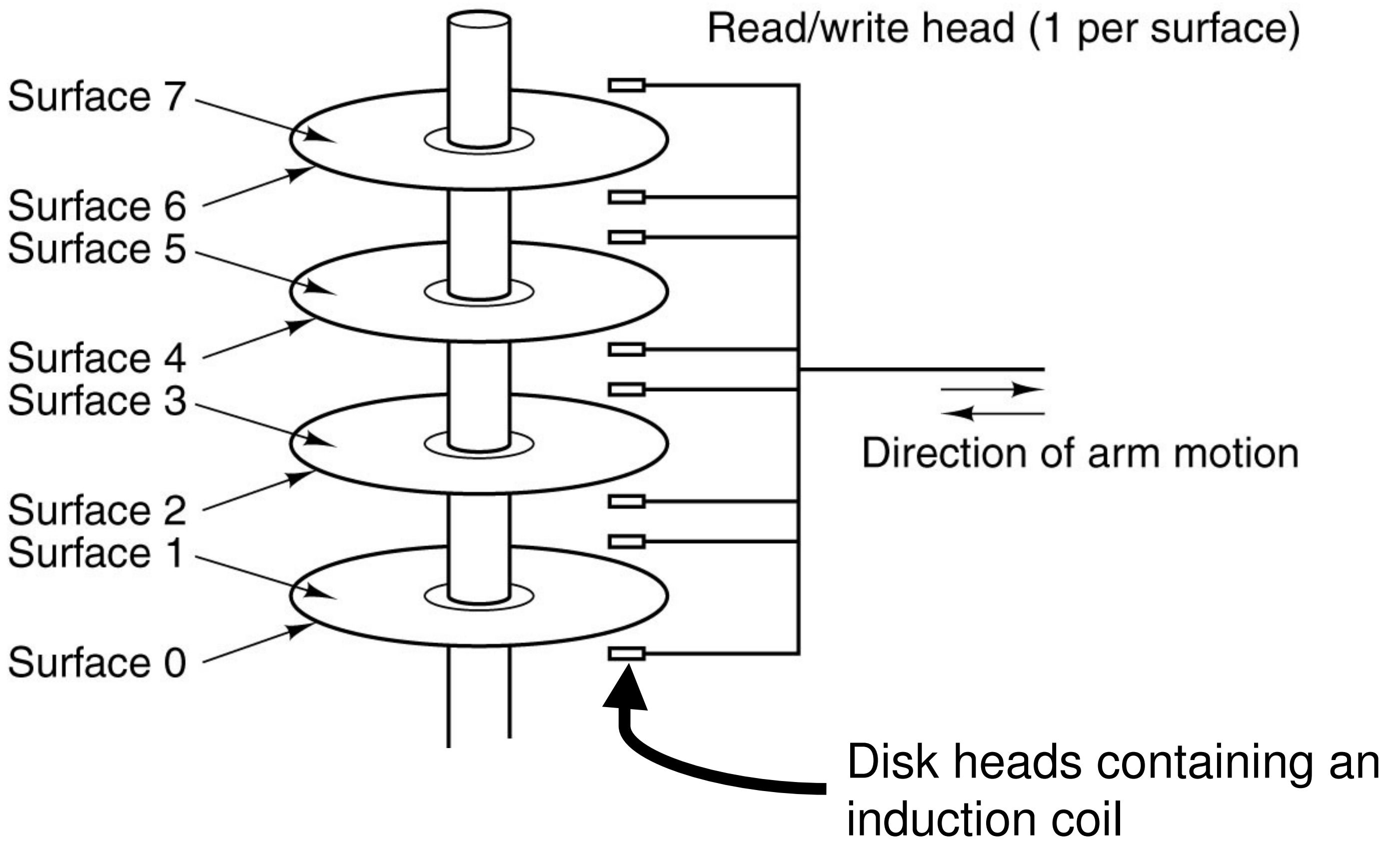
A five-level memory hierarchy



# Magnetic Disks (1)

A disk with four **platters**

- Platters: 3-12 cm in diameter
- 60-120 rev/sec



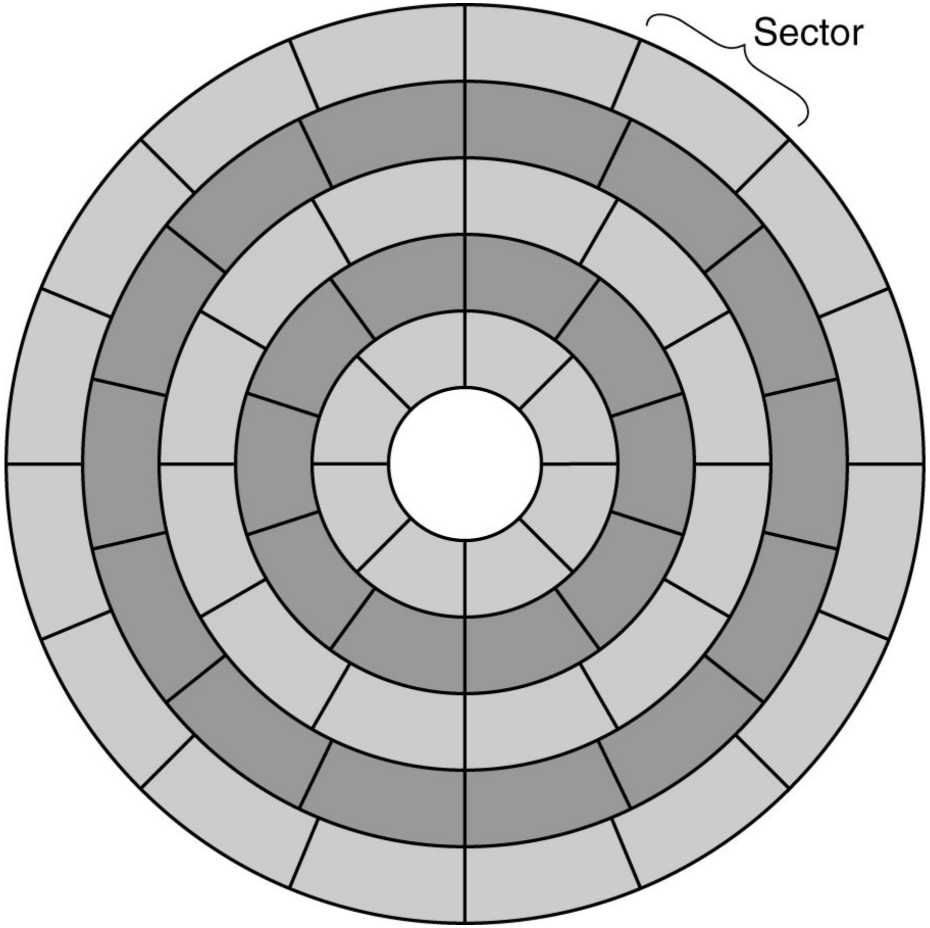
# Magnetic Disks (2)

A disk with five zones. Each zone has many tracks.

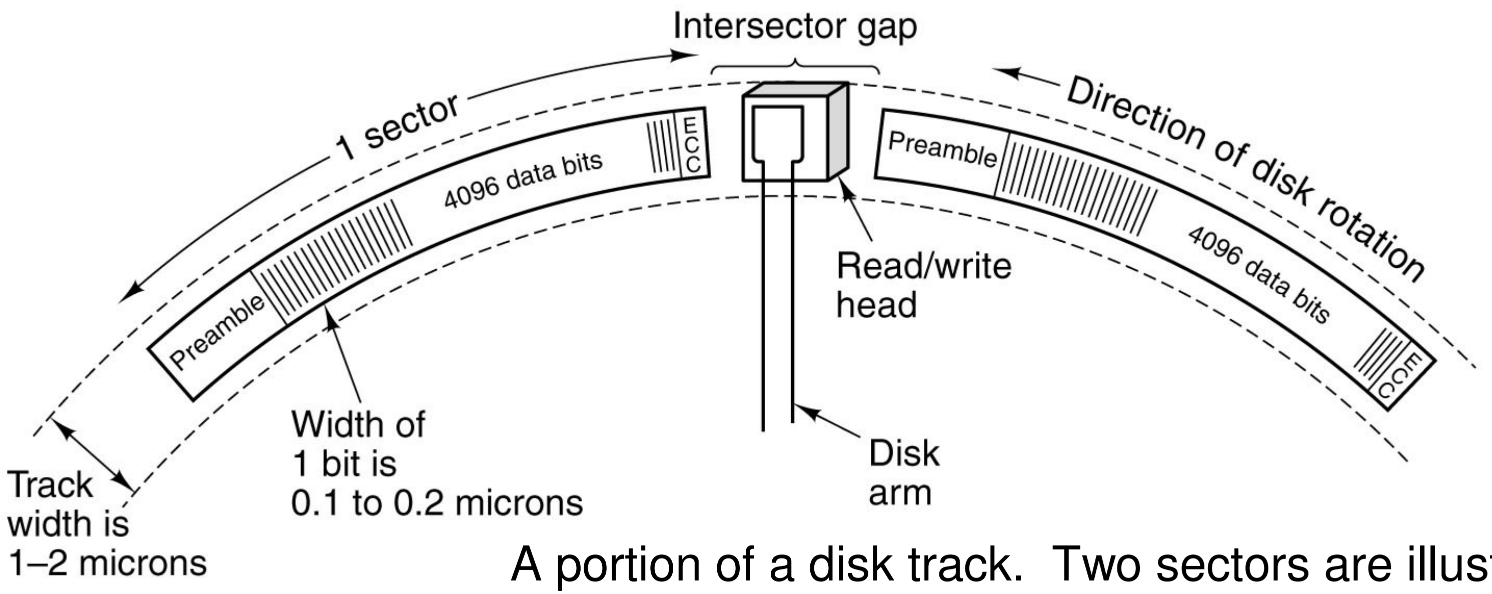
- Radial: 800-2000 tracks per cm

  5-10 micron thickness per bit
- Circumferential

  50,000-100,000 bits/cm
- 60-120 rev/sec



# Magnetic Disks (3)




A portion of a disk track. Two sectors are illustrated.

- **Preamble:** Allows the head to be synchronized before reading or writing; created during formatting.
- **ECC:** Error-Correcting Code (Hamming codes or codes that can correct burst-errors called Reed-Solomon codes).
- Difference between the <u>unformatted</u> and <u>formatted</u> disc capacity: **Preamble, ECC and gaps.**

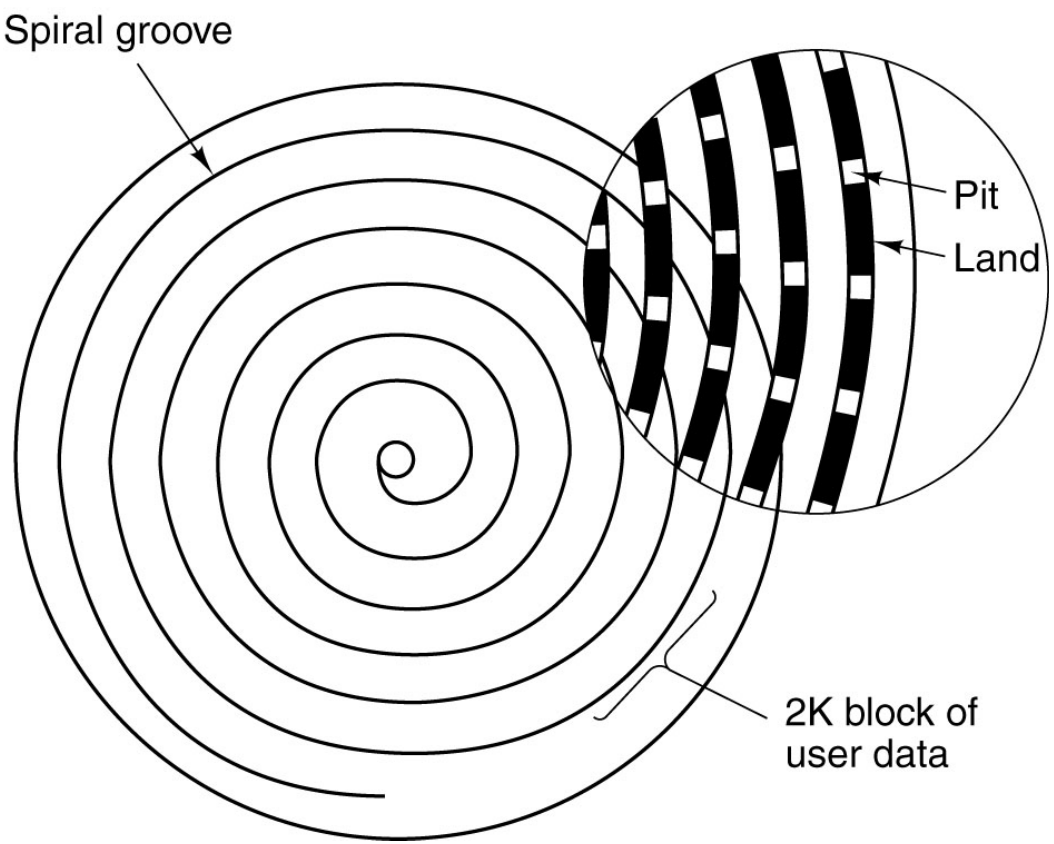
# CD-ROMs – Compact Disc – Read Only Memory (1)

- **All CDs** are 120 mm across and 1.2-mm thick, with a 15-mm hole in the middle.
- Prepared by using a **high-power infrared laser** to burn 0.8-micron diameter holes in a coated glass master disk

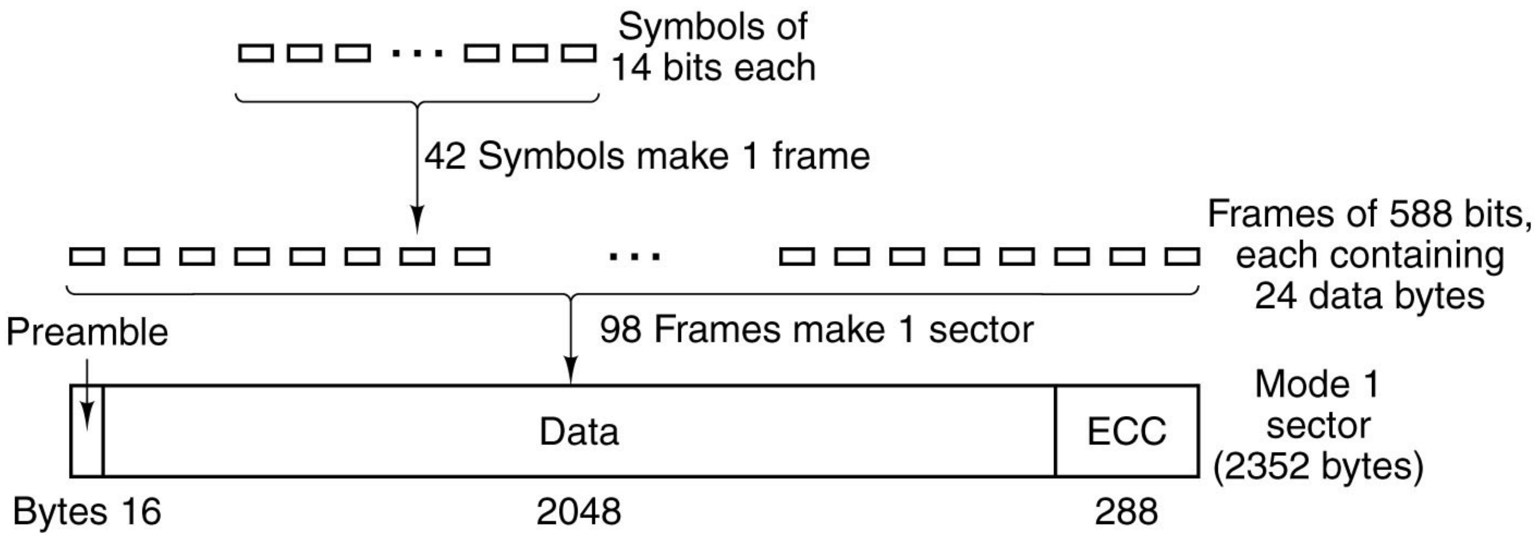
pits

- **"Pit" and "Land" structures** constructed on the polycarbonate substrate encode the data; these are illuminated by a laser diode and read by a photodetector.
- The pits and lands are written in a **single continuous spiral**, which makes 22,188 revolutions with a length of around 5.6 km, leading to a capacity of 650 MB.

**Pits** (binary value of 0 or off, due to lack of reflection when read) and **lands** (binary value of 1 or on, due to a reflection when read) on a special material on one of its flat surfaces

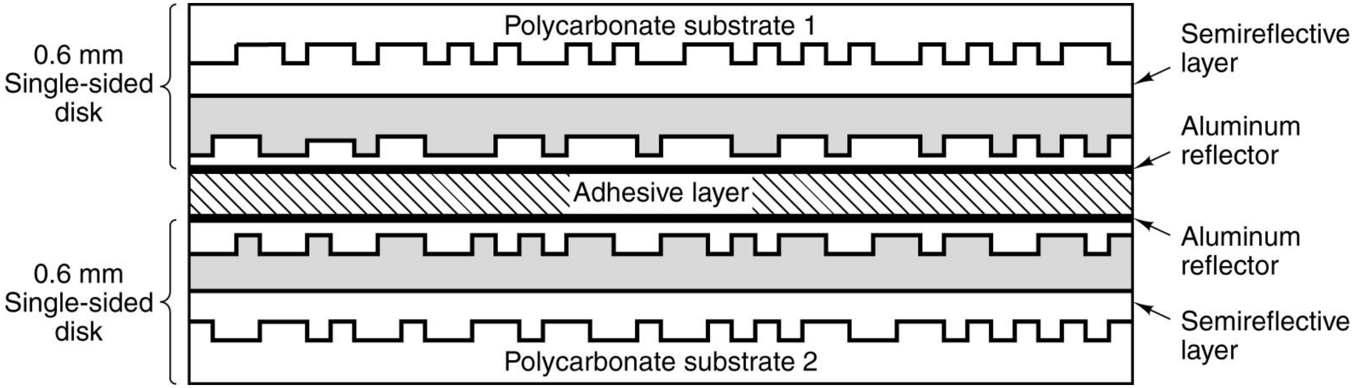


# CD-ROMs (2)




- **Preamble** includes a code for recognition of the start of a sector, the sector number, and the mode (one of the two modes of data coding)
- Every byte is encoded in a **14-bit symbol** (for error-correction)
- Single-bit errors are corrected at the lowest level, short burst errors are corrected at the frame level, and any residual errors are caught at the sector level. → 7203 bytes used for only 2048-byte data with an **efficiency of 28%**

# DVD – Digital Versatile Disc




A double-sided, dual layer DVD disk.

A human hair is about 75 micorns across

- **DVDs** use the same general design as CDs, with 120-mm injection-molded polycarbonate disks containing pits and lands that are illuminated by a laser and read by a photodetector. What is new is the use of:
  1. **Smaller pits** (0.4 microns versus 0.8 microns for CDs),
  2. A **tighter spiral** (0.74 microns between tracks versus 1.6 microns for CDs),
  3. A **red laser** (at 0.65 microns versus 0.78 microns for CDs).
- These improvements raise the capacity sevenfold to 4.7 GB

# Semiconductor Memory Types

| Memory Type | Category | Erasure | Write Mechanism | Volatility |
|---|---|---|---|---|
| Random-access memory (RAM) | Read-write memory | Electrically, byte level | Electrically | Volatile |
| Read-only memory (ROM) | Read-only memory | Not possible | Masks | Nonvolatile |
| Programmable ROM (PROM) | | | Electrically | |
| Erasable PROM (EPROM) | Read-mostly memory | UV light, chip level | | |
| Electrically Erasable PROM (EEPROM) | | Electrically, byte level | | |
| Flash memory | | Electrically, block level | | |

# Semiconductor Memory Types

| Type | Category | Erasure | Byte alterable | Volatile | Typical use |
|---|---|---|---|---|---|
| SRAM | Read/write | Electrical | Yes | Yes | Level 2 cache |
| DRAM | Read/write | Electrical | Yes | Yes | Main memory (old) |
| SDRAM | Read/write | Electrical | Yes | Yes | Main memory (new) |
| ROM | Read-only | Not possible | No | No | Large volume appliances |
| PROM | Read-only | Not possible | No | No | Small volume equipment |
| EPROM | Read-mostly | UV light | No | No | Device prototyping |
| EEPROM | Read-mostly | Electrical | Yes | No | Device prototyping |
| Flash | Read-mostly | Electrical | No | No | Film for digital camera |

**Synchronous dynamic random-access memory** (**SDRAM**) is any DRAM where the operation of its external pin interface is coordinated by an externally supplied clock signal.

**DDR SDRAM** (double data rate SDRAM) is a further development of DRAM

## Read-Only Memory (ROM)

- A **ROM** contains a permanent pattern of data that cannot be changed.
- A ROM is nonvolatile; that is, no power source is required to maintain the bit values in memory.
- The data is recorded in ROM as a part of the fabrication process.
- An important application of ROM is microprogramming.

(The execution of instructions is somewhat like running a very small program. Some machines have a little program, called a **microprogram**, to execute their instructions.)

## Programmable ROM (PROM)

- A **PROM** is nonvolatile like a ROM, and may be written into only once.
- The writing process is performed electrically and may be performed at a time later than the original chip fabrication.
- Special equipment is required for the writing or "programming" process.

## Erasable Programmable ROM (EPROM)

- An **EPROM is** read and written electrically, as with PROM; however, before a write operation all the storage cells must be erased to the same initial state by exposure of the packaged chip to ultraviolet radiation.
- Each erasure can take as much as 20 minutes.

## Electrically Erasable Programmable ROM (EEPROM)

- An **EEPROM** can be written into at any time without erasing prior contents; only the byte or bytes addressed are updated.
- The write operation takes considerably longer than the read operation, on the order of several hundred microseconds per byte.
- Combines the advantage of nonvolatility with the flexibility of being updatable in place, using ordinary bus control, address, and data lines.

# Flash Memory

- A **flash memory** uses an electrical erasing technology, like EEPROM
- An entire flash memory can be erased in one or a few seconds, which is much faster than EPROM.
- It is also possible to erase just blocks of memory rather than an entire chip.
- Flash memory gets its name because the microchip is organized so that a section of memory cells are erased in a single action or “flash”.
- However, unlike EEPROM, a flash memory does not provide byte-level erasure.

# The Future of Data Storage (1)

- Advances in technology have defied all efforts to define the ultimate upper limit for magnetic disk storage.
  - In the 1970s, the upper limit was thought to be around $2Mb/in^2$.
  - Today's disks (2015) commonly support $20Gb/in^2$.
- Improvements have occurred in several different technologies including:
  - Materials science
  - Magneto-optical recording heads.
  - Error correcting codes.

# The Future of Data Storage (2)

- As data densities increase, bit cells consist of proportionately fewer magnetic grains.
- There is a point at which there are too few grains to hold a value, and a 1 might spontaneously change to a 0, or vice versa.
- This point is called the superparamagnetic limit.
  - In 2006, the superparamagnetic limit is thought to lie between 150Gb/in$^2$ and 200Gb/in$^2$ .
- Even if this limit is wrong by a few orders of magnitude, the greatest gains in magnetic storage have probably already been realized.

# The Future of Data Storage (3)

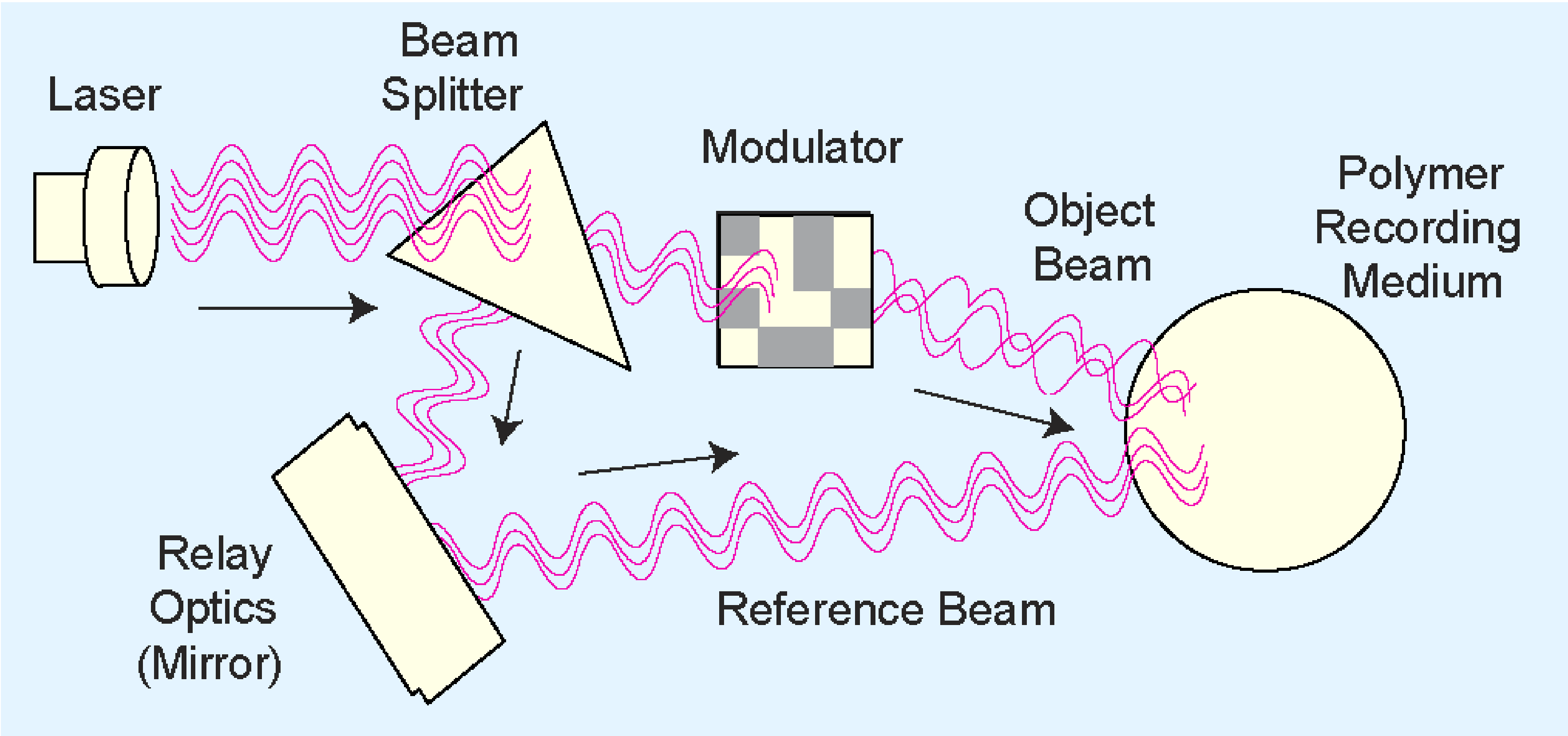
- Future exponential gains in data storage most likely will occur through the use of totally new technologies.
- Research into finding suitable replacements for magnetic disks is taking place on several fronts.
- Some of the more interesting technologies include:
  - Biological materials
  - Holographic systems
  - Micro-electro-mechanical devices
  - Memristors
  - Carbon nanotubes

# The Future of Data Storage (4)

- Present day biological data storage systems combine organic compounds such as proteins or oils with inorganic (magentizable) substances.
- Early prototypes have encouraged the expectation that densities of $1Tb/in^2$ are attainable.
- Of course, the ultimate biological data storage medium is DNA.
  - Trillions of messages can be stored in a tiny strand of DNA.
- Practical DNA-based data storage is most likely decades away.

# The Future of Data Storage (5)

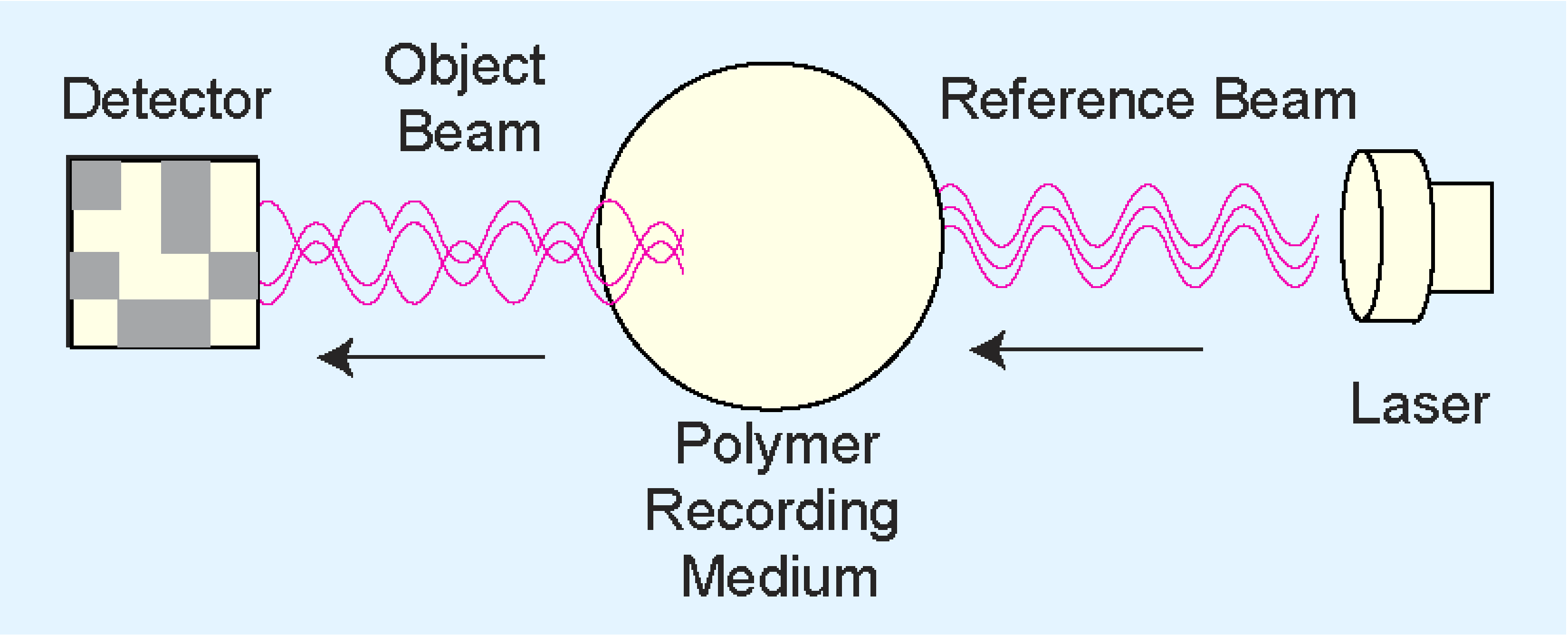
- Holographic storage uses a pair of laser beams to etch a three-dimensional hologram onto a polymer medium.




A **hologram** is a physical structure that uses light diffraction to make an image; the image can appear to be three-dimensional.

# The Future of Data Storage (6)

- Data is retrieved by passing the reference beam through the hologram, thereby reproducing the original coded object beam.



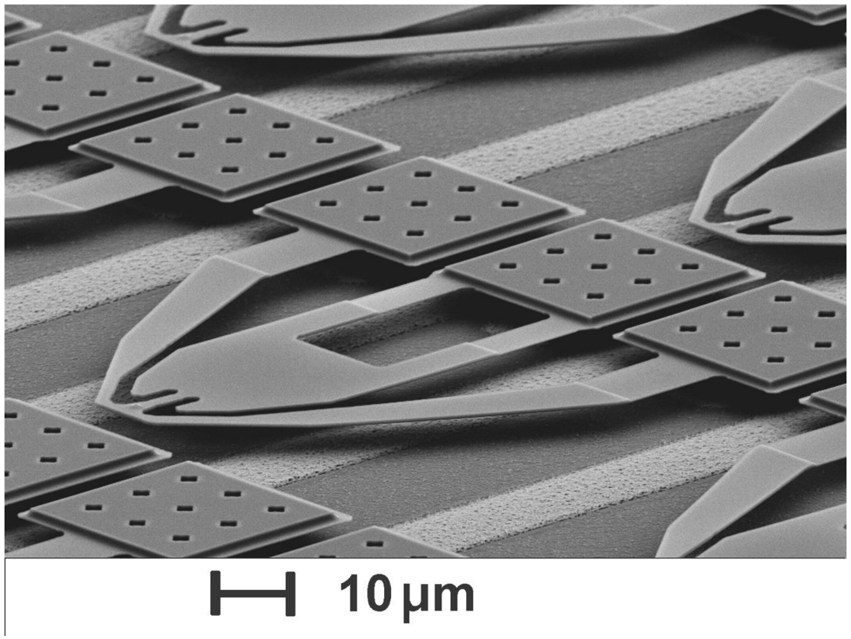
# The Future of Data Storage (7)

- Because holograms are three-dimensional, tremendous data densities are possible.
- Experimental systems have achieved over 30Gb/in$^2$, with transfer rates of around 1GBps.
- In addition, holographic storage is content addressable.
  - This means that there is no need for a file directory on the disk. Accordingly, access time is reduced.
- The major challenge is in finding an inexpensive, stable, rewriteable holographic medium.

# The Future of Data Storage (8)

- Micro-electro-mechanical storage (MEMS) devices offer another promising approach to mass storage.
- IBM's Millipede is one such device.
- Prototypes have achieved densities of 100Gb/in$^2$ with 1Tb/in$^2$ expected as the technology is refined.

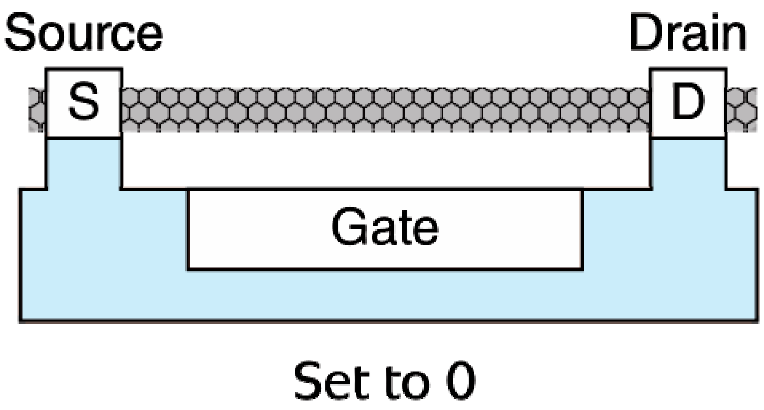
- Millipede consists of thousands of cantilevers that record a binary 1 by pressing a heated tip into a polymer substrate.
- The tip reads a binary 1 when it dips into the imprint in the polymer

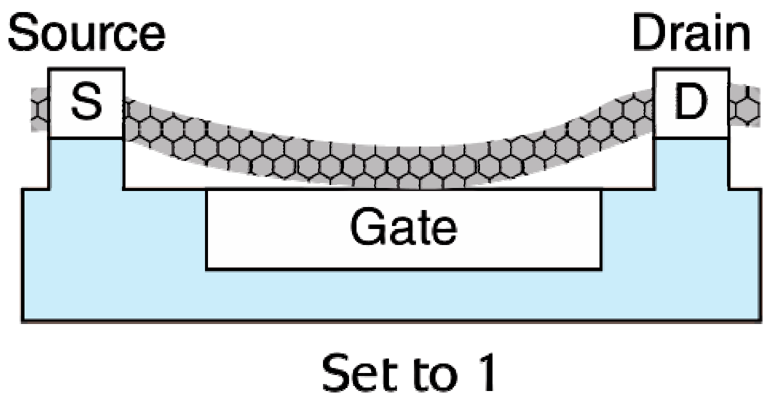



**Photomicrograph courtesy of the IBM Corporation. © 2005 IBM Corporation**

# The Future of Data Storage (9)

- Carbon nanotubes (CNTs) are a cylindrical form of elemental carbon: The walls of the cylinders are one atom thick.
- CNTs can act like switches, opening and closing to store bits.
- Once "set" the CNT stays in place until a release voltage is applied.



# The Future of Data Storage (10)

- Memristors are electronic components that combine the properties of a resistor with memory.
- Resistance to current flow can be controlled so that states of “high” and “low” store data bits.
- Like carbon nanotubes, memristor memories are non-volatile, holding their state until certain threshold voltages are applied.
- These non-volatile memories promise enormous energy savings and increased data access speeds in the very near future.