Computer Organization & Architecture

Chapter 8 – Secondary Storage

Zhang Yang 张杨

cszyang@scut.edu.cn

Autumn 2025

Contents of this lecture

- 8.10 Secondary Storage
  - Magnetic Disk
  - Solid State Drives (Supplement): Referenced from “Computer Organization and Architecture-Designing for Performance”
  - Optical Memory
  - Summary

Types of Secondary Storage

- Magnetic Disk
  - Hard Disk
  - Floppy Disk
- Solid State Drives
- Optical Memory
  - CD
  - CD-ROM
  - CD-Recordable (CD-R)
  - CD-R/W
  - DVD
  - Blu-ray Disk
- Magnetic Tape

Contents of this lecture

- 8.10 Secondary Storage
  - Magnetic Disk
  - Solid State Drives (Supplement)
  - Optical Memory
  - Summary

Magnetic Disk

- Metal or plastic or glass disk coated with magnetizable material (iron oxide…rust).
- Range of packaging
  - Winchester hard disk
  - Removable hard disk
  - Floppy disk

Disk Systems

- Physical Characteristics

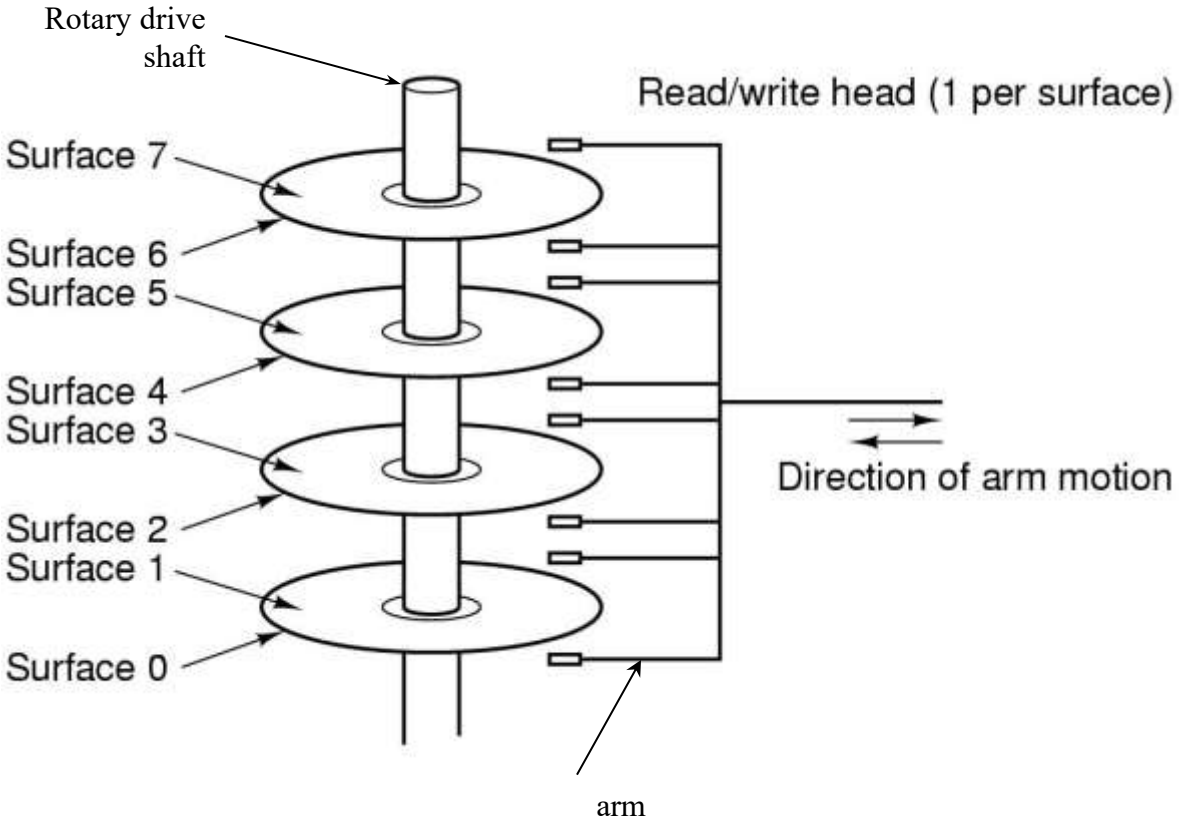
Head Motion	**Platters**
Fixed head (one per track)	Single platter
Movable head (one per surface)	Multiple platter
Disk Portability	**Head Mechanism**
Nonremovable disk	Contact (floppy)
Removable disk	Fixed gap
	Aerodynamic gap (Winchester)
Sides	
Single sided	
Double sided	

Magnetic Hard Disk (1)

- Mechanical Structure
  - Overall Structure
    - One or more disks (double-sided/single-sided) mounted on a common spindle.
    - A disk is a circular platter constructed of metal or of plastic or of glass coated with a magnetizable material.
    - The disks are placed in a rotary drive and they rotate at a uniform speed.

Magnetic Hard Disk (2)

- Mechanical Structure (ctd.)
  - Overall Structure (ctd.)

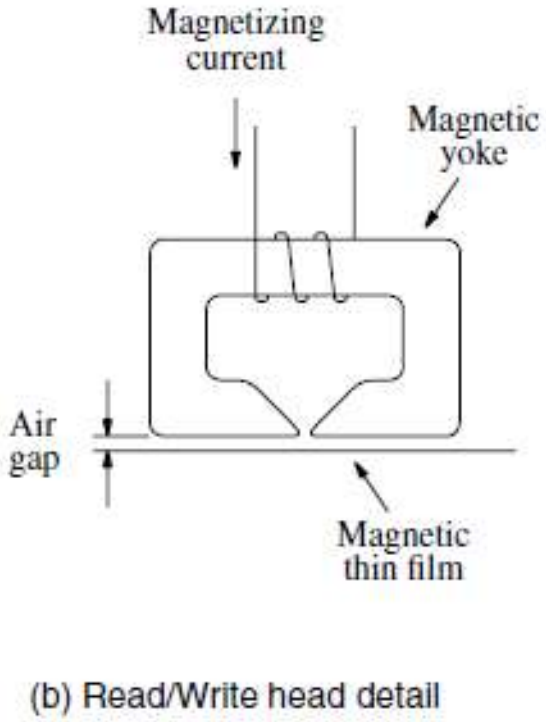


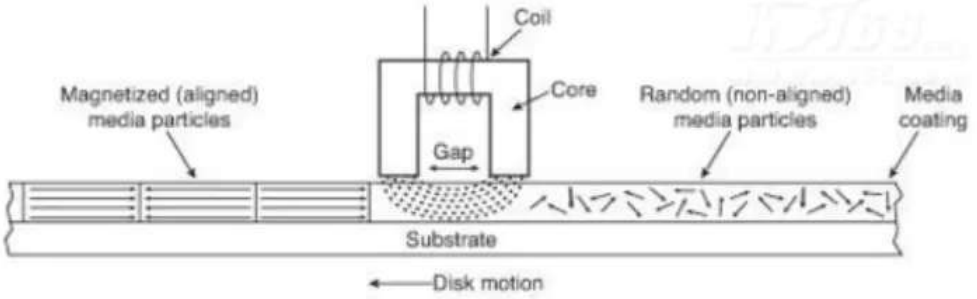
Magnetic Hard Disk (3)

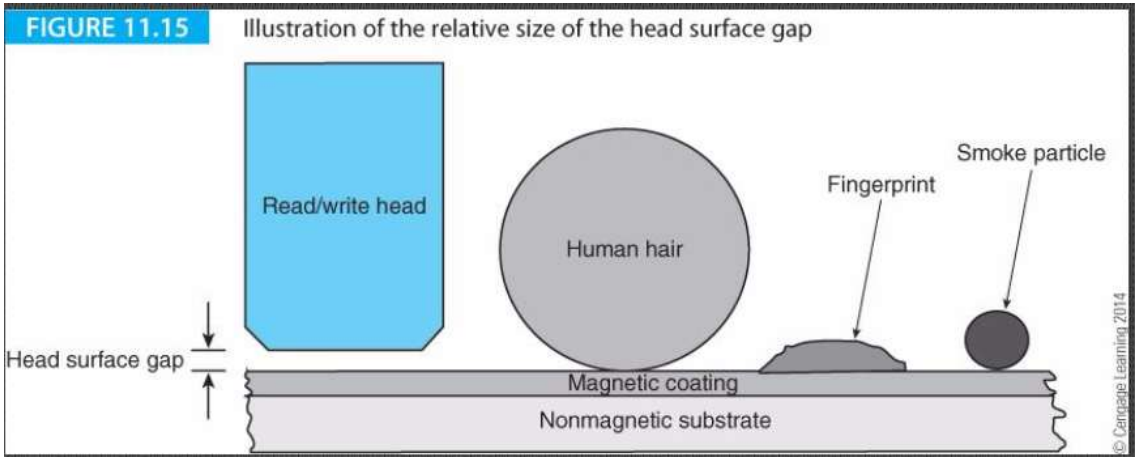
- Read/Write Head
  - Fixed Head
    - One read/write head per track.
    - Heads mounted on fixed ridged arm.
    - Expensive, no longer production.
  - Movable Head
    - One read/write head per side.
    - Mounted on a movable arm.
  - Detail
    - Each head consist of a magnetic yoke and a magnetizing coil.
    - Read/Write must be maintained at a very small distance from the moving disk surfaces.

Magnetic Hard Disk (4)

- Read/Write Head (ctd.)
  - Detail





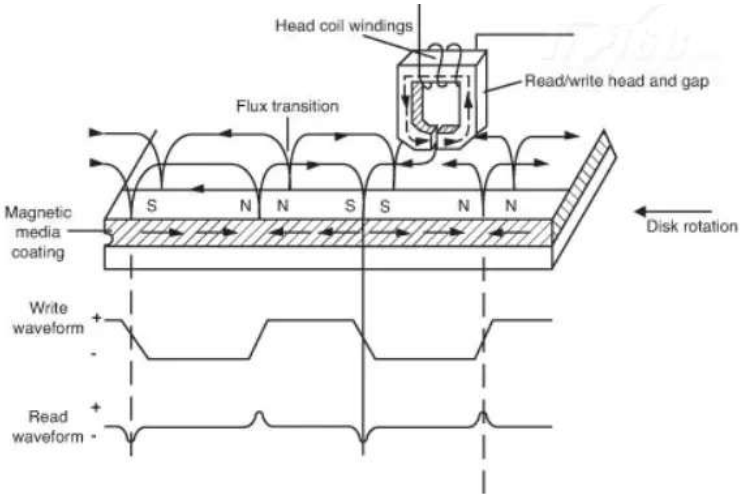


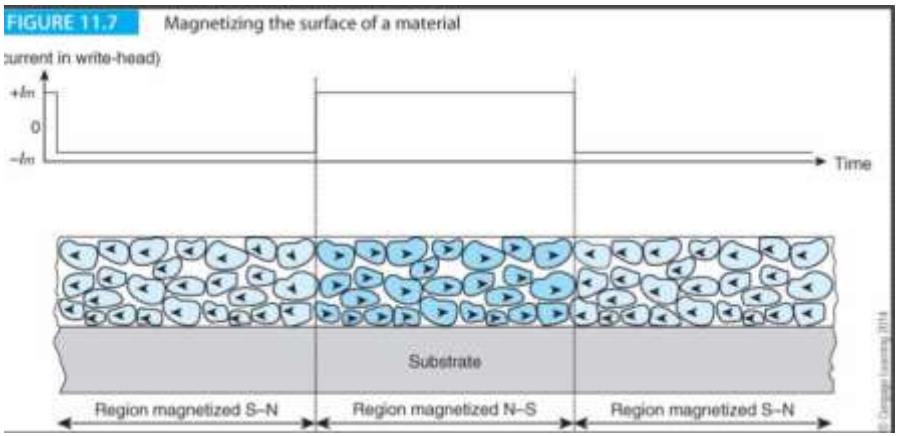
Magnetic Hard Disk (5)

- Read/Write Mechanism
  - Recording and retrieval via conductive coil(s) called a head(s).
  - May be single read/write head or separate ones.
  - During read/write, head is stationary (actually moves radially to platters) and platter rotates beneath head.

Magnetic Hard Disk (6)

- Read/Write Mechanism (ctd.)
  - Hard Drive Write
    - Current through coil produces magnetic field.
    - Pulses sent to head.
    - Magnetic pattern recorded on surface below.





Magnetic Hard Disk (7)

- Read/Write Mechanism (ctd.)
  - Hard Drive Read (Traditional)
    - Magnetic field ***moving*** relative to coil produces current. – Analogous to a generator or alternator.
    - Coil can be the same for read and write.

Magnetic Hard Disk (8)

- Disk Portability: Removable or Fixed
  - Removable disk
    - Can be removed from drive and replaced with another disk.
    - E.g. floppy, zip
    - Provides unlimited storage capacity.
    - Easy data transfer between systems.
  - Nonremovable disk
    - Permanently mounted in the drive.

Winchester Hard Disk

- Developed by IBM in Winchester (USA)
- Sealed unit
- One or more platters (disks)
- Heads fly on boundary layer of air as disk spins (crash into disk!)
- Very small head to disk gap
- Getting more robust.
- Universal
- Cheap
- Fastest external storage
- Getting larger all the time
  - Multiple Gigabyte now usual

Data Organization of Hard Disk (1)

- Each surface is divided into concentric tracks, and each track is divided into sectors.

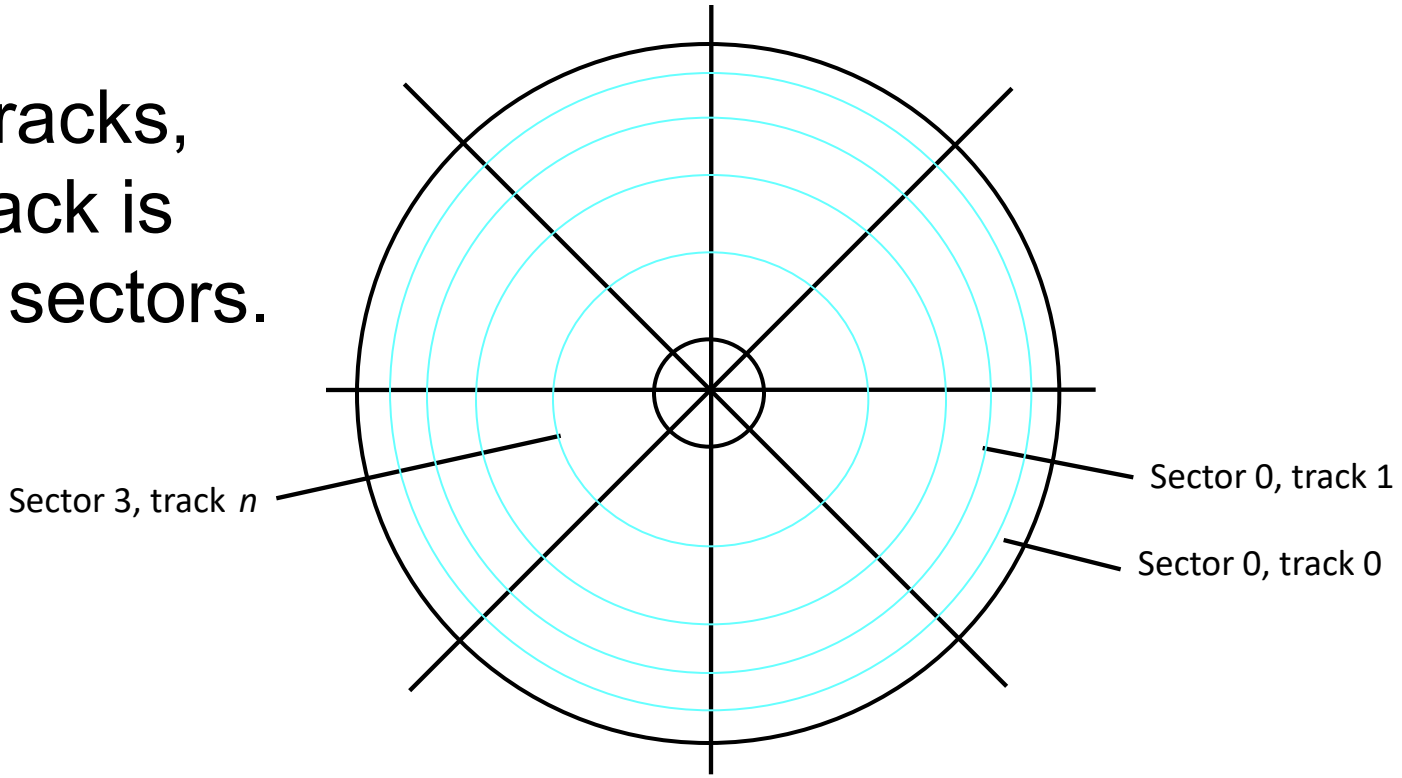
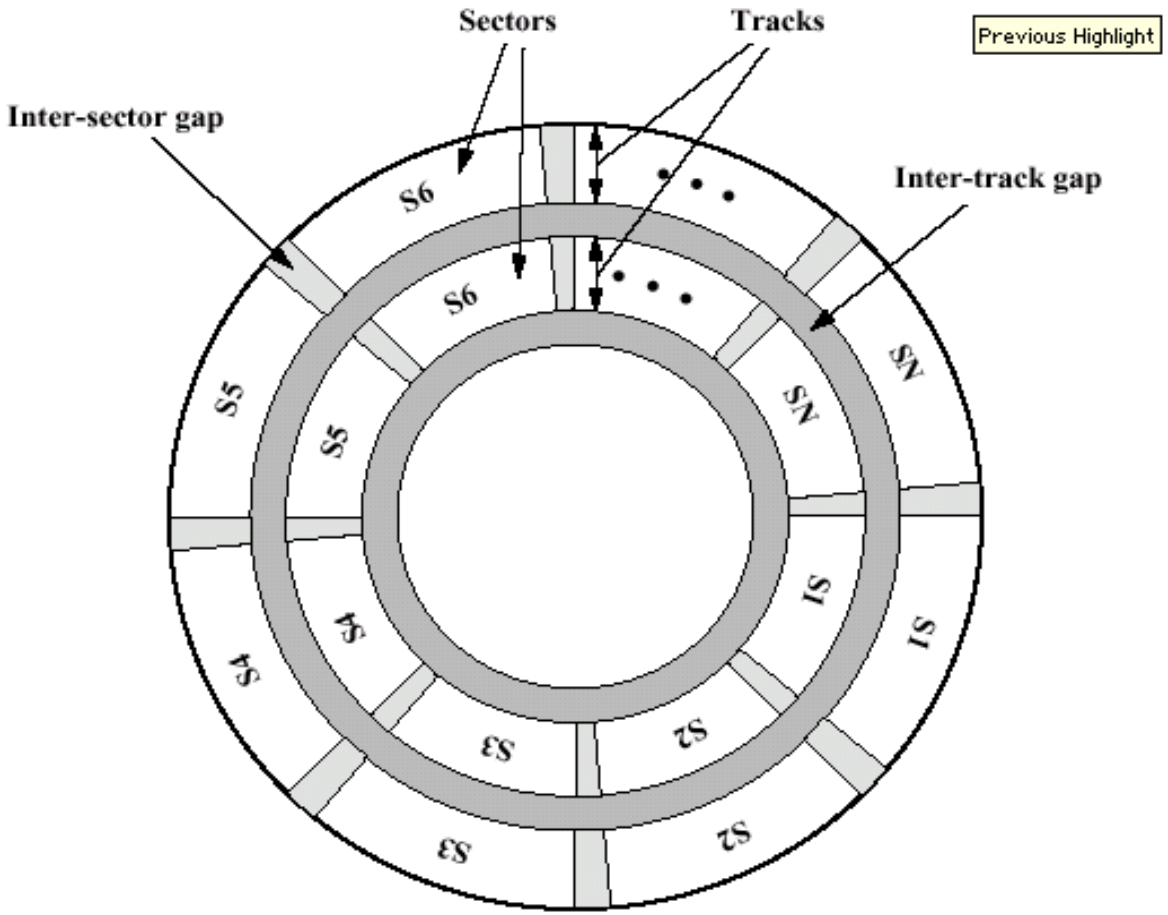


Figure 8.28. Organization of one surface of a disk.

Data Organization of Hard Disk (2)

- Tracks & Sectors

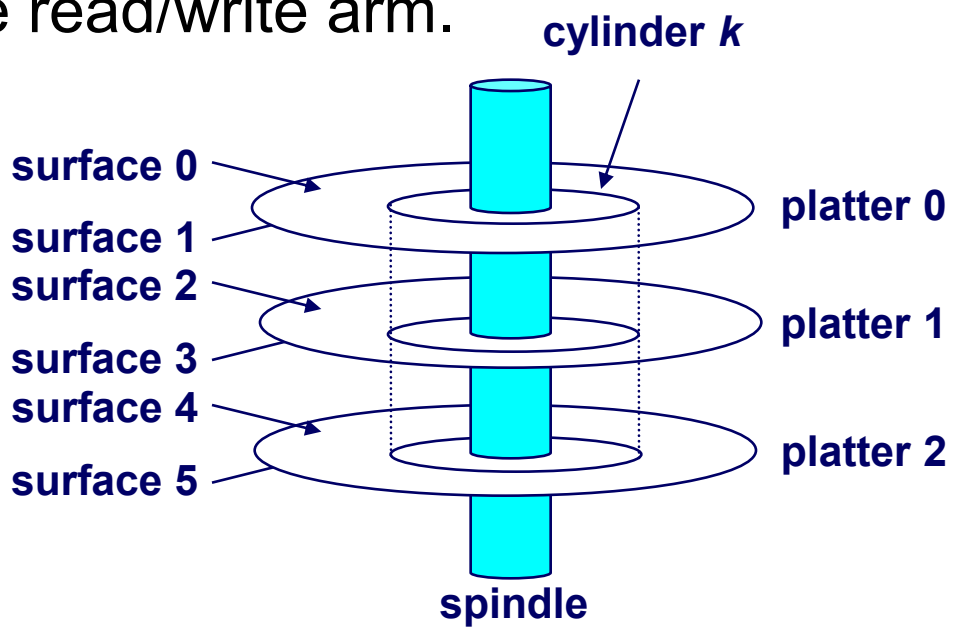


Data Organization of Hard Disk (3)

- Tracks & Sectors (ctd.)
  - Each track has the same number of sectors.
  - Outer tracks have more sectors. (Applied in large disks)
  - Tracks usually
    - 500 – 2000 tracks per surface
  - Sectors usually
    - Past: 512 bytes, Now: 4K bytes
    - 10 – 100 sectors per track
- Disk address: (surface number, track number, sector number)

Data Organization of Hard Disk (4)

- Cylinders
  - A cylinder is the set of tracks at a given radius of a disk pack.
    - i.e. a cylinder is the set of tracks that can be accessed without moving the disk arm.
    - All the information on a cylinder can be accessed without moving the read/write arm.

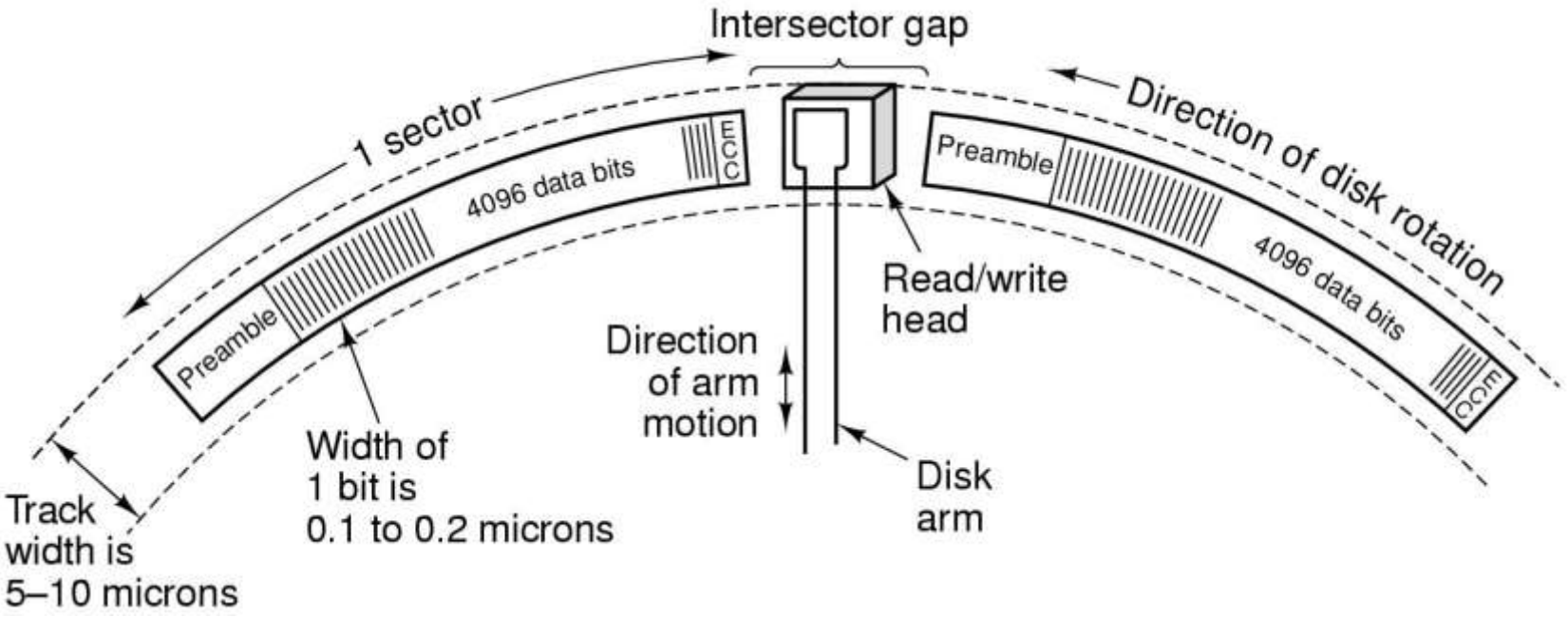


Data Organization of Hard Disk (5)

- Track Organization
  - Sector Header
    - Contains identification (addressing) information used to find the desired sector on the selected track.
  - ECC (Error-correcting Code) bits
    - Detect and correct errors that may have occurred in writing or reading of the 512 data bytes.
  - Intersector Gap
    - Distinguish between two consecutive sectors easily

Data Organization of Hard Disk (6)

- Track Organization (ctd.)
  - Figure



Disk Format

- Divide the disk into tracks and sectors.
- The formatting process may discover some defective sectors or even whole tracks.
- The formatting information accounts for about 15 percent of the total information that can be stored on a disk.

Disk Capacity (1)

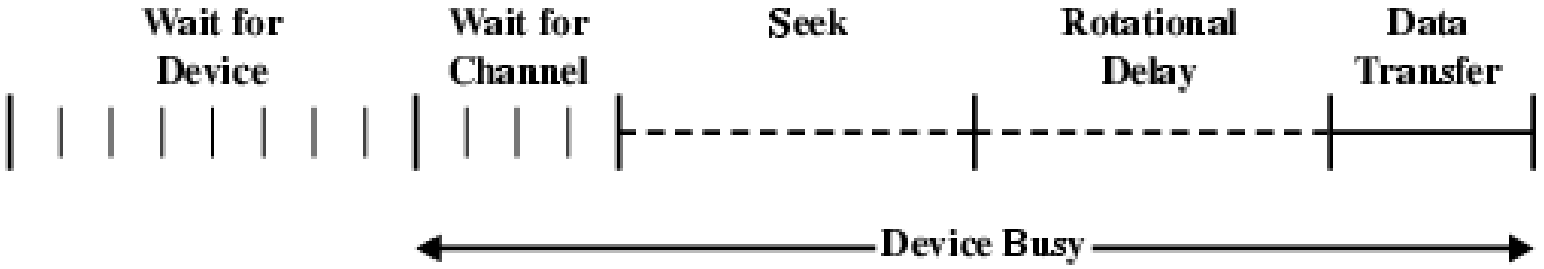
- Capacity: maximum number of bits that can be stored.
- Vendors express capacity in units of gigabytes (GB), where 1 GB = 10^9 Bytes).
- Capacity is determined by these technology factors:
  - Recording density (bits/in): number of bits that can be squeezed into a 1 inch segment of a track.
  - Track density (tracks/in): number of tracks that can be squeezed into a 1 inch radial segment. (tpi)
  - Areal density (bits/in^2): product of recording and track density.

Disk Capacity (2)

- Capacity = (# bytes/sector) x (avg. # sectors/track) x (# tracks/surface) x (# surfaces/platter) x (# platters/disk)
- Example
  - 512 bytes/sector
  - 300 sectors/track (on average)
  - 20,000 tracks/surface
  - 2 surfaces/platter
  - 5 platters/disk
  - Capacity = 512 x 300 x 20000 x 2 x 5 = 30,720,000,000 = 30.72 GB

Disk Access Time

- The time to access a sector in a track on a surface is divided into 3 components:
  - Seek time: Time to move the read/write arm to the correct cylinder. (5-15ms)
  - Rotational delay (or latency): Time it takes for the disk to rotate so that the desired sector is under the read/write head. (4-8ms)
  - Transfer time: Once the read/write head is positioned over the data, this is the time it takes for transferring data. (25-100us)

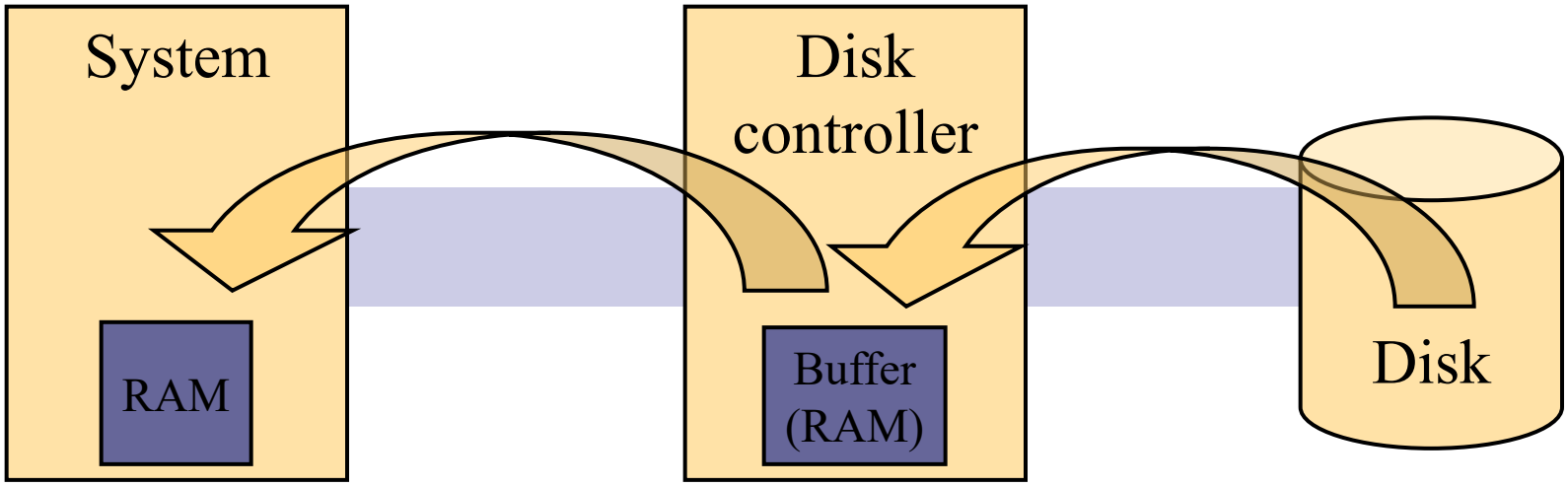


Disk Controller (1)

- Interface between the disk drive and the system is known as a disk controller.
- A primary function is to ensure data read/write operations are from/to the correct sector.
- Since data rate to/from the disk is different than data rate to/from system memory, "buffering" is needed.

Disk Controller (2)

- Disk Controller As a Buffer

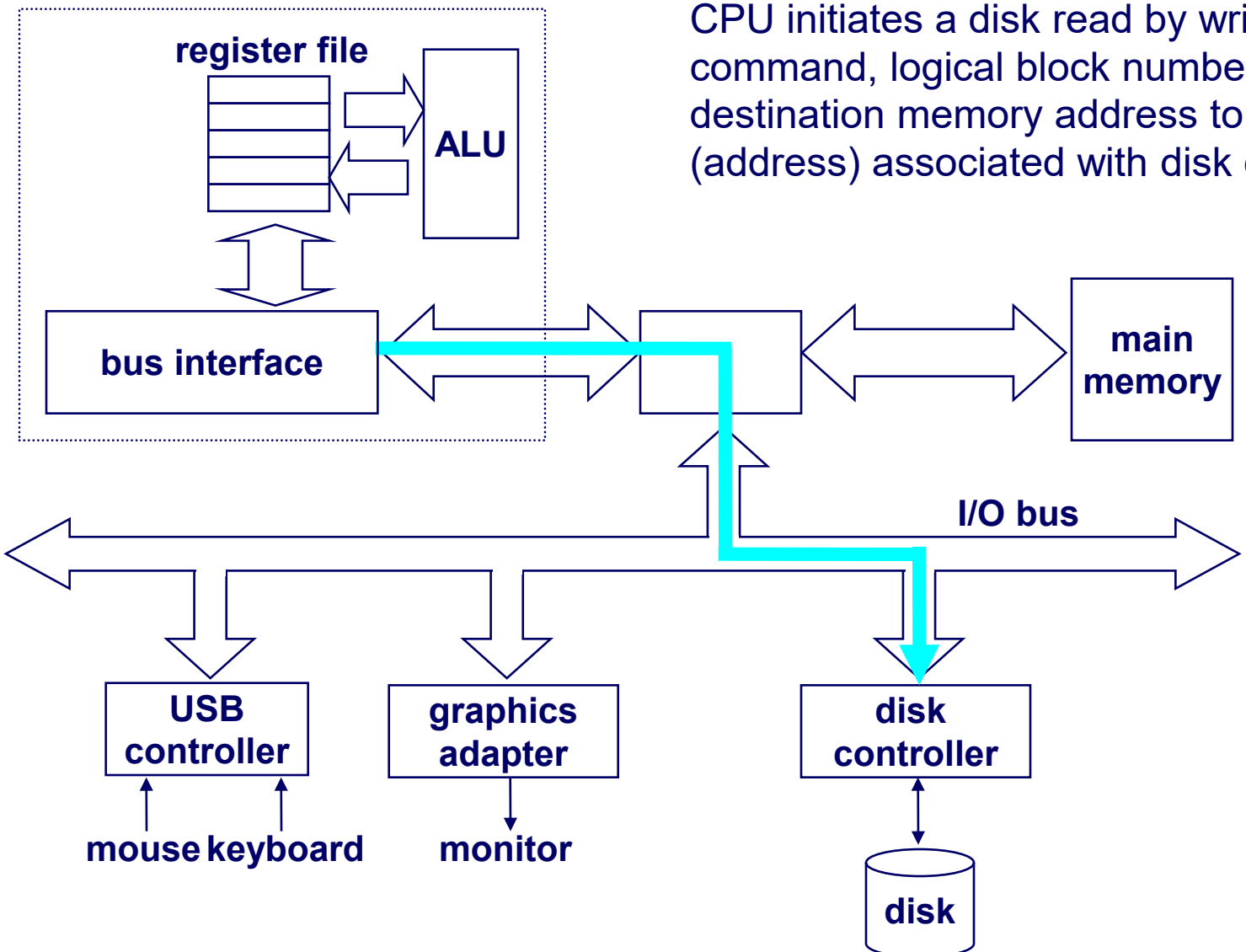


2. Transfer data from buffer to system RAM (Note: this is a DMA operation)

1. Read data from disk into a buffer in the disk controller

Disk Controller (3)

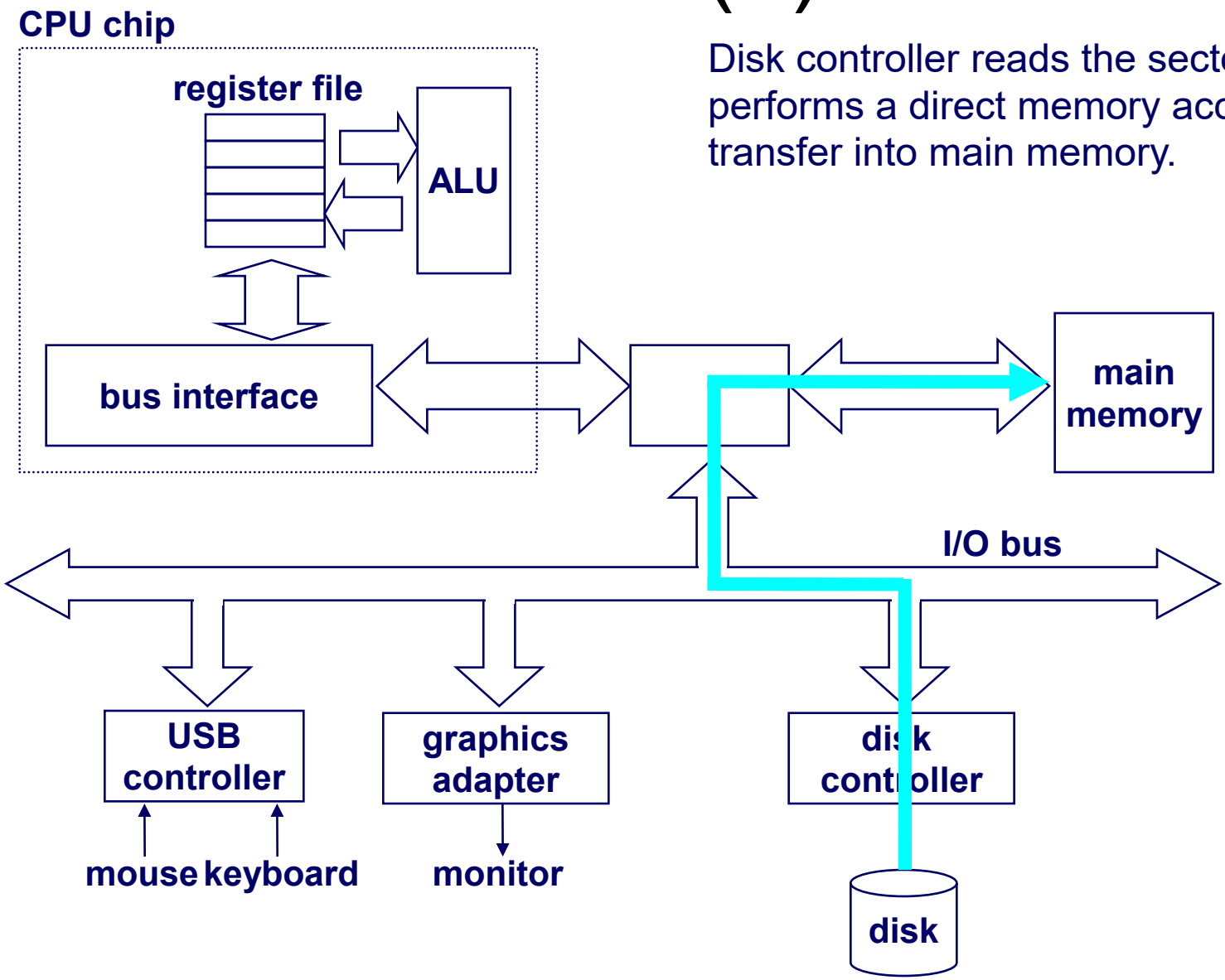
- DMA Transfer Using Disk Controller



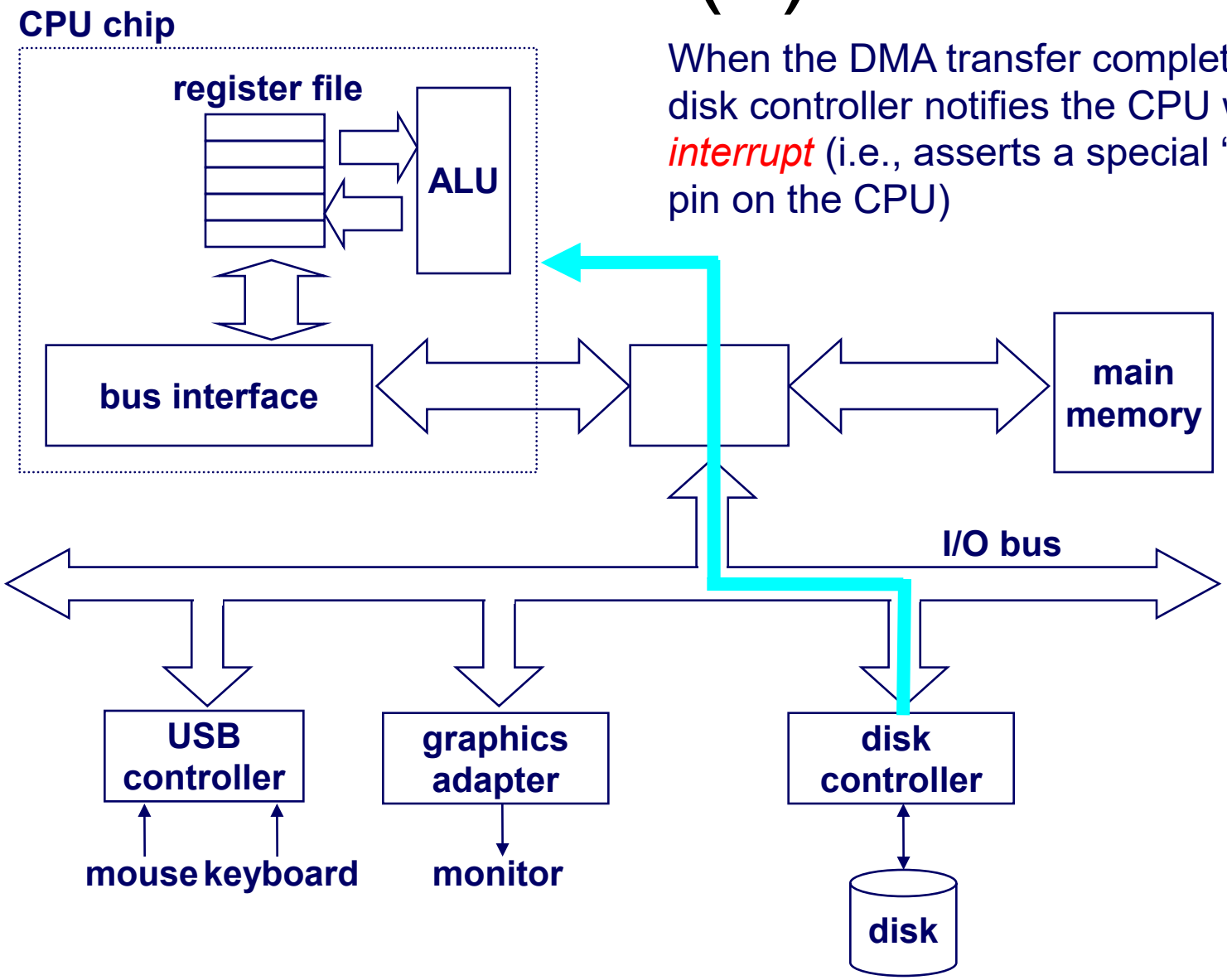
CPU initiates a disk read by writing a command, logical block number, and destination memory address to a port (address) associated with disk controller.

Disk Controller (4)

Disk controller reads the sector and performs a direct memory access (DMA) transfer into main memory.



Disk Controller (5)



When the DMA transfer completes, the disk controller notifies the CPU with an *interrupt* (i.e., asserts a special “interrupt” pin on the CPU)

Disk Controller (6)

- Main Functions of Disk Controller (from the disk drive's viewpoint)
  - Seek: Causes the disk drive to move the read/write head from its current position to the desired track.
  - Read: Initiates a Read operation, starting at the address specified in the disk address register.
  - Write: Transfers data to the disk, using a control method similar to that for Read operation.
  - Error checking: Computes the ECC value for the data read from a given sector and compares it with the corresponding ECC value read from the disk.

Solved Problems (1)

- Example 8.6 **Problem:** Consider a long sequence of accesses to a disk with an average seek time of 6 ms and an average rotational delay of 3 ms. The average size of a block being accessed is 8K bytes. The data transfer rate from the disk is 34 Mbytes/sec.
  - (*a*) Assuming that the data blocks are randomly located on the disk, estimate the average percentage of the total time occupied by seek operations and rotational delays.
  - (*b*) Repeat part (*a*) for the situation in which disk accesses are arranged so that in 90 percent of the cases, the next access will be to a data block on the same cylinder.

Solved Problems (2)

- Example 8.6 **Solution:** It takes 8K/34M = 0.23 ms to transfer a block of data.
  - (*a*) The total time needed to access each block is 6 + 3 + 0.23 = 9.23 ms. The portion of time occupied by seek and rotational delay is 9/9.23 = 0.97 = 97%.
  - (*b*) In 90% of the cases, only rotational delays are involved. Therefore, the average time to access a block is 0.9 × 3 + 0.1 × 9 + 0.23 = 3.83 ms. The portion of time occupied by seek and rotational delay is 3.6/3.83 = 0.94 = 94%.

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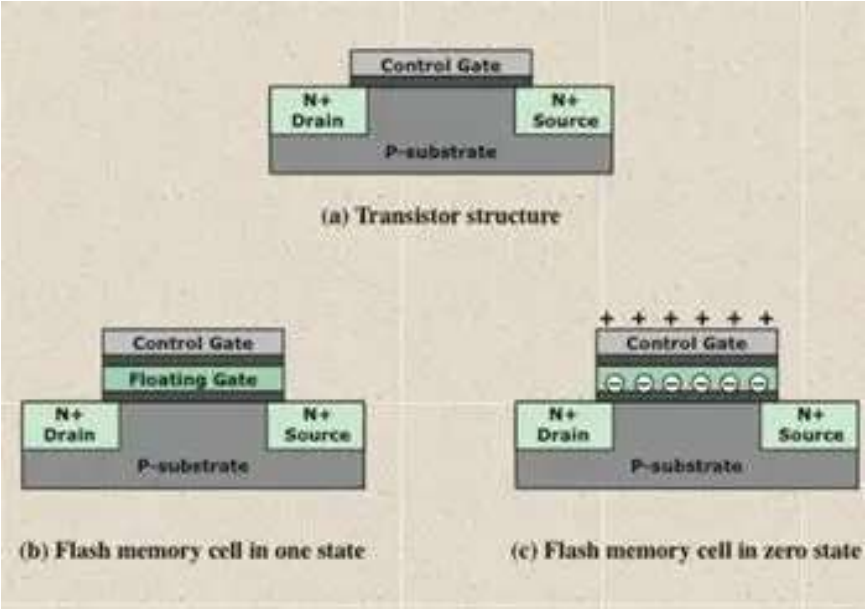
Solid State Drives

- Solid State
  - Refers to electronic circuitry built with semiconductor.
- Solid State Drive
  - A memory device made with solid state components that can be used as a replacement to a hard disk drive.
- The SSDs now on the market and coming online use a type of semiconductor memory referred to as flash memory.

Flash Memory (1)

- Flash Memory Cell
  - Floating Gate
    - When there is no electric charge in the floating gate, it is represented as "1".
    - When there are negative charges/electrons stored in the floating gate, it is represented as "0".



Flash Memory (2)

- Two Types of Flash Memory
  - NOR Flash
    - Named after the Boolean operator NOR (NOT OR)
    - NOR Flash is a form of flash memory where reminiscence cells are connected in a NOR gate configuration.
  - NAND Flash Memory
    - Named after the Boolean operator NAND (NOT AND)
    - NAND flash is a form of flash memory where information is stored in a chain of memory cells connected in a NAND gate configuration.

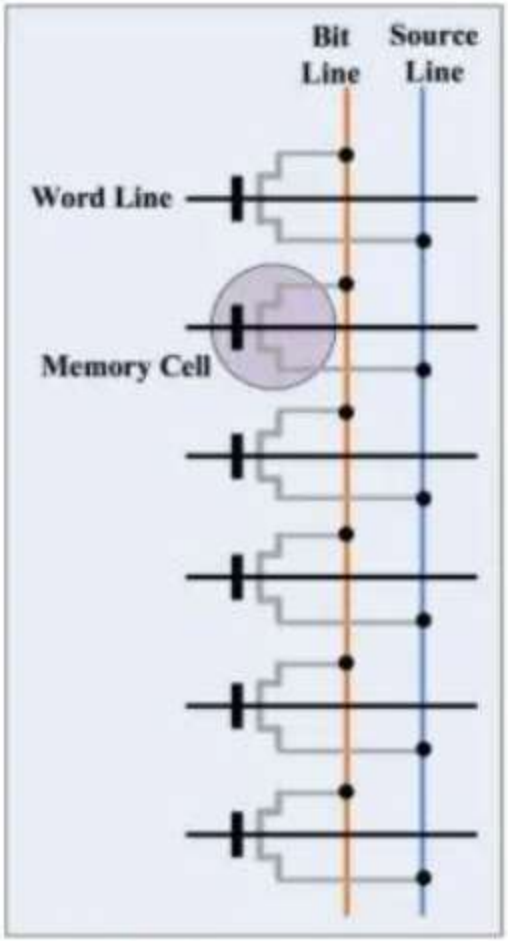
Flash Memory (3)

- Differences between NOR and NAND Flash Memory

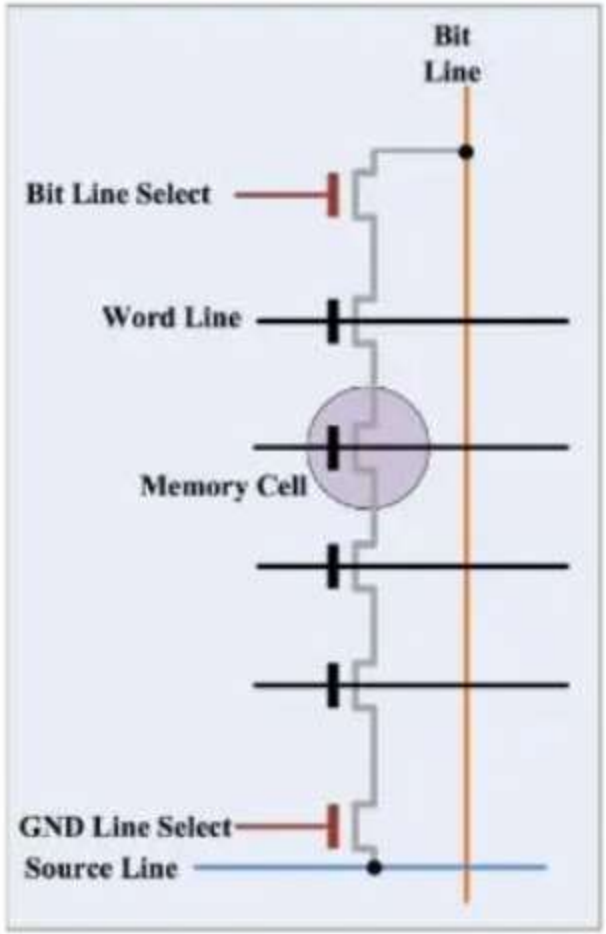
NOR Flash Memory	NAND Flash Memory
NOR flash memory is organized in a parallel of memory cells.	NAND flash memory is organized in a series of memory cells.
NOR flash memory has a lower density than NAND Flash.	NAND flash memory has a higher density(store more data in a smaller space).
NOR flash memory has faster random access time than NAND flash memory.	NAND flash memory has a faster sequential read speed and write speed.
Each bit has its own address line, similar to SRAM. Byte/Word Random Read. Byte/Word Write.	Page as the minimum read unit and Block as the erase unit. Read sequentially by page. Page write.
It is commonly used in high-density storage applications. E.g. store cell phone OS code, store BIOS.	It is used in applications that require frequent read and write operations. E.g., USB flash drives, memory cards, SSD.

Flash Memory (4)

- Differences between NOR and NAND Flash Memory



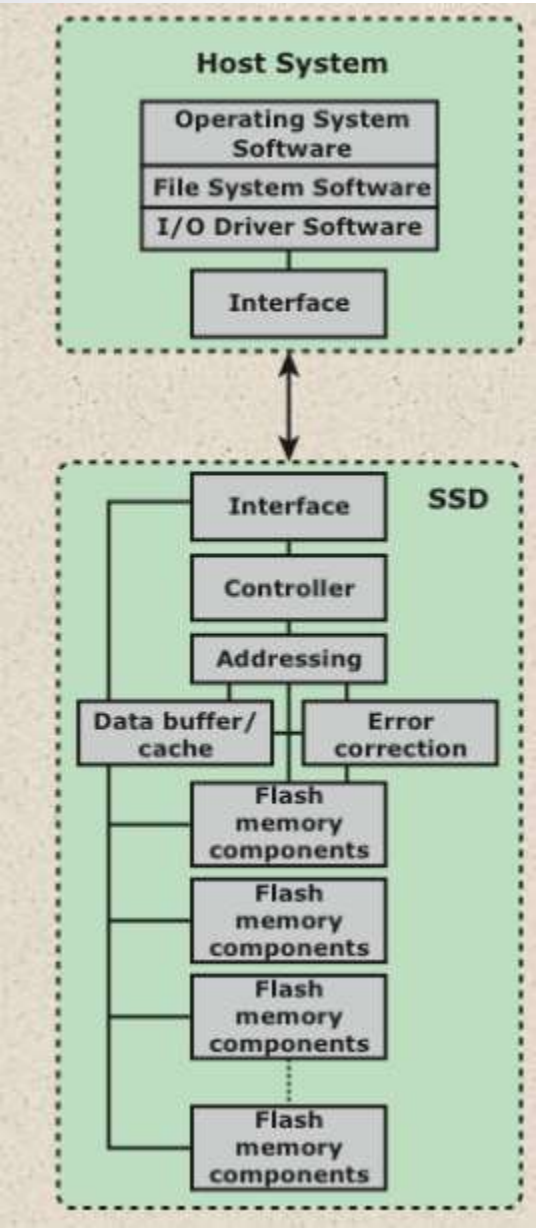
NOR Flash Architecture



NAND Flash Architecture

SSD Organization

- The SSD contains the following components:
  - Controller: Provides SSD device level interfacing and firmware execution
  - Addressing: Logic that performs the selection across the flash memory components.
  - Data buffer/cache: High speed RAM memory components used for speed matching and to increase data throughput.
  - Error correction: Logic for error detection and correction.
  - Flash memory components: Individual NAND flash chips.



SSD Compared to HDD (1)

- Comparison of Solid State Drives and Disk Drives

SSD Compared to HDD (2)

- Comparison of Solid State Drives and Disk Drives (ctd.)

Attribute	SSD	HDD
Random access time	0.1 ms	5-10 ms
Bandwidth	100-500 MB/s	100 MB/s sequential
Price/GB	0.9-2	0.1$
Size	Up to 2TB, 250GB common	4TB
Power consumption	5 watts	Up to 20 watts
Read/write symmetry	No	Yes
Noise	No	Yes (spin, rotate)

Practical Issues (1)

- Two practical issues peculiar to SSDs that are not faced by HDDs:
  - SSD performance has a tendency to slow down as the device is used.
    - Consider what must be done to write a page onto a flash memory.
      - The entire block must be read from the flash memory and placed in a RAM buffer. Then the appropriate page in the RAM buffer is updated.
      - Before the block can be written back to flash memory, the entire block of flash memory must be erased - it is not possible to erase just one page of the flash memory.
      - The entire block from the buffer is now written back to the flash memory.

Practical Issues (2)

- Two practical issues peculiar to SSDs that are not faced by HDDs:
  - A flash memory becomes unusable after a certain number of writes (typically 100,000 writes).
    - Technique for prolonging life:
      - Front-ending the flash with a cache to delay and group write operation.
      - Using wear-leveling algorithms that evenly distribute writes across block of cells.
      - Bad-block management.

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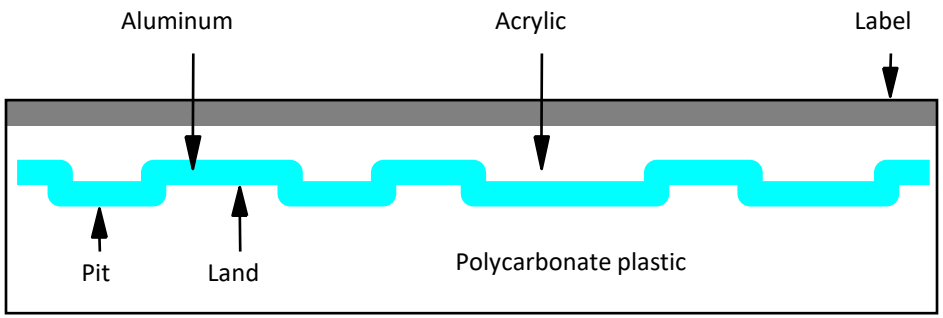
Brief History

- 1980: The first Compact Disk player is produced by Sony/Phillips.
- 1985: Sony/Philips announce the standard for compact disc storage of computer data, the CD-ROM.
- 1987: Video CD format is designed.
- 1991: CD-R (Compact Disk Recordable) technology is introduced as a new storage technology.
- 1996: Digital Versatile Disk (DVD) technology is introduced.
- 1998: DVD Recordable systems invented and begin to enter the market.
- 2002: Sony/Philips/Panasonic announce the 0.9 edition standard of Blu-ray Disc

Compact Disk (1)

- CD (Compact Disk) (IS 10149, the Red Book)
  - All CDs are 120mm across and 1.2mm thick, with a 15-mm diameter hole in the middle.
  - The disk is formed from a resin（树脂）, such as polycarbonate（聚碳酸酯） and coated with a highly reflective surface, usually aluminum.



(a) Cross-section

Pit's wideness

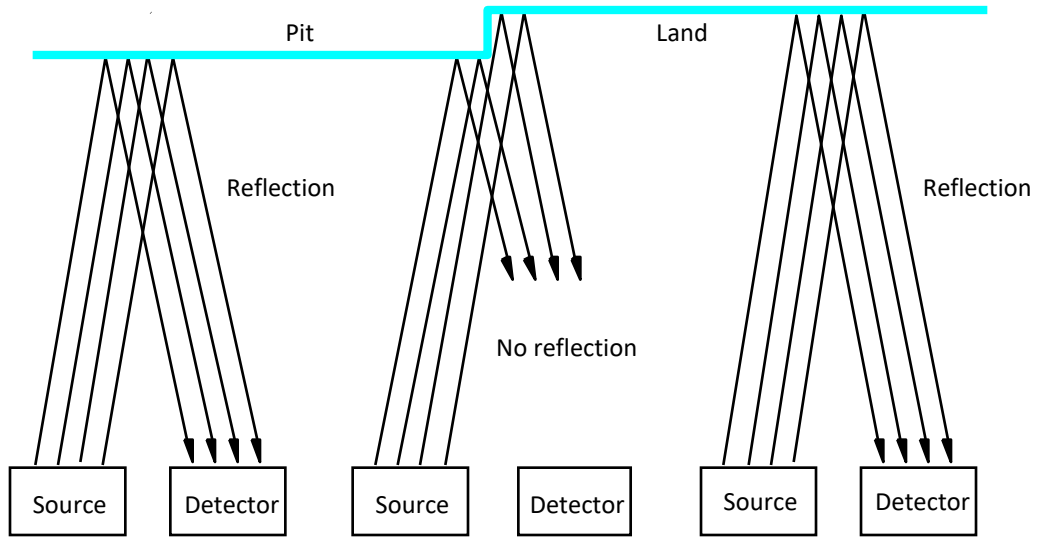
0.5 microns

Pit's length

0.8 to 3 microns

Compact Disk (2)

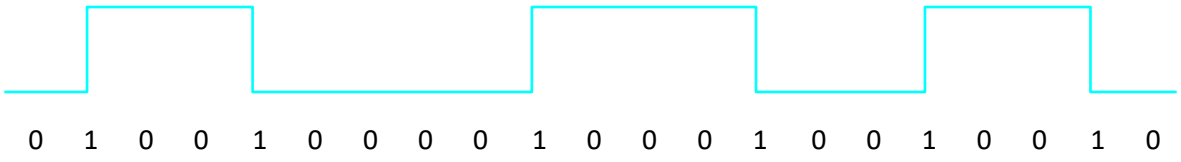
- Read CD
  - The laser source and the photodetector are positioned below the polycarbonate plastic.
    - The emmitted beam travels through this plastic, reflects off the aluminum layer, and travels back toward the photodetector.



(b) Transition from pit to land

Compact Disk (3)

- Read CD (ctd.)
  - When the light reflects solely from the pit, or solely from the land, the detector will see the reflected beam as a bright spot.
  - At the pit-land and land-pit transitions the detector will not see a reflected beam and will detect a dark spot.
  - Each transition is taken to denote the binary value 1, and the flat portions represent 0s.



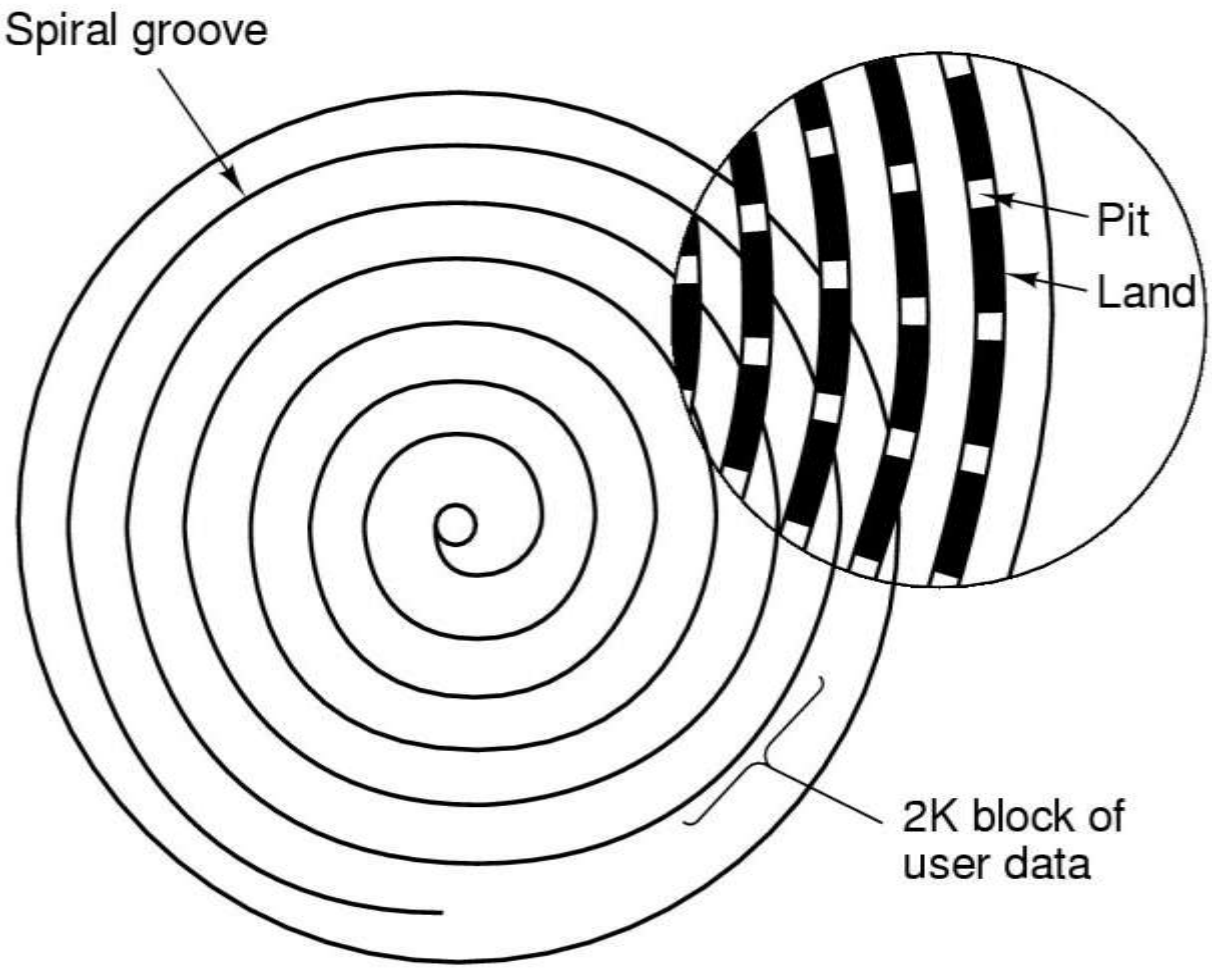
(c) Stored binary pattern

Compact Disk (4)

- Encoding Scheme
  - Complex
  - Each byte of data is represented by a 14-bit code.
- Data Organization
  - The pits and lands are written in a single continuous spiral starting near the hole and working out a distance of 32mm toward the edge.
  - The spiral makes 22,188 revolutions around the disk (about 600 per mm). If unwounded, the spiral would be 5 km long.

Compact Disk (5)

- Data Organization (ctd.)



The tracks cover the area form a 25-mm radius to a 58-mm radius.

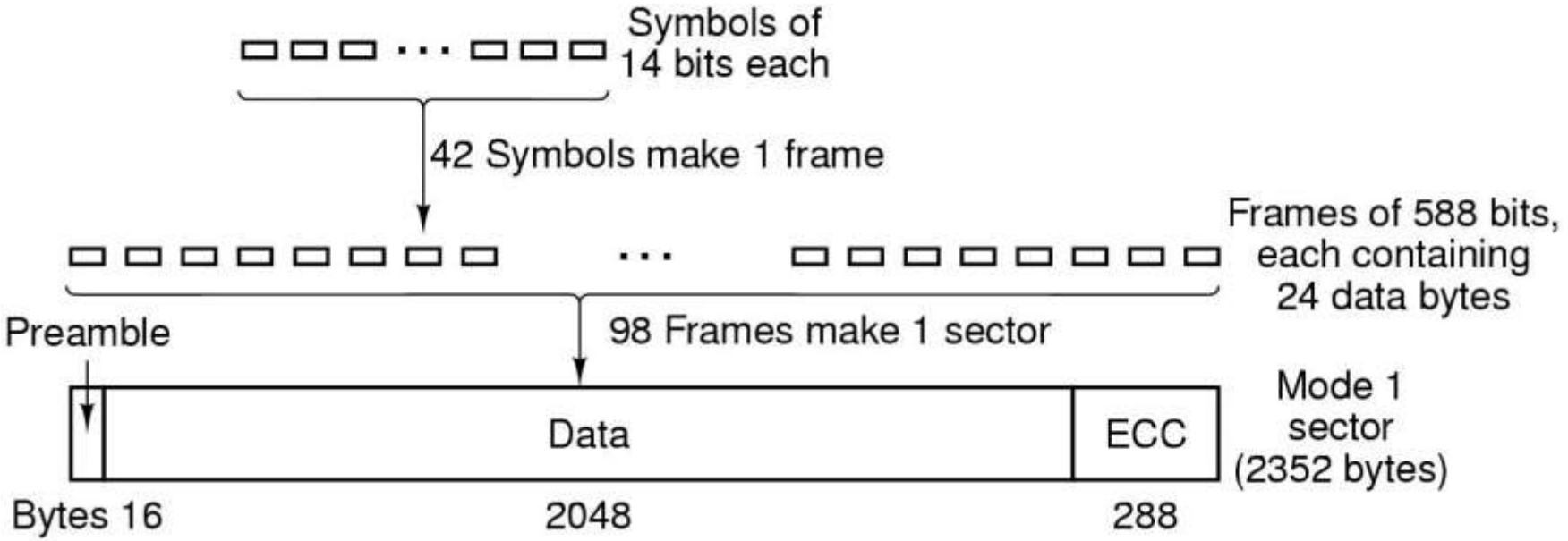
The space between the track is 1.6 microns.

CD-ROM (1)

- CD-ROM (Compact Disk-Read Only Memory) (the Yellow Book)
  - Problem of CD
    - Ensure the integrity of stored data
- Data Organization (Mode 1)
  - Encode every byte in a 14-bit symbol.
  - A group of 42 consecutive symbols forms a 588-bit frame.
  - Group 98 frames into a CD-ROM sector.

CD-ROM (2)

- Data Organization (Mode 1) (ctd.)



CD-ROM (3)

- Data Organization (Mode 1) (ctd.)
  - Every sector begins with a 16-byte preamble.
    - The first 12 bytes: 00FF FFFF FFFF FFFF FFFF FF00
    - The next 3 bytes : the sector number
    - The last byte: Mode
  - Three separate error-correcting schemes are used
    - Symbol level: single-bit errors
    - Frame level: short burst errors
    - Sector level: any residual errors

CD-ROM (4)

- CD-ROM Drive's Rotational Speed
  - Basic speed:1X, 75 sectors/s
  - Data rate: 153,600 bytes/s (Mode 1 Format)
  - High speed CD-ROM are identified in relation to the basic speed.

CD-ROM (5)

- CD-ROM Drive's Rotational Speed (ctd.)

Speed	*Data Rate*		*Approximation*
1x	153,600	bytes per second	150 KB/s
2x	307,200	bytes per second	300 KB/s
4x	614,400	bytes per second	600 KB/s
6x	921,600	bytes per second	900 KB/s
8x	1,228,800	bytes per second	1.2 MB/s
12x	1,843,200	bytes per second	1.8 MB/s
16x	2,457,600	bytes per second	2.4 MB/s
24x	3,688,400	bytes per second	3.6 MB/s
32x	4,915,200	bytes per second	4.8 MB/s
40x	6,144,000	bytes per second	6 MB/s

CD-ROM (6)

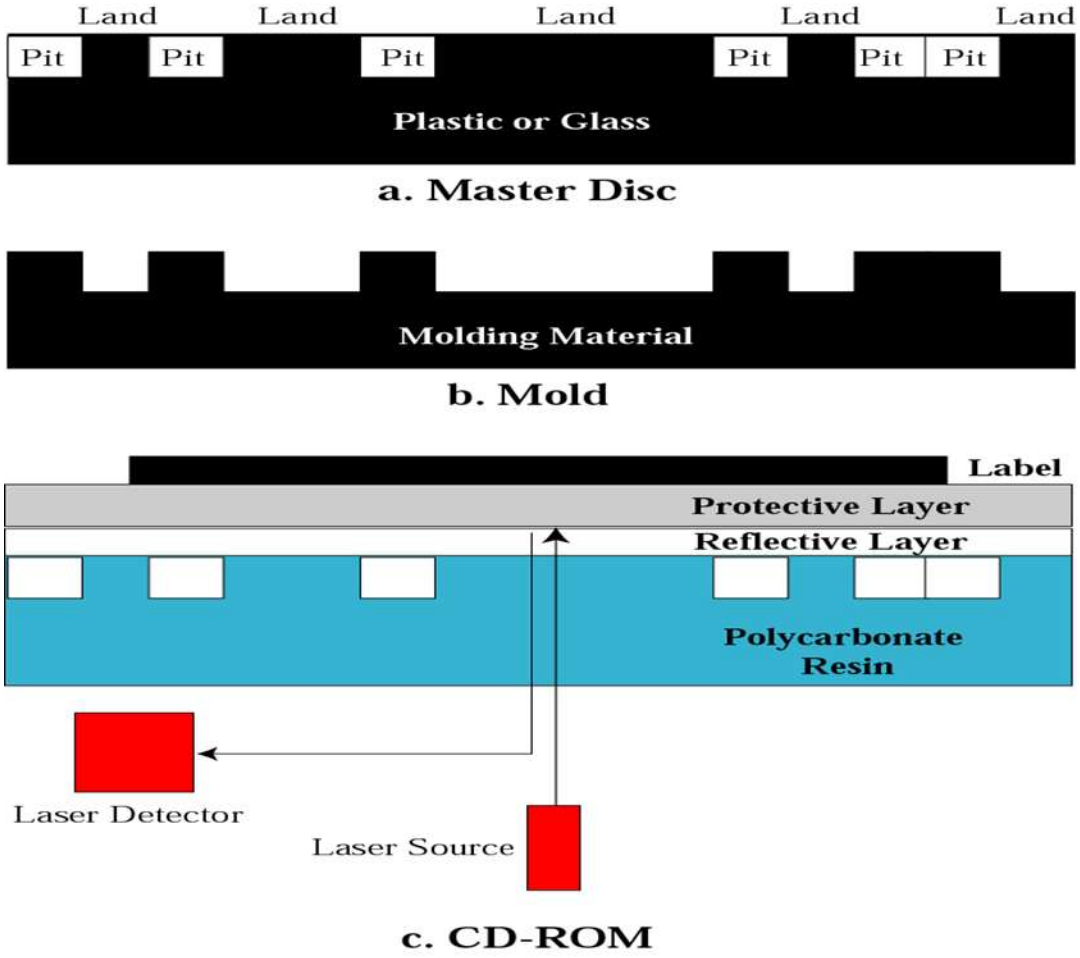
- Advantages
  - Small physical size, low cost, ease of handling as a removable and transportable mass-storage medium.
- Disadvantage
  - Lower data transfer rate

CD-ROM (7)

- CD/CD-ROM Creation
  - Create a master disk
    - Using a high-power infrared (红外线) laser to burn 0.8-micron diameter holes in a coated glass master disk.
  - Make a mold
  - Create a CD
    - Injected molten (溶解的) polycarbonate resin into the mold.
    - Add a reflective layer (aluminum) and a protective layer.

CD-ROM (8)

- CD-ROM Creation (ctd.)

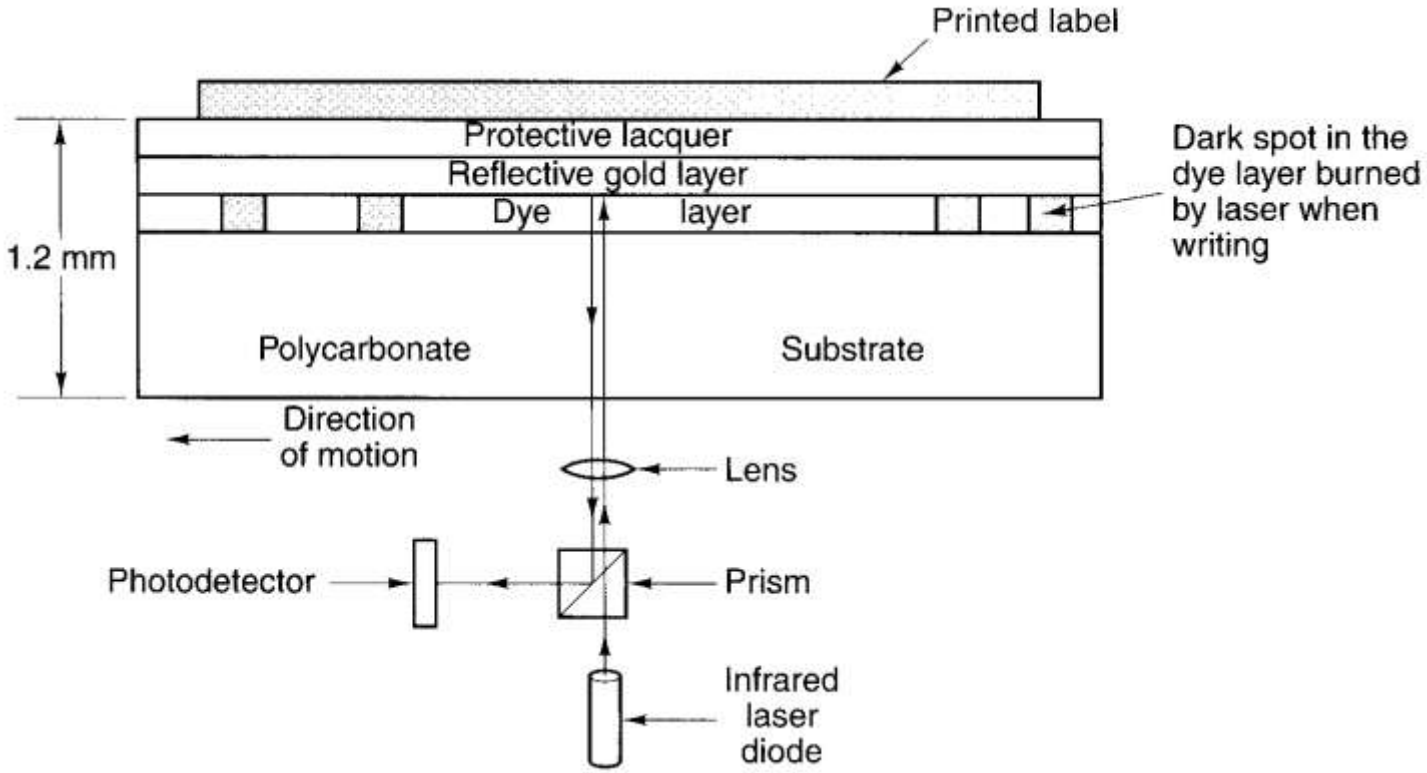


CD-Recordable (1)

- CD-R (CD-Recordable) (the Orange Book)
  - Write once, read many (WORM)
  - CD-Rs start with 120-mm polycarbonate blanks that are like CD-ROMs.
  - Also contain a 0.6-mm wide groove to guide the laser for writing.
  - Creation
    - No master disc or mold
    - Reflective layer → gold
    - No physical pits → simulated pits
    - Using a high-power laser beam
      - Dark spot in the dye (染料) to simulate a pit

CD-Recordable (2)

- CD-R Figure (ctd.)

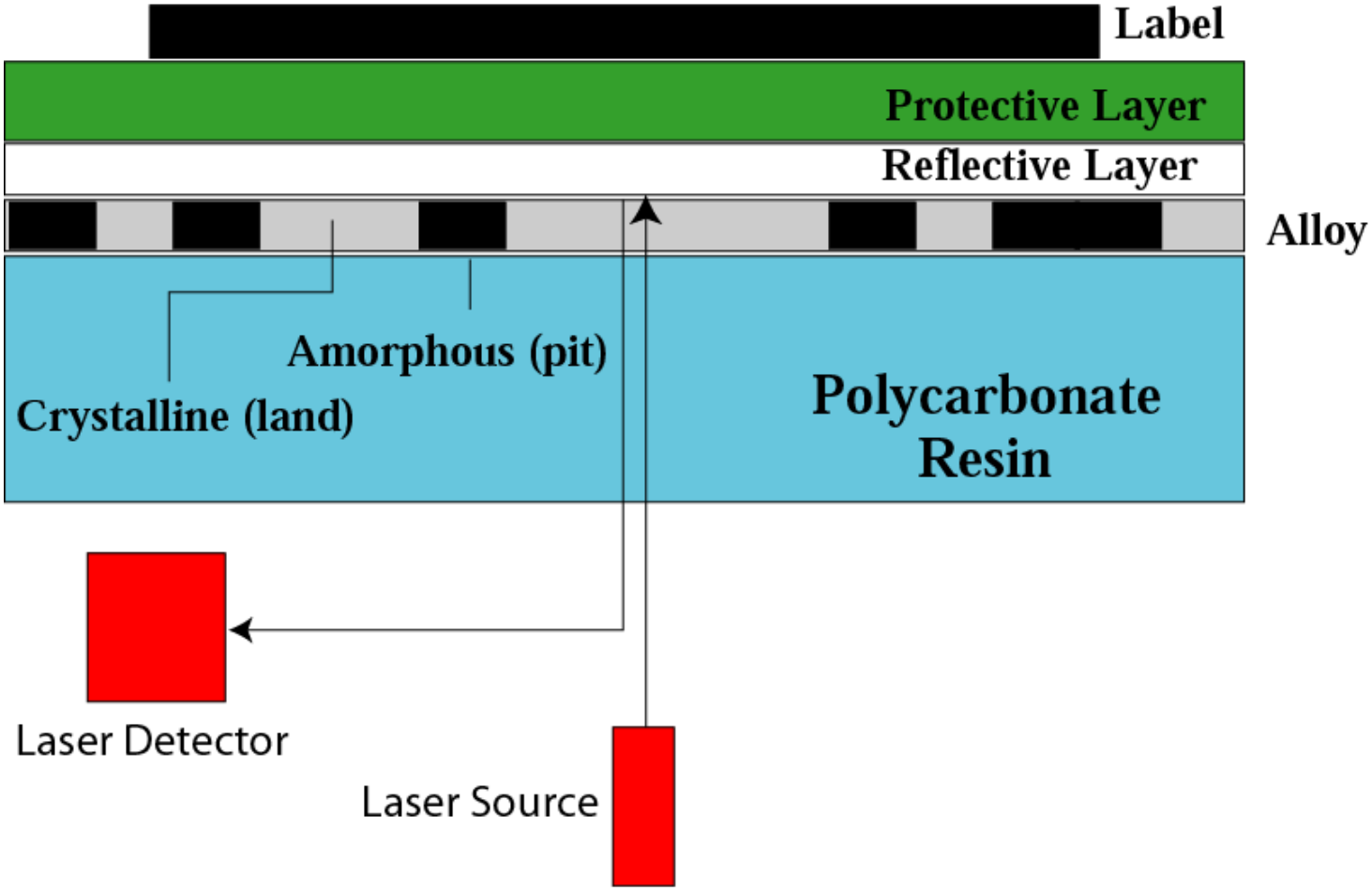


CD-ReWritable (1)

- CD-RW (CD-ReWritable)
  - Creation
    - Instead of dye → uses an alloy (合金) of silver(银), indium(铟), antimony (锑), and tellurium(碲).
    - Two states
      - Amorphous (非结晶态): pit
      - Crystalline (结晶态(可穿透)): land
    - CD-RW drive uses different laser power
      - The highest power is used to record the pits.
      - The middle power is erase power.
      - The lowest power is used to read the stored information.

CD-ReWritable (2)

- CD-RW (CD-ReWritable) (ctd.)



Digital Versatile Disk (1)

- Differences between DVD and CD-ROM
  - DVD: The pits are smaller (0.4 microns versus 0.8 microns for CDs)
  - DVD: The tracker are closer (0.74 microns between tracks versus 1.6 microns for CDs)
  - DVD: The beam is red laser (at 0.65 microns versus 0.78 microns for CDs).
  - DVD: uses one to two recording layers
    - Single-sided or Double-sided

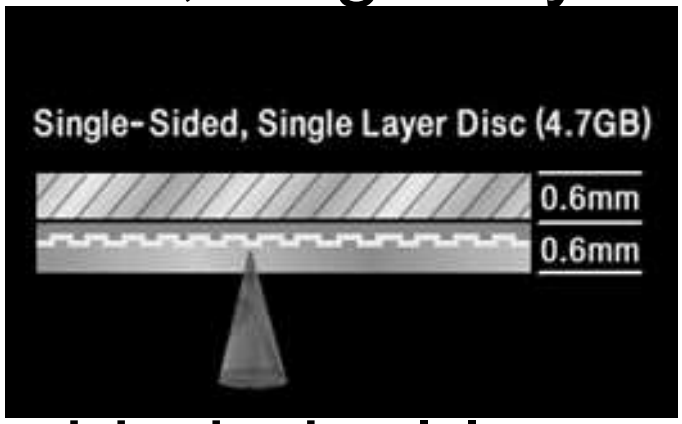
Digital Versatile Disk (2)

- DVD uses MPEG for compression
- A single-sided single-layer DVD
  - 133 minutes of video at high resolution

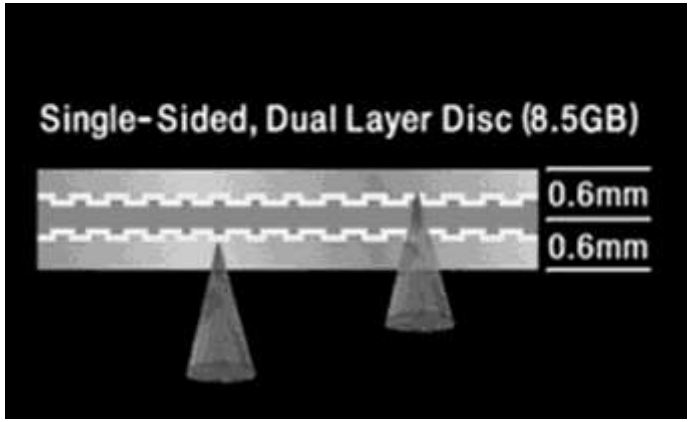
Feature	*Capacity*
single-sided, single-layer	4.7 GB
single-sided, dual-layer	8.5 GB
double-sided, single-layer	9.4 GB
double-sided, dual-layer	17 GB

Digital Versatile Disk (3)

- Single-sided, single-layer (DVD-5)

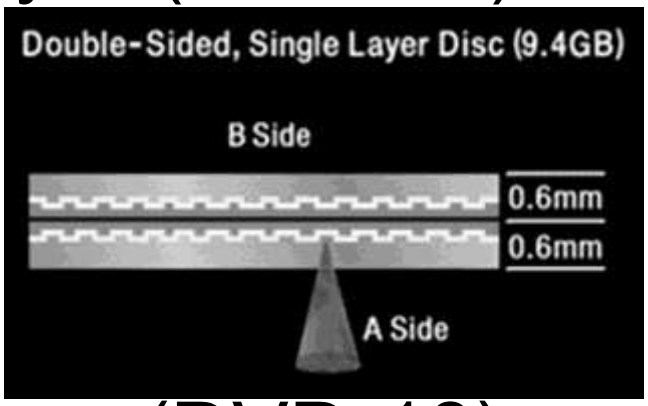


- Single-sided, dual-layer (DVD-9)
  - 3.8GB on the second layer

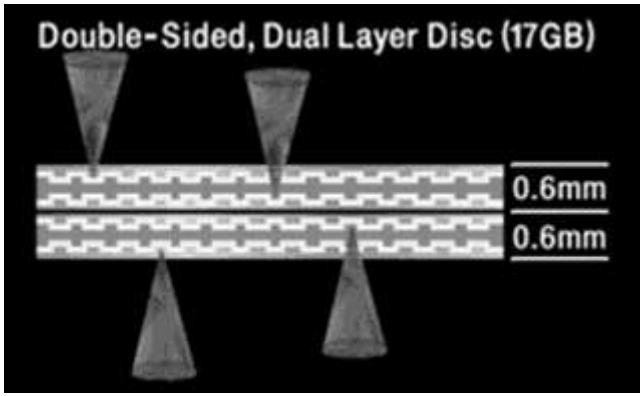


Digital Versatile Disk (4)

- Double-sided, single-layer (DVD-10)
  - 4.7GB on each side



- Double-sided, dual-layer (DVD-18)
  - 8.5GB on each side



Blu-ray Disc

- Blu-ray Disc (BD)
  - Developed by the Blu-ray Disc Association (BDA).
  - Uses a blue-violet laser (0.405 micron) instead.
  - Capacity: up to 25GB on a single-layer disc and 50GB on a dual-layer disc.
  - Recent development has pushed the storage capacity to 500GB on a single disc by using 20 layers.

Summary

- 知识点: Magnetic Hard Disk
  - 会计算Disk Capacity
  - 掌握Data Organization
    - Track
    - Sector
  - 理解Access Time
    - Seek Time
    - Rotational Delay
  - 理解Cylinder概念

Homework

- P332 8.22(1)(2)

Exercise (1)

- 1. The data of all tracks of a _____ can be accessed without moving the read-write head.
  - A. surface
  - B. platter
  - C. sector
  - D. cylinder

- Solution:
  - D. cylinder

Exercise (2)

- 2. According to the specifications of a particular hard disk, a seek takes 3 ms between adjacent tracks. If the disk has 100 cylinders, how long will it take for the head to move from the innermost cylinder to the outermost cylinder?
  - A. 3ms
  - B. 30ms
  - C. 300ms
  - D. 3000ms
- Solution:
  - C. 300ms

Exercise (3)

- 3. A hard disk with 5 double-sided platters has 2048 tracks/platter, how many movable heads does it have?
  - A. 5
  - B. 10
  - C. 2048×5
  - D. 2048×10

- Solution:
  - B.10

Exercise (4)

- 4. When we read a block of data from a disk into memory, the seek time refers to ( ).
  - A. the time required to move the read-write head to the proper track
  - B. the time required to position the read-write head and transfer the data block
  - C. the time required to rotate the correct sector under the head
  - D. none of the above
- Solution:
  - A

Exercise (5)

- 5. The amount of time required to read a block of data from a disk into memory is composed of seek time, rotational latency, and transfer time. Rotational latency refers to ( ).
  - A. the time it takes for the platter to make a full rotation
  - B. the time it takes for the read-write head to move into position over the appropriate track
  - C. the time required to rotate the correct sector under the head
  - D. none of the above
- Solution: C

Exercise (6)

- A hard disk with 5 platters has 2048 tracks/platter, 1024 sectors/track (fixed number of sectors per track), and 512-byte sectors. What is its total capacity?
  - A. 5G；
  - B. 10G；
  - C. 15G；
  - D. 20G；
- Solution:
  - A. 5G；