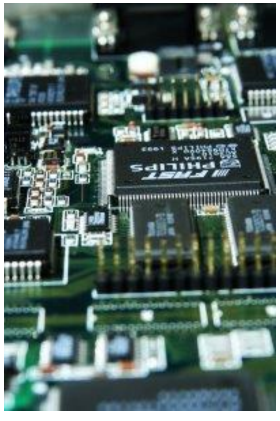
CSE 321b

Computer Organization (2)

تنظيم الحاسب (2)



3rd year, Computer Engineering

Winter 2016

Lecture #5

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Dept. of Computer & Systems Engineering

Credits to Dr. Ahmed Abdul-Monem Ahmed for the slides

Adminstrivia

- Assignment #1:
  - Solution was posted to website.

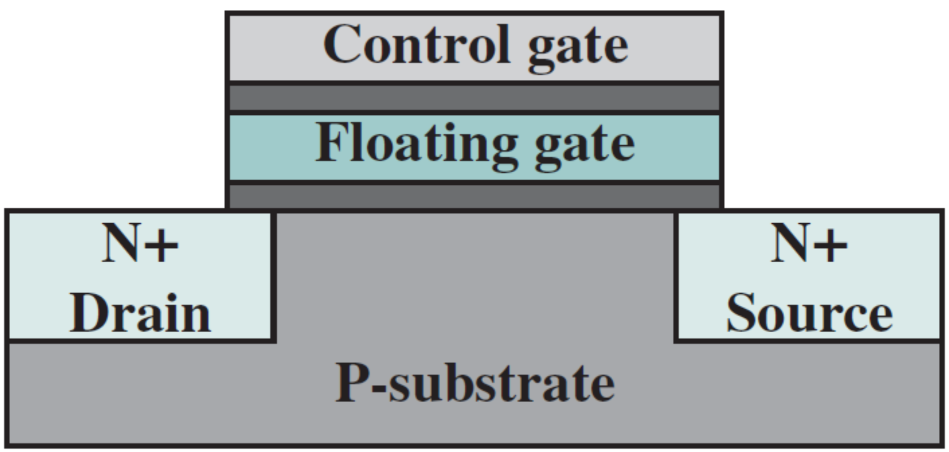
Chapter 6. External Memory (*Cont.*)

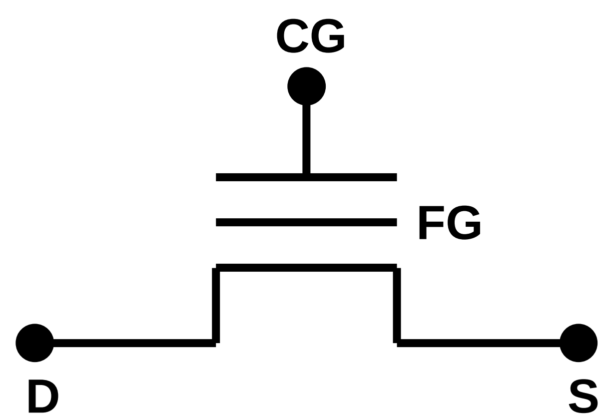
Types of External Memory

- Magnetic Disk
- Redundant Array of Independent Disks (RAID)
- Solid-State Drive (SSD)
- Optical Disk
- Magnetic Tape

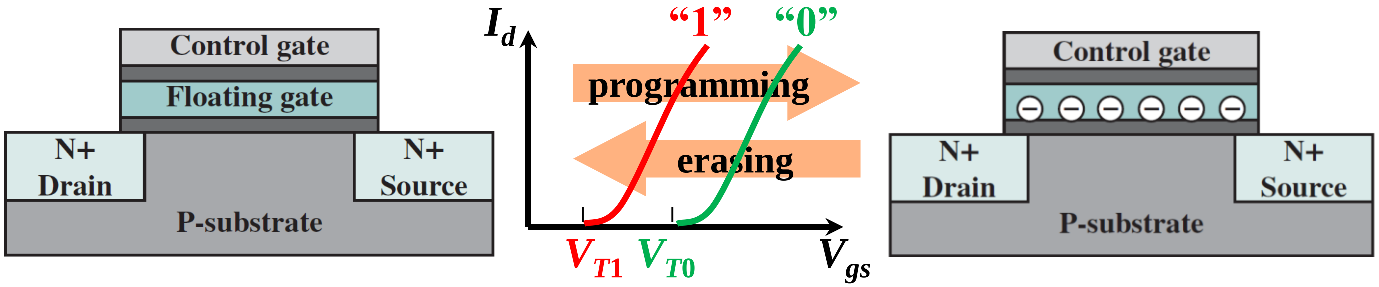
Solid-State Drive (SSD)

- Purpose: complement or even replace HDDs!
- The term "solid-state" refers to electronic circuitry built with semiconductors.
- SSD's store data in flash memory cells.
- Each flash memory cell is built using a **single** transistor: floating-gate MOSFET (FG-MOSFET).





States of FG-MOSFET



Logic 1

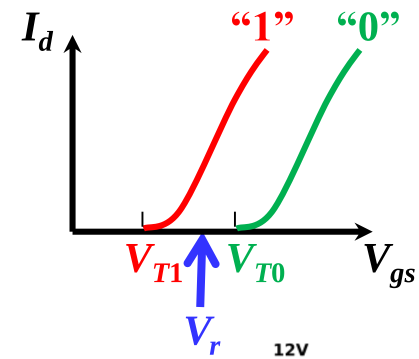
- No electrons trapped on the FG.
- Smaller threshold voltage (V_{T1})
  - Forming the channel (i.e., turning transistor on) requires applying a relatively smaller voltage to CG.

Logic 0

- Electrons trapped on the FG.
- Higher threshold voltage (V_{T0})
  - Forming the channel (i.e., turning transistor on) requires applying a slightly higher voltage to CG.

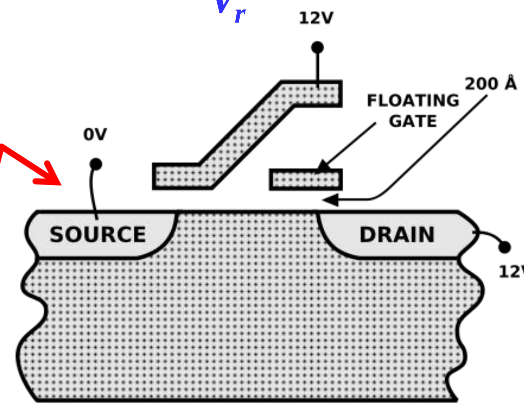
Read/Program/Erase Flash Memory Cell

- To read:
  - —Apply voltage V_r to CG s.t. $V_{T1}<V_r<V_{T0}$.
  - —Measure (sense) drain current (I_d).
    - – $I_d > 0$ ➔ transistor on ➔ logic 1.
    - – $I_d = 0$ ➔ transistor off ➔ logic 0.

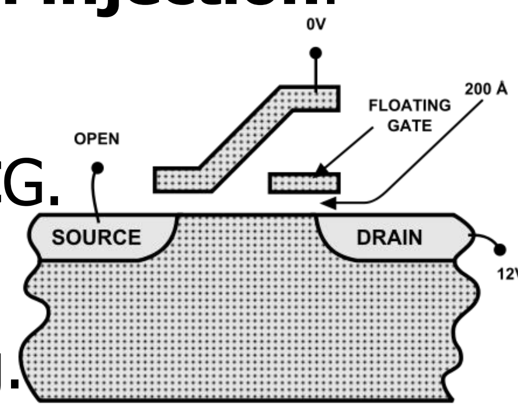


- To program (write "0"):

Only Applicable to NOR flash!!



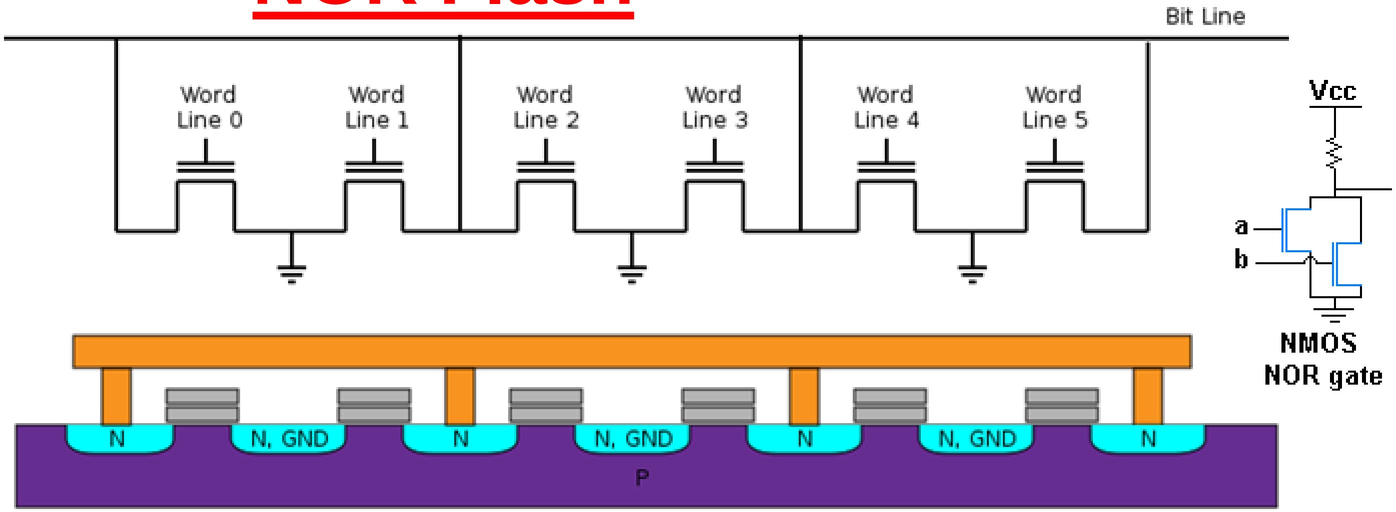
  - —Apply high +ve voltage to CG & D.
  - —Electrons jump from channel through insulating layer onto FG ➔ **hot-electron injection**.
- To erase (write "1"):
  - —Apply high voltage diff. between D & CG.
  - —Electrons pulled off FG through insulating layer to D ➔ **quantum tunneling**.



Layouts of Flash Memory

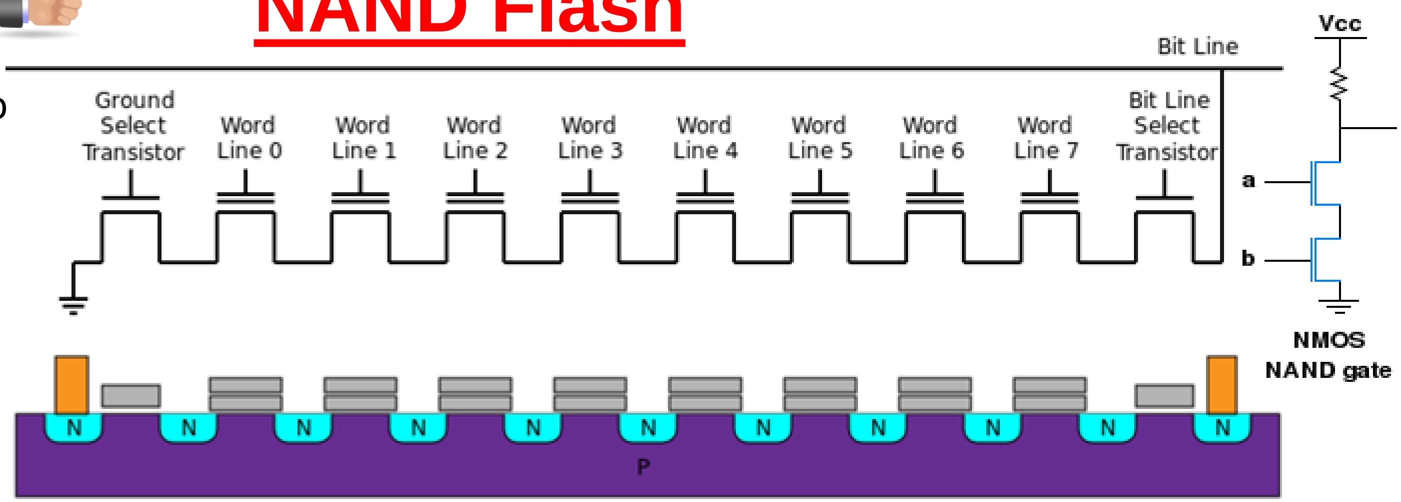
NOR Flash

- Faster read.
  - Transistors directly connected to BL.
- Simpler Interface.
  - Random access.
- Lower error rate.
- Data units
  - Bytes/words.
- Applications
  - ROM replacement.
- Capacity: < 2 Gb.



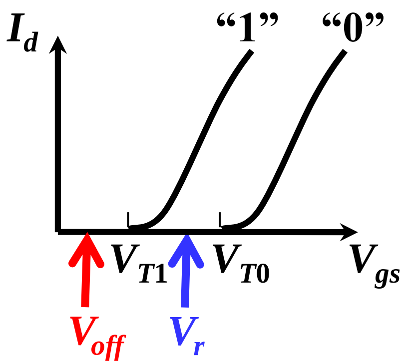
NAND Flash

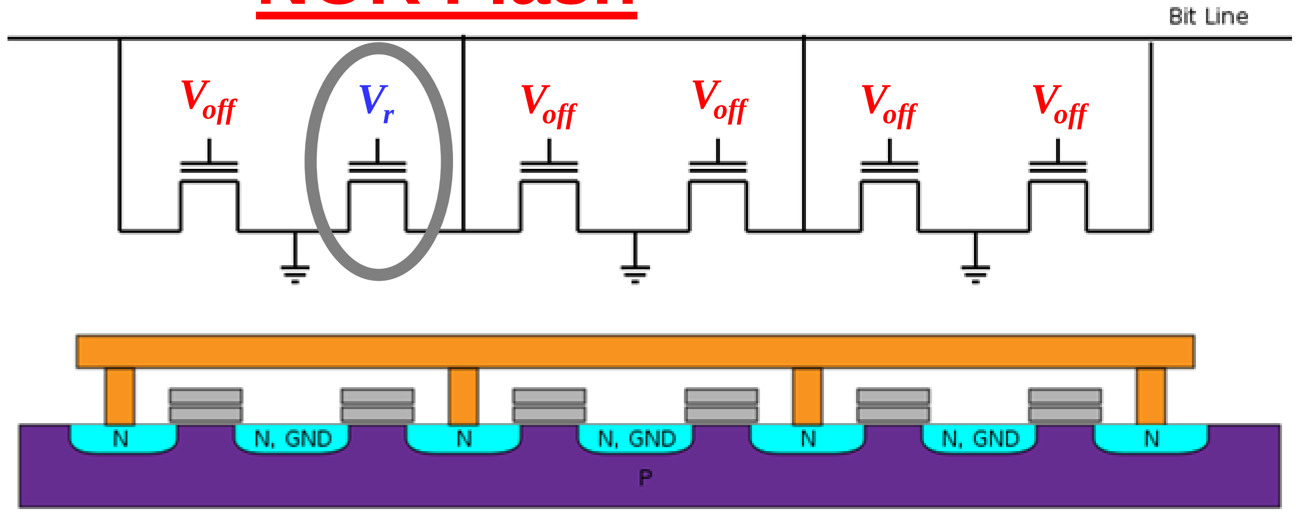
- Faster program/erase.
- Higher Density.
  - Less connections to GND/BL.
- Longer life span.
- Data units
  - Pages/blocks.
- Applications
  - **SSDs**, USB drives, SD Cards.
- Capacity: < 2 Tb.



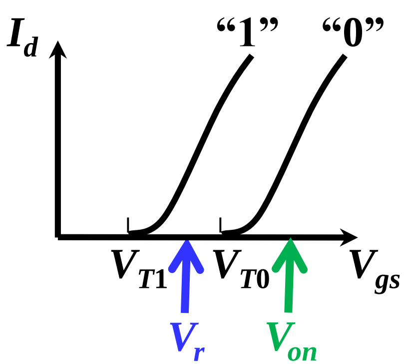
NAND/NOR Flash – Reading

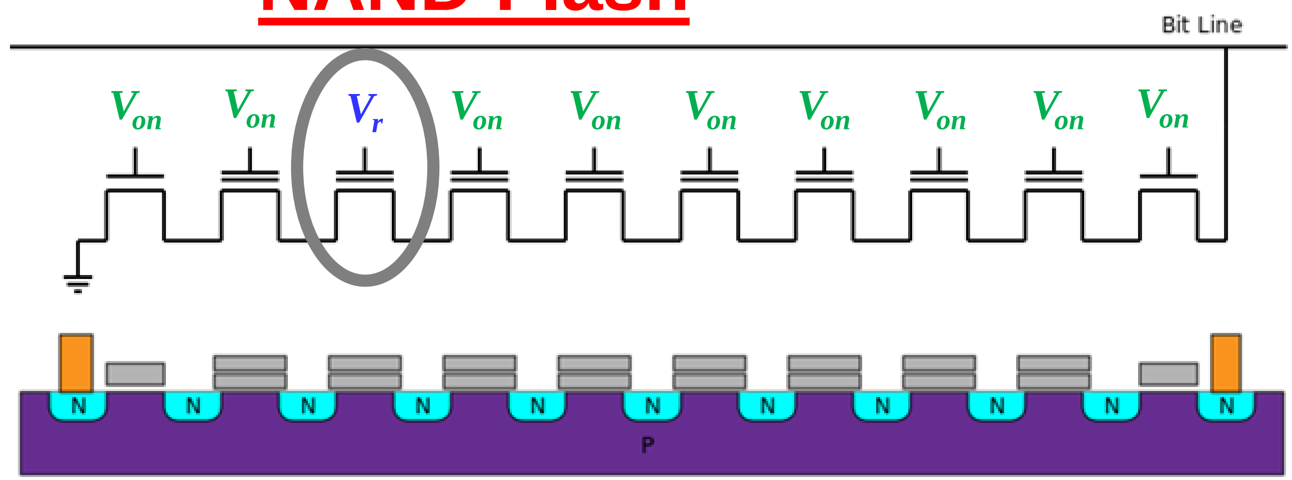
NOR Flash





NAND Flash

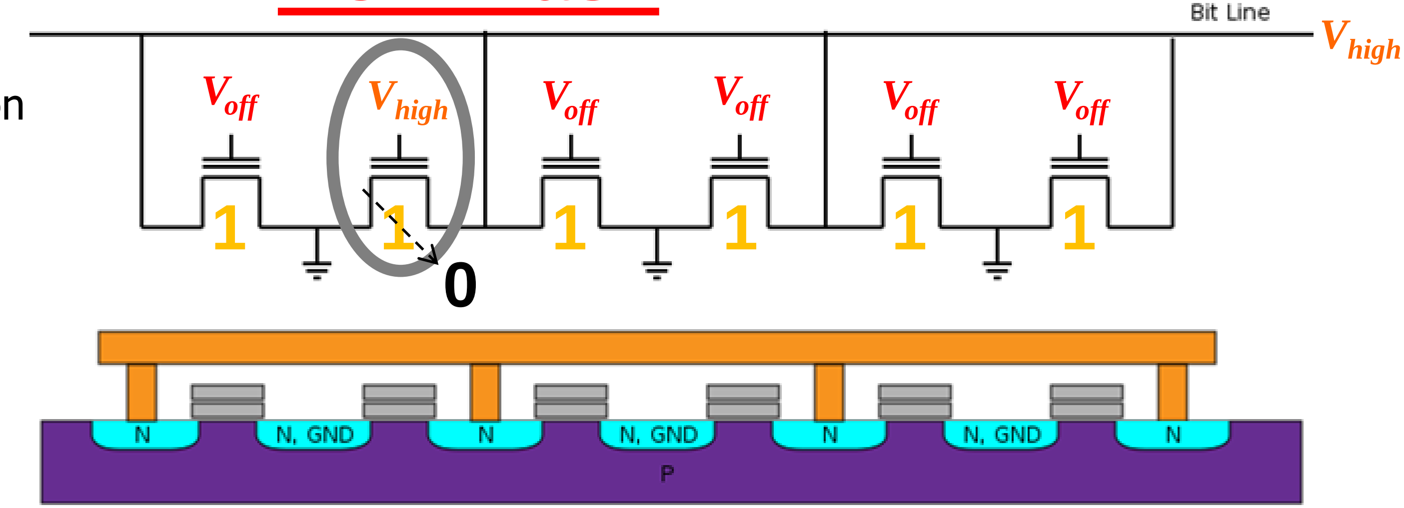




NAND/NOR Flash – Programming (X → 0)

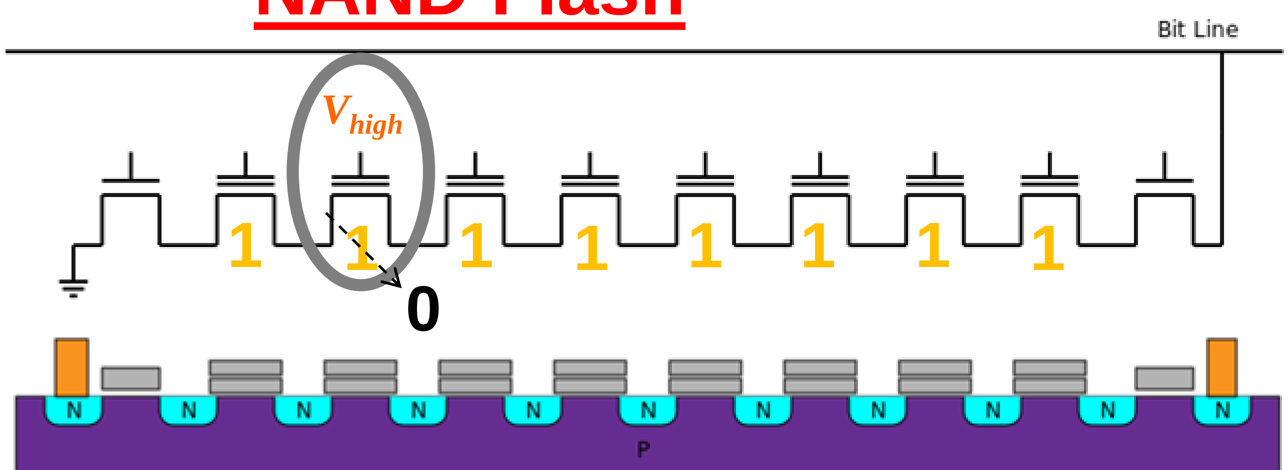
NOR Flash

- Technique:
  - Hot electron injection.
- Explanation:
  - Electrons jump from channel to FG.



NAND Flash

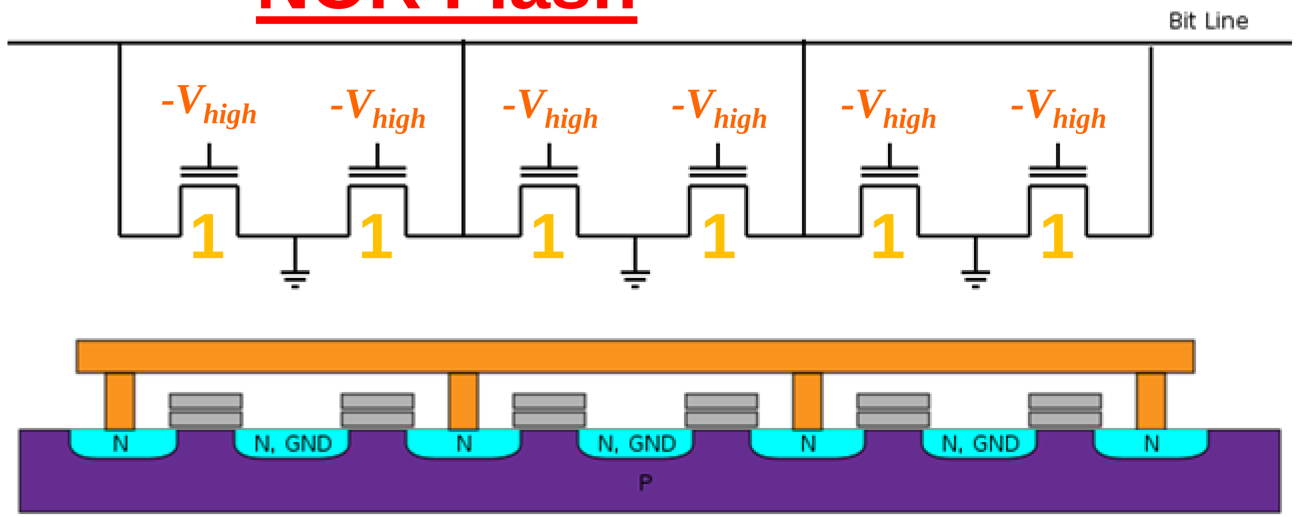
- Technique:
  - Quantum tunneling (injection).
- Explanation:
  - Electrons tunnel from B to FG.



NAND/NOR Flash – Block Erasure (X → 1)

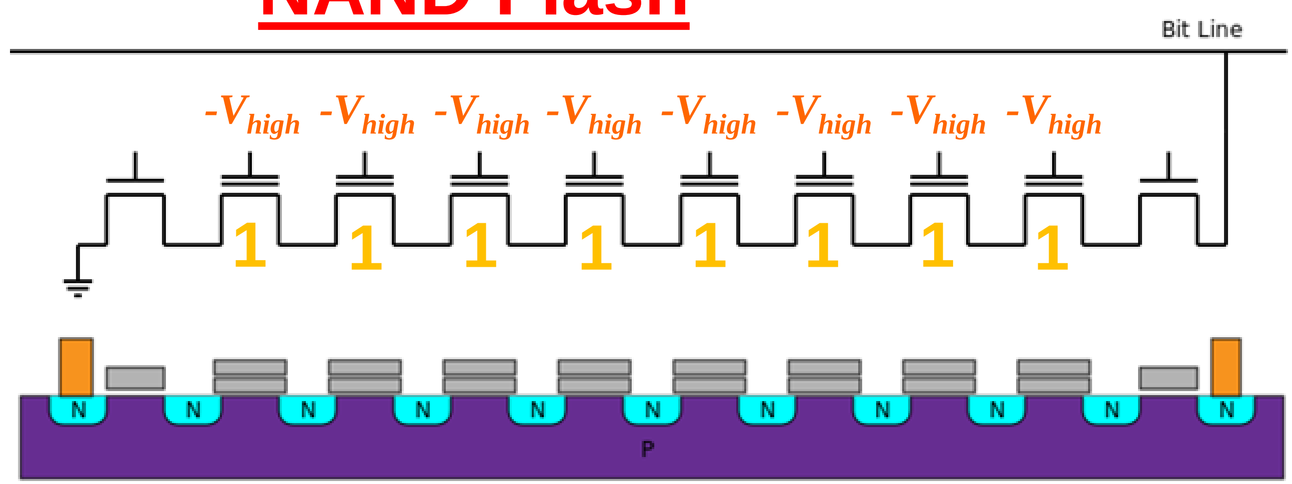
NOR Flash

- Technique:
  - Quantum tunneling (ejection).
- Explanation:
  - Electrons tunnel from FG to S/B.



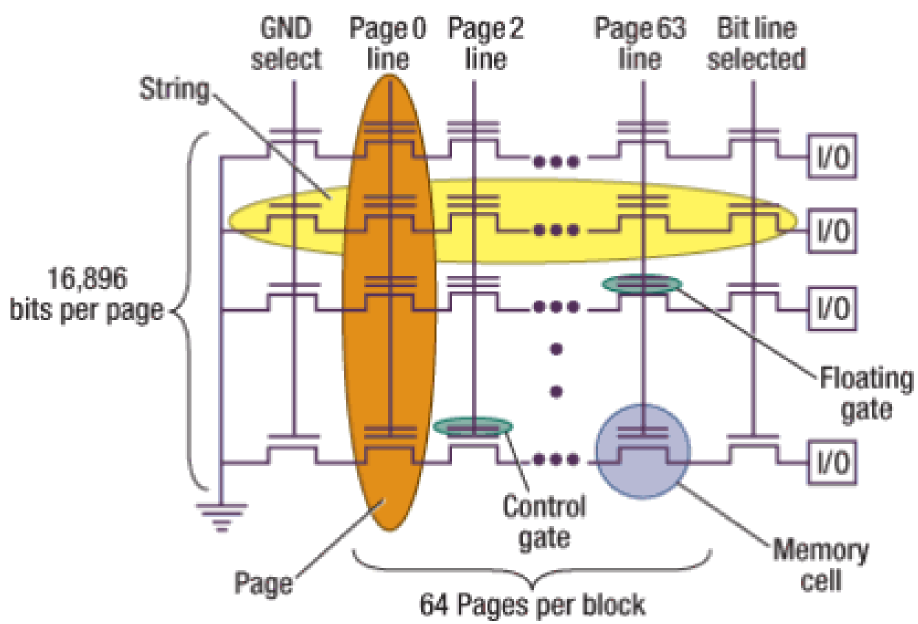
NAND Flash

- Technique:
  - Quantum tunneling (ejection).
- Explanation:
  - Electrons tunnel from FG to B.



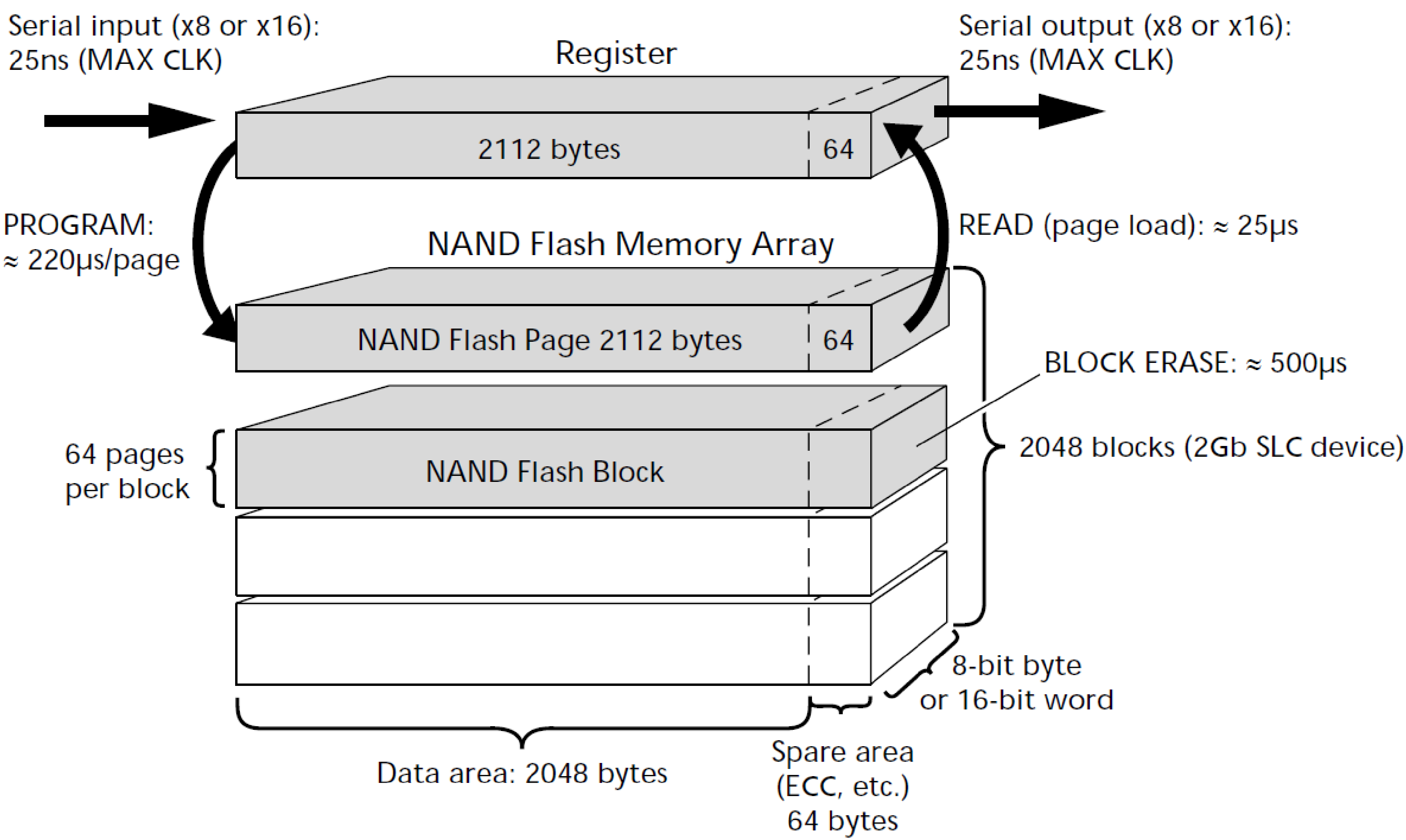
NAND Flash Block Organization

- NAND flash memory is organized as a set of independent blocks. Each block has a set of pages.
- Blocks are the smallest erasable units.
- Pages are the smallest programmable units.
  - Partial pages can be programmed in some devices!



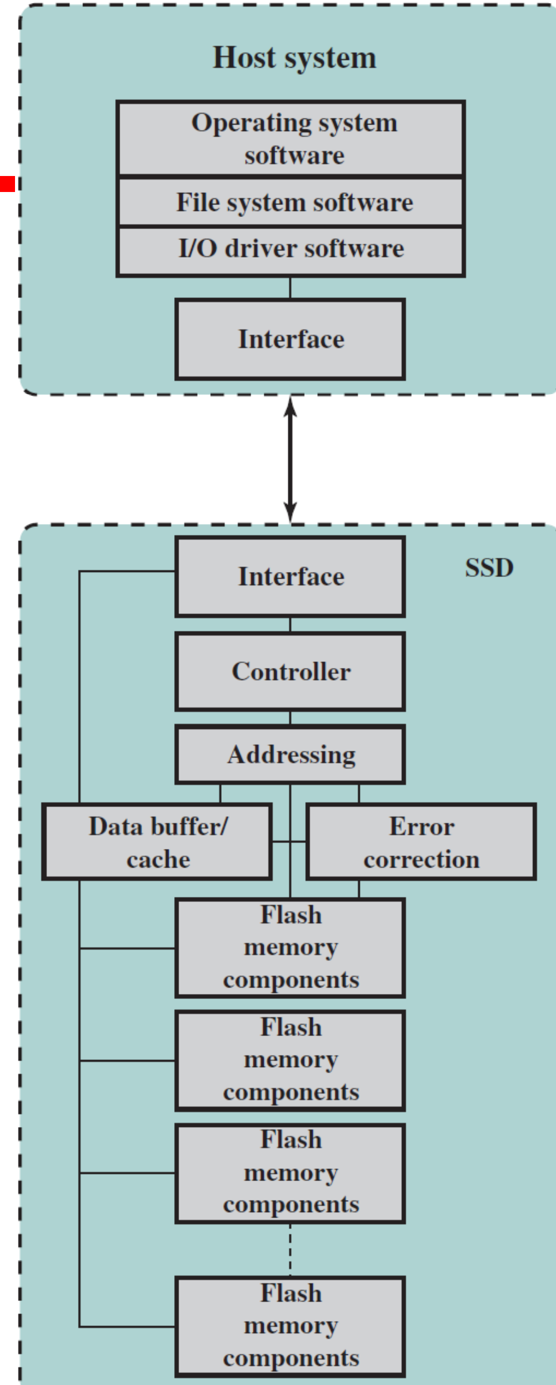
**** The numbers of bits-per-page and pages-per-block here are typical for a 2Gb NAND flash device ****

NAND Flash Memory Architecture



SSD Architecture

- Controller: provides SSD device level interfacing & firmware execution.
- Addressing: logic to select one of the flash memory components.
- Data buffer/cache: High-speed RAM for speed matching and increasing data throughput.
- Error correction: Logic for error detection and correction.
- Flash memory components: Individual NAND flash chips.



SSD vs. HDD

- SSDs have the following advantages over HDDs:
  - —Higher input/output operations per second (IOPS)
  - —Longer lifespan: no mechanical wear.
  - —Lower power consumption.
  - —Quieter and cooler running capabilities.
  - —Lower access times & latency rates: >10x faster.

	NAND Flash Drives	Disk Drives
I/O per second (sustained)	Read: 45,000 Write: 15,000	300
Throughput (MB/s)	Read: 200+ Write: 100+	up to 80
Access Time (ms)	0.1	4–10
Storage capacity (year: 2014)	up to 2 TB	up to 8 TB
Cost per capacity (year: 2014)	$0.45/GB	$0.05/GB

Optical Storage - History

- 1983 CD (Compact Disk, audio CD)

  CD-ROM

  ....

- 1996 DVD-ROM

  DVD-R

  ....

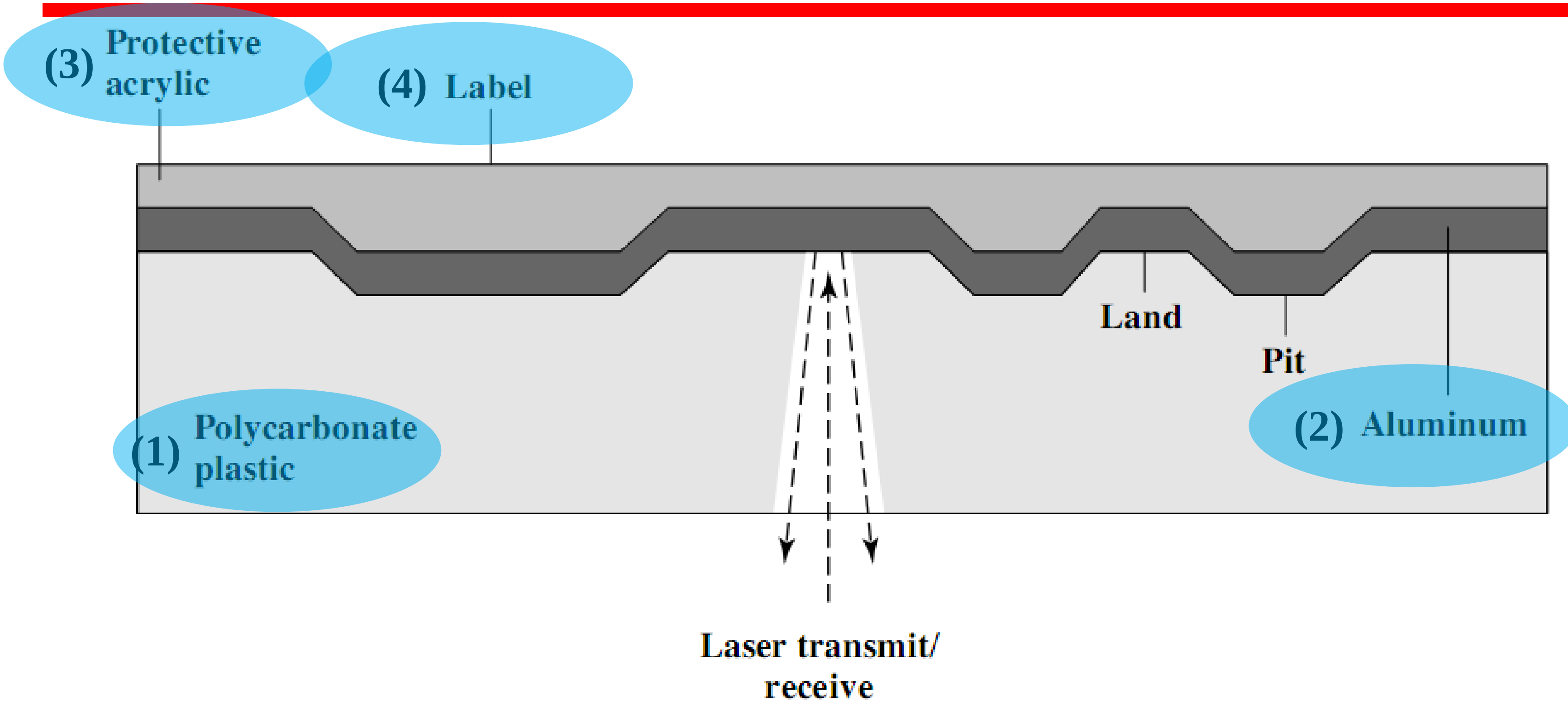
- 2002 Blu-ray

  ....

CD-ROM

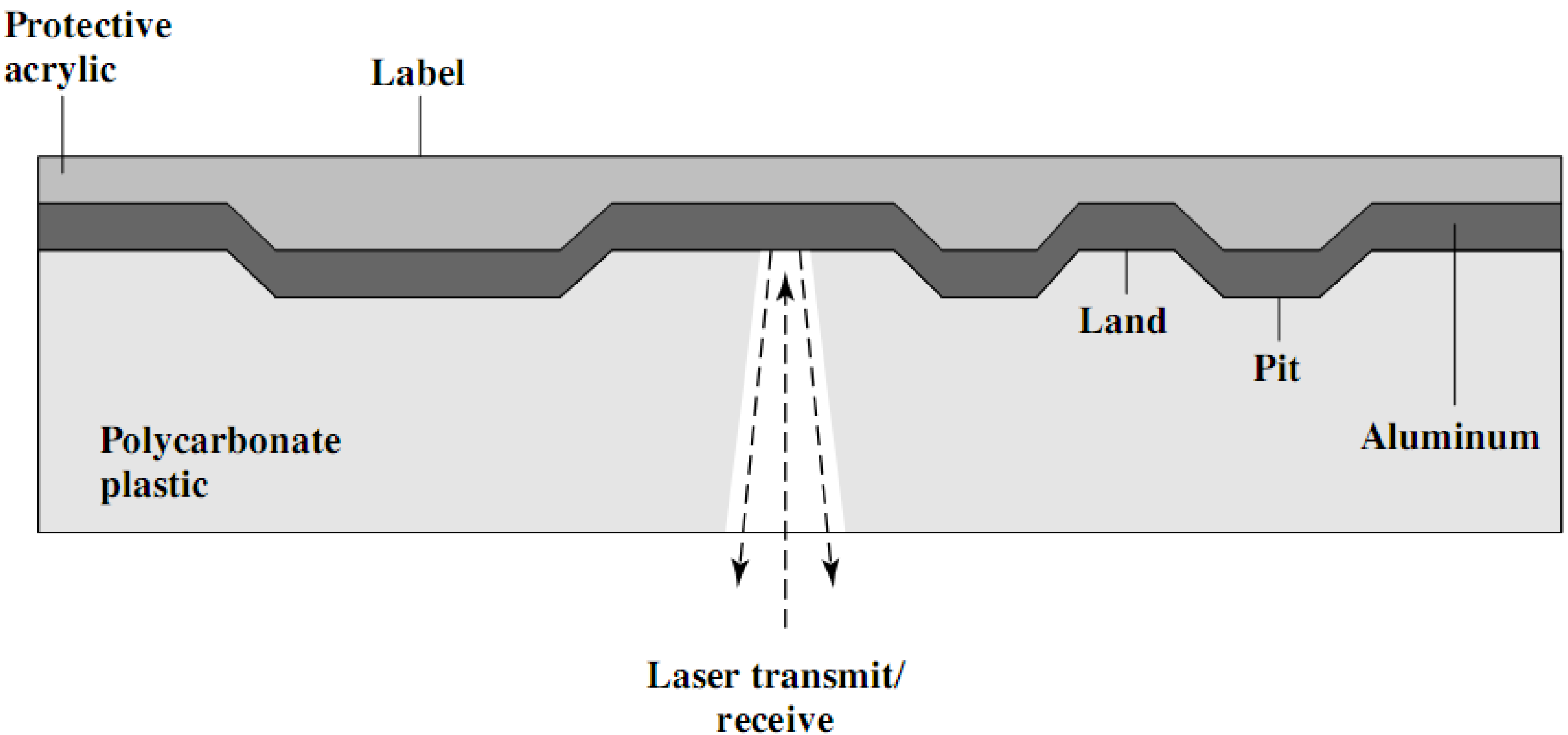
- Same technology used for audio (CD).
  - Difference: CD-ROM drives support error-correction.
- Capacity
  - Data: 650-700MB, or Audio: 74-80 minute.
- Material
  - Polycarbonate coated with highly reflective coat, usually aluminium.
- Data stored as sequence of pits engraved along a spiral track on top of polycarbonate layer.
- Read by reflecting laser.
- Constant packing density ➔ Constant Linear Velocity (CLV) ➔ variable angular velocity.

CD-ROM - Fabrication



- Master disk: Info printed as pits on the polycarbonate surface using a high-intensity laser.
- Master is used to make a die to stamp out copies.
- Pitted surface coated with a reflective material (Aluminium).
- Coat of acrylic to protect against dust and scratches.

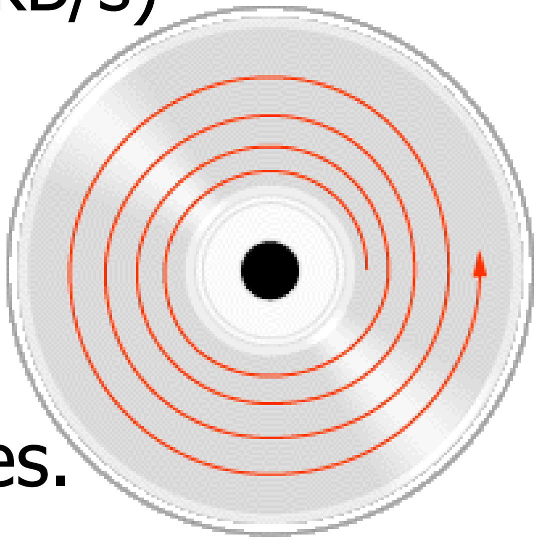
CD-ROM - Operation



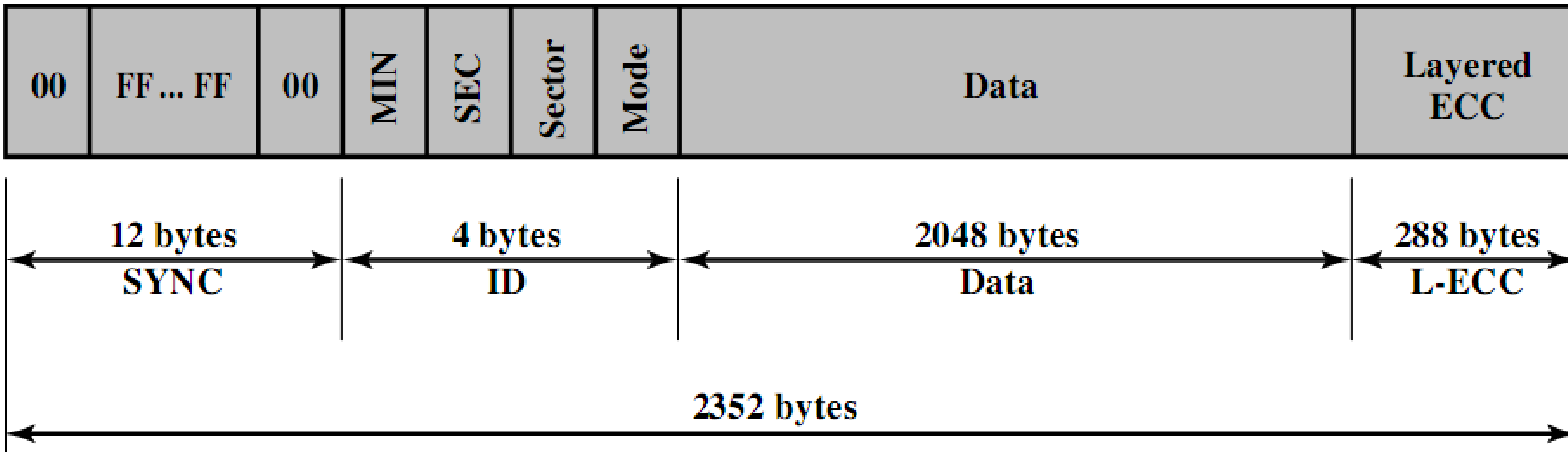
- CD drive transmits a low-power laser beam towards disk.
  - beam falls on a pit (rough surface) ➔ low intensity reflected.
  - beam falls on a land (smooth surface) ➔ high intensity reflected.
- Photo-sensor senses surface at regular intervals.
  - Change in elevation ➔ logic 1, otherwise ➔ logic 0.

CD-ROM Drive Speeds

- Audio is single speed (1x=150kB/s)
  - Constant linear velocity
  - 1.2 m/s
  - Track (spiral) is 5.27km long
  - Gives 4391 seconds = 73.2 minutes
- Other speeds are quoted as multiples.
  - e.g. 24x (24x150kB/s=3.6MB/s)
- Quoted figure is maximum drive can achieve.



CD-ROM Block/Sector Format



- Mode 0=blank data field
- Mode 1=2048 byte data+error correction
- Mode 2=2336 byte data

Mag. disks: ID(track, sector, head, CRC), Data(512+2)

CD: ID(minute, second, sector, mode), Data(2048+288)

Access on CD-ROM

- Difficult!!
  1. Move head to a rough position.
  2. Set correct speed.
  3. Read address.
  4. Adjust to required location.

CD-ROM For & Against

- Pros:
  - Large capacity (cf. floppy disks).
  - Easy to mass produce (cf. magnetic disks).
  - Removable (cf. magnetic disks).
  - Robust.
- Cons:
  - Expensive for small quantities.
  - Slow (access time ≈ 0.5 sec).
  - Read only.

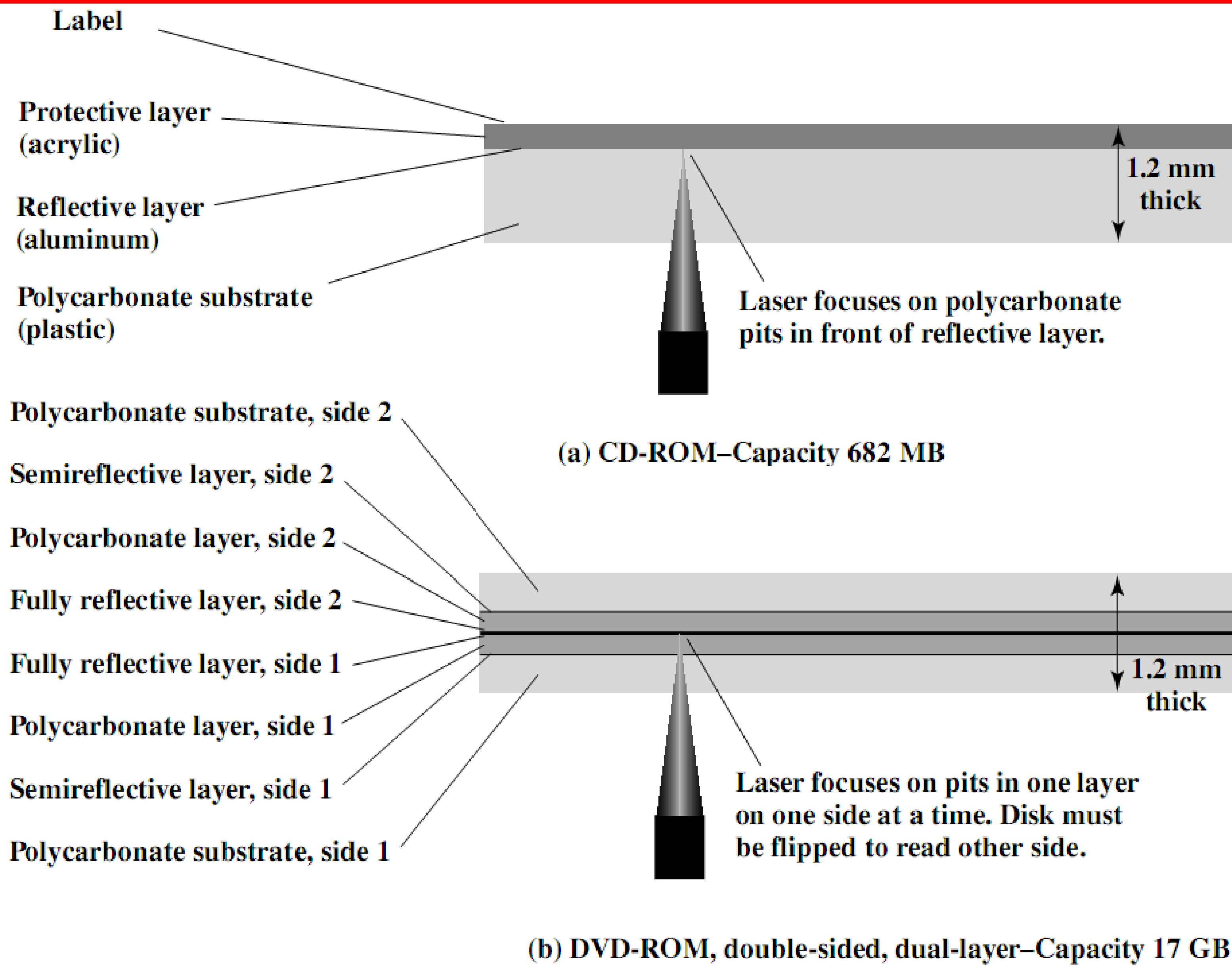
Other Optical Storage

- CD-Recordable (CD-R)
  - Write Once Read Many (WORM).
  - Quite affordable.
  - Compatible with CD-ROM drives.
  - Medium includes a dye layer. Reflectivity is activated by a high-intensity laser.
- CD-ReWritable (CD-RW)
  - Erasable.
  - Inexpensive.
  - Mostly CD-ROM drive compatible.
  - Phase change by a laser beam
    - Material has two different reflectivity's in two different phase states (crystalline or amorphous).
    - Eventually, the material loses its desirable properties (500000~1000000 erase cycles).

DVD

- Digital Video Disk
  - Used to indicate a player for movies
    - Only plays video disks.
- Digital Versatile Disk
  - Used to indicate a computer drive
    - Will read computer disks and play video disks.
- Very high capacity (4.7G per layer).
  - Small spacing between spiral loops (tracks). Pits too. Shorter wavelength.
  - Double layer: Semi-reflective layer on top of the reflective layer. Read by adjusting focus.
  - Double sided.
- Full length movie on single disk (MPEG compression).

CD vs. DVD


Label
Protective layer
(acrylic)
Reflective layer
(aluminum)
Polycarbonate substrate
(plastic)
1.2 mm
thick
Laser focuses on polycarbonate
pits in front of reflective layer.
(a) CD-ROM–Capacity 682 MB
Polycarbonate substrate, side 2
Semireflective layer, side 2
Polycarbonate layer, side 2
Fully reflective layer, side 2
Fully reflective layer, side 1
Polycarbonate layer, side 1
Semireflective layer, side 1
Polycarbonate substrate, side 1
1.2 mm
thick
Laser focuses on pits in one layer
on one side at a time. Disk must
be flipped to read other side.
(b) DVD-ROM, double-sided, dual-layer–Capacity 17 GB

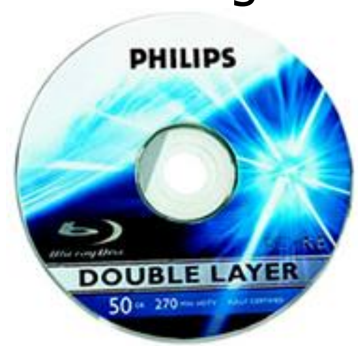
Optical Storage - Types

Optical Disk

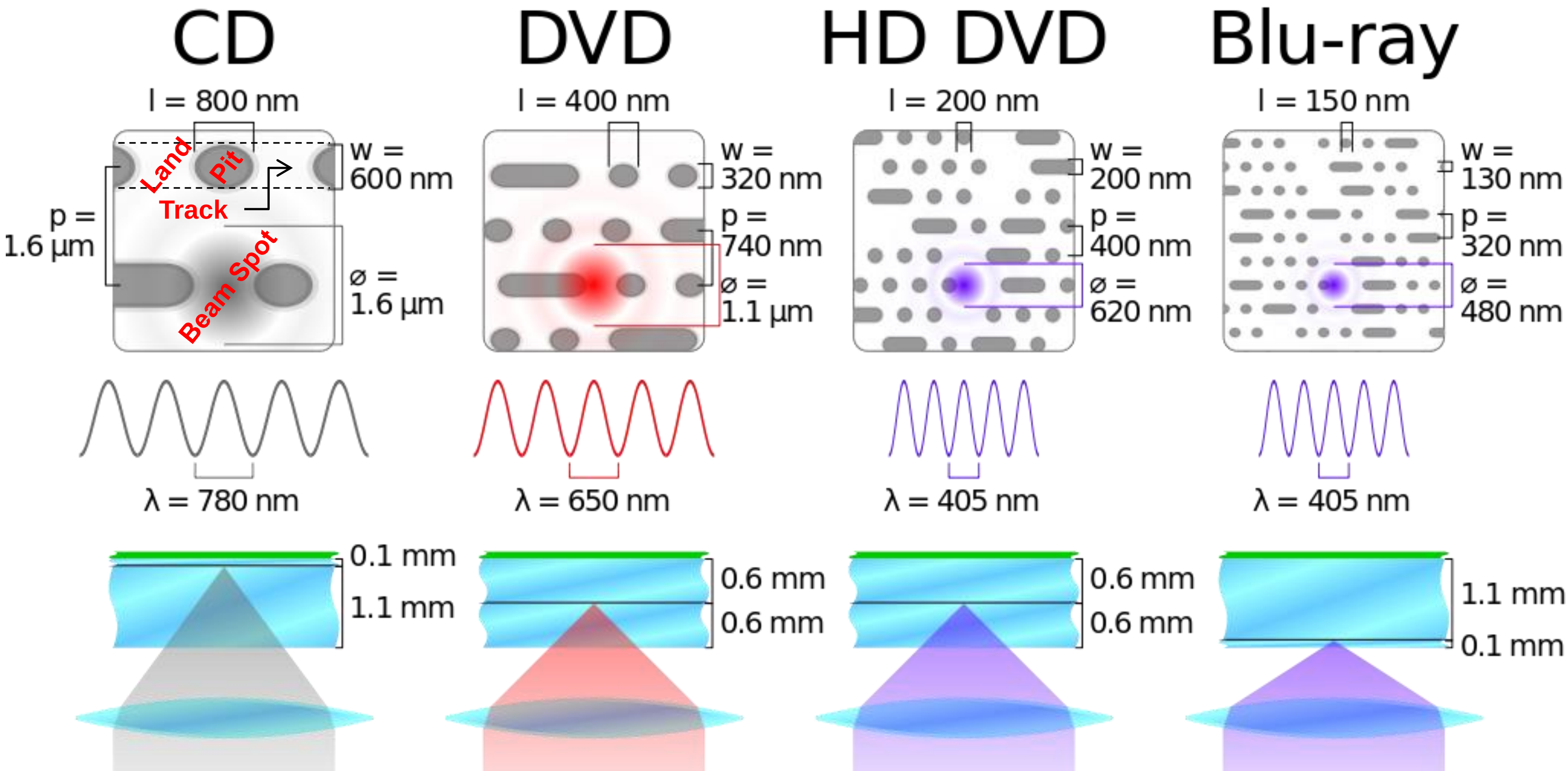
	CD	DVD
Capacity	650M~750MB	4.7G~17GB
Drive Compatibility	Incomp. with DVD	Comp. with CD
Structure	One 1.2mm base	Two 0.6mm bases
Gap	Track gap=1.6μm	0.74μm
	Pit gap=0.834μm	0.4μm
Side & layer	Single layer/side	Double layer/side
Products	CD	--
	CD-ROM	DVD-ROM
	CD-R	DVD-R
	CD-RW	DVD-RW

High-Definition Optical Disks

- Designed for high-definition (HD) videos
  - Resolution>standard-definition (SD) videos.
    - e.g., 1280 x 720 pixels or 1920 x 1080 pixels.
- Much higher capacity than DVD
  - Shorter wavelength laser in the blue-violet range.
  - Smaller pits ➔ higher bit density.
- HD-DVD
  - 15GB single side single layer.
- Blu-ray Disk (BD)
  - 25GB single side single layer.
  - Data layer closer to laser.
    - Tighter focus, less distortion, smaller pits.
  - Types: BD-ROM (read only), BD-R (recordable), and BD-RE (re-recordable).



Optical Memory Characteristics



Summary of Optical Disks

CD

Compact Disk. A nonerasable disk that stores digitized audio information. The standard system uses 12-cm disks and can record more than 60 minutes of uninterrupted playing time.

CD-ROM

Compact Disk Read-Only Memory. A nonerasable disk used for storing computer data. The standard system uses 12-cm disks and can hold more than 650 Mbytes.

CD-R

CD Recordable. Similar to a CD-ROM. The user can write to the disk only once.

CD-RW

CD Rewritable. Similar to a CD-ROM. The user can erase and rewrite to the disk multiple times.

DVD

Digital Versatile Disk. A technology for producing digitized, compressed representation of video information, as well as large volumes of other digital data. Both 8 and 12 cm diameters are used, with a double-sided capacity of up to 17 Gbytes. The basic DVD is read-only (DVD-ROM).

DVD-R

DVD Recordable. Similar to a DVD-ROM. The user can write to the disk only once. Only one-sided disks can be used.

DVD-RW

DVD Rewritable. Similar to a DVD-ROM. The user can erase and rewrite to the disk multiple times. Only one-sided disks can be used.

Blu-ray DVD

High-definition video disk. Provides considerably greater data storage density than DVD, using a 405-nm (blue-violet) laser. A single layer on a single side can store 25 Gbytes.

Reading Material

- Stallings, Chapter 6:
  - Pages 205 – 215