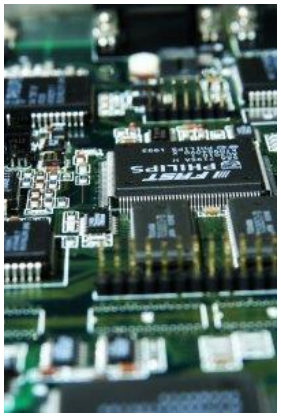
CSE 401

# Computer Engineering (2)

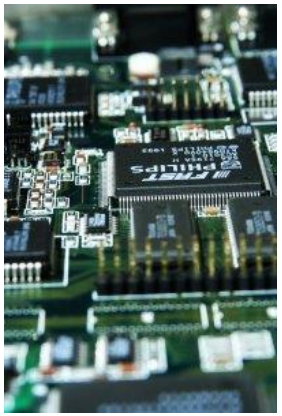
# هندسة الحاسبات (2)



4th year, Comm. Engineering

Winter 2016

**Lecture #5**



Dr. Hazem Ibrahim Shehata

Dept. of Computer & Systems Engineering

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

# Adminstrivia

- Assignment #1:
  - —Due: **Today**.
  - —Solution will be posted soon.

Website: http://hshehata.github.io/courses/zu/cse401/
Office hours: Monday 11:30am – 12:30pm

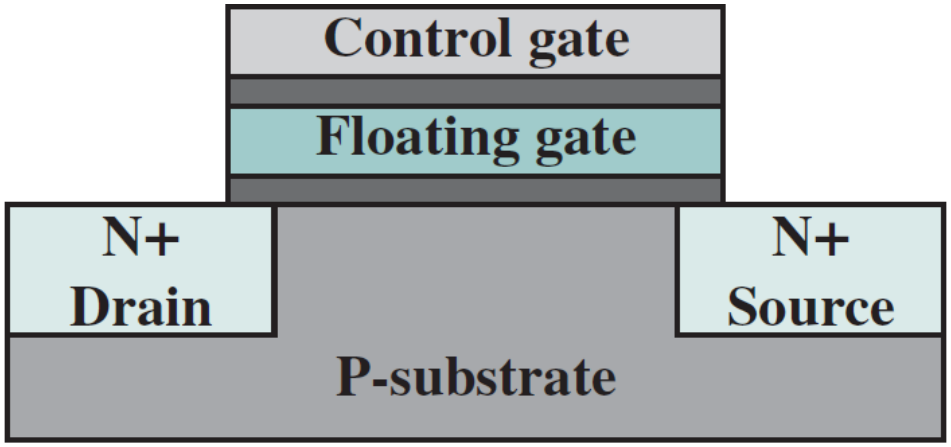
# Chapter 6. External Memory (*Cont.*)

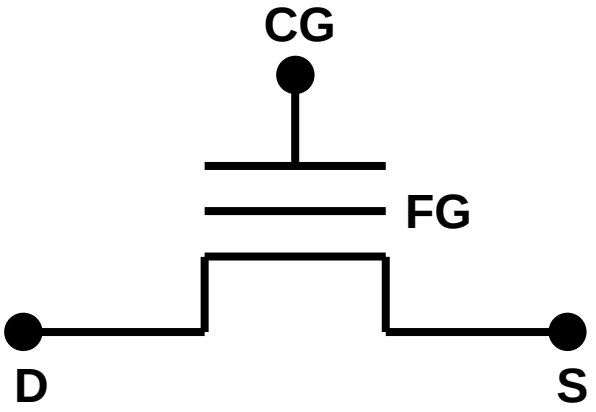
# Types of External Memory

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

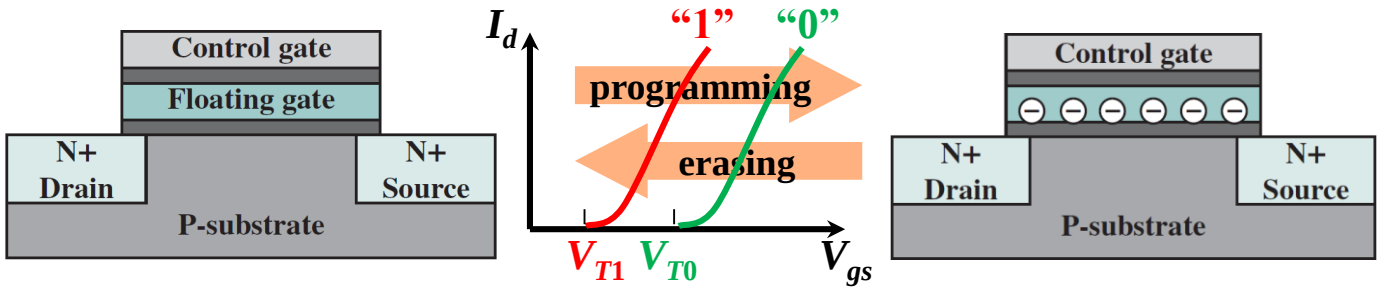
# Solid-State Drive (SSD)

- 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

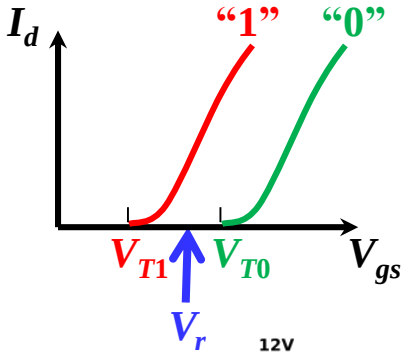
- No electrons trapped on the FG.
- Smaller threshold voltage ($V_{T1}$)
  - —Forming the channel (i.e., turning transistor on) requires applying a relatively smaller voltage to CG.

## 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.

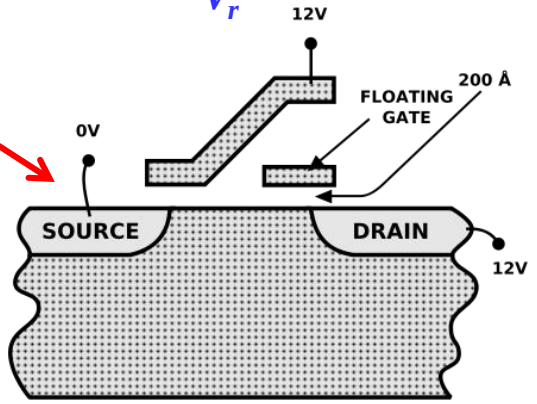
# Read/Program/Erase Flash Memory Cell

- 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.

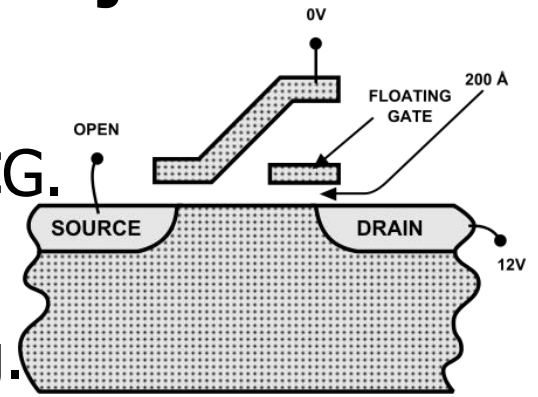



- To program (write "0"):
  - —Apply high +ve voltage to CG & D.
  - —Electrons jump from channel through insulating layer onto FG ➔ **hot-electron injection**.

**Only Applicable to NOR flash!!**



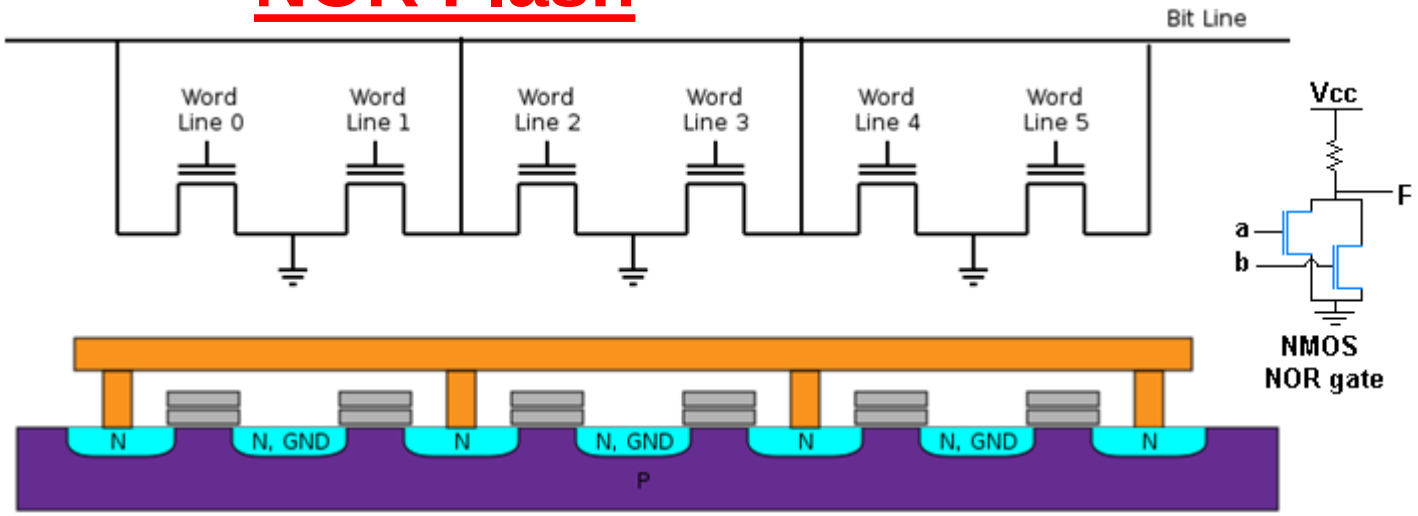

- To erase (write "1"):
  - —Apply high voltage diff. between D & CG.
  - —Electrons pulled off FG through insulating layer to D ➔ **quantum tunneling**.



# Layouts of Flash Memory

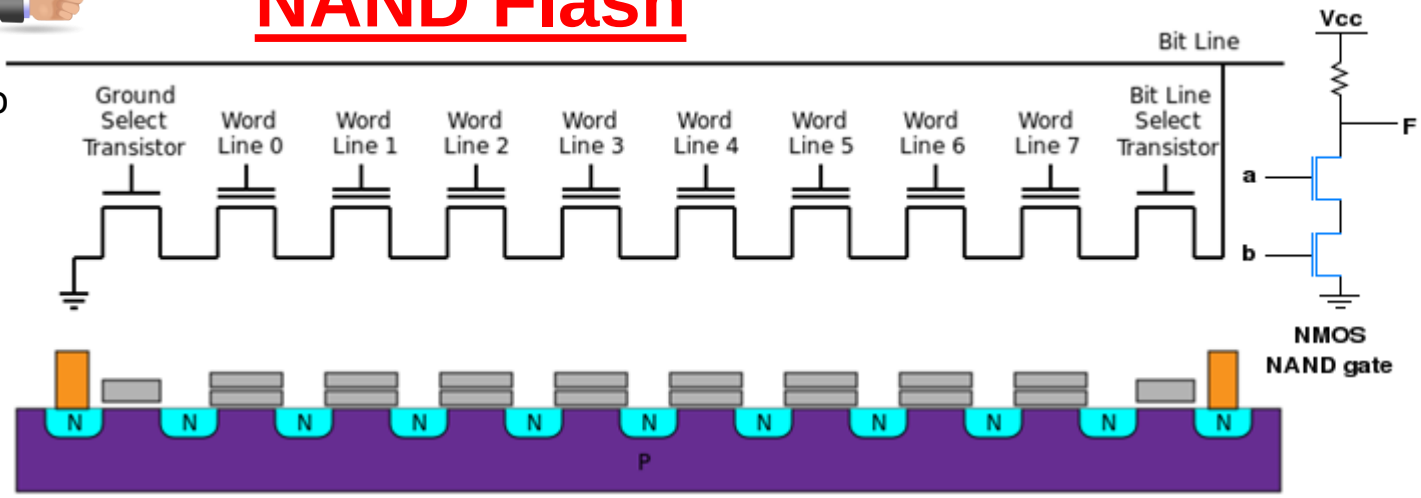
## NOR Flash

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



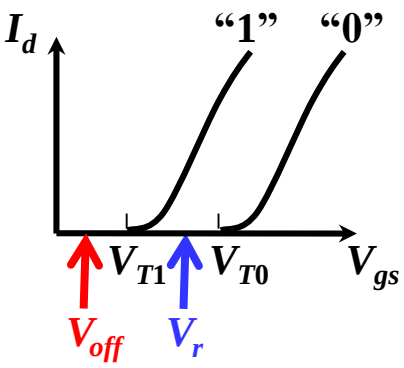

## NAND Flash

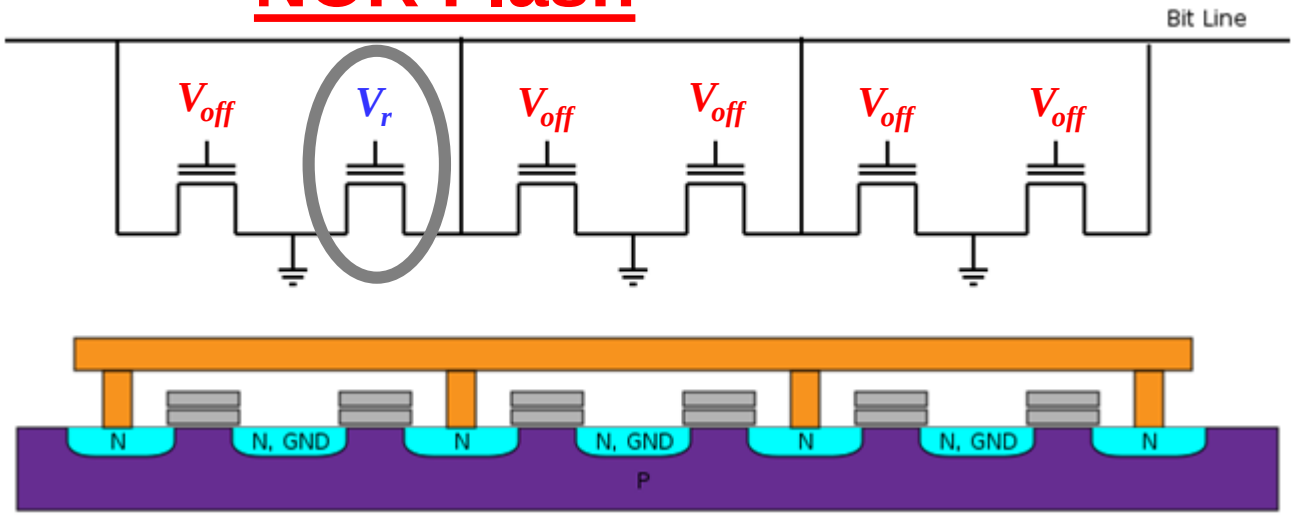
- Faster program/erase.
- Higher Density.
  - Less connections to GND/BL.
- Longer life span.
- Data units
  - Pages/blocks.
- Applications
  - **SSDs**, USB drives, SD Cards.
- Capacity: < 2 Tb.



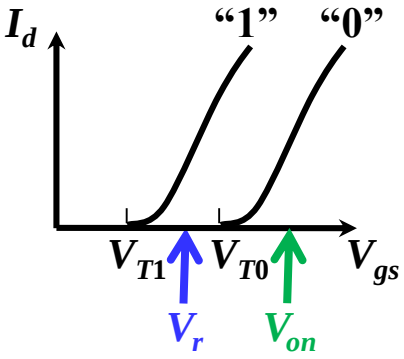
# NAND/NOR Flash – Reading

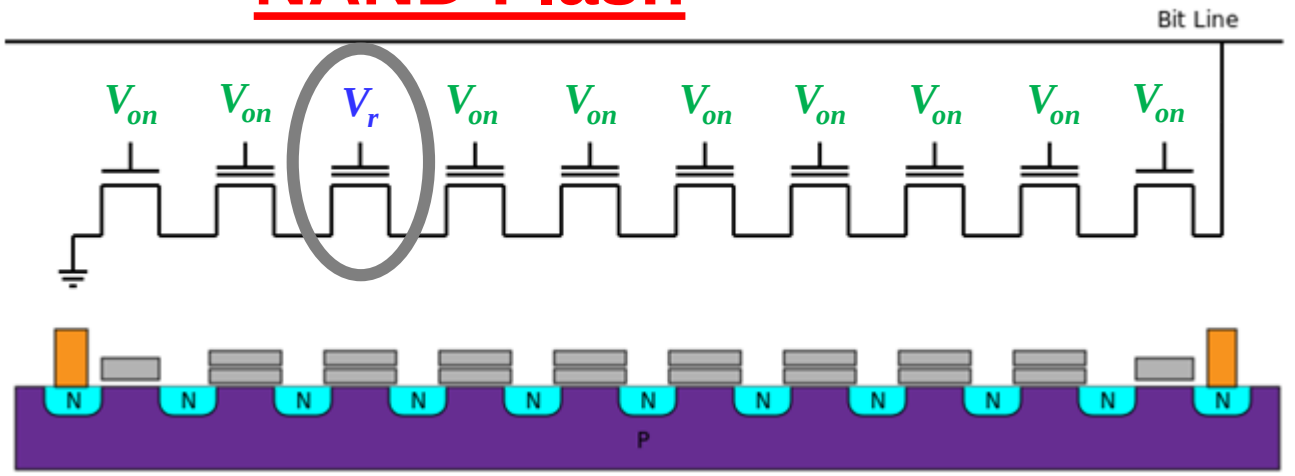
## NOR Flash




## NAND Flash

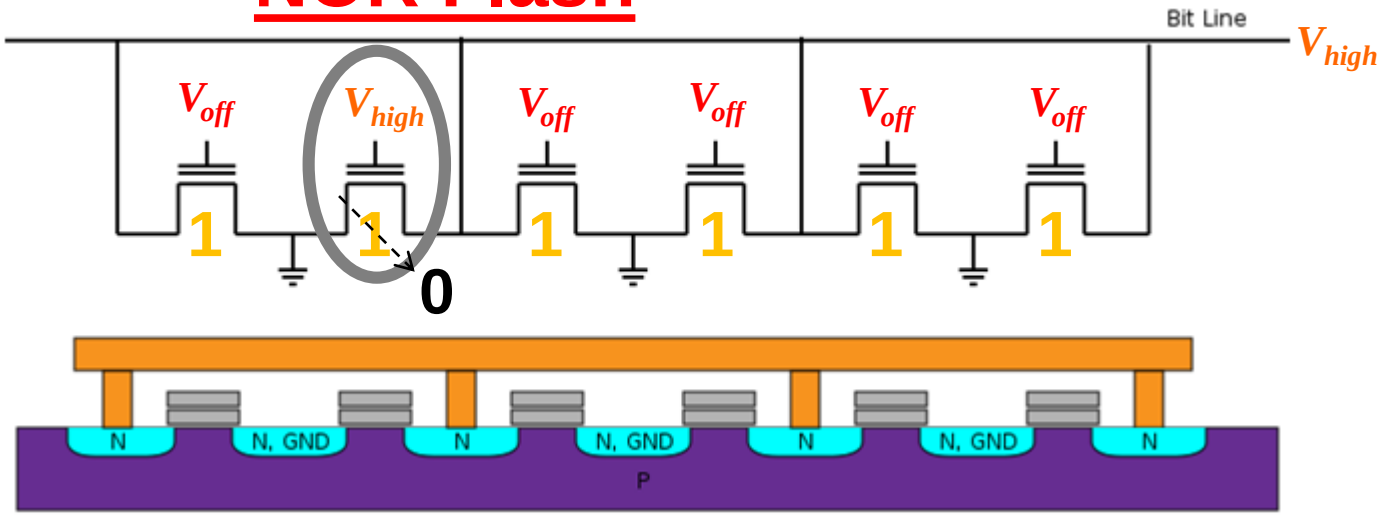


# NAND/NOR Flash – Programming (X → 0)

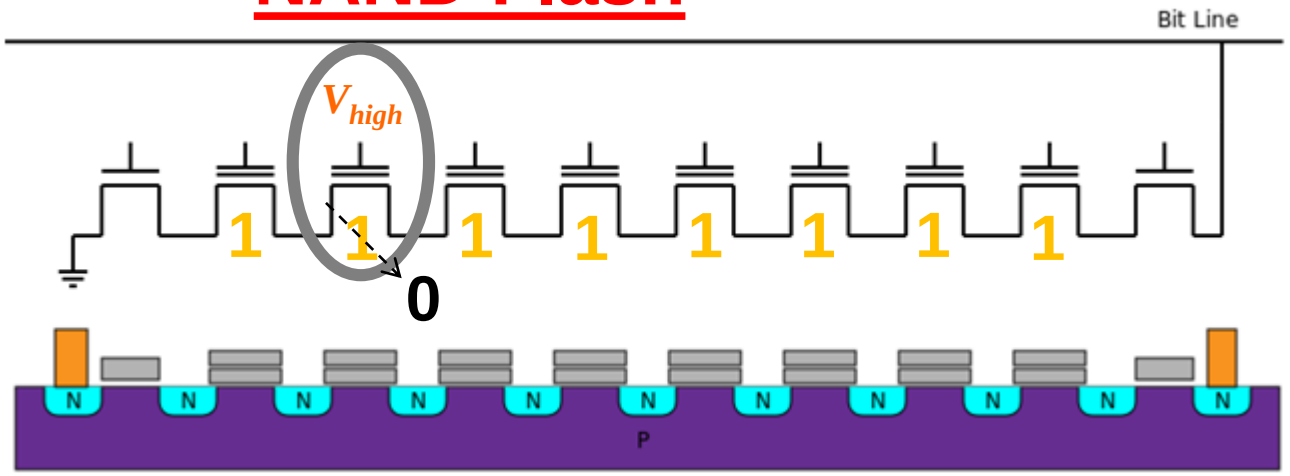
## NOR Flash

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




## NAND Flash

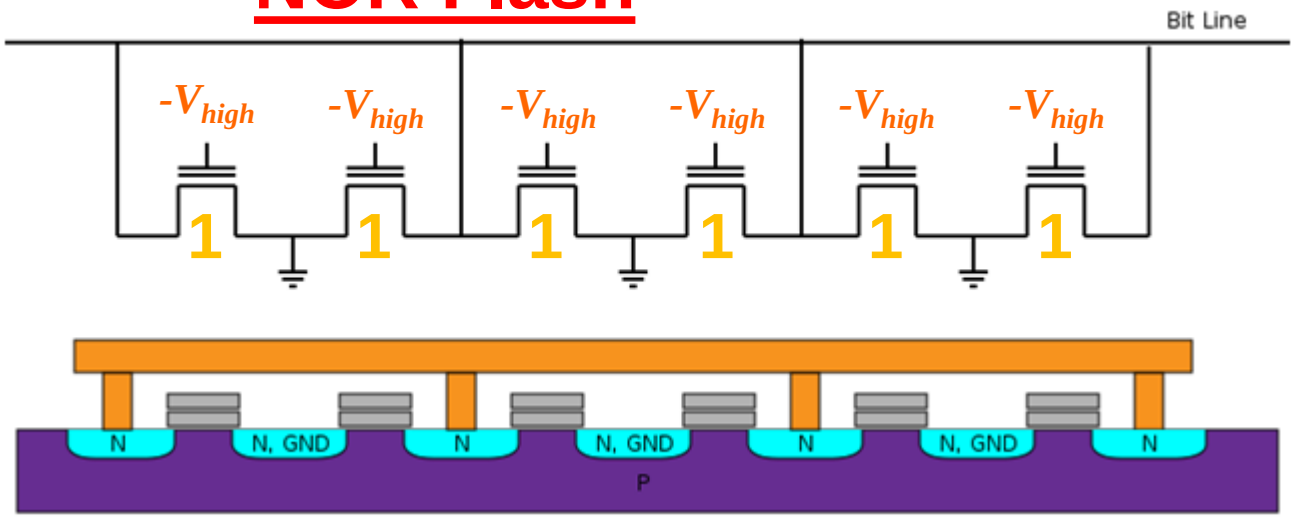
- Technique:
  - Quantum tunneling (injection).
- Explanation:
  - Electrons tunnel from B to FG.



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

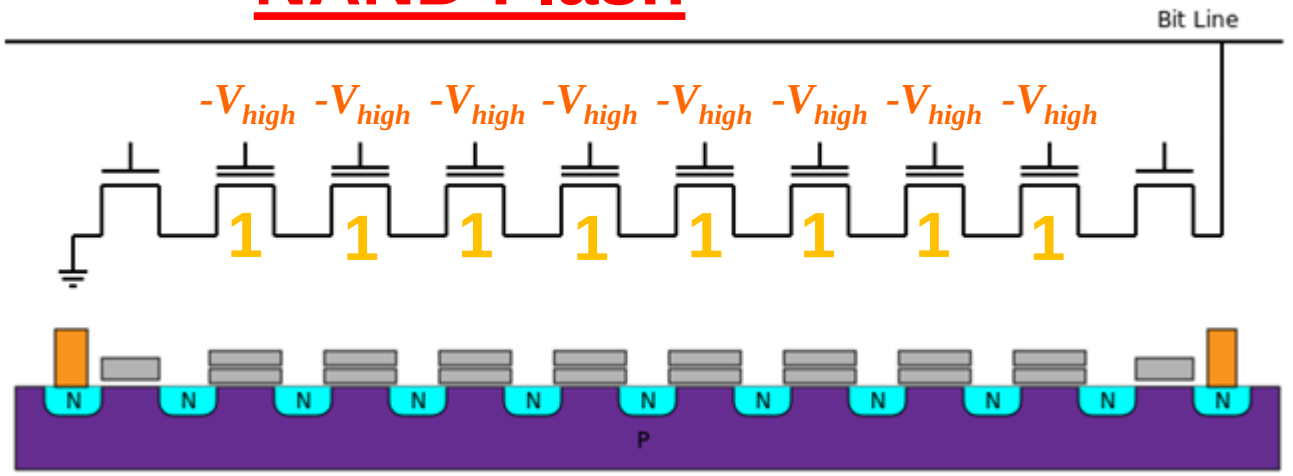
## NOR Flash

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



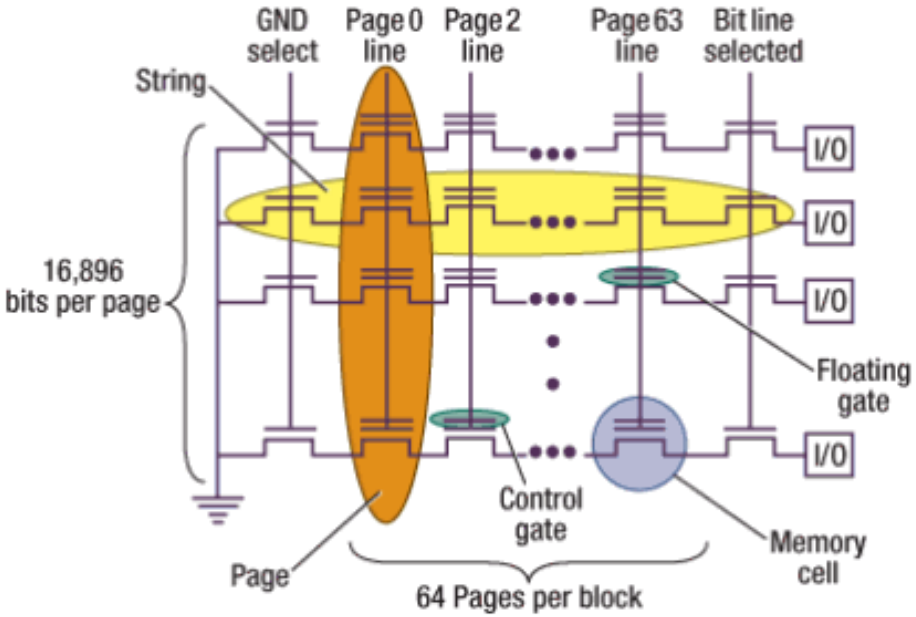

## NAND Flash

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



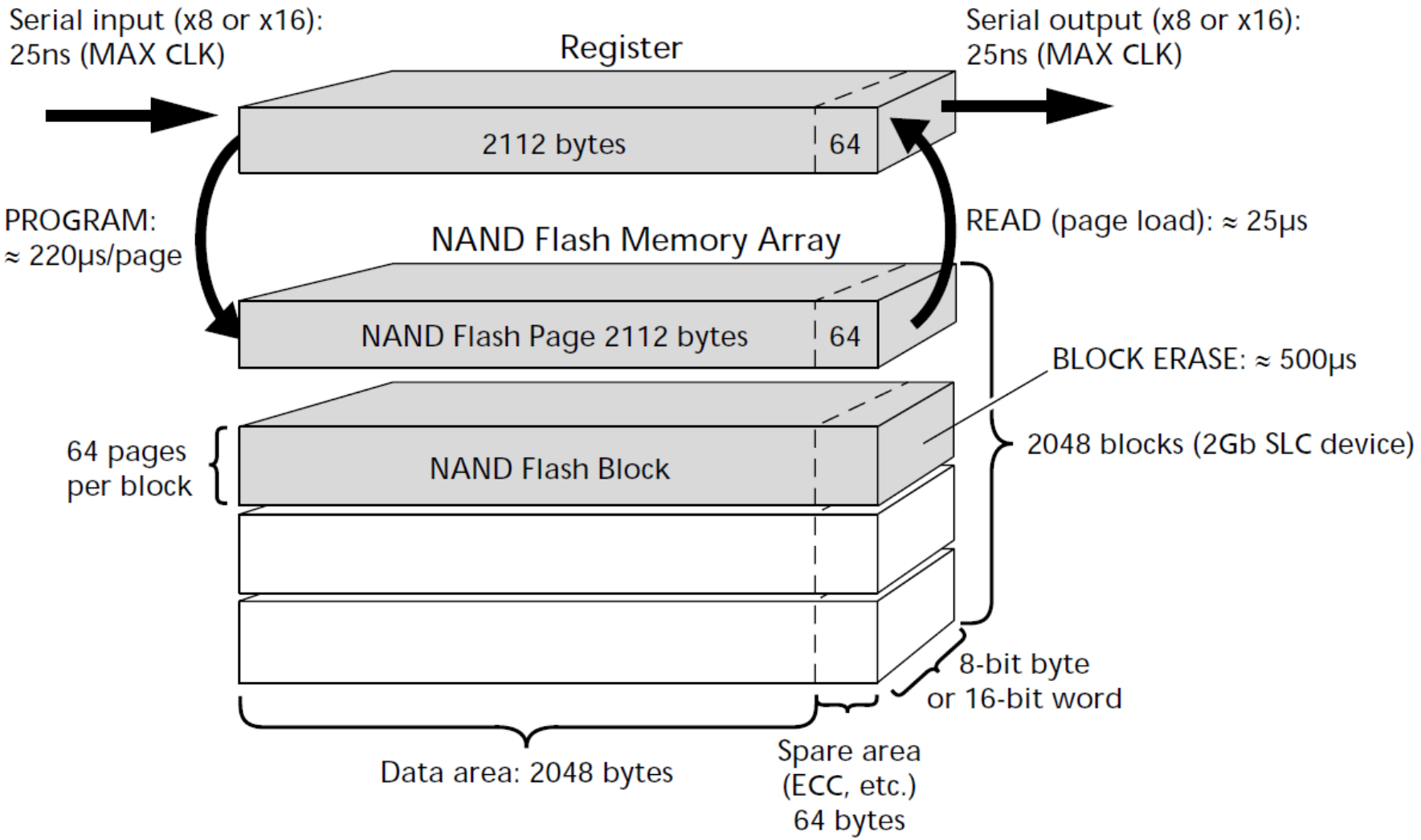
# NAND Flash Block Organization

- 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!



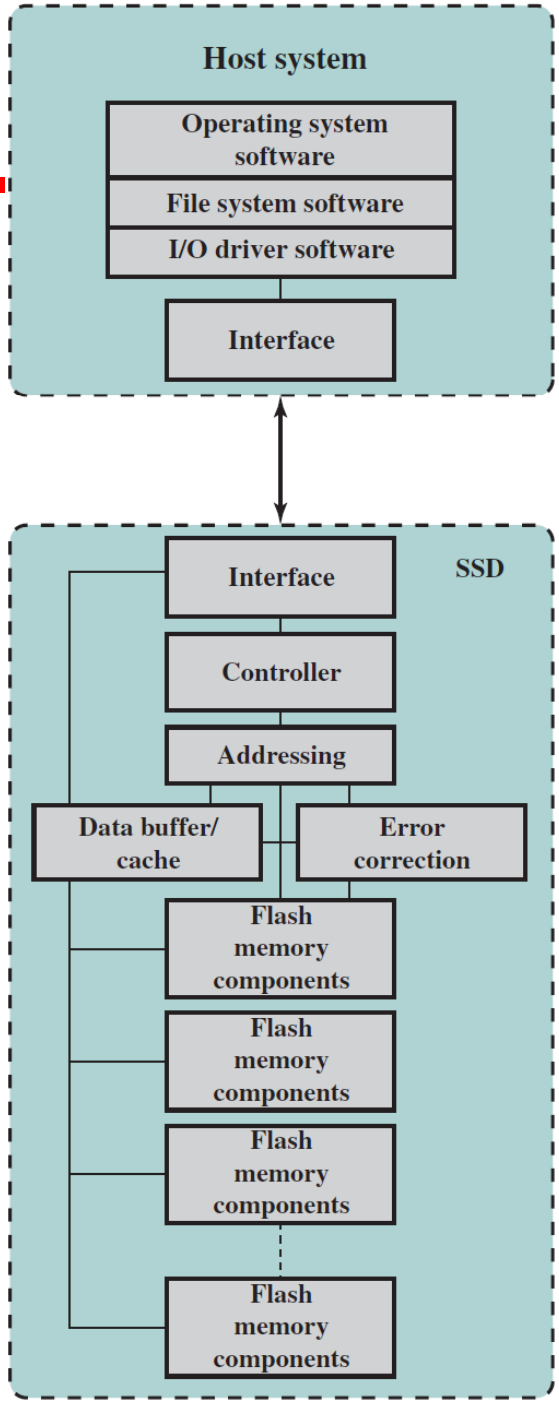

**** The numbers of bits-per-page and pages-per-block here are typical for a 2Gb NAND flash device ****

# 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<br>Write: 15,000 | 300 |
| Throughput (MB/s) | Read: 200+<br>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 |

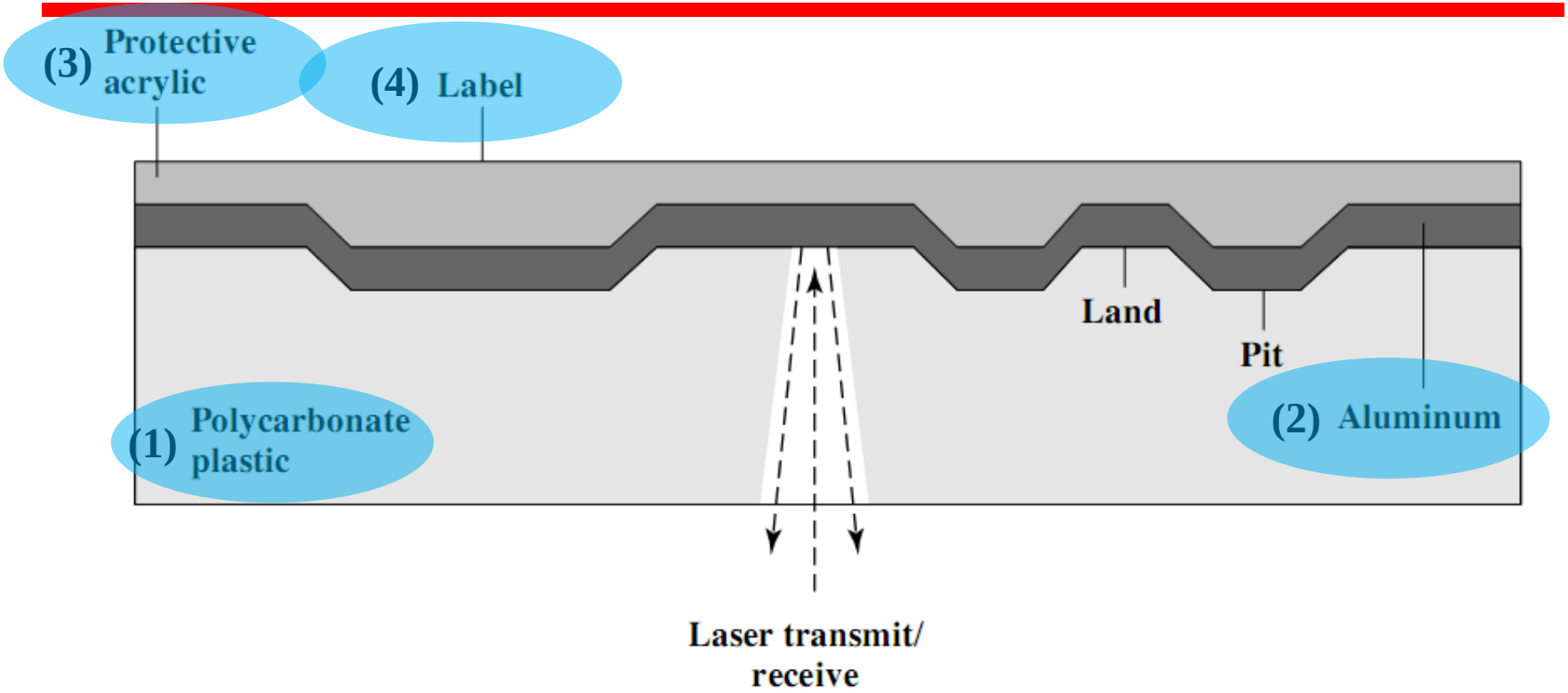
# Optical Storage - History

- 1983 CD (Compact Disk, audio CD)
  CD-ROM
  .....
- 1996 DVD-ROM
  DVD-R
  .....
- 2002 Blu-ray
  .....

# CD-ROM

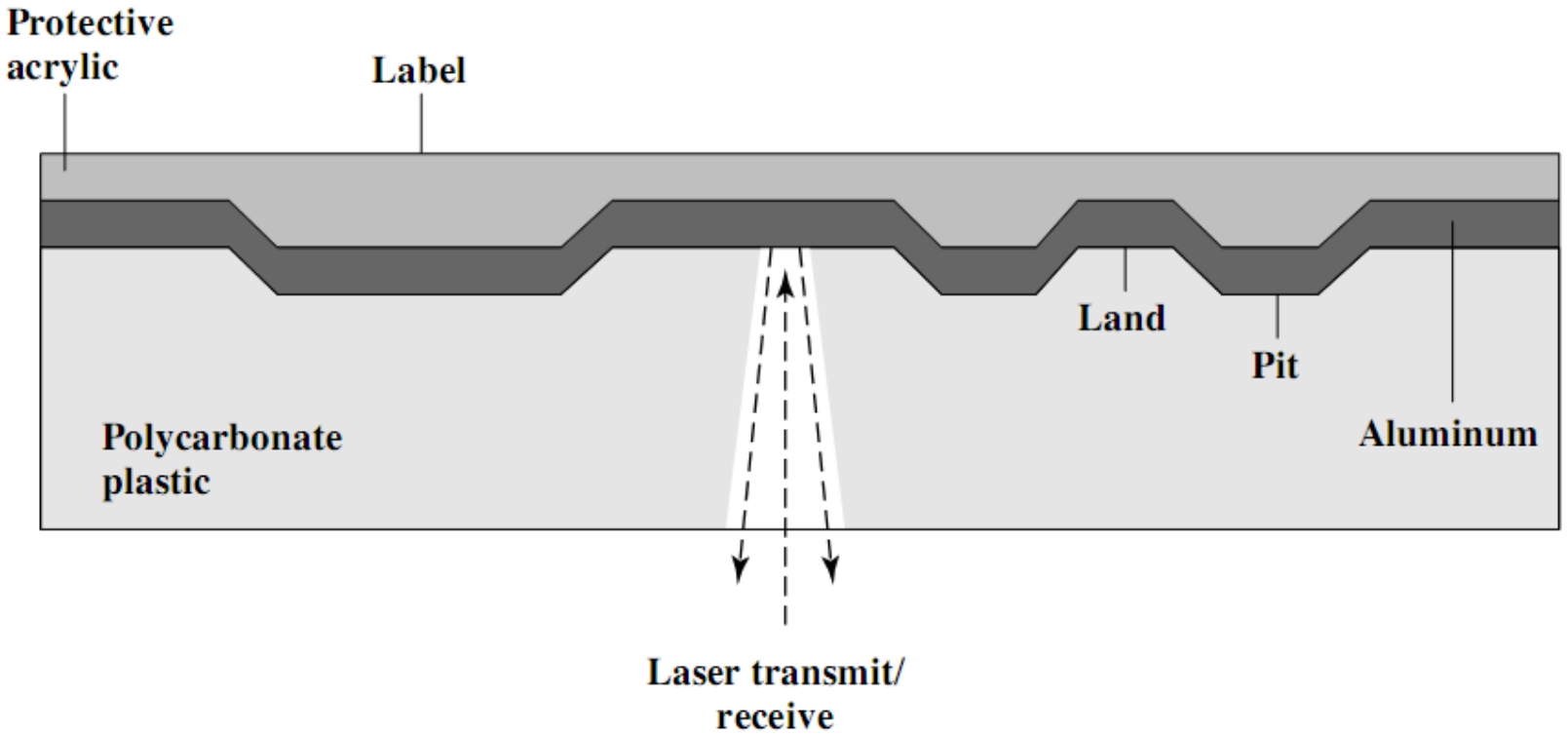
- Same technology used for audio (CD).
  - —Difference: CD-ROM drives support error-correction.
- Capacity
  - —Data: 650-700MB, or Audio: 74-80 minute.
- Material
  - —Polycarbonate coated with highly reflective coat, usually aluminium.
- Data stored as sequence of pits engraved along a spiral track 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.

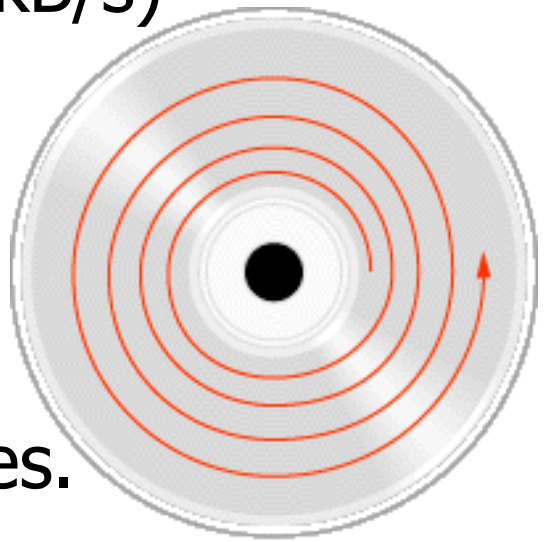
# CD-ROM - Operation



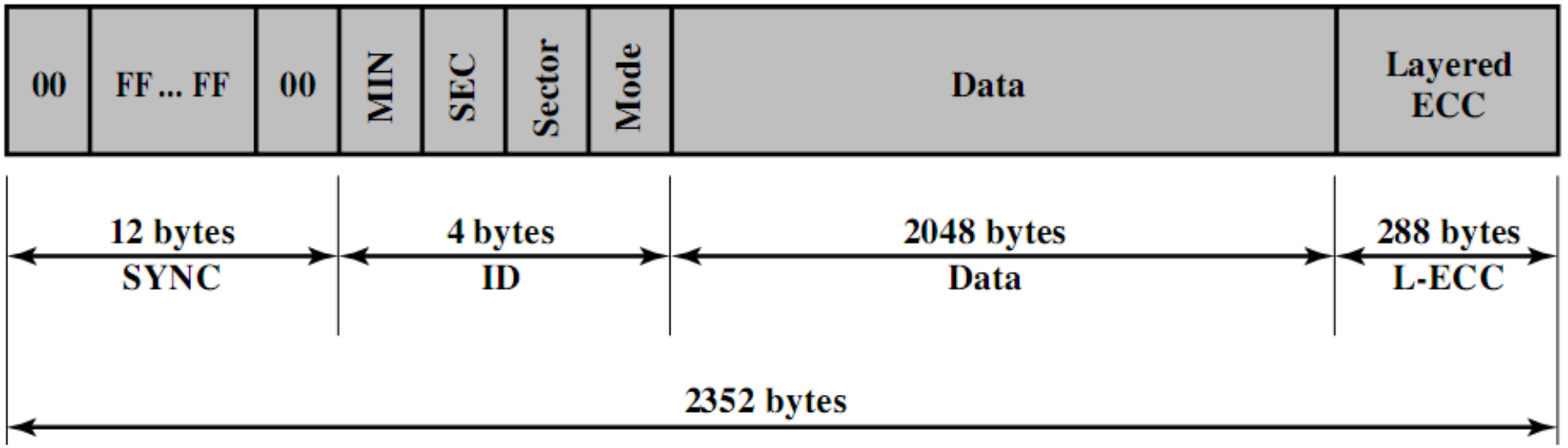

- CD drive transmits a low-power laser beam towards disk.
  - beam falls on a pit (rough surface) ➔ low intensity reflected.
  - beam falls on a land (smooth surface) ➔ high intensity reflected.
- Photo-sensor senses surface at regular intervals.
  - Change in elevation ➔ logic 1, otherwise ➔ logic 0.

# 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.

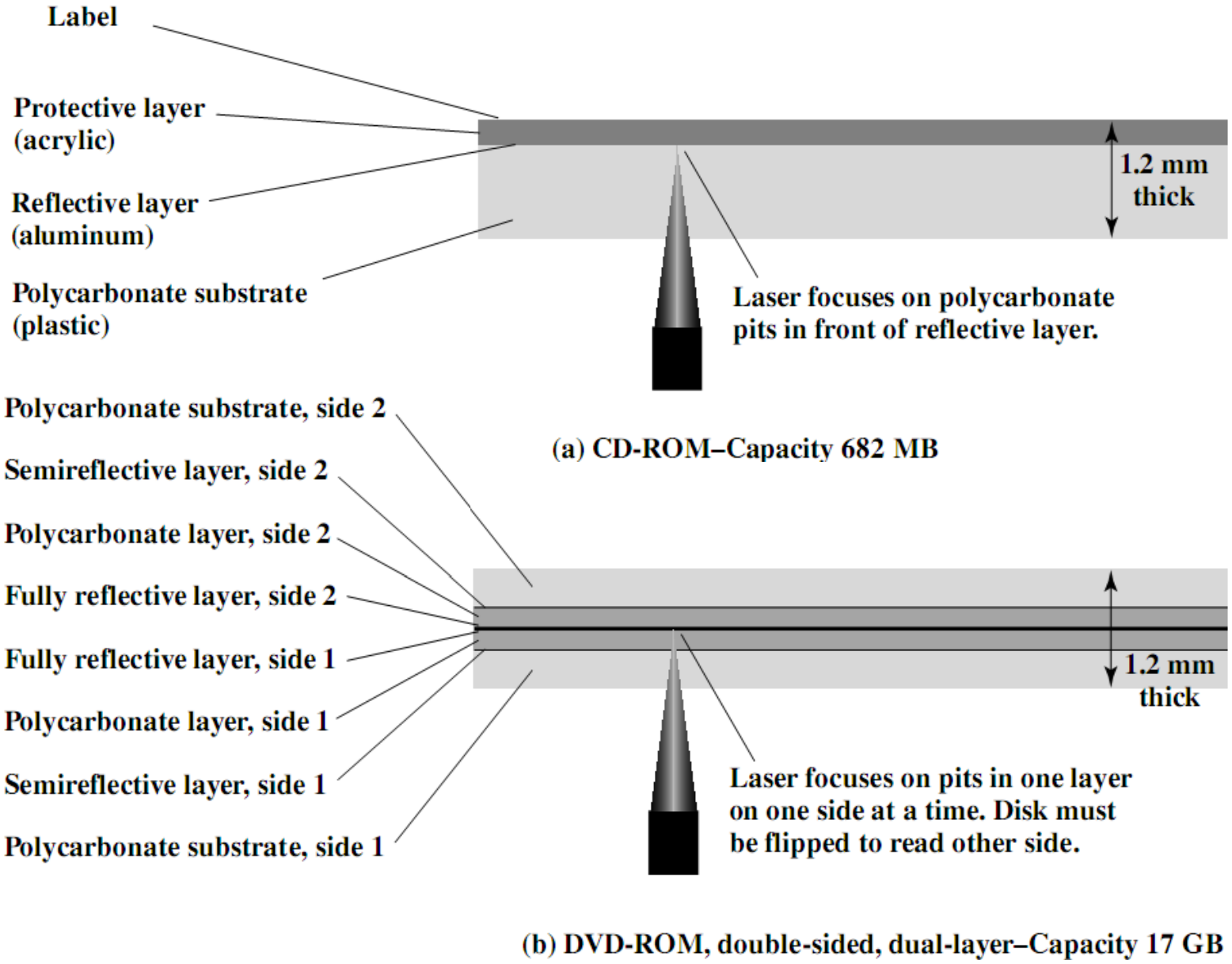
# Other Optical Storage

- 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).

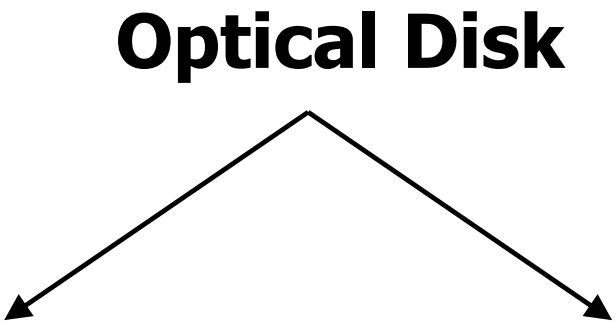
# DVD

- 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



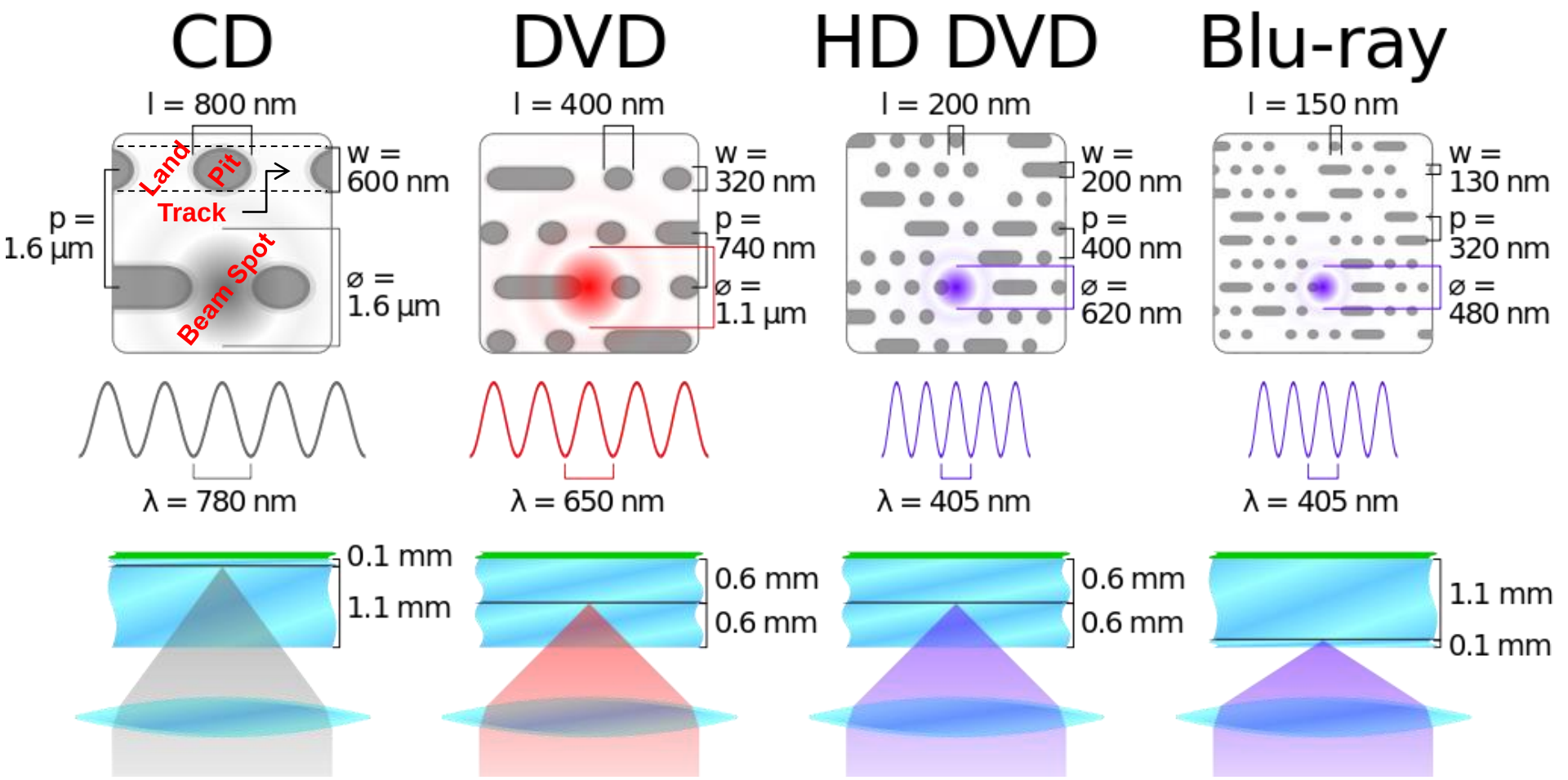

| | CD | DVD |
|---|---|---|
| Capacity | 650M~750MB | 4.7G~17GB |
| Drive Compatibility | Incomp. with DVD | Comp. with CD |
| Structure | One 1.2mm base | Two 0.6mm bases |
| Gap | Track gap=1.6μm | 0.74μm |
| | Pit gap=0.834μm | 0.4μm |
| Side & layer | Single layer/side | Double layer/side |
| Products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