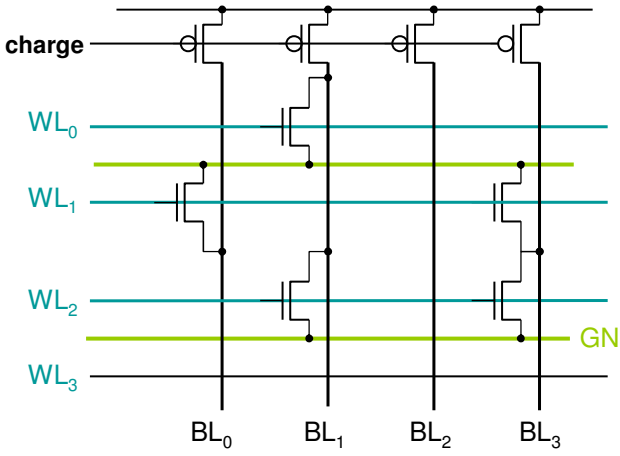
07 Memory

07.02 Non-volatile memory chips

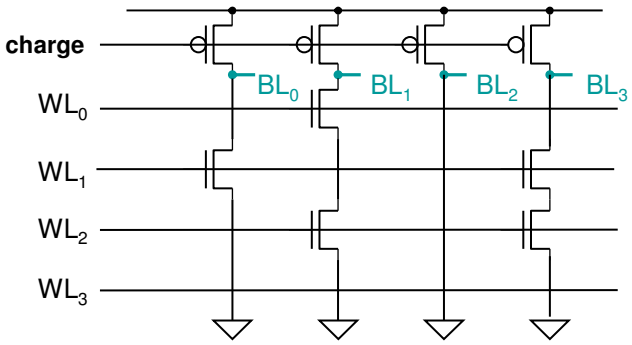
- NAND and NOR memories
- Floating gate transistors
- FLASH memories

NOR-based ROM



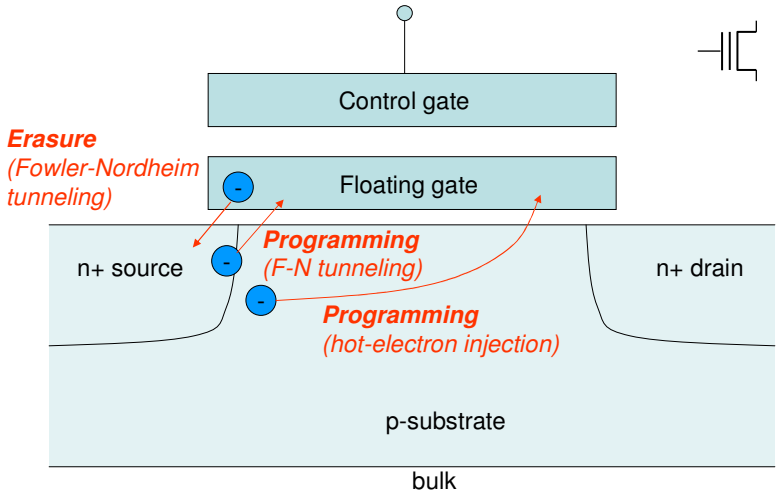
	BL_0	BL_1	BL_2	BL_3
WL_0	1	0	1	1
WL_1	0	1	1	0
WL_2	1	0	1	0
WL_3	1	1	1	1

NAND-based ROM



	BL_0	BL_1	BL_2	BL_3
WL_0	0	1	0	0
WL_1	1	0	0	1
WL_2	0	1	0	1
WL_3	0	0	0	0

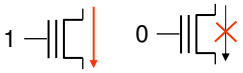
Floating gate transistor



Floating gate transistor
(programming/writing)

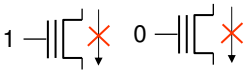
$$\Delta V_T = -\frac{\Delta Q_{FG}}{C_{FG}}$$

Without charge in the FG



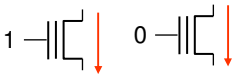
Works like a transistor

With negative charge in the FG



Works like an open line

With positive charge in the FG



Works like a short circuit

NOR-based flash memories

- Read
  - Random access, like a ROM
- Erase
  - F-N tunneling
- Write (programming)
  - Hot-electron injection
- Interface
  - Common flash interface
- Applications
  - Execute in place

NAND-based flash memories

- Read
  - Sequential
- Erase
  - F-N tunneling (release)
- Write (programming)
  - F-N tunneling (injection)
- Interface
  - Like a block device
  - MMU required to support execute-in-place
- Applications
  - File system

Multi-level flash cells

- Multi-level cell
  - Control the amount of charge in the floating gate
  - Sense the current level rather than the presence of current
  - Store 2 or more bits in a single cell
- DiskOnChip
  - High storage capacity
  - Built-in file system
  - Built-in execute-in-place

DiskOnChip *vs* NOR *vs* NAND

	DiskOnChip	NOR	NAND
Capacity	8MB-1024MB	1MB-32MB	16MB-512MB
XIP (code execution)	XIP boot block	Yes	None
Performance	Fast erase (3 msec) Fast write Fast read	VERY SLOW erase (5 sec) Slow write Fast read	Fast erase (3 msec) Fast write Fast read
Reliability	**Extremely high:** Built-in EDC/ECC solves bit-flipping. Bad block managed by TrueFFS.	**Standard:** Bit-flipping issues reported Less than 10% the life span of NAND.	**Low:** Requires 1-4 bit EDC/ECC due to bit-flipping issue. Requires bad-block management.
Erase Cycles	100,000 - 1,000,000	10,000 - 100,000	100,000 - 1,000,000
Interface	SRAM/NOR-like	Full memory interface	I/O only
Access Method	RND on code area, SEQ on data area.	Random	Sequential
Ideal Usage	Both data and code storage in any application that requires a file system.	Code storage - limited capacity due to price in high capacity. May save limited data as well.	Data storage only - due to complicated flash management. Code will usually not be stored in raw NAND flash.
Examples	Smartphones PDAs Point-Of-Sale Workstations SCB/IPC Digital Gateways Telecom Equipment Set-Top Boxes Thin Clients	Simple home appliances Embedded designs Low-end set top boxes Low-end mobile handsets PC BIOS chips	PC Cards Compact Flash Secure Digital MP3 players Digital Cameras
Price	Low	High	Low

http://www.m-sys.com/site/en-US/Corporate/Technology/NANDandNOR_Flash_Technologies.htm

Flash vs HDD

- No random-access rewrite
  - Require complex built-in interfaces
- Higher cost
  - NAND flashes have the lowest cost per bit
- Limited number of erase-write cycles
  - Read-most memories
- Much lower power consumption