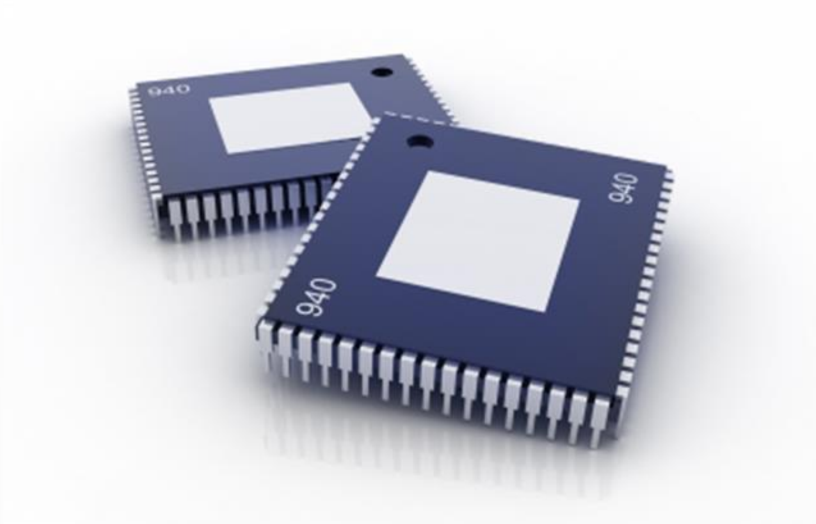

LECTURE 1

Soo-Won Kim

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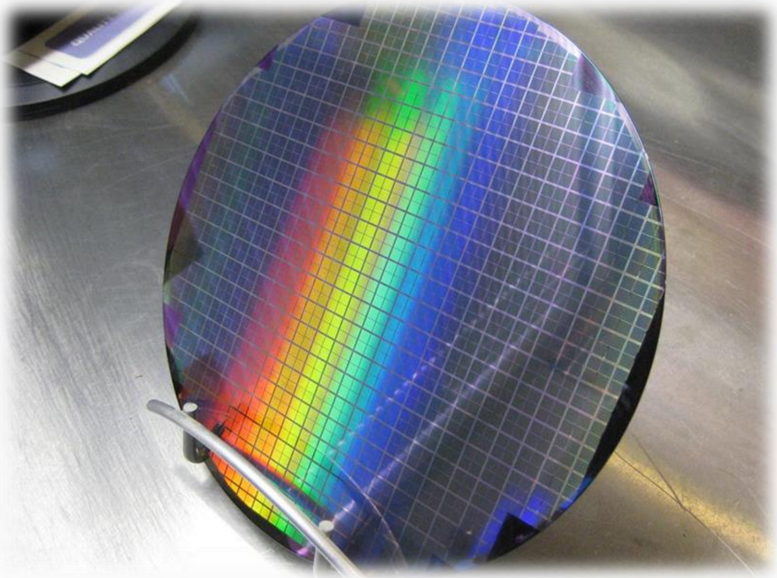
1. Integrated-Circuit Devices And Modeling

Semiconductors



- Semiconductor = crystal lattice structure (free electrons + free holes)
- ***Intrinsic*** silicon has equal numbers of free electrons and holes
- Intrinsic carrier concentration, $n_i = 1.1 \times 10^{16}$ carriers/cm^3

History of Semiconductors

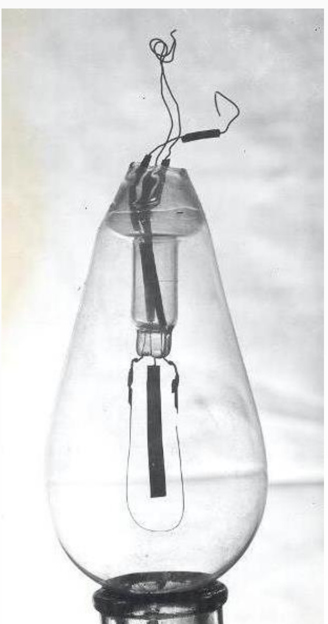
- Incandescent lamp(백열등) : By Edison (1879.10.21)

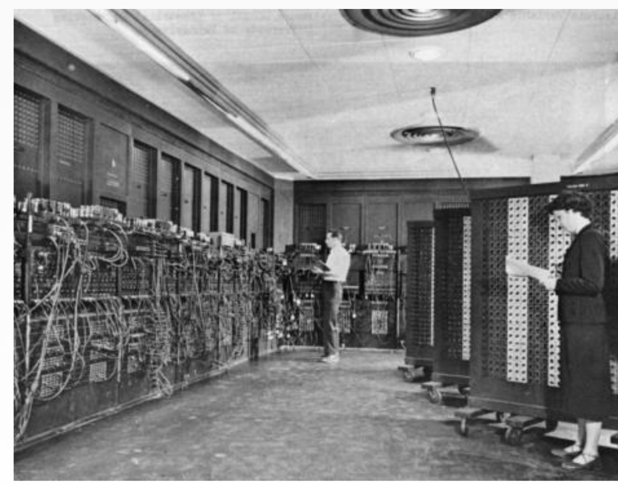
- Vacuum Tube(진공관) : By John Ambrose Fleming(1904)

  Ex) ENIAC: First computer

  → Consists of 17,468 Vacuum Tube + other devices

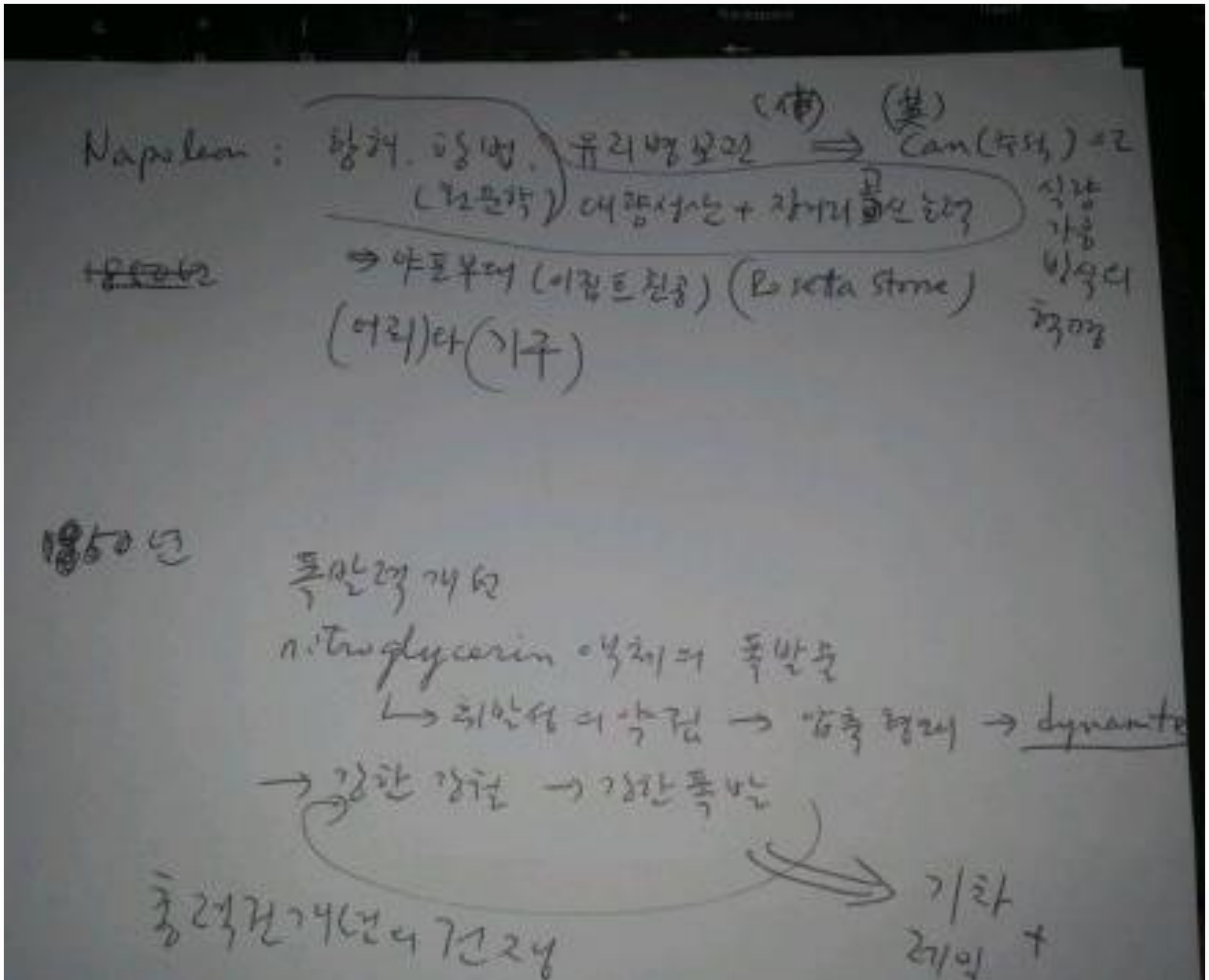
Size, power, stability issue



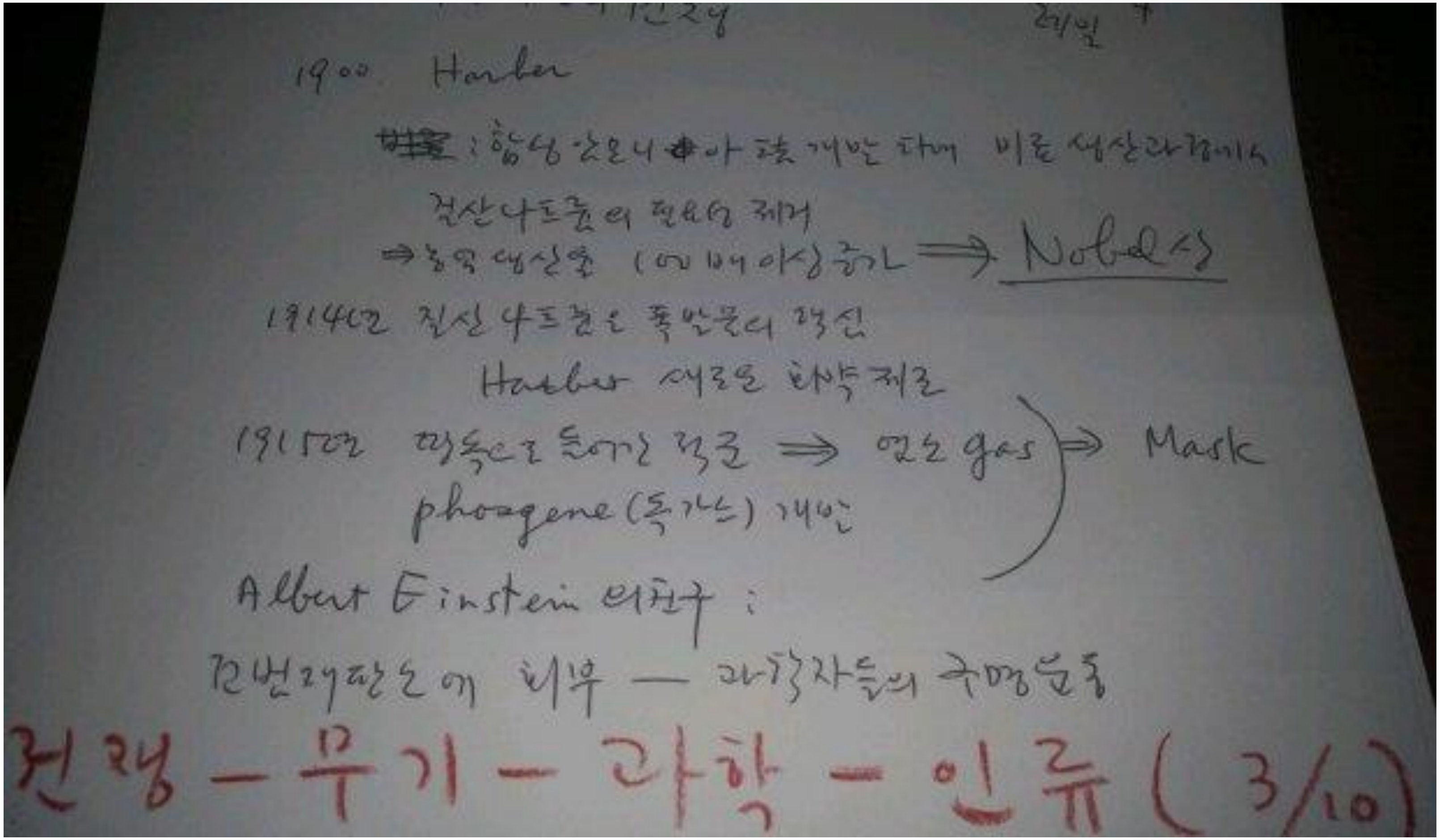


History of Semiconductors

- **World war Ⅱ**: 1939.9 ~ 1945.8

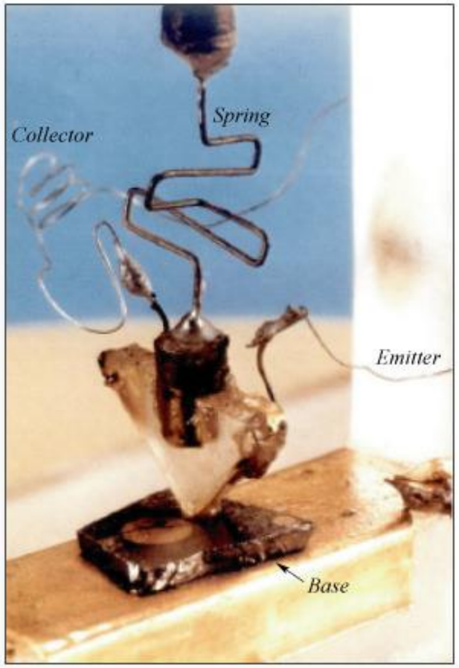


History of Semiconductors



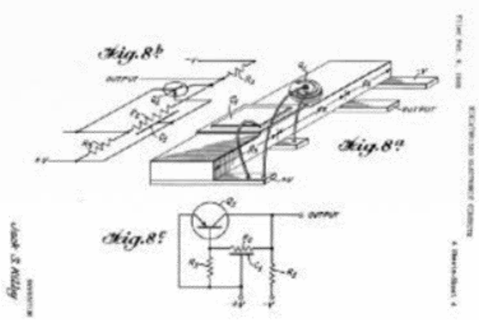
History of Semiconductors

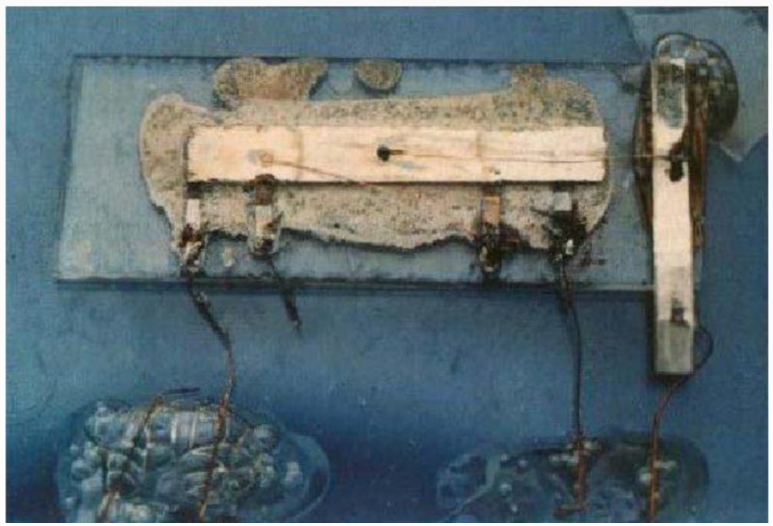
- Transistor
  - In 1947: The first point contact transistor was developed
    - ✓ John Bardeen and Walter Brattain in Bell Lab.)
  - In 1956: The Nobel Prize winner
    - ✓ William Shockley was included



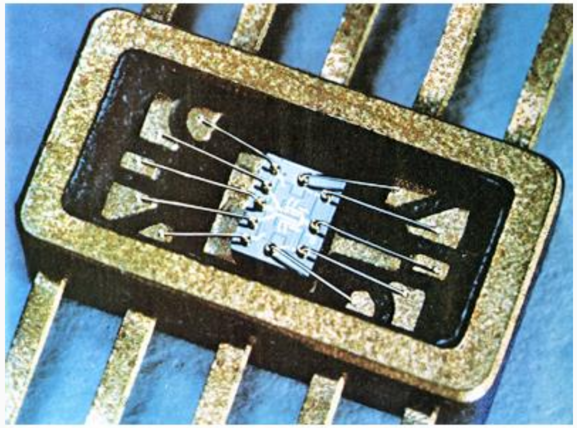
History of Semiconductors

- In 1958: The first IC was invented
  - By Jack Kilby of Texas Instruments
    - ✓ The Nobel Prize winner in 2000

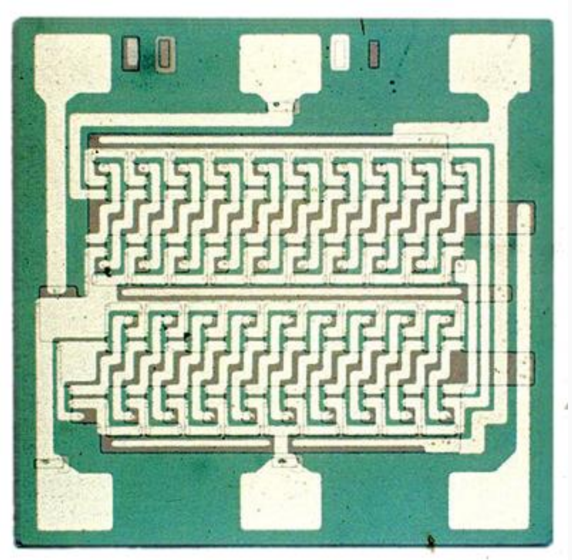




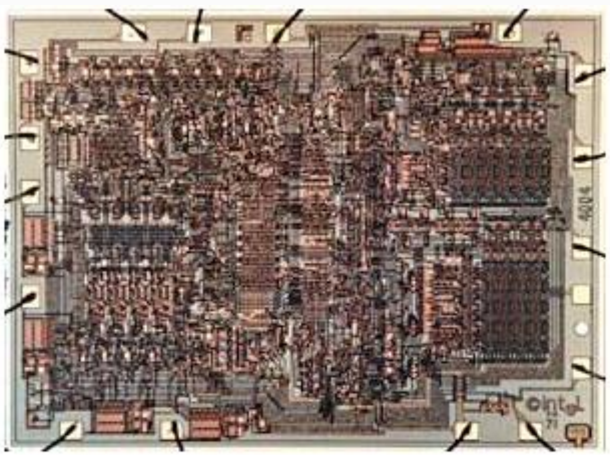
History of Semiconductors



1962 Fairchild IC



1964 First MOS IC



1971 Intel 4004 microprocessor

(2,300 transistors, 144mm^2)

2011 Intel i7

?

(560,000,000 transistors, 296mm^2)

Diodes (=PN junction)

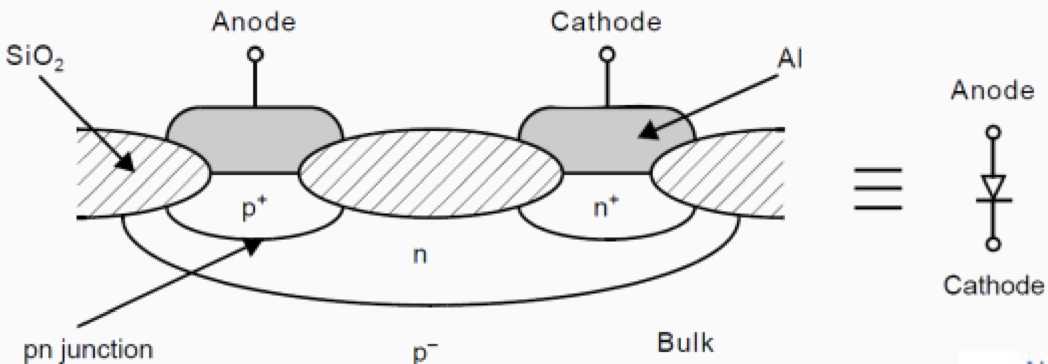


Fig. 1.1 A cross section of a pn diode

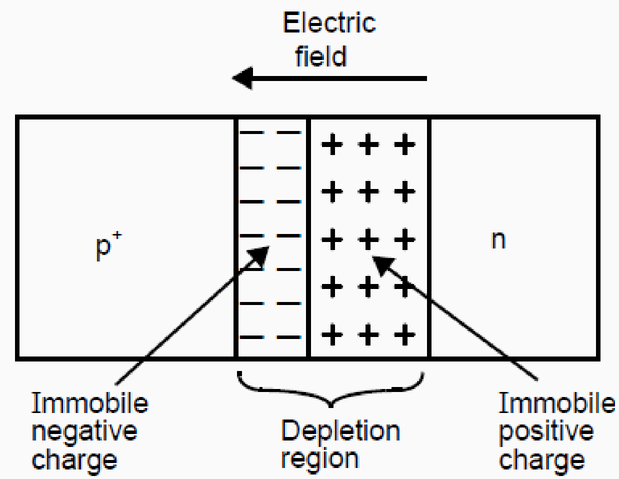
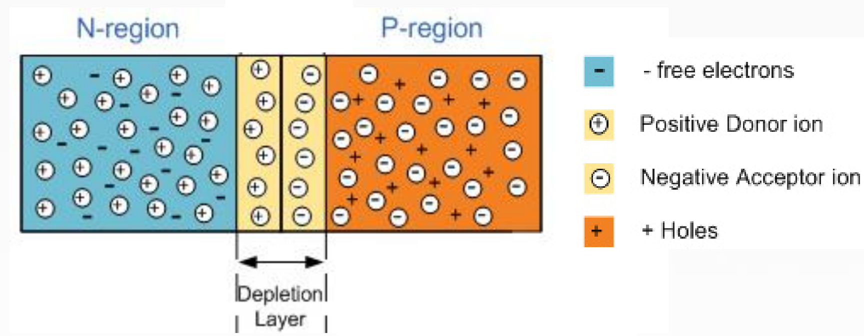


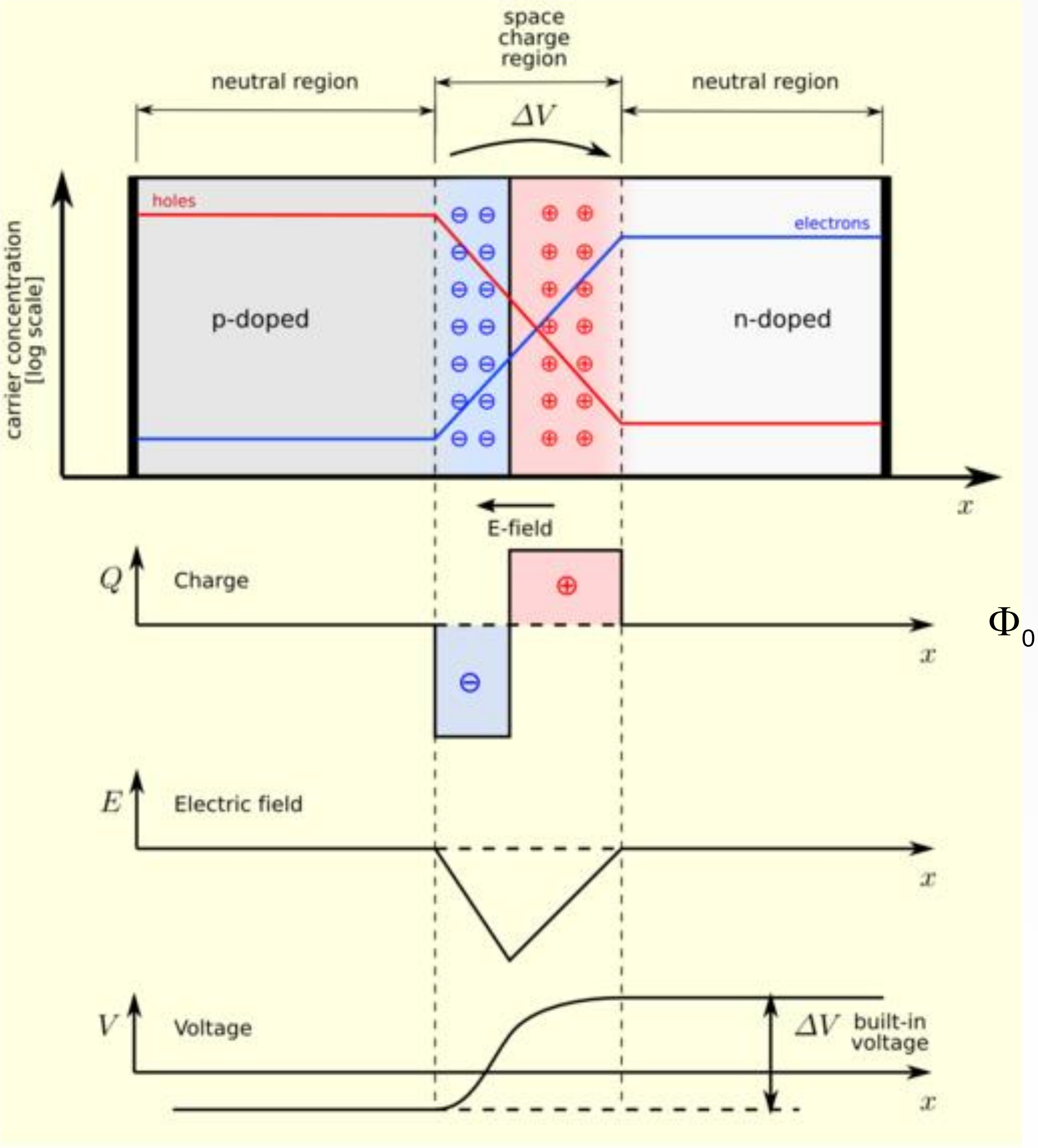
Fig. 1.2 A simplified model of a diode



- **Anode** : p-type, **Cathode** : n-type
- ***Depletion region***
  1. Diffusion of free carriers of p side & n side
  2. It extends farther into the more lightly doped side
- ***Built-in voltage*** = potential difference between the n and p side

$$\Phi_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) \quad (1.6)$$

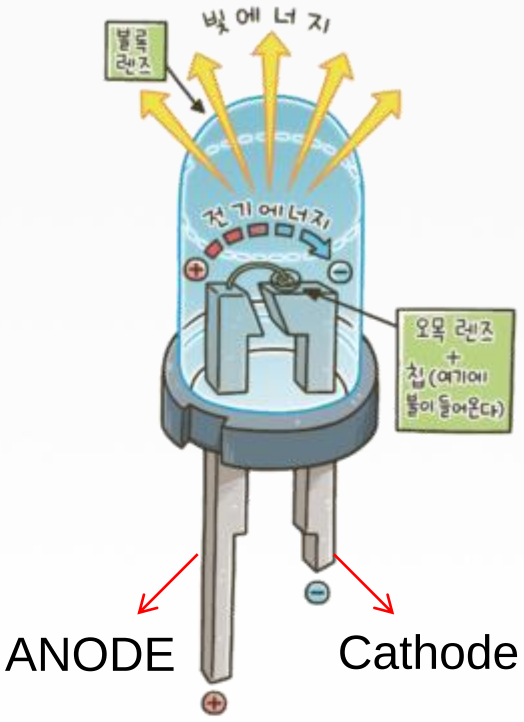
Diodes (=PN junction)

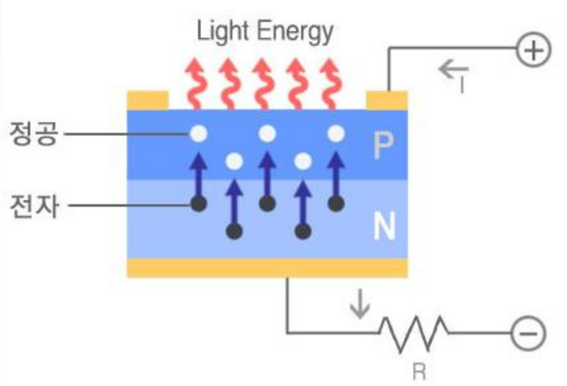


$$\Phi_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) \quad (1.6)$$

Diode's Application: LED

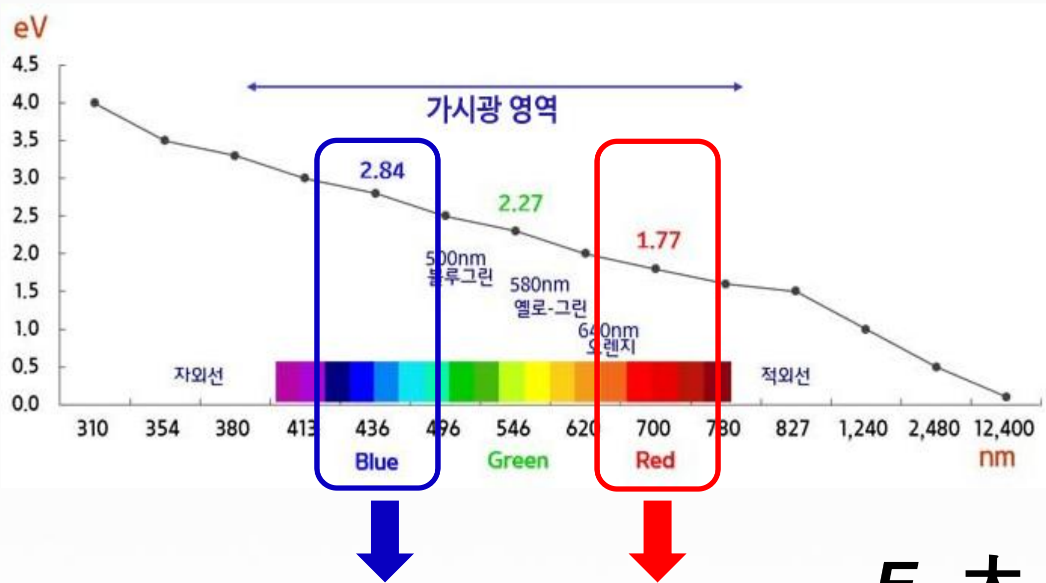
- PN junction은 실리콘만 사용하지 않고 다른 물질을 사용하여 다양한 용도로 사용이 가능하다.
- LED(Light Emitting Diode) : 다이오드를 이용하여 순방향 전류가 흐르는 경우 전기 에너지를 빛 에너지로 변환하는 소자!





Diode's Application: LED

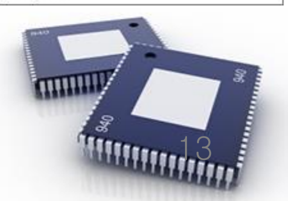
- 실리콘이 아닌 3-5족 반도체 다이오드의 경우 Lighting energy(eV)로 발산(발광) 한다.



2.84 eV 1.77 eV

E_g 大

	Color	Wavelength [nm]	Semiconductor material
	Infrared	λ > 760	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
	Red	610 < λ < 760	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Orange	590 < λ < 610	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Yellow	570 < λ < 590	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Green	500 < λ < 570	**Traditional green:** Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP) **Pure green:** Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN)
	Blue	450 < λ < 500	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate—under development
	Violet	400 < λ < 450	Indium gallium nitride (InGaN)
	Purple	multiple types	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
	Ultraviolet	λ < 400	Diamond (235 nm) Boron nitride (215 nm) Aluminium nitride (AlN) (210 nm) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)—down to 210 nm
	Pink	multiple types	Blue with one or two phosphor layers: yellow with red, orange or pink phosphor added afterwards, or white with pink pigment or dye.
	White	Broad spectrum	Blue/UV diode with yellow phosphor



MOS Transistors

- Diode → [Bipolar Transistor / MOS(Metal-Oxide Semiconductor) Transistor]

CMOS circuit (*Complementary* MOS): contains n-type and p-type transistor

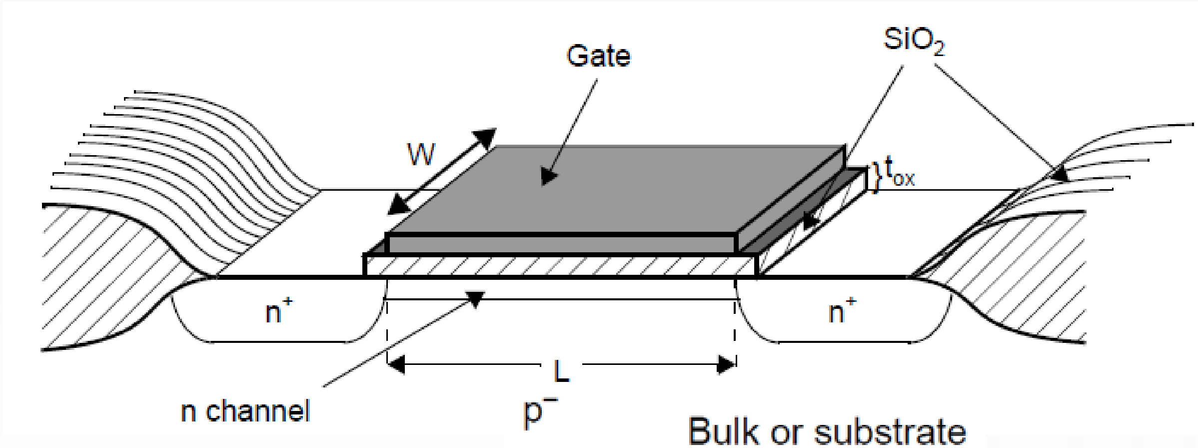


Fig. 1.10 The important dimensions of a MOS transistor

- The used MOS technologies in the Lab, the minimum channel length is about 0.35μm and 0.18μm
- ***p substrate*** is connected to the most negative voltage (NMOS)
- ***n well*** is connected to the most positive voltage (PMOS)

Symbols for MOS transistors

- MOS transistor are actually four-terminal devices

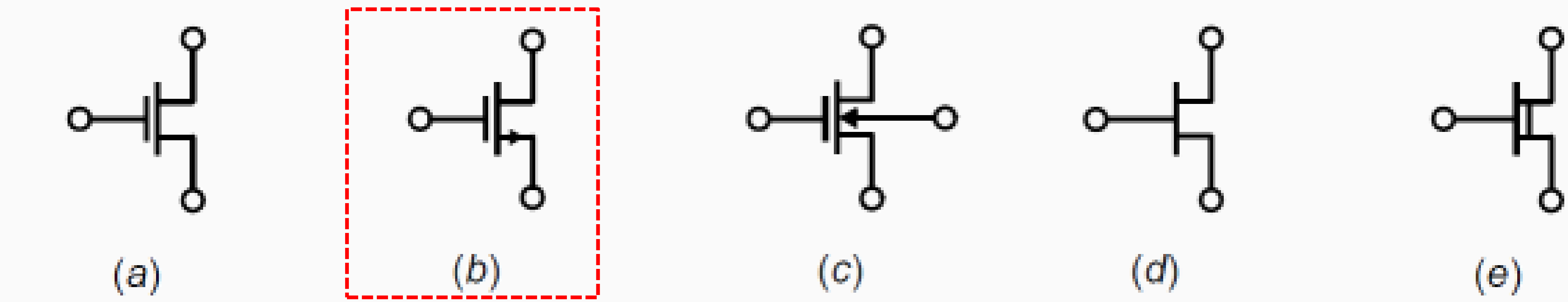


Fig. 1.7 Commonly used symbols for n-channel transistors

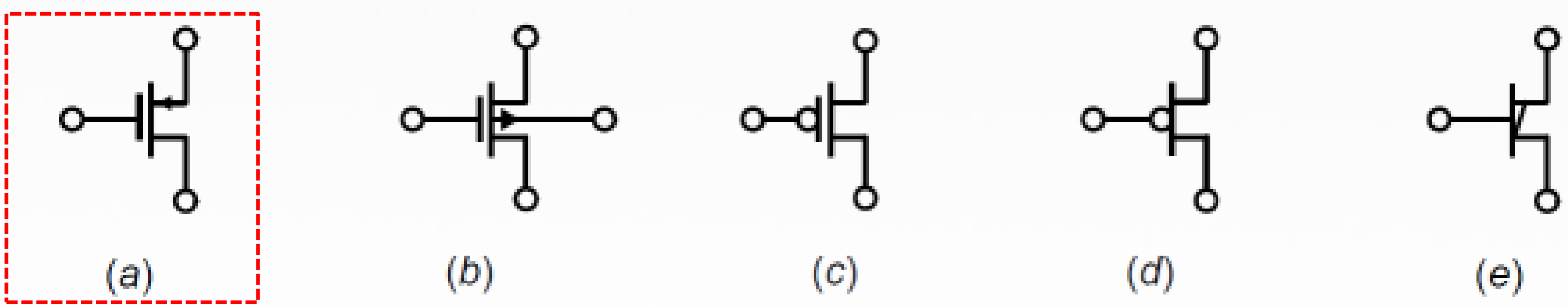


Fig. 1.8 Commonly used symbols for p-channel transistors

3. Basic Current Mirrors and Single-Stage Amplifiers

3.1 Simple CMOS Current Mirrors

3.2 Common-Source Amplifier

3.3 Source-Follower or Common-Drain Amplifier

3.4 Common-Gate Amplifier

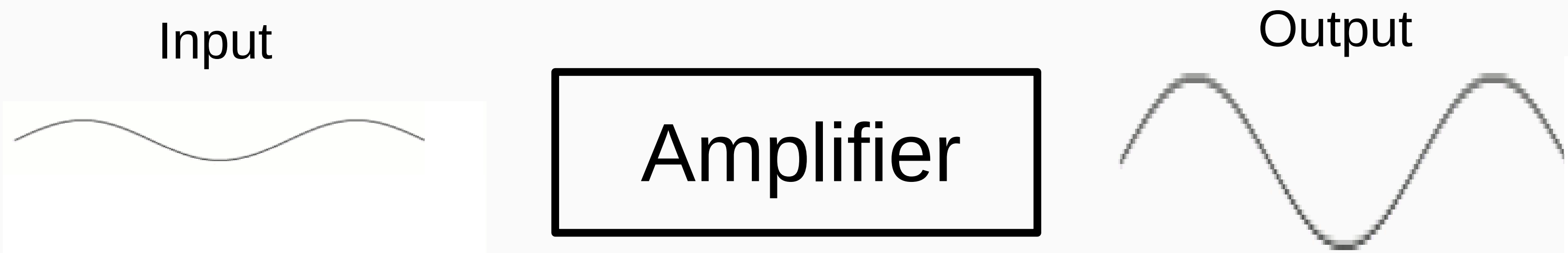
3.5 Source-Degenerated Current Mirrors

3.6 Cascode Current Mirrors

3.7 Cascode Gain Stage

3.8 MOS Differential Pair and Gain Stage

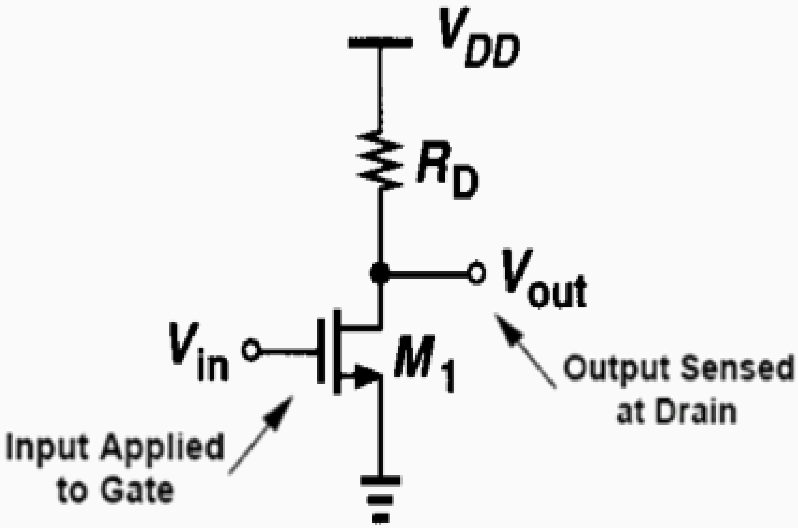
Amplifier

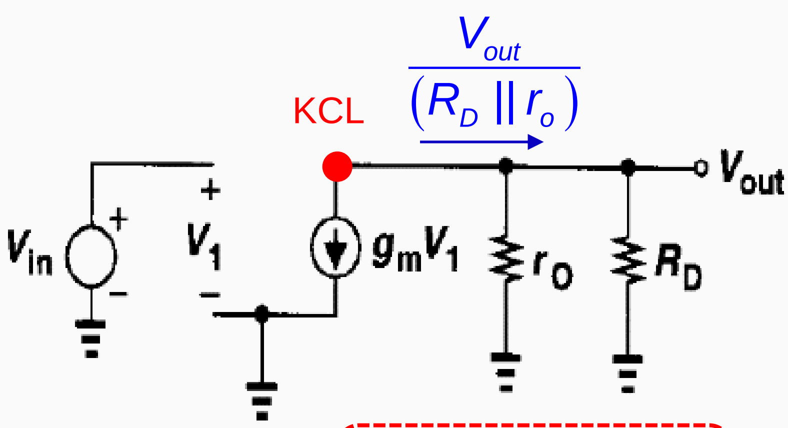


– **Amplification의 목적**

- ✓ 부하를 구동시킬 만큼의 큰 신호를 만들기 위해
- ✓ 다음 단 회로 블록의 Noise를 무시할 만큼의 큰 신호를 만들기 위해
- ✓ 디지털회로에서 논리레벨을 제공하기 위해

Common source stage





$$\frac{V_{out}}{V_{in}} = -g_m (R_D \,||\, r_O)$$

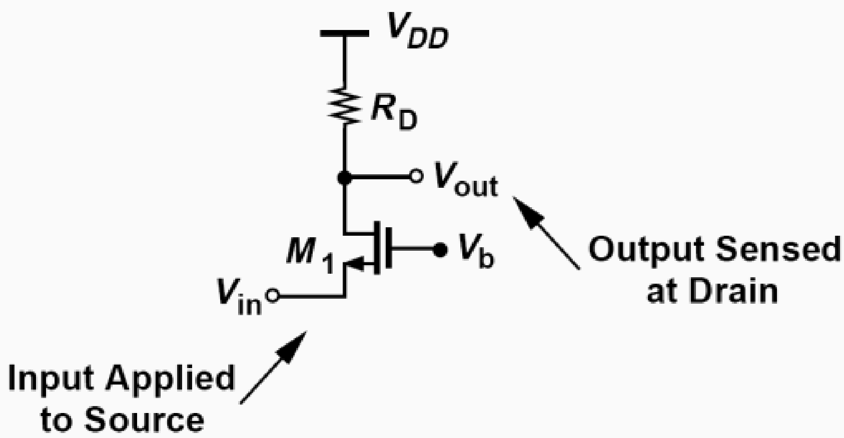
Since $g_m = \sqrt{2\mu_n C_{ox}(W/L)I_D}$,

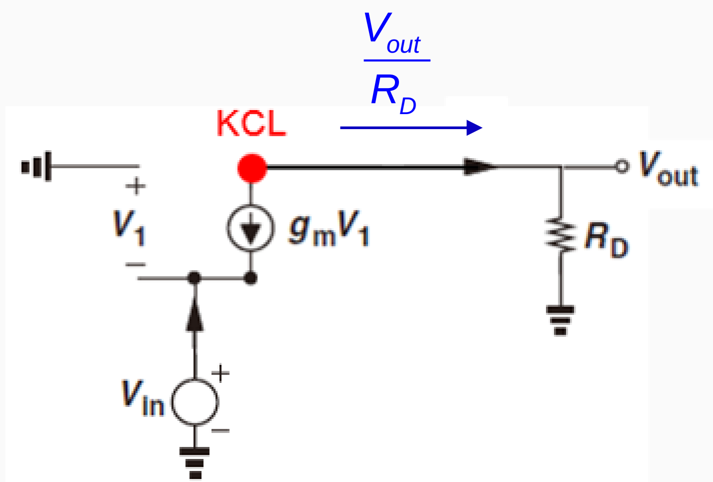
$$\Rightarrow \quad A_v = -g_m (R_D \,||\, r_O) = -\sqrt{2\mu_n C_{ox}\frac{W}{L}I_D}\,(R_D \,||\, r_O)$$

For M1 to remain in saturation, $V_{GS} < V_{DS} + V_{TH}$

$$\Rightarrow \quad V_{GS} < V_{DD} - R_D I_D + V_{TH}$$

Common-gate stage





$$A_v \approx g_m R_D \quad (\lambda = 0)$$

- **Trade-off : Voltage headroom and gain.**

V_{in} increase

⬇

V_{GS} decrease

⬇

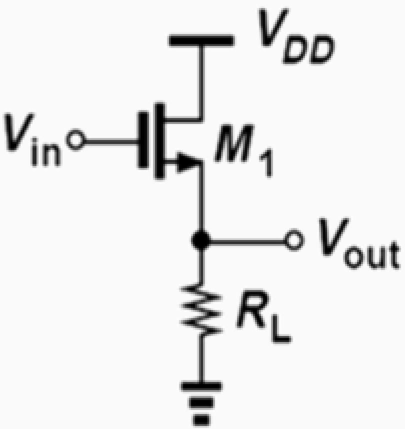
I_D decrease

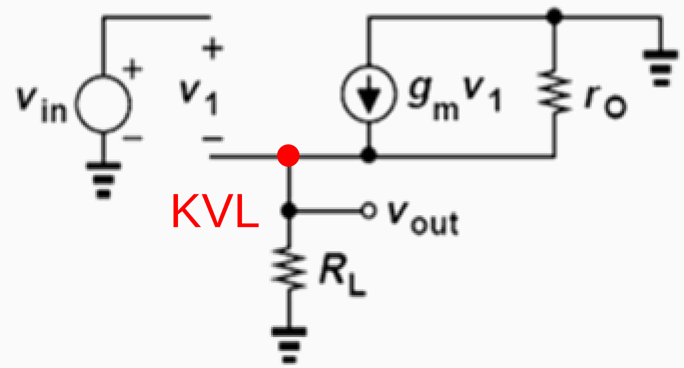
⬇

V_{out} increase

V_{out}* is dependent on *V_{in}

Source follower stage





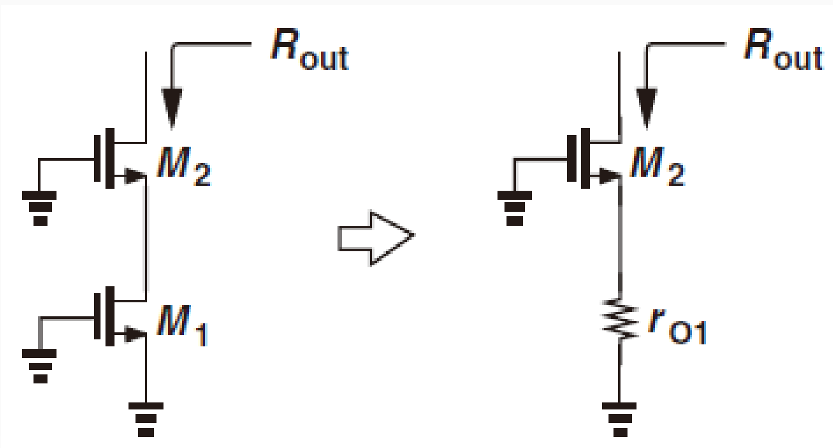
$$\left.\begin{aligned} g_m v_1 \left(r_o \| R_L\right) &= v_{out} \\ v_{in} &= v_1 + v_{out} \end{aligned}\right\} \quad \frac{v_{out}}{v_{in}} = \frac{g_m\left(r_o \| R_L\right)}{1+g_m\left(r_o \| R_L\right)}$$

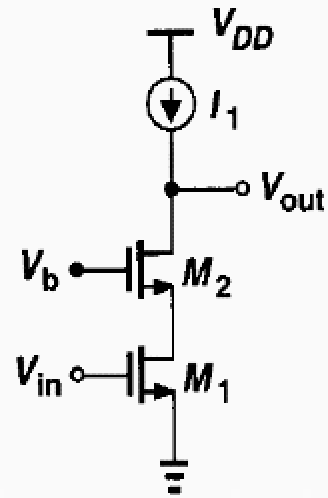
$$= \frac{r_o \| R_L}{\frac{1}{g_m} + \left(r_o \| R_L\right)} \quad \xrightarrow{\lambda = 0} \quad = \frac{R_L}{R_L + \frac{1}{g_m}}$$

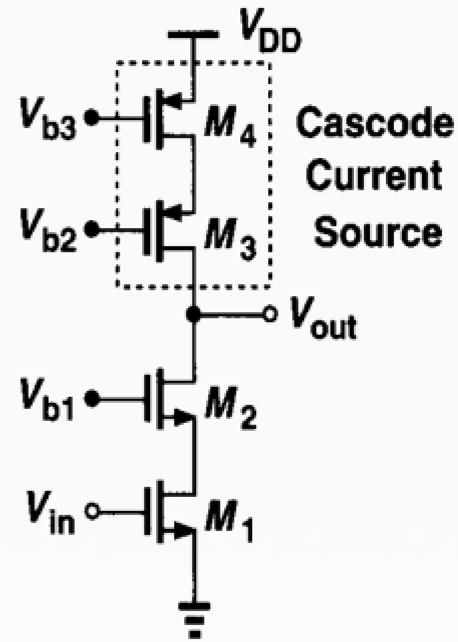
The voltage gain is positive and less than unity

MOS Cascodes

- Gain($A_v \approx g_m R_{out}$)을 증가시키기 위해서 R_{out}을 증가시킨다.







$$R_{out} = (1 + g_{m2} r_{O2}) r_{O1} + r_{O2}$$

$$\approx g_{m2} r_{O1} r_{O2},$$

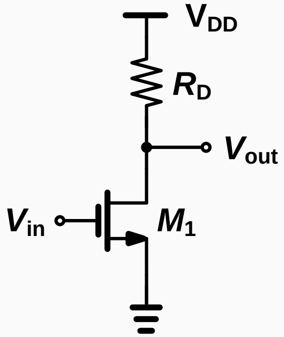
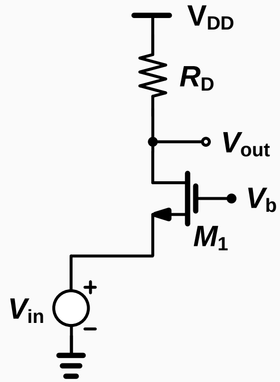
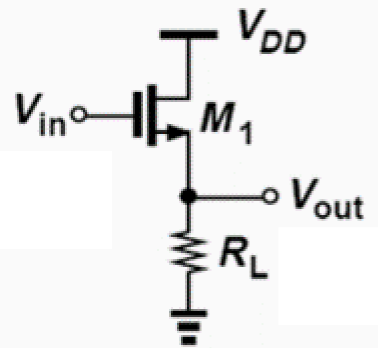
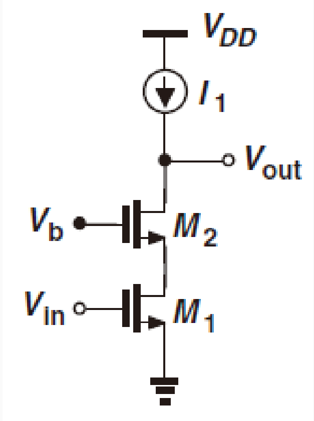
where it is assumed $g_m r_{O1} r_{O2} >> r_{O1}, r_{O2}$

$$R_{on} = \{[1 + (g_{m2} + g_{mb2}) r_{O2}] r_{O1} + r_{O2}\}$$

$$R_{op} = \{[1 + (g_{m3} + g_{mb3}) r_{O3}] r_{O4} + r_{O3}\}$$

$$A_v \approx -g_{m1}[(g_{m2} r_{O2} r_{O1}) \| (g_{m3} r_{O3} r_{O4})]$$

Single stage Amplifiers

			
Common Source	Common Gate	Source Follower	Cascode
$-g_m R_D\ (\lambda = 0)$	$g_m R_D\ (\lambda = 0)$	$\frac{R_L}{R_L + \frac{1}{g_m}}$	$g_{m1} g_{m2} r_{o1} r_{o2}$
▪ Inverted gain ▪ High R_{in}, High R_{out}	▪ Non-inverted gain ▪ Low R_{in}, High R_{out}	▪ Gain is lower than 1 ▪ High R_{in}, Low R_{out} ▪ Voltage buffer, Voltage level shifter	▪ Higher gain ▪ High R_{in}, Higher R_{out} ▪ Voltage swing is degraded