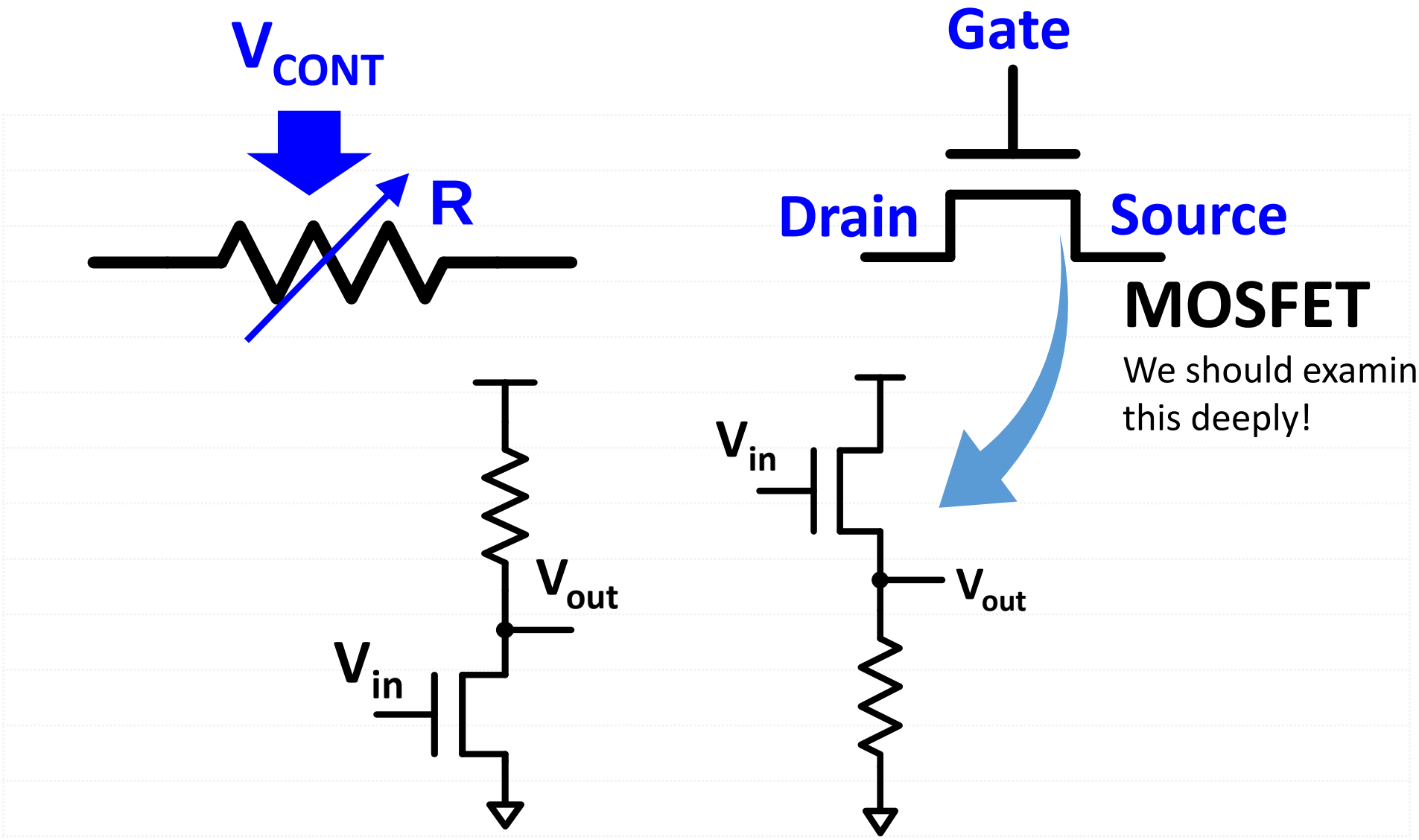
Review; Motivation for Using Transistor

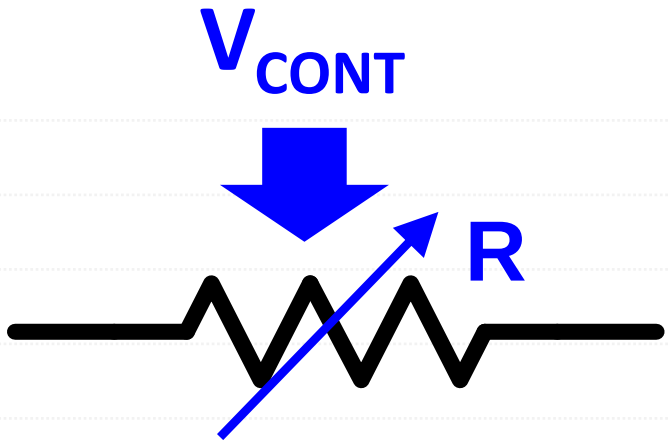


Operation of MOSFET; Qualitative Respect

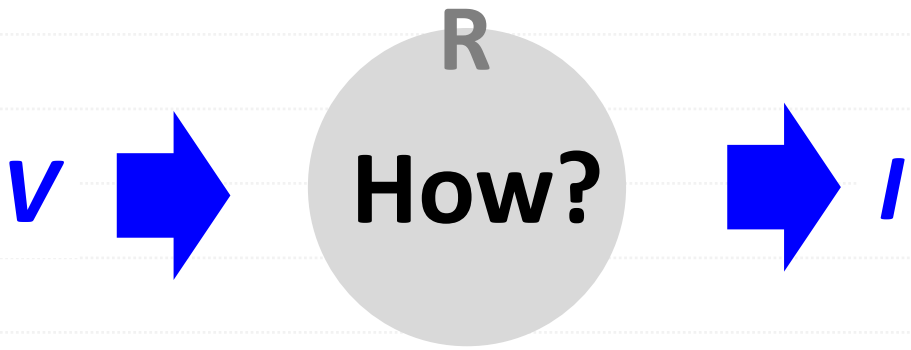
Hanwool Jeong

hwjeong@kw.ac.kr

Control R?



$$V = I \times R$$



Definition of Current?

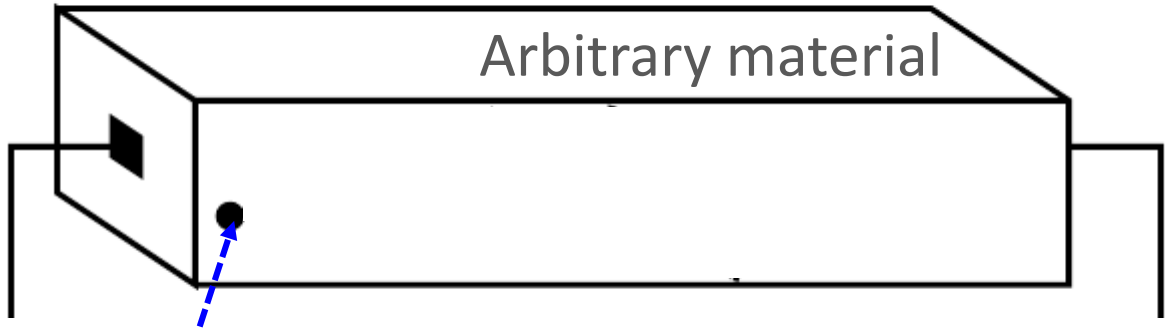
$$I = Q/t$$

Charge Moves
= Current Forms

➔ **How does charge moves in response to voltage applied?**

How Charge Moves for Applied Voltage; R Determination Factor in Materials

Electric field = *Force/charge* ∝ V



Roughly **Uniform velocity**
Not **Uniform acceleration**

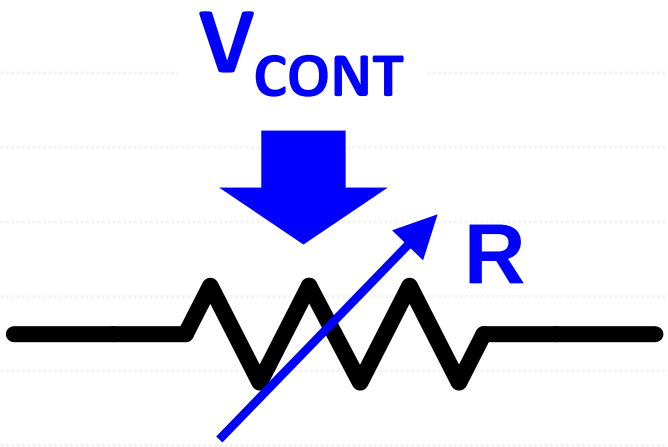
+ charge carrier

Voltage = *Energy/charge*

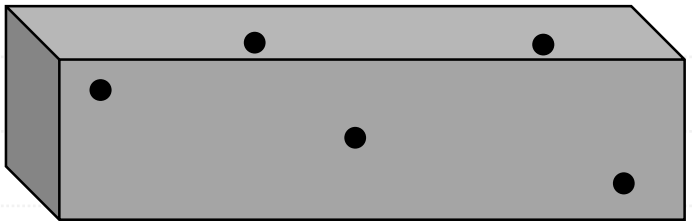
Charge Velocity $v \propto E \propto V$

- What if charge amount for the same volume change?
  charge density ➔ We can expect a current change

Carrier "Density" Can be Key for R Control

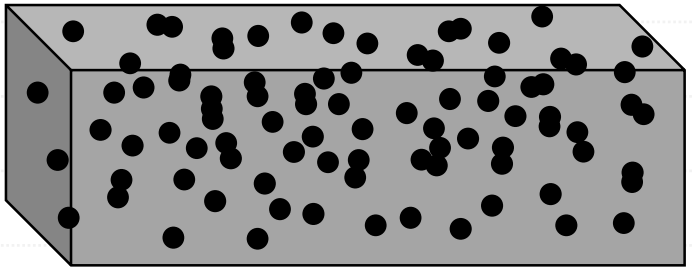


V_{CONT} = 0V



Low carrier density

V_{CONT} = 3V

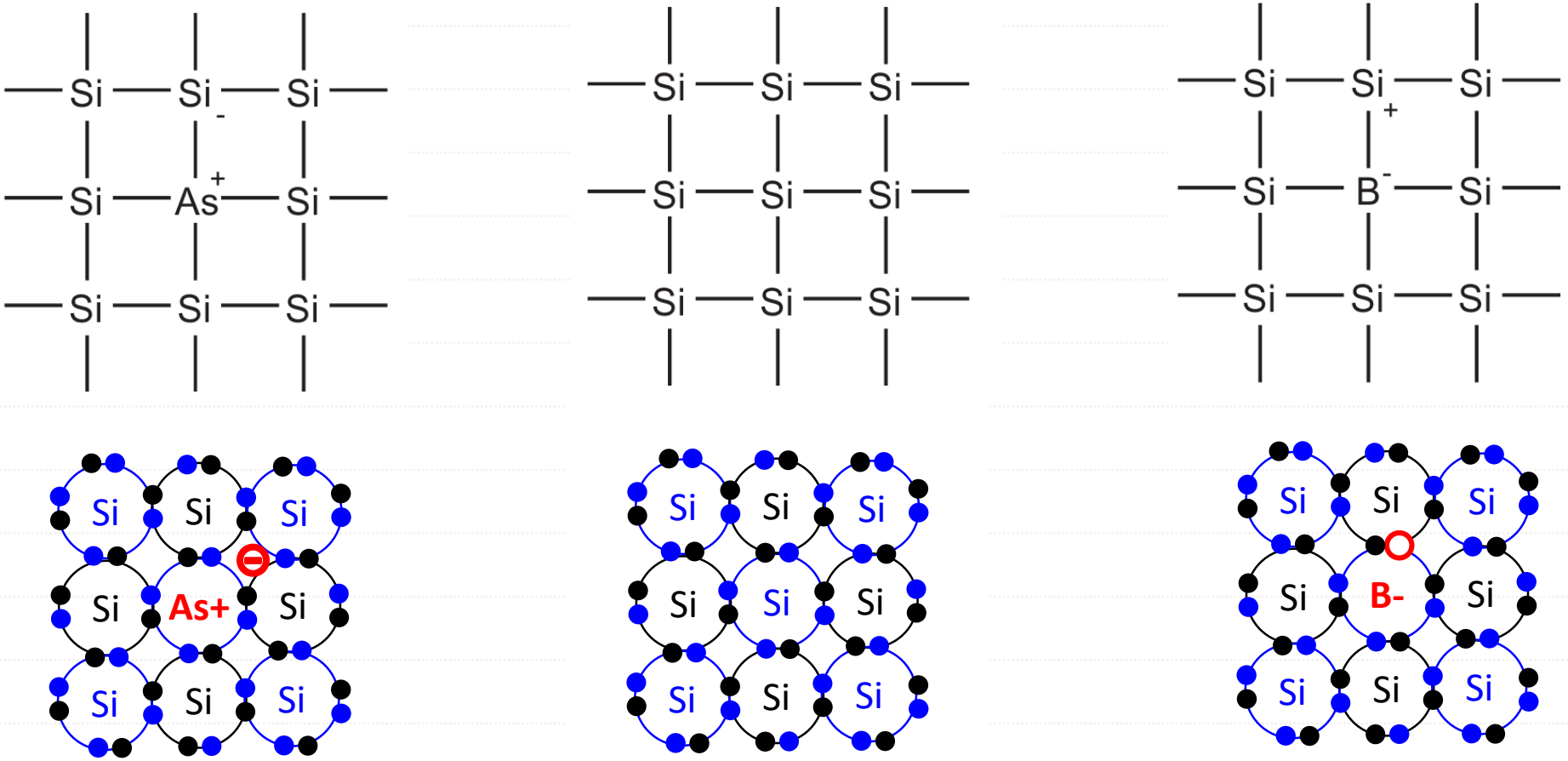


High carrier density

➔ **How?**

Silicon As a Semiconductor Material

- Representative Material for Integrated Circuits
- Group IV ➔ Covalent bonds with four adjacent atoms
- **After doping, carriers are only movable.**

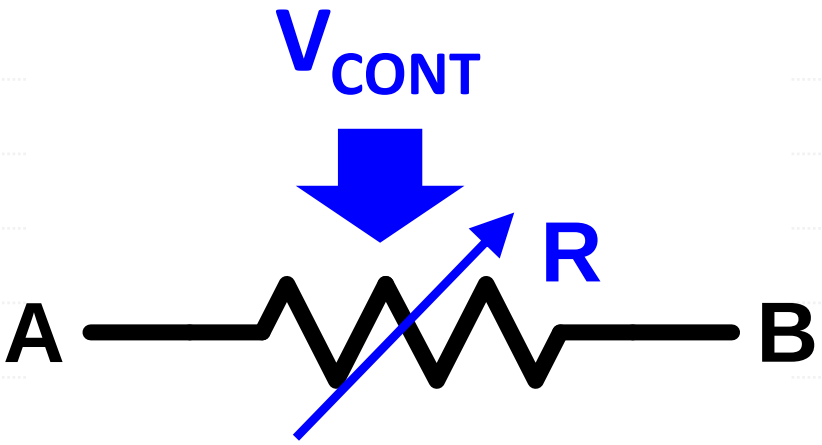


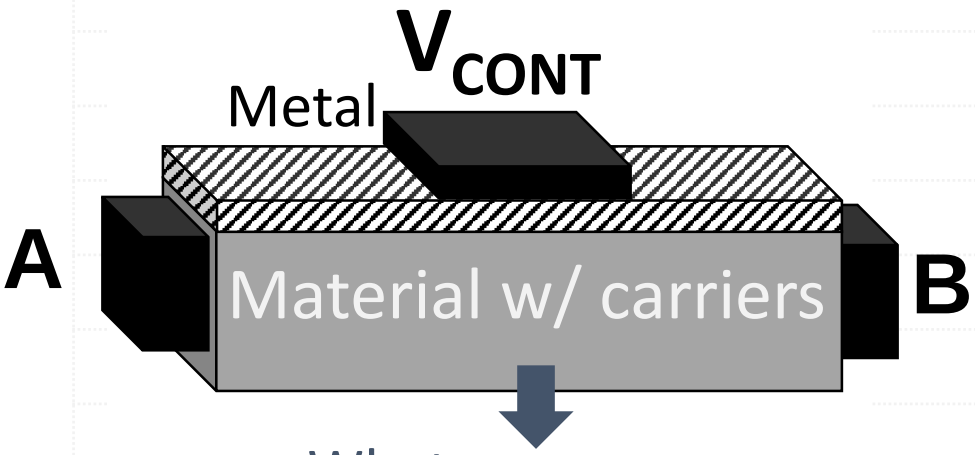
N-type vs. P-type Semiconductor

	N-type (Extrinsic)	Intrinsic	P-type (Extrinsic)
Structure			
Majority Carrier	**Electron**	Hole density = Electron density	**Hole**
Minority Carrier	Hole		Electron
Dopant	Group VI **(Donor)**	x	Group III **(Acceptor)**

Carrier density is exceedingly larger in doped silicon!

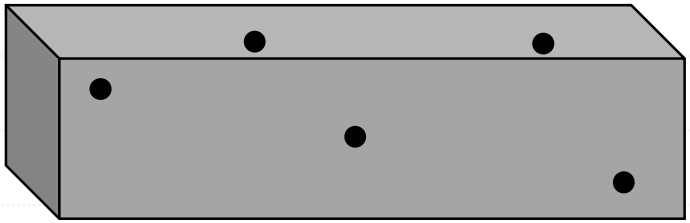
Can We Use V_{CONT} as Attracter for Carrier?





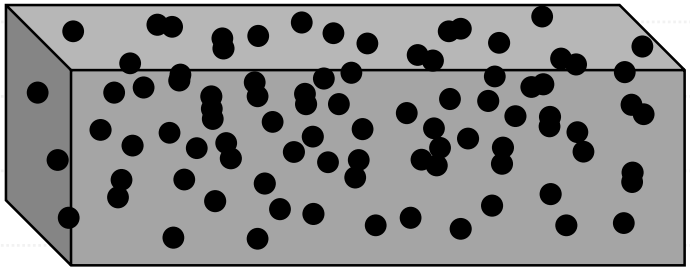
What can we use for this material?

V_{CONT} = 0V



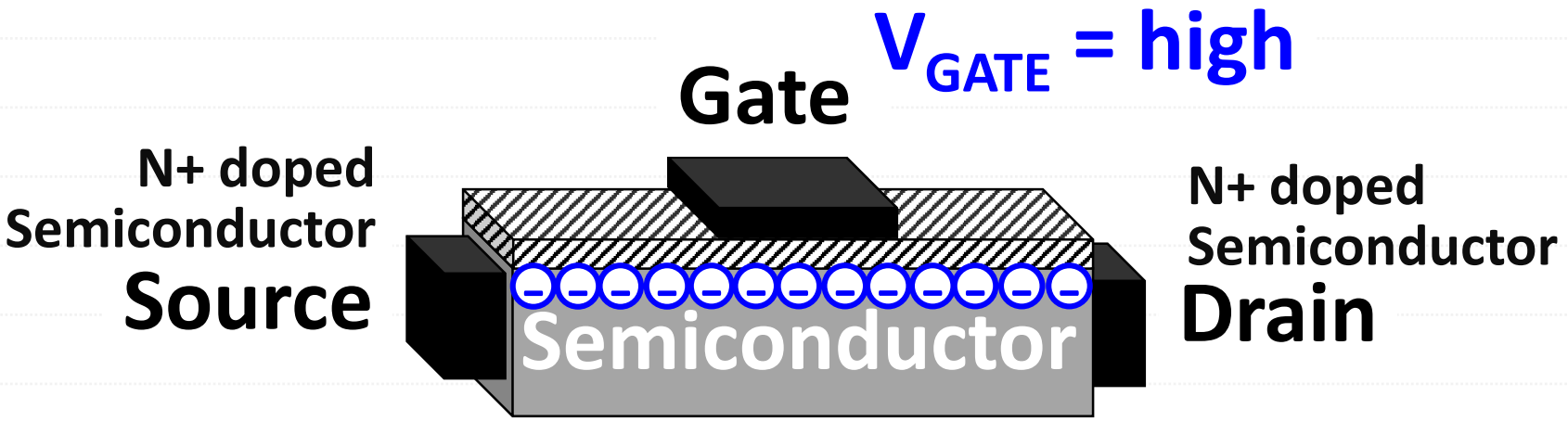
Low carrier density

V_{CONT} = 3V



High carrier density

Let's Attract Electrons for Conducting!



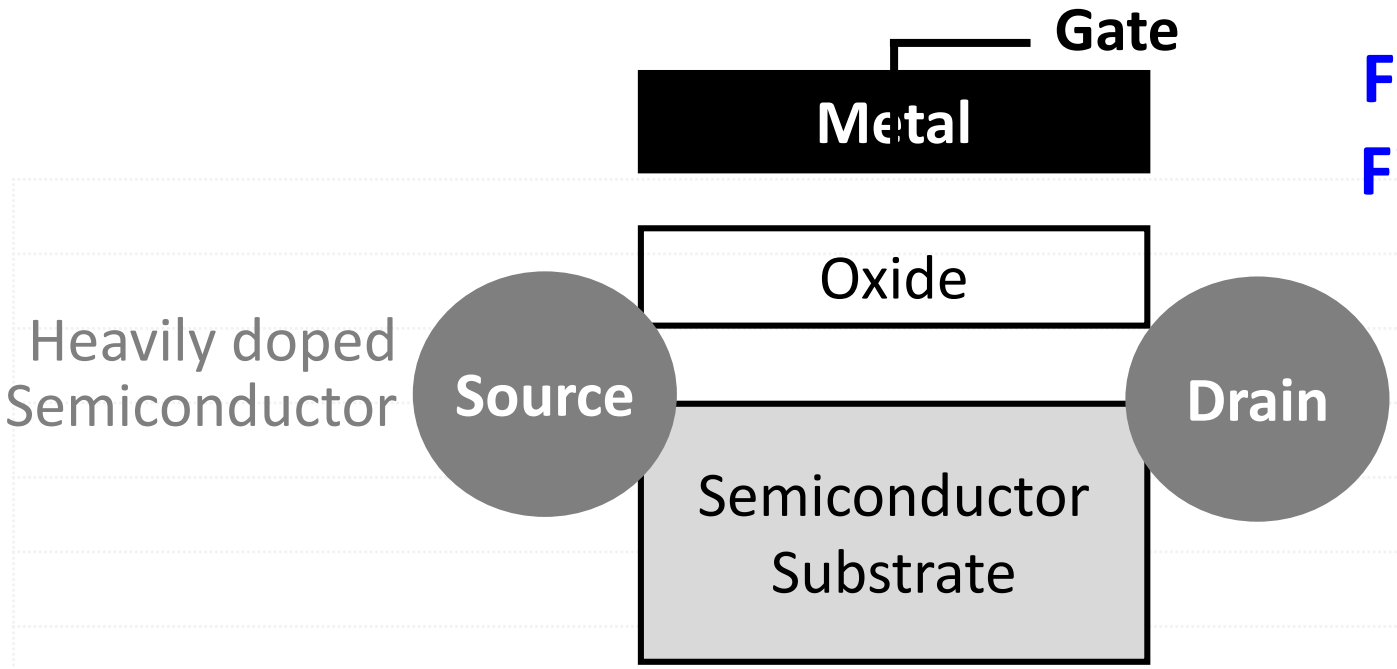
Then, can we flow current through Drain-source path?

➔ **Only if S/D are the same Semiconductor material!**

➔ **S/D should be conductor!**

➔ **Heavily doped semiconductor works!**

MOSFET; Semiconducting Device



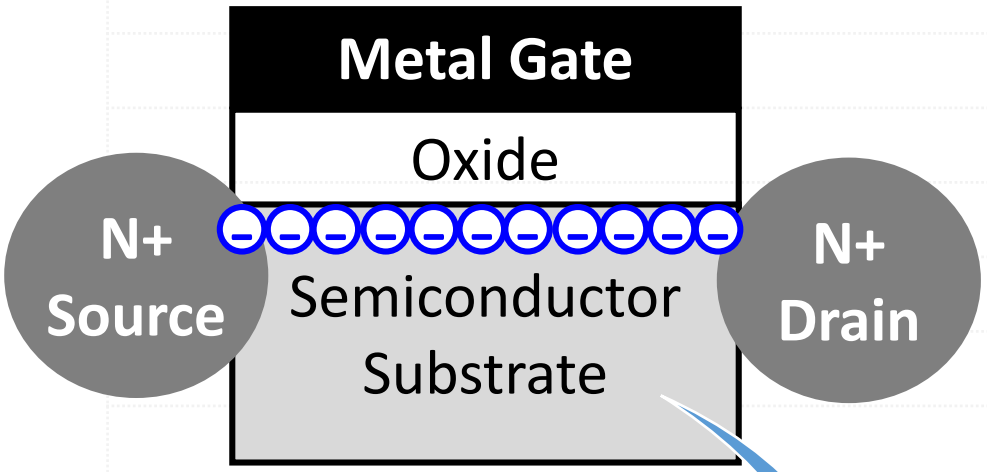
FET stands for?

Field effect? Why?

- Current flow is controlled by gate voltage
- **n**MOSFET : Carriers forming current are **electrons**
- **p**MOSFET : Carriers forming current are **holes**

nMOSFET vs. pMOSFET

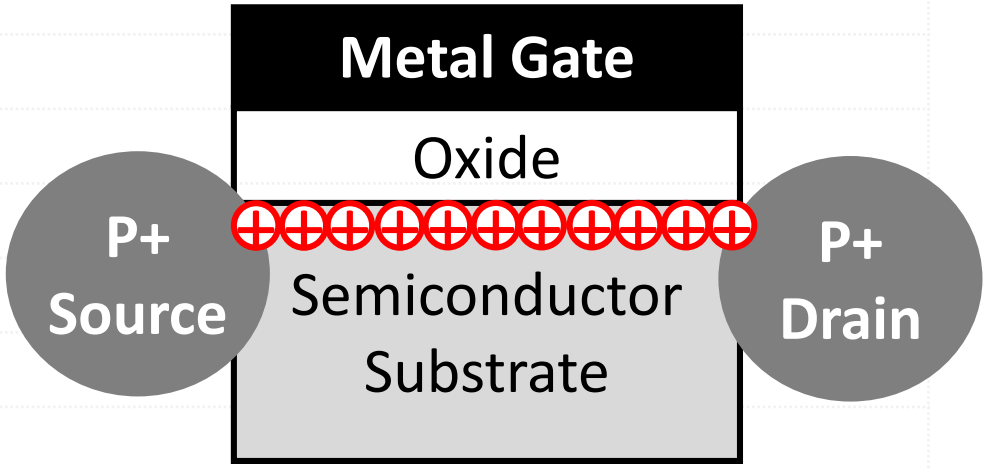
- How the gate voltage (V_G) should be for turning on/off in two MOSFETs?



nMOSFET

Higher V_G : turn-on

Lower V_G : turn-off



pMOSFET

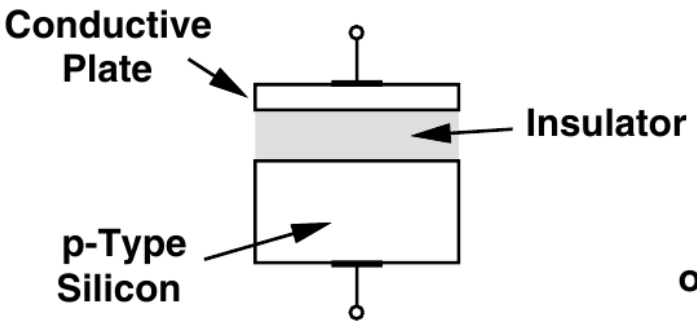
Higher V_G : turn-off

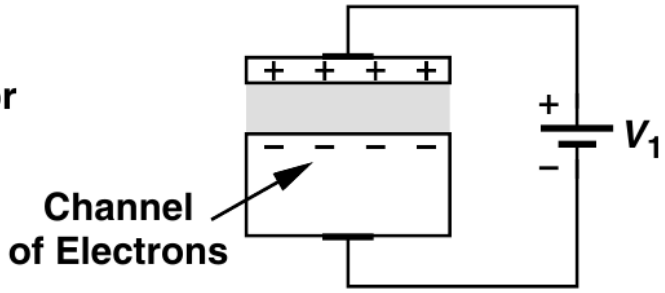
Lower V_G : turn-on

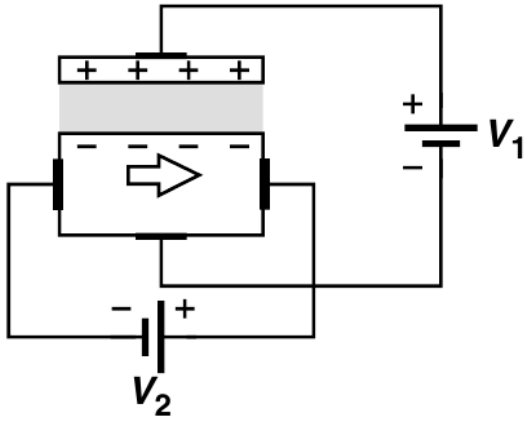
What should we use for the substrate?

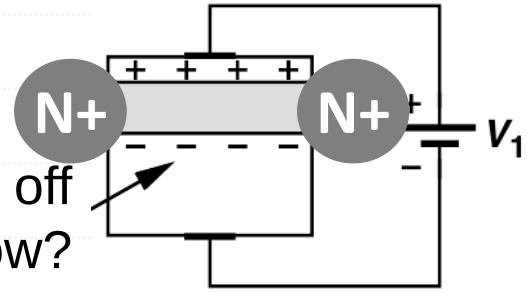
Focus on that
Device Should be able to “Cut off”

- What does “block” the current in the p-n junction?





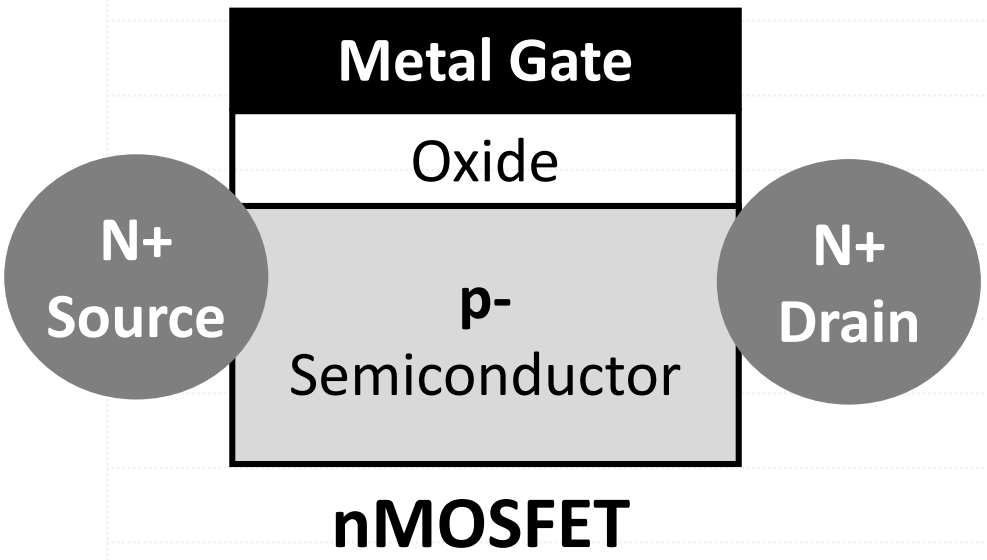




How can you turn off
Effectively when V_1 is low?

Revisit nMOSFET vs. pMOSFET

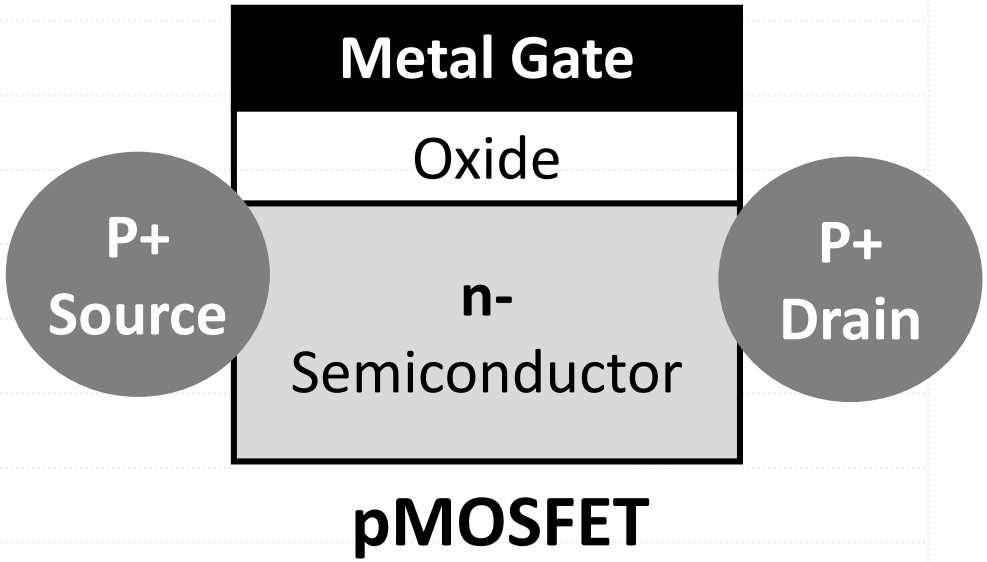
- One more! We can use poly-silicon instead of metal gate



nMOSFET

Higher V_G : turn-on

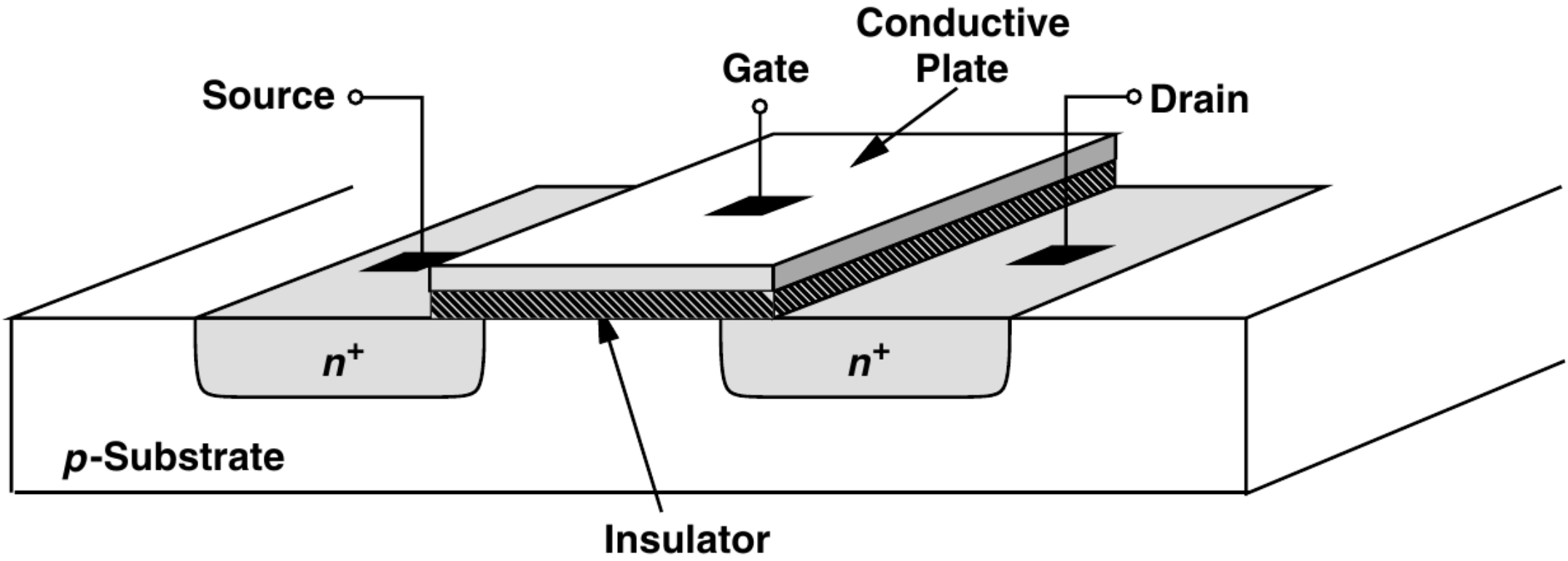
Lower V_G : turn-off



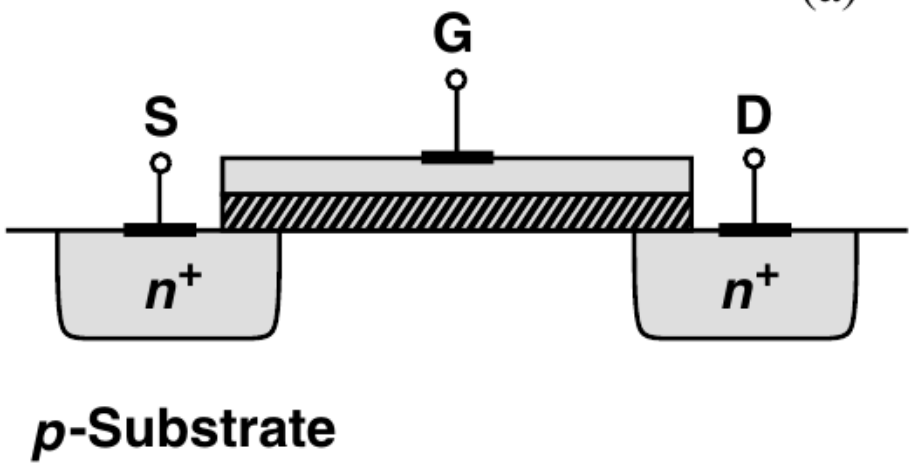
pMOSFET

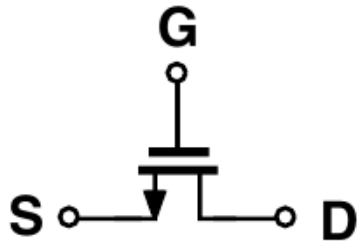
Higher V_G : turn-off

Lower V_G : turn-on

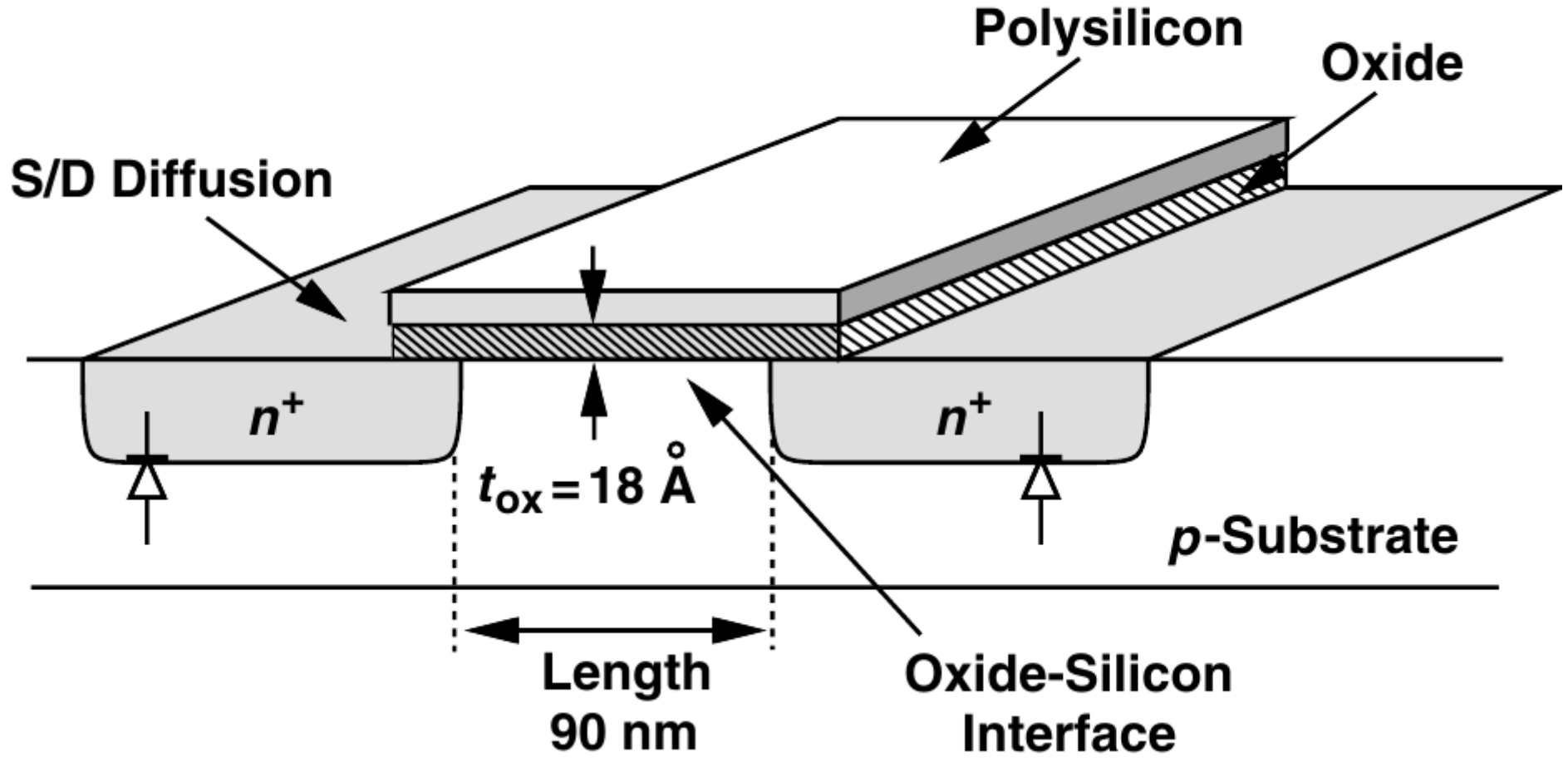

Conductive
Plate
Gate
Source
Drain
n^+
n^+
p-Substrate
Insulator

(a)


G
S
D
n^+
n^+
p-Substrate

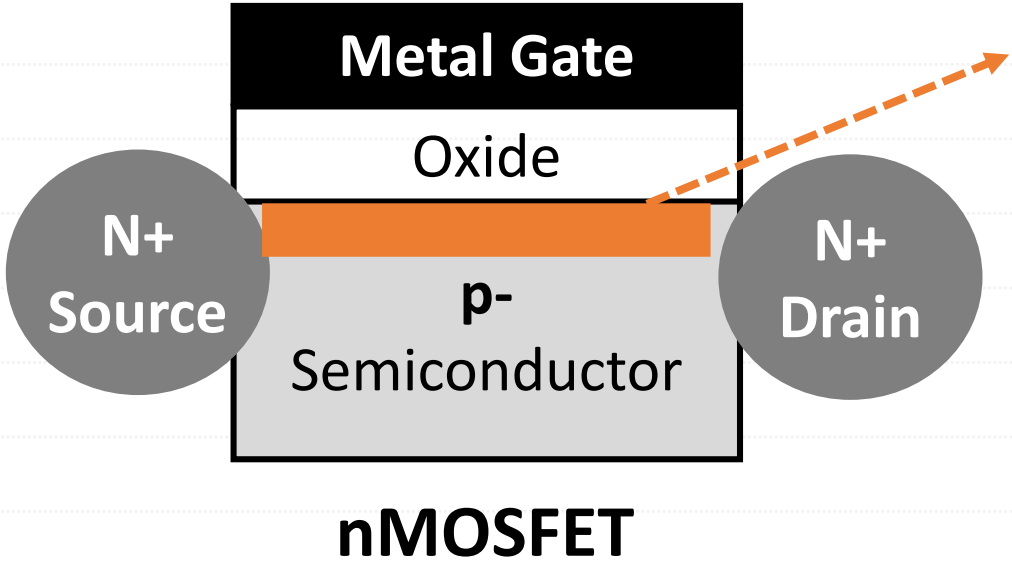

G
S
D

Typical Dimension



Body Voltage & Compensating Energy Band Difference

Control V_G for turn on : +0.5V



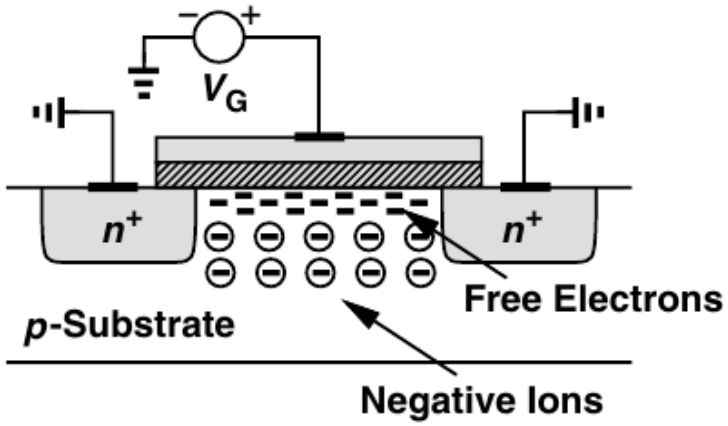
Actual feel here is not V_G

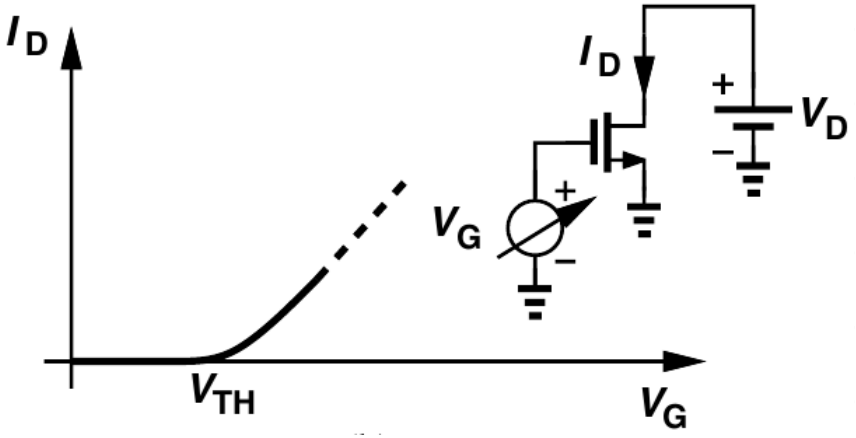
Due to use of different material

(M-O-S) V_G – **V_{TH}** is felt instead

Meaning of Threshold Voltage V_{TH}

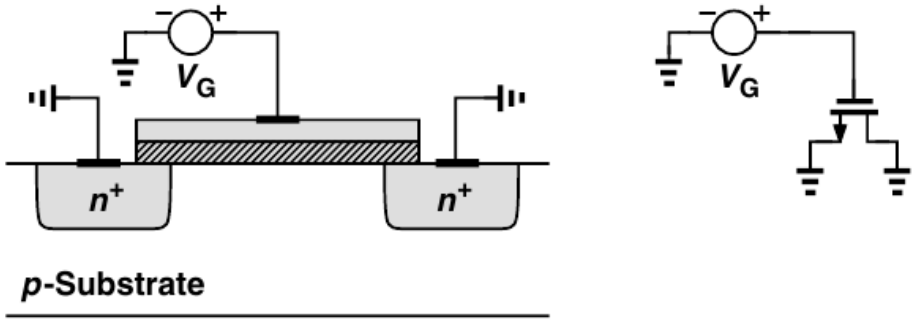
- It is a voltage representing what gate voltage should overcome to effect on the substrate across MOS interface.
- When we compare the voltage metal side and substrate side, we should consider the effect of V_{TH}.



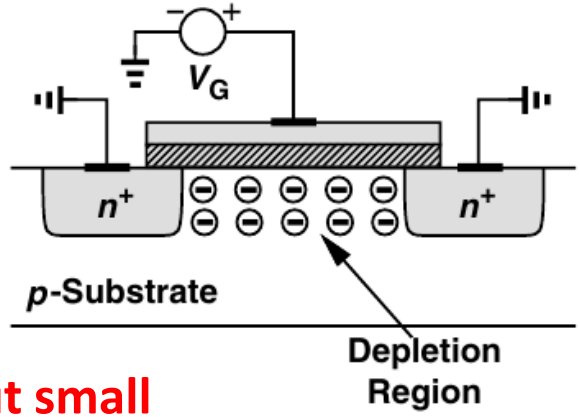


Turn on & Turn off of MOSFET

- S/D are grounded, while V_G is swept



- Formation of **depletion region** and **channel**

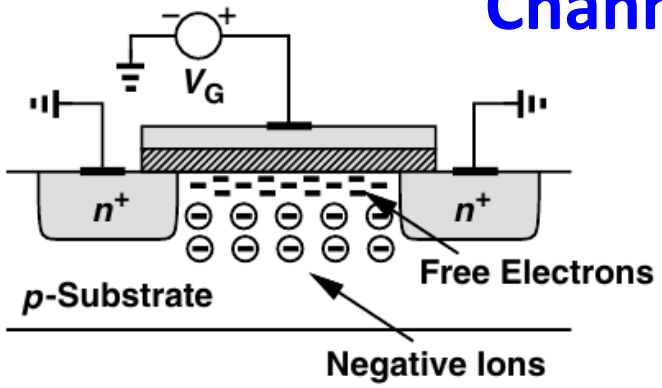


V_G > 0, but small

Repels holes, forming depletion region

No carrier below the oxide yet

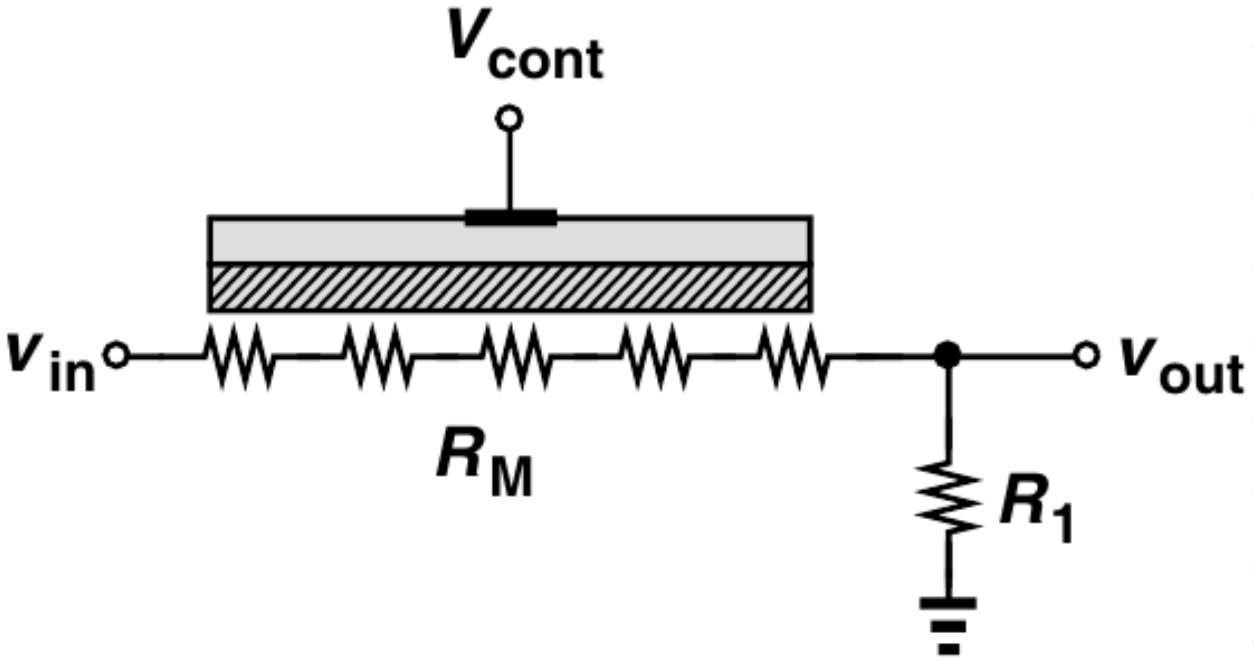
Channel is formed



V_G > V_{TH} = threshold voltage

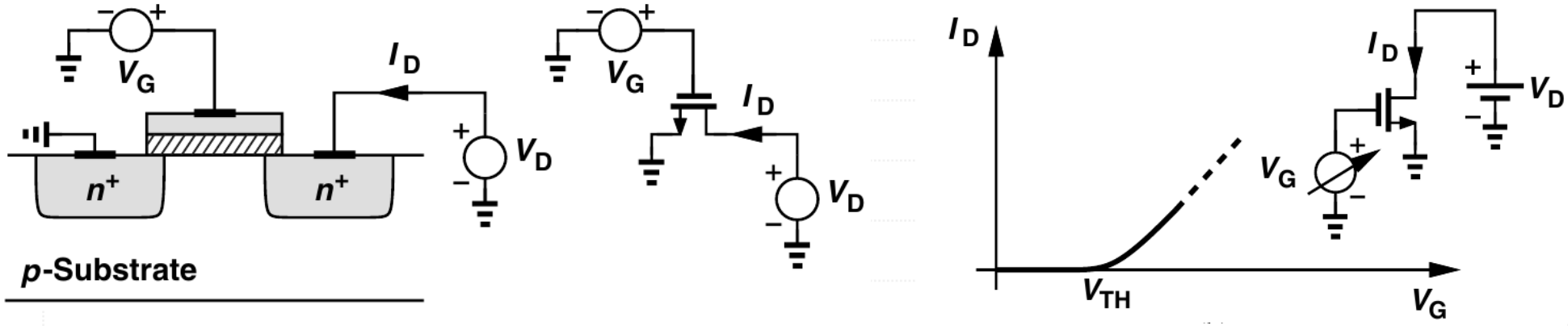
Carriers are attracted

MOSFET as a Variable Resistor



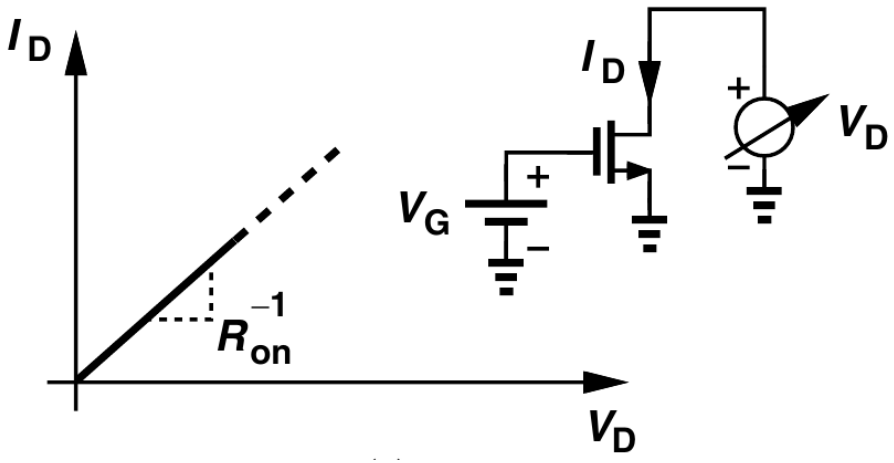
What Happens for Larger V_G?

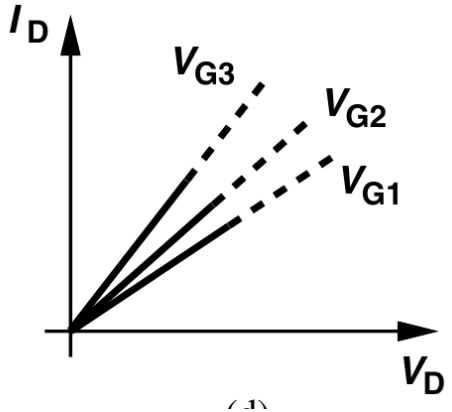
- For fixed $V_D > 0$



For Fixed $V_G > V_{TH}$

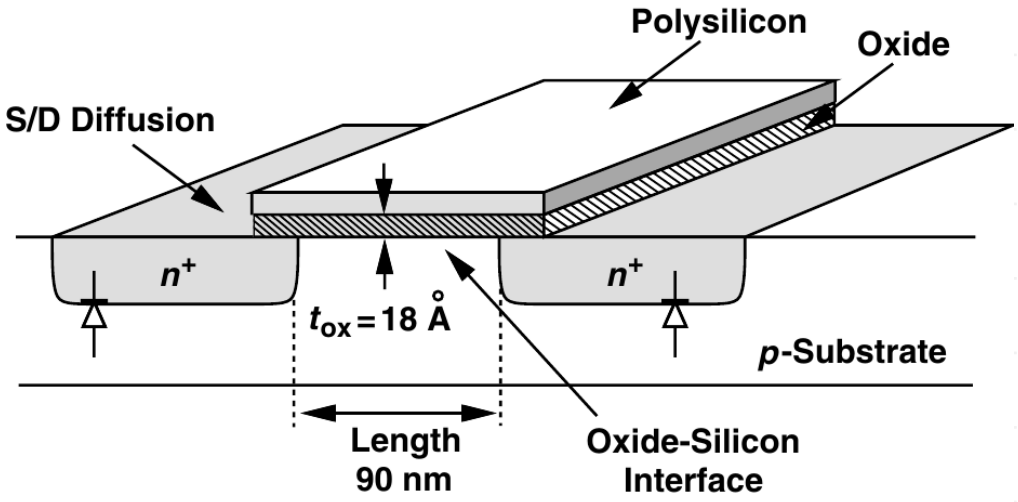
- Current change according to different V_D
- It is nothing but a resistor





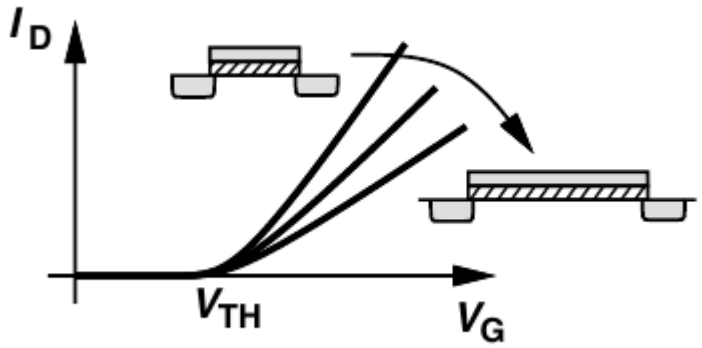
Effect of Device Dimension

- Think about how the drain current I_D changes according to L, W, t_{ox}?

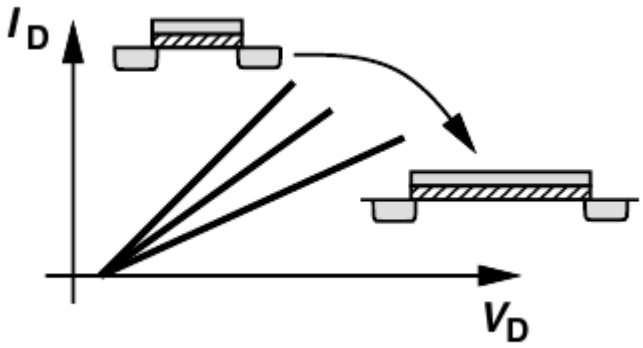


Example 6.2

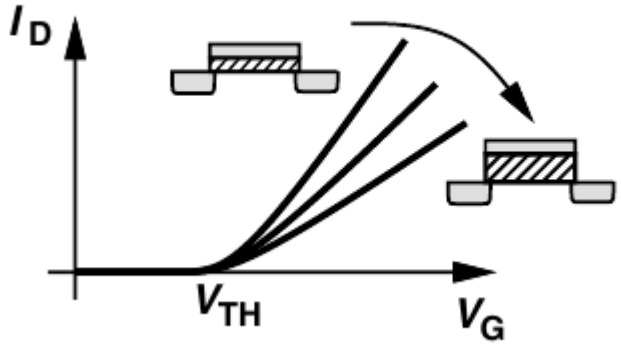
Sketch the I_D-V_G and I_D-V_D characteristics for (a) different channel lengths, and (b) different oxide thicknesses.

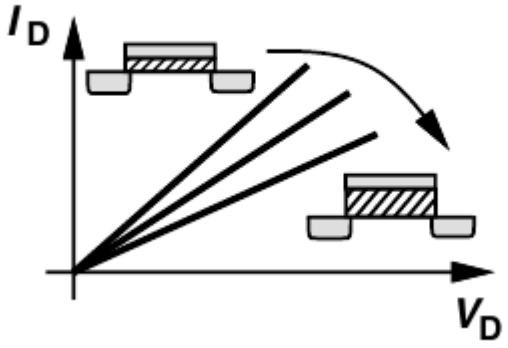


(a)



(b)

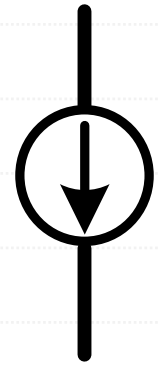


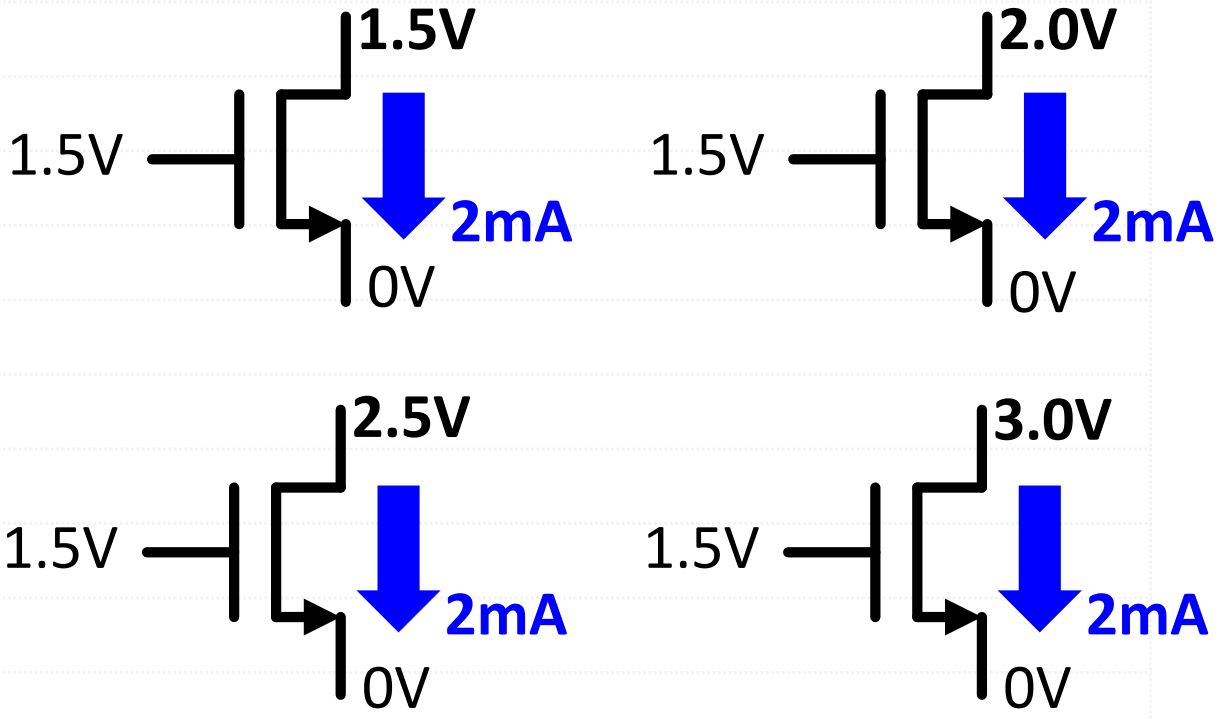


Current Source Operation of MOSFET in Large V_{DS}

- MOSFET operates as a **current source** if the drain voltage is sufficiently positive. What does it mean?

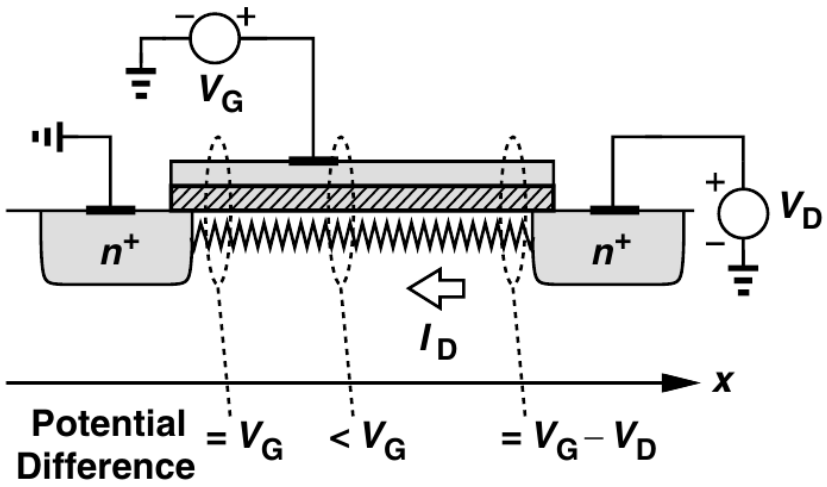
Constant current flows independent of voltage across

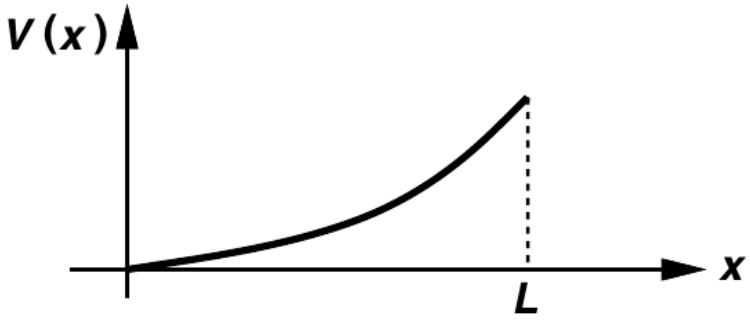


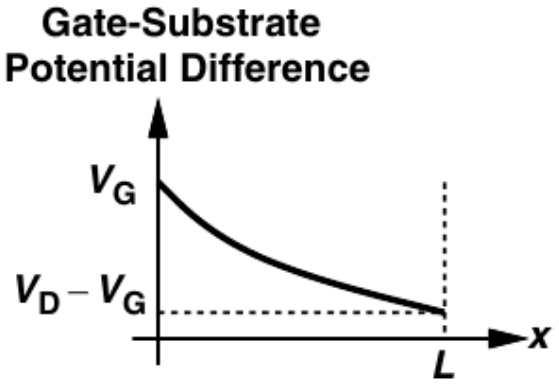


- Constant current flows independent of V_{DS}. **Why?**

Potential Difference in Substrate Location

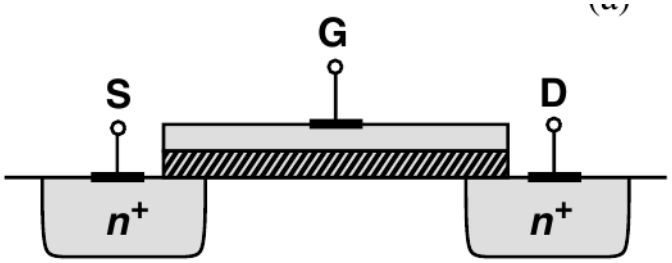


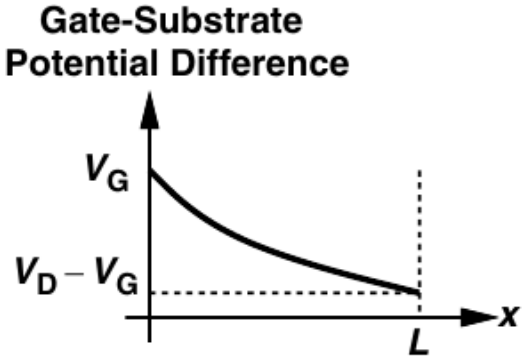




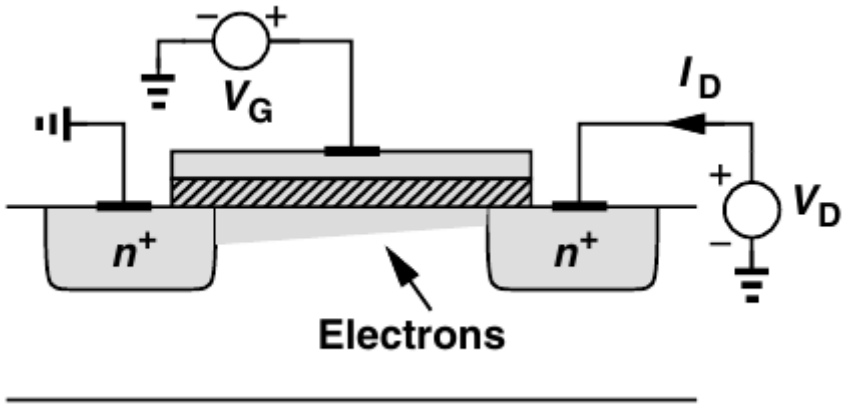
Different Potential Respect to V_G?

- How does this have effect?



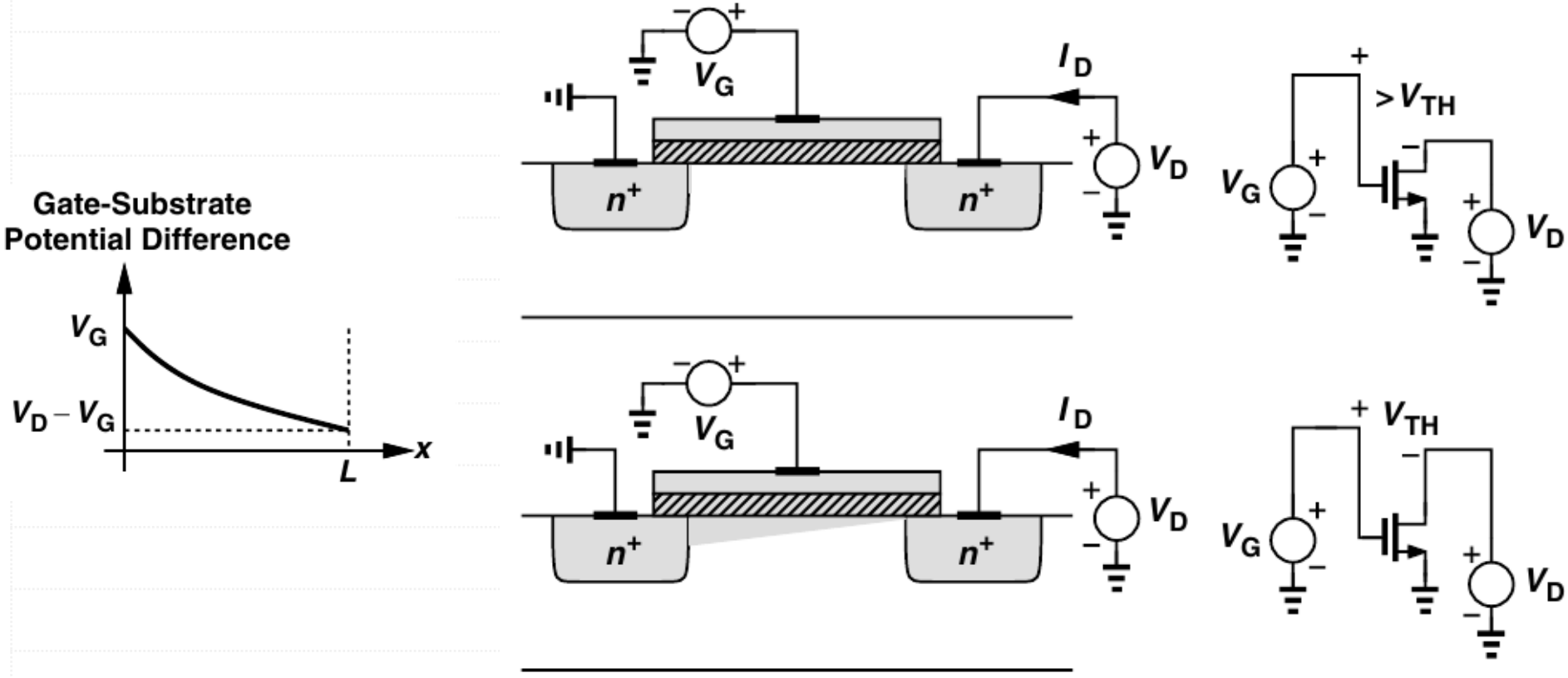


- Electron density is different according to the location of silicon-oxide interface. That is,

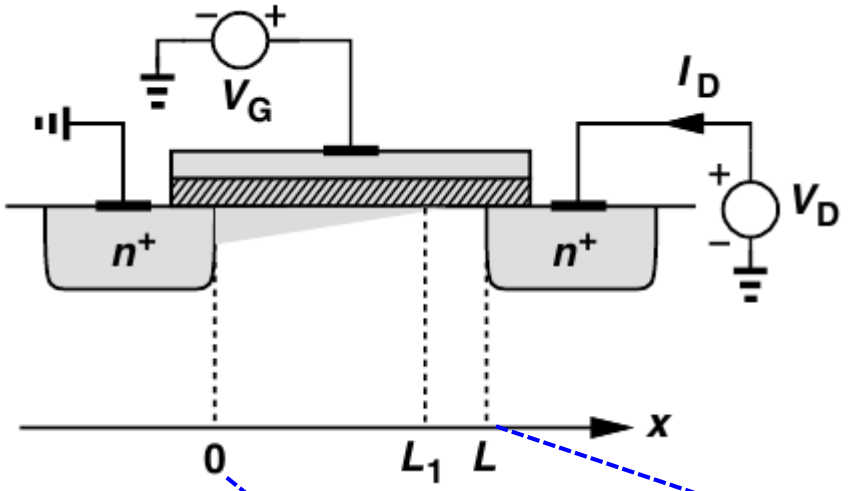


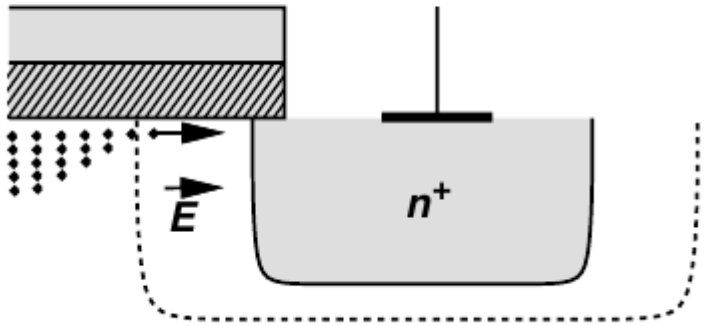
Different V_D effect

- Should we compare V_G **vs.** V_D or V_G-V_{TH} **vs.** V_D?
- V_G-V_{TH} < V_D **vs.** V_G-V_{TH} > V_D : Electron prefers which side?



Potential According to Locations when V_D increases Further





Effect of V_D?

0V

V_D

Channel pinches off

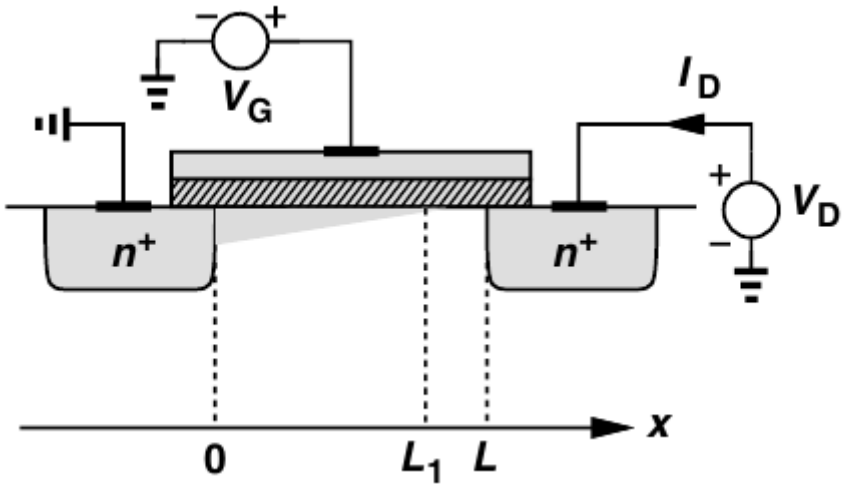
Further Increase in V_D over V_G - V_{TH}

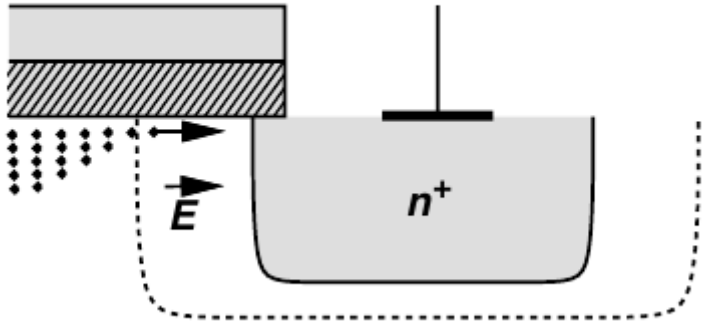
- Channel Pinch off: There is no channel near the drain.

➔ Cannot flow the current? NO!

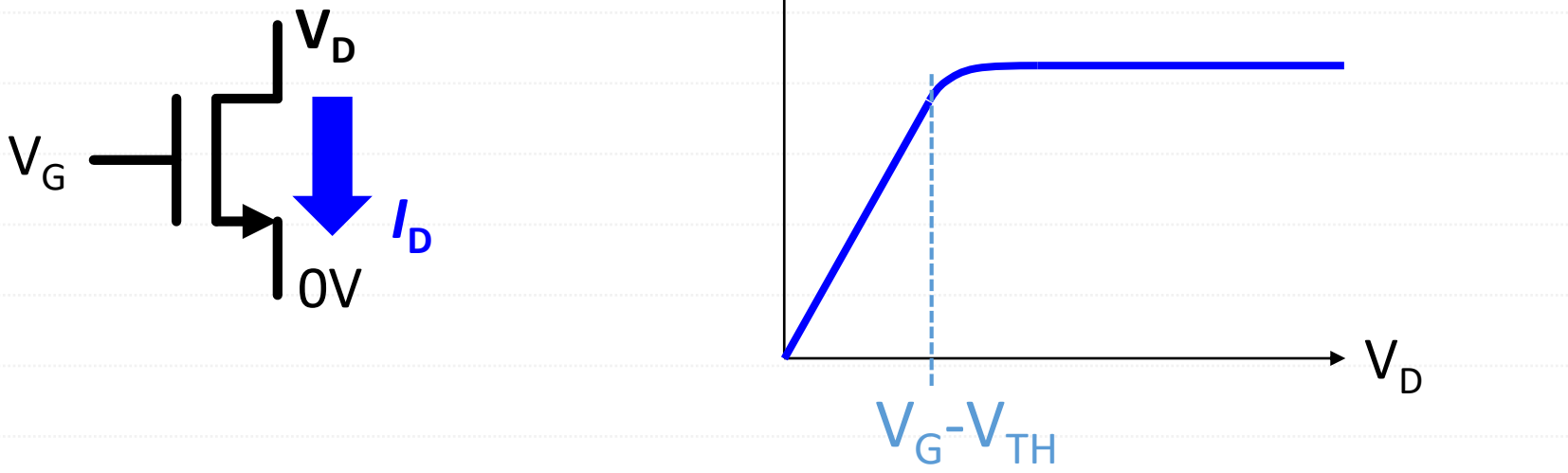
- Electrons experience the high electric field in the depletion region surrounding the drain junction and are rapidly swept to the drain terminal.

➔ V_D no longer affects the current significantly, and the MOSFET acts as a constant current source





Exact Point of Channel Pinch-off



Checkpoints

- Motivation of using MOSFET structure
- Qualitative effect of MOSFET structure on the current
- Channel pinch off
- Coming-up next; Derivation of I-V relation in MOSFET