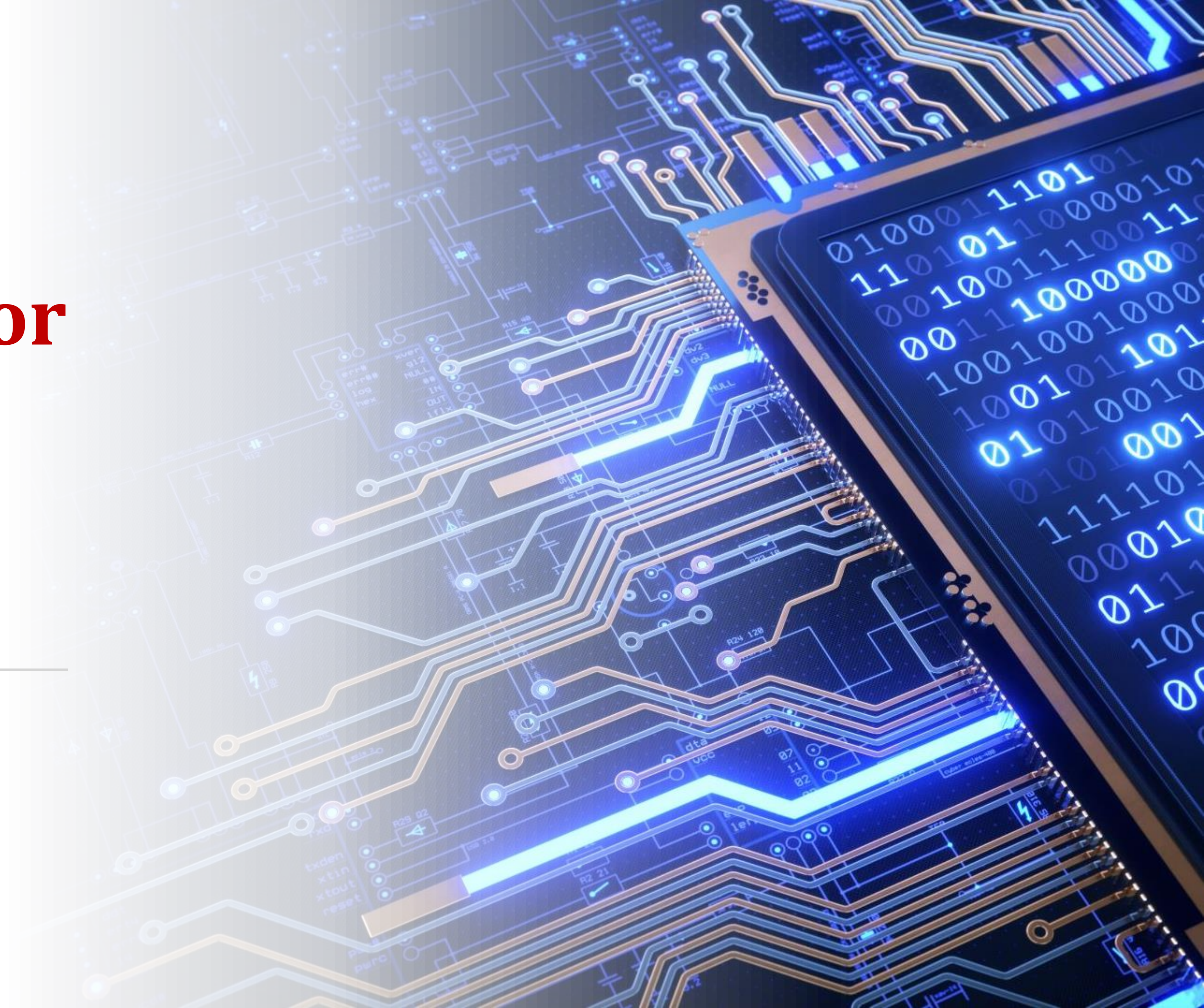
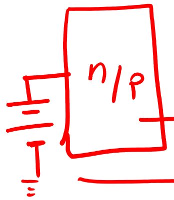
# Metal Oxide Semiconductor Field Effect Transistor (MOSFET)



# The Field Effect Transistor (FETs)




→ semiconductor
→ Field effect

Unipolar

- The FET is a single carrier device and is often called the unipolar transistor because the carriers involved in the operation are either electrons or holes.

  ↳ Majority charge carriers

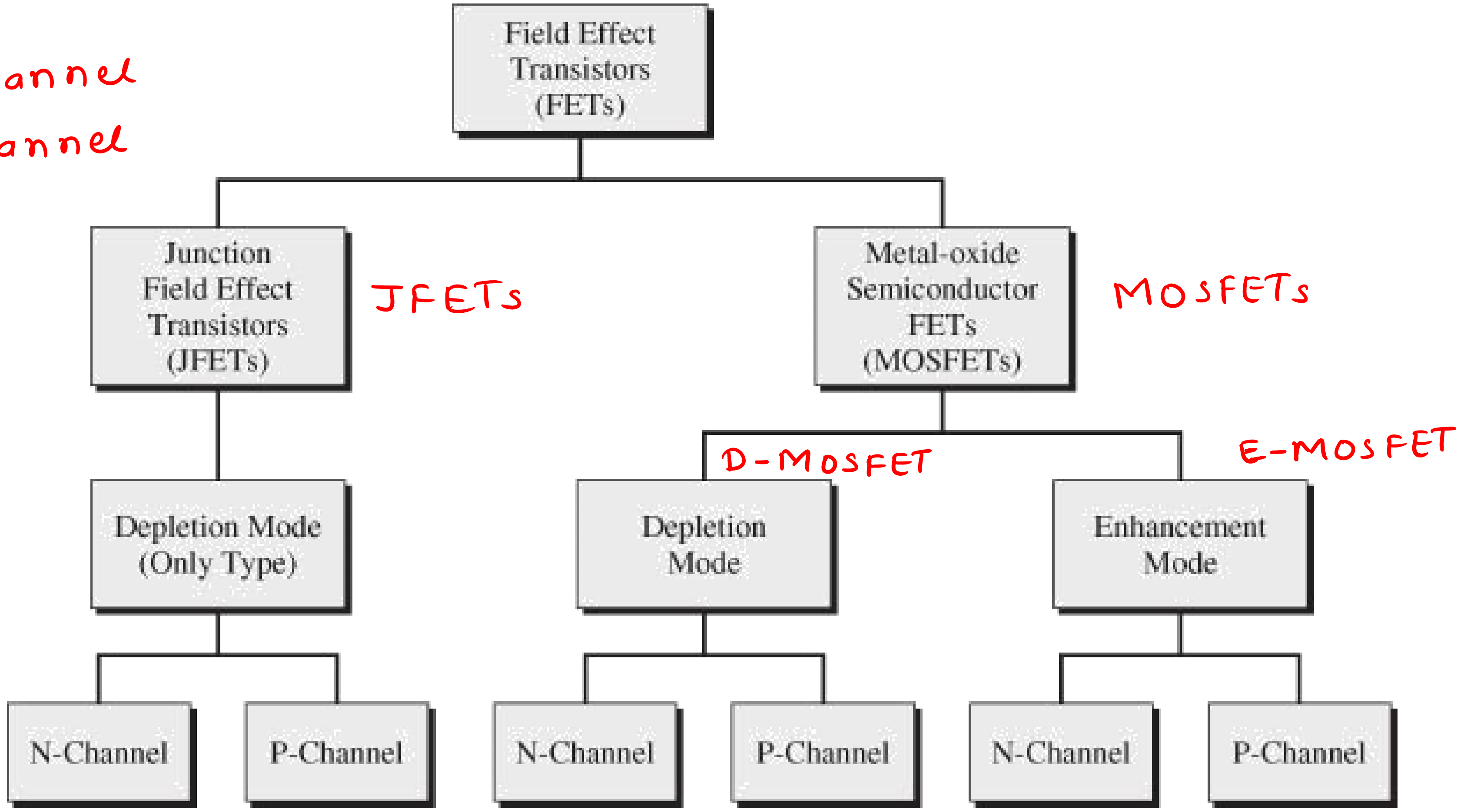
- The FET is also a semiconductor device in which the output quantity is controlled by an electric field, which is often the input quantity. → voltage controlled device

- The phenomenon where the conductivity of the semiconductor is modulated by an electric field applied normally to the surface of the semiconductor is called **field effect**, and this principle is brought into operation by extending the depletion region deep into the bulk of the semiconductor.

  ↳ controlled

# Field Effect Transistors - Classification

1) n-p-n ⇒ n-channel
2) p-n-p ⇒ p-channel



# MOSFET: Introduction

BJT – i) Base
ii) Emitter
iii) Collector

- Category of **FET (Field Effect Transistor)**.

$SiO_2$

- **MOSFET** stands for Metal Oxide Semiconductor Field Effect Transistor. It is capable of voltage gain and power gain. → Amplifiers.
- The **MOSFET** is the core of integrated circuit designed as thousands of these can be fabricated in a single chip because of its very small size. → High Integration density → Low Power consumption
- Widely used for switching and amplifying electronic signals in the electronic devices.

↳ Digital ↳ Analog

- The MOSFET is a **three-terminal device**.
  - **Gate** ⟷ Base (i/p terminal)
  - **Drain** ⟷ collector (o/p terminal)
  - **Source** ⟷ Emitter

Fourth terminal
* Substrate
(Internally shorted to source)

$V_{BB} > 0.7V$

# MOSFET: Types

There are two Types of MOSFETs:

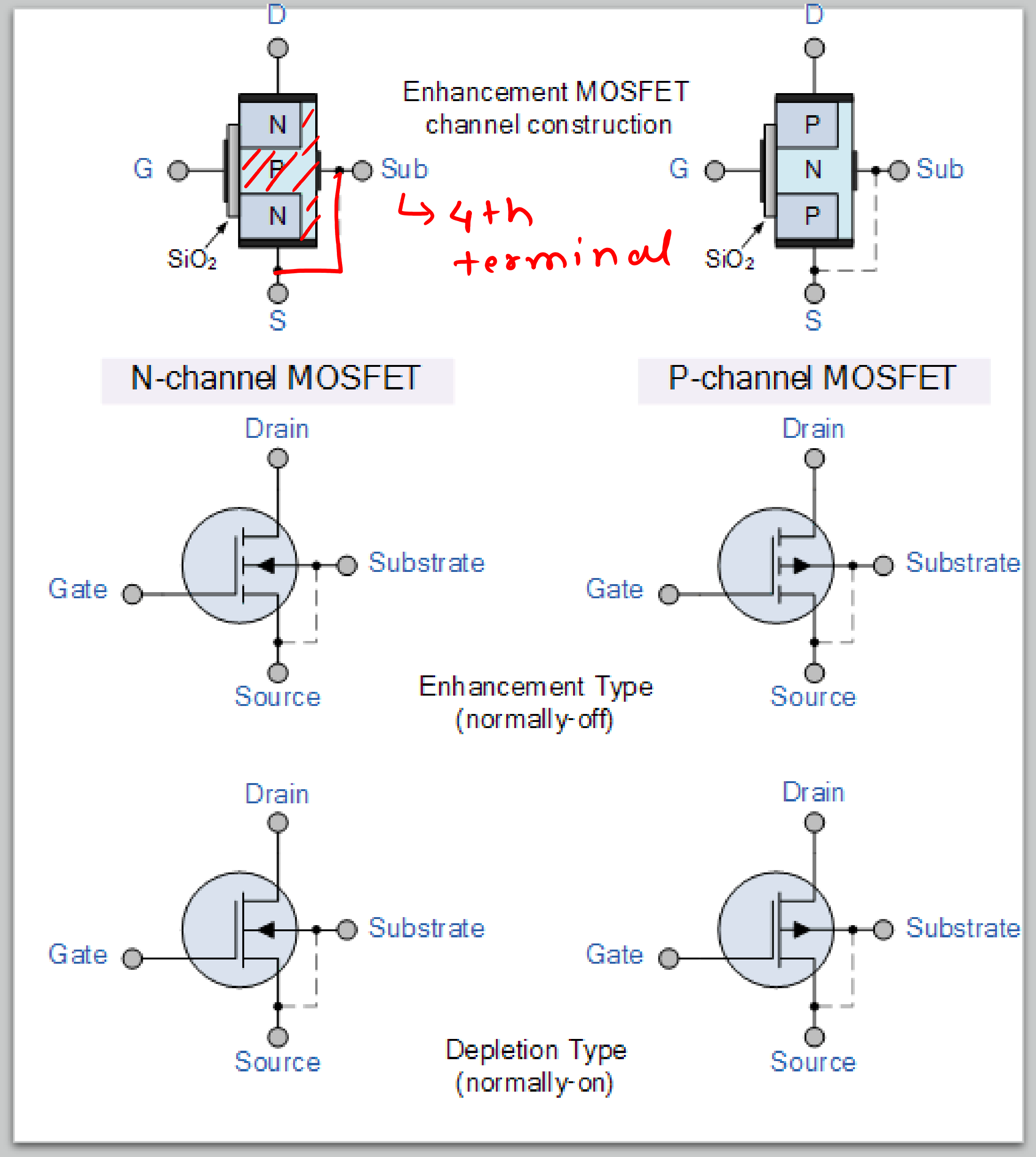
D-MOSFET : Normally ON → It acts as a closed switch w/o application of i/p voltage (VGS)

- **Depletion Type:** The transistor requires the Gate-Source voltage, ($V_{GS}$) to switch the device "OFF". The depletion mode MOSFET is equivalent to a "Normally Closed" switch.

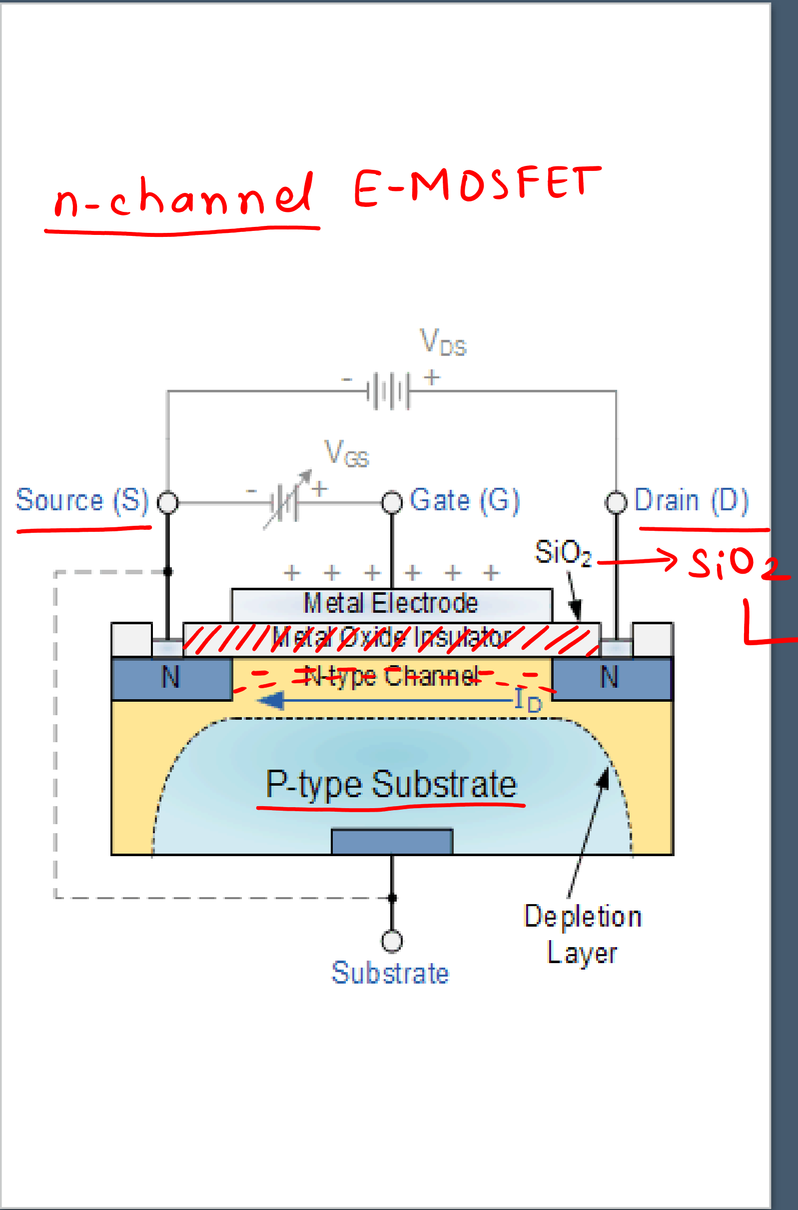
- **Enhancement Type:** The transistor requires a Gate-Source voltage, ($V_{GS}$) to switch the device "ON". The enhancement mode MOSFET is equivalent to a "Normally Open" switch.

→ E-MOSFET : Normally OFF → It acts as an open switch
→ External i/p vtg $V_{GS}$ is required to turn it ON.

# MOSFET: Basic Construction and Symbol




- The four MOSFET symbols show have additional terminal called the **Substrate** and is not normally used as either an input or an output connection but instead it is used for grounding the substrate.
- It connects to the main semiconductive channel through a diode junction to the body or metal tab of the MOSFET.
- Usually in discrete type MOSFETs, this substrate lead is connected internally to the source terminal.

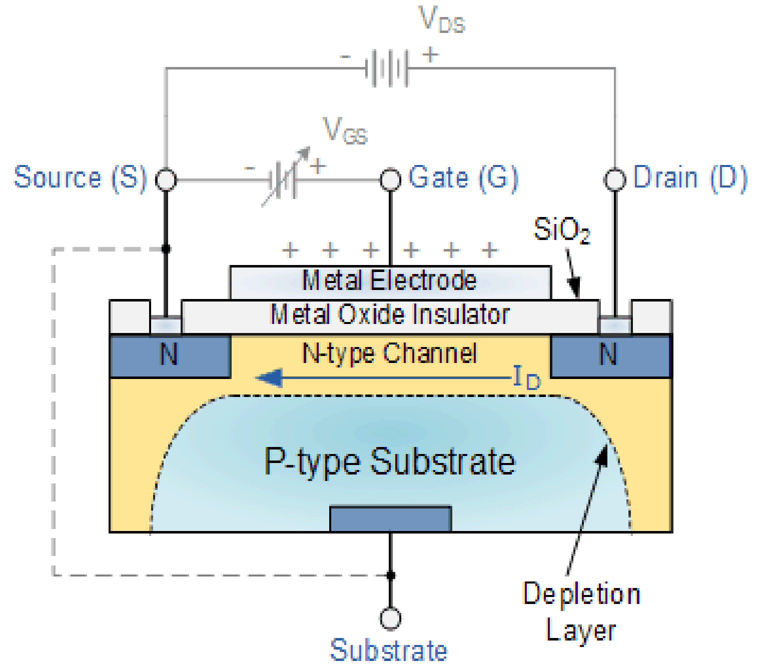



# MOSFET: Basic Structure

- MOSFETs use an electrical field produced by a gate voltage ($V_{GS}$) to alter (↳ control/modulate) the flow of charge carriers, electrons for n-channel or holes for P-channel, through the semiconductive (↳ Majority) drain-source channel.

- The gate electrode is placed on top of a very thin insulating ($SiO_2$) layer and there are a pair of small n-type regions just under the drain and source electrodes.

→ Insulating layer




# MOSFET: Basic Structure

- With an insulated gate MOSFET device no such limitations apply so it is possible to bias the gate of a MOSFET in either polarity, positive (+ve) or negative (-ve).

- This makes the MOSFET device especially valuable as electronic switches or to make logic gates because with no bias they are normally non-conducting, and this high gate input resistance means that very little or no control current is needed as MOSFETs are voltage-controlled devices.

normally OFF

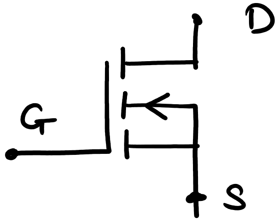
# E-MOSFET → Works only in Enhancement mode

+$V_{GS}$ is applied

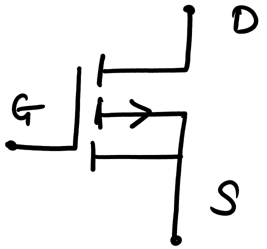
n-channel E-MOSFET

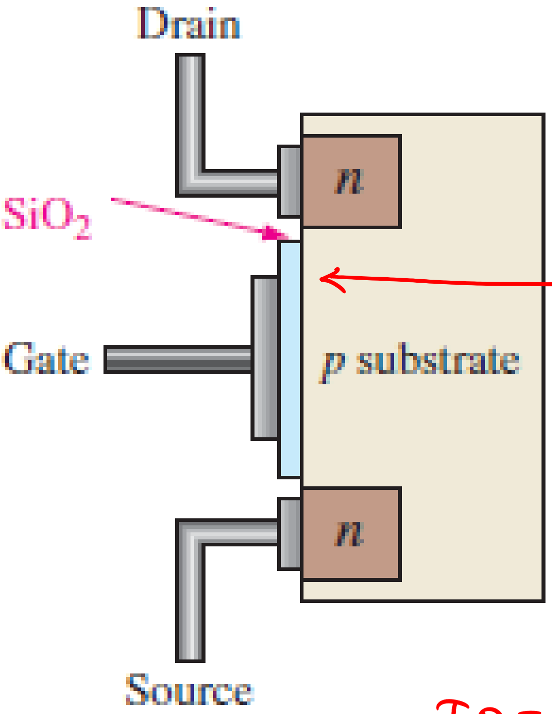
symbol:

n-channel:



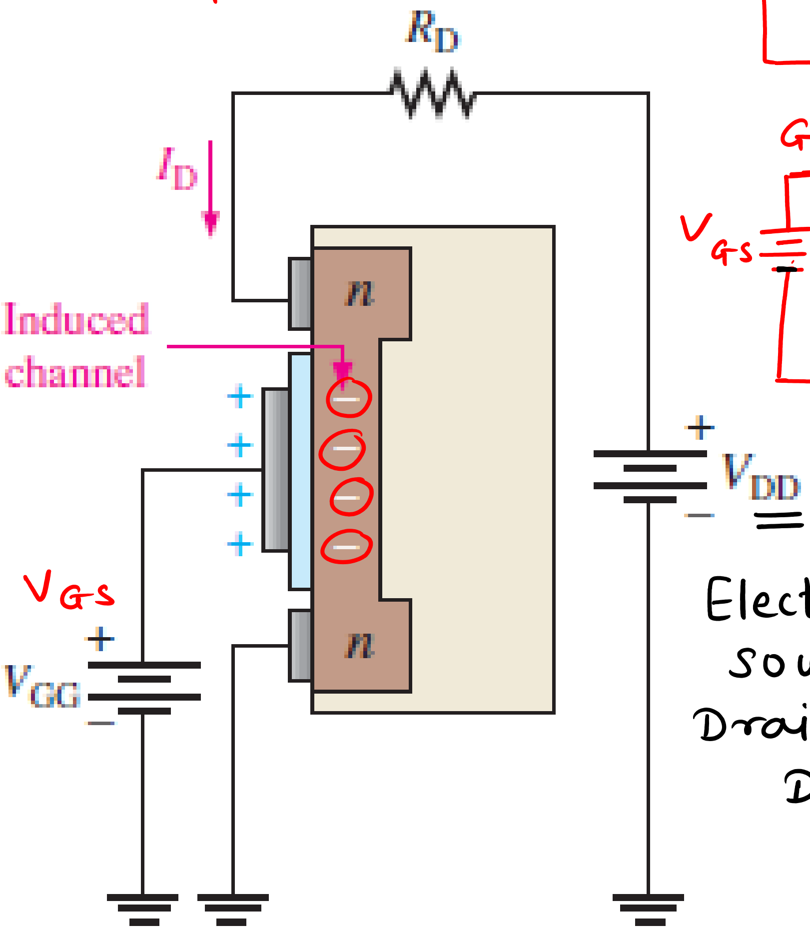

p-channel:



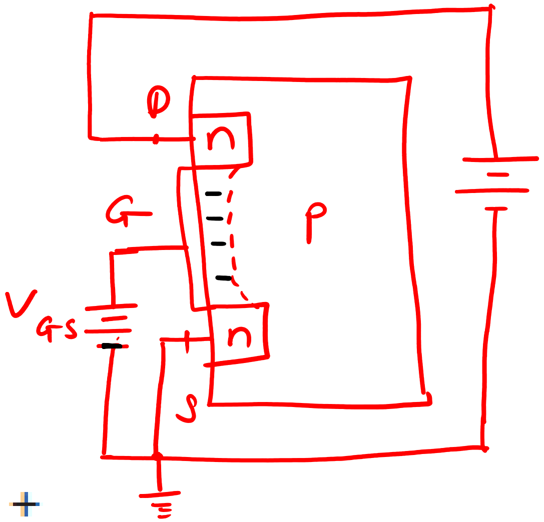

channel is absent between drain & source
↓
$I_D = 0$

(a) Basic construction




(b) Induced channel ($V_{GS} > V_{GS(th)}$)

$V_{GS} > V_{GS(TH)}$




Electrons → source to drain

Drain curr, $I_D$ → Drain to source

# E-MOSFET: Working

- The E-MOSFET operates only in the enhancement mode and has no depletion mode.
- It differs in construction from the D-MOSFET.
- The substrate extends completely to the SiO2 layer. For an n-channel device, a positive gate voltage above a threshold value induces a channel by creating a thin layer of negative charges in the substrate region adjacent to the SiO2 layer, as shown in Figure (b).

  $\uparrow V_{GS}\uparrow, I_D\uparrow \quad (V_{GS} > V_{GS(TH)})$
- The conductivity of the channel is enhanced by increasing the gate-to-source voltage and thus pulling more electrons into the channel area. For any gate voltage below the threshold value, there is no channel.

For

$V_{GS} < V_{GS(TH)} \longrightarrow$ No channel

$\downarrow$

$I_D = 0$

# E-MOSFET: Working

- Increasing this positive gate voltage will cause the channel resistance to decrease further causing an increase in the drain current, $I_D$ through the channel.
- In other words, for an n-channel enhancement mode MOSFET: $+V_{GS}$ turns the transistor "ON", while a zero or $-V_{GS}$ turns the transistor "OFF". Thus, the enhancement-mode MOSFET is equivalent to a "normally-open" switch.
- The reverse is true for the p-channel enhancement MOS transistor.
- When $V_{GS} = 0$ the device is "OFF" and the channel is open. The application of a negative (-ve) gate voltage to the p-type EMOSFET enhances the channels conductivity turning it "ON". $-V_{GS}$
- Then for an p-channel enhancement mode MOSFET: $+V_{GS}$ turns the transistor "OFF", while $-V_{GS}$ turns the transistor "ON".

# E-MOSFET

- The n-channel device requires a positive gate-to-source voltage, and a p-channel device requires a negative gate-to-source voltage.

n-channel : $+V_{GS}$
p-channel : $-V_{GS}$

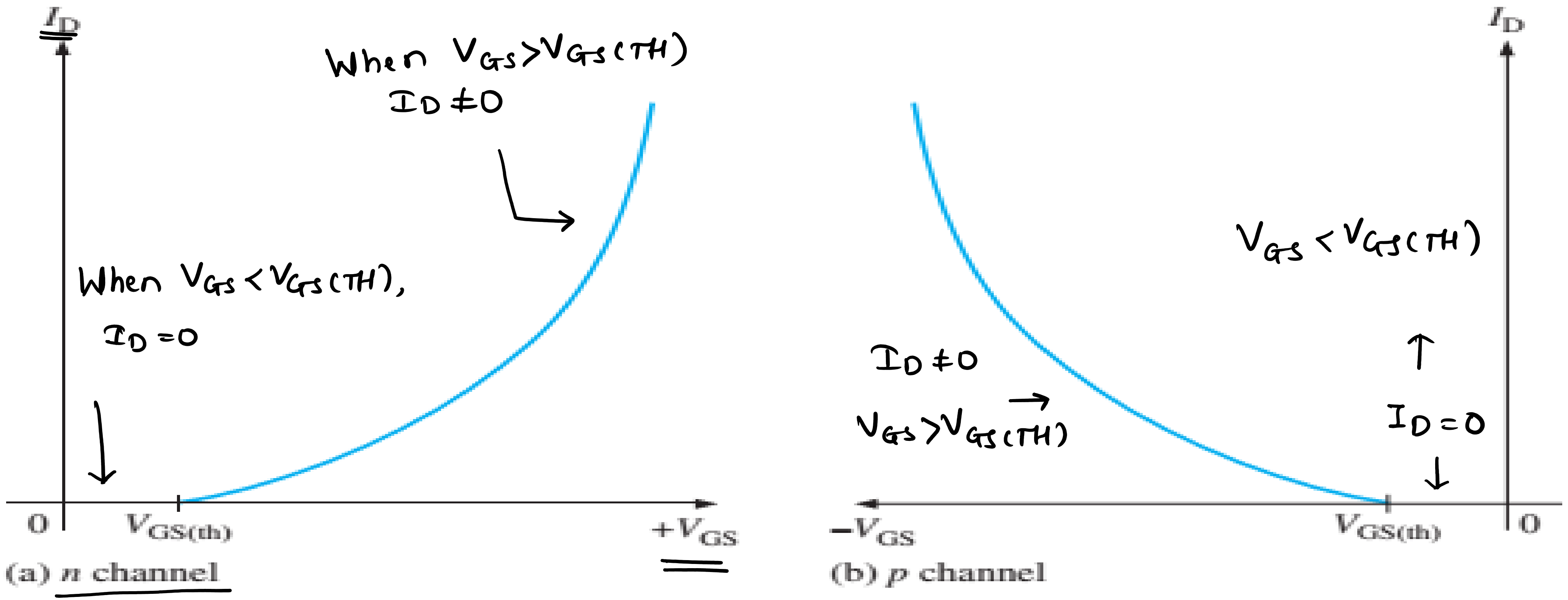
- There is no drain current when $V_{GS}=0$. Therefore, the E-MOSFET does not have a significant $I_{DSS}$ parameter, as do the JFET and the D-MOSFET.

- Also, that there is ideally no drain current until VGS reaches a certain nonzero value called the threshold voltage, $V_{GS(TH)}$.

$$\boxed{I_D = K(V_{GS} - V_{GS(TH)})^2}$$

↳ Non-linear

# E-MOSFET: Input Characteristics



# Numerical Problem

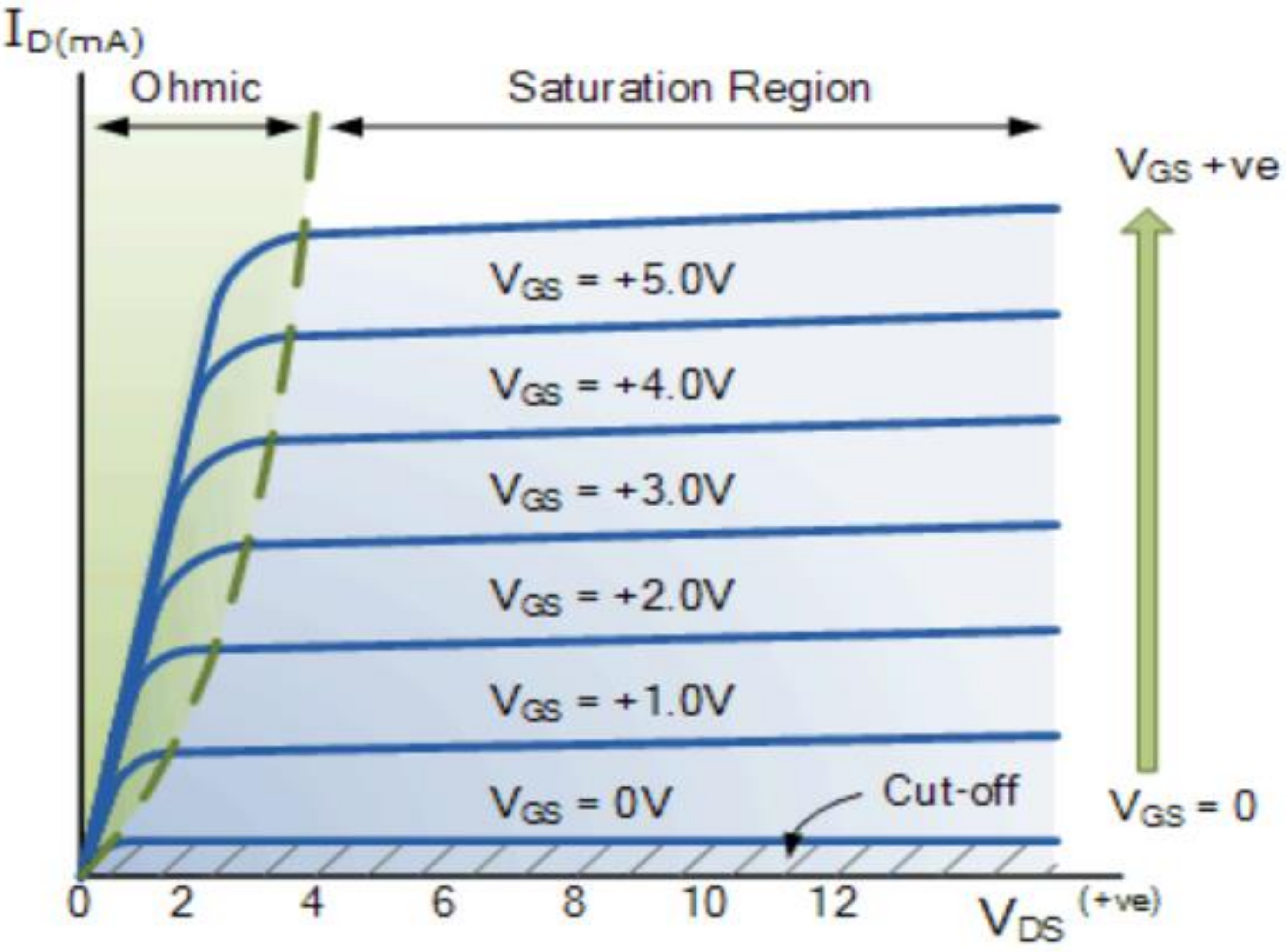
- **The datasheet for a 2N7002 E-MOSFET gives ID(on) 500mA(minimum) at VGS 10 V and VGS(th) 1V. Determine the drain current for VGS=5 V.**

$$k = \frac{I_D}{(V_{GS} - V_{GS(th)})^2} = \frac{500mA}{(10V - 1V)^2} = \frac{500mA}{81\, V^2} = 6.17mA/V^2$$

Next, using the value of K, calculate ID for VGS 5 V

$$I_D = K(V_{GS} - V_{GS(th)})^2 = \left(\frac{6.12mA}{V^2}\right)(5V - 1V)^2 = 98.7mA$$

# E-MOSFET: Output Characteristics



# Acknowledgements

1. Electronic Devices, Thomas L. Floyd
2. Web Resources

# Thank You..