MOSFET

Metal Oxide Semiconductor Field Effect Transistor

Chapter Objectives

- In the end of this chapter, we'll be able
  - To understand types of MOSFET's.
  - To discuss and differentiate the operation of MOSFET's.

FET

FET's (Field – Effect Transistors) are much like BJT's (Bipolar Junction Transistors).

Similarities:

- Amplifiers
- Switching devices
- Impedance matching circuits

Differences:

- FET's are voltage controlled devices whereas BJT's are current controlled devices.
- FET's also have a higher input impedance, but BJT's have higher gains.
- FET's are less sensitive to temperature variations and because of there

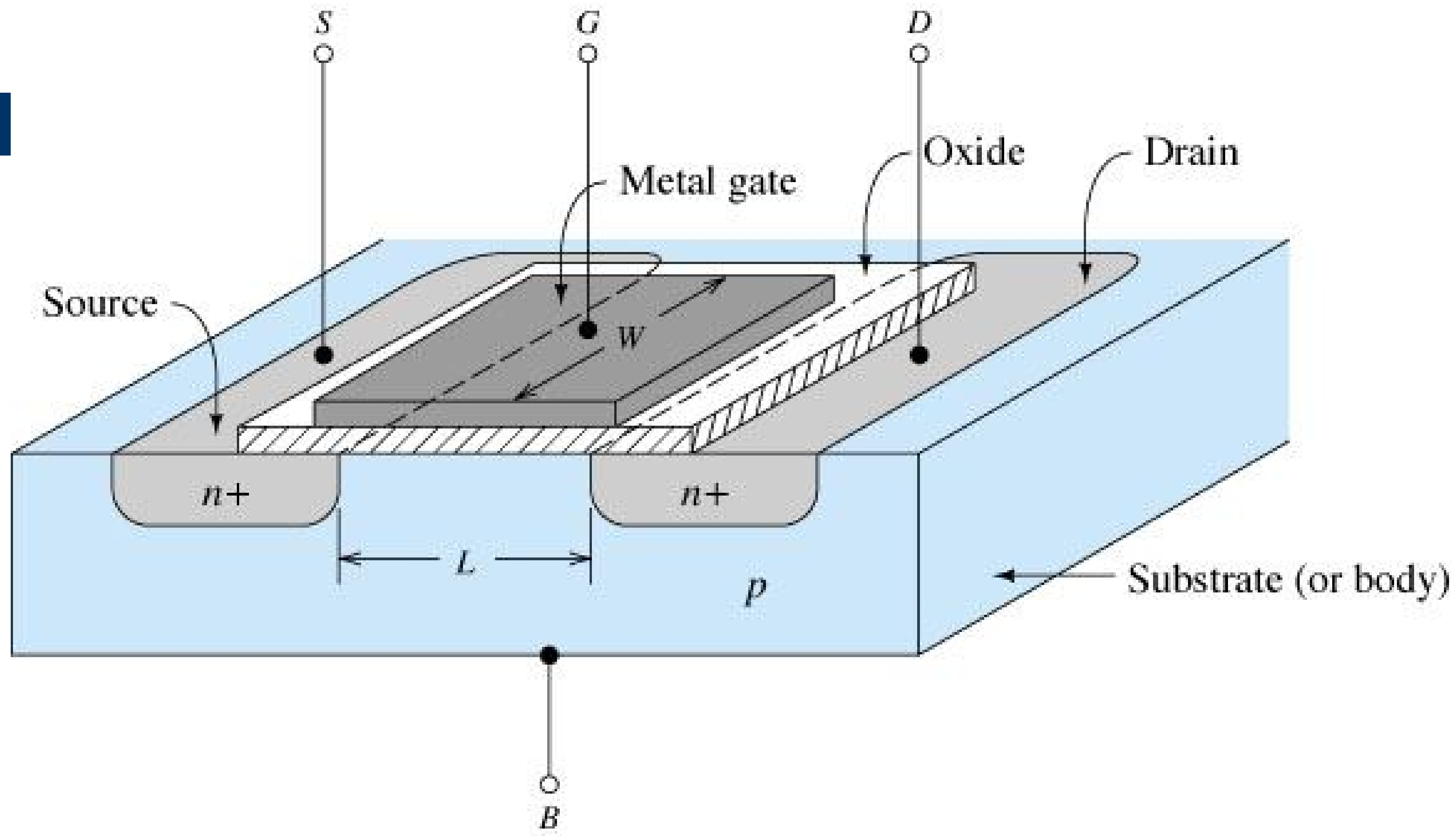
MOSFET’s

MOSFETs have characteristics similar to JFETs and additional characteristics that make then very useful

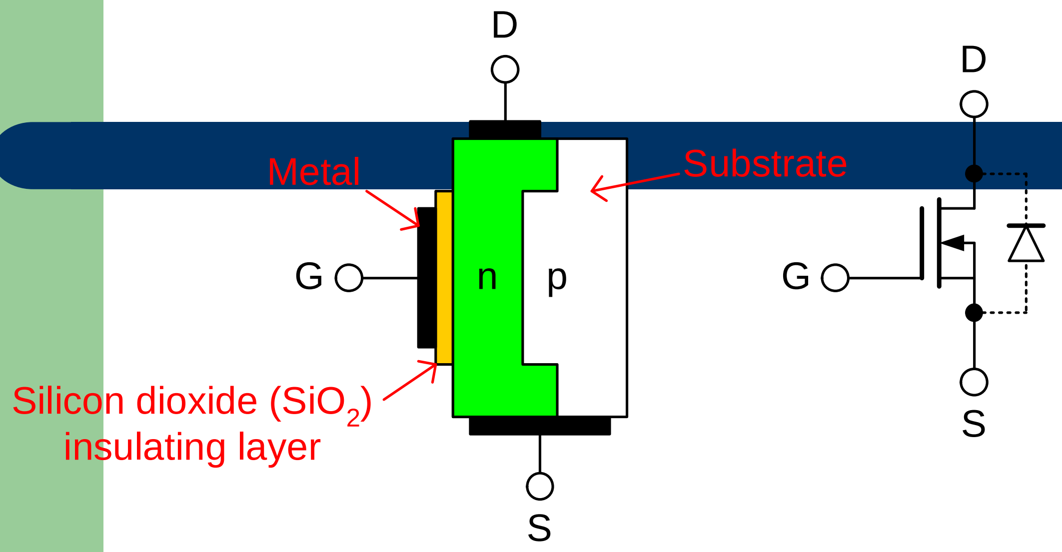
There are 2 types of MOSFET’s:

- Depletion mode MOSFET (D-MOSFET)
  - Operates in Depletion mode the same way as a JFET when $V_{GS} \leq 0$
  - Operates in Enhancement mode like E-MOSFET when $V_{GS} > 0$
- Enhancement Mode MOSFET (E-MOSFET)
  - Operates in Enhancement mode
  - $I_{DSS} = 0$ until $V_{GS} > V_T$ (threshold voltage)

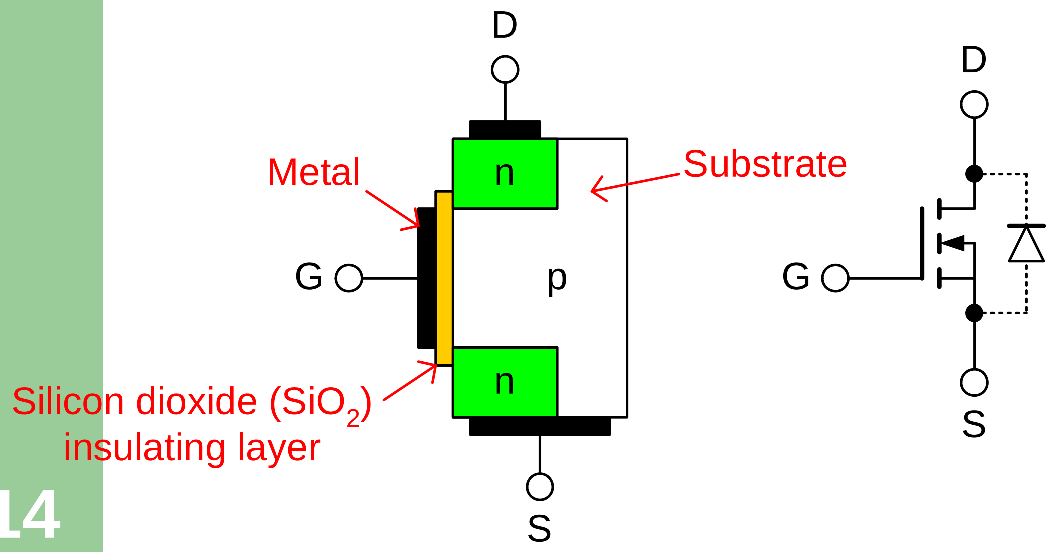
n-Channel E-MOSFET showing channel length L and channel width W



n-channel MOSFET.

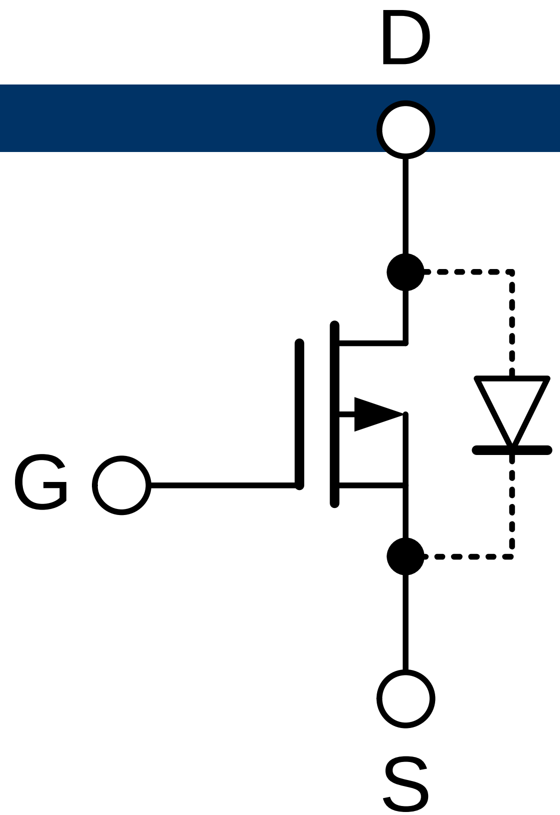


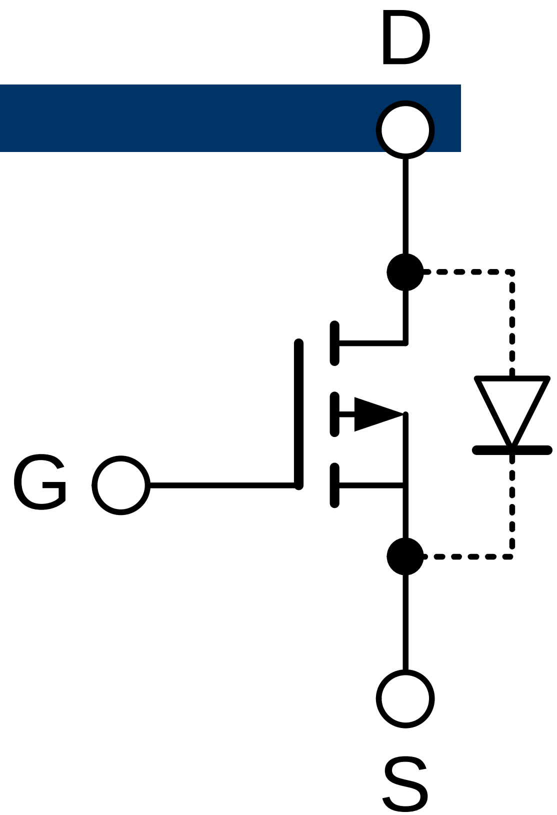
Depletion-type
MOSFET (D-MOSFET)



Enhancement-type
MOSFET (E-MOSFET)

p-channel MOSFET

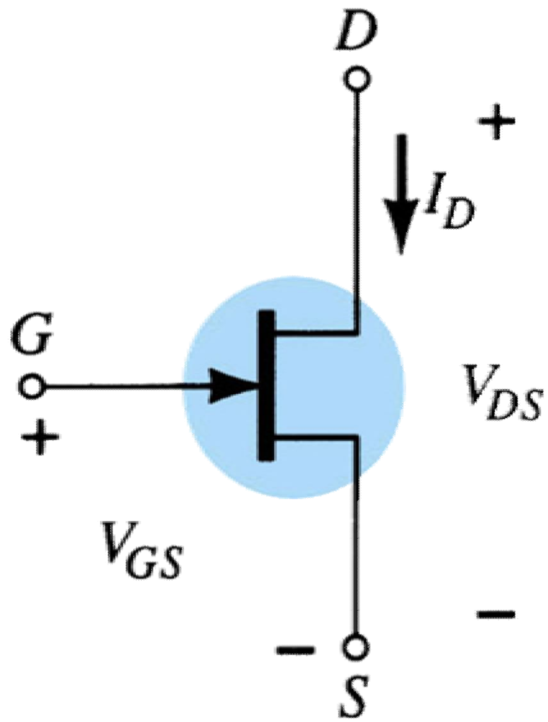




Depletion-type MOSFET (D-MOSFET)

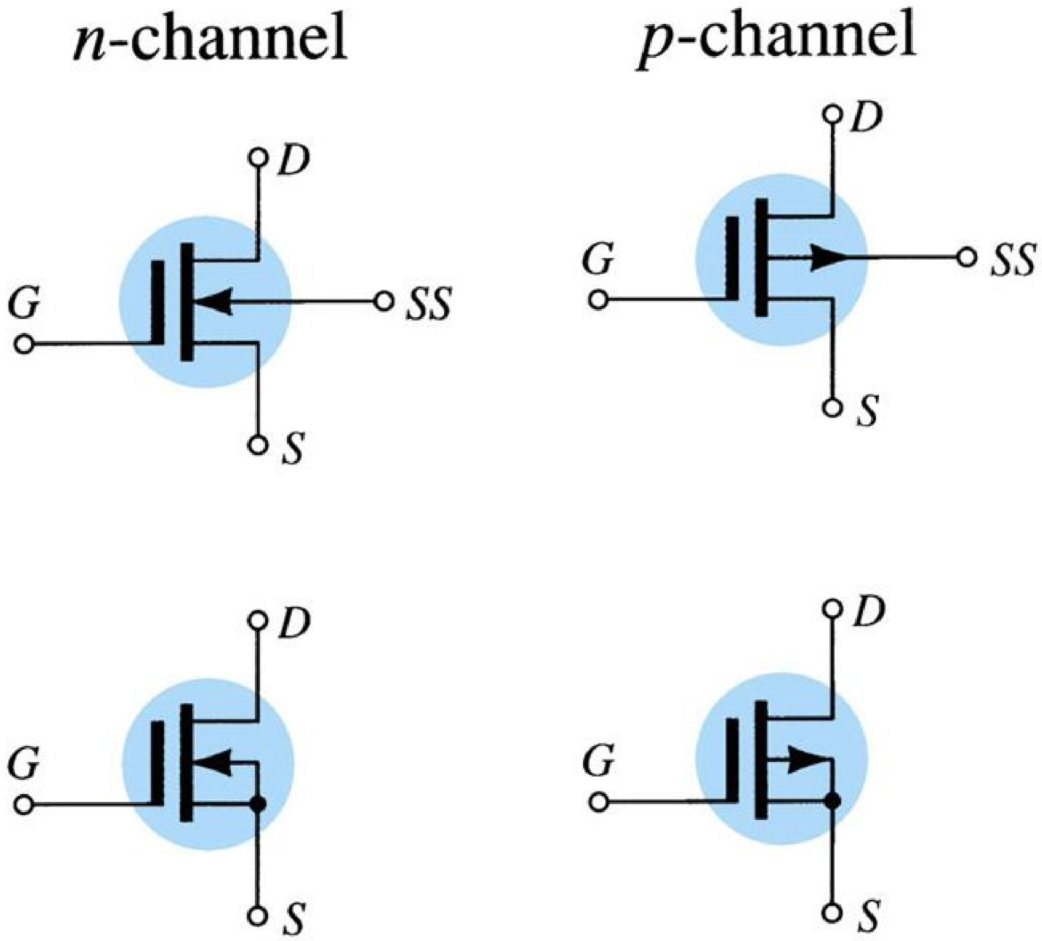
Enhancement-type MOSFET (E-MOSFET)

MOSFET Symbols



(a)

Symbols



(a) (b)

MOSFET Operating Characteristics

• Cutoff Region: Where the current flow is essentially (Accumulator Region)

$$V_{DS} = 0 \; ; \; V_{GS} < V_t$$

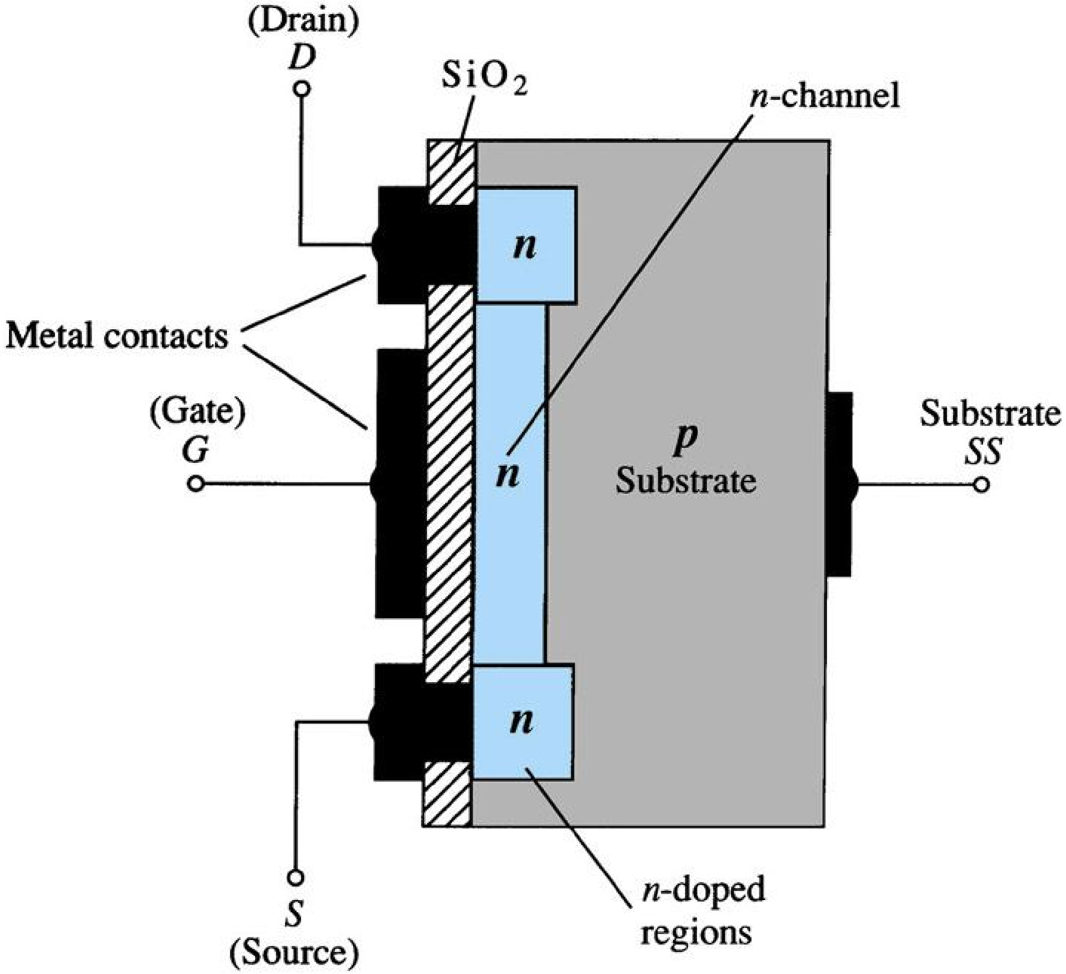
• Non-saturated Region: Weak inversion region where the drain current is dependent on the gate and drain voltage (w.r.t. substrate).

$$V_{DS} < V_{GS} - V_t$$

• Saturated Region : Channel is strongly involved and drain current flow is ideally independent of the drain-source voltage (Inversion)

$$V_{DS} > V_{GS} - V_t$$

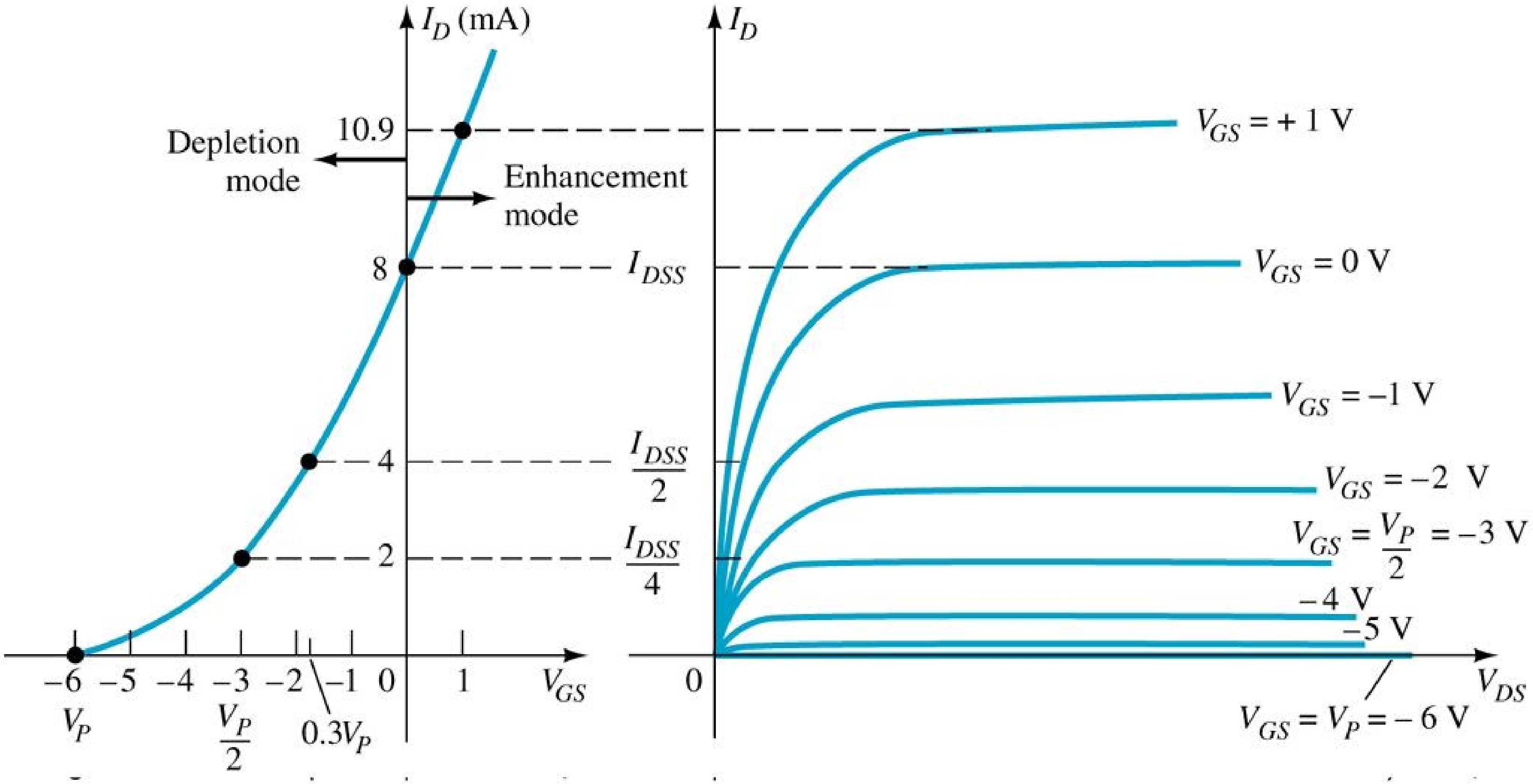
Depletion-Type MOSFET Construction



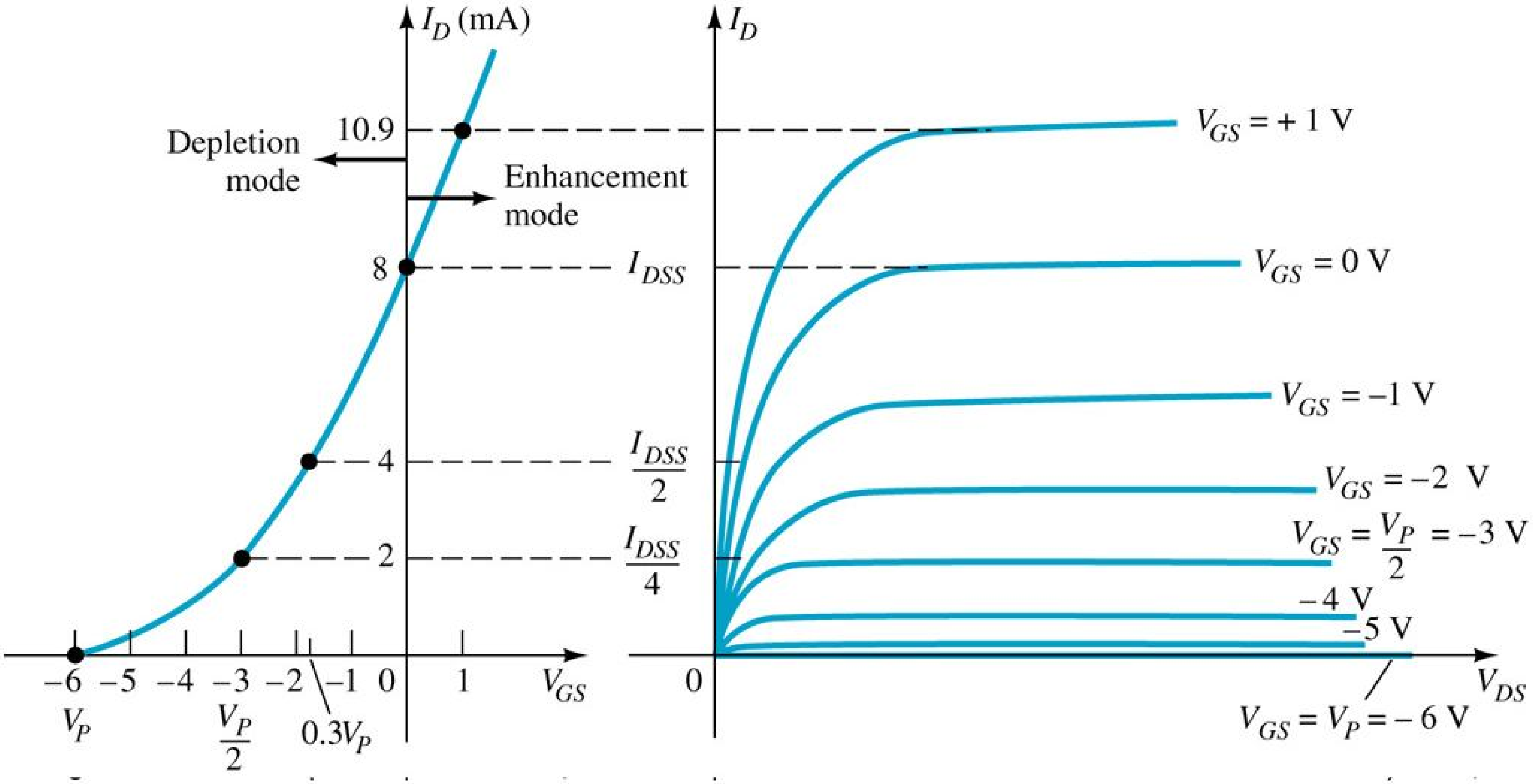
The Drain (D) and Source (S) connect to the to n-doped regions. These N-doped regions are connected via an n-channel. This n-channel is connected to the Gate (G) via a thin insulating layer of SiO_2. The n-doped material lies on a p-doped substrate that may have an additional terminal connection called SS.

Basic Operation

A Depletion MOSFET can operate in two modes: Depletion or Enhancement mode.



Depletion-type MOSFET in Depletion Mode



Depletion mode

The characteristics are similar to the JFET.

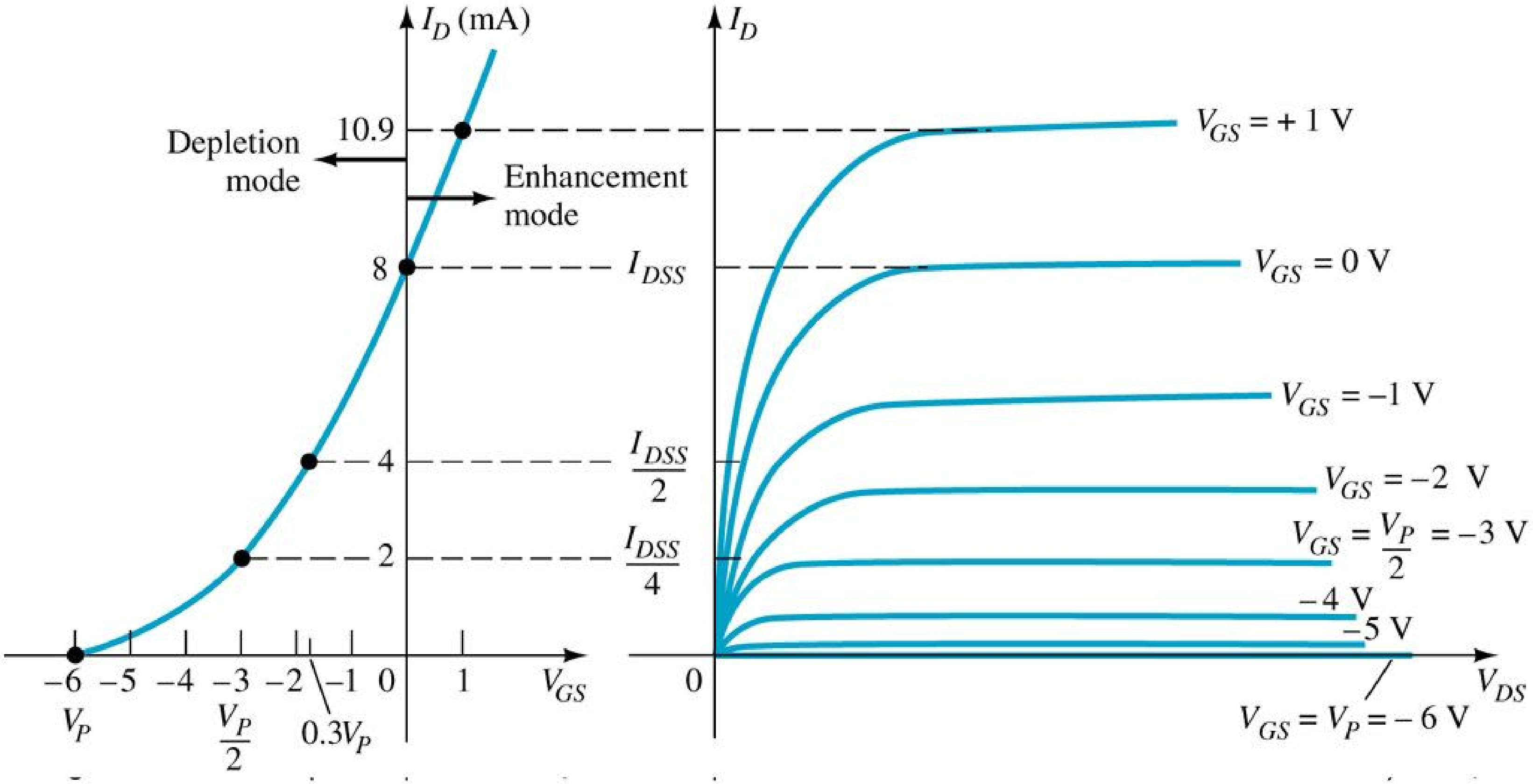
When V_{GS} = 0V, $I_D = I_{DSS}$

When V_{GS} < 0V, $I_D < I_{DSS}$

The formula used to plot the Transfer Curve still applies:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

Depletion-type MOSFET in Enhancement Mode



Enhancement mode

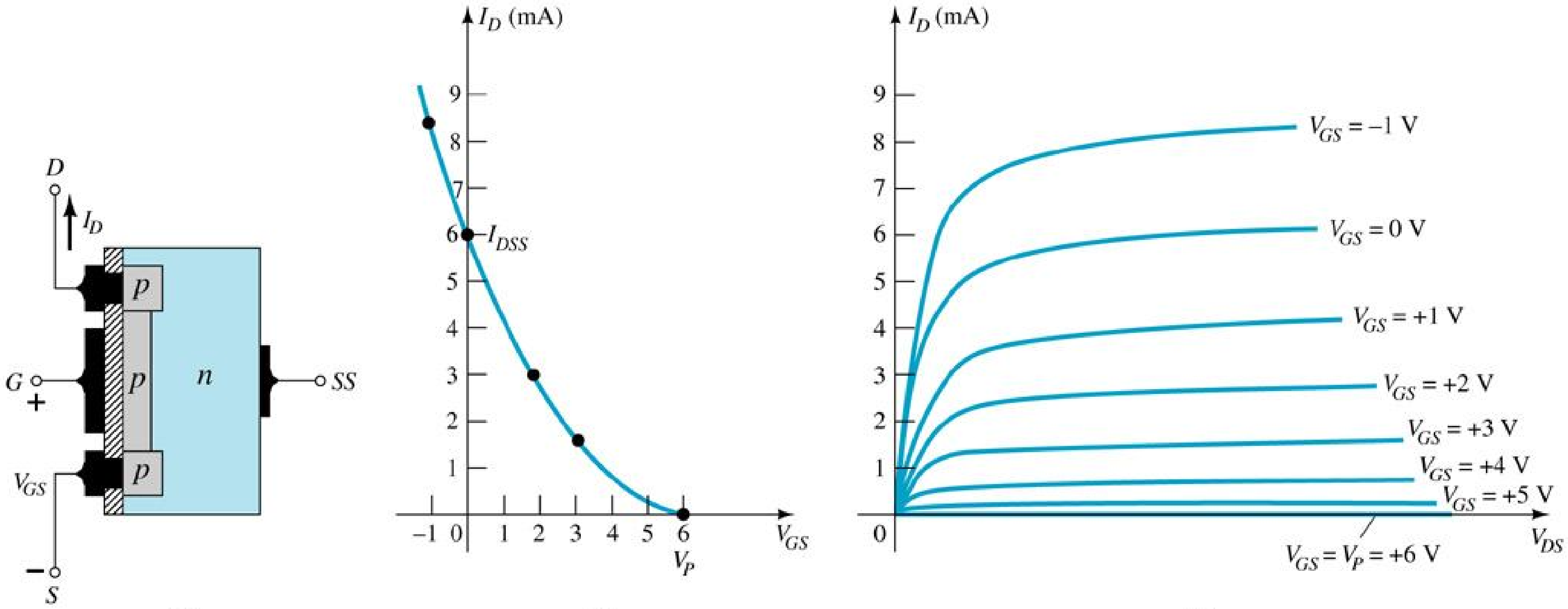
$V_{GS} > 0V$, I_D increases above I_{DSS}

The formula used to plot the Transfer Curve still applies:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

(note that VGS is now a positive polarity)

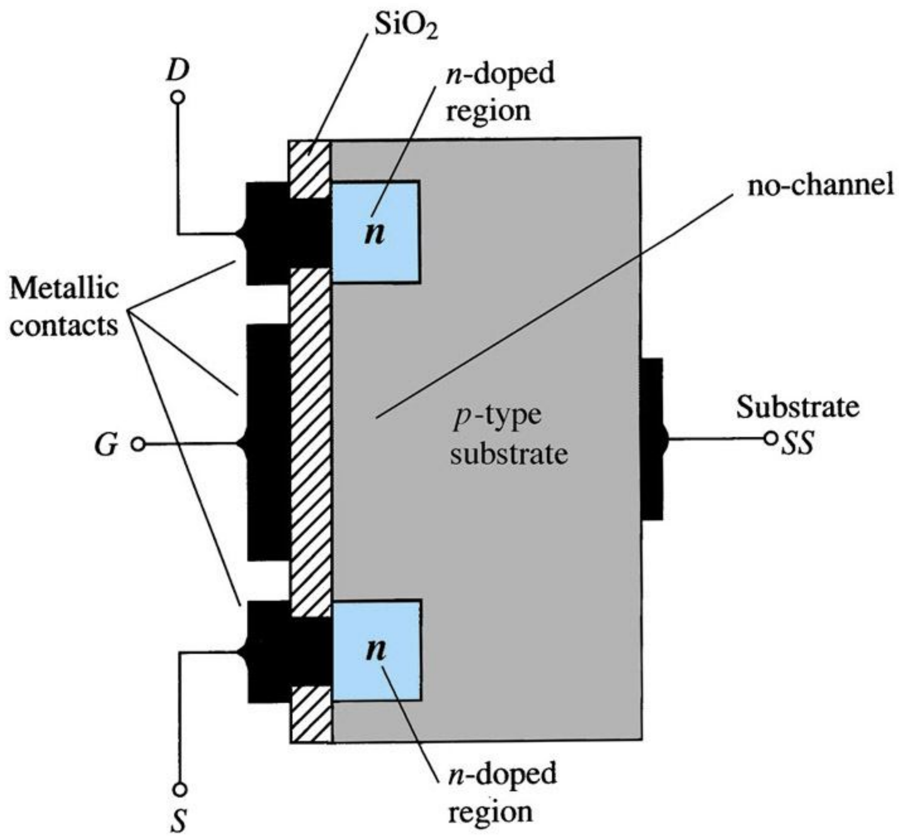
p-Channel Depletion-Type MOSFET



(a) (b) (c)

The p-channel Depletion-type MOSFET is similar to the n-channel except that the voltage polarities and current directions are reversed.

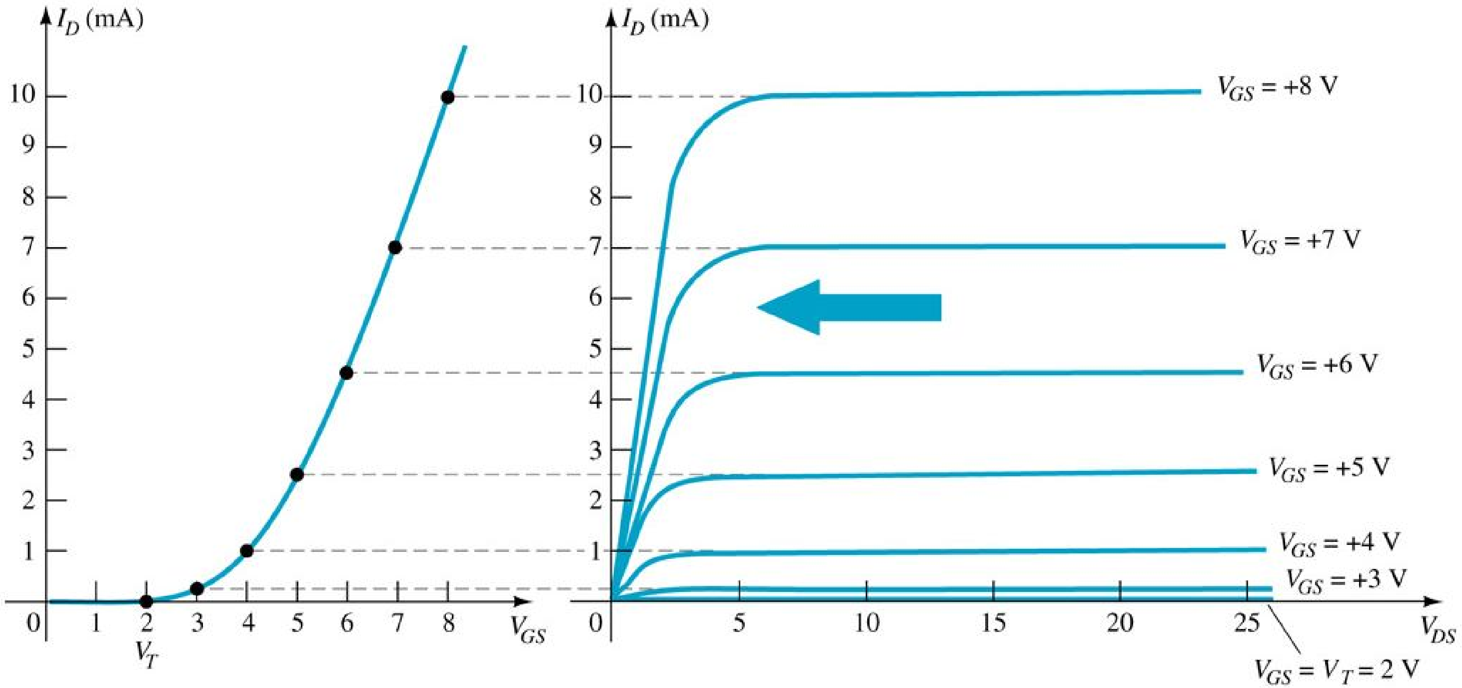
Enhancement-Type MOSFET Construction



The Drain (D) and Source (S) connect to the to n-doped regions. These n-doped regions are connected via an n-channel. The Gate (G) connects to the p-doped substrate via a thin insulating layer of SiO_2. There is no channel. The n-doped material lies on a p-doped substrate that may have an additional terminal connection called SS.

Basic Operation

The Enhancement-type MOSFET only operates in the enhancement mode.



V_{GS} is always positive

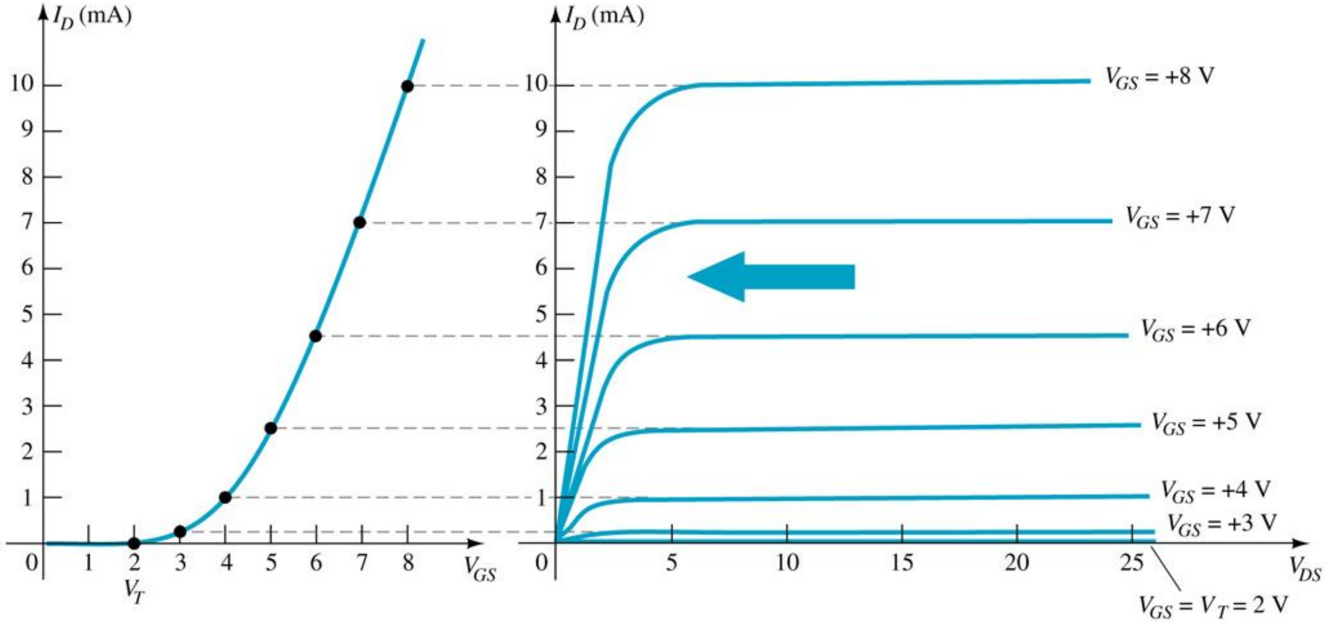
As V_{GS} increases, I_D increases

But if V_{GS} is kept constant and V_{DS} is increased, then I_D saturates (I_{DSS})

The saturation level, V_{DSsat} is reached.

$$V_{Dsat} = V_{GS} - V_T$$

Transfer Curve



To determine I_D given V_{GS}: $I_D = k(V_{GS} - V_T)^2$

where V_T = threshold voltage or voltage at which the MOSFET turns on.

k = constant found in the specification sheet

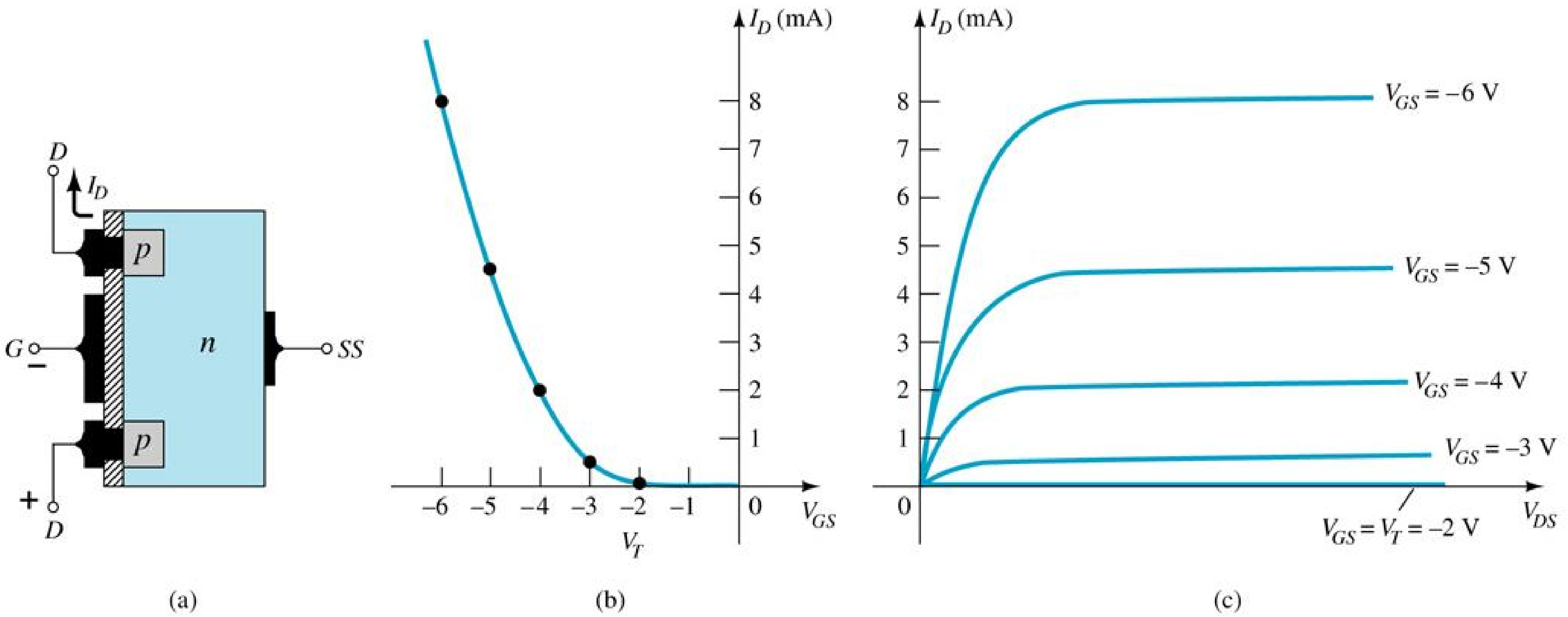
k can also be determined by using values at a specific point and the formula:

$$k = \frac{I_{D(on)}}{(V_{GS(ON)} - V_T)^2}$$

V_{DSsat} can also be calculated: $V_{Dsat} = V_{GS} - V_T$

p-Channel Enhancement-Type MOSFETs

The p-channel Enhancement-type MOSFET is similar to the n-channel except that the voltage polarities and current directions are reversed.



MOSFET Handling

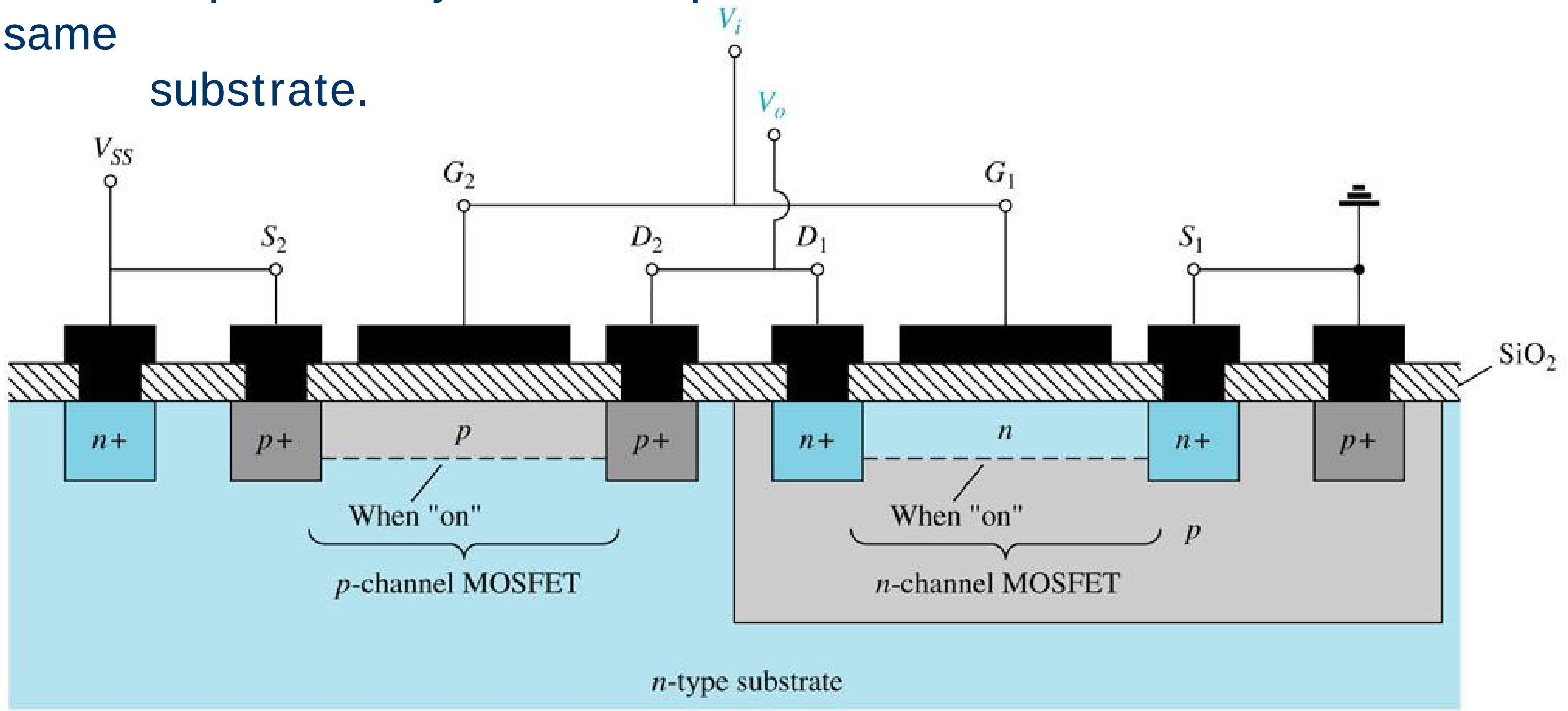
MOSFETs are very static sensitive. Because of the very thin SiO_2 layer between the external terminals and the layers of the device, any small electrical discharge can stablish an unwanted conduction.

Protection:

- Always transport in a static sensitive bag
- Always wear a static strap when handling MOSFETS
- Apply voltage limiting devices between the Gate and Source, such as back-to-back Zeners to limit any transient voltage.

CMOS

CMOS – Complementary MOSFET p-channel and n-channel MOSFET on the same substrate.

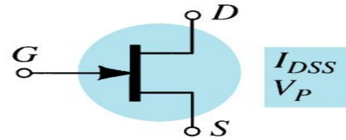


Advantage:

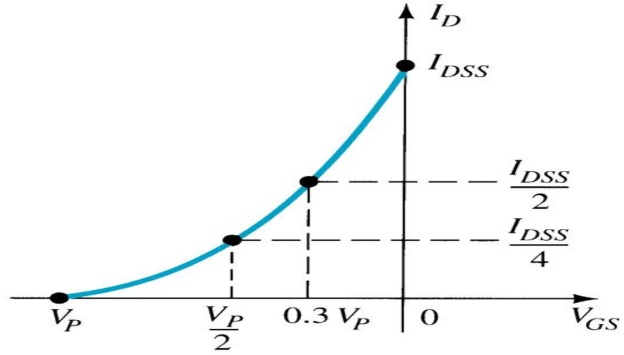
- Useful in logic circuit designs
- Higher input impedance
- Faster switching speeds
- Lower operating power levels

Summary Table

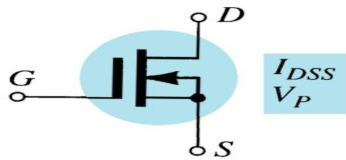
$I_G = 0\ \text{A},\ I_D = I_S$



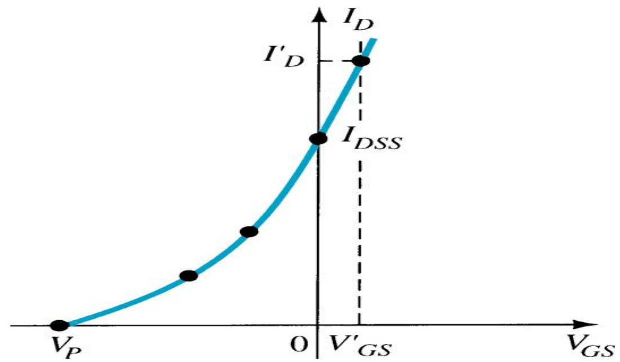
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$



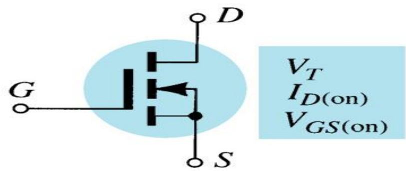
$I_G = 0\ \text{A},\ I_D = I_S$



$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$



$I_G = 0\ \text{A},\ I_D = I_S$



$$I_D = k\,(\ _{GS} - V_{GS\,(\text{Th})})^2$$

$$k = \frac{I_{D(\text{on})}}{(V_{GS(\text{on})} - V_{GS\,(\text{Th})})^2}$$