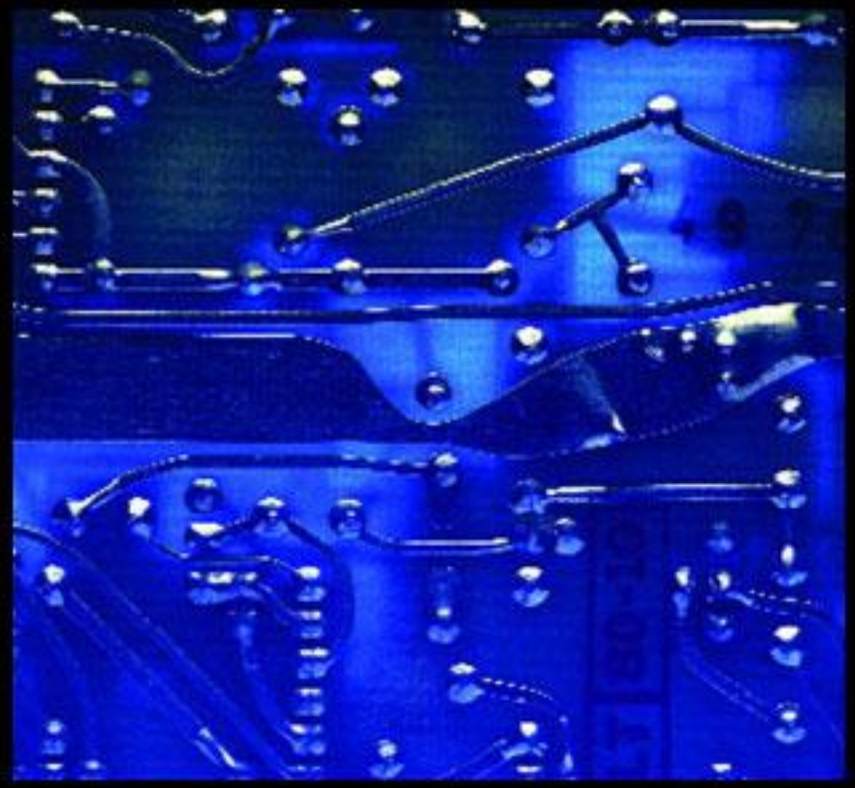
Electronic Devices and Circuit Theory

Tenth Edition



BOYLESTAD

PEARSON

Chapter 6:
Field-Effect Transistors

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MOSFETs

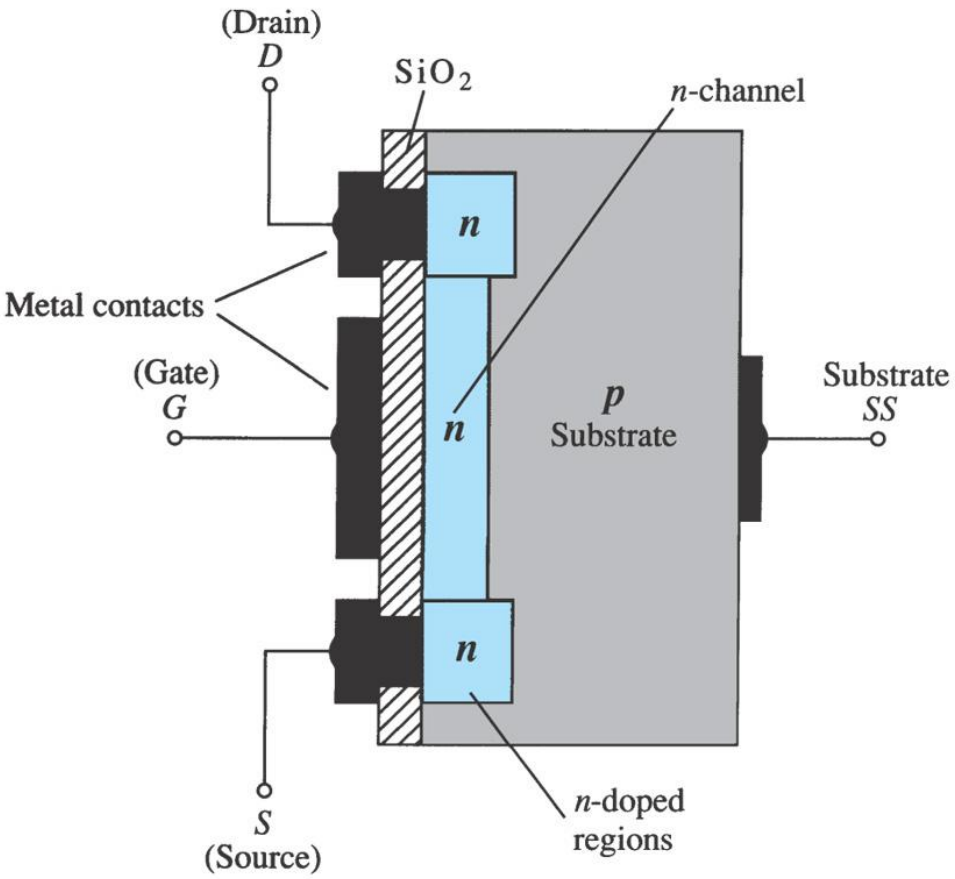
MOSFETs have characteristics similar to JFETs and additional characteristics that make then very useful.

There are two types of MOSFETs:

- **Depletion-Type**
- **Enhancement-Type**

Depletion-Type MOSFET Construction

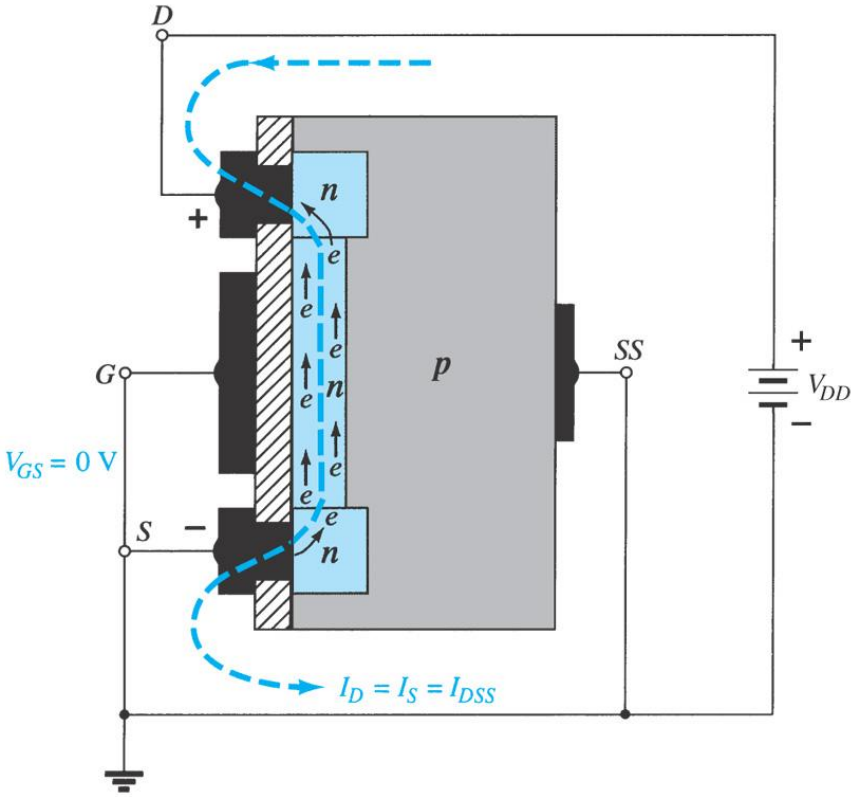
- The Drain (D) and Source (S) connect to the to *n*-doped regions.
- These *n*-doped regions are connected via an *n*-channel.
- This *n*-channel is connected to the Gate (G) via a thin insulating layer of SiO_2.
- The *n*-doped material lies on a *p*-doped substrate that may have an additional terminal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



n-Channel depletion-type MOSFET.

Depletion-Type MOSFET :Basic Operation and Characteristics

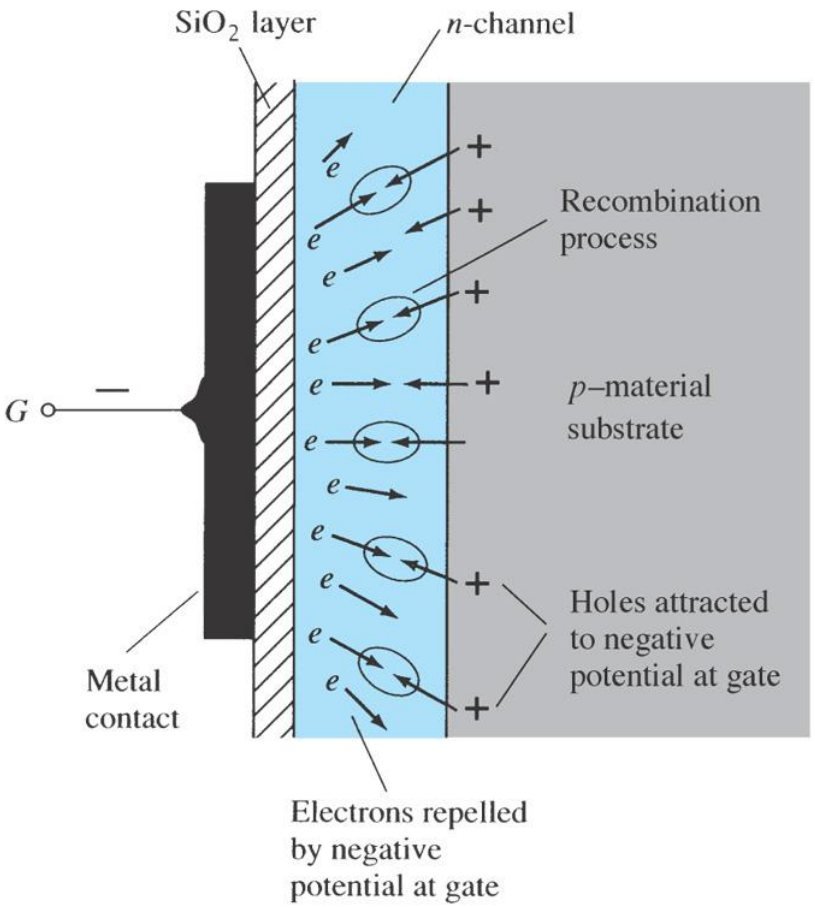
- V_{GS}=0 and V_{DS} is applied across the drain to source terminals.
- This results to attraction of free electrons of the n-channel to the drain, and hence current flows.



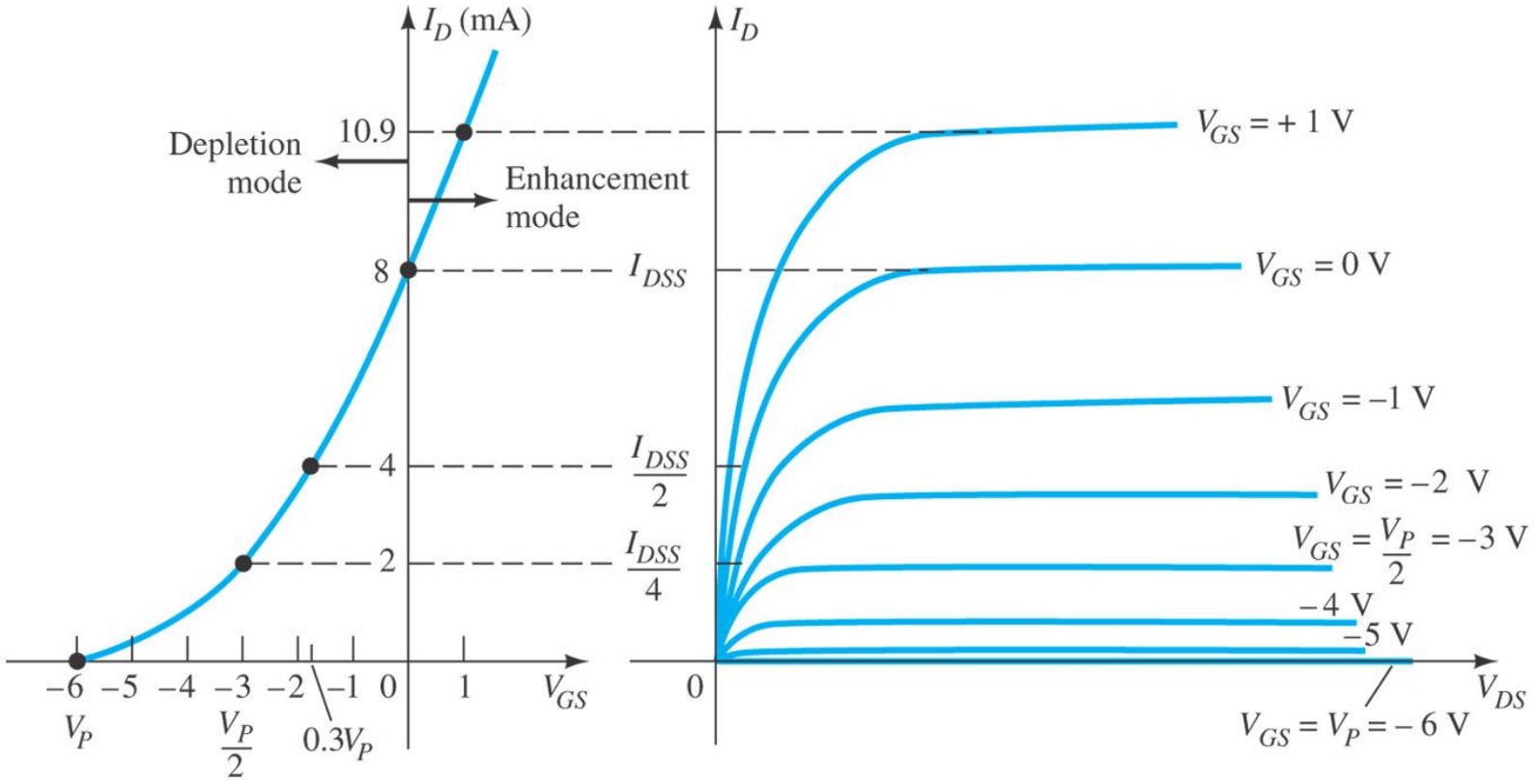
n-Channel depletion-type MOSFET with V_{GS} = 0 V and applied voltage V_{DD}.

Depletion-Type MOSFET :Basic Operation and Characteristics

- V_{GS} is set at a negative voltage such as -1 V.
- The negative potential at the gate pressures electrons toward the p-type substrate and attract holes from the p-type substrate.
- This will reduce the number of free electrons in the *n*-channel available for conduction.
- The more negative the V_{GS}, the resulting level of drain current I_D is reduced.
- When V_{GS} is reduced to V_P (Pinch-off voltage), then I_D=0 mA.



Depletion-Type MOSFET :Basic Operation and Characteristics

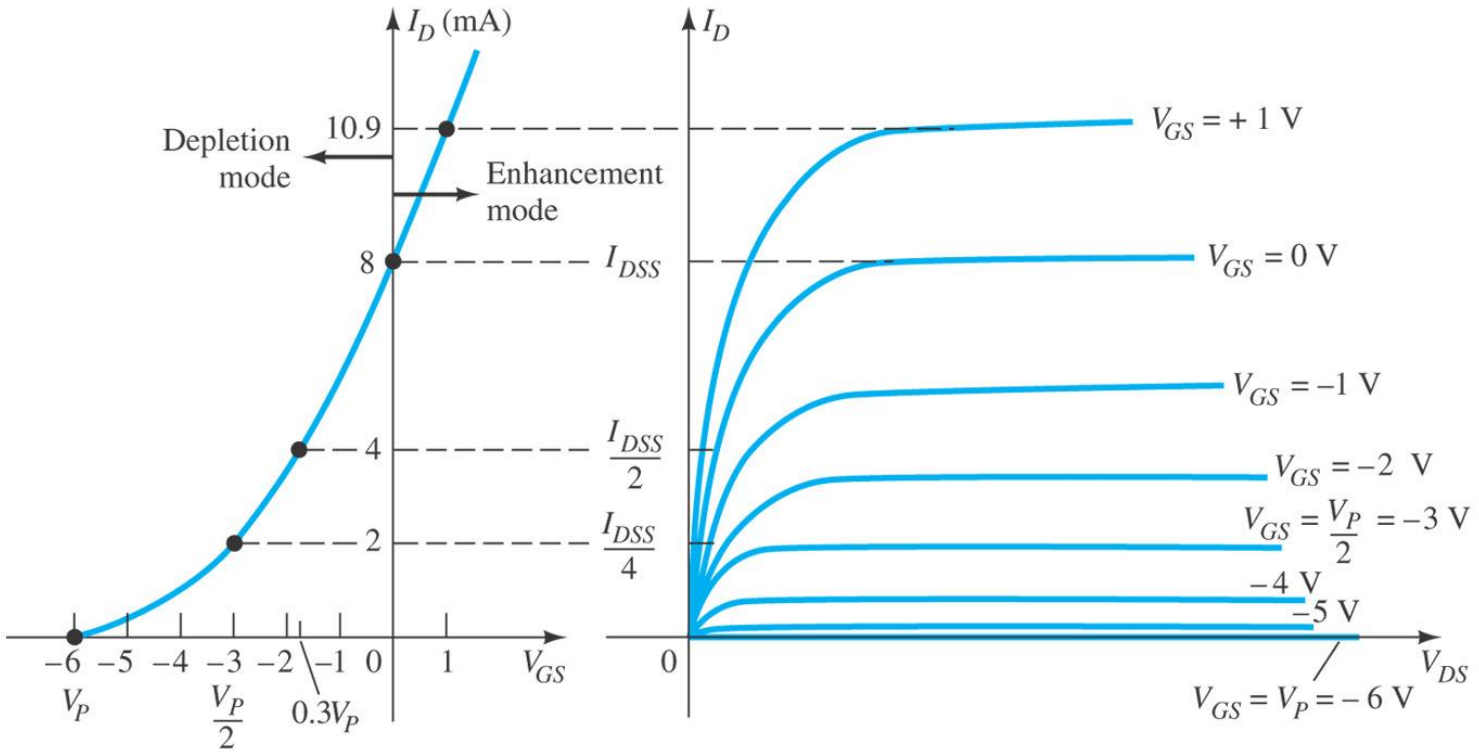


- When V_{GS} is reduced to V_P (Pinch-off) [i.e. V_p=-6V], then I_D=0 mA.
- For **positive** values of V_{GS}, the positive gate will draw additional electrons (free carriers) from the p-type substrate and hence I_D increases.

Basic MOSFET Operation

A depletion-type MOSFET can operate in two modes:

- **Depletion mode**
- **Enhancement mode**



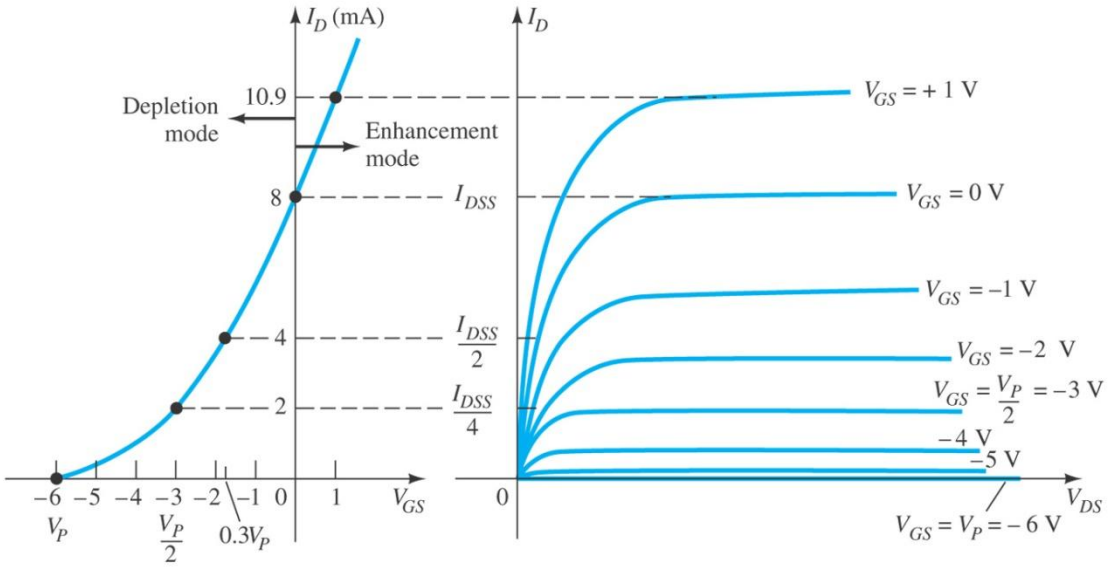
D-Type MOSFET in Depletion Mode

Depletion Mode

The characteristics are similar to a JFET.

- When $V_{GS} = 0$ V, $I_D = I_{DSS}$
- When $V_{GS} < 0$ V, $I_D < I_{DSS}$
- The formula used to plot the transfer curve still applies:

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

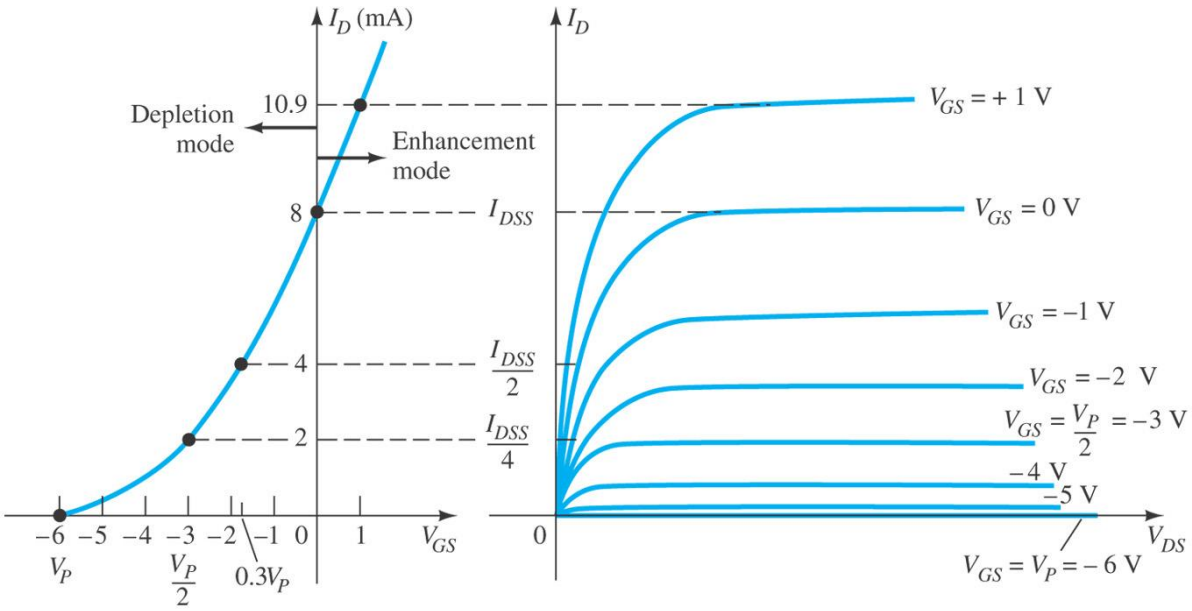


D-Type MOSFET in Enhancement Mode

Enhancement Mode

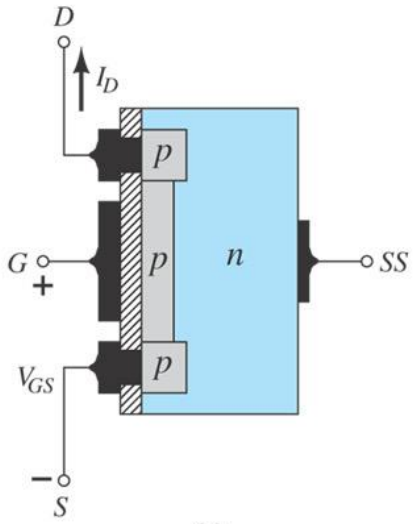
- $V_{GS} > 0$ V
- I_D increases above I_{DSS}
- The formula used to plot the transfer curve still applies:

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

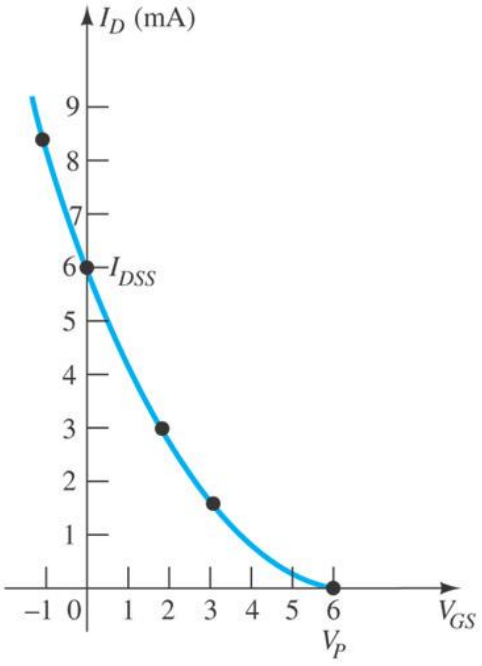


Note that V_{GS} is now a positive polarity

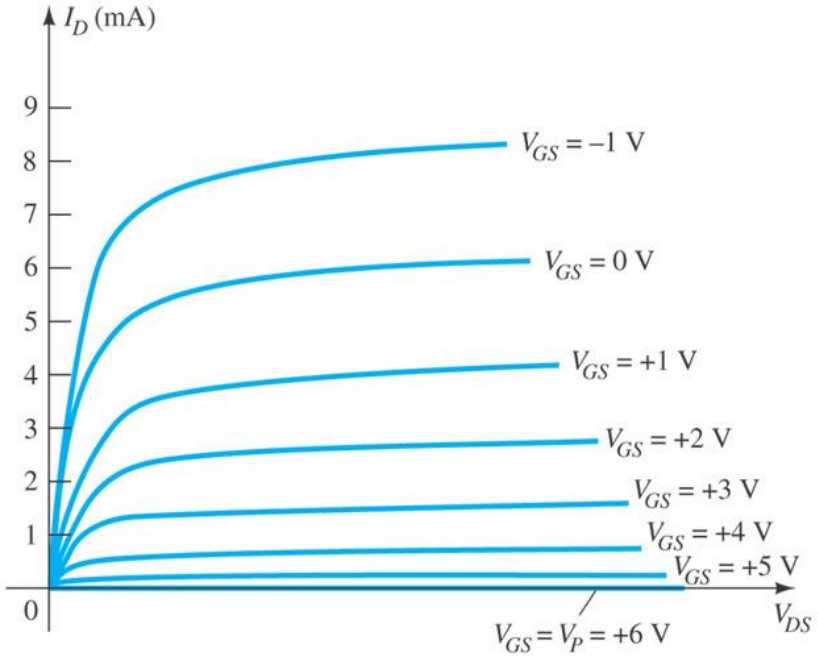
p-Channel D-Type MOSFET



(a)

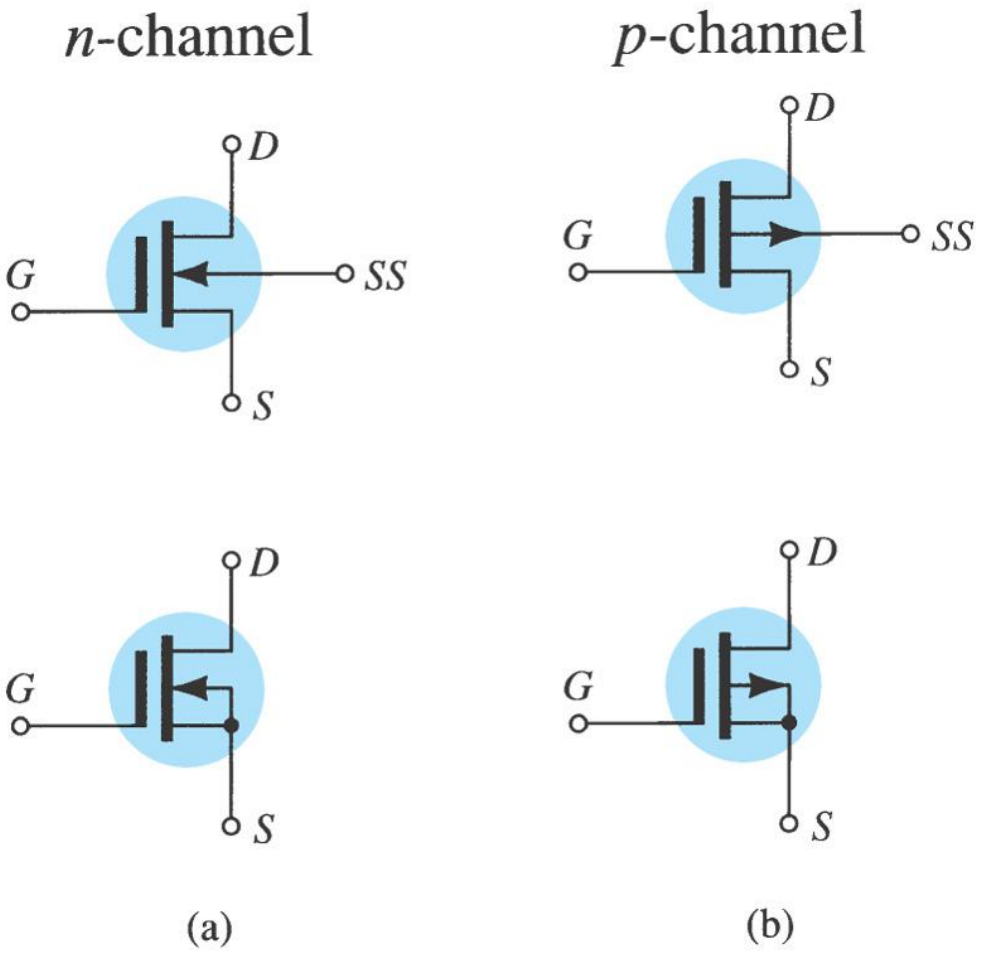


(b)



(c)

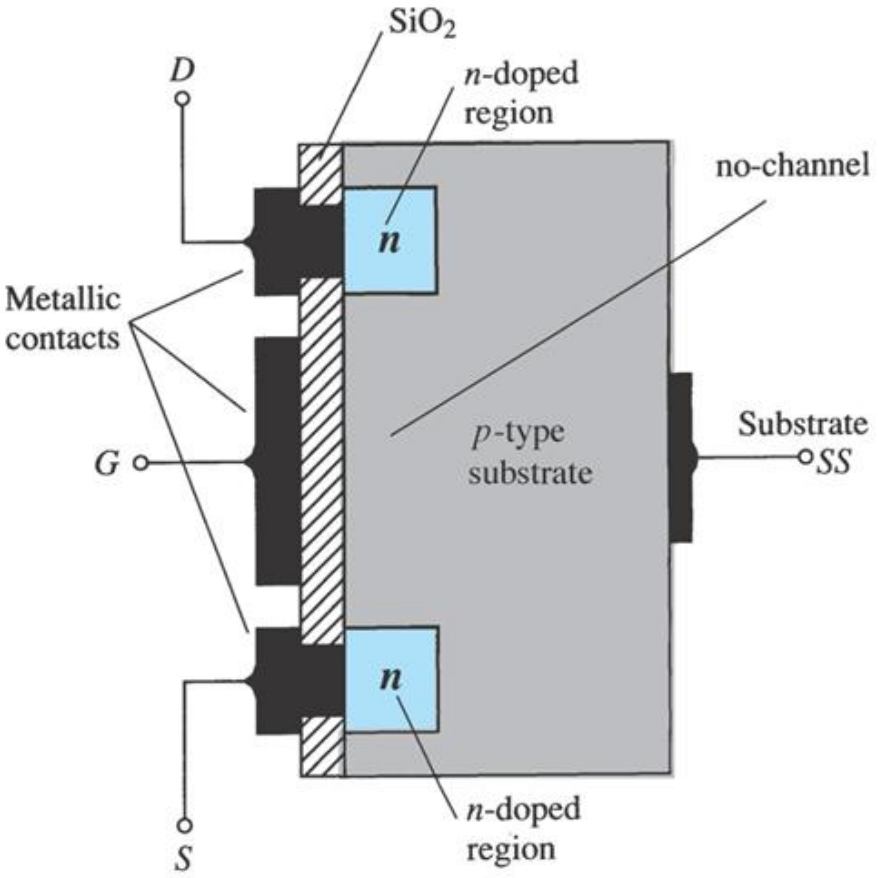
D-Type MOSFET Symbols



(a) *n*-channel depletion-type MOSFETs ,(b) *p*-channel depletion-type MOSFETs

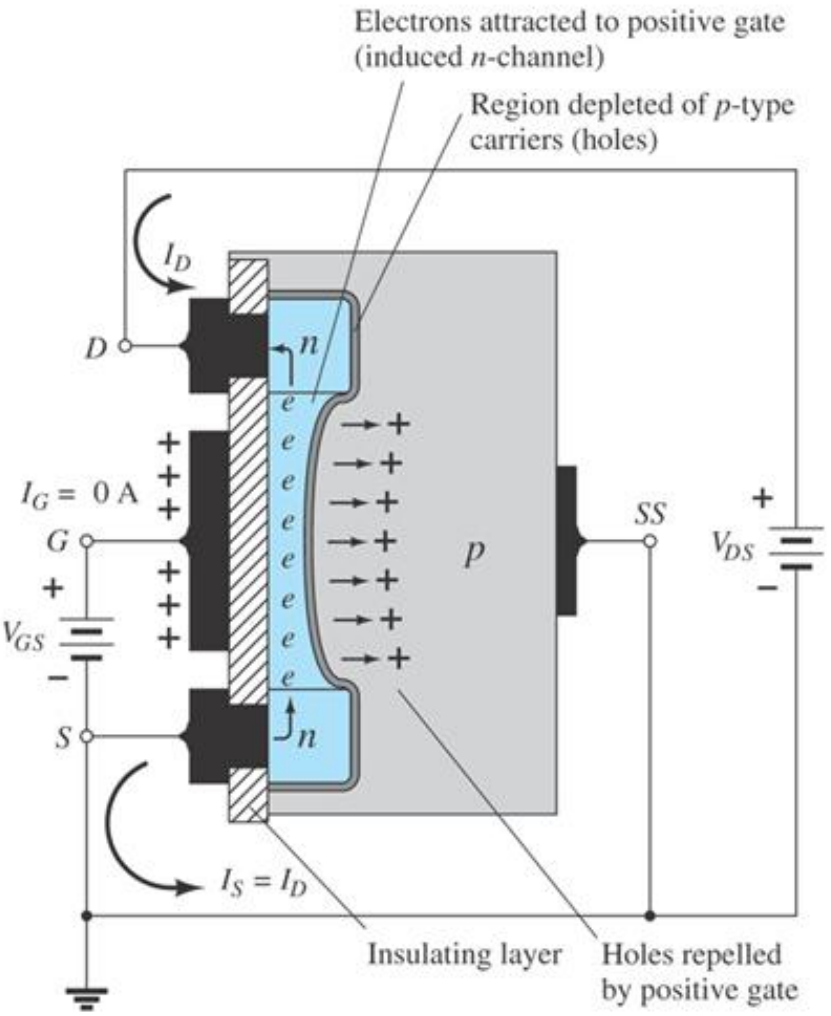
Enhancement-Type MOSFET Construction

- The Drain (D) and Source (S) connect to the to *n*-doped regions.
- 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 the Substrate (SS)



Enhancement-Type MOSFET Construction

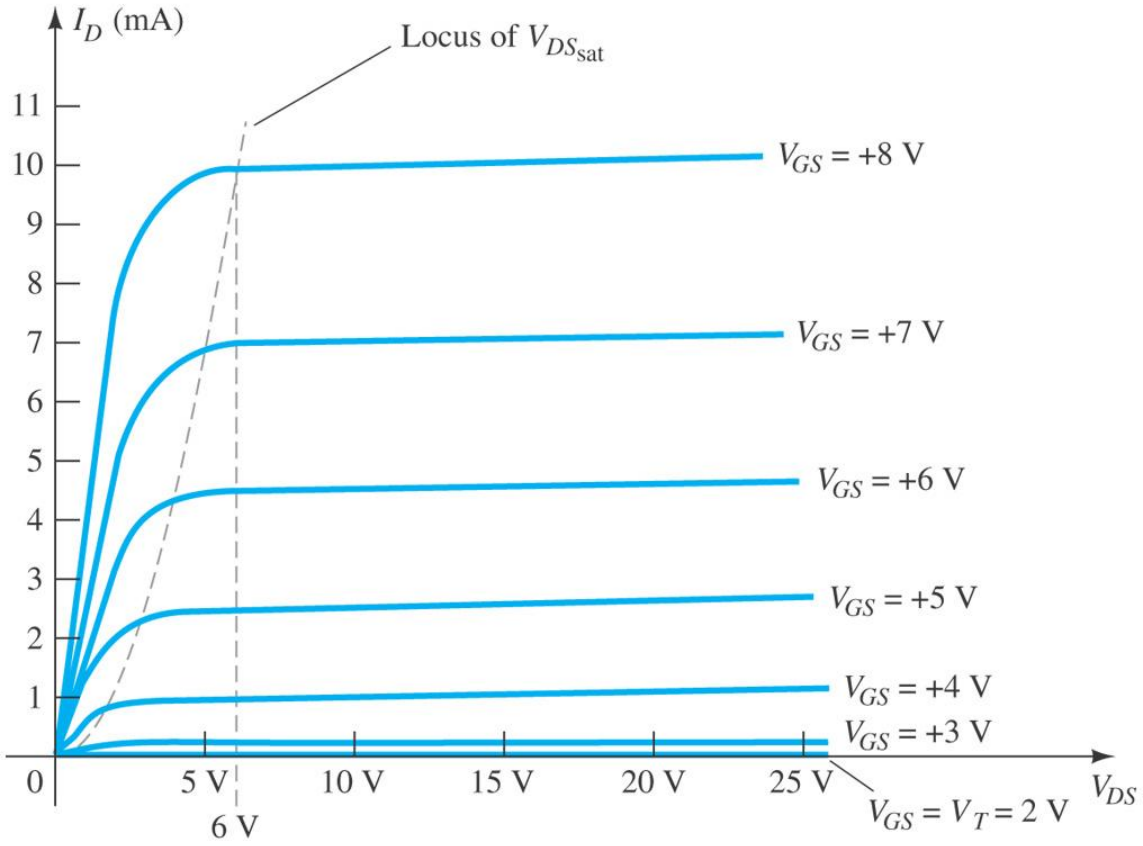
- For $V_{GS}=0$, $I_D=0$ (no channel).
- For V_{DS} some positive voltage, and $V_{GS}=0$, two reverse biased p-n junctions and no significant flow between drain and source.
- For $V_{GS}>0$ and $V_{DS}>0$, the positive voltage at gate pressure holes to enter deeper regions of the p-substrate, and the electrons in p-substrate will be attracted to the positive gate.
- The level of V_{GS} that results in the significant increase in drain current is called ***threshold voltage*** (V_T).
- For $V_{GS}<V_T$, $I_D=0$ mA.



Basic Operation of the E-Type MOSFET

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

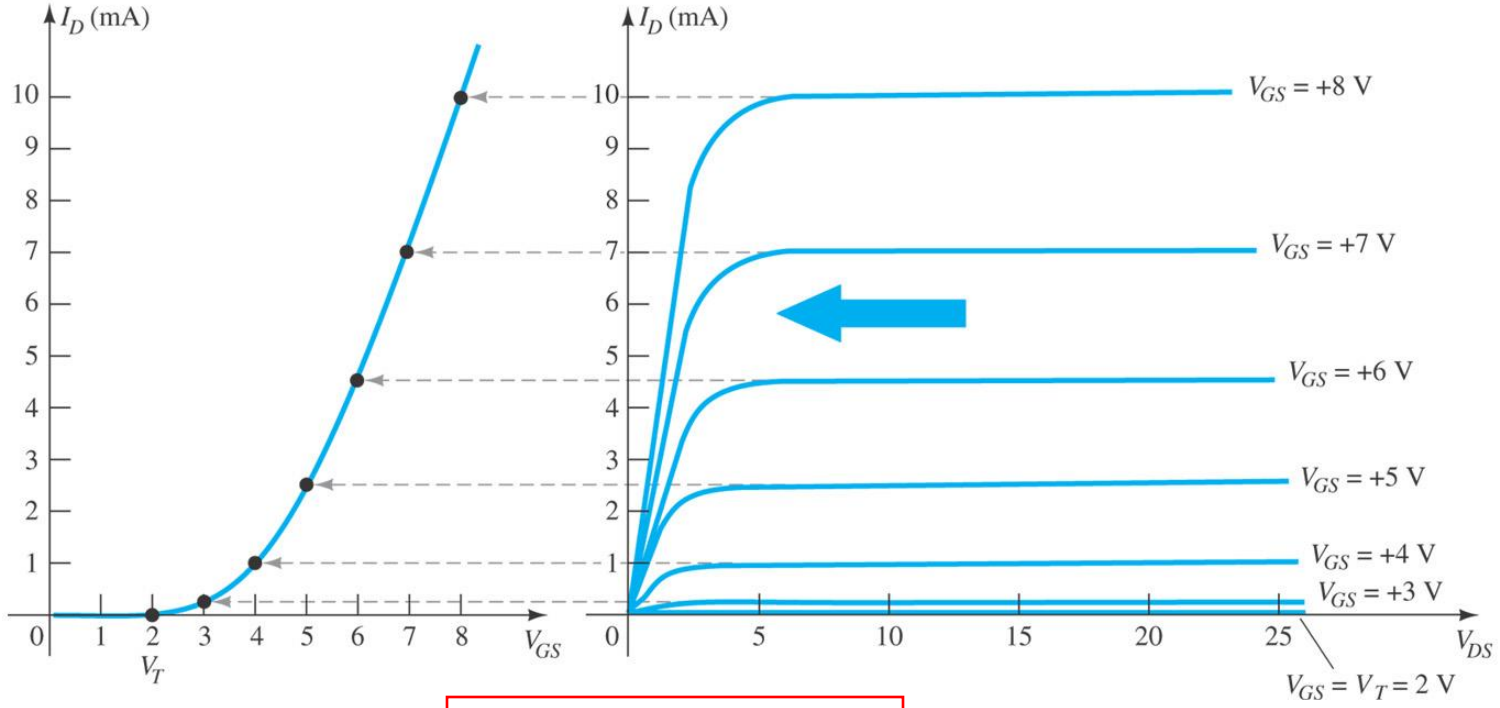
- V_{GS} is always positive.
- As V_{GS} increases, I_D increases
- As V_{GS} is kept constant and V_{DS} is increased, then I_D saturates (I_{DSS}) and the saturation level, V_{DSsat} is reached



V_{DSsat} can be calculated by:

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

E-Type MOSFET Transfer Curve



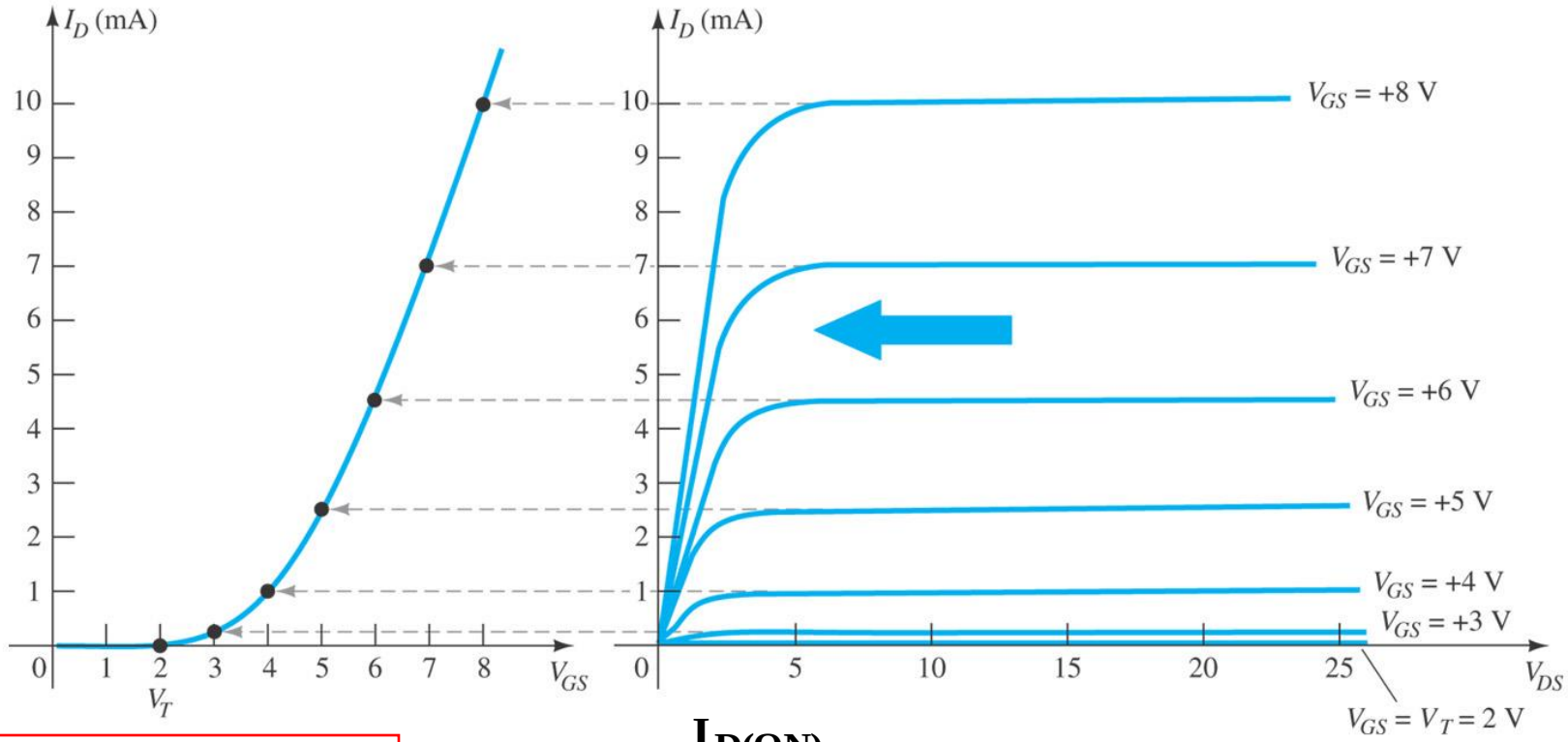
To determine I_D given V_{GS}: $\mathbf{I_D = k(V_{GS} - V_T)^2}$

Where: V_T = threshold voltage or voltage at which the MOSFET turns on

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

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

E-Type MOSFET Transfer Curve



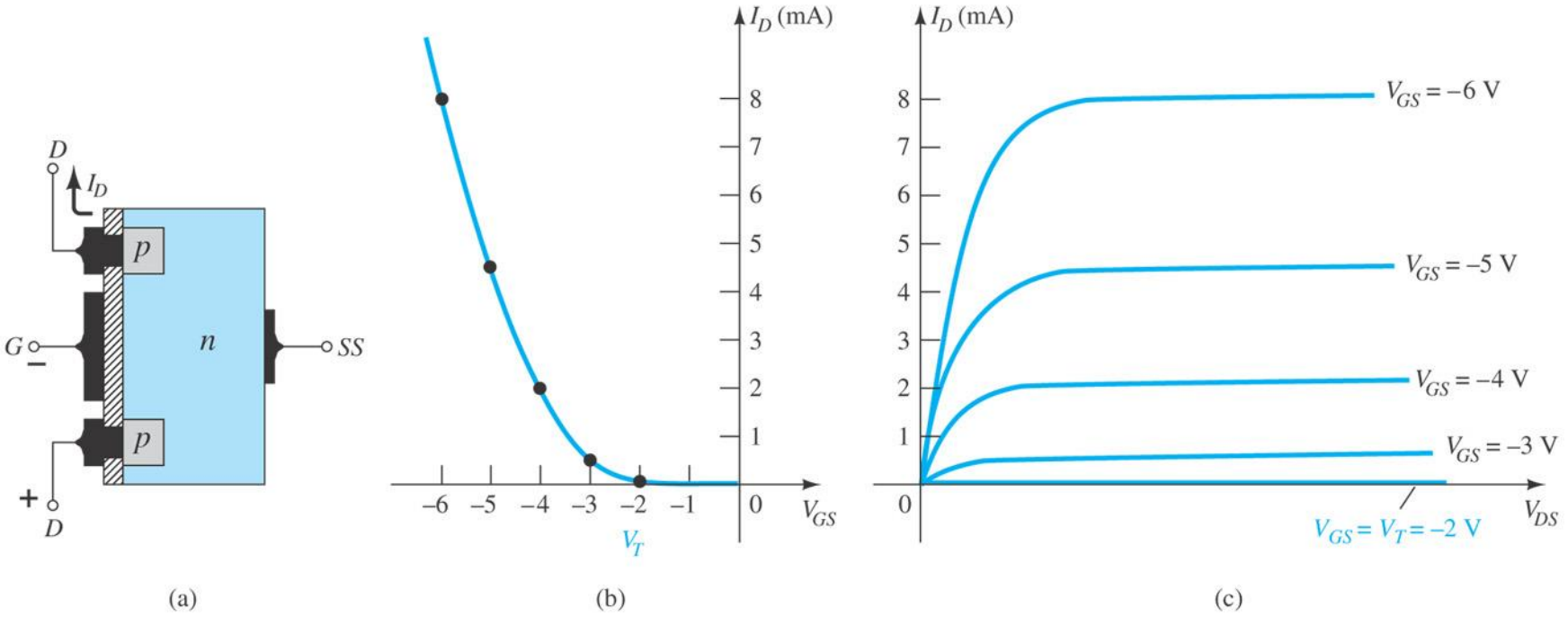
$$\mathbf{I_D = k(V_{GS} - V_T)^2}$$

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

Substituting $I_D(on)$ =10 mA when $V_{GS}(on)$=8V from the characteristics:

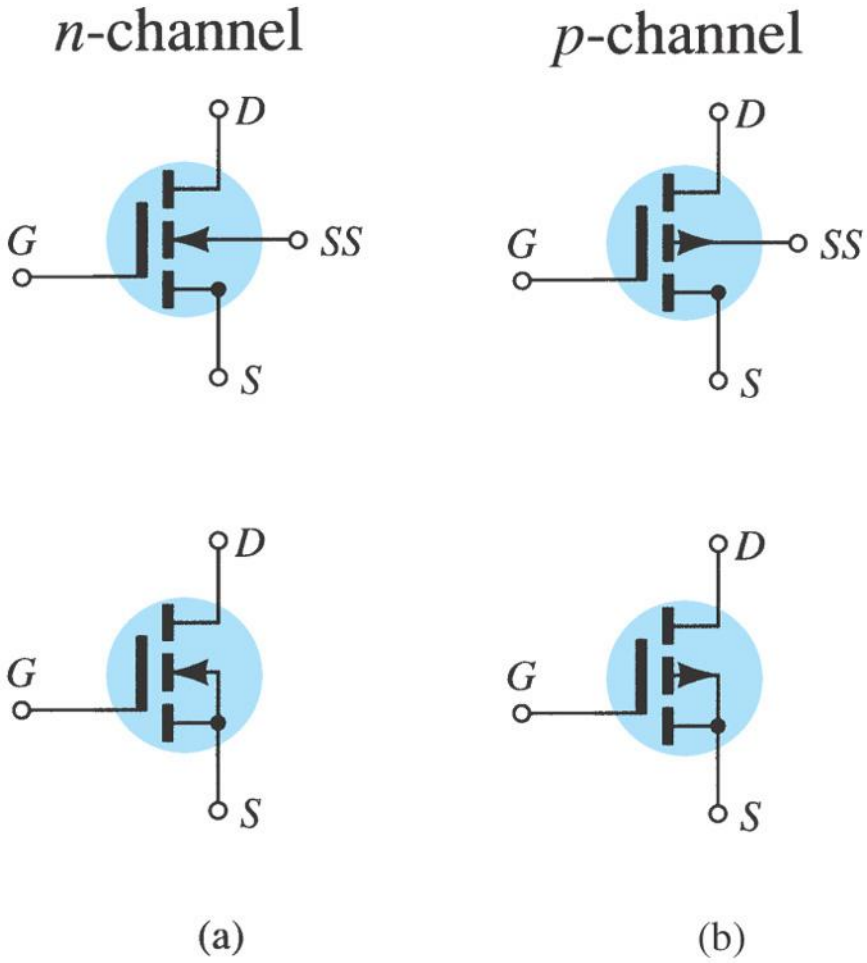
$$k = \frac{10\text{ mA}}{(8-2)^2} = 0.278\times10^{-3}\ \text{A/V}^2 \Rightarrow I_D = 0.278\times10^{-3}(V_{GS} - 2V)^2$$

p-Channel E-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 Symbols



Symbols for (a) *n*-channel enhancement-type MOSFETs and (b) *p*-channel enhancement-type MOSFETs.