

# Electronic Devices

## Final Term Lecture - 05

Reference book:

**Electronic Devices and Circuit Theory (Chapter-6)**

Robert L. Boylestad and L. Nashelsky , (11<sup>th</sup> Edition)



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# 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:

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

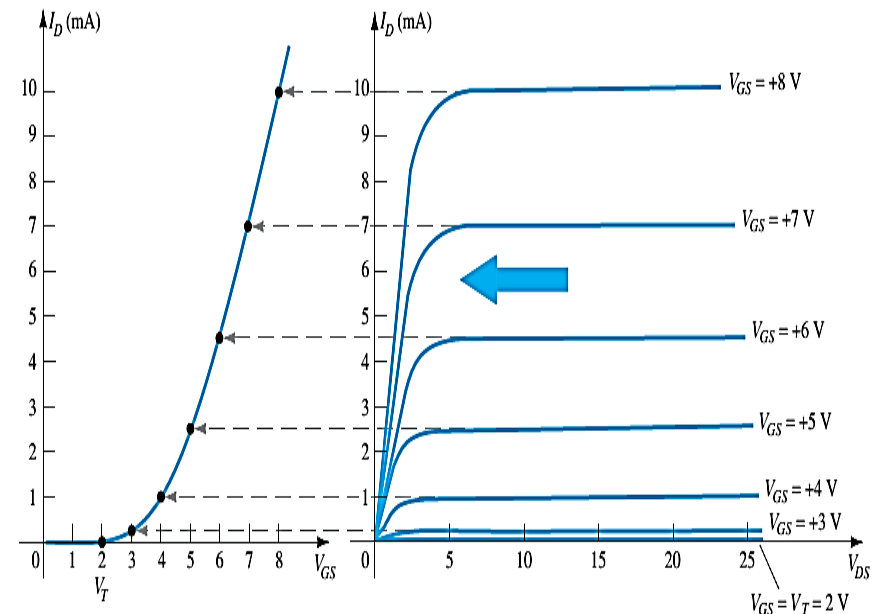
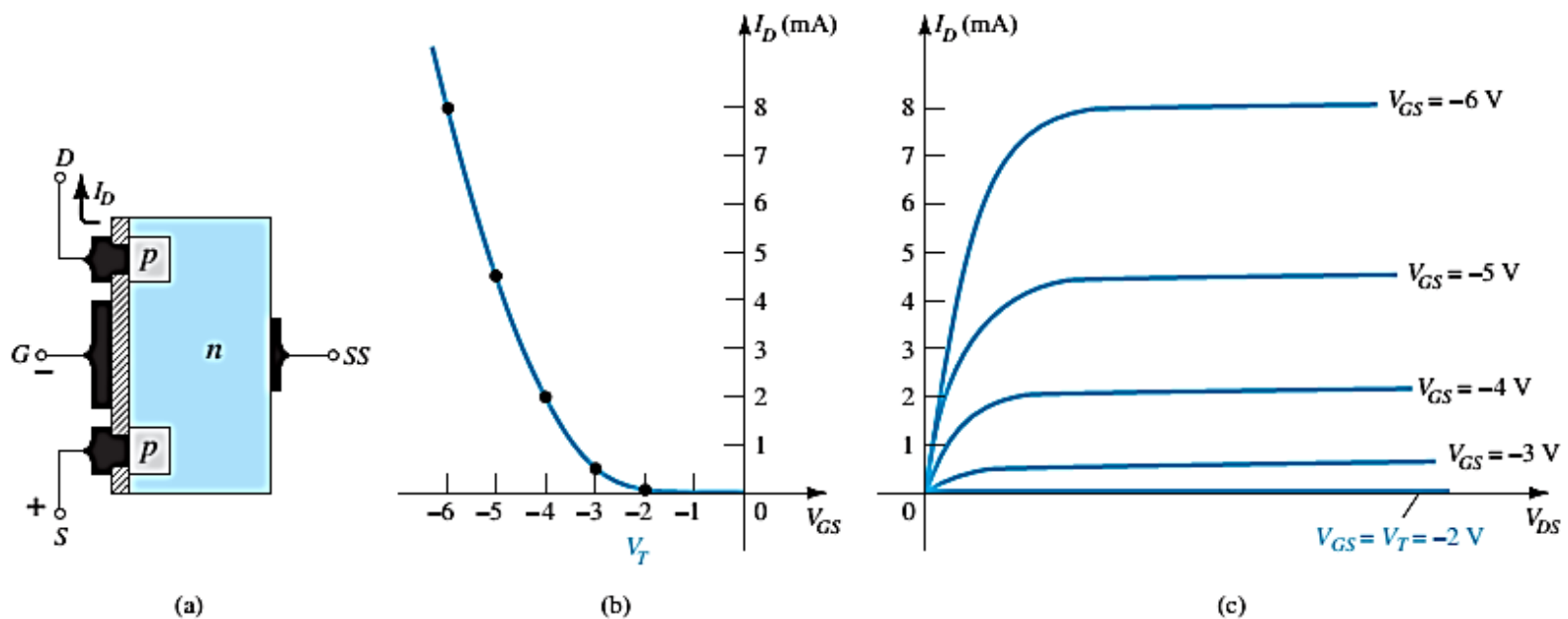


FIG. 6.36

Sketching the transfer characteristics for an n-channel enhancement-type MOSFET from the drain characteristics.

## P-CHANNEL ENHANCEMENT-TYPE MOSFETS

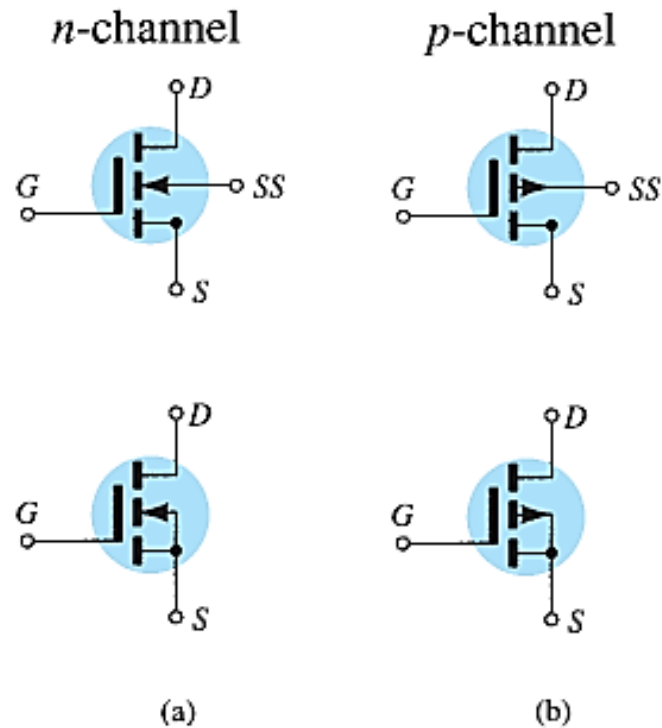
- The p-channel Enhancement-type MOSFET is similar to the n-channel except that the voltage polarities and current directions are reversed.



**FIG. 6.38**

*p*-Channel enhancement-type MOSFET with  $V_T = 2$  V and  $k = 0.5 \times 10^{-3}$  A/V<sup>2</sup>.

# SYMBOLS

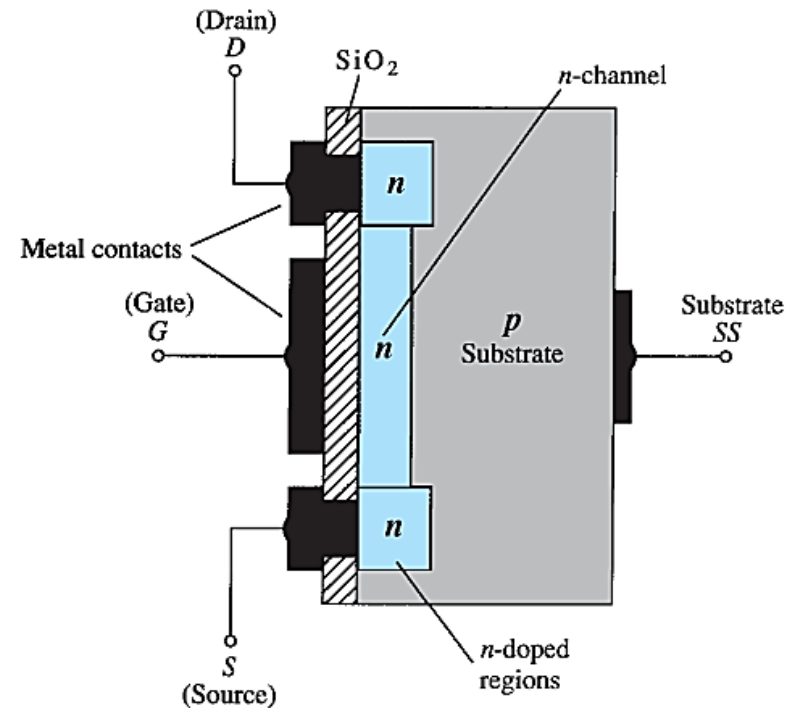


**FIG. 6.39**

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

# DEPLETION-TYPE MOSFET CONSTRUCTION

- The Drain (D) and Source (S) connect to the 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<sub>2</sub>.
- The n-doped material lies on a p-doped substrate that may have an additional terminal connection called SS.

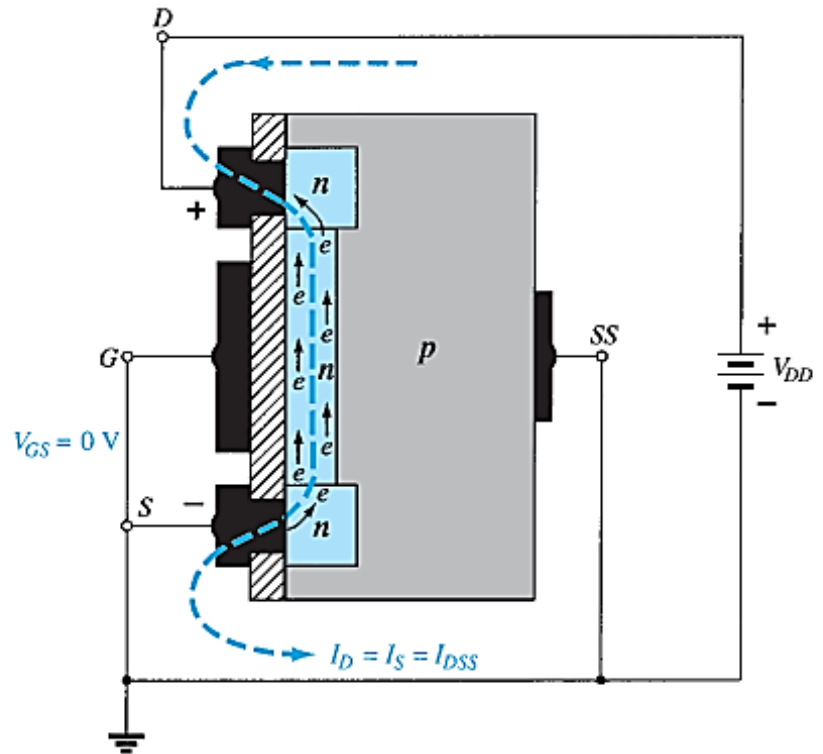


**FIG. 6.24**

*n-Channel depletion-type MOSFET.*

# BASIC OPERATION

- In Fig. 6.25 the gate-to-source voltage is set to 0 V by the direct connection from one terminal to the other, and a voltage  $V_{DD}$  is applied across the drain-to-source terminals.
- The result is an attraction of the free electrons of the n-channel for the positive voltage at the drain.
- The result is a current similar to that flowing in the channel of the JFET. In fact, the resulting current with  $V_{GS} = 0$  V continues to be labeled  $I_{DSS}$ .

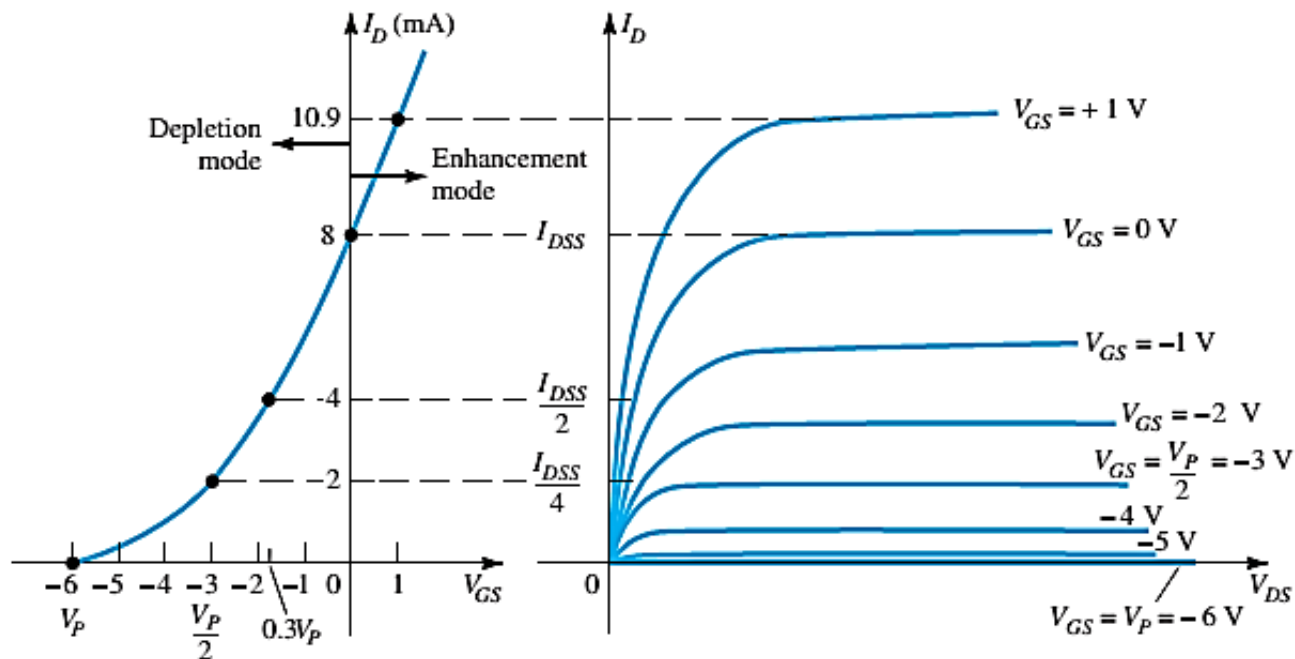


**FIG. 6.25**

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

# BASIC OPERATION

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

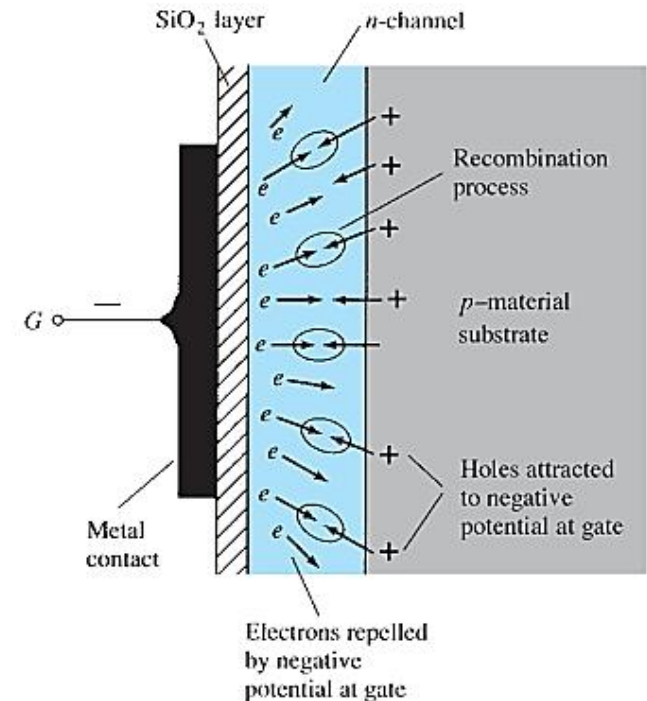


**FIG. 6.26**

*Drain and transfer characteristics for an n-channel depletion-type MOSFET.*

# BASIC OPERATION CONTD.

- In this figure  $V_{GS}$  has been set at a negative voltage such as 1 V. The negative potential at the gate will tend to pressure electrons toward the p-type substrate (like charges repel) and attract holes from the p-type substrate (opposite charges attract).
- Depending on the magnitude of the negative bias established by  $V_{GS}$ , a level of recombination between electrons and holes will occur that will reduce the number of free electrons in the n-channel available for conduction. The more negative the bias, the higher the rate of recombination.
- The resulting level of drain current is therefore reduced with increasing negative bias for  $V_{GS}$  for  $V_{GS} = 1$  V, 2 V, and so on, to the pinch-off level of 6 V. The resulting levels of drain current and the plotting of the transfer curve proceeds exactly as described for the JFET.



**FIG. 6.27**

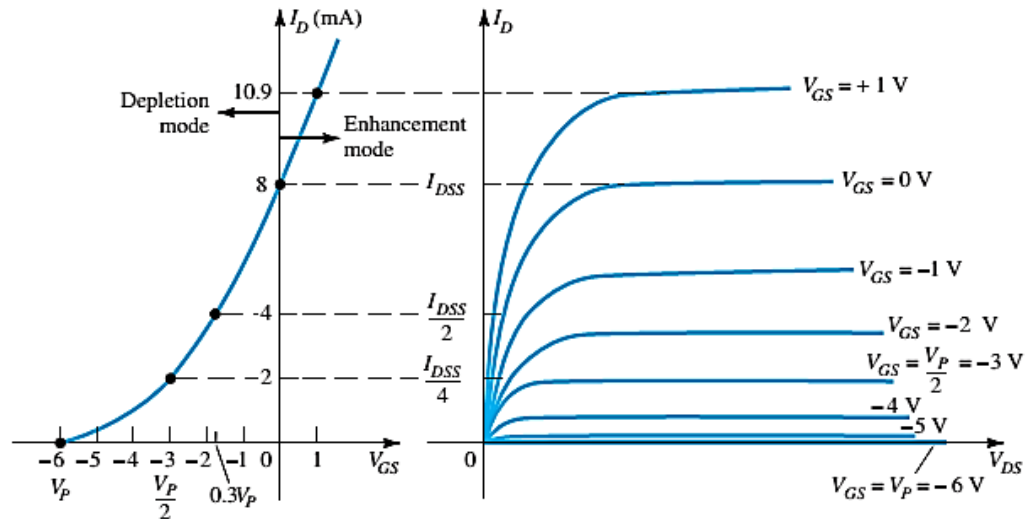
*Reduction in free carriers in a channel due to a negative potential at the gate terminal.*



# 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:

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



**FIG. 6.26**

*Drain and transfer characteristics for an n-channel depletion-type MOSFET.*

# ENHANCEMENT MODE

- For positive values of  $V_{GS}$ , the positive gate will draw additional electrons (free carriers) from the p-type substrate due to the reverse leakage current and establish new carriers through the collisions resulting between accelerating particles.
- As the gate-to-source voltage continues to increase in the positive direction, the drain current will increase at a rapid rate.
- The application of a positive gate-to-source voltage has “enhanced” the level of free carriers in the channel compared to that encountered with  $V_{GS} = 0$  V. For this reason the region of positive gate voltages on the drain or transfer characteristics is often referred to as the enhancement region,
- The region between cutoff and the saturation level of  $I_{DSS}$  referred to as the depletion region.



# 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:  
(note that  $V_{GS}$  is now a positive polarity)

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

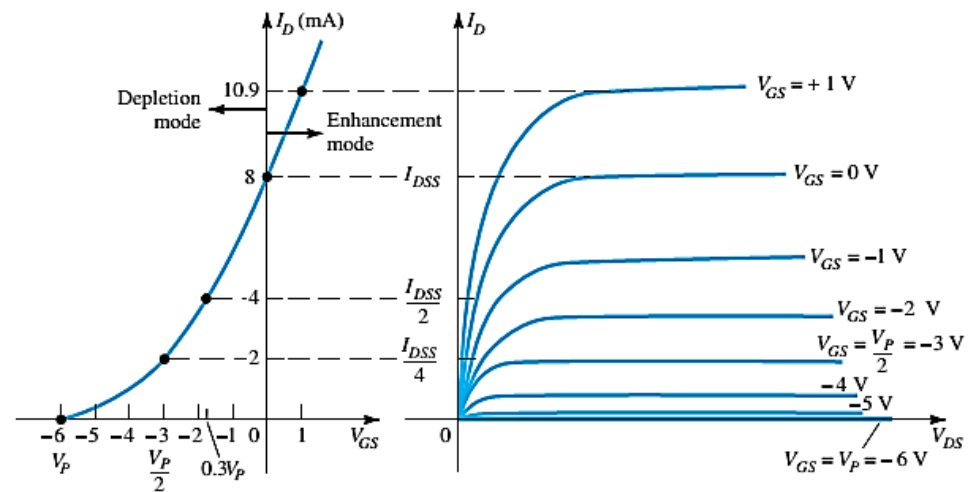
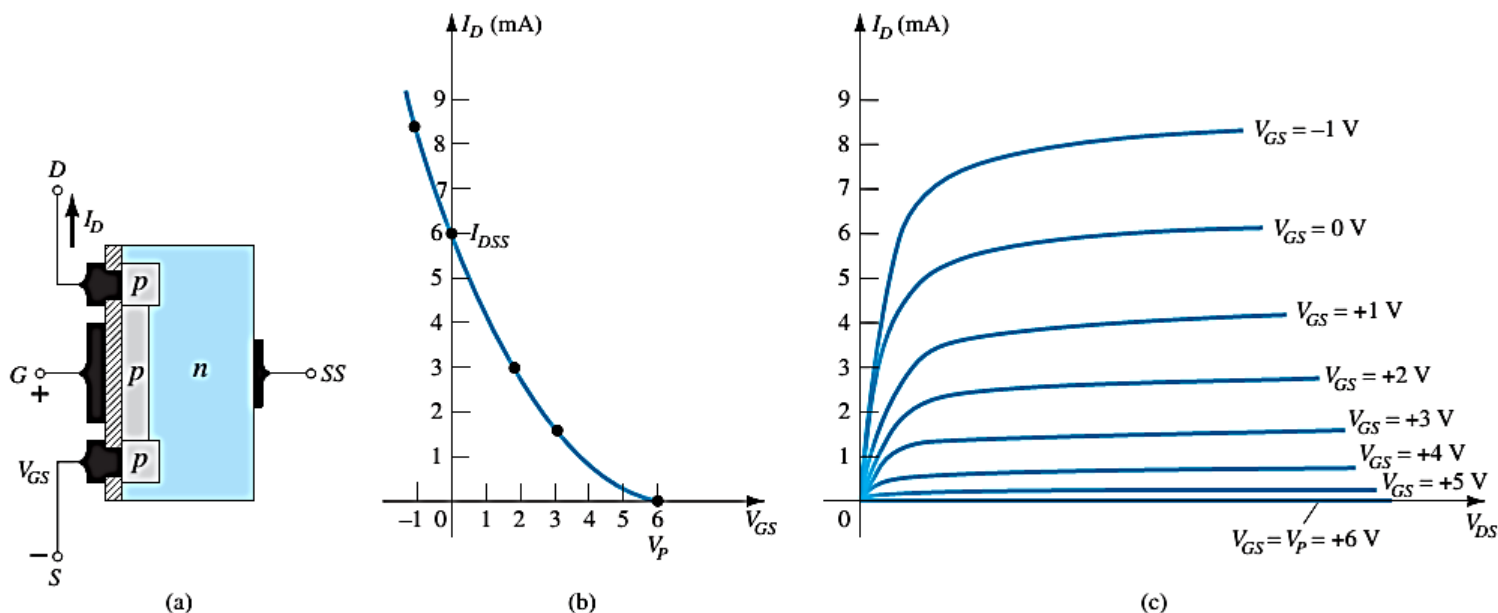


FIG. 6.26

Drain and transfer characteristics for an n-channel depletion-type MOSFET.

# P-CHANNEL DEPLETION-TYPE MOSFET

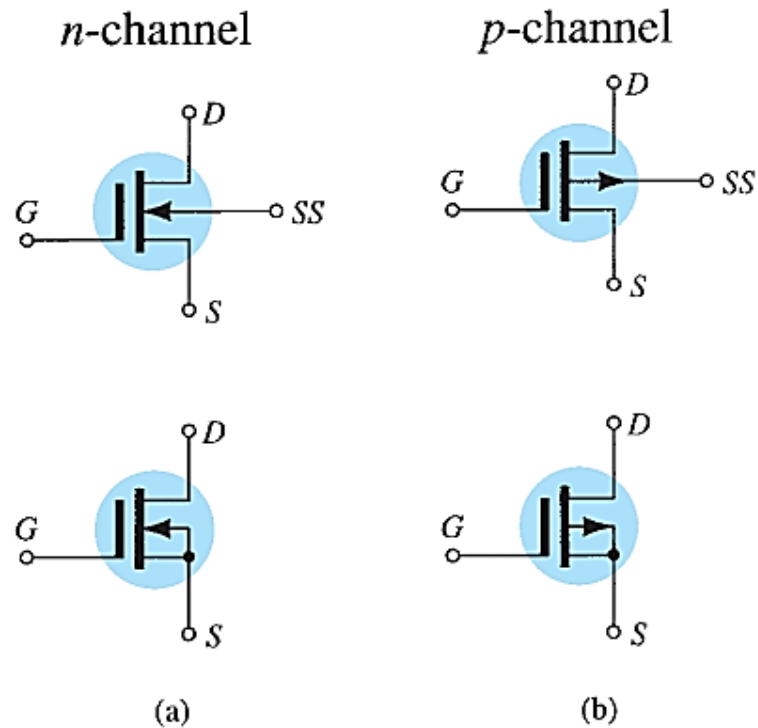
- The p-channel Depletion-type MOSFET is similar to the n-channel except that the voltage polarities and current directions are reversed.



**FIG. 6.29**

*p*-Channel depletion-type MOSFET with  $I_{DSS} = 6$  mA and  $V_P = +6$  V.

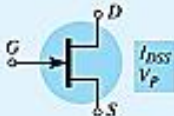
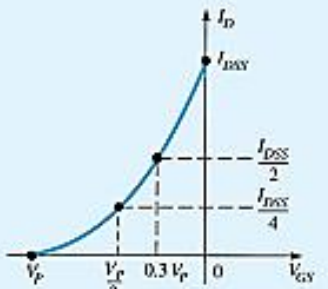
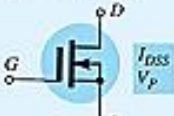
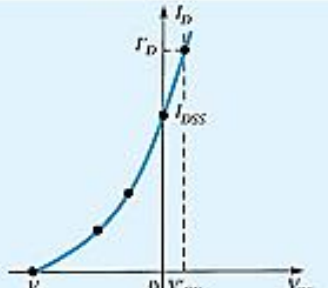
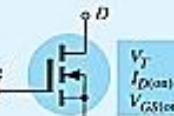
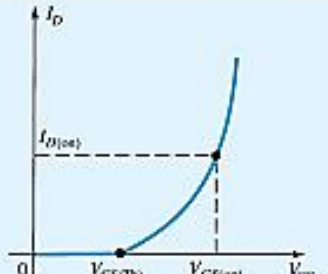
# SYMBOLS



**FIG. 6.30**

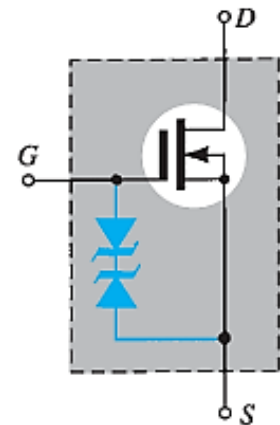
*Graphic symbols for: (a) n-channel depletion-type MOSFETs and (b) p-channel depletion-type MOSFETs.*

# SUMMARY TABLE

<p><b>JFET</b> (n-channel)</p>	<p><math>I_G = 0 \text{ A}, I_D = I_S</math></p>  <p><math>I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_P}\right)^2</math></p>	
<p><b>MOSFET</b> depletion type (n-channel)</p>	<p><math>I_G = 0 \text{ A}, I_D = I_S</math></p>  <p><math>I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_P}\right)^2</math></p>	
<p><b>MOSFET</b> enhancement type (n-channel)</p>	<p><math>I_G = 0 \text{ A}, I_D = I_S</math></p>  <p><math>I_D = k (V_{GS} - V_{GS(Th)})^2</math> <math>k = \frac{I_{D(on)}}{(V_{GS(on)} - V_{GS(Th)})^2}</math></p>	

# MOSFET HANDLING

- MOSFETs are **very static sensitive**. Because of the very thin SiO<sub>2</sub> layer between the external terminals and the layers of the device, any small electrical discharge can establish 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.

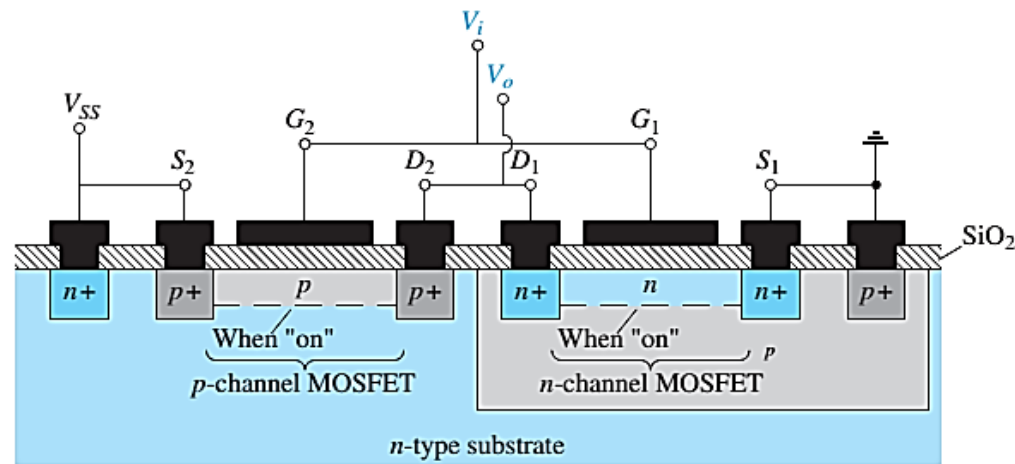


**FIG. 6.42**

*Zener-protected MOSFET.*

# 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
- Application:
  - CMOS Inverter



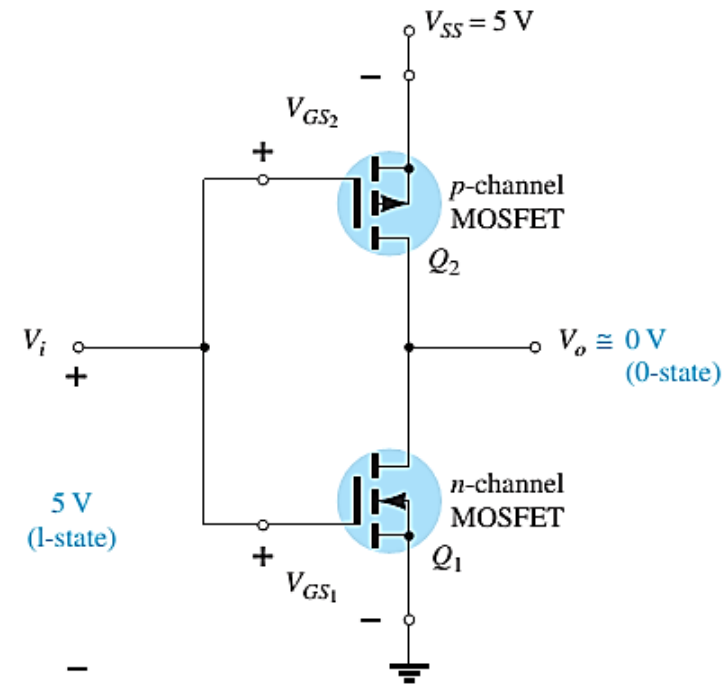
**FIG. 6.44**

*CMOS with the connections indicated in Fig. 6.45.*



# CMOS INVERTER

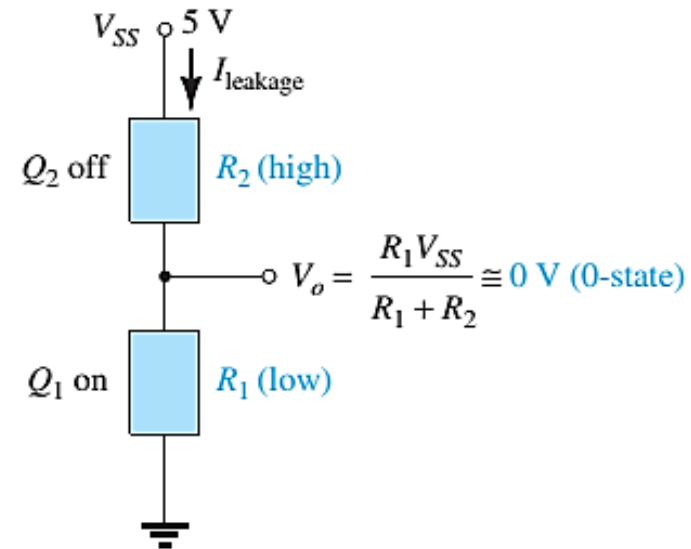
- An inverter is a logic element that “inverts” the applied signal. That is, if the logic levels of operation are 0V (0-state) and 5V (1-state), an input level of 0V will result in an output level of 5V, and vice versa.
- Here, **both gates are connected to the applied signal** and **both drain to the output  $V_o$** . The **source of the p-channel MOSFET ( $Q_2$ ) is connected** directly to the **applied voltage  $V_{SS}$** , while the **source of the n-channel MOSFET ( $Q_1$ ) is connected to ground**.
- Here, the application of 5V at the input should result in approximately 0 V at the output. **With 5V at  $V_i$**  (with respect to ground),  $V_{GS1} = V_i$  and  $Q_1$  is “on,” resulting in a relatively **low resistance between drain and source**.
- Since  $V_i$  and  $V_{SS}$  are at 5 V,  $V_{GS2} = 0$  V, which is **less than the required  $V_T$**  for the device, resulting in an “off” state. The resulting resistance level between drain and source is **quite high for  $Q_2$** .



**FIG. 6.45**  
CMOS inverter.

# CMOS INVERTER

- A simple application of the voltage-divider rule will reveal that  $V_o$  is very close to 0 V or the 0-state, establishing the desired inversion process.
- For an applied voltage  $V_i$  of 0V (0-state),  $V_{GS1} = 0V$  and  $Q_1$  will be off with  $V_{SS2} = -5V$ , turning on the p-channel MOSFET. The result is that  $Q_2$  will present a small resistance level,  $Q_1$  a high resistance, and  $V_o = V_{SS} = 5V$  (the 1-state).



**FIG. 6.46**

Relative resistance levels for  $V_i = 5V$  (1-state).

# End of Lecture-5

