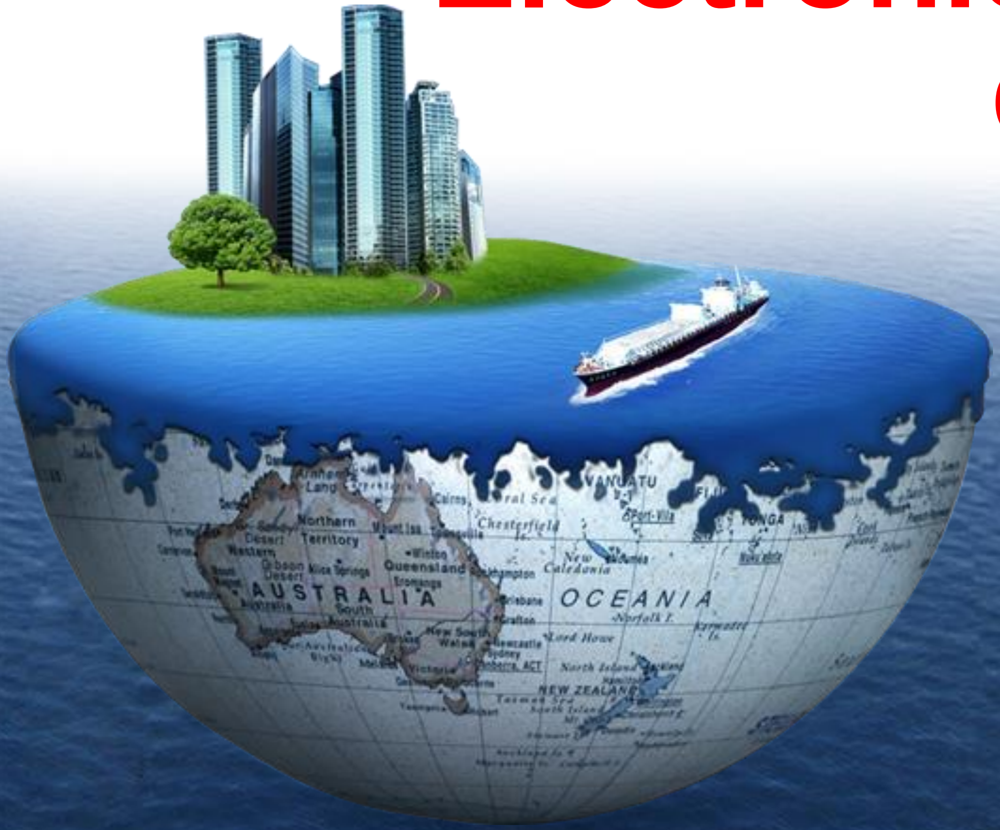
Electronic Engineering
COM 121

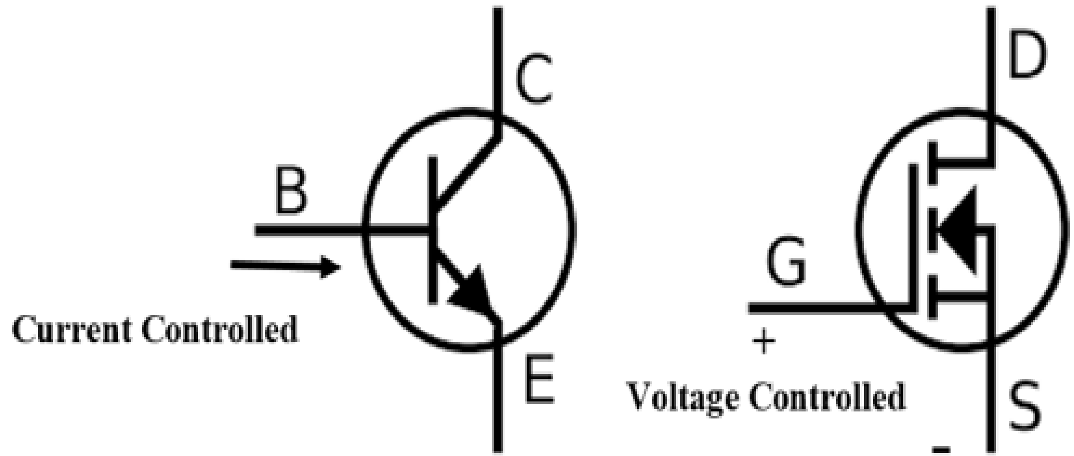


**Assist. Prof.
Basma M. Yousef**

Introduction

Main differences between the FET and BJT:

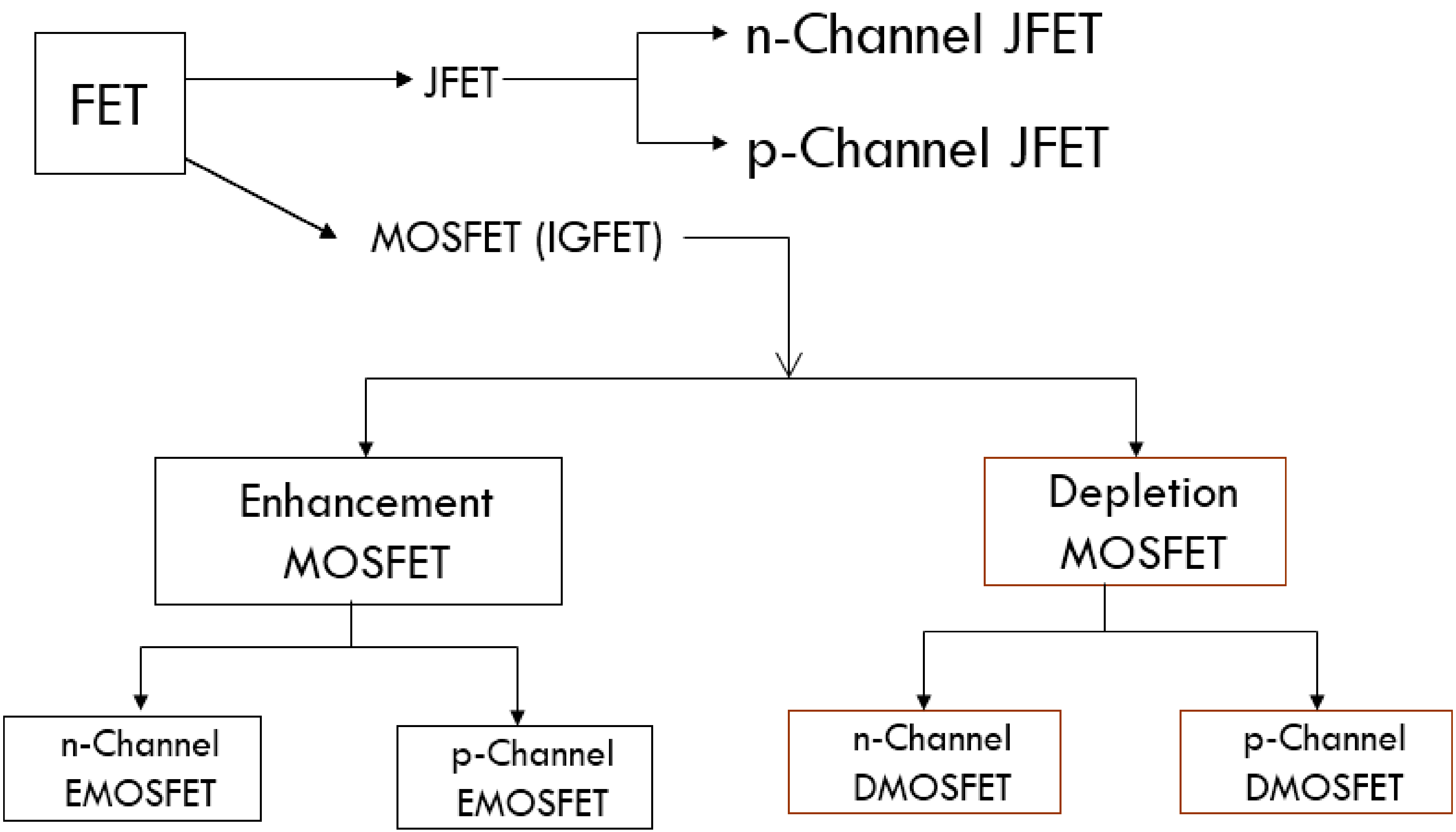
- ➢ The BJT transistor is a current-controlled device, while the FET transistor is a voltage-controlled device.
- ✓ The current I_C in Figure is a direct function of the level of I_B.
- ✓ For the FET the current I_D will be a function of the voltage V_{GS} applied to the input circuit.



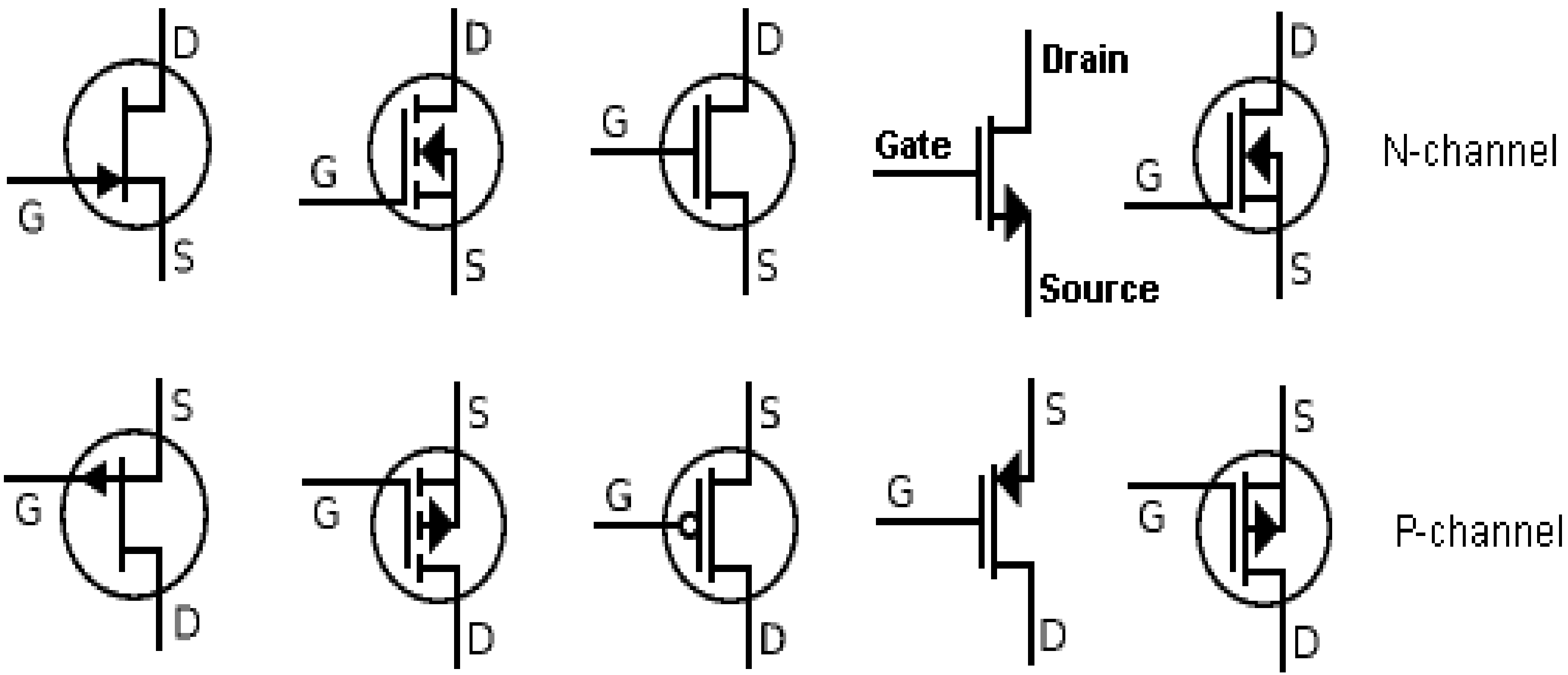
Introduction

- The BJT transistor is a bipolar device, the prefix (bi) revealing that the conduction level is a function of two charge carriers, electrons and holes.
- The FET is a unipolar device depending solely on either electron (n-channel) or hole (p-channel) conduction.
- There are two types of FETs transistors.
- The types are JFET and MOSFET.
- .MOSFET type can be broken down into depletion MOSFET and Enhancement MOSFET.

Introduction



Graphic symbols for the N channel and P-channel FETs



JFET

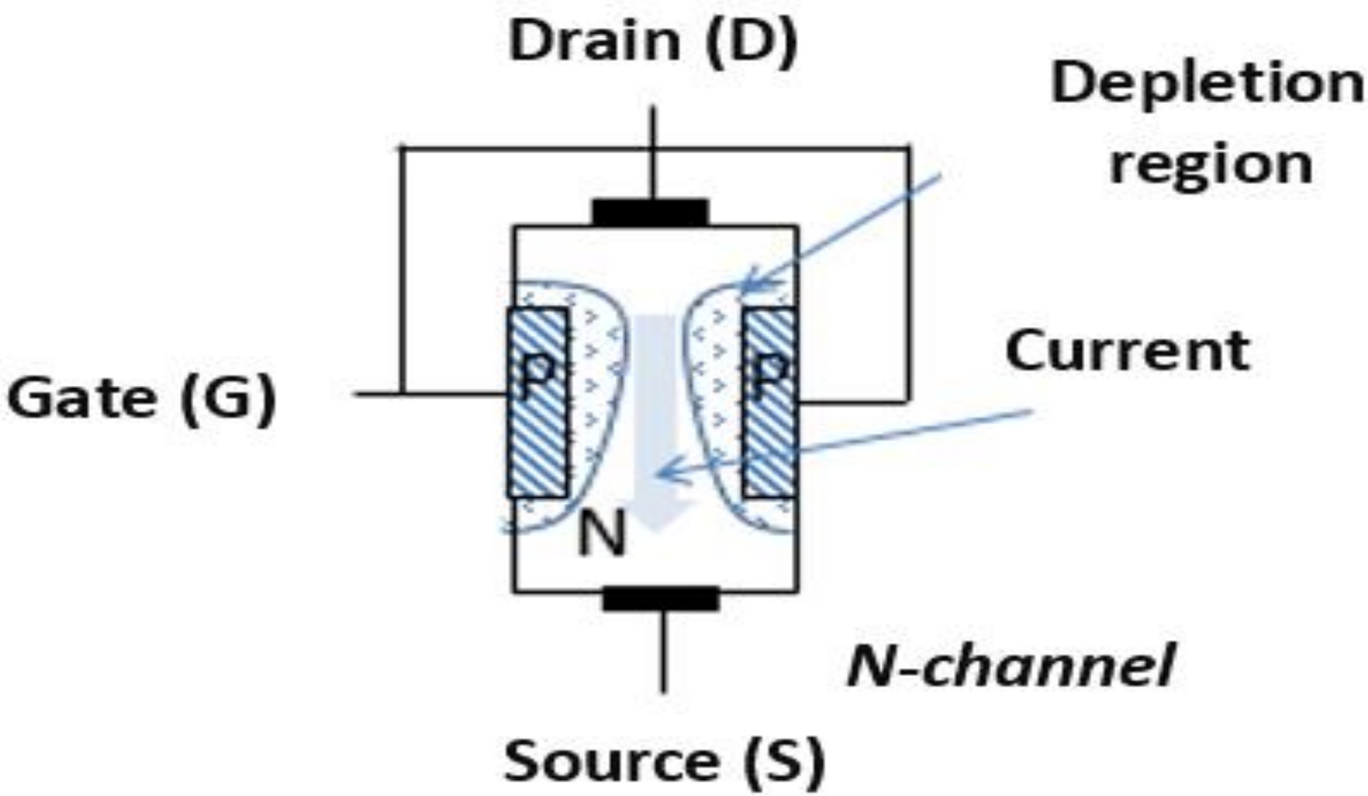
MOSFET enhancement mode

MOSFET enhanced without bulk (body terminal) shown

MOSFET depletion mode

JFET Type

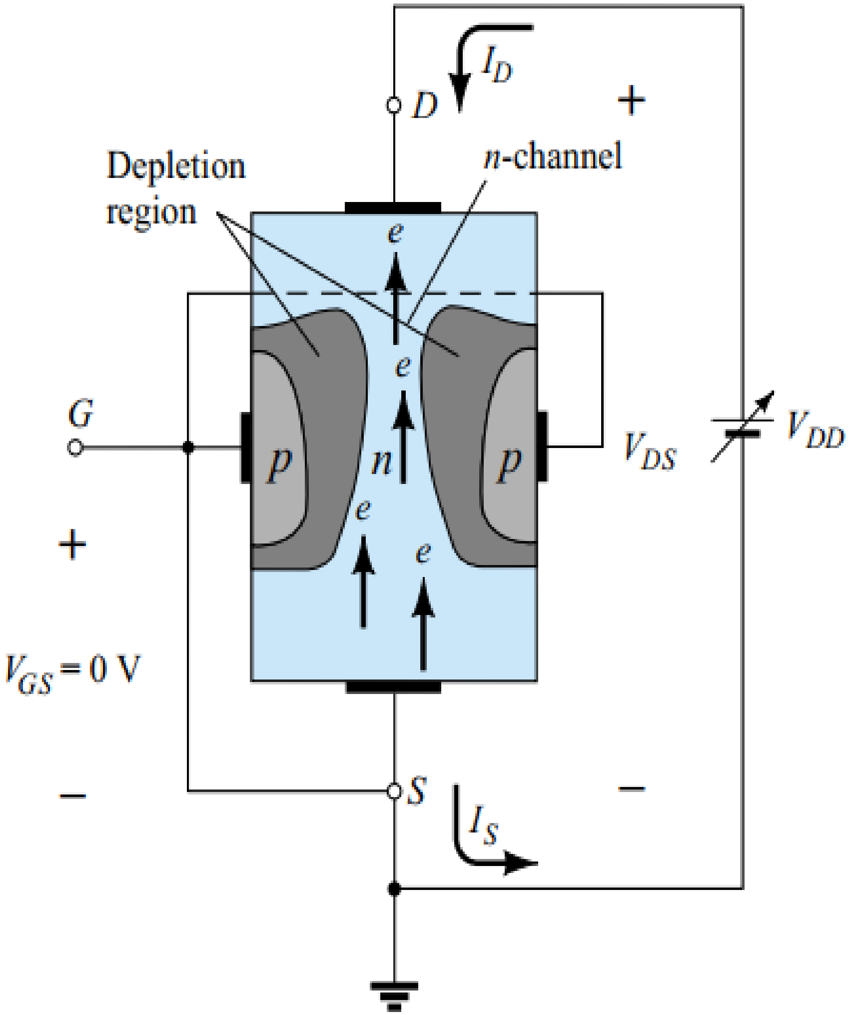
- The basic construction of the n-channel JFET is shown in Figure.
- Note that the major part of the structure is the n-type material that forms the channel between the embedded layers of p-type material.



Operation mechanism of JFET

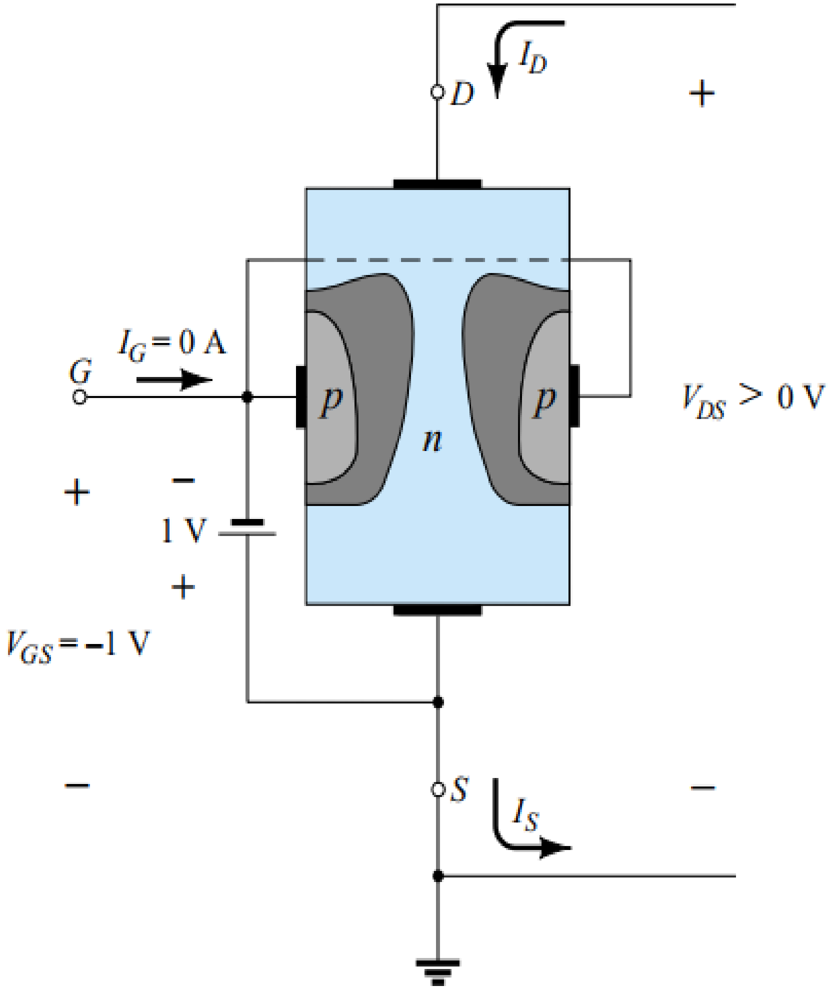
- **Case 1:** $V_{GS} = 0V$**, and** $V_{DS} > 0V$

- The result is a gate and source terminal at the same potential and a depletion region in the low end of each p-material similar to the distribution of the no-bias condition.
- The instant the voltage $V_{DD} = V_{DS}$ is applied, the electrons will be drawn to the drain terminal current I_D with the defined direction .

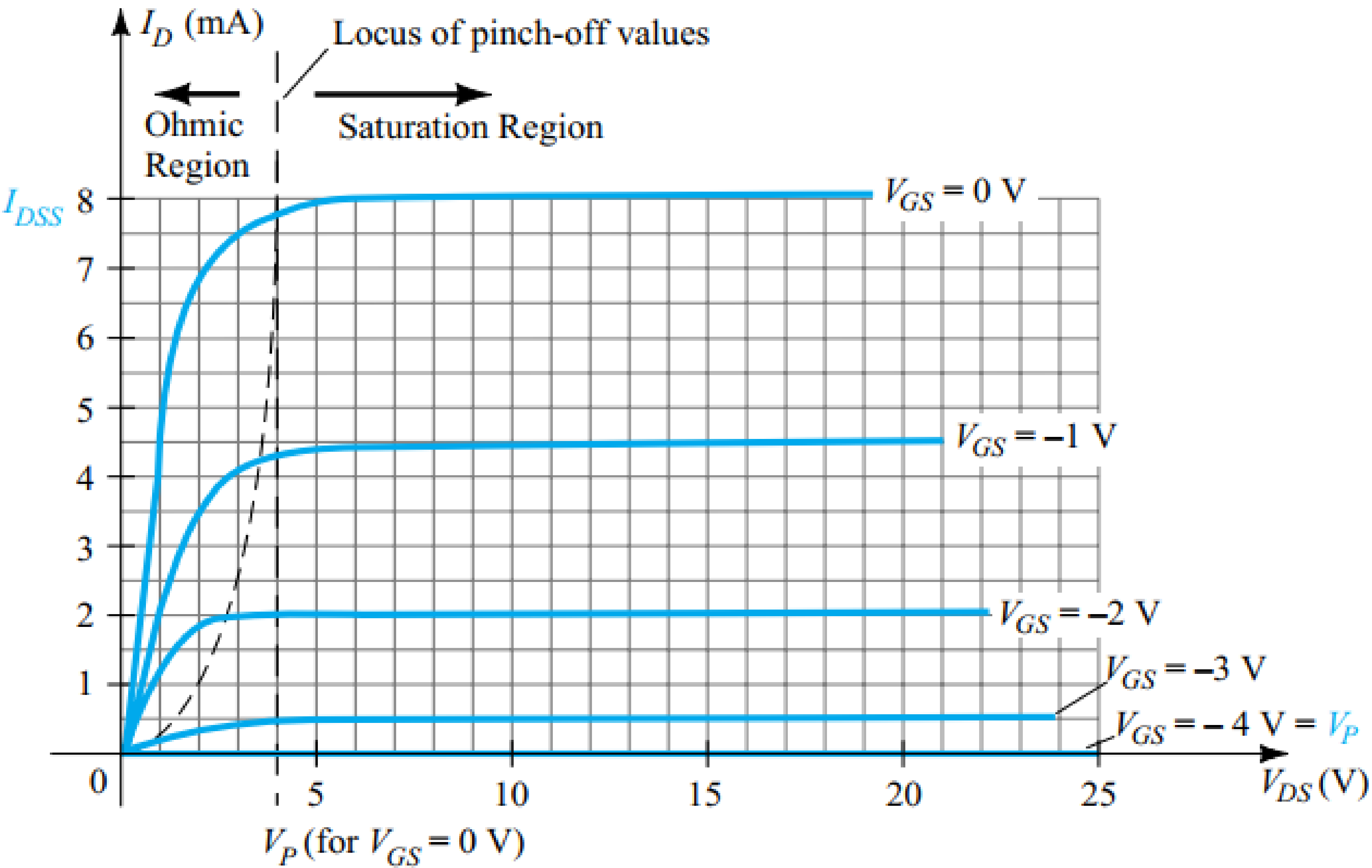


Operation mechanism of JFET

- I_{DSS} ***is the maximum drain current for a JFET and is defined by the conditions*** $V_{GS} = 0\,V$ ***and*** $V_{DS} > |VP|$.
- **Case 2:** $V_{GS} < 0V$:
- The gate terminal will be set at lower and lower potential levels as compared to the source.
- The resulting saturation level for $I_{D\_}$ has been reduced.
- when $V_{GS} = -V_p$,the current saturation level reaches $0\ mA$, and the device has been "turned off".



Characteristics Curve for N-Channel JFET

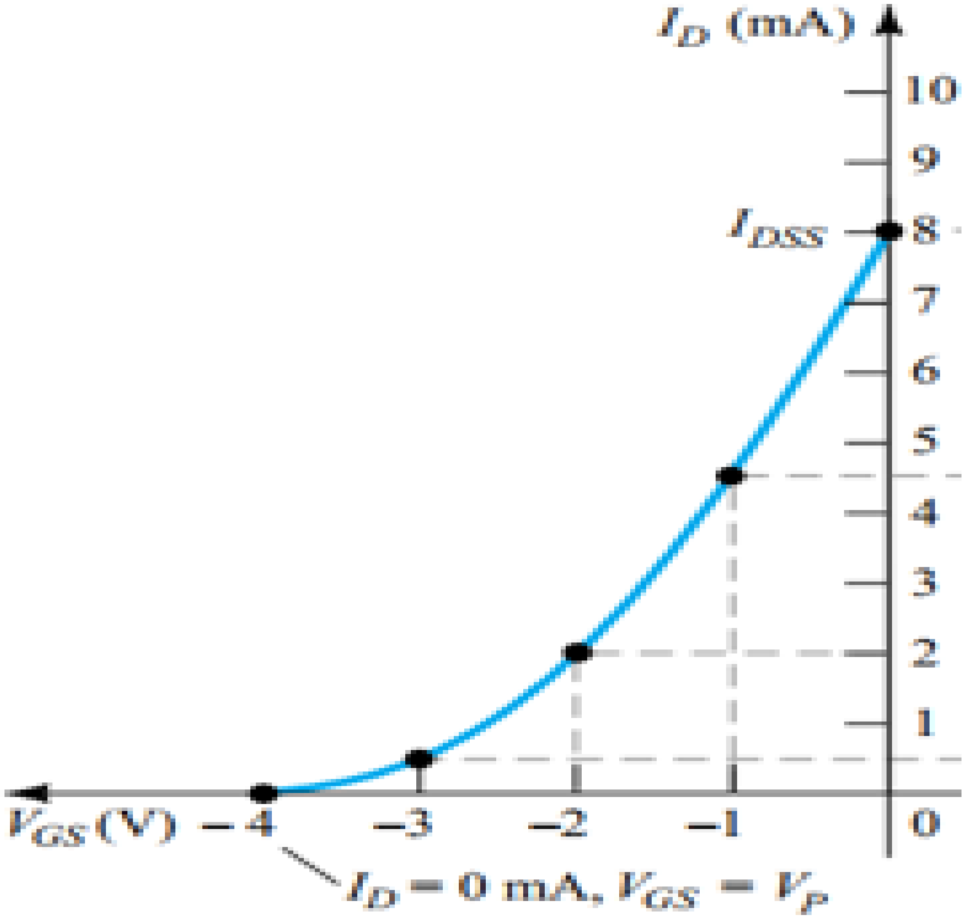


Transfer Curve for N-Channel JFET

- **The relationship between I_D and V_{GS} is defined by *Shockley's equation:***

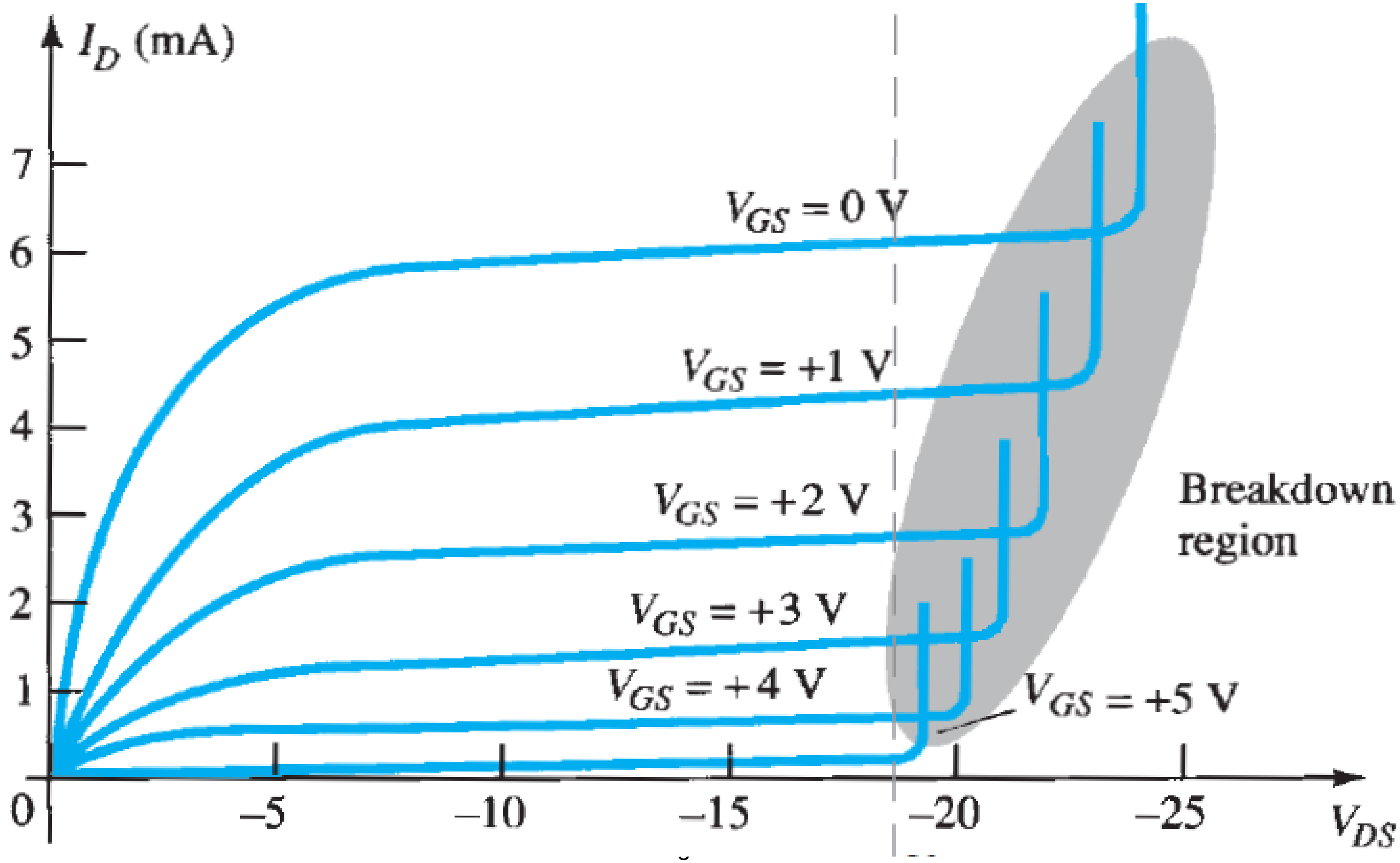
➢ $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

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



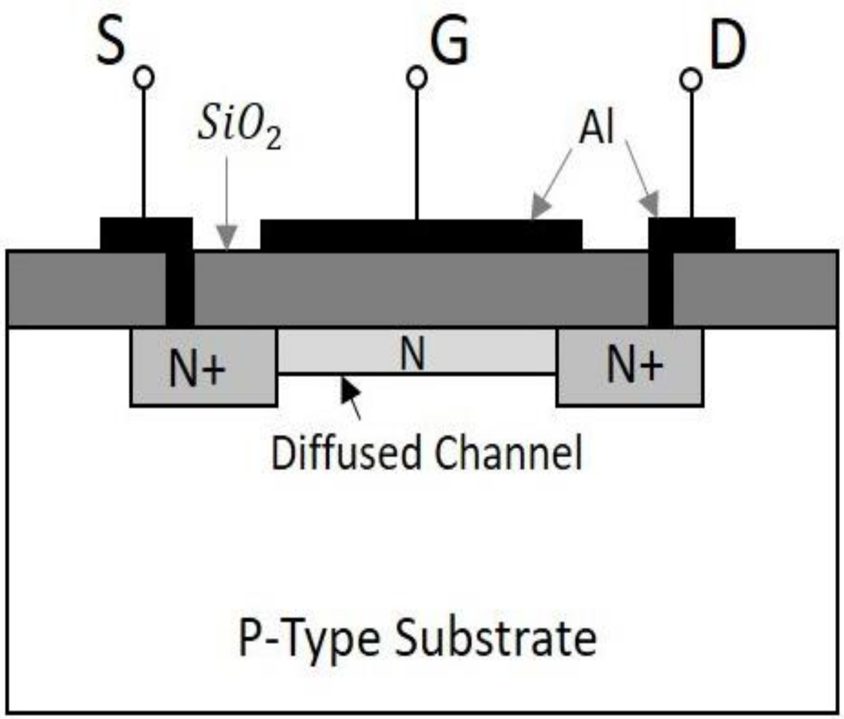
Principal of Operation: P-Channel JFET

- The VGS is positive for P-Channel JFET.
- The below figure the characteristic curve of P-Channel JFET.



Depletion-Type MOSFET.

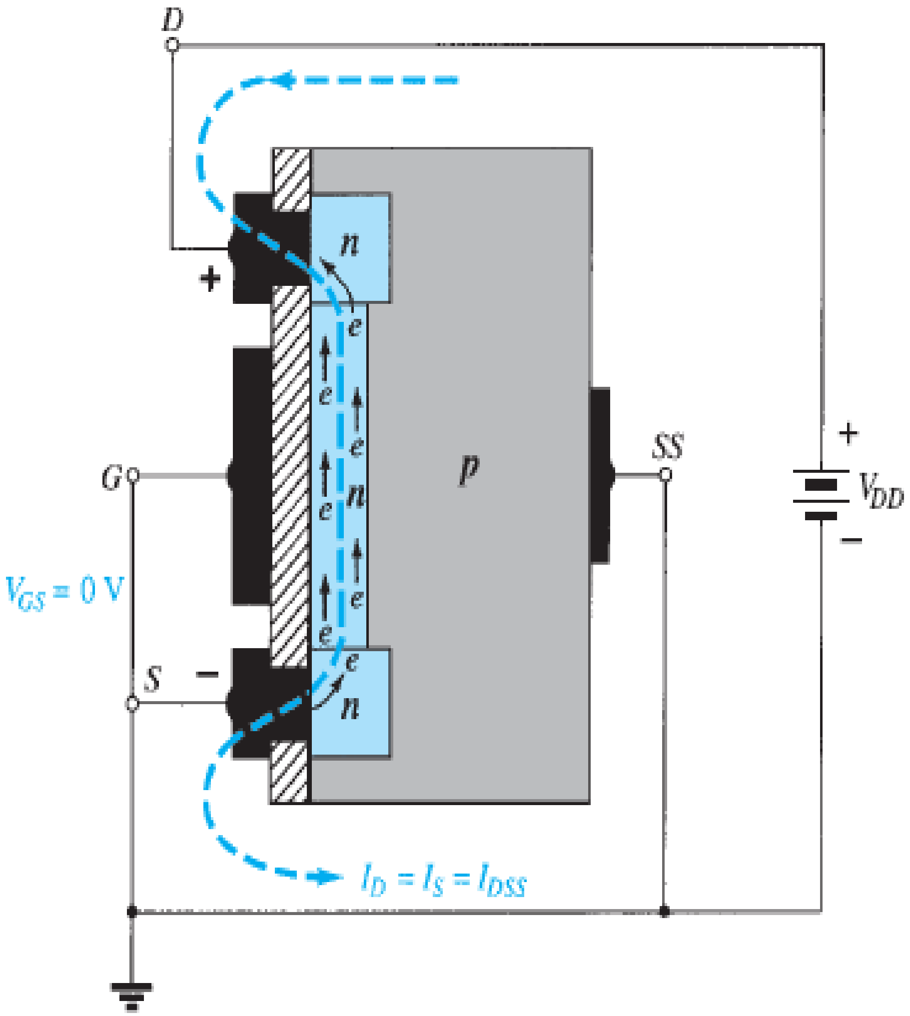
- The gate current (I_G) is essentially zero amperes for dc-biased configurations.
- The drain and source are connected by a narrow channel adjacent to the insulated gate.
- D-MOSFET can be operated in either of two modes the depletion mode or enhancement mode and is sometimes called a depletion/enhancement MOSFET.



Structure of N-channel MOSFET

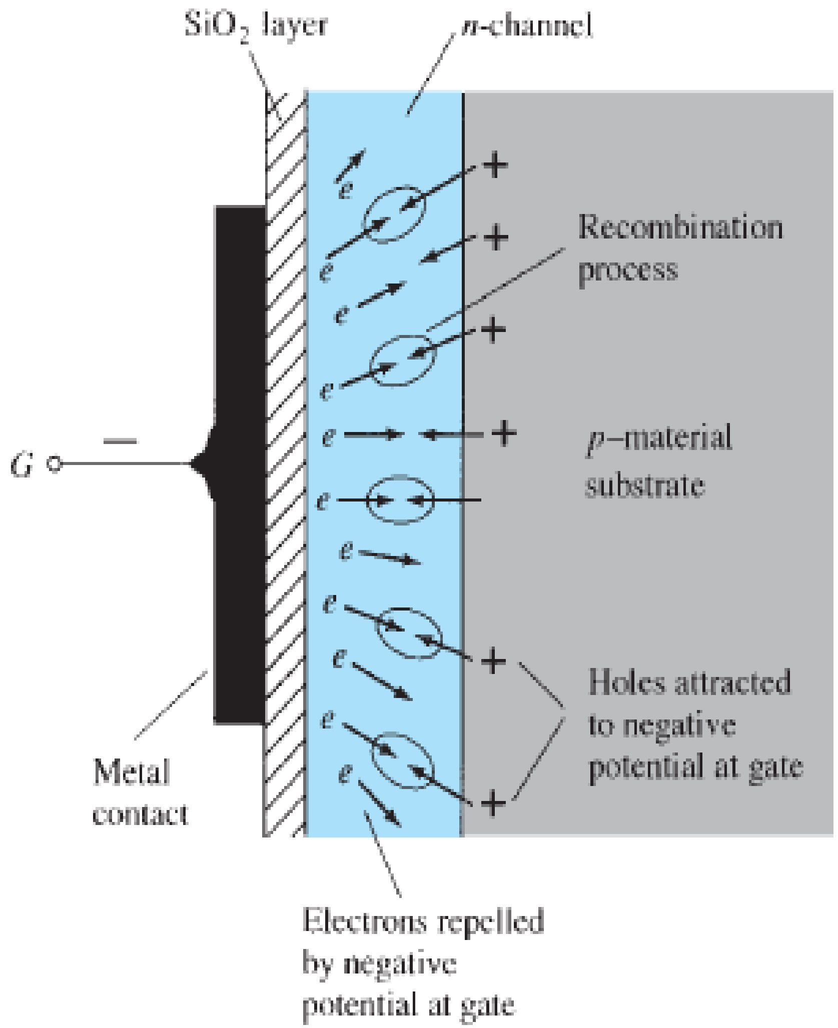
Operation of D-MOSFET

- The gate-to-source voltage is set to zero volts by the direct connection from one terminal to the other.
- The voltage V_{DS} is applied across the drain-to-source terminals.
- So an attraction for the positive potential at the drain by the free electrons of the n-channel and a current similar to that established through the channel of the JFET.

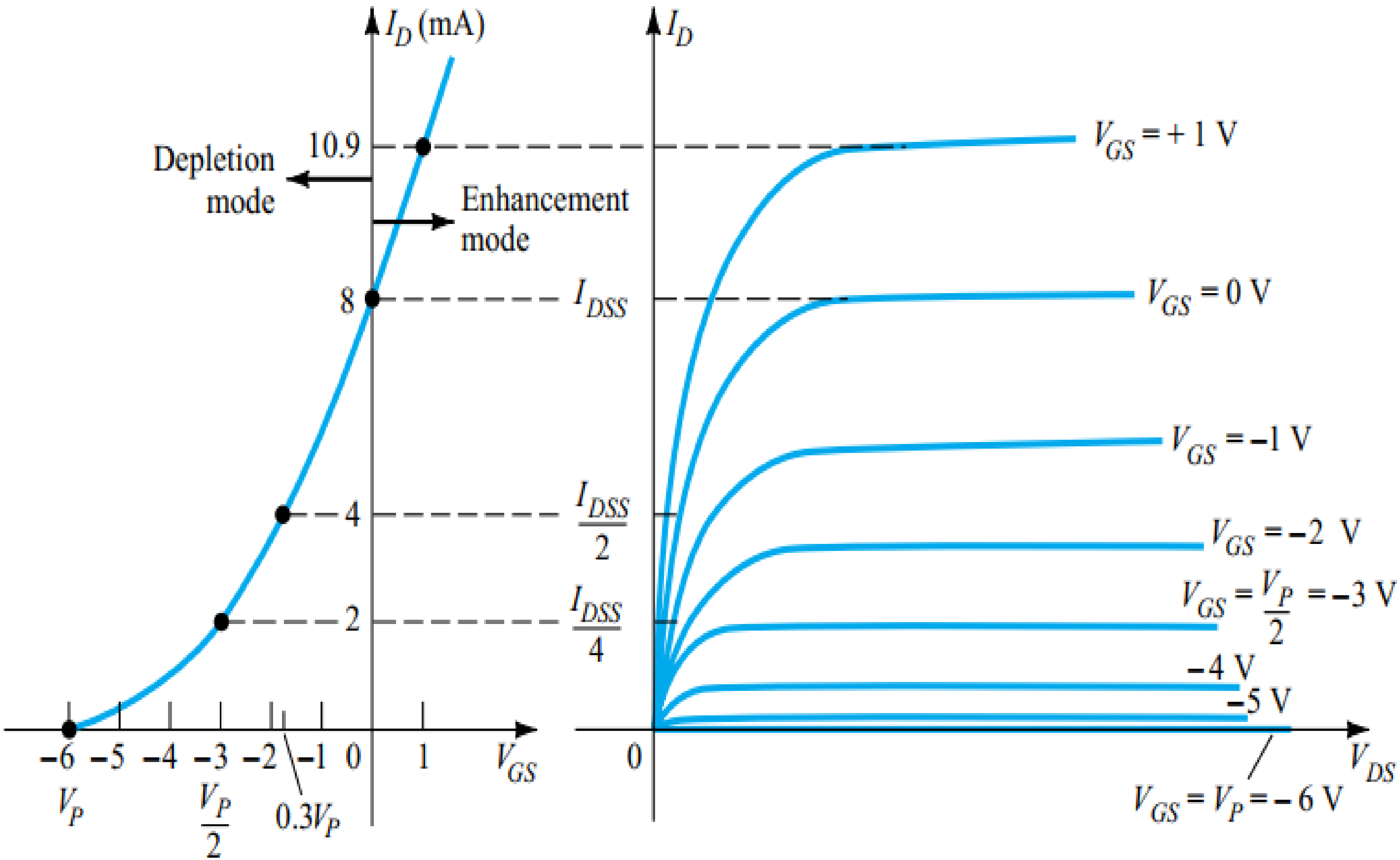


Operation Mechanism of D-MOSFET

- The negative potential at the gate will tend to pressure electrons toward the p-type substrate.
- 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.



Characteristics Curve for N-Channel D-MOSFET



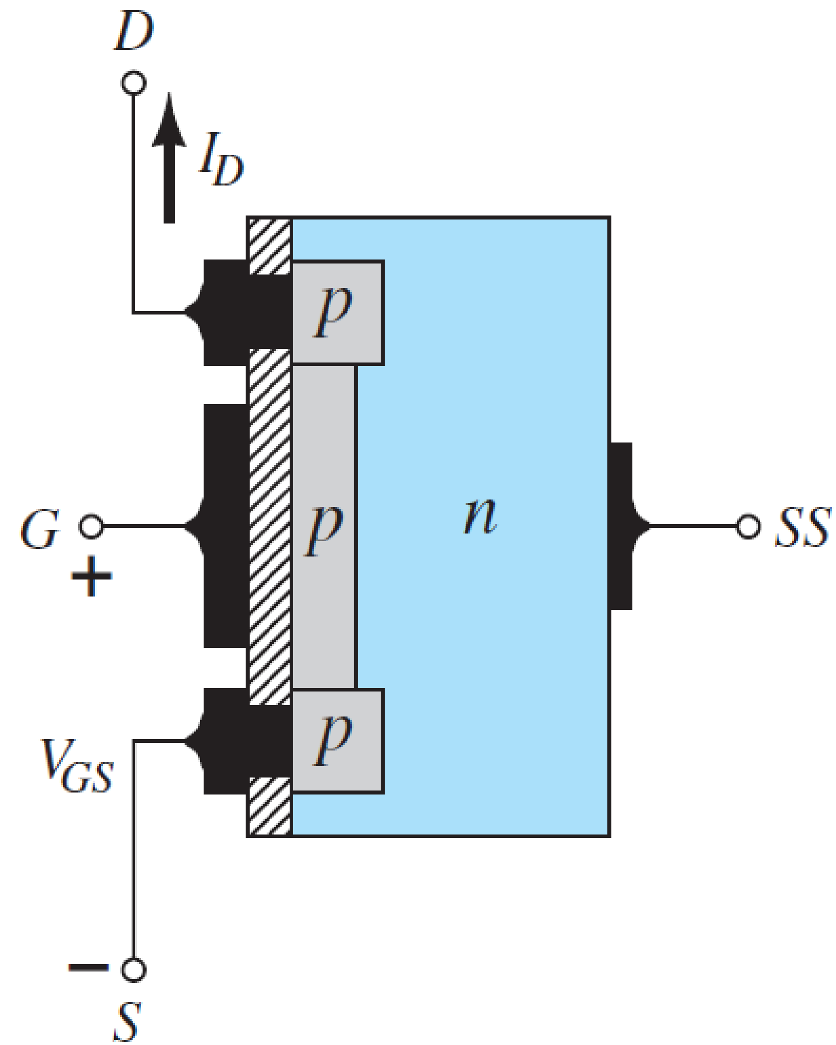
Operation of D-MOSFET

- 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 so the drain current will increase at a rapid rate for these reasons.
- The application of a positive gate-to-source voltage has "enhanced" the level of free carriers in the channel compared to that encountered with $V_{GS} = 0\,V$.
- The n-channel MOSFET operates in the depletion mode when a negative *GS* voltage is applied and in the enhancement mode when a positive *GS* voltage is applied.
- ***The drain current***

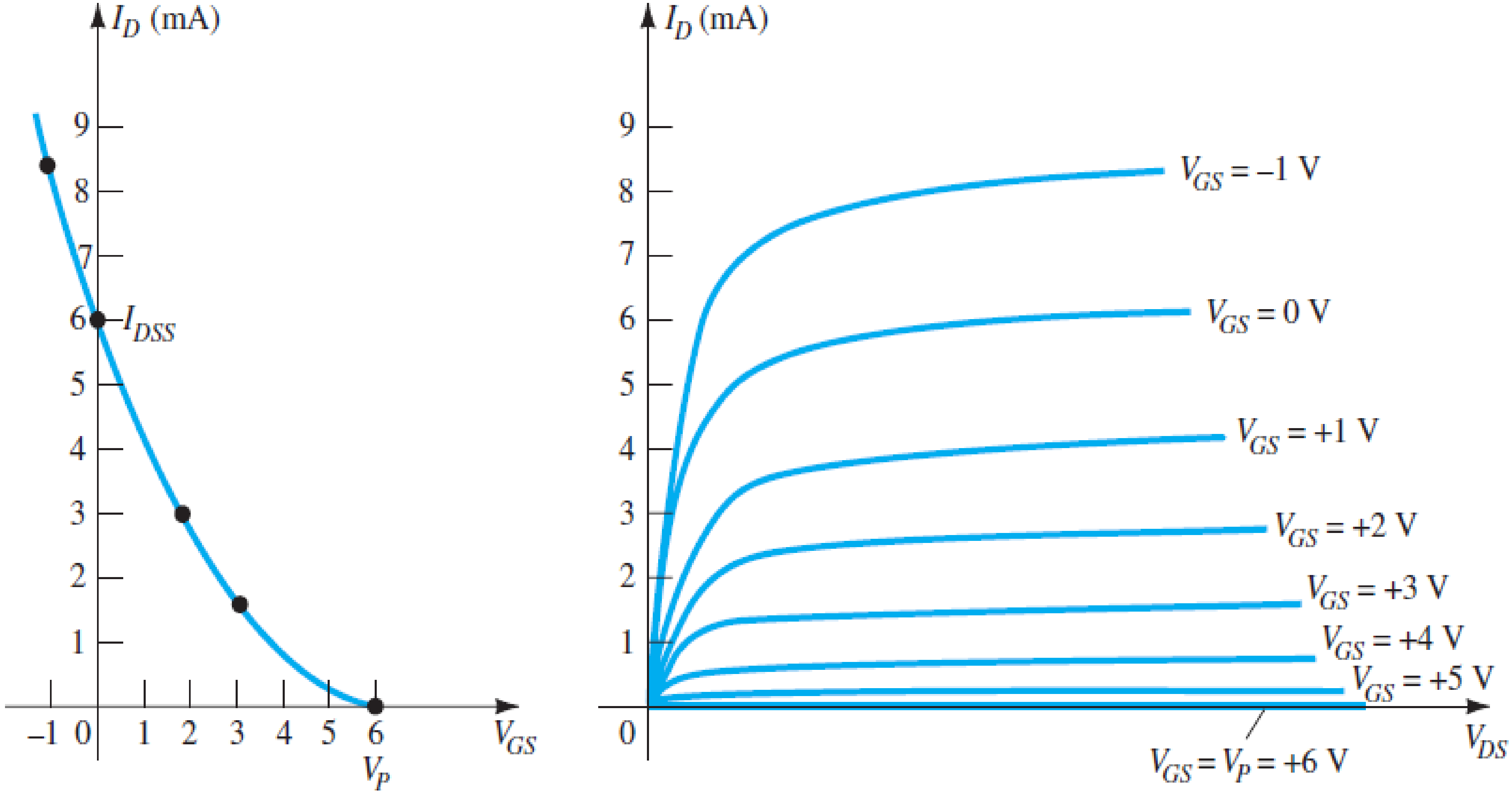
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

P- Channel D-MOSFET

- The construction of a p-channel depletion-type MOSFET is exactly the reverse of N-Channel D-MOSFET.
- The terminals remain as identified, but all the voltage polarities and the current directions are reversed.



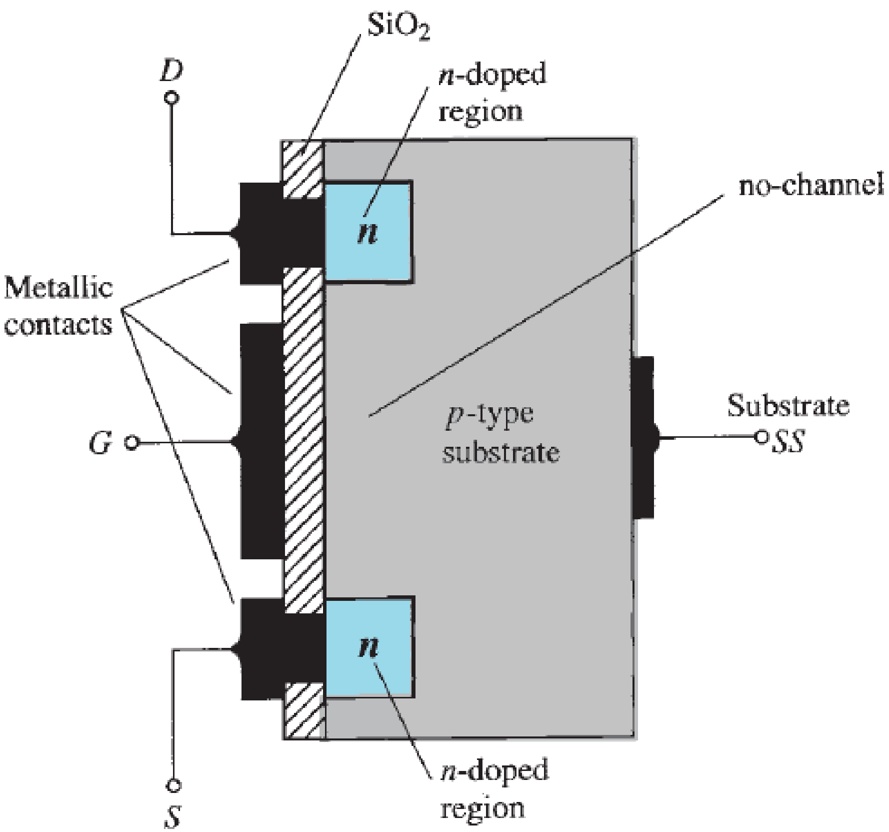
Characteristics Curve for P-Channel D-MOSFET



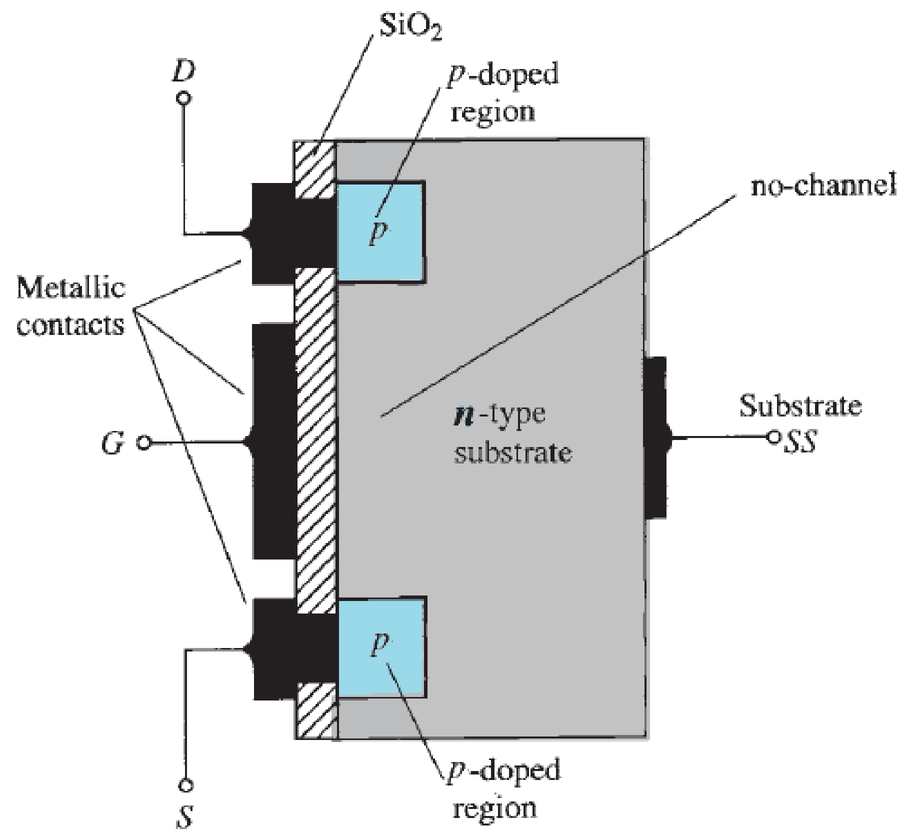
p-Channel depletion-type MOSFET with I_{DSS} = 6 mA and V_P = +6 V.

Enhancement-type MOSFET.

➢ The **absence of a channel** between the two n or p doped regions.



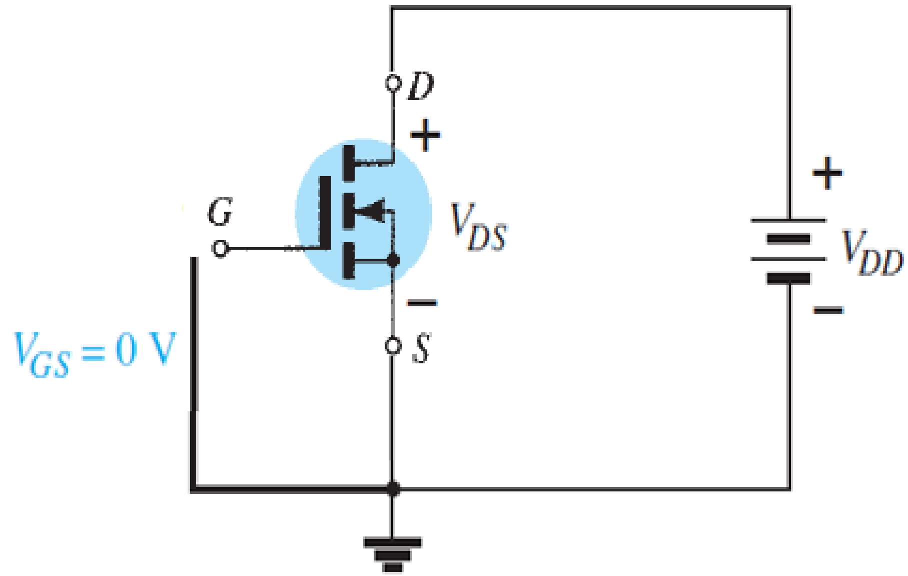
n-Channel enhancement-type MOSFET.



p-Channel enhancement-type MOSFET.

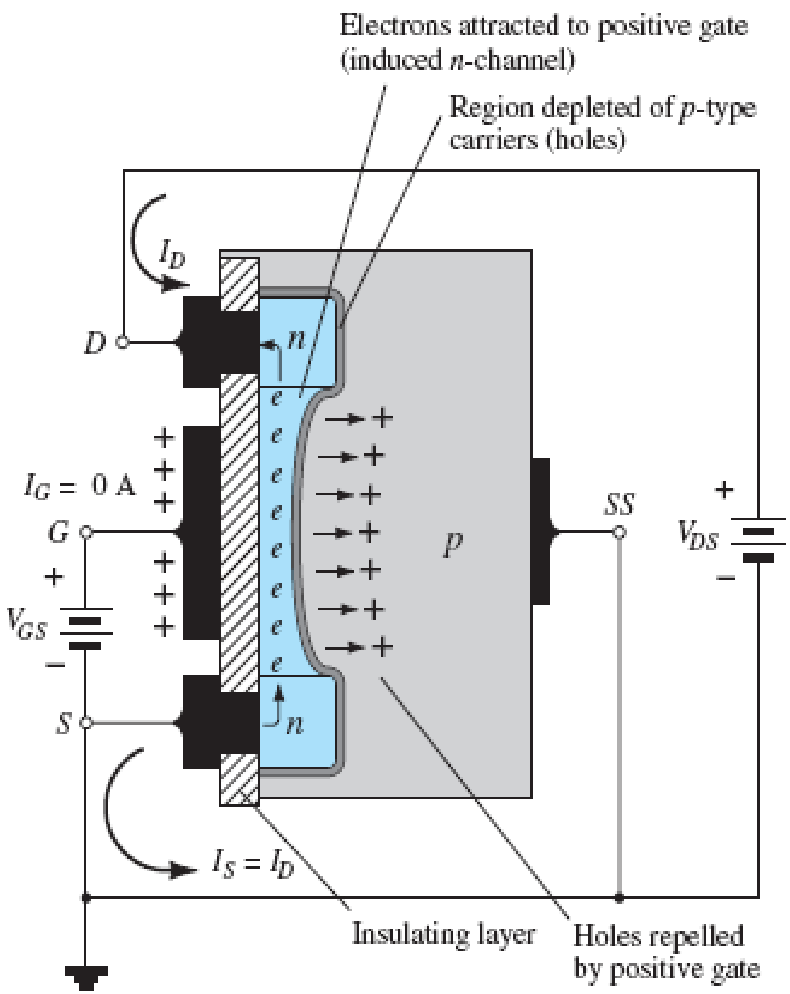
Operation Mechanism of E-MOSFET

- At $V_{GS} = 0\ V$ a voltage applied between the drain and the source of the device of the absence of an n -channel will result in a current.
- It is not sufficient to have a large accumulation of carriers (electrons) at the drain and the source (due to the n -doped regions).
- $V_{GS} < 0\ V$ (Negative Voltage) Same as when $V_{GS} = 0\ V$.



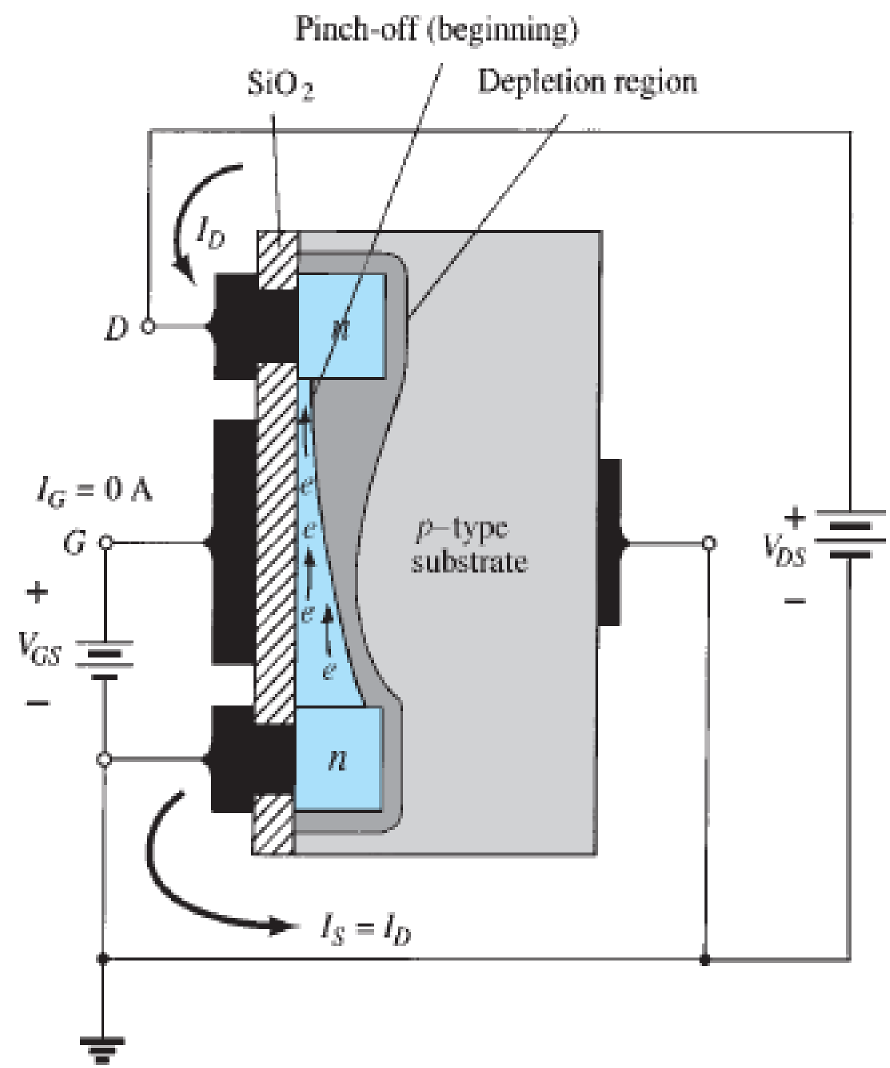
Operation mechanism of E-MOSFET

- $V_{GS} > 0\,V$(Positive Voltage),the positive potential at the gate will pressure the holes in the p – substrate.
- The electrons in the p-substrate will be attracted to the positive gate and accumulate in the region near the surface of the SiO_2layer.

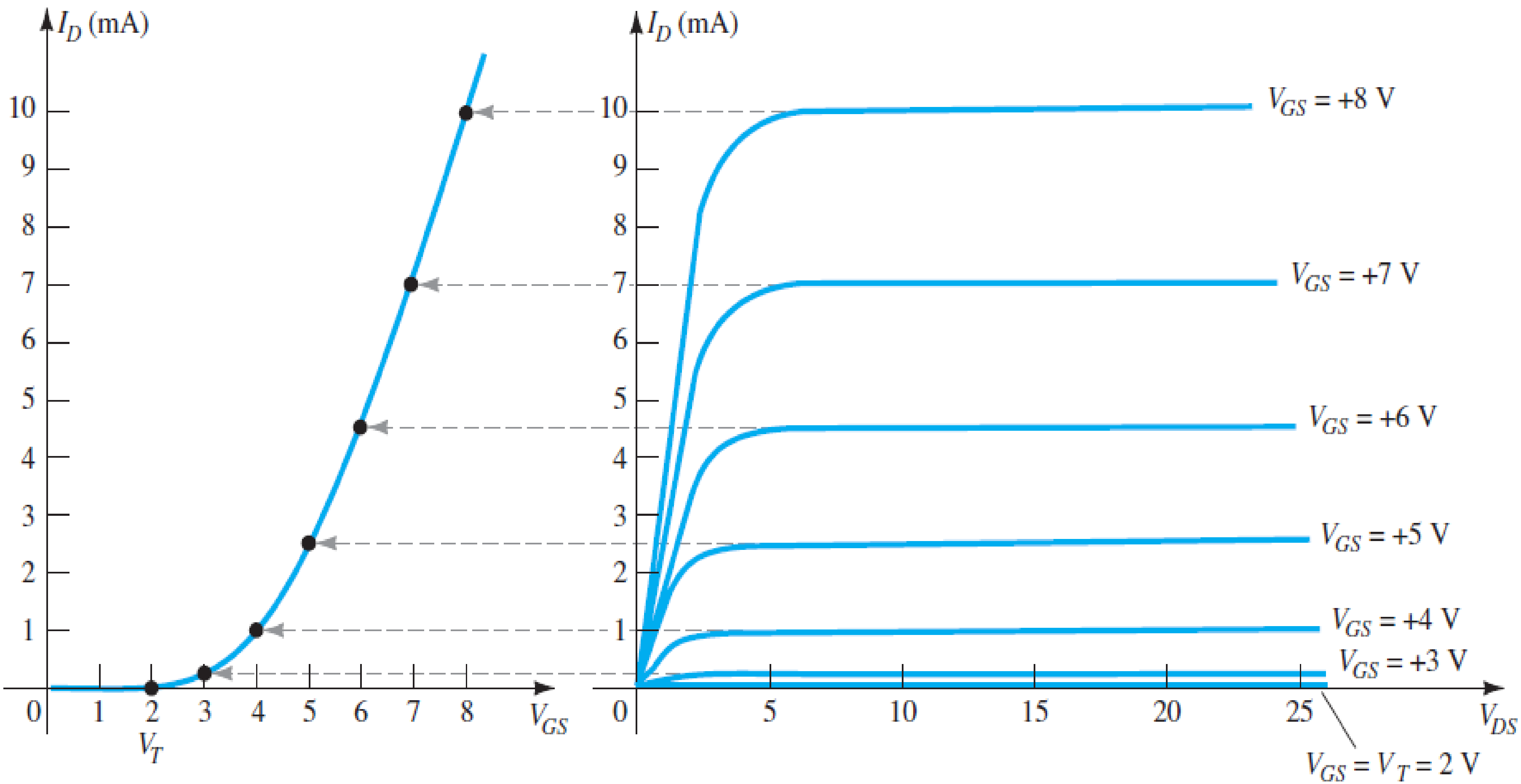


Operation mechanism of E-MOSFET

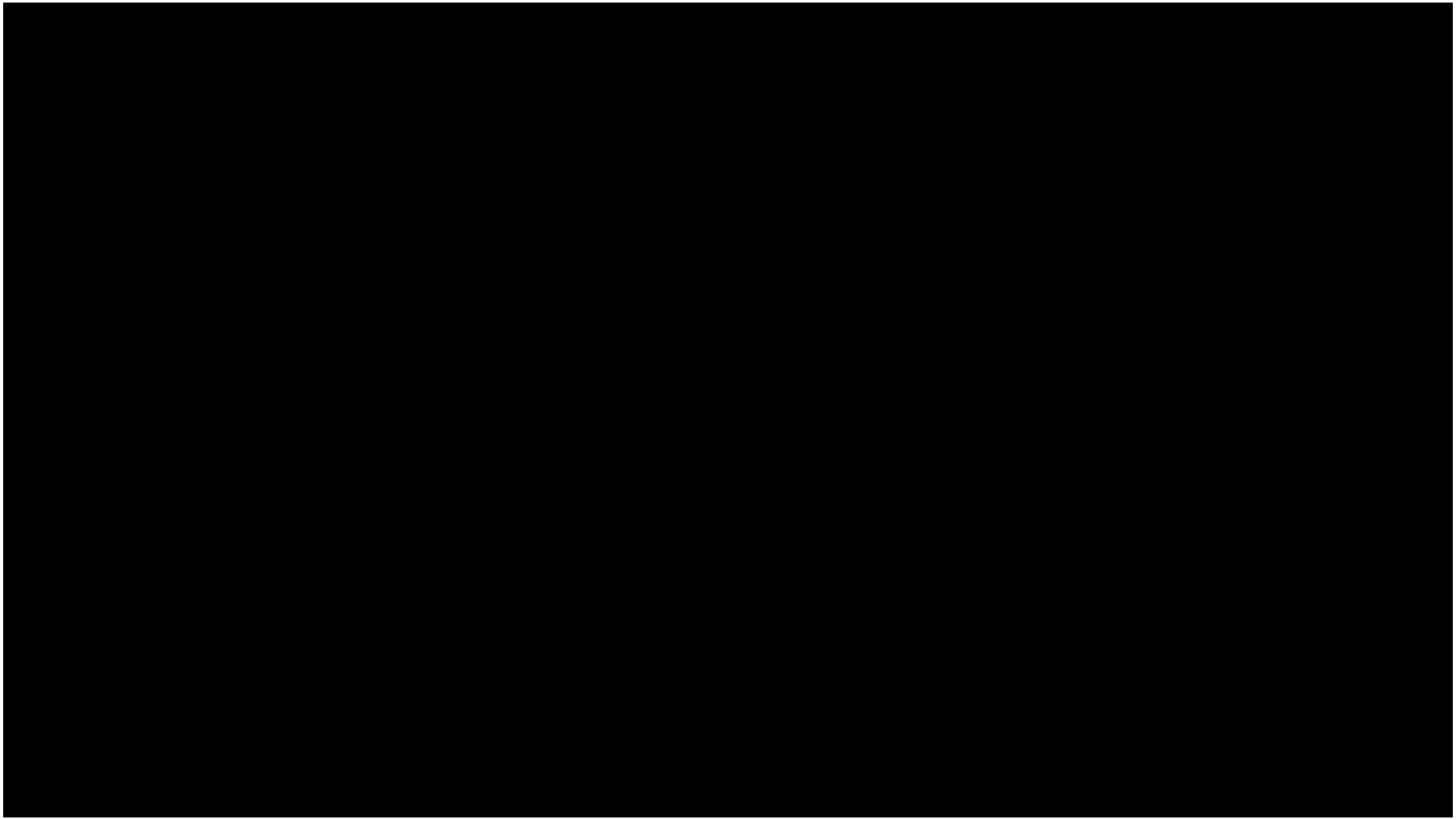
- As V_{GS} increases in magnitude, the concentration of electrons near the SiO_2 surface increases until the induced n-type region can support a measurable flow between drain and source.
- The level of V_{GS} that results which increases in drain current or minimum voltage to create channel between drain and source is called the threshold voltage V_T .



Characteristics Curve for N-Channel E-MOSFET



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



Operation mechanism of E-MOSFET

- Saturation level for V_{DS} is related to the level of applied V_{GS} by
  - $V_{DS(sat)} = V_{GS} - V_T$
- For values of V_{GS} less than the threshold level, the drain current of an enhancement type MOSFET is $0mA$.
- For levels of $V_{GS} > V_T$, the drain current is related to the applied gate-to-source voltage by the following nonlinear relationship:
  - $I_D = k(V_{GS} - V_T)^2$
- The k term is a constant that is a function of the construction of the device.
- The value of k can be determined from the following equation:

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

- where $I_{D(on)}$ and $V_{GS(on)}$ are the values for each at a particular point on the characteristics of the device.

Differences between JFETs and MOSFETs

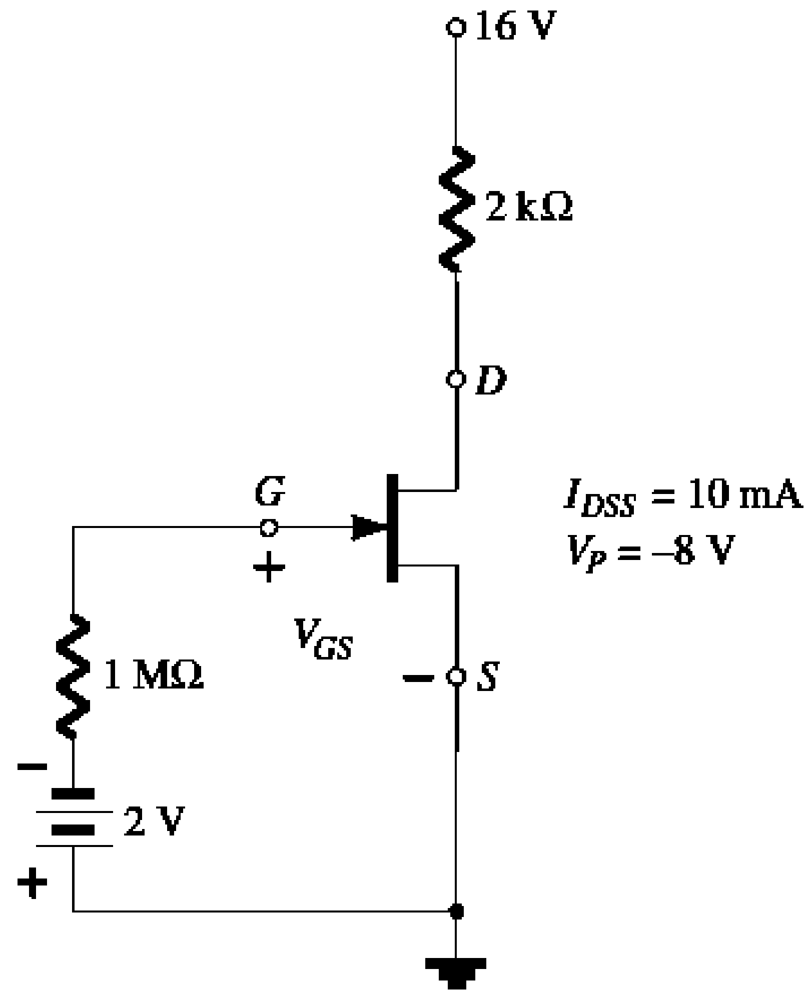
JFET	MOSFET
• Operate only in depletion mode	• Operate in both depletion and enhancement mode
• Low input resistance (> $10^9\Omega$)	• High input resistance (around $10^{13}\Omega$)
• High drain resistance	• Low drain resistance
• Large Leakage current	• Small Leakage current
• Not easy Construction	• Easy Construction

Example

For a n -channel JFET with $V_p = -8$ V, $I_{Dss} = 10\ mA$. Determine:

a. The transfer characteristic curve .

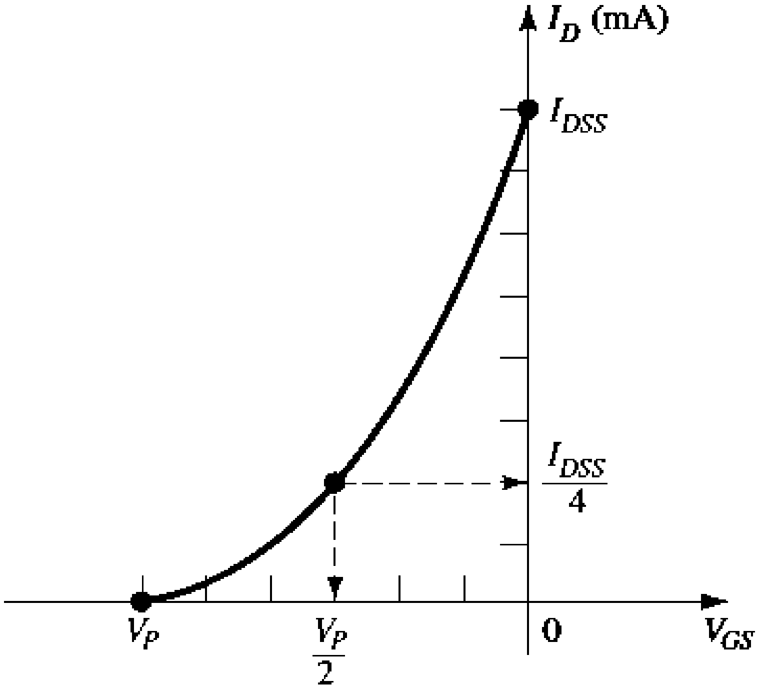
b. I_{DQ}.

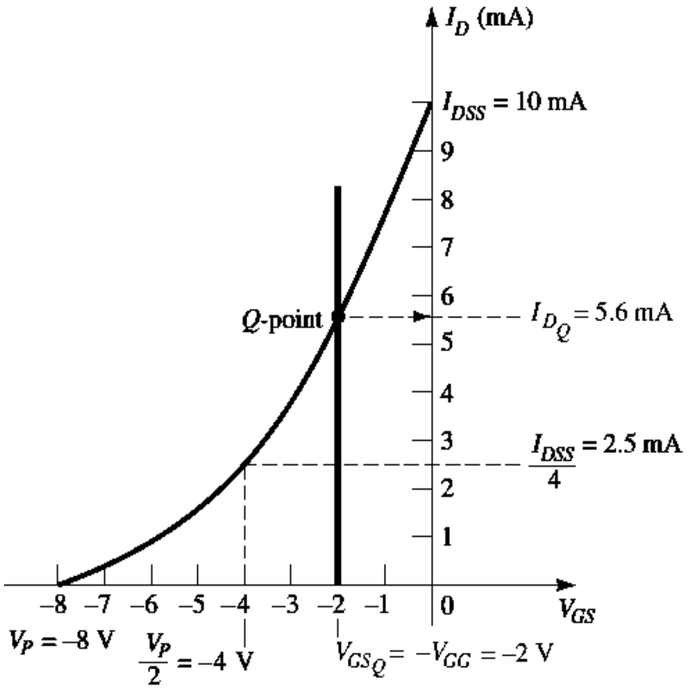


Solution

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

$$I_{DQ} = 5.6\ mA$$





Example

Using the data provided on the $specification\ VGS(on)\ 10\ V\ ,\ ID(on) = 3mA$ and an average threshold voltage of $V_{GS}(Th) = \ 3\ V$, determine:

(a) The resulting value of k for the MOSFET.

(b) The transfer characteristics.

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

$$= \frac{3\text{ mA}}{(10\text{ V} - 3\text{ V})^2} = \frac{3\text{ mA}}{(7\text{ V})^2} = \frac{3 \times 10^{-3}}{49}\text{ A/V}^2$$

$$= \mathbf{0.061 \times 10^{-3}\ A/V^2}$$

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

$$= 0.061 \times 10^{-3}(V_{GS} - 3\text{ V})^2$$

For $V_{GS} = 5$ V,

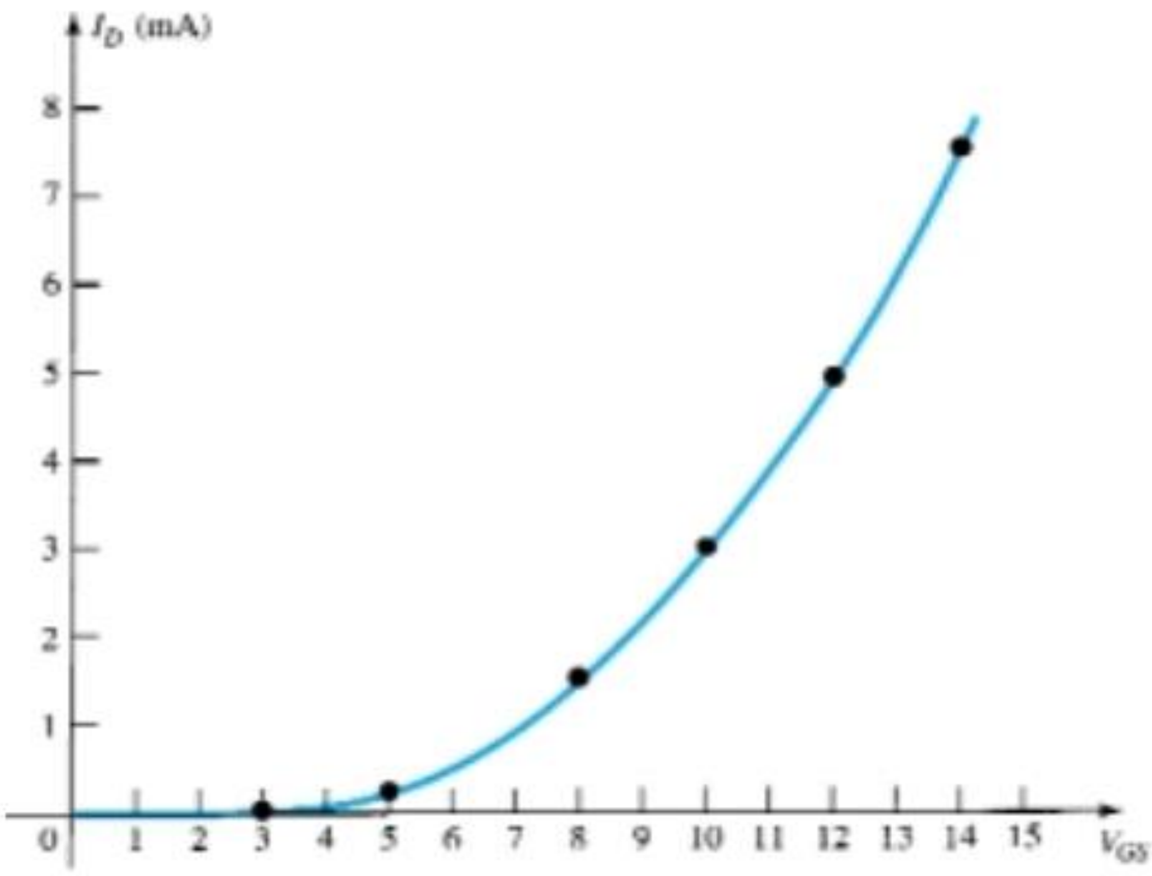
$$I_D = 0.061 \times 10^{-3}(5\text{ V} - 3\text{ V})^2 = 0.061 \times 10^{-3}(2)^2$$

$$= 0.061 \times 10^{-3}(4) = 0.244\text{ mA}$$

Example

For V_{GS} = 8, 10, 12, and 14 V, I_D will be 1.525, 3 (as defined), 4.94, and 7.38 mA, respectively.

The transfer characteristics are sketched in Fig.



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