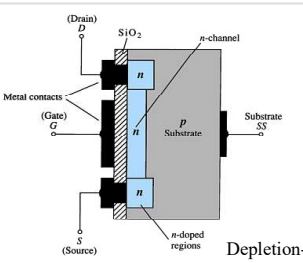
Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

MOSFETs

MOSFETs have characteristics similar to JFETs, but having having no gate junction. Ut has few additional characteristics that make then very useful.

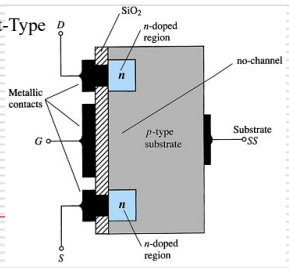
There are two types of MOSFETs:

- Depletion-Type
- Enhancement-Type



Depletion-Type

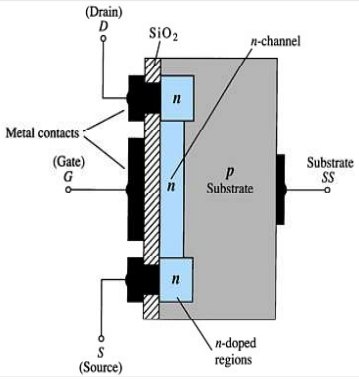
Enhancement-Type



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).

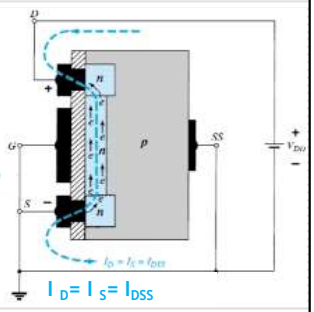


Depletion-Type MOSFET Operation in Enhancement Mode (E-MODE)

When the ***drain*** is made ***+ve*** with respect to source, a drain current will flow, even with ***zero gate potential*** and the MOSFET is said to be operating in enhancement mode (***E-mode)***.

$V_{GS} = 0$

In this mode of operation gate attracts the *electron* from the P-substrate to the N-channel and thus reduces the channel resistance and increases the drain current. The more positive the gate is made, the more drain current flows.

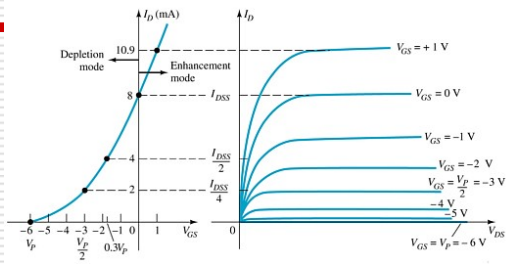


$I_D = I_S = I_{DSS}$

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:

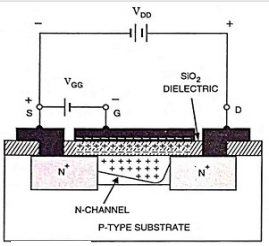


$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

Note that V_{GS} is now a positive polarity

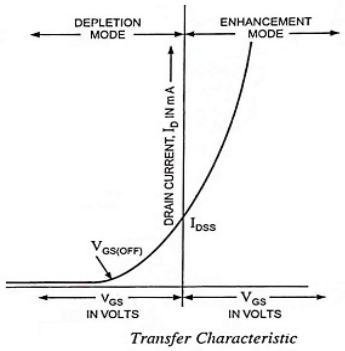
Depletion-Type MOSFET Operation in *Depletion MODE*

On the other hand when the ***gate is made -ve*** with respect to the substrate, the gate repells some of the electrons out of the N-channel. This creates a depletion region in the channel, as illustrated in Fig, and, therefore, increases the channel resistance and reduces the drain current. The more -ve the gate, the less the drain current. In this mode of operation the device is referred to as a Depletion Type MOSFET. Here too much negative gate voltage can pinch off the channel. Thus operation is similar to that of JFET.

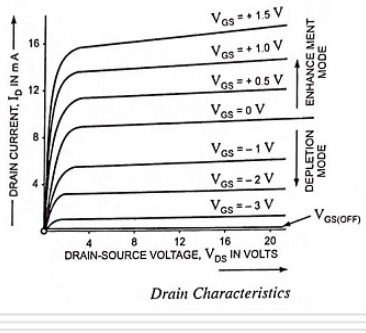


Depletion Mode Operation

Basic depletion-type MOSFET Characteristics



Transfer Characteristic

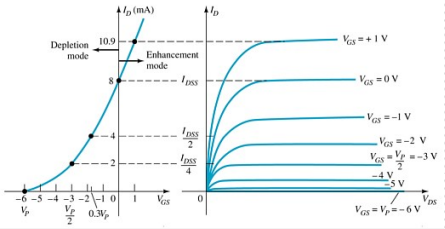


Drain Characteristics

D-Type MOSFET in Depletion Mode

Depletion Mode

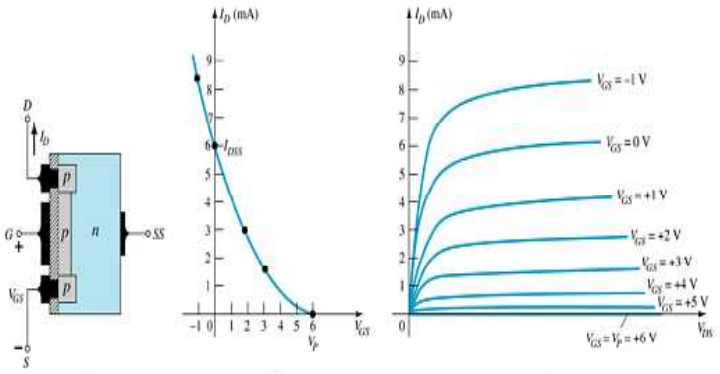
The characteristics are similar to a JFET.



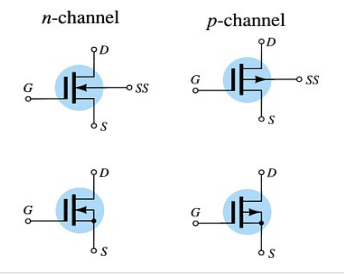
When $V_{GS} = 0$ V, $I_D = I_{DSS}$
When $V_{GS} < 0$ V, $I_D < I_{DSS}$
The formula used to plot the transfer curve still applies:

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

p-Channel D-Type MOSFET

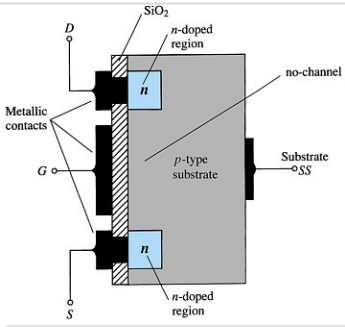


D-Type MOSFET Symbols



E-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 the Substrate (SS)**

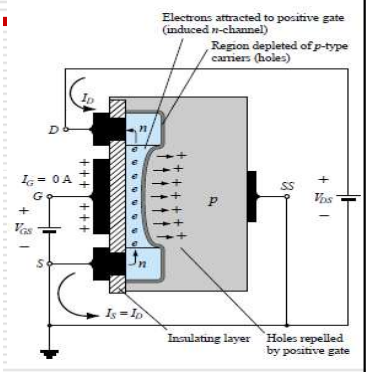


Basic Operation and Characteristics of an n-Channel E-MOSFET

When $V_{GS} > 0$ & $V_{DS} > 0$,
A depletion region is created near the SiO_2 layer void of holes.

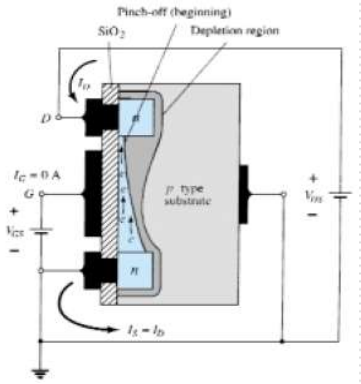
As V_{GS} increases, the concentration of electrons near the SiO_2 increases and there is some flow between drain and source.

The level of V_{GS} that results in the significant increase in I_D is called the Threshold Voltage (V_T).



Basic Operation and Characteristics of an n-Channel E-MOSFET

If $V_{GS} > V_T$ is constant and V_{DS} is increased, I_D will Increase and will reach saturation.



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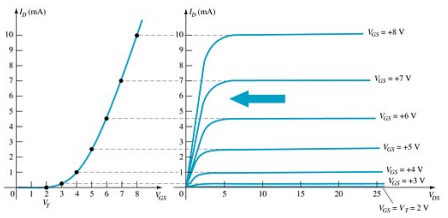
Basic Operation of the E-Type MOSFET

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



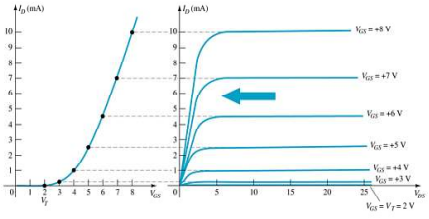
E-Type MOSFET Transfer Curve

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



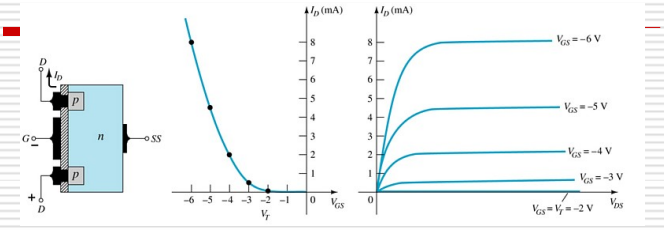
k, a constant, can be determined by using values at a specific point and the formula:

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

V_{DSsat} can be calculated by:

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

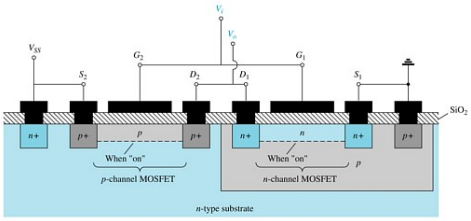
p-Channel E-Type MOSFETs



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

CMOS Devices

CMOS (complementary MOSFET) uses a *p*-channel and *n*-channel MOSFET; often on the same substrate as shown here.



Advantages

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