UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 29-30

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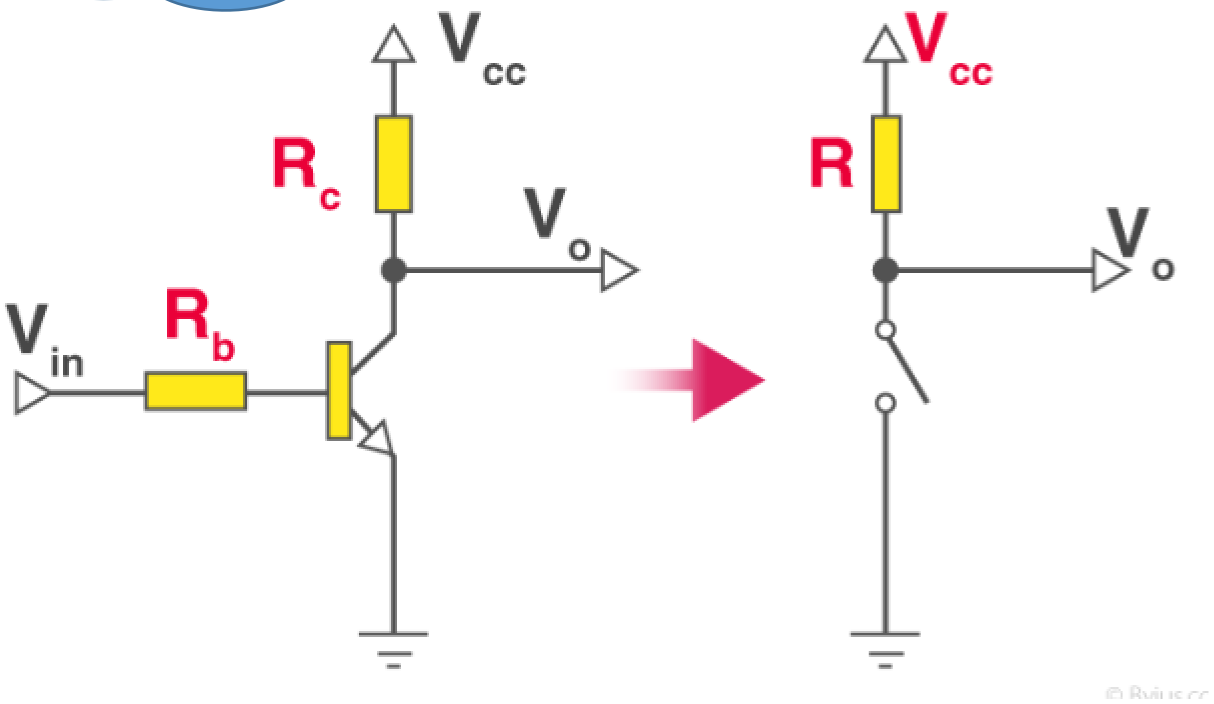
Transistor as a Switch

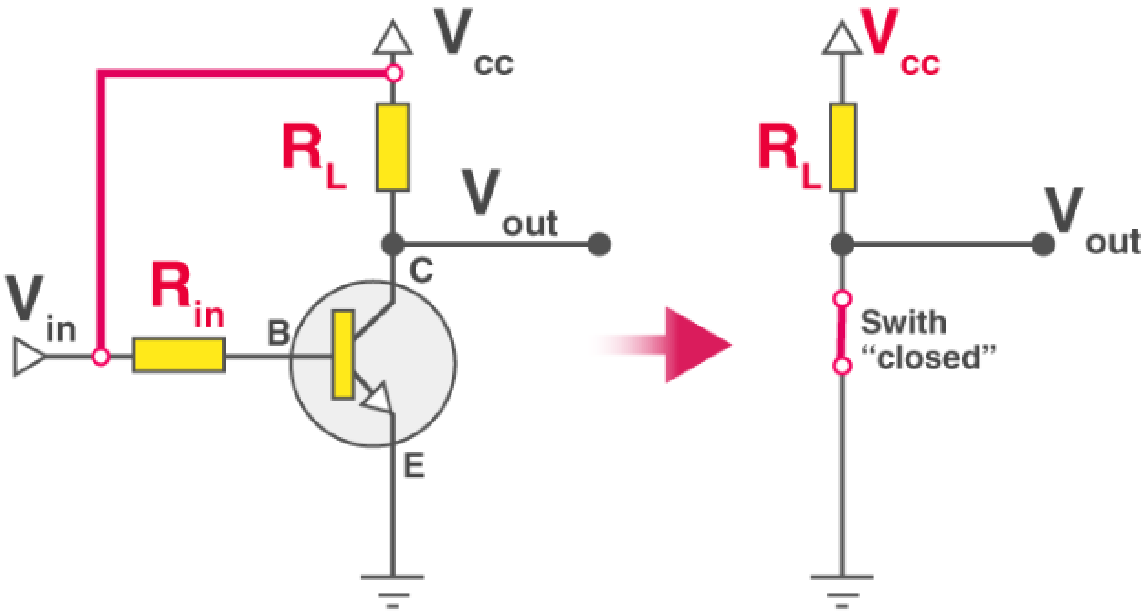
- To act as a switch, transistor operates under the Saturation Region and the Cut-off Region.

Use of Rb ??

OFF state

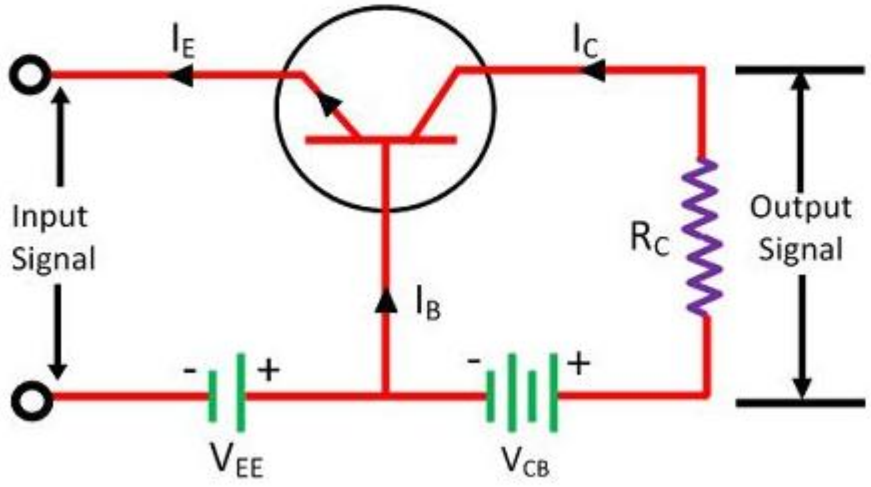


ON state



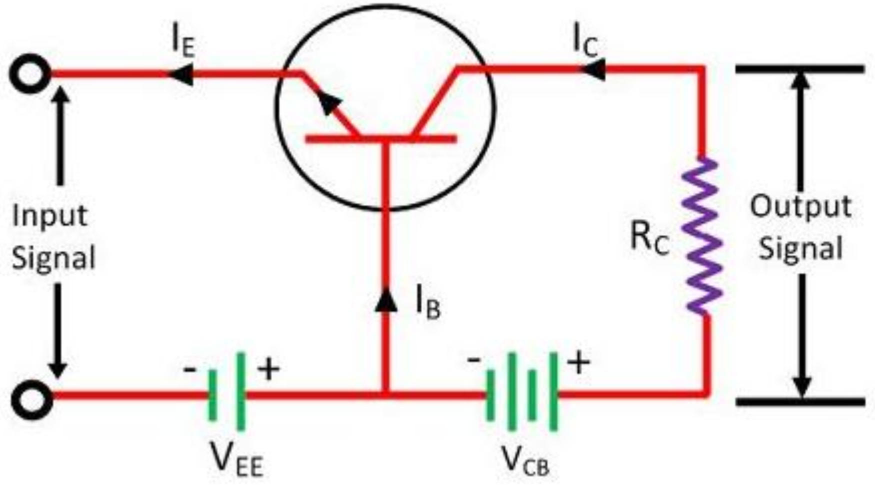
Transistor as an Amplifier

- The input signal or weak signal is applied across the emitter base and the output is obtained to the load resistor R_C which is connected in the collector circuit.
- When a weak signal is applied to the input, a small change in signal voltage causes a change in emitter current (or we can say a change of 0.1V in signal voltage causes a change of 1mA in the emitter current) because the input circuit has very low resistance. This change is almost the same in collector current because of the transmitter action.



Transistor as an Amplifier

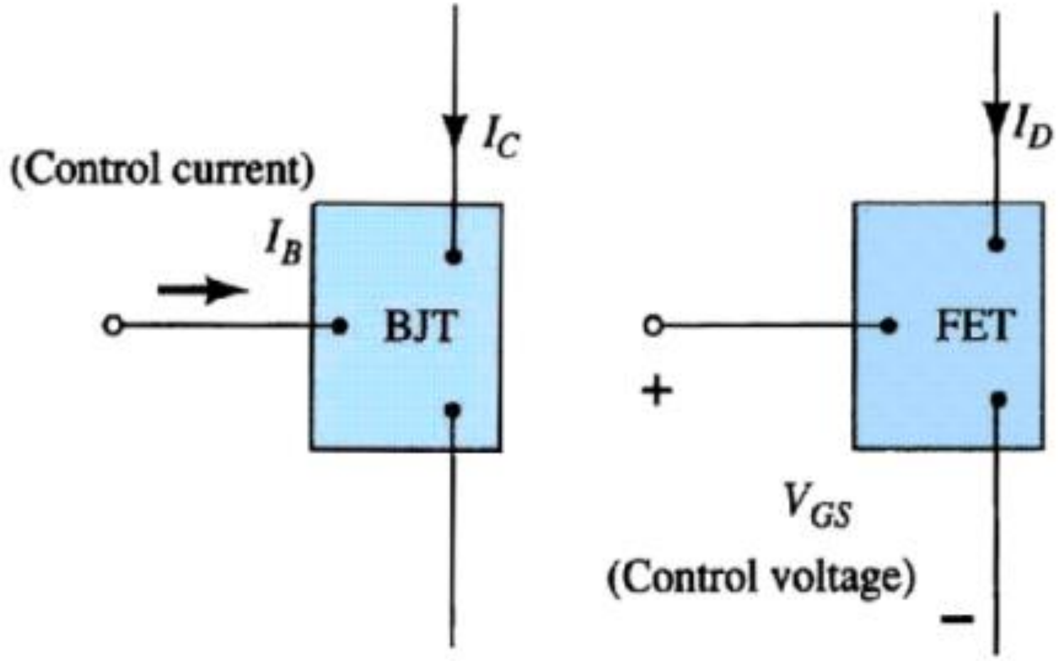
- In the collector circuit, a load resistor RC of high value is connected.
- When collector current flows through such a high resistance, it produces a large voltage drop across it.
- Thus, a weak signal (0.1V) applied to the input circuit appears in the **amplified** form (10V) in the collector circuit.



What should be the value of RC ?..... So that 10V appear across RC

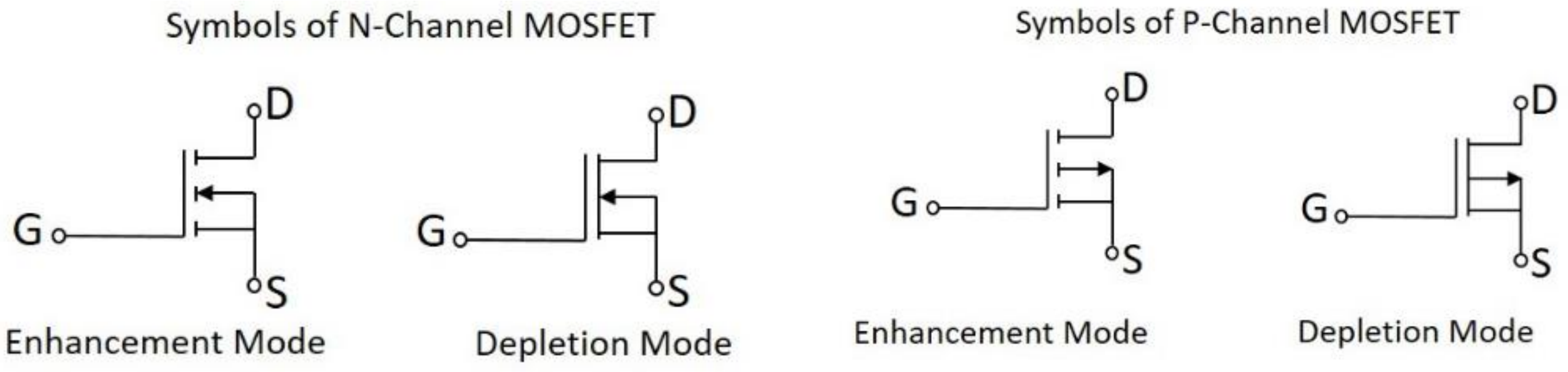
MOSFET

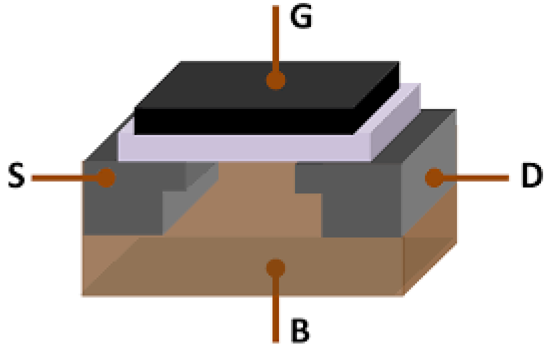
- Stands for: **Metal Oxide Semiconductor Field Effect Transistor.**
- It is a voltage controlled device.



MOSFET Symbol

In general, the MOSFET is a four-terminal device with a **Drain (D), Source (S), gate (G)** and a Body (B) / Substrate terminals.





QUICK QUIZ (POLL)

Which of the following terminals does not belong to the MOSFET?

a) Drain
b) Gate
c) Base
d) Source

Explanation Slide

Types of MOSFET

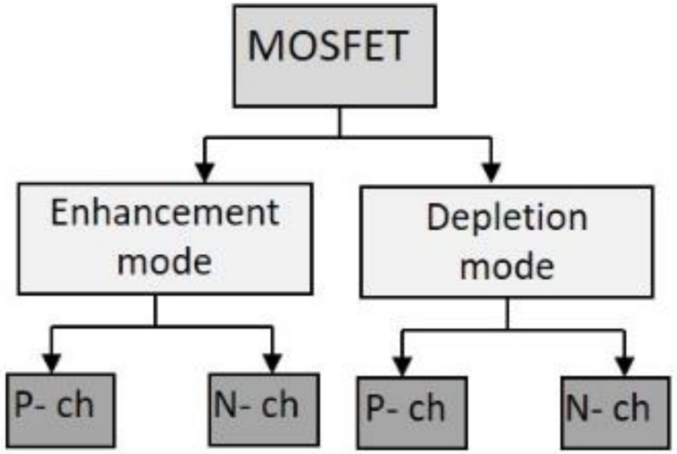
The MOSFET is classified into two types:

- **Enhancement** mode MOSFET

The Enhancement mode MOSFET is equivalent to “Normally Open” switch and these types of transistors require gate-source voltage to switch ON the device.

- **Depletion** mode MOSFET

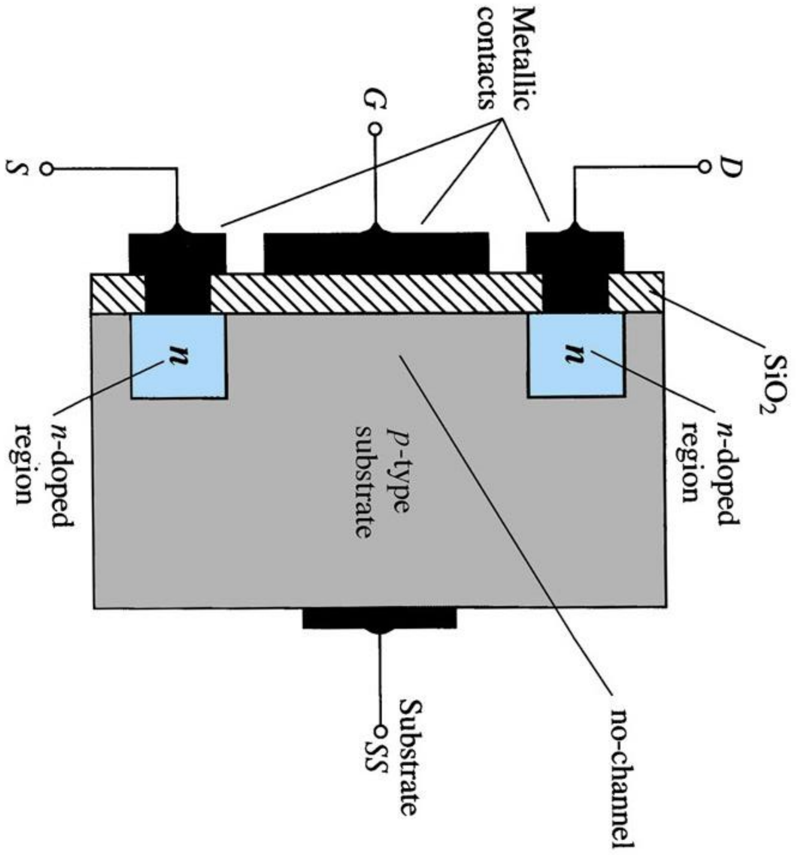
The depletion mode MOSFETs are generally known as ‘Switched ON’ devices, because these transistors are generally closed when there is no bias voltage at the gate terminal.



- P- ch = P- channel
- N- ch = N- channel

N Channel E-MOSFET: Construction

- A slab of p-type material is formed from a silicon base and is referred to as the substrate.
- The source and drain terminals are connected through metallic contacts to n-doped regions.
- **the absence of a channel**
- SiO_2 layer is still present to isolate the gate metallic platform from the region between the drain and source

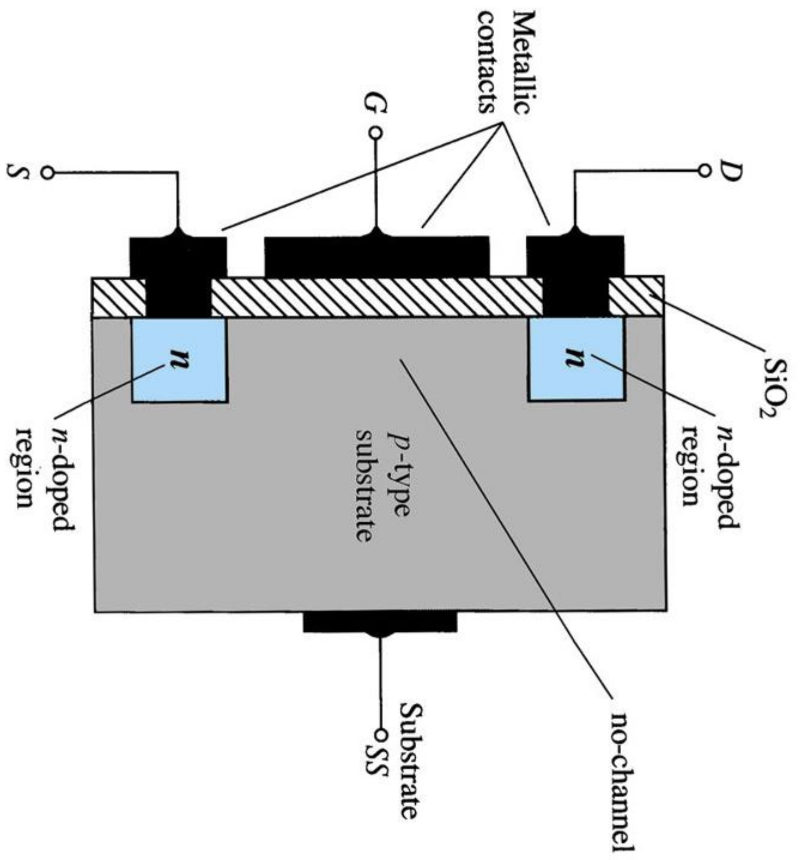


N Channel E-MOSFET: Operation

- If V_{GS} is set at 0 V and a voltage applied between the drain and source of the device, the absence of an n-channel will result in a current of effectively zero amperes.
-

Case1:+VGS,VDS=0

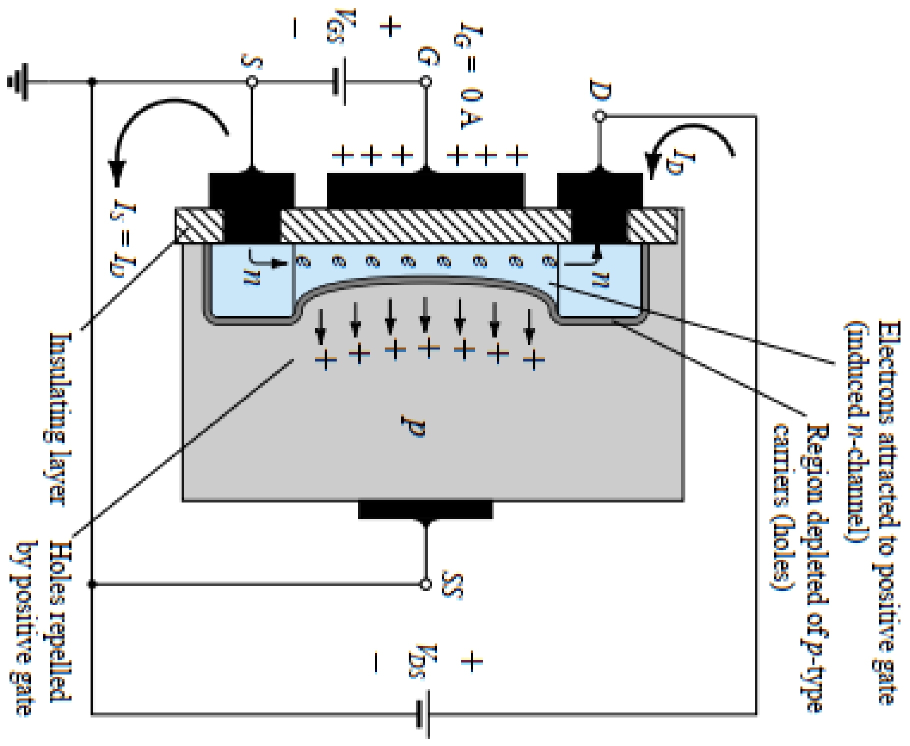
Depletion , accumulation and inversion ………..channel enhance (formed)



N Channel E-MOSFET: Operation

Case2:VGS>0,VDS>0

- In Fig., both V_{DS} and V_{GS} have been set at some positive voltage greater than 0 V, establishing the drain and gate at a positive potential with respect to the source.
- The positive potential at the gate will pressure the holes (since like charges repel) in the p-substrate along the edge of the SiO_2 layer to leave the area and enter deeper regions of the p-substrate, as shown in the figure.
- The result is a depletion region near the SiO_2 insulating layer void of holes. However, the electrons in the p-substrate (the minority carriers of the material) will be attracted to the positive gate and accumulate in the region near the surface of the SiO_2 layer.
- The SiO_2 layer and its insulating qualities will prevent the negative carriers from being absorbed at the gate terminal.
- As V_{GS} increases in magnitude, the concentration of electrons near the SiO_2 surface increases until eventually the induced n-type region can support a measurable flow between drain and source.
- The level of V_{GS} that results in the significant increase in drain current is called the threshold voltage and is given the symbol V_T



What happened if VGS>>VT

N Channel E-MOSFET: Operation

- Since the channel is nonexistent with $V_{GS=}0\ Volt$,and **“enhanced”** by the application of a positive gate-to-source voltage, this type of MOSFET is called an enhancement-type MOSFET.
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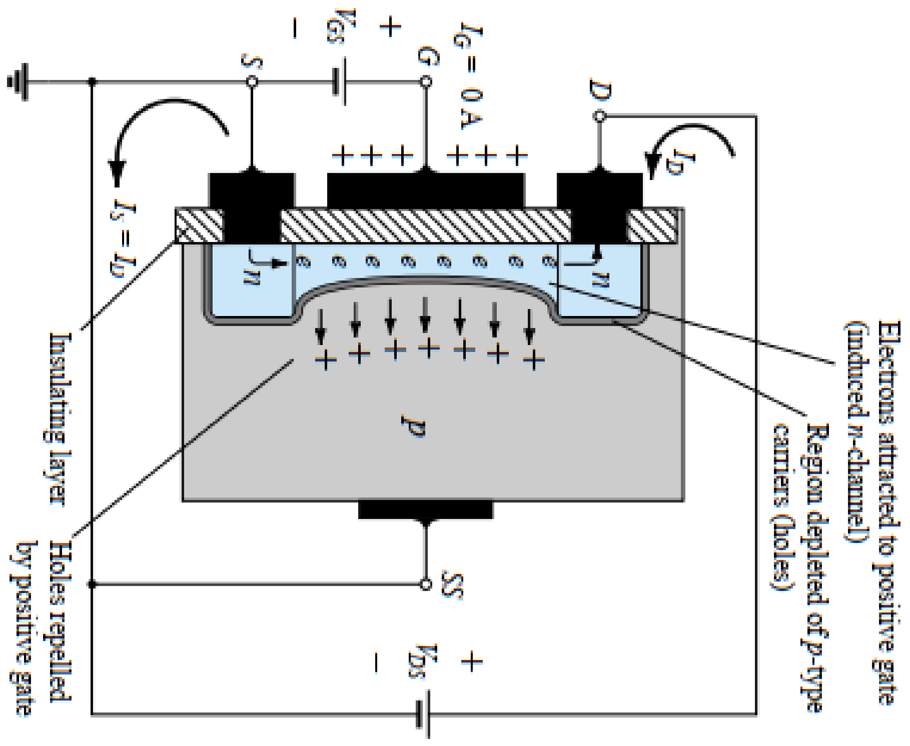
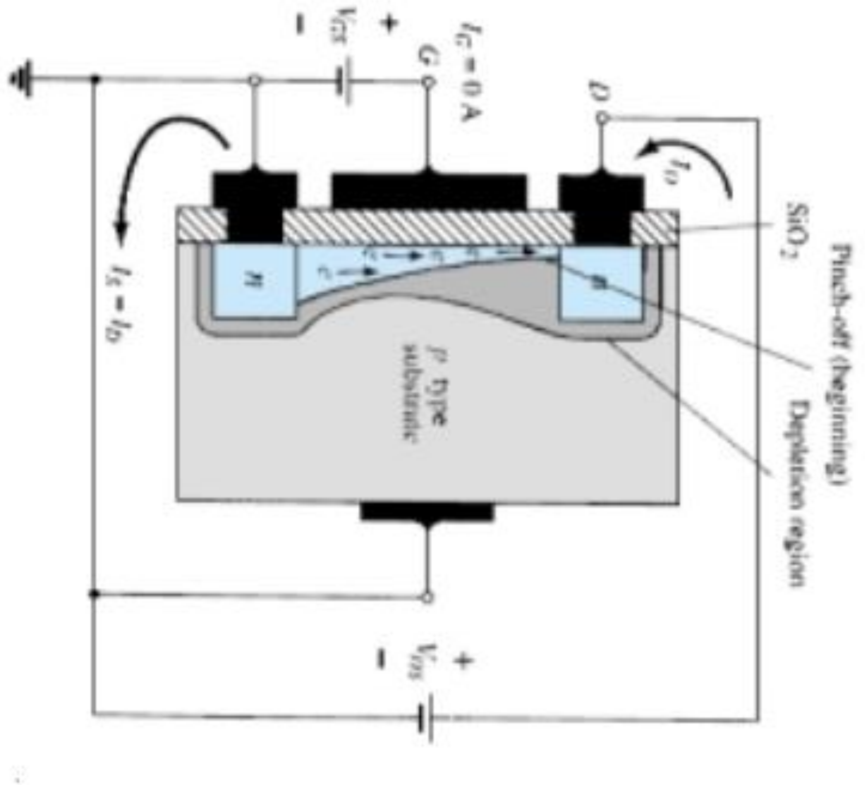


N Channel E-MOSFET: Operation

Case3:
1.VGS>>VT
2. VDS>>VP

- As V_{GS} is increased beyond the threshold level, the density of free carriers in the induced channel will increase, resulting in an increased level of drain current.
- However, if we hold V_{GS} constant and increase the level of V_{DS}, the drain current will eventually reach a saturation level as occurred for the JFET and depletion-type MOSFET.
- The leveling off of I_D is due to a pinching-off process depicted by the narrower channel at the drain end of the induced channel.
- For levels of $V_{GS} > V_T$ the drain current is related to the applied gate-to-source voltage by the following nonlinear relationship:

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



N Channel E-MOSFET: Transfer Characteristics

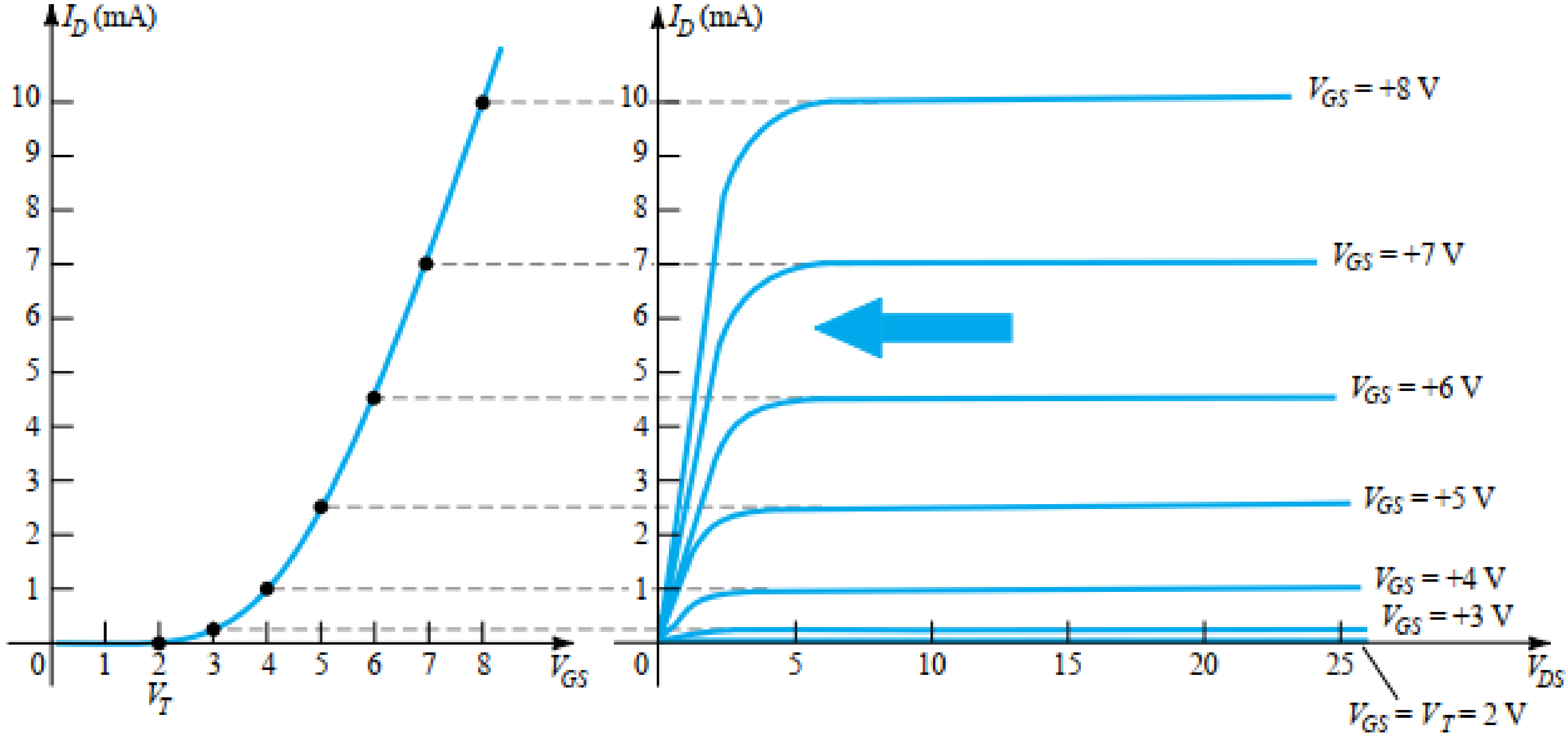


Figure Sketching the transfer characteristics for an *n*-channel enhancement-type MOSFET from the drain characteristics.

MOSFET: Regions of Operation

- MOSFET also operates under three regions:
- **Cut-Off Region**

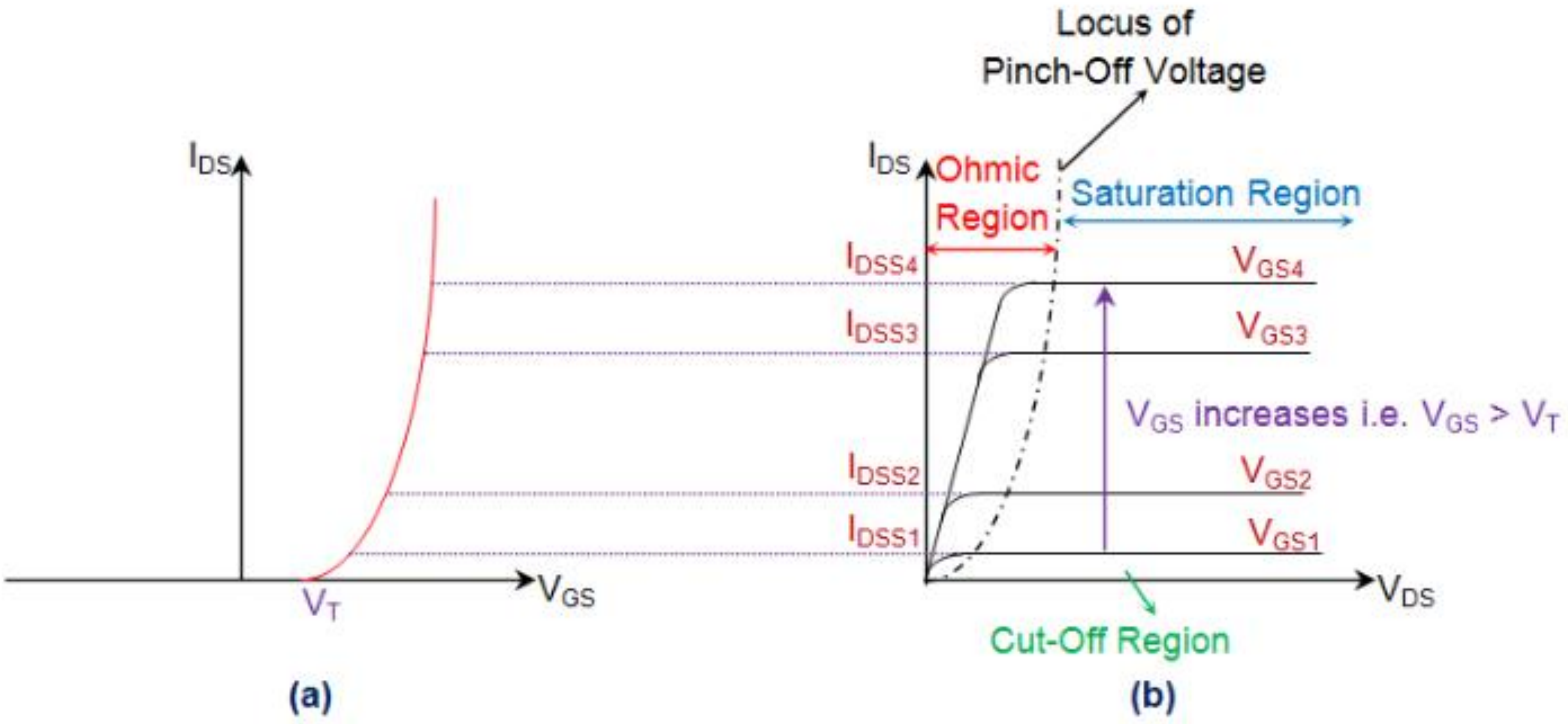
The region in which the MOSFET will be OFF as there will be no current flow through it. In this region, MOSFET behaves like an open switch and is thus used when they are required to function as electronic switches.

- **Ohmic or Linear Region**

The region where in the current I_{DS} increases with an increase in the value of V_{DS}. When MOSFETs are made to operate in this region, they can be used as amplifiers.

- **Saturation Region**

In saturation region, the MOSFETs have their I_{DS} constant and occurs once V_{DS} exceeds the value of pinch-off voltage V_P. Under this condition, the device will act like a closed switch through which a saturated value of I_{DS} flows. As a result, this operating region is chosen whenever MOSFETs are required to perform switching operations.



Kind of MOSFET	Region of Operation		
	Cut-Off	**Ohmic/Linear**	**Saturation**
n-channel Enhancement-type	$V_{GS} < V_T$	$V_{GS} > V_T$ and $V_{DS} < V_P$	$V_{GS} > V_T$ and $V_{DS} > V_P$

QUICK QUIZ (POLL)

Consider an ideal E-MOSFET. If Vgs = 0V, then Id = ?

a) Zero

b) Maximum

c) Id(on)

d) Idd

QUICK QUIZ (POLL)

The controlling parameter in MOSFET is

a) Vds

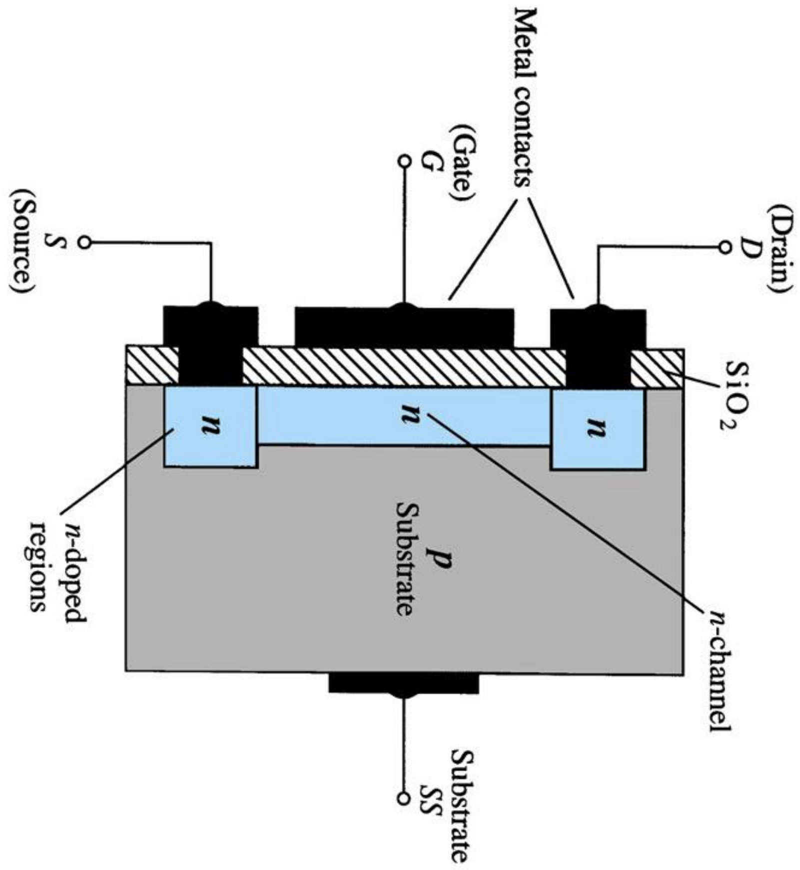
b) Ig

c) Vgs

d) Is

N Channel D-MOSFET: Construction

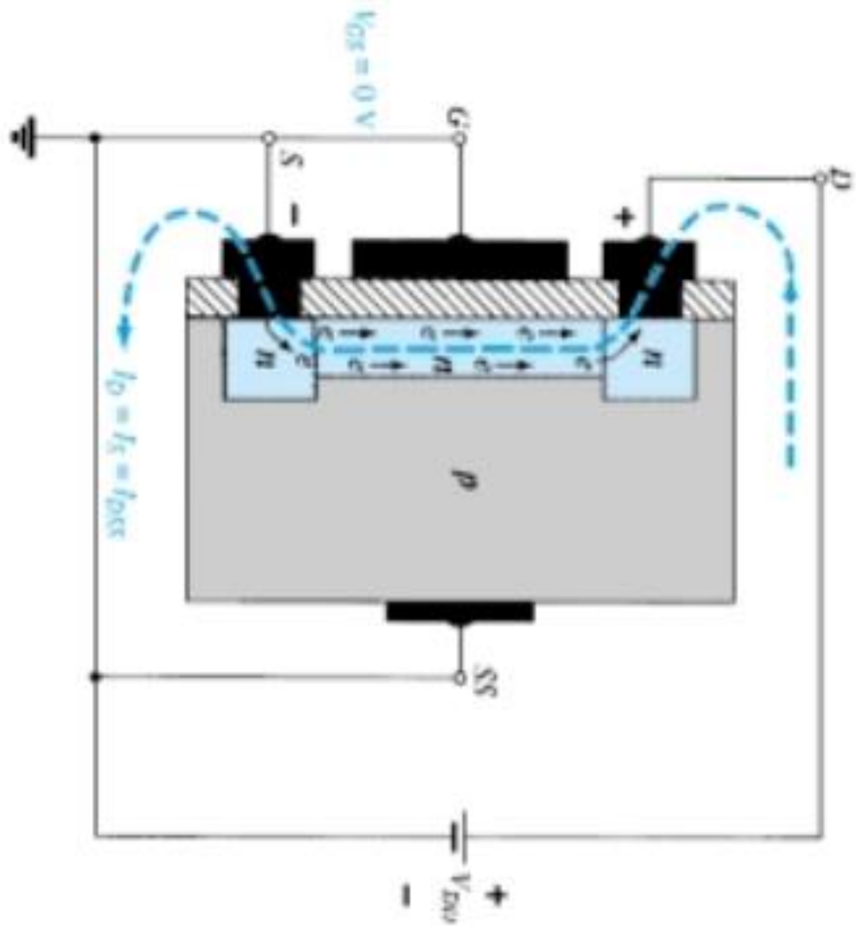
- A slab of p-type material is formed from a silicon base and is referred to as the substrate.
- The source and drain terminals are connected through metallic contacts to n-doped regions.
- **the presence of a channel**
- SiO_2 layer is still present to isolate the gate metallic platform from the region between the drain and source



CASE1:
VGS=0,VDS=0

N Channel D-MOSFET: Operation

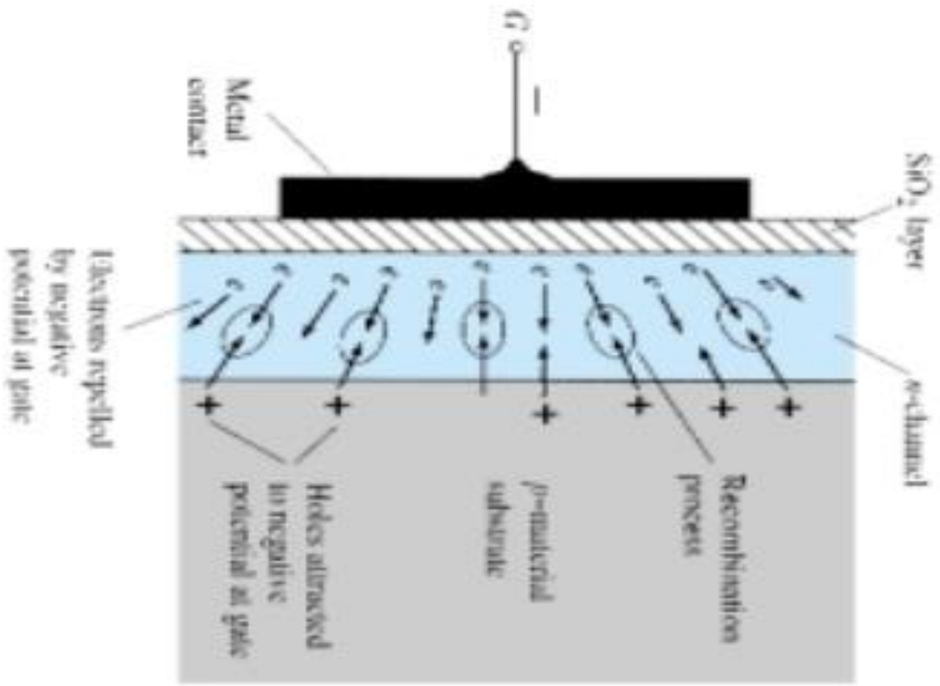
- In Fig., the gate-to-source voltage is set to zero volts by the direct connection from one terminal to the other, and a voltage V_{DS} is applied across the drain-to-source terminals.
- The result is an attraction for the positive potential at the drain by the free electrons of the n-channel and a current would get established.
- The resulting current with $V_{DS} = 0\,Volt$ is labeled I_{DSS}



What happened
VDS>0

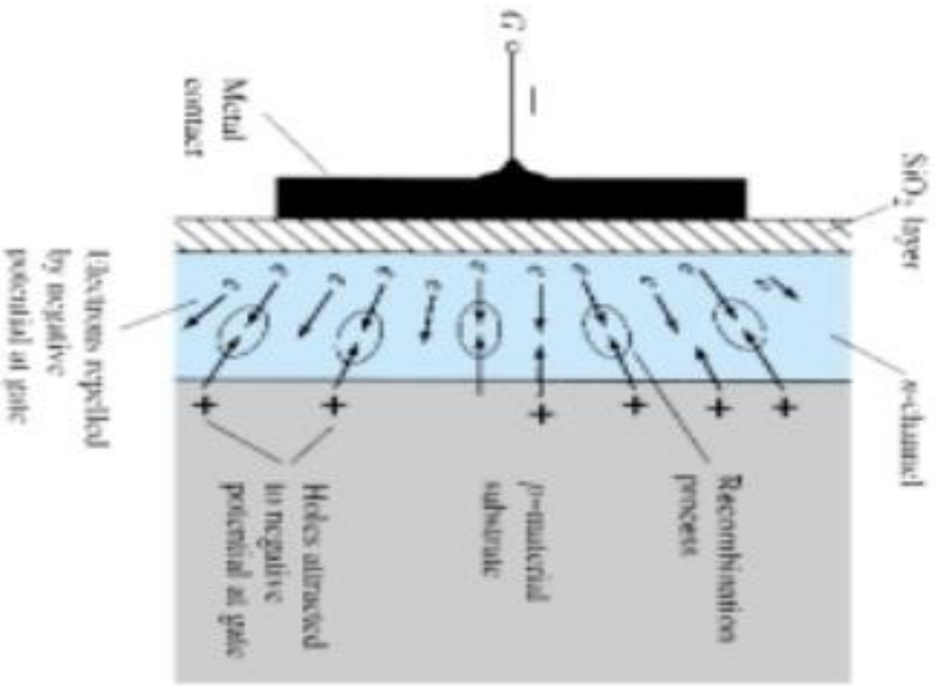
N Channel D-MOSFET: Operation

- Suppose 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) as shown in Fig.
- 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}



N Channel D-MOSFET: Operation

- 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, **transfer characteristics curve** reveals that the drain current will increase at a rapid rate for the reasons listed above



N Channel D-MOSFET: Transfer Characteristics

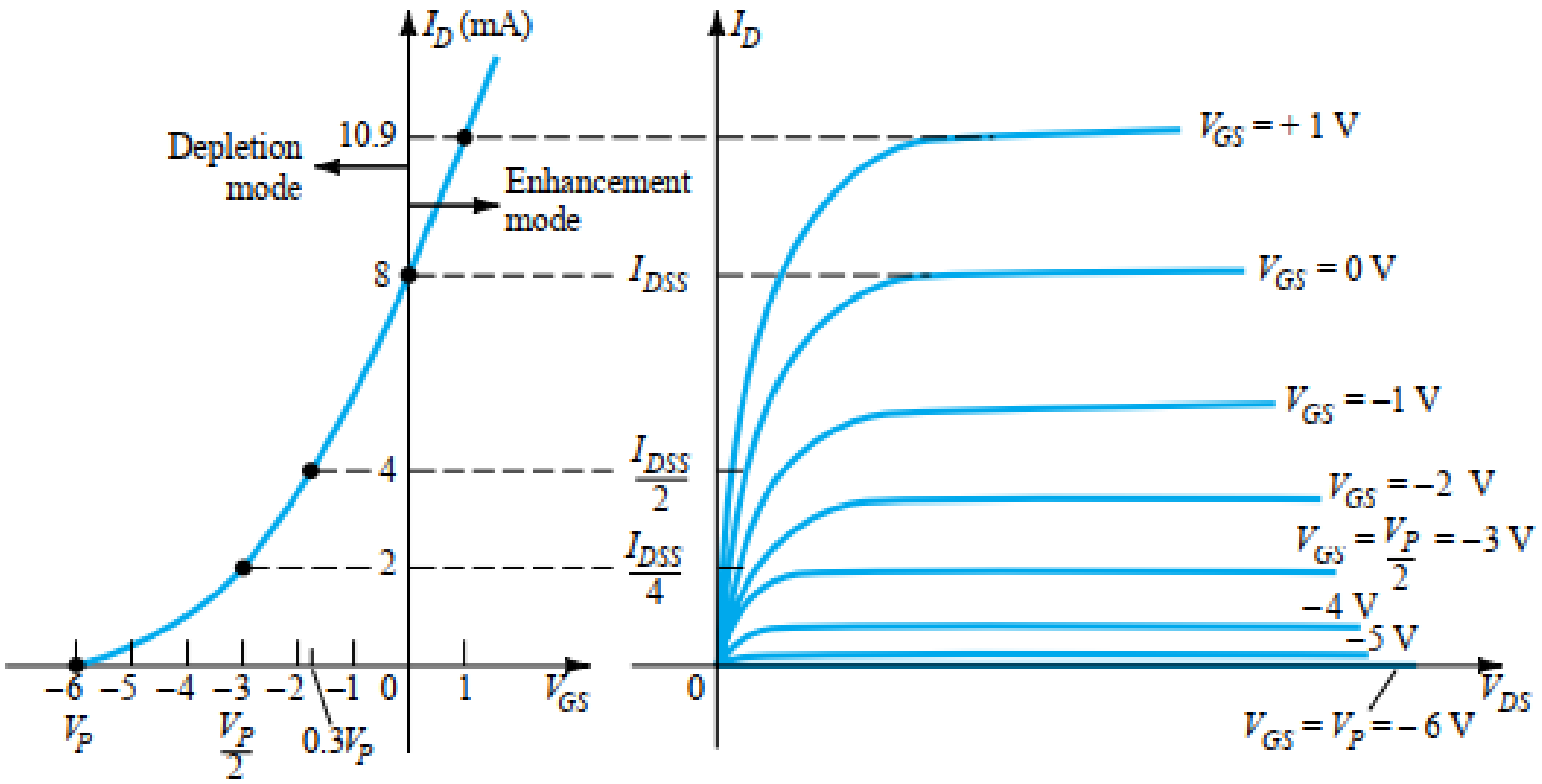


Figure Drain and transfer characteristics for an *n*-channel depletion-type MOSFET.

QUICK QUIZ (POLL)

Choose the correct statement(s)
i) The gate circuit impedance of MOSFET is higher than that of a BJT
ii) The gate circuit impedance of MOSFET is lower than that of a BJT
iii) The MOSFET has higher switching losses than that of a BJT
iv) The MOSFET has lower switching losses than that of a BJT

a) Both i & ii
b) Both ii & iv
c) Both i & iv
d) Only ii

QUICK QUIZ (POLL)

MOSFET has greatest application in digital circuit due to

A. Low power consumption

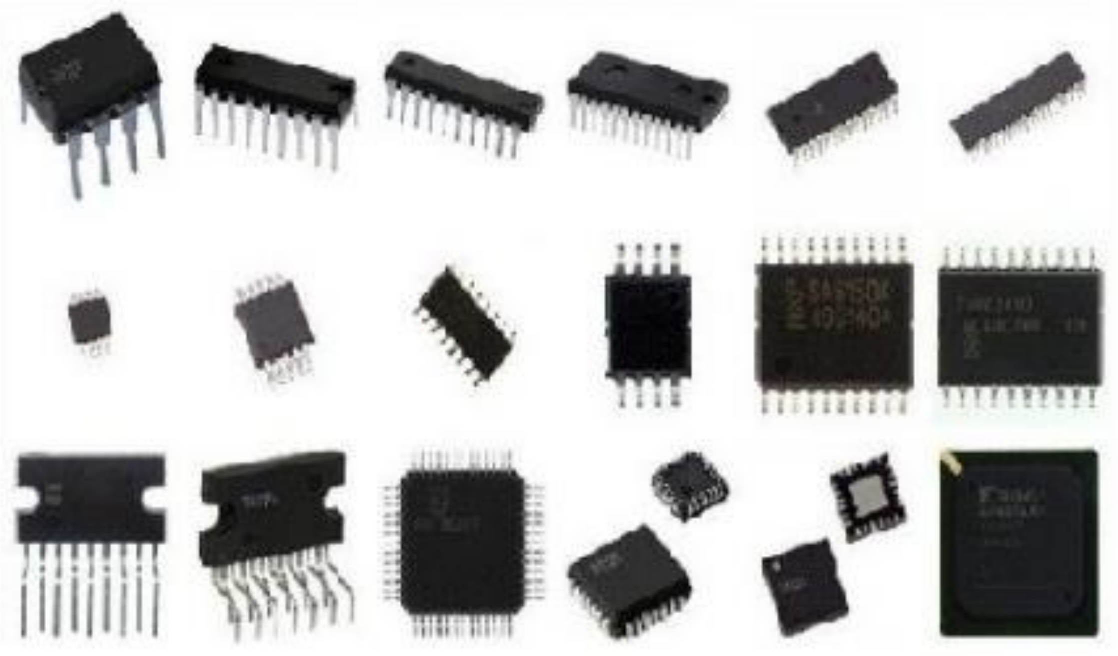
B. Less noise

C. Small amount of space it takes on a chip

D. All of the above

Integrated Circuits

- Integrated circuits (ICs) are a keystone of modern electronics. They are the heart and brains of most circuits. They are the ubiquitous little black "chips" you find on just about every circuit board.
- **Jack Kilby** is probably most famous for his invention of the integrated circuit, for which he received the Nobel Prize in Physics in the year 2000.



Types of Integrated Circuits

Why are ICs popular?

- It is reliable with complex circuits.
- It meets the need for low power consumption.
- It offers small size and weight.
- It is economical to produce.
- It offers new and better solutions to system problems.

Limitations

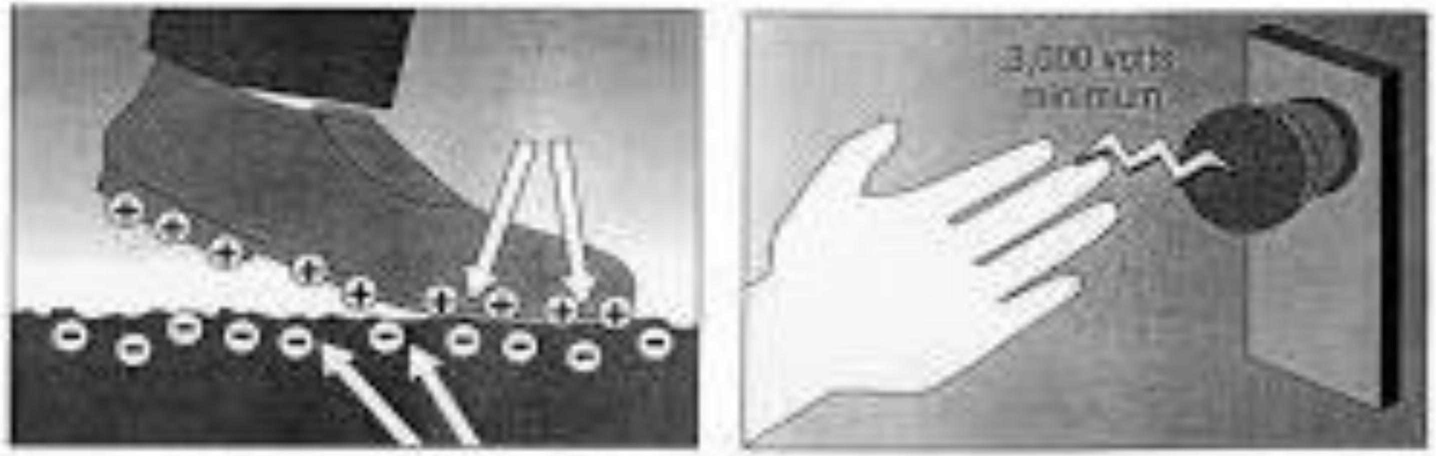
- Coils or indicators cannot be fabricated.
- It can be handle only limited amount of power.
- High voltage operation are not easily obtained.

Electrostatic Discharge (ESD)

- Static electricity is created when two substances are rubbed together or separated. The rubbing or separating causes the transfer of electrons from one substance to the other. This results in one substance being positively charged and the other substance being negatively charged. When either substance comes in contact with a conductor, an electrical current flows until it is at the same electrical potential as ground. This is referred to as electrostatic discharge (ESD).

Electrostatic Discharge (ESD)

- Static electricity is commonly experienced during the winter months when the environment is dry. Synthetics, especially plastic, are excellent generators of static electricity. When walking across a vinyl or carpeted floor and touching a metal door knob or other conductor, an electrical arc to ground may result and a slight shock is felt. For a person to feel a shock, the electrostatic potential must be 3,500 to 4,000 volts. Lesser voltages are not apparent to a person’s nervous system even though they are present.



Potential electrostatic sources.

OBJECT/PROCESS	MATERIAL/ACTIVITY
Clothes	• Synthetic garments • Nonconductive shoes • Virgin cotton at low humidity levels
Chairs	• Finished wood • Vinyl • Fiberglass
Floors	• Sealed concrete • Waxed finished wood • Vinyl tile or sheeting
Work Surface	• Waxed, painted, or varnished surfaces • Vinyl or plastic
Work Area	• Spray cleaners • Plastic solder suckers • Soldering iron with ungrounded tip • Solvent brushes with synthetic bristles • Heat guns
Personal Items	• Styrofoam or plastic drinking cups • Plastic/rubber hair combs or brushes • Cellophane or plastic candy/gum wrappers • Vinyl purses
Packing and Handling	• Regular plastic bags, wraps, envelopes • Bubble wrap or foam packing material • Plastic trays, tote boxes, parts bin

FIGURE 39–28

Electrostatic charges in the work environment.

PROCESS	RELATIVE HUMIDITY LOW (10–20%)	RELATIVE HUMIDITY HIGH (65–90%)
Walking on carpet	35,000 V	1,500 V
Walking on vinyl floor	12,000 V	250 V
Working at workbench	6,000 V	100 V
Work stool padded with urethane foam	18,000 V	1,500 V
Plastic bag picked up from bench	20,000 V	1,200 V
Opening vinyl envelope used for instructions	7,000 V	600 V

FIGURE 39–29

Semiconductor devices that can be damaged by electrostatic discharge.

DEVICE TYPE	SENSITIVITY (VOLTS)
Bipolar transistors	380–7000
CMOS	250–2000
ECL	500
JFET	140–10,000
MOSFET	100–200
Schottky diodes, TTL	300–2500
SCR	680–1000

FIGURE 39–26

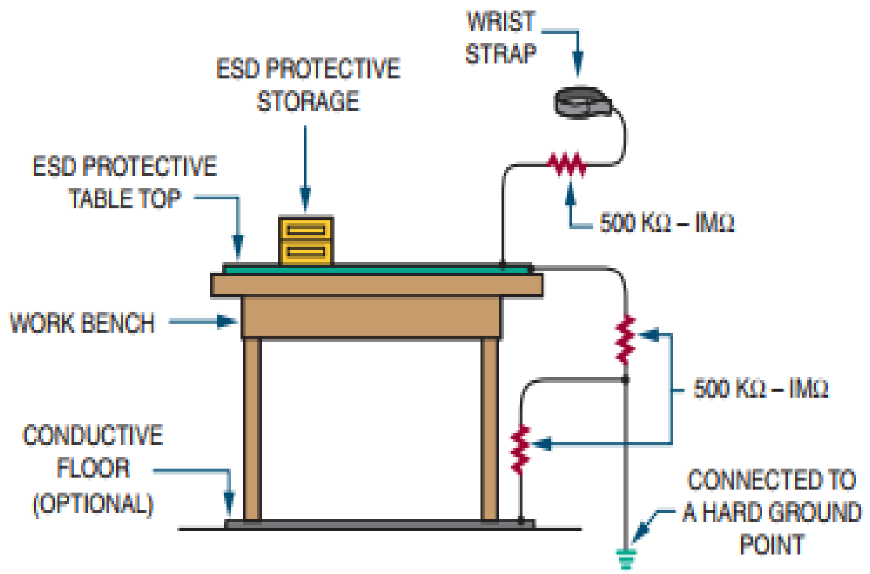
Warning labels for components sensitive to static electricity.

Safety Precautions

- Antistatic workstations (Figure 39–30) are designed to provide a ground path for static charges that could damage a component. They have a conductive or antistatic work surface that is connected to both a ground and the worker’s skin through a wrist strap. The wrist strap has a **minimum** of 500 k resistance to prevent shock in case of contact with a live circuit.

FIGURE 39–30

Antistatic work station.



Safety Precautions

1. Prior to starting work on sensitive electronic equipment or circuits, the electronics technician should be grounded using a wrist strap to discharge any static electric charge built up on the body.
2. Always check manuals and package materials for ESD warnings and instructions.
3. Always discharge the package of an ESD sensitive device prior to removing it. Keep the package grounded until the device is placed in the circuit.
4. Minimize the handling of ESD devices. Handle an ESD device only when ready to place it in the circuit.
5. When handling an ESD device, minimize physical movement such as scuffing feet.
6. When removing and replacing an ESD device, avoid touching the component leads

Safety Precautions

7. Do **not** permit an ESD device to come in contact with clothing or other ungrounded materials that could have an electrostatic discharge.

8. Prior to touching an ESD device, always touch the surface on which it rests for a minimum of one second to provide a discharge path.

9. When working on a circuit containing an ESD device, **do not** touch any material that will create a static charge.

10. Use a soldering iron with the tip grounded. Do not use plastic solder suckers with ESD devices.

End of Unit 4 Syllabus