

E246: Electronics & Instrumentation

Lecture: Transistor Fundamentals:
MOSFET



Plan

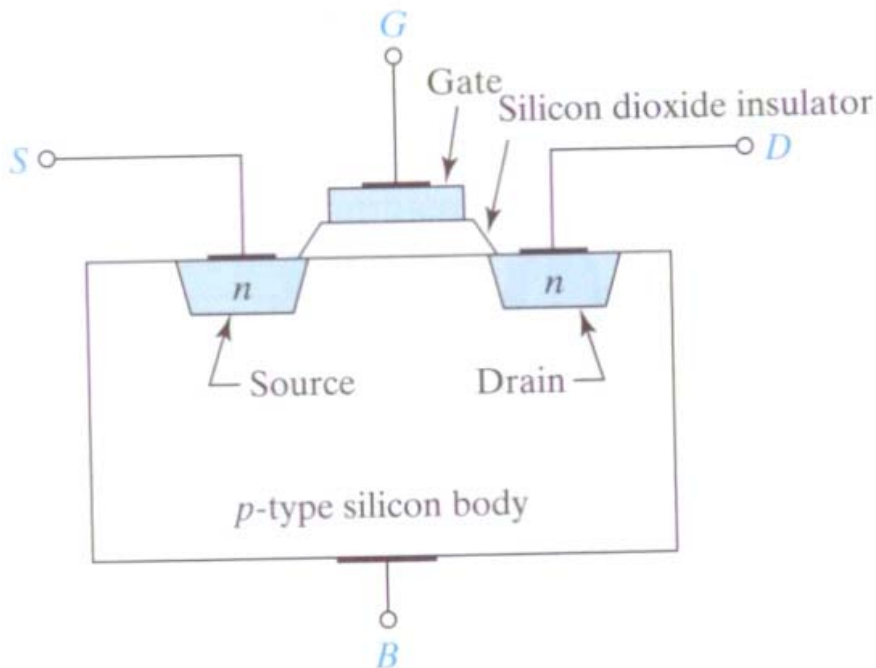
- # Introduction
 - # MOSFET Structure and Operation
 - # MOSFET Output Curves
 - # MOSFET Implementation: The NOT Gate
 - # Sections in Textbook: 11.1-11.4
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Introduction

- # Transistors are electronic devices that acts as an electronically controlled switch in digital circuits and acts as an electronic amplifier in analog circuits
 - # Two basic types of transistors: FET (field effect transistor) and BJT (bipolar junction transistor)
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MOSFET Structure

- MOSFET (metal-oxide-semiconductor FET) is a primary type of FET

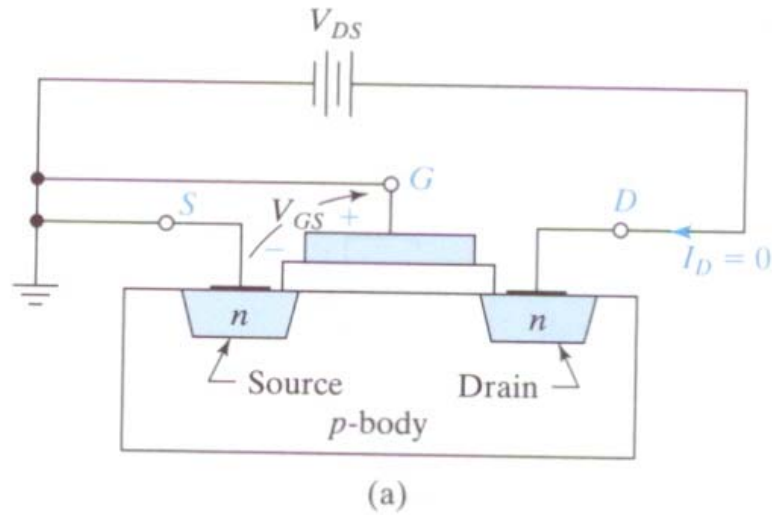


The region between S and D in the substrate just below the gate is called “channel”

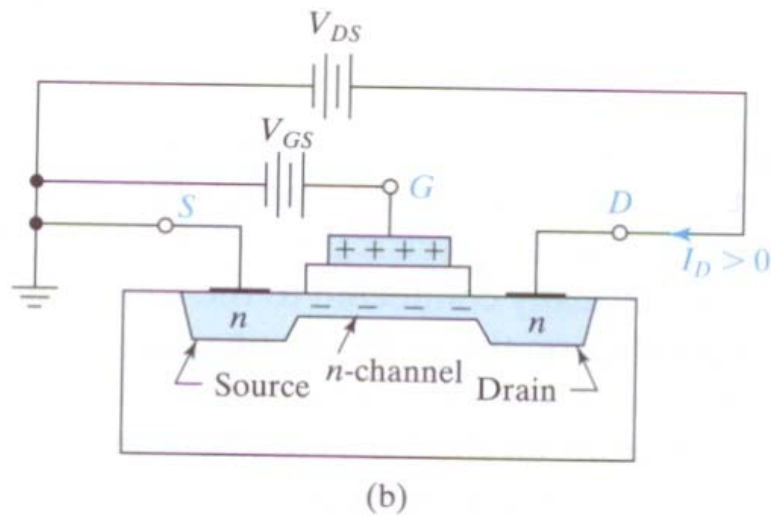
The body is grounded and usually plays little role

MOSFET Operation

- # For current to flow, a channel has to be formed
 - # When a large voltage is applied to the gate, electrons in the p-type substrate are attracted to this voltage
 - # All such electrons come up and accumulate right under the gate forming the channel
 - # Gate voltage controls channel formation, hence the current in the channel.
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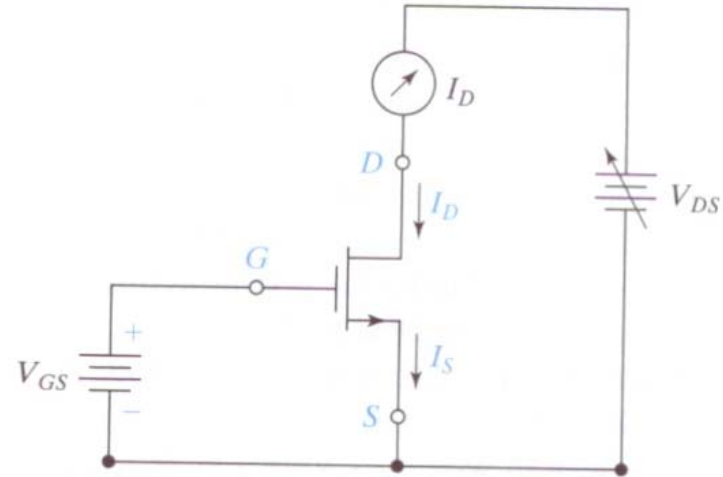
For $V_{GS} = 0$
there is no
conduction; $I_D \approx 0$



For $V_{GS} > V_T$
there is
conduction $I_D > 0$

FIGURE 11.6 The operation of an *n*-channel MOSFET.

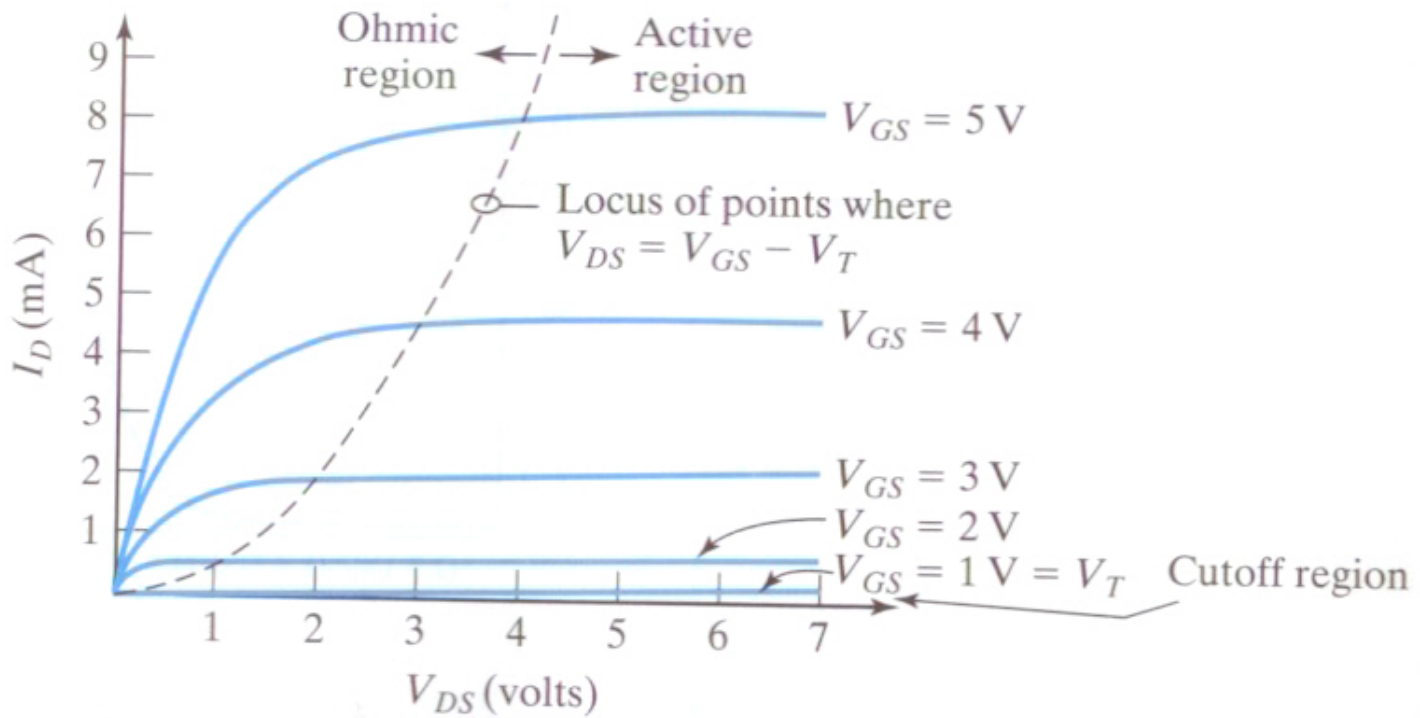
Circuit Model



Region of Operation

- # Region 1: if $V_{GS} < V_T$ (V_T is threshold voltage, i.e., minimum voltage required to form a channel), \Rightarrow cut off (no current)
 - # Region 2: if $V_{DS} < V_{GS} - V_T$, \Rightarrow Ohmic region (or linear region)
 - # Region 3: if $V_{DS} > V_{GS} - V_T$, \Rightarrow saturation region
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Output Curves



Quantity Description

In the Ohmic region,

$$I_D = K \left[2(V_{GS} - V_T)V_{DS} - V_{DS}^2 \right]$$

In the saturation region,

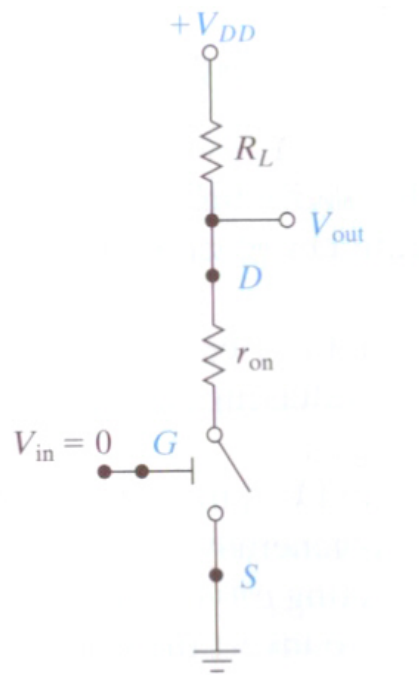
$$I_D = K (V_{GS} - V_T)^2$$

where K is a device parameter.

MOSFET Applications

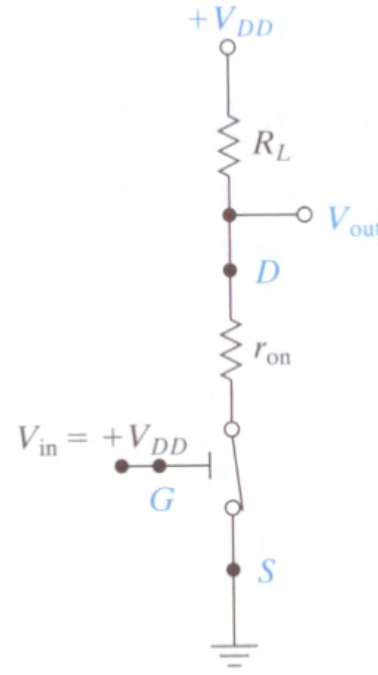
- # In digital circuits, enhanced-model MOSFET acts like a switch, which has a open or closed status. This corresponds to Ohmic operating region of MOSFET.
 - # In amplifier circuits, MOSFET acts as a dependent current source controlled by V_{GS} . This corresponds to saturation operating region of MOSFET.
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The NOT Gate Implementation



For $V_{in} = 0$,
 $V_{in} = V_{GS} = 0$
 $0 \ll V_T$
The switch is open

(a)



For $V_{in} = +V_{DD}$
 $V_{in} = V_{GS} = V_{DD}$
 $V_{DD} \gg V_T$
The switch is closed*

(b)

*and $V_{DS} < V_{GS} - V_T$

For (a), $V_{out} = V_{DD}$,
i.e., low input \Rightarrow high output

For (b), $V_{out} = \frac{r_{on}}{r_{on} + R_L} V_{DD}$

r_{on} is very small, so high input \Rightarrow low output
