Al-Mustaqbal University / College of Technical Engineering
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Lecturer (Dr. Basim Atiyah Khudhair Al-Qargholi)
2nd term – Lecture No: 2. (Introduction to Field Effect Transistors)

Introduction to Field-Effect Transistors (FETs)
Metal–Oxide–Semiconductor FET (MOSFET)

A MOSFET differs from a JFET in that its gate is separated from the channel by a thin insulating layer of silicon dioxide (SiO_2). This structure gives MOSFETs even higher input impedance and allows for two distinct modes of operation:

D-MOSFET: depletion-mode (normally on)
E-MOSFET: enhancement-mode (normally off).

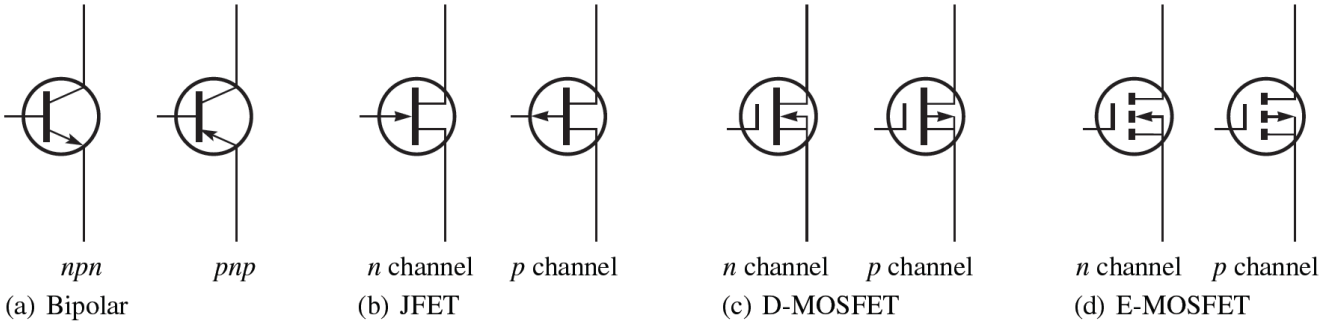

Figure 1Transistor symbols

a) Construction

In an n-channel enhancement-mode MOSFET, the source and drain are heavily doped n-type regions implanted in a lightly doped p-type substrate. A thin layer of SiO_2 insulates a metal (or polysilicon) gate electrode from the substrate. The gate overlaps the region between source and drain but is electrically isolated by the oxide layer. Because of this insulating layer, virtually no DC current flows into the gate – the device's input resistance is on the order of giga-ohms. p-channel MOSFETs are constructed similarly but with opposite doping.

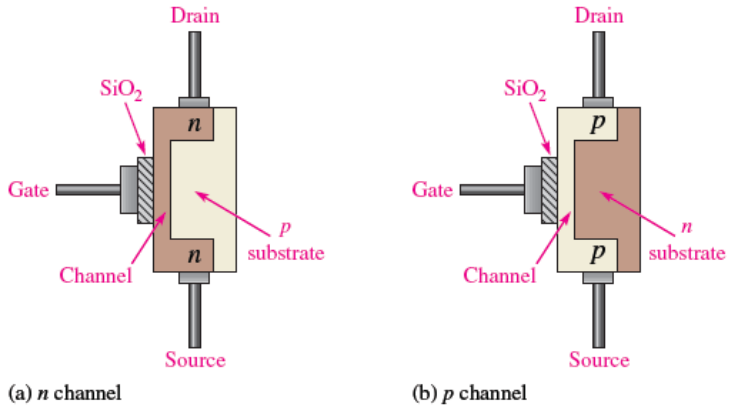

*Figure 2: Cross-section of **a)** n-channel **b)** p-channel enhancement MOSFET. The gate sits above a SiO_2 layer and controls the formation of an inversion channel between source and drain.*

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b) Operation and Characteristics

When a positive gate–source voltage is applied to an n-channel enhancement-mode MOSFET, an electric field pulls electrons toward the interface, creating an inversion layer that forms a conductive channel between source and drain. Important aspects of MOSFET operation include:

- **Threshold voltage (V_{TH}):** A minimum gate-source voltage is required to create the inversion layer. Below V_{TH}, the channel is effectively off. Above V_{TH}, the channel conducts and the drain current increases.
- **Region of operation:** For small drain–source voltages the MOSFET behaves like a variable resistor (ohmic or triode region). As V_{DS} increases, a point is reached where the channel becomes pinched off near the drain and the device enters **saturation**; further increases in V_{DS} produce little change in I_D. The drain current in saturation depends primarily on V_{GS} and is roughly proportional to $(V_{GS} - V_{TH})^2$ for enhancement-mode devices.
- **Depletion-mode MOSFETs:** These devices have a built-in channel at zero bias. Applying a negative gate voltage depletes carriers and reduces the channel conductivity; a positive gate voltage enhances it.
- **High input impedance and fast switching:** Because of the insulated gate, MOSFETs draw negligible gate current and can switch rapidly, making them ubiquitous in CMOS logic circuits and analog switches.

Figure 3 illustrates typical drain characteristics for an enhancement-mode MOSFET. For gate–source voltages of 2 V, 3 V and 4 V (above the threshold), the drain current initially increases linearly with V_{DS} then saturates at a level that grows with increasing V_{GS}.

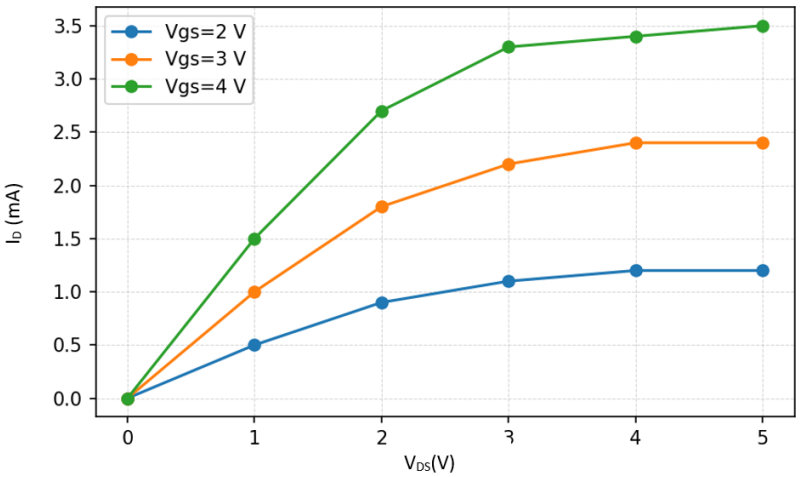

Figure 3: Simulated MOSFET drain–source characteristics for three gate–source voltages. Higher gate voltages create a stronger inversion channel and produce higher saturation currents.

Conclusion

Field-effect transistors are central components of modern electronics. Their ability to control current with an electric field rather than charge injections gives them extremely high input impedance, low power consumption and excellent noise performance. JFETs use a p-n-junction gate to modulate a conductive channel; as the gate–source voltage becomes more negative, the channel narrows until pinch-off and the device behaves as a voltage-controlled current source. MOSFETs insulate their gate with an oxide layer, requiring a threshold voltage to form an inversion layer; their construction enables enhancement- and depletion-mode devices and underpins the entire CMOS technology family. Because MOSFETs can switch extremely fast and are easy to integrate densely, they are used in virtually all digital ICs, while JFETs and MOSFETs alike serve as low-noise amplifiers, analog switches and high-impedance buffers.