Lecture 7A - The MOSFET

The metal oxide semiconductor field-effect transistor (MOSFET). Principle of operation. Output and transfer characteristics. Basic amplifier circuit (Q-point, biasing). Load line.

The MOSFET (*n*-channel)

The metal-oxide-semiconductor field-effect transistor (MOSFET) is the most widely used electronic device – it forms the basis of nearly every digital logic integrated circuit (IC), and is increasingly common in analog ICs.

There are two types of MOSFET – depletion-type and enhancement-type. The enhancement-type MOSFET is the mot widely used. An enhancement-type MOSFET is formed by the following process. Starting with a *p*-type *substrate*, two heavily doped *n*-type regions, called the *source* and *drain*, are created. A thin layer of silicon dioxide (SiO_2) is grown on the surface of the substrate between the drain and the source. Metal is deposited on top of the oxide layer, to from the *gate*. Metal contacts are also made to the source, drain and substrate (also known as the *body*). The device therefore has four terminals – gate (G), source (S), drain (D) and body (B).

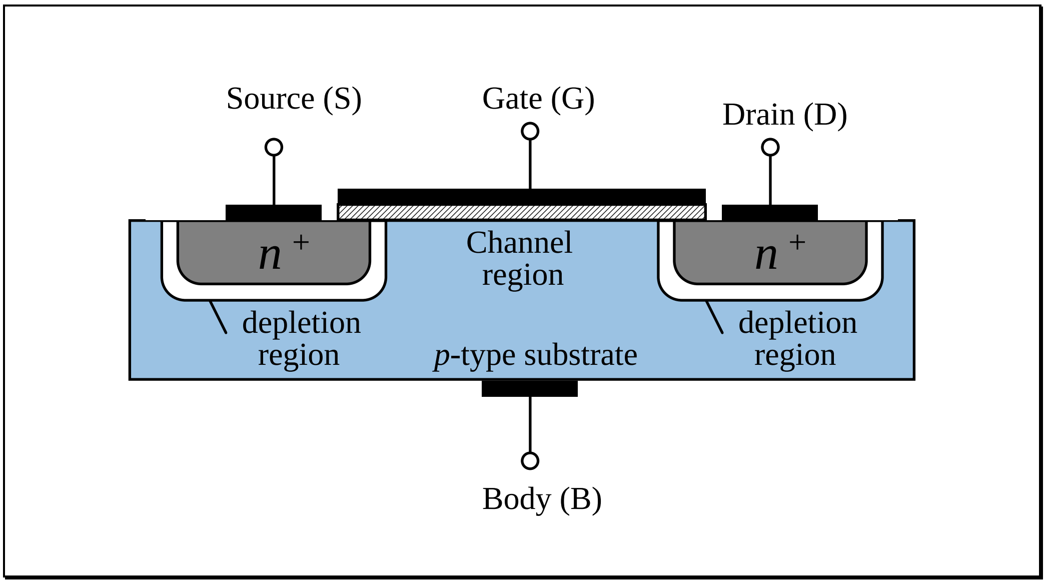

Figure 7A.1 – MOSFET Device Structure

7A.2

The substrate forms a *p*-*n* junction with the source and drain regions, which are normally kept reverse-biased by connecting the substrate to the source. The MOSFET can then be treated as a three-terminal device.

A positive voltage applied to the gate will induce an *n*-type channel between drain and source (the channel is induced by the attraction of electrons from the heavily doped source and drain regions to the region beneath the positively charged gate electrode). This channel then allows conduction between the drain and the source, and the MOSFET is called an *n*-channel MOSFET, or an NMOS transistor.

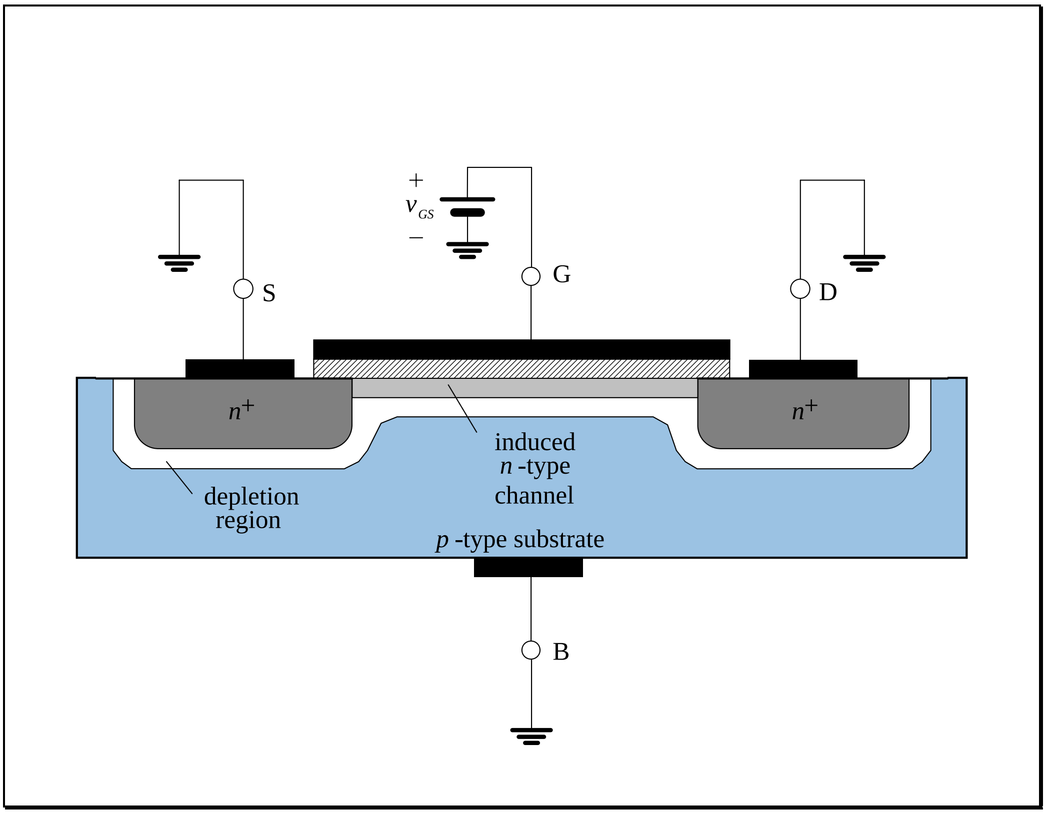

Figure 7A.2 – MOSFET with Induced Channel

The value of v_{GS} at which a conducting channel is induced is called the *threshold voltage*, and is denoted by V_t. For an *n*-channel MOSFET, the threshold voltage is positive.

Once a channel is induced, if a small voltage v_{DS} is applied between drain and source, then there will be a current between drain and source. The channel effectively looks like a resistor. If we increase the gate voltage, more charge will be induced into the channel, the channel will grow, and the resistance will fall. Thus, the gate voltage controls the resistance of the channel, and hence the current between drain and source. This operation forms the basis of a transistor – one terminal of the device controls the current between the other two terminals.

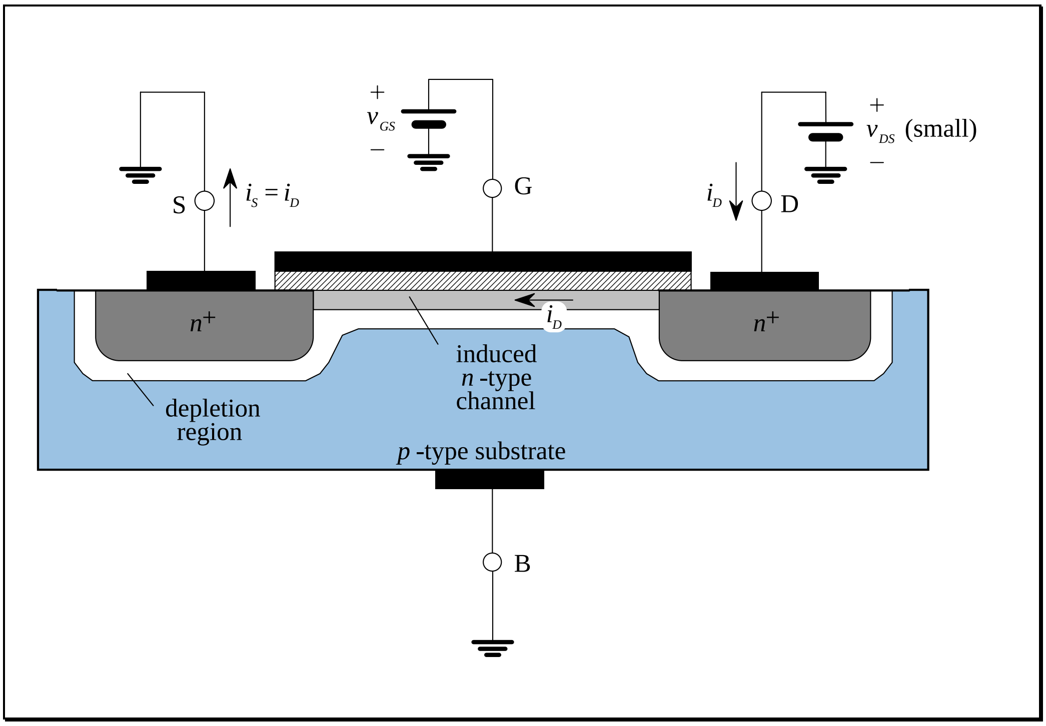

Figure 7A.3

As the voltage between the drain and source is increased, v_{DS} appears as a voltage drop across the length of the channel. The channel now appears tapered. When v_{DS} is increased to a value that reduces the voltage between the gate and the channel at the drain end to V_t, the channel depth decreases to almost zero and is said to be *pinched off*. Further increases in v_{DS} cannot change the channel shape, and so the current in the channel remains constant at the value reached at pinch off. The MOSFET is said to enter the *saturation region*, and the voltage v_{DS} at which this occurs is given by:

$$\boxed{v_{DS\text{sat}} = v_{GS} - V_t} \qquad (7A.1)$$

It can be shown that in the saturation region, the relationship between drain current and gate-source voltage is given by:

$$\boxed{i_D = K(v_{GS} - V_t)^2} \tag{7A.2}$$

where K is a value that is dependent on the device construction.

References

Sedra, A. and Smith, K.: *Microelectronic Circuits*, Saunders College Publishing, New York, 1991.