3.6. Metal-Semiconductor Field Effect Transistor (MESFETs)

The Metal-Semiconductor-Field-Effect-Transistor (MESFET) consists of a conducting channel positioned between a source and drain contact region as shown in the Figure 3.6.1. The carrier flow from source to drain is controlled by a Schottky metal gate. The control of the channel is obtained by varying the depletion layer width underneath the metal contact which modulates the thickness of the conducting channel and thereby the current between source and drain.

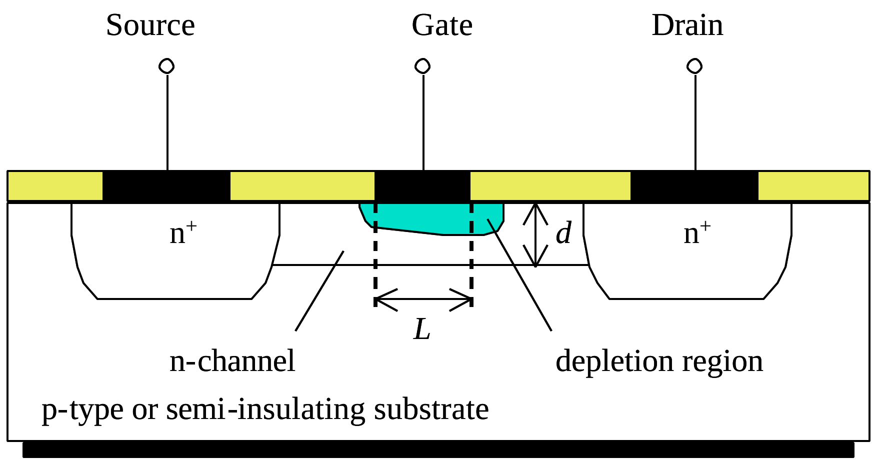

Figure 3.6.1 Structure of a MESFET with gatelength *L* and channel thickness *d*.

The key advantage of the MESFET is the higher mobility of the carriers in the channel as compared to the MOSFET. Since the carriers located in the inversion layer of a MOSFET have a wavefunction, which extends into the oxide, their mobility - also referred to as surface mobility - is less than half of the mobility of bulk material. As the depletion region separates the carriers from the surface their mobility is close to that of bulk material. The higher mobility leads to a higher current, transconductance and transit frequency of the device.

The disadvantage of the MESFET structure is the presence of the Schottky metal gate. It limits the forward bias voltage on the gate to the turn-on voltage of the Schottky diode. This turn-on voltage is typically 0.7 V for GaAs Schottky diodes. The threshold voltage therefore must be lower than this turn-on voltage. As a result it is more difficult to fabricate circuits containing a large number of enhancement-mode MESFET.

The higher transit frequency of the MESFET makes it particularly of interest for microwave circuits. While the advantage of the MESFET provides a superior microwave amplifier or circuit, the limitation by the diode turn-on is easily tolerated. Typically depletion-mode devices are used since they provide a larger current and larger transconductance and the circuits contain only a few transistors, so that threshold control is not a limiting factor. The buried channel also yields a better noise performance as trapping and release of carriers into and from surface states and defects is eliminated.

The use of GaAs rather than silicon MESFETs provides two more significant advantages: first of all the room temperature mobility is more than 5 times larger, while the saturation velocity is about twice that in silicon. Second it is possible to fabricate semi-insulating (SI) GaAs substrates, which eliminates the problem of absorbing microwave power in the substrate due to free carrier absorption.

The threshold voltage, V_T, of a MESFET is the voltage required to fully deplete the doped channel layer. This threshold voltage equals:

$$V_T = f_i - \frac{qN_d d^2}{2e_s} \tag{3.6.1}$$

where f_i is the built-in potential and d is the thickness of the doped region. This threshold voltage can also be written as a function of the pinch-off voltage V_P:

$$V_T = f_i - V_P \tag{3.6.2}$$

Where the pinch-off voltage equals:

$$V_P = \frac{qN_d d^2}{2e_s} \tag{3.6.3}$$

The derivation of the current in a MESFET starts by considering a small section of the device between y and $y + dy$. The current density at that point can be written as a function of the gradient of the channel voltage:

$$J = qnv = qN_d m_n E = -qN_d m_n \frac{dV_C(y)}{dy} \tag{3.6.4}$$

The drain current is related to the current density and the part of the MESFET channel that is not depleted.

$$I_D = -JW(d - x_n(y)) \tag{3.6.5}$$

Where the depletion layer width at position y is related to the channel voltage, $V_C(y)$

$$x_n(y) = \sqrt{\frac{2e_s(f_i - V_G + V_C(y))}{qN_d}} \tag{3.6.6}$$

The equation for the current can now be integrated from source to drain, yielding:

$$\int_0^L I_D\, dy = qN_d m_n dW \int_0^{V_D} (1 - \sqrt{\frac{f_i - V_G + V_C}{V_P}})\, dV_C \tag{3.6.7}$$

Since the steady-state current in the device is independent of position, the left hand term equals $I_D L$ so that:

$$I_D = qN_d m_n d \frac{W}{L}(V_C\Big|_0^{V_D} - \frac{(f_i - V_G + V_C)^{3/2}}{\sqrt{V_P}}\Bigg|_0^{V_D}) \tag{3.6.8}$$

Two regions:

quadratic region where the depletion layer is less than the channel thickness d

$$I_D = qm_n N_d d \frac{W}{L}\left[V_D - \frac{2}{3}\left(\frac{(f_i - V_G + V_D)^{3/2}}{\sqrt{V_P}} - \frac{(f_i - V_G)^{3/2}}{\sqrt{V_P}}\right)\right] \tag{3.6.9}$$

saturated region where the depletion layer at the drain end equals the channel thickness d

$$V_{D,sat} = V_G - V_T \tag{3.6.10}$$

The drain current become independent of the drain voltage and equals:

$$I_{D,sat} = qm_n N_d d \frac{W}{L}\left[V_G - V_T - \frac{2}{3}\left(V_P - \frac{(f_i - V_G)^{3/2}}{\sqrt{V_P}}\right)\right] \tag{3.6.11}$$

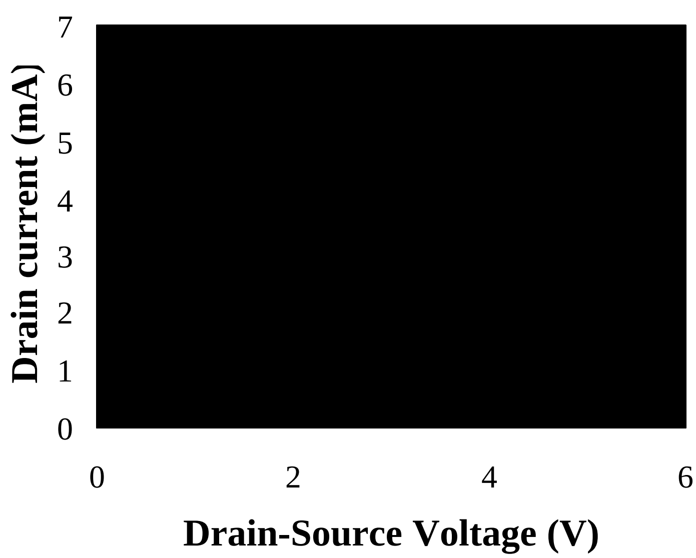

Figure 3.6.2 Drain current versus Drain-Source voltage at a gate-source voltage of 0.2, 0.4, 0.6 0.8 and 1.0 Volt for a silicon MESFET with built-in potential of 1 V. Channel parameters and device dimensions are listed in the table below.

Parameter	**Symbol**	**Value**
Channel width	*W*	1 mm

Channel length	L	1 µm
Channel mobility	m_n	100 cm^2/V-s
Channel doping	N_d	10^{17} cm^{-3}
Channel thickness	D	115 nm
Built-in potential	f_I	1 V

Table 3.6.1 MESFET parameters

The transfer characteristic of a MESFET is shown in /8.

Figure **3.6.3** and compared to a quadratic expression of the form:

$$I_{D,sat} = m_n \frac{e_s}{\overline{w}} \frac{W}{L} \frac{(V_G - V_T)^2}{2} \quad (3.6.12)$$

where $\overline{w}$ is the average depletion layer width in the channel layer. The quadratic expression yields the same current at $V_G = f_i$ for $\overline{w} = 3d/8$.

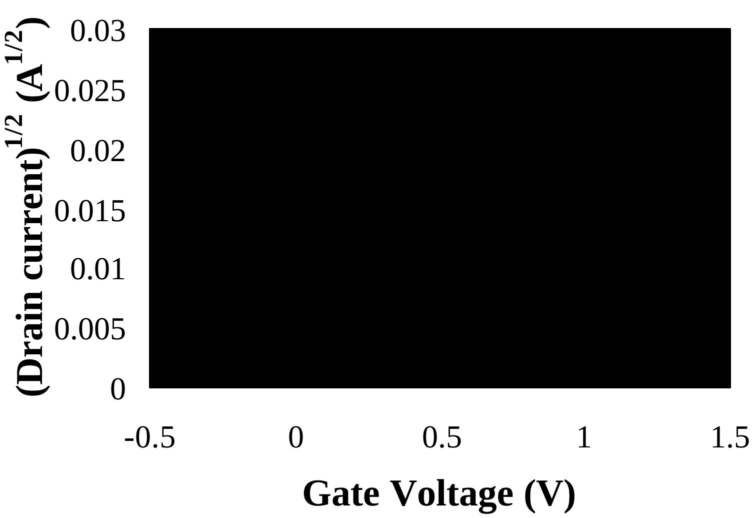

Figure 3.6.3 Transfer characteristic of a MESFET. Shown is the square root of the drain current of the MESFET (solid line) and a quadratic fit with $\overline{w}$ =3d/8.