Semiconductor Technology from A to Z

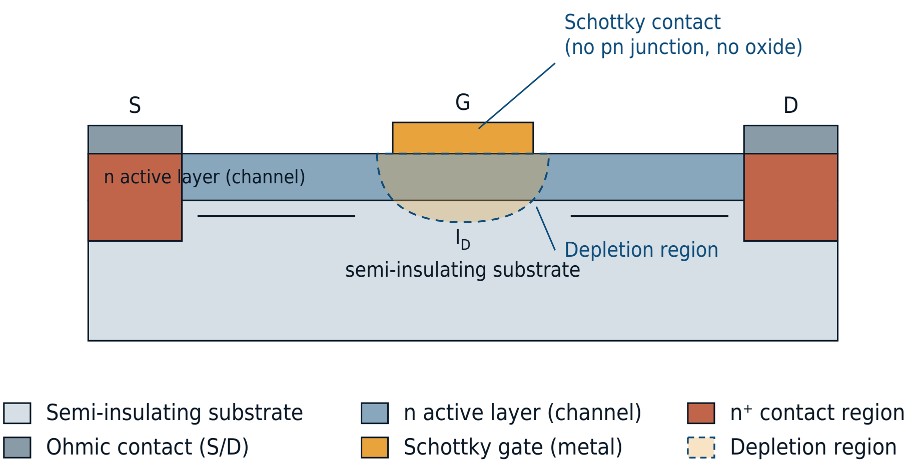
Devices

The Metal-Semiconductor FET (MESFET)

Structure

The MESFET is typically fabricated on a semi-insulating substrate (for GaAs, usually chromium-doped or undoped with deep trap states), which conducts practically no current when unbiased. A thin, lightly doped active layer is introduced into this substrate, usually by ion implantation or epitaxy – this forms the actual conduction channel. Source and drain are connected via heavily doped regions with ohmic contacts. The gate consists of a metal deposited directly on the semiconductor, forming a Schottky contact with the channel beneath it – unlike the JFET, there is therefore no pn junction here, and unlike the MOSFET, no insulating oxide layer between gate and channel.

Structure of a MESFET (Metal-Semiconductor FET)
Schottky gate on a semi-insulating GaAs substrate



The gate metal forms a Schottky contact directly with the n-channel. Even without an applied voltage, a depletion region forms beneath it; a negative gate voltage widens it and pinches off the channel — similar to the JFET, but without a pn junction or gate oxide.

Operation: Schottky Barrier and Depletion Region

At any metal-semiconductor junction with sufficient barrier height, a depletion region forms in the semiconductor even without an applied voltage, its width depending on the built-in Schottky barrier potential. Applying a negative gate-source voltage widens this depletion region and increasingly pinches off the underlying channel – the operating principle is thus essentially the same as that of the JFET, only with a Schottky junction instead of a pn junction as the control element. The Shockley relationship between I_D, V_{GS}, and a pinch-off voltage V_p applies approximately to the MESFET as well, with the exact channel geometry (thickness and doping of the active layer) determining the device parameters.

Operating Modes: D-MESFET and E-MESFET

If the active layer is thick enough or doped highly enough that a conductive residual channel already exists at $V_{GS} = 0\,V$, the device is a depletion-mode type (D-MESFET, “normally-on”) – the classic case that dominates RF technology. If instead the active layer is made thin and lightly doped enough that the built-in depletion region already fills the entire channel at $V_{GS} = 0\,V$, the result is an enhancement-mode type (E-MESFET, “normally-off”), which only becomes conductive once a positive gate voltage is applied. This combination of D- and E-MESFETs on a single chip enabled so-called DCFL logic (Direct Coupled FET Logic) in the 1980s and 90s – a fast, if power-hungry, form of GaAs digital logic used, among other things, in early supercomputers and satellite applications.

Material System, Advantages and Drawbacks

MESFETs are fabricated almost exclusively in III-V compound semiconductors such as GaAs or InP, since – unlike silicon – these materials do not form a stable, low-defect native oxide suitable for a MOS structure; the Schottky contact elegantly sidesteps this problem. The significantly higher electron mobility of GaAs compared to silicon enables very high cutoff frequencies and low noise at high frequencies. Drawbacks include higher gate leakage current compared to the MOSFET (a Schottky contact blocks less effectively than an oxide layer), pronounced sensitivity to surface states and traps in the substrate, which can cause drift and delay effects, and limited scalability of gate length, since very short channels lead to short-channel effects and poorer control of the channel potential.

Applications and Outlook

For decades, MESFETs were the dominant transistor technology for radio-frequency and microwave applications such as satellite communications, radar, and low-noise RF amplifiers (LNAs). In recent decades they have increasingly been displaced in many of these applications by the HEMT (High-Electron-Mobility Transistor), which achieves even higher electron mobilities and cutoff frequencies through heterostructure-based channel formation (e.g. AlGaAs/GaAs or GaN-based). Nonetheless, the MESFET remains relevant as a conceptual predecessor and, owing to its comparatively simple fabrication process, in certain niche applications.