Impact of gate currents on III-N HFET performance

RF Power saturation correlates with the gate current increase
Impact of gate currents on III-N HFET performance

RF Power degradation correlates with the gate current increase
HFET power triangle

Mechanism of dynamic gate current increase at large input signals, peak gate voltage may be positive: $V_{GS} > 0$
when the gate voltage goes positive, the drain voltage decreases; the gate – drain voltage also becomes positive: $V_{GD} > 0$;
Impact of gate currents on III-N HFET performance

SPICE simulation of the HFET voltages and currents at high input RF powers

Gate Leakage Currents Cause RF Power Limitations, Degradation, Noise
Insulated Gate HFET approach:
reducing the gate leakage current (10^4 - 10^6 times)

MOSHFET (SiO₂)

MISHFET (Si₃N₄)

SiO$_2$/AlGaN/GaN MOSHFET Fabrication

1. Start with regular AlGaN/GaN HFET structure over i-SiC or Sapphire

2. Ti/Al/Ti/Au Ohmic Contact Deposition and Anneal

3. PECVD Dielectric Deposition

4. E-beam Gate Writing

5. Probe contacts formation and plating
MOSHFET basic properties

MOSHFET: Depletion mode (normally-on) MOSFET with 2DEG channel

![MOSHFET schematic](image)

- $W_g = 200\mu m$
- $L_g = 0.3\mu m$
- $V_{DS} = 20V$

- $I_{DS}$ (A/mm)
- $V_{GS}$ (V)

- HFET
- MOSHFET
MOSHFET gate currents are ~ 4 orders lower compared to HFET

MOSHFET gate currents are low at POSITIVE gate bias

MOSHFET gate currents are low even at 150 C

\[ I_g = I_o \exp\left(-\frac{q\Delta}{kT}\right)\left(\exp\left(\frac{qV_g}{n(T)kT}\right) - 1\right) \]

\[ \Delta = 0.496eV, \quad I_o = 490A/cm^2, \quad n(T) = 80 \]
First High-performance MOSHFETs – USC 2000

High positive gate current operation

$V_{gs} = +9\text{V}$

$I_d (\text{mA/mm})$

$V_{ds}(\text{V})$

-6 V

-3 V

0 V

+3 V

+6 V


$M.\text{ Asif Khan Appl.Phys.Lett. v. 77 pp 1339-1341 (2000)}$

MOSHFET vs. HFET: Threshold and Knee Voltages

Gate capacitance:

\[ C_{MOS} = \frac{\varepsilon \varepsilon_B}{d_B} \left( 1 + \frac{d_{OX}}{d_B} \frac{\varepsilon_B}{\varepsilon_{OX}} \right)^{-1} = C_{MS} \left( 1 + \frac{d_{OX}}{d_B} \frac{\varepsilon_B}{\varepsilon_{OX}} \right)^{-1} \]

Threshold voltage:

\[ V_{TMOS} = V_{TMS} C_{MS} / C_{MOS} = V_{TMS} \left( 1 + \frac{d_{OX}}{d_B} \frac{\varepsilon_B}{\varepsilon_{OX}} \right) \]

Knee voltage (a.k.a. \( V_{SAT} \)) for sub-micron gate devices:

\[ V_{KN} = E_S \cdot L_G + I_S \left( R_S + R_D \right) \]

\[ V_{KN MOSHFET} \sim V_{KN HFET} \]

MOSHFET cut-off frequencies

\[ f_T \text{ MOSHFET} \approx 40 \text{ GHz} \]

\[ f_{\text{MAX}} \text{ MOSHFET} \approx 82 \text{ GHz} \]

\[ \left( \frac{g_m}{C_g} \right)_{\text{HFET}} \approx \left( \frac{g_m}{C_g} \right)_{\text{MOSHFET}} \]

\[ f_T = \frac{g_m}{2 \pi C_g} \approx \frac{V_S}{2 \pi L} \]

\[ f_{T \text{ MOSHFET}} \approx f_{T \text{ HFET}} \approx 40 \text{ GHz} \]

\[ f_{\text{MAX}} \text{ MOSHFET} \approx f_{\text{MAX}} \text{ HFET} \approx 82 \text{ GHz} \]
10GHz CW; $V_D=35V$; 0.25x100 $\mu$m;

MOSHFET vs. HFET RF output powers
High-power Field-plated MOSHFET

![Diagram of Field-plated MOSHFET structure](image)

**Graph:**
- **RF Power, W/mm** vs. **Drain Voltage, V**
- **MOSHFET**
  - ■ with FP
  - ▼ w/o FP

**Layers:**
- **i-SiC**
- **Al$_x$Ga$_{1-x}$N barrier**
- **i-GaN**
- **Buffer**
- **FP dielectric**
- **FP**
Field-plated MOSFET RF power stability

![Graph showing power stability over time for MOSFET and HFET.

- Power, W/mm is plotted against Time, Hours.
- MOSFET and HFET are compared.
- Gate Current, mA is plotted against Time, ns.
- Voltage, V is also shown.

Legend:
- MOSFET
- HFET
- Gate Current, mA
- Voltage, V
- Time, ns
- Time, Hours

The graph illustrates the stability of power output for MOSFET and HFET over time, highlighting the differences in performance and stability between the two.