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SIMULATION ANALYSIS of a GaN MESFET

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Abstract*-A simulation analysis for the I-V characteristics of n-doped GaN metal semiconductor field-effect transistors (MESFET) has been presented in COMSOL Multiphysics. The analysis considers the response of a GaN MESFET with respect of different drain and gate voltages. The simulation also includes the surface analysis of electron concentration, hole concentration and electric potential. The results indicate very good performance of the GaN MESFET device as prospect of others material based MESFET devices.*

Keywords: MESFET, GaN, I-V characterization, Surface analysis, COMSOL.

1. INTRODUCTION

Recently, growing interest has been paid over the wide bandgap (WBG) materials such as GaN [1] because of its low thermal generation rates and high breakdown fields, for its potential use in high-power [2], high-temperature [3], and microwave [4] applications. The use of GaN based devices as efficient, linear, high power RF amplifiers is expected to create an entirely new and low life cycle cost advanced multifunctional RF systems (AMRFS) for military applications. 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 key advantage of the MESFET is the higher mobility of the carriers in the channel as compared to the MOSFET. GaN based transistors such as metal-semiconductor field-effect transistors (MESFETs) [5]–[7] and AlGaN/GaNheterostructure field effect transistors (HFETs) [8] have been fabricated and reported by several groups.

The purpose of this paper is to present a simulation model for analyze the DC characteristics of an n-doped GaN MESFET. In addition, surface formulation analysis of electron concentration area, hole concentration area and electric potential is also investigated. Surface analysis of GaN MESFET represents the expecting electron and hole concentration surfaces with different drain and gate voltages. The V_{ds}-I_{ds} analysis presents the majority carrier current with gate and drain voltages.

2. SIMULATION THEORY AND MODEL

The cross-sectional view of MESFET is shown in Fig.1. The fundamental physical mechanism arising in

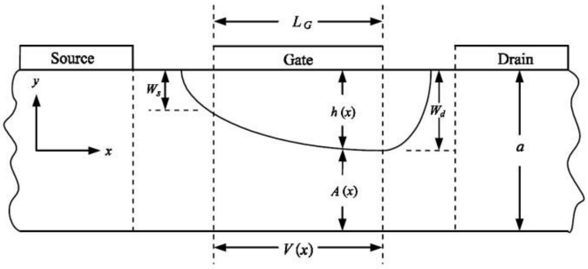

Fig.1: Cross sectional view of MESFETs.

optical illumination of the MESFET is the production of free carriers within the semiconductor material. The threshold voltage, V_T, of a MESFET is the voltage required to fully deplete the doped channel layer.

This threshold voltage equals:

$$V_T = \phi - \frac{qN_d d^2}{2\epsilon} \quad (1)$$

Where, ϕ is the built-in potential and d is the thickness of the doped region.

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

$$I_d = qN_d\mu_n d\frac{W_d}{L}\left(V_S \Big|_0^{V_d} - \frac{(\phi - V_g + V_S)^{\frac{3}{2}}}{\sqrt{V}_p}\Big|_0^{V_d}\right) \quad (2)$$

Where V_P the pinch-off voltage, which equals:

$$V_P = \frac{qN_d d^2}{2\epsilon} \quad (3)$$

The integration results in:

$$I_d = q\mu_n N_d d \frac{W_d}{L}\left[V_d - \frac{2}{3}\left(\frac{(\phi - V_g + V_d)^{\frac{3}{2}}}{\sqrt{V_P}} - \frac{(\phi - V_g)^{\frac{3}{2}}}{\sqrt{V_P}}\right)\right] \quad (4)$$

Now, the corresponding current is the saturation current, $I_{d,sat}$:

$$I_{d,sat} = q\mu_n N_d d \frac{W_d}{L}\left[V_g - V_T - \frac{2}{3}\left(V_P - \frac{(\phi - V_g)^{\frac{3}{2}}}{\sqrt{V_P}}\right)\right] \quad (5)$$

The parameters which used in the simulation model are shown on the Table 1.

The simulation work is done with COMSOL Multiphysics 4.4 software. For characterize the GaN, relative permittivity, band gap, electron affinity, Effective density of states (valance band), Effective density of states (conduction band), electron mobility and hole mobility is considered. The simulation analysis is investigating the DC characteristics of GaN MESFET by varying gate voltage (V_g) from 0V to 3V and drain voltage (V_d) from 0V to 10V. Besides, surface analysis of GaN MESFET is done by varying gate voltage (V_g) from 0V to 2V and drain voltage (V_d) from 0V to 5V. The simulation result shows the accepting characteristics of MESFETs.

Table 1: Parameters used in the simulation

Name	Value	Description
L	0.5μm	Gate length
W_d	2μm	Device width
H_d	0.25m	Device height
W_S	0.5μm	Source width
W_{dd}	0.5μm	Drain width
V_g	0V	Gate voltage
V_d	0V	Drain voltage
V_S	0V	Source voltage
N_d	$1 \times 10^{16} cm^{-3}$	Doping concentration

3. SIMULATION RESULTS AND DISCUSSION

For a n-doped material the electron concentration is expected to be orders of magnitude larger than the hole concentration. Fig.2 shows the surface analysis of 2μm × 0.25m GaN MESFET device. Its shows the electron concentration, hole concentration and the electric potential at different values of the drain voltage for a gate voltage of 0 V. It's seemed that, the electron concentration is larger magnitude on the two sides of MESFET devices. With the increase of the drain voltage the length of the hole concentration area is increased and electron concentration area is decreased vice-versa.

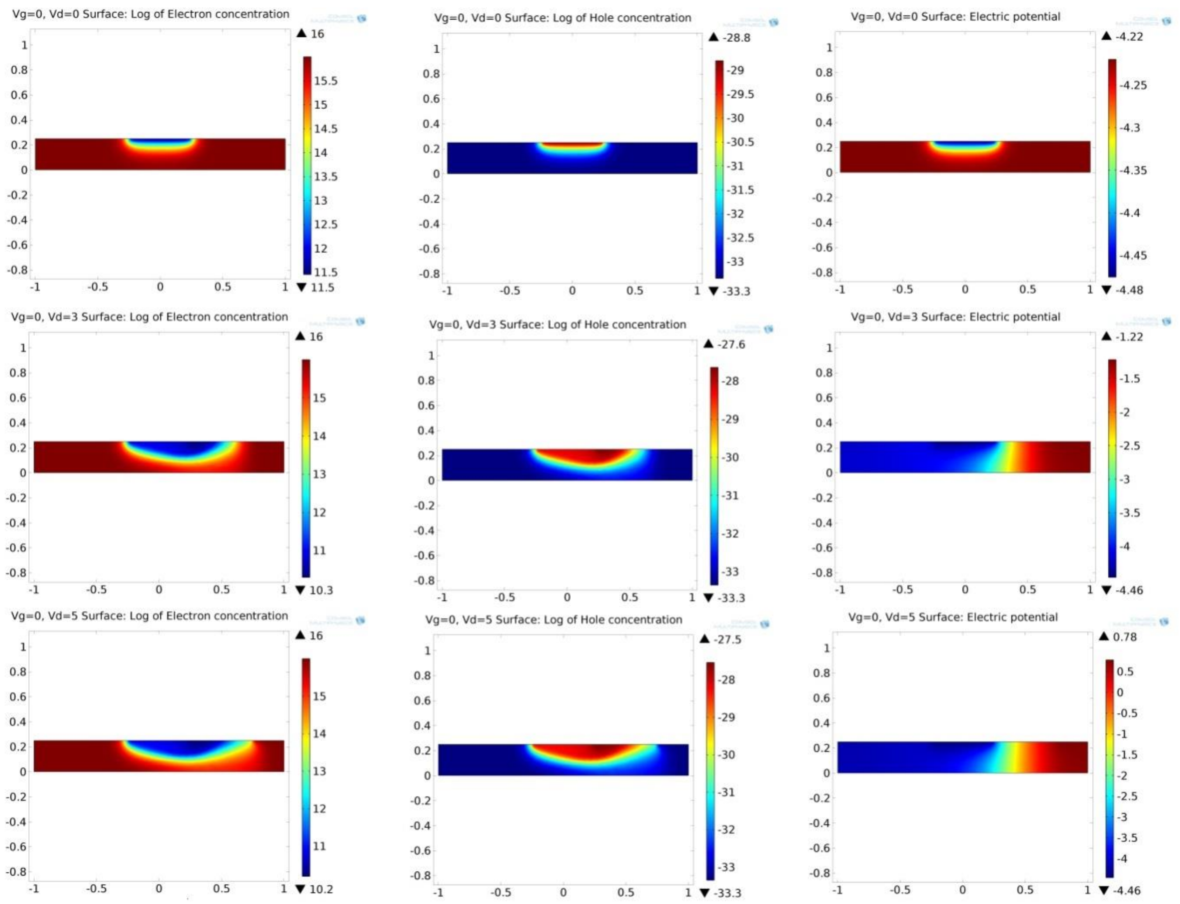

Fig.2: Left: Electron concentration for different drain voltage, Middle: Hole Electron concentration for different drain voltage and Right: Electric Potential for different drain voltage when gate voltage is fixed at 0V.

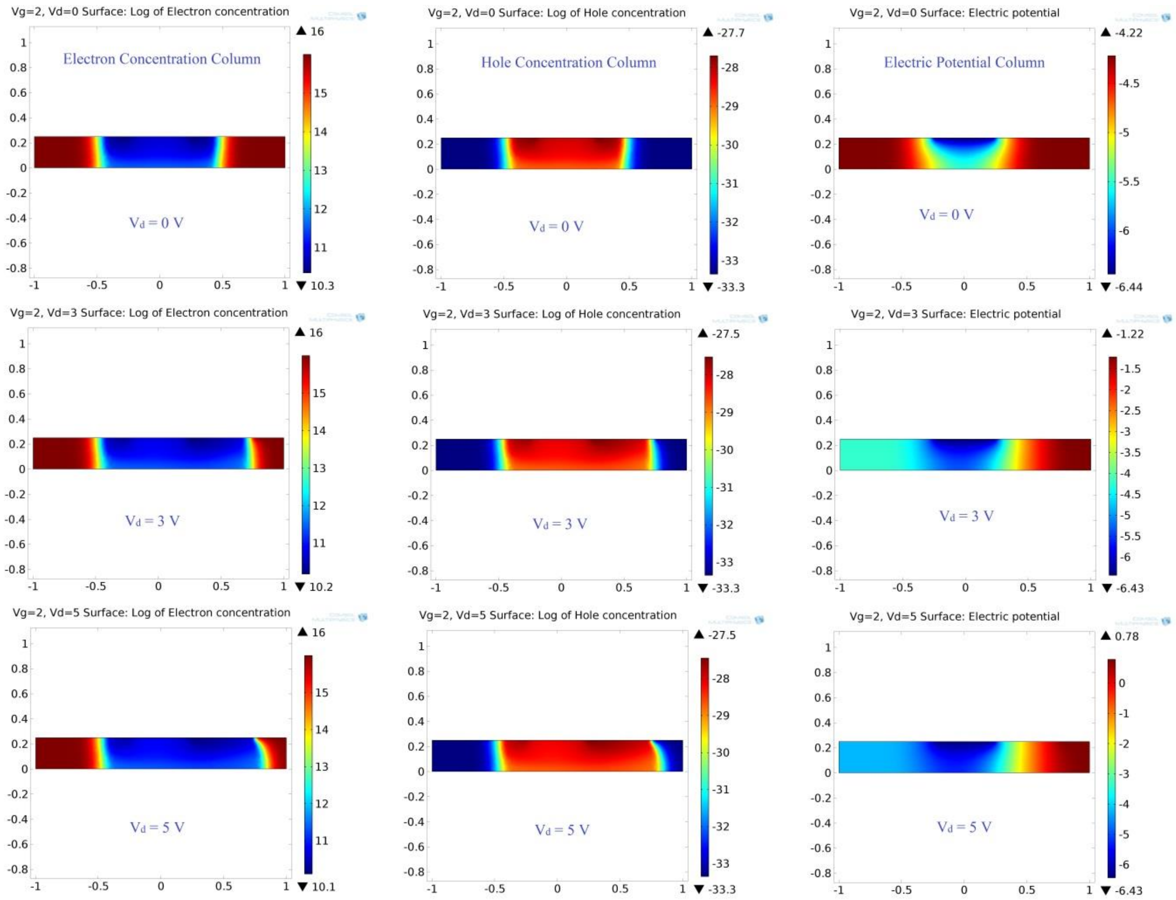

Fig.3: Left: Electron concentration for different drain voltage, Middle: Hole Electron concentration for different drain voltage and Right: Electric Potential for different drain voltage when gate voltage is fixed at 2V.

Fig.3 shows the electron concentration area, hole concentration area and the electric potential at different values of the drain voltage for a gate voltage of 2 V. In similar with Fig. 2, with the increase of the drain voltage the length of the hole concentration area is increased and electron concentration area length is decreased vice-versa. The length of the hole concentration area of gate voltage 0V is greater than the length of gate voltage 2V.

Fig.4 shows the drain-source current (I_{ds}) vs drain-source (V_{ds}) voltage curves of 4μm × 0.5μm GaN MESFET for different values of the gate voltage.

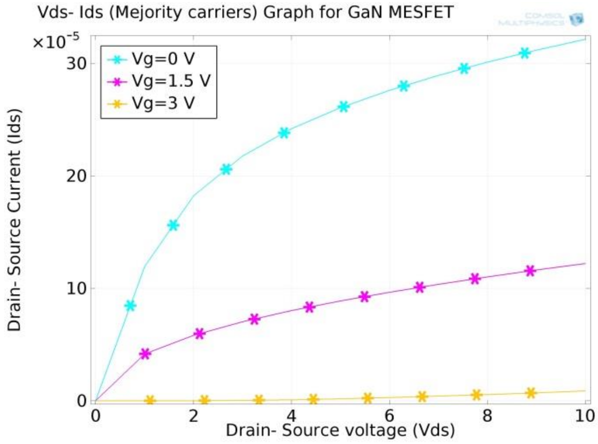

Fig.4: V_{ds}-I_{ds} graph for GaN MESFET.

It's seemed that the drain current I_{ds} is increasing with increasing drain to source voltage V_{ds} for different gate voltages. The gate voltage V_g was varied from 0V to 3V in steps of 1.5 V. The curve shows three regions: a linear region at low voltages, a nonlinear region at intermediate voltages and an approximately constant region at higher voltages (the saturation region). The current saturation occurs due to a phenomenon known as pinch–off. As the drain voltage is increased more current flows along the channel and the potential drop along its length increases.
The simulation model provides a basic understanding of the operational modes surface analysis of the GaN MESFET. The V_{ds}-I_{ds} graph shows the output Dc characteristics of MESFET. The output results are in close agreement with respect of the other material based MESFETs [9-10]. The modeling is particularly efficient because of its characterization and simple analysis of surface formulation.

4. CONCLUSION

In this paper, a simple analytical model for DC characteristics of GaN MESFET has been presented. The device DC behavior is first observed and then by using a non-linear DC model the surface formulation is presented. The validity of the simulation has been checked with others material based devices and the result showed a good match. The developed simple analytical model can be implemented for both electrical applications.

5. REFERENCES

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