

# EFFECT OF VARYING TEMPERATURE ON GAAS-MESFET ELECTRICAL PARAMETERS

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## Abstract

*The present paper introduces a simulation model for the drain-current (I-V) characteristics of a submicron GaAs MESFET. This simulation takes into account different electrical and physical parameters as well as the charge distribution in the device active region. In addition, the simulation includes the doping profile and device parameters effects on the ID-VDS characteristic curves for an ion implanted channel MESFET. The temperature effect on device drain current is evidenced and plotted for different biasing conditions. The GaAs MESFET I-V characteristics versus gate length and temperature variations are measured and plotted and then discussed. The simulation results are compared to that published in literature.*

## Keywords:

*GaAs, MESFET, Simulation, I-V Characteristics, Silvaco, Doping Profile, submicron MESFET*

## 1. INTRODUCTION

MESFET transistors are devices intended for high frequency and (or) high power applications. One of these MESFETs is the Schottky gate GaAs MESFET which is the basis for fast digital integrated and microwave circuits operating within the frequency range 30-100GHz. they offer superior performance over the JFET, especially in RF applications as an amplifier. MESFET's devices generally use compound (III-V) semiconductor technologies for their construction such as GaAs, InP or SiC [1]. Such devices can be used in radar systems, telecommunications satellites, data transmissions, mobile telephony, and vehicle electronics [2] [3]. Due to better features such as high breakdown voltage, high saturation speed, wide bandgap energy and high temperature operation and high mobility in GaAs material [4], these parameters acquire a major importance in determining the output characteristics of a MESFET in GaAs. The power MOSFET transistors have been well promoted in recent technological applications, particularly in energy conversion and transportation fields (aeronautics, railway and automobile) [5].

Several research groups have studied the operation of MESFET transistors at temperatures of 300 to 400° [6] [7]. Considerable efforts have been made to improve the power and frequency performances of GaAs-MESFETs. Several significant challenges have impeded progress on the P-type counterparts including lower intrinsic carrier mobility and difficulties in the growth, doping, and fabrication of high-quality gates and ohmic contacts [7].

The dependence of the characteristics of ion implanted MESFET as a function of their electrical parameters such as the substrate doping and impurity concentrations, is necessary to make adjustments and optimization of the device model used for computer simulations [8-9]. The ion-implantation technique and their low cost and low price of production [10] makes this

technique effective in creating a Gaussian doping profile in the channel with better performances for GaAs MESFET, in general, there are a large number of techniques for using uniform doping profile techniques, among which ion implantation is effective for improving MESFET performance in GaAs material [11]. The influence and the effect of temperature on the drain current of GaAs MESFET's has been compared and performed under a variety of bias and temperature conditions using different voltage-width [6]. In this work we developed a simulation work using SILVACO software. The model is applied to a typical GaAs MESFET under static biasing conditions. The simulation takes into account the reduction of the geometrical parameters such as the channel thickness and the grid length as well as the related physical phenomena. The choice of the substrate doping concentration and the temperature variation scheme, are found to have a noticeable impact on the device current-voltage characteristics. Initially, these characteristics are first obtained at 300°K and then obtained for higher and different temperatures.

The steps of the MESFET structure preparation and doping are achieved using the Athena DC simulation of the  $I_{ds} = f(V_{ds})$  and  $I_{ds} = f(V_{gs})$  characteristics. The above planar MESFET structure is formed by ion implantation. The active channel region of the device is an n-GaAs layer which can be obtained by ion implanting Si into semi-insulating substrate [11]. Initially, the considered substrate is a semi-insulator which is the intrinsic GaAs with a thickness of 0.305 $\mu\text{m}$ , and low doping level of  $N_a = 1e^{13}$  [1/cm<sup>3</sup>]. Next, an active layer of thickness  $d = 0.145\mu\text{m}$  of n-type GaAs is deposited with a uniform profile of maximum concentration of the  $N_d = 1e^{17}$  [1/cm<sup>3</sup>]. After that a hard nitride mask is used to define the n+ zones of 0.05 $\mu\text{m}$  thickness implanted under the source and drain electrodes. Their concentrations are maximum of value  $N_d = 2.e^{18}$  [1/cm<sup>3</sup>] and highly strongly doped with a GaAs implant. Finally, the deposition of the aluminum metallic contacts Drain and Source of 0.15 $\mu\text{m}$  length is achieved and the resulting device length to consider is 1.2 $\mu\text{m}$ , provided that the gate length is  $L_g = 0.3\mu\text{m}$  (eventually variable).

Once the data are introduced to the Atlas software, the function Grid Electrode Gate with the work function of 4.87eV is assigned. The numerical methods used in this simulation are conservative initially. The Gummel Newton Method was chosen and this notation indicates that the decoupled method (Gummel) is used at the beginning of the simulation for each bias point, if the convergence is not obtained it will be switched to the coupled method (Newton) [12]. The advantage of the method is the most robust for initial preload steps and for complex devices. Moreover, it consumes more processor time. Other models have been activated, SRH recombination (Shockley-Read-Hall recombination), the fldmob parameter activates the mobility dependent on the electric field, Conmob specifies the mobility

dependent on the concentration, the model of Selberherr impact ionization is activated and activated, Temp (temperature dependence),  $V_{sat}$  (the parameter saturation velocity). The simulation work is done under few experimental data and considerations as listed in Table 1, the structure that has been considered shown in Fig.1.

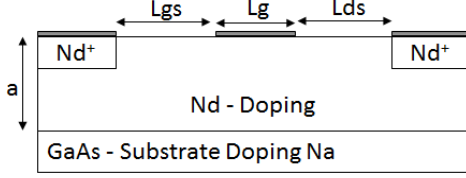


Fig.1. Typical 2D Structure of GaAs MESFET

## 2. DEVICE AND PARAMETERS

The basic MESFET device structure used in the present simulation shown in Fig.1 and its electrical and physical parameters are given in Table.1. The device in Fig.1 considered in this study. Their parameters are described in Table.1. The main parameters are the gate length and channel doping concentration.

Table.1. Parameters of the Structure for MESFET

Parameters	Value	Description
$L_g$	0.3 $\mu\text{m}$	Length Gate
$N_d$	2.10 <sup>17</sup> cm <sup>-3</sup>	Channel doping
$N_d^+$	2.10 <sup>18</sup> cm <sup>-3</sup>	Drain and Source donors Doping
$N_a$	1.10 <sup>13</sup> cm <sup>-3</sup>	Acceptors Concentration Substrate
$A$	0.145 $\mu\text{m}$	Channel Thickness
$L_{gd}$	0.15 $\mu\text{m}$	Gate-Drain Electrode Spacing
$L_{gs}$	0.15 $\mu\text{m}$	Gate-Source Electrode Spacing
$V_{bi}$	0.87V	Potential barrier
$V_{sat}$	1.2e <sup>7</sup> cm/s	Saturation Velocity

## 3. NUMERICAL ANALYSIS

In this work, we used the simulator TCAD-SILVACO to study the performances of MESFET GaAs transistors, namely the influence of certain geometric and physical parameters on the characteristics of this device.

The basic equations are: The Poisson equation that relates the electrostatic potential to the space charge density given by Eq.(1).

$$\frac{\partial^2 \psi}{\partial^2 x} = -\frac{q}{\epsilon_{GaAs}} (N_D - N_A + p - n + N_D^+ - N_A^-) \quad (1)$$

where,  $\psi$  is the electrostatic potential,  $\epsilon_{GaAs}$  is the local permittivity for GaAs,  $q$  represent the elementary charge,  $N_D$  and  $N_A$  are the donor density and acceptor density respectively,  $n$  and  $p$  is the concentrations of free electrons and free holes respectively,  $N_A^-$  and  $N_D^+$  are the ionized deep acceptors and deep donor's density respectively.

The current densities of electrons and holes, are given by Eq.(2) and Eq.(3),

$$\vec{J}_n = q\mu_n n \nabla \phi_n \quad (2)$$

$$\vec{J}_p = q\mu_p p \nabla \phi_p \quad (3)$$

These equations are expressed in terms of quasi-Fermi levels, where,  $\vec{J}_n$  and  $\vec{J}_p$  are the current density of electrons and holes respectively,  $\mu_n$ ,  $\mu_p$ ,  $q$  are the mobility of electrons, mobility of holes and charge electron respectively.

The more conventional formulation of current density equations given by Eq.(2) and Eq.(3), can be written taking into account the drift-diffusion (Einstein equation) as well as the effective electric field are given by the two-following relation:

$$\vec{J}_n = qD_n \nabla + q\mu_n n \vec{E}_n \quad (4)$$

$$\vec{J}_p = qD_p \nabla + q\mu_p p \vec{E}_p \quad (5)$$

where,  $D_n$  and  $D_p$  represents the diffusion coefficient of electrons and holes respectively  $\vec{E}_n$  and  $\vec{E}_p$  are the effective electric field for electrons and holes respectively,  $n$  as electrons concentration and  $p$  as hole concentration.

The diffusion coefficient and the effective electric field will be replaced by the flowing quantities (Eq.(6) and Eq.(7))

$$\vec{D}_{n,p} = \frac{kT}{q} \mu_{n,p} \quad (6)$$

$$\vec{E}_{n,p} = -\nabla \left( \psi + \frac{kT}{q} \ln(n_i) \right) \quad (7)$$

where,  $\vec{E}_{n,p}$  and  $\vec{D}_{n,p}$  represents the effective electric field and the drift-diffusion of electrons and holes respectively,  $T$  being the lattice temperature,  $n_i$  is the effective intrinsic concentration,  $\mu_{n,p}$  is the mobility (indices  $n$ ,  $p$ ) of electrons or holes concentration and  $k$  is the Boltzmann constant.

### 3.1 FIELD DEPENDENT MOBILITY MODEL

The field dependent mobility for  $n$  and  $p$  respectively used by Silvaco are:

$$\mu_n = \frac{\mu_n^D}{\sqrt{1 + 1.54e^{-5} E}} \quad (8)$$

$$\mu_p = \frac{\mu_p^D}{\sqrt{1 + 5.35e^{-5} E}} \quad (9)$$

where,  $\mu_n^D$  and  $\mu_p^D$  is the low field electron and hole mobility respectively,  $E$  is the electric field parallel to the current flow, and  $D$  is a unitless experimentally determined parameter.

These equations are solved by the method of Newton Gummel, several models used in the simulation, which take into account (Fldmob model), (Conmob model), (impact of Selb.model), (SRH model) and (TEMP model) [12].

- **Fldmob model**: the parallel field depending on the electric mobility.
- **Conmob model**: the concentration as fonction mobility.
- **Impact of Selb.model**: impact ionization.

- **SRHmodel**: ShockleyRead-Hall recombination.
- **TEMP**: temperature dependence.

## 4. RESULTS AND DISCUSSIONS

### 4.1 DEVICE DC-CHARACTERISTICS

The simulations are performed on the MESFETs and the curves obtained underline the performances of the device.

The IV characteristics =  $f(V_{ds}, V_{gs})$  for a device which holds variations of the different physical and geometrical parameters of the proposed structure are presented by the figures below. The current  $I_{ds}$  increases with the increase of the density of the charge concentration in the channel Fig.2, Fig.3, and one pays well a saturation difference for two gate length used in our simulation, this difference is related to the metal-semiconductor contact interface and the trap density on the space charge area and length gate.

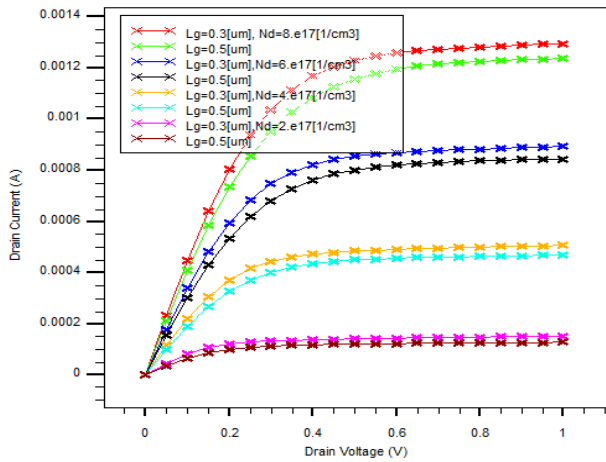


Fig.2. Characteristics of  $I_{ds}$ - $V_{ds}$  of the MESFET in comparison with two gate lengths with different concentrations, obtained at  $V_{gs} = -0.2V$ , the drain voltage from 0 to 1V with a 0.05V step

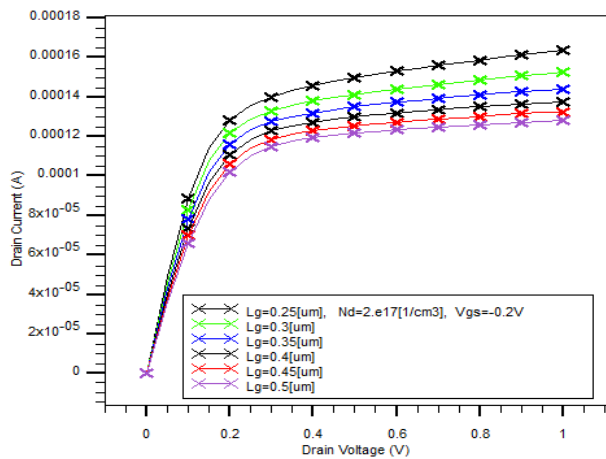


Fig.3. Characteristics of  $I_{ds}$ - $V_{ds}$ , with variety of values of  $L_g$ , the concentration of donors set at  $N_d = 2.e^{17}cm^{-3}$ ,  $V_{gs} = -0.2V$ , the drain voltage from 0 to 1V in steps of 0, 05V

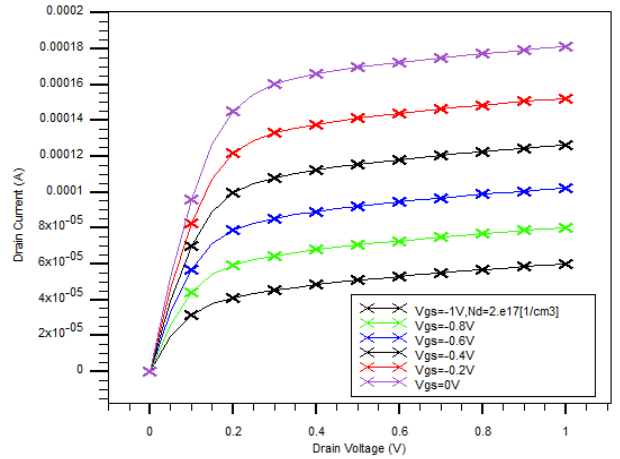


Fig.4. Characteristics of the currents  $I_{ds}$  as a function of the voltage  $V_{ds}$  of the MESFET, with different values of  $V_{gs}$ , the concentration of the donors  $N_d = 2.e^{17}cm^{-3}$ ,  $L_g = 0.3\mu m$

The Fig.4 shows the variations of drain-to-source current ( $I_{ds}$ ) as function drain-source voltage ( $V_{ds}$ ) for different values of  $V_{gs}$  at room temperature condition. It can be seen that the apparatus indicates a maximum drain current at  $V_{ds} = 1V$  for  $V_{gs} = 0V$  is 0.18mA, note that this value connected to the doping of the channel. The origin of these anomalies was attributed to the presence of traps in such devices, increase of the charge density in the (ZCE), therefore the current will be larger with maximum doping.

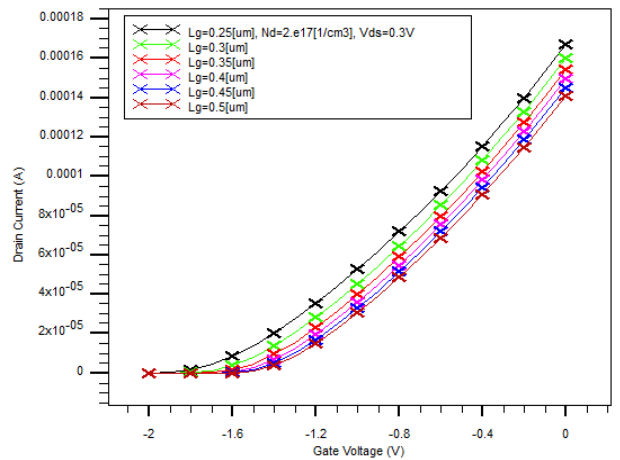


Fig.5. Characteristics of  $I_{ds}$ - $V_{gs}$  of the MESFET at different values  $L_g$ , the drain voltage  $V_{ds} = 0.3V$ , the Donors concentration fixed  $N_d = 2.e^{17}cm^{-3}$

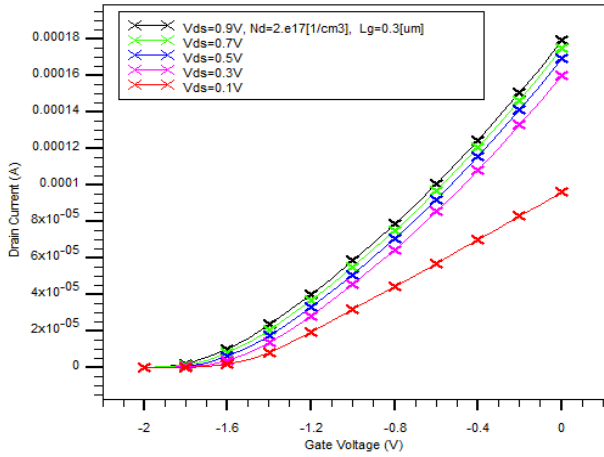


Fig.6. Characteristics of  $I_{ds}$  as function  $V_{gs}$  with various values of  $V_{ds}$ , Gate length  $L_g = 0.3\mu\text{m}$ ,  $N_d = 2.e^{17}\text{cm}^{-3}$

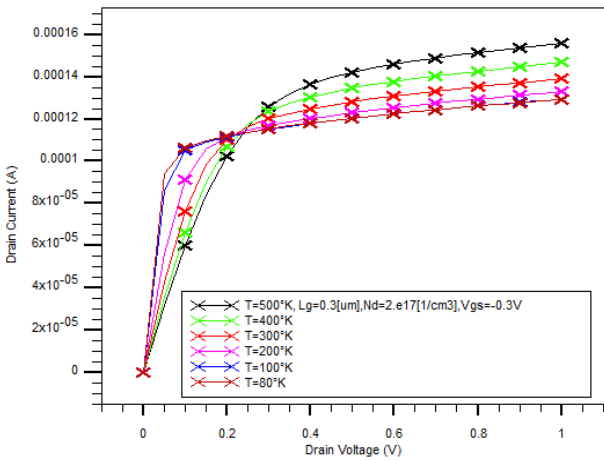


Fig.7. Characteristics I-V for the MESFET, in dependence with the temperature, voltage bias  $V_{gs} = -0.3\text{V}$ , the concentration of the donors  $N_d = 2.e^{17}\text{cm}^{-3}$ ,  $L_g = 0.3\mu\text{m}$

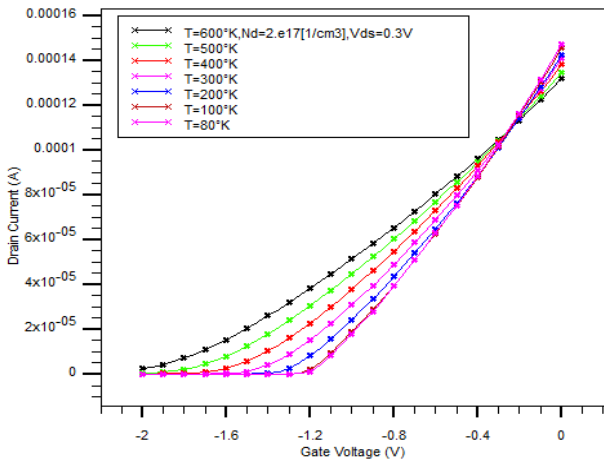


Fig.8. Characteristics  $I_{ds}$ - $V_{gs}$  in dependence with the temperature,  $V_{ds} = 0.3\text{V}$ , the concentration of the donors  $N_d = 2.e^{17}\text{cm}^{-3}$ ,  $L_g = 0.3\mu\text{m}$

The Fig.5, Fig.6 show the current characteristic  $I_{ds}$  as a function of  $V_{gs}$  for different values of drain voltage  $V_{ds}$  these curves are obtained in the same way with which we obtained  $I_{ds}$ -

$V_{gs}$ . The significant device dependence on the temperature shown in the first figures for  $T = 300\text{K}$ , to compare with Fig.7 and Fig.8 is clearly remarkable and visible on device characteristics IV for different temperatures, the temperature changes the forms curves in the linear region as nonlinear just before saturation, we can say that at low temperatures, the device is rapidly saturated at low drain voltages, this is due to electron generation and recombination speeds, electrostatic potential, electric field strength, electron concentrations, electron current density, electron speeds and mobility.

## 5. CONCLUSIONS

The present contribution achieved a simulation for an eventual implementation of a MESFET device under typical conditions of temperature and biasing. The influence of the physical, geometrical and electrical parameters of the GaAs MESFET transistor is studied using the TCAD-SILVACO simulator that is used in its two-dimension version.

The simulations results of the GaAs MESFET structure are obtained using the Atlas-SILVACO tool. We notice that the temperature is one of the basic parameters to consider in the analysis. It has been found that the temperature gives the possible of modifying the device performances, i.e., the electronic circuits' parameters operating conditions used in high frequency and high power applications.

Our simulation results are done for submicron GaAs MESFET for different gate lengths and different doping concentrations. This is under the uniform charge distribution in the active region and in the semi-insulating substrate. These characteristics are obtained for the case of ion implementation method. The effects of these parameters on the drain current-voltage characteristics are presented and compared to that published in literature. The results are found to be in good agreement, which validates our simulations.

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