Journal of New Technology and Materials
JNTM
Vol. 03, N°01 (2013) 28-32

OEB Univ. Publish. Co.

A new drain current I-V model for MESFET with submicron gate

M. Azizi[a] *and C. Azizi*[b]
[a] *Department of Material Sciences. Larbi Ben Mhidi University, Oum El Bouaghi. Algeria. Email: mounir.perso@gmail.com*
[b] *Department of Material Sciences. Larbi Ben Mhidi University, Oum El Bouaghi. Algeria. email: aziziche@yahoo.fr*

Received: August 28, 2012, revised: May 19, 2013, accepted: May 28, 2013

Abstract

In this work we present a new nonlinear approach for the calculation of the static characteristics of MESFET GaAs with submicron gate. First, we compare the results of the numerical simulations of the three main models for the MESFETs with submicron gate : Ahmed [1], Islam [2] and Memon [3] with experimental results. Then we propose a new approach that takes into account the surface states of the Schottky junction through a new mobility law for the determination of the output characteristics. The thermal effect is also represented in the mobility law. The comparison of our model with the three previous models referring to the experimental data shows that our approach gives the most accuracy result. Also, the proposed model can be used in the case of logic or analog circuits based on submicron GaAs MESFET.

Keywords: *MESFET; GaAs; nonlinear models; interface states; submicron gate.*

1. Introduction

The widespread use of field-effect transistor with gallium arsenide "GaAs MESFET" in telecommunications and technology using the microwave field effect operating in the gigahertz band warrants a critical need for the analytical study of the physical behavior of this component. The development of a simple mathematical model describing the output characteristics of the MESFET is the main objective of this work.

Indeed, several models have been proposed since the fifties. Most proposals simulate a perfect Schottky junction barrier with no surface effects, therefore distorting their results.

The MESFET with a submicron gate has a better treatment of high-frequency signals. But this creates a large conductance, a decrease of the transconductance and a change in the threshold voltage V_T. This is called the short channel effect, and it makes the development of a theoretical model very complex. In the case of a submicron channel, the interface state due to the Schottky barrier cannot be eliminated.

In this work, we relied on the model of Memon [1] and that of Islam [2] in order to verify the accuracy of the results by comparing them with experimental data. An extension of the models was proposed by the introduction of the electron mobility in terms of current intensity, conductance and transconductance. A study of the thermal effect on the electronic behavior of GaAs MESFET using the proposed model was performed. The treatment was carried out through software simulation, programmed using MATLAB 7, 2010.

2. Nonlinear models of the MESFET

Memon's model [3] which describes the electrical behavior of the MESFET was proposed in 2006. This model is an extension of the Ahmed model [1] that also mades changes to other theories.

The relationship between the drain-source current I_{ds} and the drain-source voltage V_{ds} is given in the model of Ahmed [1] by:

$$I_{ds} = I_{dss}\left[1-\frac{V_{gs}}{V_T+\Delta V_T+\gamma V_{ds}}\right]\times\tanh\left(\alpha V_{ds}\right)\left(1+\lambda V_{ds}\right) \qquad (01)$$

V_{gs}: gate-source voltage.
I_{dss}: saturation current.
V_T: threshold voltage.
ΔV_T: shift in the threshold voltage.
α: saturation current parameter, used to simulate the linear region on V_{ds}.
λ: simulation parameter of the dependence of the I_{ds} to V_{ds} in the saturation region.
γ: parameter simulation of the threshold voltage on V_{ds}.

Where:

$$V_T = \frac{qN_d a^2}{2\varepsilon_s} - \Phi_b \quad \text{and} \quad \Delta V_T = \frac{4a}{3L_g}V_T \qquad (02)$$

q: electron charge.
N_d: carrier density in the channel.
a: channel thickness.
Φ_b: Schottky barrier height.
ε_s: semiconductor permittivity.
L_g: intrinsic channel length (controlled by the gate).

$$I_{dss} = \left(\frac{\beta}{1+\mu\left(V_{gs}-V_T-V_{ds}-\Delta V_T\right)}\right) \qquad (03)$$

β: transconductance parameter.
μ: simulation of the effect of electron mobility parameter.

Ahmed [1] based his model on those of Rodriguiz [4] and Materka [5]. He introduced ΔV_T which is a variation of V_T caused by the submicron geometry of the gate.

Islam [2] proposed another model in 2004. He added μV_{gs} in the term $(1 + \lambda V_{ds})$. The expression that he proposed for the current intensity is as follows:

$$I_{ds} = I_{dss}\left[1 - \frac{V_{gs}}{V_T + \Delta V_T + \gamma V_{ds}}\right]^2 \times \tanh\left(\alpha V_{ds}\right)\left(1 + \lambda V_{ds} + \mu V_{gs}\right) \qquad (04)$$

Memon's model [3] is an extension of Ahmed's model [1]. He notes the principle of the presence of an interface effect in the metal-semiconductor junction, which makes the Schottky barrier not perfect. This effect is the main cause of the decrease in V_{gs} received in the semiconductor channel compared to the applied V_{gs}. Ignoring this effect causes a remarkable difference between the experimental characteristics of the MESFET and those simulated.

The I_{ds} expression in the Memon's model is given by:

$$I_{ds} = I_{dss}\left[1 - \frac{V_{eff}}{V_T + \Delta V_T + \gamma V_{ds}}\right]^2 \times \tanh\left(\alpha V_{ds}\right)\left(1 + \lambda V_{ds}\right) \qquad (05)$$

where:

$$V_{eff} = \frac{V_{gs}}{1 + \eta e^{V_{gs}}} \qquad (06)$$

The main difference between the Memon's model [3] and those of Ahmed [1] and Islam [2] is in the term η describing the effect of the Schottky barrier interface. Memon [3] did not revise the term $(1 + \lambda V_{ds})$ in the expression of I_{ds}. While the model of Islam [2] introduced a modification in this term that makes his model a better approximation.

3. New approach

In our study, we propose the introduction of the term μV_{gs} in the expression of I_{ds} to take into account both the interface states at the metal-semiconductor junction effect and the electron mobility parameter effect. It gives:

$$I_{ds} = I_{dss}\left[1 - \frac{V_{eff}}{V_T + \Delta V_T + \gamma V_{ds}}\right]^2 \times \tanh\left(\alpha V_{ds}\right)\left(1 + \lambda V_{ds} + \mu V_{gs}\right) \qquad (07)$$

Our model is a combination of Memon's model [3] and that of Islam [2].

The choice of a law for carrier mobility in GaAs is important for a correct description of the physical phenomena in submicron-gate MESFET. In the case of weak fields, free carriers are in thermal equilibrium with the grid and their average speed is proportional to the electric field:

$$v(E) = \mu_n E \qquad (08)$$

However, there is no law that truly reflects the variation of mobility with the electric field and several approximate analytical expressions have been proposed for this function. For our part we propose the following law:

$$v(E) = \mu(E)E = \frac{\mu_n E}{1 + \left(\frac{E}{E_c}\right)} \qquad (09)$$

The expression of mobility is given by [7]:

$$\mu(E) = \frac{\mu_n}{1 + \left(\frac{E}{E_c}\right)} \qquad (10)$$

with

$$E_c = v_s / \mu_n \qquad (11)$$

Where μ_n is the electron mobility at low electric fields, and v_s is their saturation velocity.

The dependence of the mobility on the electric field at room temperature allowed us to see the influence of the thermal effect on the output characteristics I_{ds} - V_{ds}. Indeed, an increase of junction temperature causes a decrease of electron mobility and consequently a decrease of the drain current I_{ds}.

Equation (12) gives the variation of the classical electron mobility as a function of temperature for gallium arsenide [8].

$$\mu = \mu_0(300^0 K)[300/T]^{2/3} \qquad (12)$$

The saturation velocity is given by [9]:

$$v_s = \frac{2.4 10^5}{1 + \exp(T/600)} m/s \qquad (13)$$

The dependence of the threshold voltage can be approximately given by [9]:

$$V_T = V_T(300°K) - \alpha_{vT} T \qquad (14)$$

The value of α_{vT} is about the order of 1.2 *mV/°C*.

4. Models simulation and comparison with experimental data

A comparative study of the different models mentioned above was performed. The accuracy of these models for GaAs MESFET has been verified by a simulation of the expressions I_{ds} - V_{ds} and then comparing them with experimental data.

We used Matlab 7.10.2010. Once the best approach is reached, the calculations will be interrupted and the best result will count. The fit of the model will be done by choosing the best fitting parameter values.

The physical and geometrical parameters of the component studied here (ref. A4-74-3) are as follows:

$N_d = 5 \times 10^{17}$ cm-3;
a = 90 nm;
$L_g = 0.28$µm;
W = 100 µm;
Φ_b= 0.60 V;
V_T = -3.49V;
ΔV_T = -1.32 V.

The experimental results for this component were obtained from [6].

Figures (1) to (3) shows the output characteristics I_{ds} - V_{ds}, both experimental and simulated for different values of V_{gs}, for a submicron-gate GaAs MESFET component using the models of Ahmed [1], Islam [2] and Memon [3].

In the case of Ahmed [1] the results are quite satisfactory in the linear region for $V_{gs} = -2.2V$ and $-3.3V$ with a slight difference in the saturation region. For $V_{gs} = -1.1V$ the results are much better in the saturation region. The results are worse for $V_{gs} = 0.0V$.

For the case of Islam [2] presented in figure (2), we notice a marked improvement over the previous case for both values of V_{gs} = *-1.1* and *0.0 V.* This is due to the incorporation of the term electron mobility parameter effect (μV_{gs}).

Figure (3) illustrates the comparison of the results obtained by the Memon model [3] with the experimental data. The gap is smaller because Memon considered the effect of the interface state of the metal-semiconductor junction in his model, unlike the two previous models where the effect was considered negligible.

In Figure (4) we present our simulation results of output characteristics based on the new proposed approach, for GaAs MESFET components with a $0.28 \times 100\,\mu m^2$ gate dimensions. We can clearly see that it gives results that are better than those demonstrated previously, even with a slight discrepancy in the linear region for $V_{gs} = -1.1$ V.

In Figure (5) we can clearly see the comparison between the Memon's model [3] and the one proposed here in reference to the experimental results.

The accuracy of the models can be better estimated by calculating the error of each simulation using the least squares method, which gives a numerical result of the shift in then measured curves relative to those observed. Table (1) illustrates the different values of the errors of the models for different values of V_{gs}. We clearly see that the average error of the new approach is smaller and it is equal to 0.5984, while in the Memon's model [3] is 0.7915. Those of Ahmed [1] and Islam [2] exceed the unity. According to these results, we deduce that the new model is more accurate than those cited above, especially for $V_{gs} = 0.0V$ and $-1.1V$.

The thermal effect has been studied through the law of mobility using equation (12) in the case of Memon [3] and in the new method. Figures (6) and (7), representing the simulation of the characteristics $I_{ds}(V_{ds})$ for $V_{gs} = 0.0V$, clearly shows the variations of drain-source current depending on drain-source voltage for various values of temperature. Indeed, the current increases when the temperature T decreases in the model we have proposed.

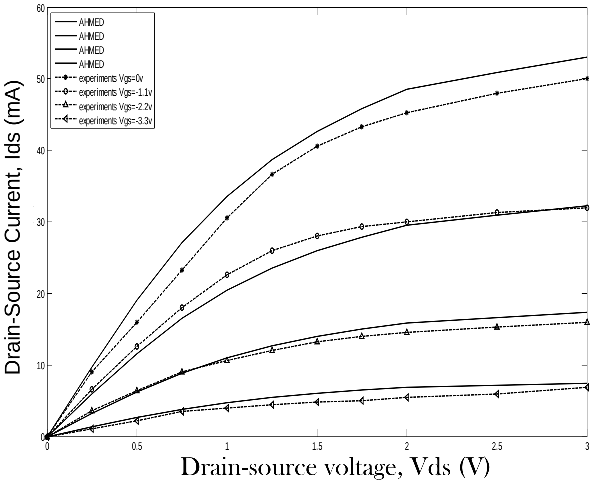

Figure 1. Comparison of the characteristics I_{ds} (V_{ds}) simulated and observed using the model of Ahmed [1] for a GaAs MESFET (0.28 x 100 µm^2)

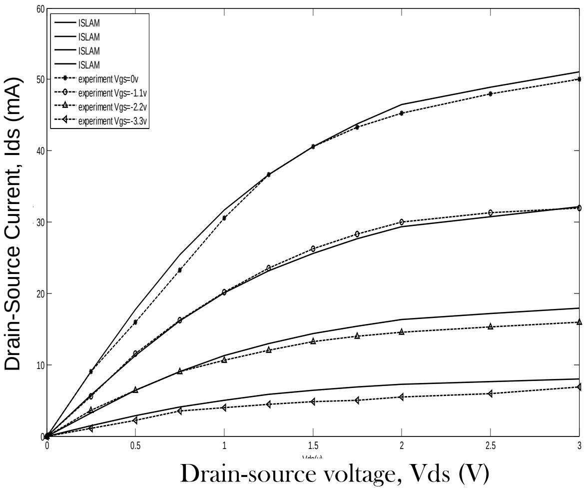

Figure 2. Comparison of the characteristics I_{ds} (V_{ds}) simulated and observed using the model of Islam [2] for a GaAs MESFET (0.28 x 100 µm2).

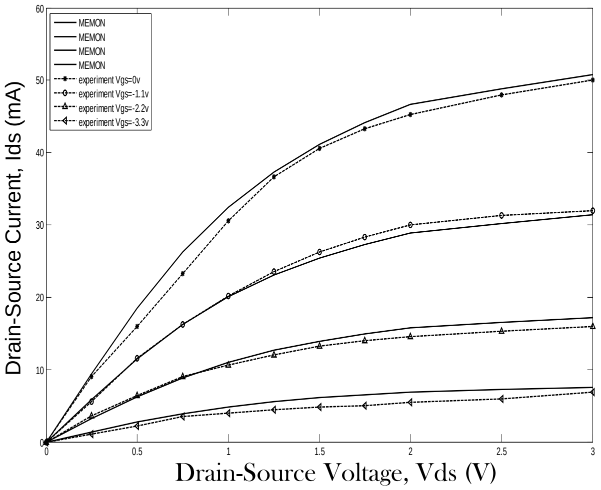

Figure 3. Comparison of the characteristics I_{ds} (V_{ds}) simulated and observed using the model of Memon [3] for a GaAs MESFET (0.28 x 100 μm2).

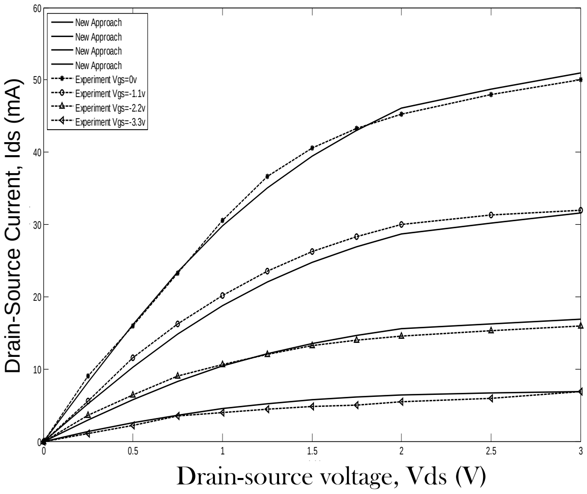

Figure 4. Comparison of the characteristics I_{ds} (V_{ds}) simulated and observed using the new approach [1] for a GaAs MESFET (0.28 x 100 μm2).

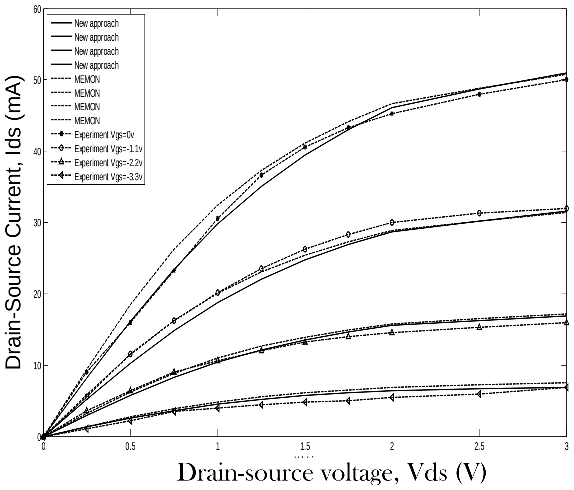

Figure 5. Comparison of the characteristics I_{ds} (V_{ds}) of the model Memon [3] and the new approach for a GaAs MESFET (0.28 x 100 μm2).

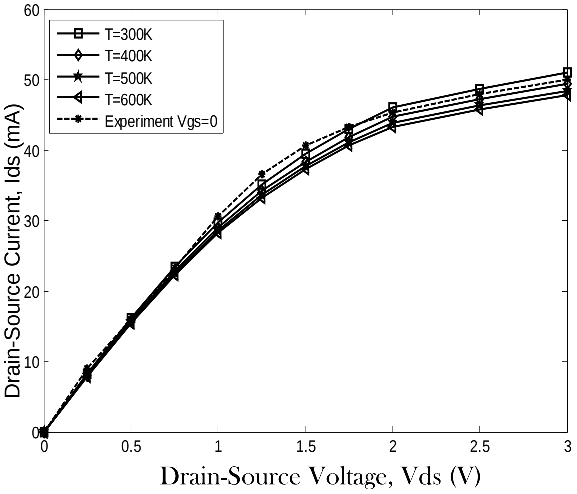

Figure 6. Variation of I_{ds} (V_{ds}) with temperature for a GaAs MESFET (0.28 x 100 μm2) using the new approach.

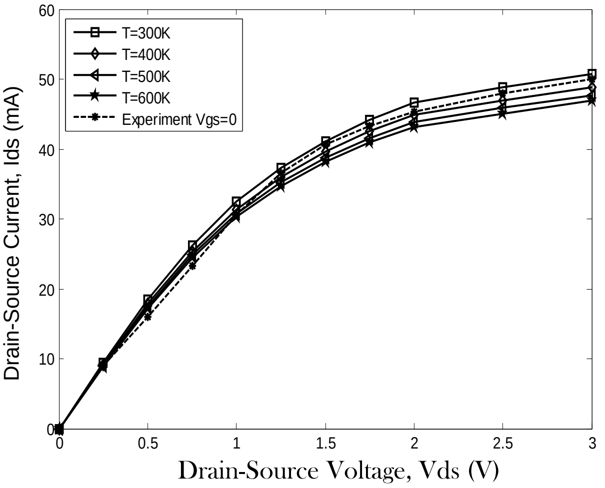

Figure 7. Variation of I_{ds} (V_{ds}) with temperature for a GaAs MESFET (0.28 x 100 μm2) using the Memon's model.

Table 1. Comparison of RMS errors of different MESFET models as a function of V*gs*.

VGS THE MODEL	Vgs = -3.3 V	Vgs = -2.2 V	Vgs = -1.1 V	Vgs = 0.0 V	Average Error
AHMED	3.037	0.244	1.358	0.584	1.306
ISLAM	1.103	0.146	1.886	1.062	1.049
MEMON	0.775	0.580	1.189	0.621	0.791
New Approach	1.009	0.442	0.895	0.046	0.598

5. Conclusion

First we performed simulations using three mathematical models to study the static properties of submicron gate GaAs MESFET. The results of these simulations were then compared with experimental data. Among the models of Ahmed [1], Islam [2] and Memon, we established that Memon's [3] is closest to experiment. This was verified by the calculation of RMS errors.

A new model was performed by the taking into account both the interface effect in the metal-semiconductor junction and the electron mobility effect. The simulation based on the new approach confirmed that it contain the smallest error.

It confirms that it is the most accurate method of simulation of the static characteristic of GaAs MESFET with submicron gate.

Finally we have seen the thermal effect on the output static characteristic of the MESFET GaAs.

Acknowledgment

The authors gratefully acknowledge the contributions of the department of material sciences of the University of Oum El Bouaghi.

References

[1] Mansoor M. Ahmed, Haroon Ahmed, and Peter H. Ladbrooke," An Improved DC Model for Circuit Analysis Programs for Submicron GaAs MESFET's", *IEEE Transactions On Electron Devices*, Vol. 44, No. 3, (March 1997).

[2] Islam M. S and Zaman M. M, "A seven parameter nonlinear I-V characteristics model for sub-μm range GaAs MESFETs," *Journal of Solid-State Electronics*, Vol. 48 pp. 1111-1117, (2004).

[3] N. M. Memon, M. M .Ahmed and F.Rehman "A Comprehensive Four Parameters I-V Model for GaAs MESFET Output Characteristics" *Journal of Solid State Electronics*, Vol. 51, pp511-516 (2007).

[4] Rodriguez T. J, England, "A five-parameter dc GaAs MESFET model for nonlinear circuit design," Proc. IEEE , pt. G, Vol. 139, No. 3, pp. 325-332, (1992).

[5] Tomasz Kacprzak And Andrzej Materka, "Compact dc Model of GaAs FET's for Large-Signal Computer Calculation" *IEEE Journal Of Solid-State Circuits*, Vol. Sc-18, No. 2, (April 1983).

[6] NEC data sheet California eastern laboratories.

[7] Nicolas Dubuc "Modélisation Electrothermique de transistors MESFET SiC et optimisation d'une architecture Doherty pour l'amplification de puissance à haut rendement" Thèse doctorat d'état, Université de Limoges, (2003) N°84.

[8] Issam Hamma "Contribution à l'étude des propriétés statiques du MESFET GaAs" Mémoire de magister, C .U d'Oum El bouaghi, (2007).

[9] T.A. Fjedly. T. Yterdal, M.S.Shur "Introduction to Device Modeling and circuit "New York ‘Wiley ‘"simulation, (1998).