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EFFECT OF MOBILITY ON (IV) CHARACTERISTICS OF GaAs MESFET.

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Abstract

We present in this paper an analytical model of the current-voltage (I-V) characteristics for submicron GaAs MESFET transistors. This model takes account the analysis of the charge distribution in the active region and incorporate a field depended electron mobility, velocity saturation and charge build-up in the channel. We propose in this framework an algorithm of simulation based on mathematical expressions obtained previously. The results obtained of the model are discussed and compared with those of the experimental data reading obtained from the literature. The agreement has been shown to be good.

Keywords: Modelling,mobility,MESFET,GaAs

I. INTRODUCTION

The GaAs MESFET transistors are attractive devices for the use in microwave applications because of their relatively simple processing and they high-speed and low noise performances. The current voltage depends on the law of carrier mobility as a function of electric field, the choice of a law of mobility is very important for a proper description of physical phenomena in submicron-gate MESFET.

The principal object in these papers is to propose a physical and analytical model of the characteristics current voltage of these devices with different laws of mobility's [1].

In the first part, we calculate the potential and the potential field in the depletion layer S.C.Z due to the electrical charge formed under the gate which can be obtained by resolving the Poisson's equation by the conventional approximation. Then we determine the drain current Id, the characteristic I-V obtained by this model, using two different expressions of the electrons velocity v(E) for different dimensions of channel. This model takes into account in the hand the specifics physical phenomena in devices and on the other hand simplicity of mathematical expressions. We have elaborated a software for simulation which enable to solve the system of differential equations and to trace the various series of curves.

II. THEORY

II.1 Calculation of the potential in the channel and the electrical field:

To calculate the potential and the electric field under the gate, the channel is divided into two principal regions figure (1)

- ♦ The first region (1) below the gate directly, it is said a region controlled by the gate.
- ♦ The second region (2) outwards of the first region known as region not controlled by the gate.

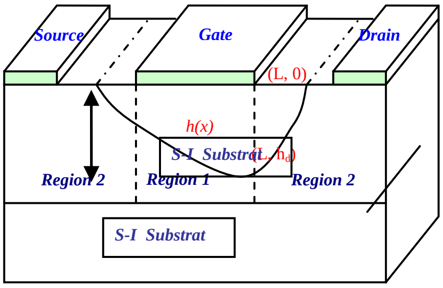

Figure 1: Depletion regions: (1) controlled by the gate, (2) not controlled by the gate.

The electric potential due to the electrical charge formed under the gate can given by [2]:

$$V_q(x,y)=\int_0^y \frac{eNd(x,y)}{\varepsilon}ydy+y\int_y^{h(x)}\frac{eNd(x,y)}{\varepsilon}dy+Vbi-Vg \tag{1}$$

$$Nd(x,y)=Nd(y)-n(x,y) \tag{2}$$

Nd,y) is th density of the donors which can be varied with y and *n(x,y)* the density of the free electrons in the depletion layer. ,*Vbi* is the built in potential of Schottky barrier gate and ε is the permittivity

It should be noted that the approximations in (1) is based on the fact that the depletion layer thickness under the gate, h(x) is a slowly varying function in the channel an is giving by:

$$h(x)=a\sqrt{\frac{V(x)+Vbi-Vg}{Vp}} \tag{3}$$

The channel potential is obtained by integration limits with y=h(x)

$$V(y)=\frac{q.Nd}{\varepsilon}\left[h.y-\frac{y^2}{2}\right] \tag{4}$$

The equation of the potential takes a maximum of values in diffusion potential $Vb_i\,(y=h)$.

$$Vbi=V(y=h)-V(y=0) \tag{5}$$

The dimensional potential of the channel under the gate is given as follows:

$$V(x)=\frac{qN_D h^2(x)}{2\varepsilon}+V_G-V_{bi} \tag{6}$$

II.2 Calculation of drain current in the channel:

To calculate the drain current expression as a function of the drain voltage, we must make some approximations [3]:

- One neglects the current flow in the y-direction; this approximation is valid for the components with the length short gate.
- An abrupt junction Schottky barrier.
- A channel of uniform doping Nd (x, y) = Nd ,Nd is constant.

- Neglecting edge effects, the overflow area depopulated on the sides of the gate

The density of the current is given by:

$$J_x = \sigma(x,y,z).E_x \tag{7}$$

$$J_x = qN_D\mu_n.E_x = -q\mu_n Nd\,\frac{dV(x)}{dx} \tag{8}$$

μ_n (E_x) is the electron mobility witch depends of the electric field.

The drain current Id counted positively in the sense drain source is obtained by integrating across the Jx-conductor section of the channel:

$$I_d = -\int_0^Z \int_{h(x)}^a J_x dydz = -Z\int_{h(x)}^a J_x dy \tag{9}$$

with $v_x(E_x) = \mu_n.E_x(x)$. (10)

The calculations made above, unaware of the contribution depletion layer located below the free surface in the potential, we put:

$$Ip = \frac{(qNd)^2\mu_n Za^3}{2L\varepsilon} \tag{11}$$

.

$$Vp = \frac{qNda^2}{2\varepsilon} = V_{bi} - Vg \tag{12}$$

$$a = \left[\frac{2\varepsilon}{qN_D}\left(V_{bi} - Vg\right)\right]^{1/2} \tag{13}$$

$$\frac{h(x)}{a} = \left[\frac{V_{bi} + V(x) - Vg}{V_{bi} - Vg}\right] \tag{14}$$

Then the expression final of the current I_d [4];

$$I_d(V_d,V_g) = Ip\left\{\frac{Vd}{Vp} - \frac{2}{3}\left[\left(\frac{Vd + V_{bi} - Vg}{V_P}\right)^{3/2} - \left(\frac{V_{bi} - Vg}{V_P}\right)^{3/2}\right]\right\} \tag{15}$$

II.3 Effect of variable mobility

The characteristics current -voltage depends with the variations on the electron mobility according to the electric field. In area of weak electric fields, free carriers are in thermal equilibrium with the network and their average speed is proportional to the electric field:

$$V(E) = \mu_n E. \tag{16}$$

μ_n is the mobility of electrons at low electric field.

But, when the electric field is high, the electron transfer intervals induced in the GaAs, a decrease of the carrier velocity and leads to strong negative differential mobility. However, there is not a law witch descript the variations of the mobility with the electric field in the submicron GaAs and several approximate analytical expressions have been proposed for this function. The mobility's law used in our I-V model are expressed by : For the weak electrical fields where $E < Eo$, $\mu = \mu_n$ and on the high electric fields beyond Eo ($E \geq Eo$) [5,6] :

the expressions of mobility's are:

$$\begin{cases} v_1(E) = \mu_1(E)E = \dfrac{\mu_n E}{1+\left(\dfrac{E}{Ec}\right)} & (17) \\[2ex] v_2(E) = \mu_2(E)E = \dfrac{\mu_n E + v_s\left(\dfrac{E}{Ec}\right)^4}{1+\left(\dfrac{E}{Ec}\right)^4} & (18) \end{cases}$$

$$\begin{cases} \mu_1(E) = \dfrac{\mu_n}{1+\left(\dfrac{E}{Ec}\right)} & (19) \\[2ex] \mu_2(E) = \dfrac{\mu_n + v_s\left(\dfrac{E^3}{Ec^4}\right)}{1+\left(\dfrac{E}{Ec}\right)} & (20) \end{cases}$$

where:
$E_c = (v_s / \mu_n)$ (21)
$E_0 = 0{,}5[E_t + (E_t^2 - 4E_c^2)^{0{,}5}]$ (22)
E_t : is the threshold field at which the electron velocity attains the maximum value[7].

$E_{C=}\ v_{s/}\ \mu_n$, v_s is the saturation of velocity. We note that the expression of $V_1(E)$ is simpler than$V_2(E)$.;
by deferring successively these two laws in equation(15) and takes account the effect of parasites resistances ,we replace the intrinsic terms by the extrinsic terms .

$$\begin{cases} Ids = Id & \text{(23-a)} \\ Vg = Vgs - RsId & \text{(23-b)} \\ Vd = Vds - (Rs + Rd)Id & \text{(23-c)} \end{cases}$$

The general equation of current becomes:

$$Id = IpA1\left\{ \frac{Vds - (Rs + Rd)Id}{Vp} - \frac{2}{3}\left(\frac{Vds + Vbi - Vgs + RsId}{Vp}\right)^{\frac{3}{2}} + \frac{2}{3}\left(\frac{Vbi - Vgs + RsId}{Vp}\right)^{\frac{3}{2}} \right\}. \tag{24}$$

$$\begin{cases} A1 = \dfrac{1}{1 + \dfrac{Vds - (Rs + Rd)Id}{LEc}} \\ . \end{cases} \tag{25}$$

Second Law of mobility :

$$Id = IpB1\left\{ \frac{Vds - (Rs + Rd)Id}{Vp} - \frac{2}{3}\left(\frac{Vds + Vbi - Vgs - RsId}{Vp}\right)^{\frac{3}{2}} + \frac{2}{3}\left(\frac{Vbi + Vgs - RsId}{Vp}\right)^{\frac{3}{2}} \right\}. \tag{26}$$

$$B1=\frac{1+\dfrac{v_s\left(Vds-(Rs+Rd)Id\right)^3}{\mu_\eta L^3 Ec^4}}{1+\left(\dfrac{Vds-(Rs+Rd)Id}{LEc}\right)} \tag{27}$$

.

III. RESULTS AND DISCUSSION:

The numerical calculation of the current of drain according to the biasing calls upon the expressions (24), (26) established previously. The study was carried out on a submicronic gate GaAs MESFET transistor which parameters gathered in the table (1) [8]

:

Table 1 : Parameter of the GAT1.

transistors	L(μm)	a (μm)	z (μm)	Vbi (V)	Nd (m^{-3})	μ_0 ($m^2V^{-1}s^{-1}$)	v_s ($m\,s^{-1}$)
GAT1	4	0.3	360	0.8	6.7 10^{22}	0.3740	0.9710^5

Figure (2) represents the dependence of the two laws of mobility as a function of electric field Changes in the corresponding rate laws.

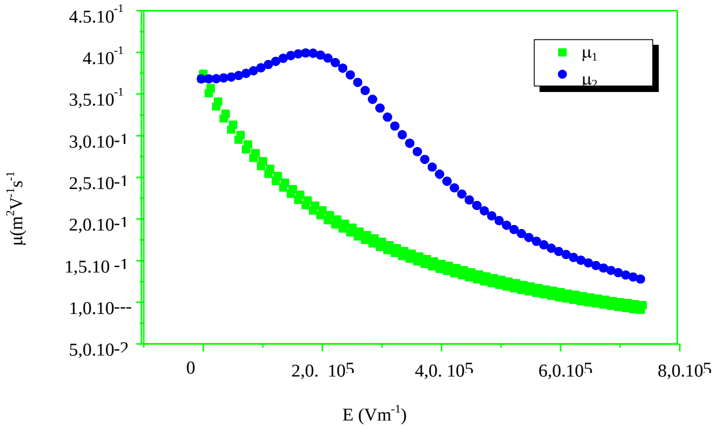

Fig2 Variation of the mobility of the electrons with the electrical field for the GAT 1.

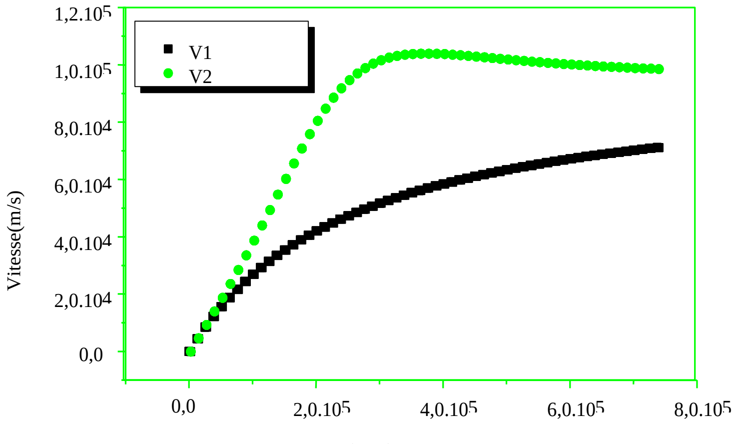

Fig3 :Variation of the velocity of the electrons with electrical field for le GAT1.

(V1 = μ_1 E; V2 = μ_2E)

In the figures (4), (5) and (6), we presented the transistor characteristics GAT1 , in the case of constant mobility μ_n and expressions (19) and (20) successively correspond to the laws of mobility :

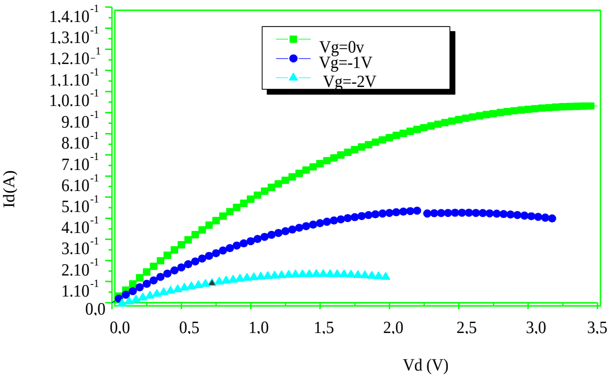

Figure 4 : Characteristics I-V with constant mobility for the GAT1.

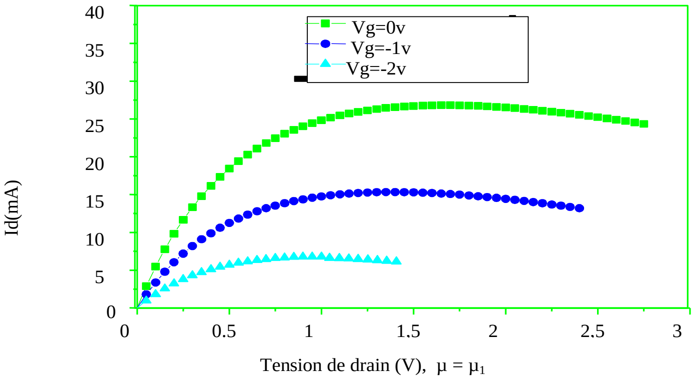

Figure 5 : Characteristics I-V with mobility variable μ_1 for the GAT1.

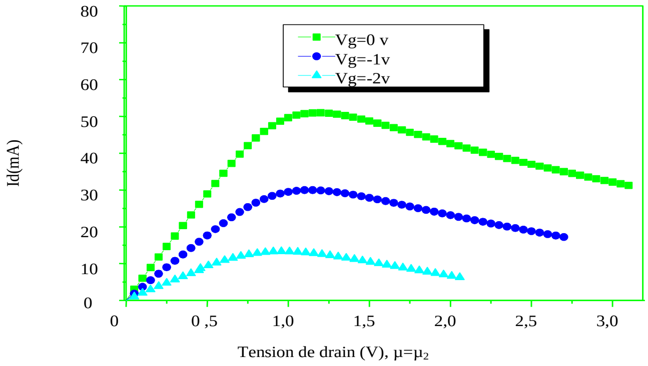

Figure 6 : Characteristics I-V with a variable mobility μ_2 for the GAT1.

To validate these results, we compared the two previous expressions of the current, and that we have considered the case of constant mobility with experimental measurements [9] of the same transistor, the gate voltages as follows: Vg = 0V (Figure 7)

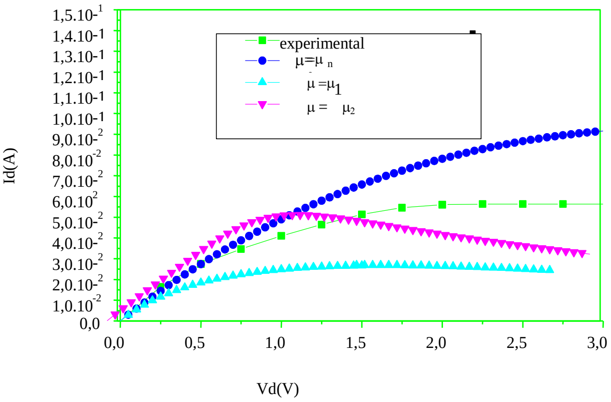

Figure 7 : Comparaison theory – experimental for the GAT1 (Vg = 0V).

In the linear regime, we notice a good coincidence between experiment values and theory and those that, for various acts of mobility, especially in the case of constant mobility, demonstrating the independence of the mobility of electrons in the field power, low drain voltages and also the close correlation between experience and the model proposed in the linear regime

This gap is negative in the case of constant mobility. This is due to the variation linear velocity of electrons with electric field, which does not take into account the limit of the carrier velocity saturation velocity that electrons can not exceed. In the other two curves where we have considered the variation of mobility, the gap between theory and experiment becomes positive, the values of current intensities computed in the two cases become increasingly weak as the drain voltage progresses.

IV. CONCLUSION

In this study we have developed an analytical model to calculate the I-V characteristics of short gate length GaAs MESFET which takes into account the one-dimensional analysis of the charge distribution in the active region and incorporates a field depended electron mobility, velocity saturation and effect of these parameter to the current voltage expressions. The model compares favourably from a submicron GaAs MESFET. More ever, comparisons between the analytical models with different values of mobility proposed shown the effect of mobility it affects directly the output characteristics (I-V) of GaAs MESFET.

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