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IMPACT OF GATE LENGTH ON EQUIVALENT CIRCUIT ELEMENTS IN GaAs MESFET TRANSISTORS

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ABSTRACT

In the information science and technology such as computer science, telecommunications, processing of the signals or images transmission, the field effect components plays a major role. We are interested in this study in Schottky gate gallium arsenide field-effect transistors commonly called GaAs MESFET. In this paper, we mainly present the results of calculating the influence of gate length on input and output impedances of GaAs MESFET Transistors, this physical model is based on the analysis of two-dimensional Poisson equation in the active region under the gate. The theoretical results, based on analytical expressions that we have established, are discussed and compared with those of the simulation.

Key Words: GaAs MESFET, technological parameters, parasitisc elements, Schottky gate.

I. EQUIVALENT CIRCUIT OF THE MESFET

The equivalent circuit of a MMIC component must sufficiently represent all the important physical characteristics of the device and exploit the relationship between the elements of the equivalent circuit and the physics of the device which will be useful in the mathematical formulation. The MESFET transistor to study is represented on figure 1.

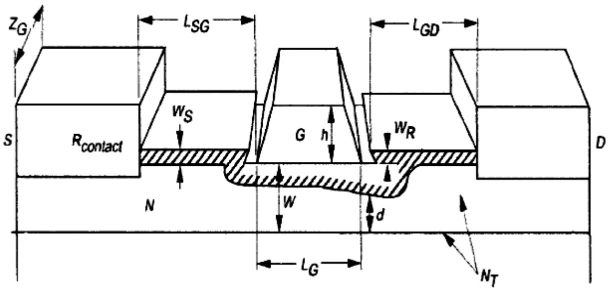

Figure1: Geometric parameters of MESFET

N is the doping density in the N layer of the channel, W is the thickness of the layer N of the channel under the gate, Z_G is the width of the gate, L_G is the length of the metal gate, L_{SG} is the separation gate-source, L_{GD} is the separation gate-drain, W_R the depression depth of the gate, Ws is the exhaustion depth of the surface, d is the depth of exhaustion, h is the height of the gate, X is the extension of the gate charge space under the gate.

II. MODEL AND VOLTAGE-CURRENT (I-V) EQUATIONS

For all length gate of transistor GaAs MESFET, the actual physics model [1] is based to resolve the two dimensional physical model of the Poisson equation. This equation known in the semiconductor physics is used in all the models to explain the different physical phenomena specific to the GaAs MESFET.

The main problem for these models lies in the coupling of partial and non-linear differential equations which require to be simultaneously solved. The difficulty of putting down valid hypothesis for the limit conditions at the free interface requires the resort to approximations the negligence of a certain number of terms which act negatively on the model exactness. In this paper we present an analytical model which associates the description of physical phenomena and the simplicity of mathematical equation.

In order to calculate the drain current expression as a function of the drain voltage for different values of the gate voltage, we use the following hypothesis:

- We neglect the current in the Y axis; this approximation is valid for the short gate components.
- The analytical expression of the variations of the electron mobility with electric field [2] is given by:

$$\mu = \begin{cases} \dfrac{\mu_0}{\left[1+\left(\frac{E-E_0}{E_S}\right)^2\right]^{1/2}} & if\ E \geq E_0 \\ \mu_0 & if\ E < E_0 \end{cases} \qquad (1)$$

where: E is the electric field, μ_0 is the low mobility (μ_0=7500 $cm^{2/}V.s$ for the *GaAs* [2]), E_0 is a critical field (E_0 = 3, 5 kV/cm for the *GaAs* [2]) and E_S field saturation.

For low fields $E<E_0$ the mobility μ is linear with electric field E [2], and for strong fields it is known that the frequency of particles shocks on the phonon increases with the energy of electrons, this increase results in the transfer of a significant proportion of electrons in the upper valleys of the conduction band. This leads to a significant increase in the mass of the electrons thus a decrease in electrons speed. The variation of the mobility rate becomes non-linear as a function of the intensity of the electric field.

To calculate the drain current general equation we used the one-dimensional approximation to simplify the mathematical expressions. We also use the following expressions:

$$J_x = -e\mu_n Nd(y)E_x = -e\mu_n Nd\frac{dV}{dx} \ . \qquad (2)$$

The drain current expression which is given by:

$$Id = -\int_{(s)} Jxds = -Z\int_{h(x)}^{a} Jxdy \qquad (3)$$

where h(x) is depth for gate to direction of x and a is width of zone doped N.

Using single integrals, the current expression is obtained by relation:

$$Id = \frac{(eNd)^2 Z\mu_n}{\varepsilon L}\left[\frac{a}{2}(h_d^2 - h_s^2) - \frac{1}{3}(h_d^3 - h_s^3)\right] \qquad (4)$$

where:

$$h_s = \left[\frac{2\varepsilon}{eNd}(Vbi - Vg)\right]^{1/2} \qquad (5)$$

$$h_d = \left[\frac{2\varepsilon}{eNd}(Vd + Vbi - Vg)\right]^{1/2} \qquad (6)$$

are the widths of the space charge area (SCA) respectively source side and drain side.

Defining the pinch-off current I_P by:

$$Ip = \frac{(eNd)^2 Z\mu a^3}{2\varepsilon L} \qquad (7)$$

and the pinch-off voltage V_P by:

$$Vp = \frac{eNd}{2\varepsilon}a^2 \ . \qquad (8)$$

The general equation expression I_d in the channel becomes:

$$Id = \frac{(eNd)^2 Z\mu a^3}{2\varepsilon L}\left[\frac{Vd}{Vp} - \frac{2}{3}\left(\frac{Vd + Vbi - Vg}{Vp}\right)^{3/2} + \frac{2}{3}\left(\frac{Vbi - Vg}{Vp}\right)^{3/2}\right] . \qquad (9)$$

The saturation value VDsat is taken as the voltage where the conduction channel depleted near the drain. So:

$$Vbi - VGS + VDSat = Vp \ . \qquad (10)$$

From this we can find

$$VDSat = Vp - bi + VGS = VGS - VT \ . \qquad (11)$$

The simplified expression for the saturation drain current is:

$$IDSAT = \frac{(eNd)^2 Z\mu a^3}{2\varepsilon L}\left[\frac{1}{3} - \left(\frac{Vbi - Vg}{Vp}\right)^{3/2} + \frac{2}{3}\left(\frac{Vbi - Vg}{Vp}\right)^{3/2}\right] \ . \qquad (12)$$

This law allows for mobility of the different expressions of the drain current in various operating modes and linear saturation.

For characteristics I_d (V_d, V_g) of GaAs MESFET transistor corresponding to different operating regimes we have studied and determined the magnitudes of the intrinsic and extrinsic elements of the component, then considered the effect of parasitic resistances of source port R_s and R_d drain and also the effect of parallel resistance Rp to the channel that was added to the parasitic capacitances and links in Figure 2.

The ratio of change in the output current to change in the gate voltage is called transconductance and is an important figure of merit to evaluate the device MESFET performance. The transconductance G_m of MESFET GaAs figure 2 is a measure of gain and it's expressed as:

$$G_m = \left.\frac{\partial I_D}{\partial V_m}\right|_{V_D\ is\ constant} \qquad (13)$$

where I_D is the drain current, V_D is the drain voltage and V_G the gate voltage.

III. MESFET EQUIVALENT CIRCUIT

The structure that determines the sub-micronique behavior of a MESFET transistor is identified on the figure 2; a few important parameters are reported in [1].

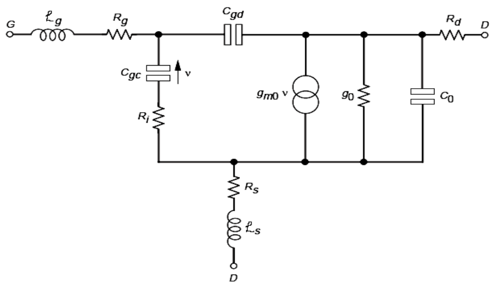

Figure 2: High frequency equivalent circuit

IV. MICRONIC MODEL MESFET

The DC simulation of the influence of gate length on output characteristics of GaAs MESFET transistors is shown on figure 3.

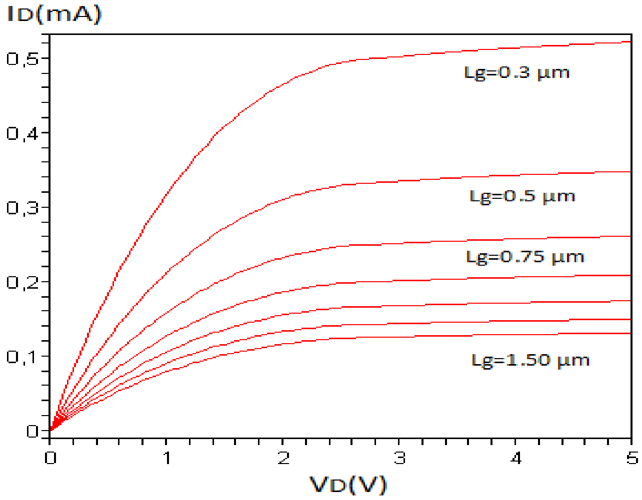

Figure 3: The calculated I-V characteristics of GaAs MESFET device for different gate lengths, simulation parameters are: a=0.2µm, Z=100 µm, N_D=1.0* 10^{17} cm^{-3}, V_{GS}=0V.
Gat lengths are: 0,3µm, 0,5µm, 0,75µm, 1,25µm, 1,25µm, 1,50µm.

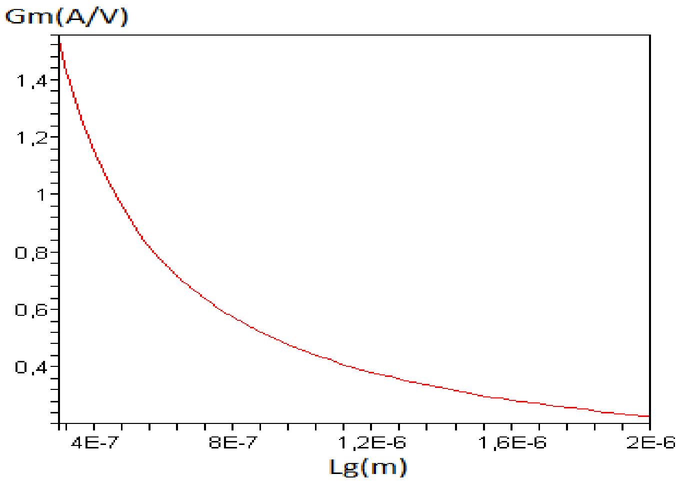

Figure 4: Transconductance of MESFET device with gate lengths Lg=0,3 µm to 2 µm.

V. SUB-MICRONIC MESFET MODEL

The resistance associated to the gate metallization deteriorates the microwaves and commutation performances. To carry out weak noise MESFET, it is important to decrease the gate resistance. This gate resistance Rg was identified a long time as a parasitic parameter which deteriorates the noise factor and limits the power gain of the Schottky-barrier-gate MESFETS (SBGMESFETs). We add a metallization resistance: Rga to Rg as shown on the figure 2. This gate metallization resistance contributes clearly to Rg [3]. It is given in a distributed way, and confirms the effect of the resistance end to end of the gate finger:

$$Rga = \frac{r_{ga}W_g}{3Nk^2}. \quad (14)$$

To distinguish this well-known resistance from the component MESFET which is the aim of this article, we presented this access resistance along the gate finger rga, it is then the end to end normal metallization resistance given by:

$$r_{ga} = \frac{\rho}{A_{gx}} \quad (15)$$

where ρ is the metal resistivity of gate and Agx is the gate section. W_g is the gate and N_k is the number of parallel fingers. Because the undercarriage length of door is narrowed with major sub-micronique dimensions it is usual to limit the increase in the r_{ga} by using a formed cut T, and to increase the number of parallel fingers. The skin effect will present the frequency response in the metallization access resistance of the gate in AC regime [4]:

$$r_{ga}^{ae}(f) = r_{ga}\sqrt{1+\frac{f}{f_{se}}} \qquad (16)$$

wwhere the frequency characteristic for the beginning of the significant skin effect is:

$$f_{se} = \beta \frac{r_{ga}}{\mu_0} \qquad (17)$$

and $\mu_0 = 4.10^{-7}$ Vs/A.m is the free space permeability, and β a geometrical factor, roughly equal to 3,5 for a cross section of the cross-section. For r_{ga}=150 Ω/mm, the f_{se} is 420 GHz. Although β can be reduced by the presence of a plane on the ground [5], the skin effect seems certainly to be negligible. We prove numerically that the skin effect is indeed negligible, and that eqns. (16)-(17) are precise and adapted for SBGMESFET. Another resistive component on the input side of the MESFET is the filling resistance Ri (or Rgs) for the gate-source capacity. This parameter is often hard to separate from Rg during the extraction of the equivalent circuit [6]. However, Ri is between a sixth and a fifth of the channel resistance for a used zero-drain-polarization [7].

$$Ri = \frac{1}{5} Ro(\frac{Lg}{Wg})(\frac{Idmax}{Id}) = \frac{Lg.vsat}{5\mu.Id} \qquad (18)$$

where: Ro is the plate resistance and Idmax the current saturation of the channel, vsat is the speed of saturation, and μ the mobility. The factor 1/5 in eqn. (18) is the higher limit of quantity:

$(R_{11}-R_{12})/(I_{11}-I_{12})^2$

Where Rij and Iij parameters determine the Y parameters, and are derived from the wave linear equation of the MESFET inside [8]. It explains both the distributed nature of Ri, and the change of the electron concentration of the sheet along the channel. Both eqns. (14) and (18) foresee very small resistances, often much smaller than the values produced by methods of extraction of equivalent circuit. It is an indication of an additional component in the input resistance, whose physics must be established in order to understand better the MESFET component, and to produce measurable models. To finish the study of effect of the conducting semi metal interface, we add a component R_g another resistance R_{gi} [9]. Which defines the gate resistance normalized interfacial resistance. This resistance is defined as a contact resistance with the substrate, r_{gi} being the normal gate resistance of the normalized interfacial resistance.

$$R_{gi} = \frac{r_{gi}}{W_g L_g}. \qquad (19)$$

Simulation AC of the influence of the gate resistance and gate length on the input and output impedance of GaAs MESFET transistors are represented on figures 5, 6 and 7.

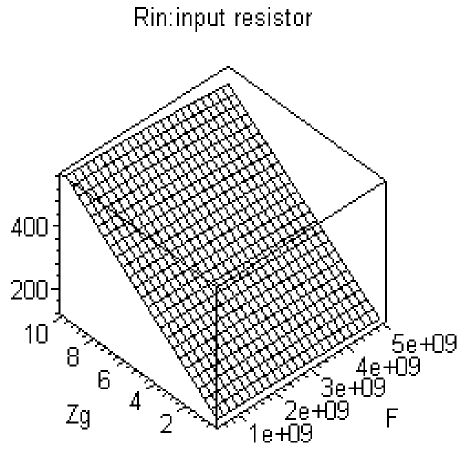

Figure 5: Gate influence on R_{in}

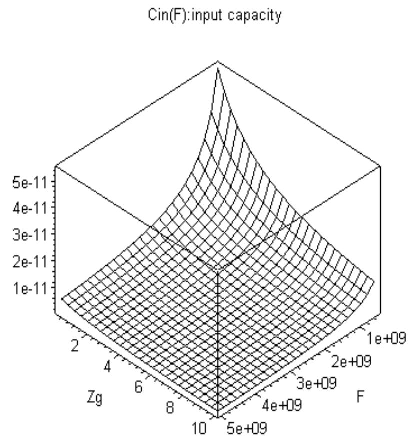

Figure 6: Gate influence on C_{in}

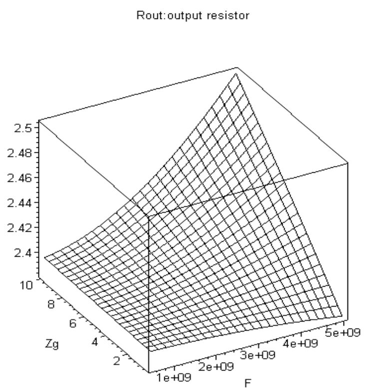

Figure 7: Gate influence on R_{out}

VI. CONCLUSION

After we solved analytically the two-dimensional Poisson equation we are presented the influence of gate lengths for I-V characteristic, to the show that the differences become smaller for the greater gate-length values the I_D decrease and same them the transconductance.

We presented the effect of the gate lengths of 2 to 0.3 µm of Schottky gate GaAs MESFETS. The metallization resistance R_{gi} is practically undetectable for wider gate lengths. This resistance R_g due to the skin effect can be induced starting from theoretical R_i. The considerations and the experimental observations prove that these resistances are not defined in an obvious manner by a fraction of input series resistance of the short gate MESFETS.

We note that resistance r_{gi} has a capacitive effect at higher frequencies and cannot be ignored at the microwave and millimetre-length wave frequencies.

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