

## Effect of temperature on (IV) statics characteristics of GaAs Mesfet

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**Abstract.** The GaAs metal semiconductor field effect transistors called MESFETS are the most active components used in microwave applications. To better exploit the performance of these components circuits, it is necessary to develop techniques for sophisticated numerical computation based on physical mechanisms that govern the operation of these devices. The static properties of GaAs MESFET could be determined from an original analytical study based on the resolution of the semiconductor fundamental equations. Then we will study the equation of thermal resistance as a function of the physical parameters of MESFETs by analogy electric thermal resistance RTH will be determined as the ratio of the difference of temperature on the thermal dissipation. The model took into account the difference between the temperature of the component and the ambient temperature and the effect of temperature on the parameters of the component.

### 1-Introduction:

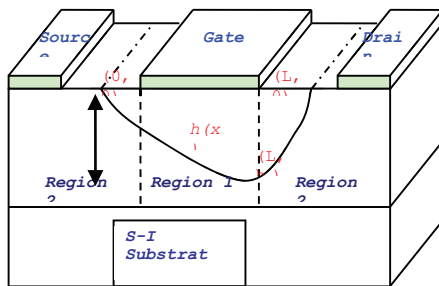
The GaAs MESFETS are attractive devices for the used in microwave applications because of their relatively simple processing and they high-speed and low noise performance. The principal object in the paper is to propose a physical and analytical model of the characteristics current voltage of these devices with different laws of temperature. In the first ,we calculate the potential in the depletion layer 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  $I_d$ , the characteristic I-V obtained by this model, using effect of temperature on IV characterisation.

### 2- Calculation of the potential and the current in the channel:

To calculate the potential and the electric field under the gate, the channel is divided into two principal regions [1] as shown in 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]:

$$V_q(x, y) = \int_0^y \frac{eN_d(x, y)}{\epsilon} y dy + y \int_y^{h(x)} \frac{eN_d(x, y)}{\epsilon} dy + V_{bi} - V_g \quad (1)$$

With  $N_d(x, y)$  is the density of the donors,  $V_{bi}$  is the built in potential of Schottky barrier gate and  $\epsilon$  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 and is giving by:

$$h(x) = \left[ \frac{2\epsilon(V_{bi} - V)}{qN_d} \right]^{1/2} \quad (2)$$

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

$$V(y) = \frac{qN_d}{\epsilon} \left[ h.y - \frac{y^2}{2} \right] \quad (3)$$

The equation of the potential take a maximum of values in diffusion potential  $V_{bi}$  ( $y = h$ ):

$$V_{bi} = V(y = h) - V(y = 0) \quad (4)$$

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

$$V(x) = \frac{qN_d h^2(x)}{2\epsilon} + V_G - V_{bi} \quad (5)$$

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 Schottky barrier junction.

- A channel with uniform donors doping  $N_D(x, y) = N_D$ ,  $N_D$  is constant.
- Neglecting edge effects, and the overflow depleted area on the sides of the gate

The density of the current is given by:

$$J_x = \sigma(x, y, z) \cdot E_x \quad (6)$$

$$\sigma(x, y) = \rho(y) \mu_n(E_x)$$

$$J_x = qN_D \mu_n E_x = -q\mu_n N_D \frac{dV(x)}{dx} \quad (7)$$

$\mu_n(E_x)$  is the electron mobility which depends of the electric field.

The drain current  $I_d$  is considered positive in the drain source is obtained by integrating the current density  $J_x$  over the conducting channel section:

$$I_d = -\int_0^Z \int_{h(x)}^a J_x dy dz = -Z \int_{h(x)}^a J_x dy \quad (8)$$

The calculations made above don't take into account the contribution of the space charge region located below the gate contact. In order to consider this contribution we introduce the pinch off voltage  $V_p$  at drain voltage equation and the saturation current  $I_p$  as following:

$$I_p = \frac{(qN_D)^2 \mu_n Z a^3}{2L\epsilon} \quad V_p = \frac{qN_D a^2}{2\epsilon} = V_{bi} - V_g$$

$$a = \left[ \frac{2\epsilon}{qN_D} (V_{bi} - V_g) \right]^{\frac{1}{2}}; \quad \frac{h(x)}{a} = \left[ \frac{V_{bi} + V(x) - V_g}{V_{bi} - V_g} \right]$$

Then the expression final of the current  $I_d$ :

$$I_d(V_d, V_g) = I_p \left\{ \frac{V_d}{V_p} - \frac{2}{3} \left[ \left( \frac{V_d + V_{bi} - V_g}{V_p} \right)^{\frac{3}{2}} - \left( \frac{V_{bi} - V_g}{V_p} \right)^{\frac{3}{2}} \right] \right\} \quad (9)$$

### 3.Effect of temperature .

The current characteristics are strongly related to the temperature. However, most simulations assume that the temperature of the component is constant, usually equal to the ambient temperature (300 ° K). A rigorous thermal model requires solving the equation of heat [4]

$$C_R \rho_R \frac{\partial T_R}{\partial t} = \nabla (K_R \nabla T_R) + H_S \quad (10)$$

$C_R$  : specific heat of the network,  $\rho_R$ : Network density ,  $K_R$  : temperature of the network.

$T_R$  : thermal conductivity of the network,  $H_S$ : Heat generation network.

The dependence of the carrier mobility with temperature [5]:

$$\mu = \mu_0 (300^0 K) \left[ \frac{300}{T_R} \right]^{0.6} \quad (11)$$

The saturation velocity varies with temperature as

$$v_s = \frac{2.410^5}{1 + \exp(T / 600)} m s^{-1} \quad (12)$$

according to Conger [3] the dependence of the threshold voltage may be approximately given by:

$$V_{TH} = V_{TH}(300^0 K) - \alpha_{VT} T \quad (13)$$

The value of  $\alpha_{VT}$  is in the order of 1.2mV/°C .

#### 4. Results and discussion

To show the effect of temperature on the characteristics (I-V), we perform the numerical simulation with the laws of mobility, velocity saturation and the threshold voltage as a function of temperature:

$$\mu_n = \mu_n(300^0 K) \left[ \frac{300}{T_R} \right]^{0.6} \quad (14)$$

$$v_s = \frac{2.410^5}{1 + \exp(T / 600)} \quad (15)$$

As the diffusion voltage of the junction " $V_{bi}$ " varies with temperature as follows:

$$V_{bi}(T) = V_{bi}(300^0 K) \left( \frac{T}{T_0} \right) \quad (16)$$

The structure used for the calculation is shown in Figure (1)

For the mobility we have choice these expressions:

$$\begin{cases} \mu_1(E) = \frac{\mu_n}{1 + \left(\frac{E}{Ec}\right)} \\ \mu_2(E) = \frac{\mu_n + v_s \left(\frac{E^3}{Ec^4}\right)}{1 + \left(\frac{E}{Ec}\right)} \end{cases} \quad (17)$$

In table 1. we give the characteristic of our MESFET.

MESFET	$L(\mu m)$	$a(\mu m)$	$Z(\mu m)$	$N_D(Cm^{-3})$	$\mu_n(Cm^2S^{-1}V)$	$V_{bi}(V)$	$R_S(\Omega)$	$R_D(\Omega)$
MESFET	4	0.3	360	$6.7 \times 10^{16}$	3740	0.8	16	16

The Figures (2) and (3) present the change of speed of the electrons as a function of electric field for various values of the temperature; the speed is highest when the temperature increases.

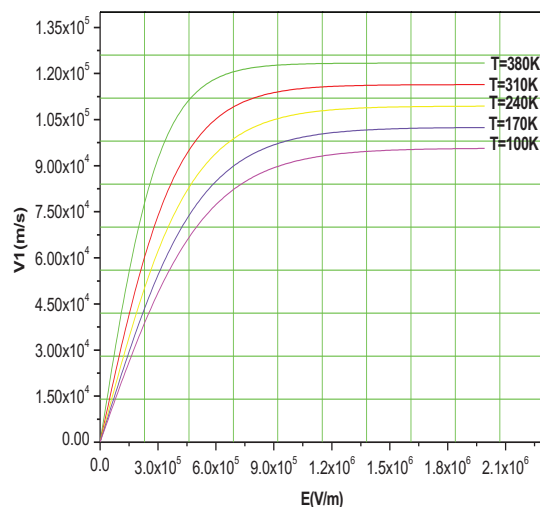


Figure 2. Variation of the velocity  $V_1$  versus electric field for different values of temperatures.

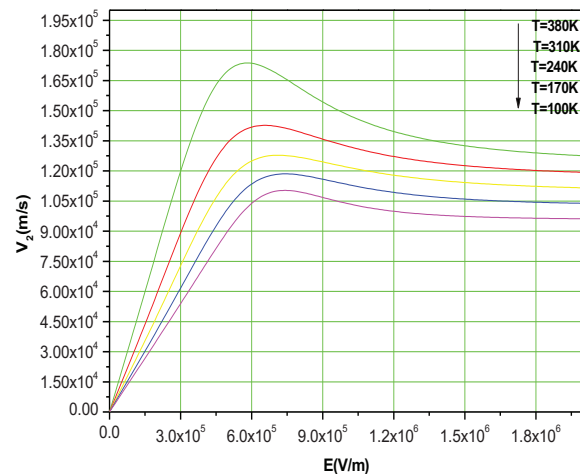


Figure 3. Variation of the  $V_2$  velocity versus electric field for different values of temperatures.

The Figures (4) and (5) shows the variation of the mobility of electrons as a function of electric field for various values of temperature. We find that mobility is higher as the temperature decreases.

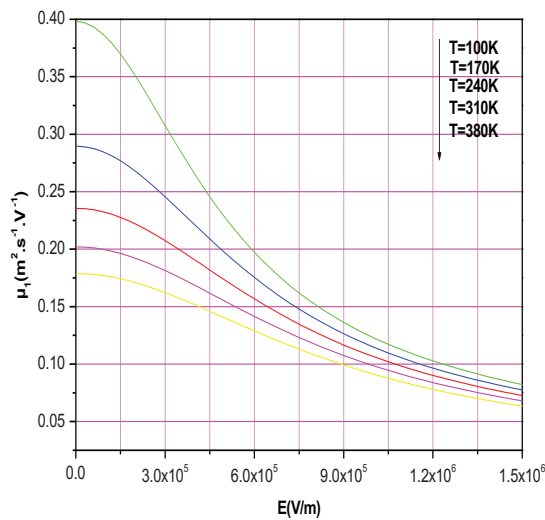


Figure 4. Variation of the  $\mu_1$  mobility with electric field Electric field for different values of temperature

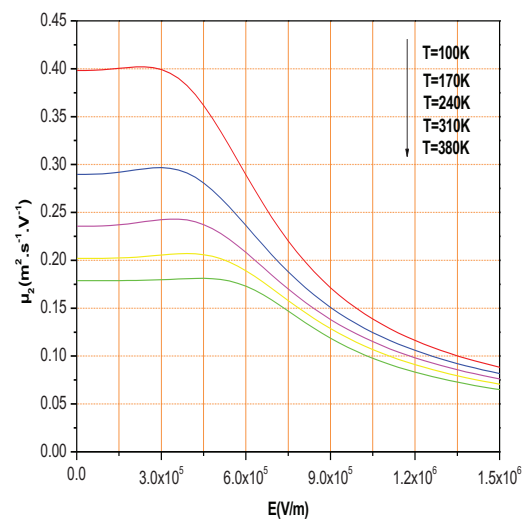


Figure 5: Variation of the  $\mu_2$  mobility with for different values of temperature

The figure (6) show the variation of the drain current as a function of the voltage  $V_{DS}$  for different values of temperature. The current increases as the temperature  $T$  decreases, constant mobility.

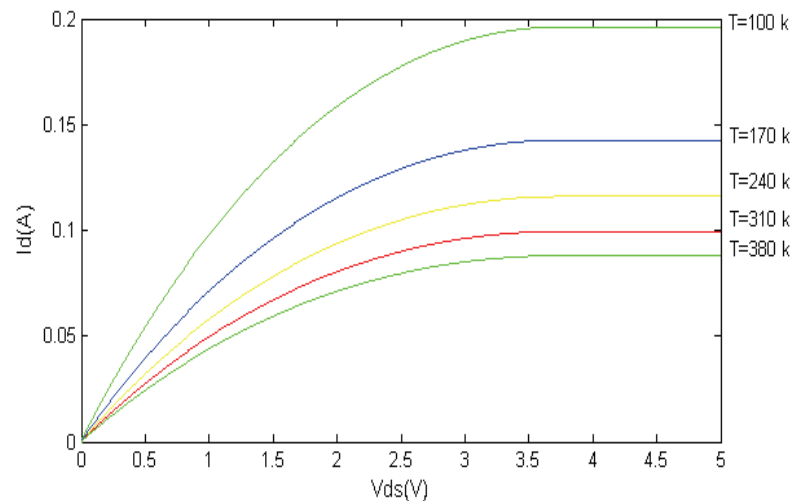
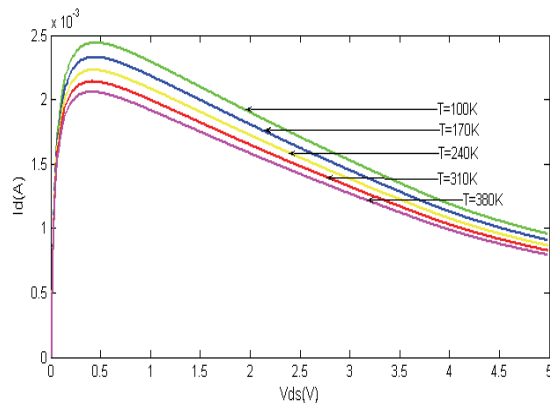


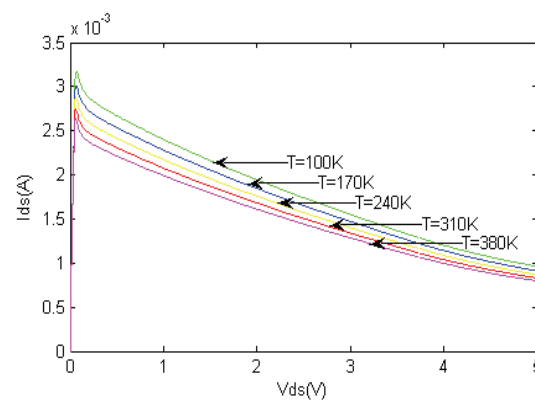
Figure 6 Characteristics (I-V) for different values of temperature  $T$   
with constant mobility  $\mu_0$  for GAT1

The same manner when the mobility varies, we present in Figures (7) and (8), the influence of temperature on the I-V characteristics of transistors "GAT1". We choose five values of temperature " $T = 100 \text{ K}$ ," " $T = 170 \text{ K}$ " and " $T = 240 \text{ K}$ ," " $T = 310 \text{ K}$ ," " $T = 380 \text{ K}$ ". From these figures, we find that the performance and reliability of the transistors are strongly influenced by temperature. Conduction along the channel is due to the majority carriers (electrons), it will be affected by the temperature variation for certain parameters (electron mobility, the Schottky barrier height, the saturation velocity, the dielectric constant and the same the specific resistance of ohmic contacts). If the temperature increases, thermal motion of the carriers also increases and hence the electron mobility of the channel

decreases from expression (5), which causes a decrease in the current " $I_{ds}$ ". Similarly the height of the potential barrier increases with increasing temperature from expression (8), therefore the width of the space charge region increases against the conductive channel narrows, and thus the drain current decreases.



**Figure 7.** The characteristics (I-V) different values of temperature using the expression of  $\mu_1$  mobility for GAT1



**Figure 8.** The characteristics (I-V) for different values of temperature using the expression of  $\mu_2$  mobility for GAT1

## 5. 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 the effect of temperature on field electron mobility, velocity saturation and effect of this parameter to the temperature expressions. Moreover, comparisons between the analytical models with different values of temperature showed the effect the output characteristics (I-V) of GaAs MESFET, then the MESFET structure allows very significant improvement in performance when it is operated at low temperatures.

## 6. References

- [1] S. Morarka, S. Mishra "has 2-D model for the potential distribution and threshold voltage off fully depleted short-Chanel ion-implanted silicon MESFET' S", newspaper off semiconductor technology and science, Vol 5, NO3, p 173-181, Marsh 2005.
- [2] T.A. Fjedly, T. Yterdal, M.S.Shur "Introduction to Device Modeling and circuit simulation", Wiley, New " York, 1998.
- [3] F.S.Shoucair and Pekka K. Ojala, " High-Temperature Electrical Characteristics of GaAs MEFET's", IEEE uary.19Transactions on Electron Devices. Vol.39.No.7. Febrs
- [4] S. P. Chin, G. Y. We, "A new two dimensional model for the potential distribution of short gate lenght MESFET's and its applications," IEEETrans. Elec 5881, Dev, vol **39**, pp. 1928-1937, August 1992.