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I-V Characteristics Model For AlGaN/GaN HEMTs Using Tcad-Silvaco

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Abstract

We report some results the drain current characteristics of AlGaN/GaN HEMT(High Electron Mobility Transistor). on are simulated by changing the different device parameters such as Al content x and the barrier thickness for different values of the gate voltage using Tcad-Silvaco numerical simulation software. Drift–diffusion model has taken for simulating the proposed device. we use SiC as a substrate for this structure, The channel is made of GaN and source-drain spacing is 1 µm.

Keywords: AlGaN/GaN, HEMT, Tcad-Silvaco;

1. Introduction

The active components are the basic elements of the design of microwave monolithic integrated circuits. The active elements are formed of transistors and diodes. Today, we must design transistors and diodes capable of meeting the requirements in terms of power and increase in frequency [1] [2] [3].

The III-N semiconductor materials are good candidates for the fabrication of these types of transistors and diodes. The III-N semiconductor materials have several advantages such as a wide bandgap, a high chemical stability, and exceptional physical properties other outstanding mechanical properties. These semiconductors possess the necessary qualities to make power components.

Thus, since many years, the industry uses microwave technology HEMT. Until now, the transistors are HEMTs formed in a die Gallium nitride (GaN). However, GaN and other materials such as silicon are used too close to their ultimate physical limitations, especially at the power densities supplied.

2. AlGaN/GaN HEMT STRUCTURE: 2-DEG Formation & Polarization effect

The basic concept in a HEMT (Fig.1) is the aligning of a wide and narrow bandgap semiconductor adjacent to each other to form a heterojunction. The carriers from a doped wide energy gap material (AlGaN) diffuse to the narrow band gap materials (GaN) where a dense 2-DEG (Two Dimensional Electron Gas) is formed in the GaN side but close to the boundary with AlGaN.

The unique feature of the HEMT is channel formation from carriers accumulated along a grossly asymmetric heterojunction, i.e. a junction between a heavily doped high bandgap and a lightly doped low bandgap region [4].

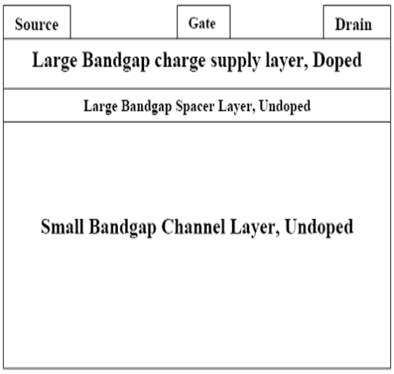


Fig 1: Layered structure of High Electron Mobility Transistor.

To achieve proper operation of the device, the barrier layer $Al_xGa_{1-x}N$ must be at a higher energy level than the conduction band of the GaN channel layer. This conduction band offset transfers electrons from the barrier layer to the channel layer. The electrons that are transferred are confined to a small region in the channel layer near the hetero-interface. This layer is called the 2DEG (Fig.2) and a defining characteristic of the HEMT. There are many factors that determine the quality of the 2DEG.

The factors involved in the development of the 2DEG are type of substrate, growing method, and level of doping of the carrier supply layer [8].

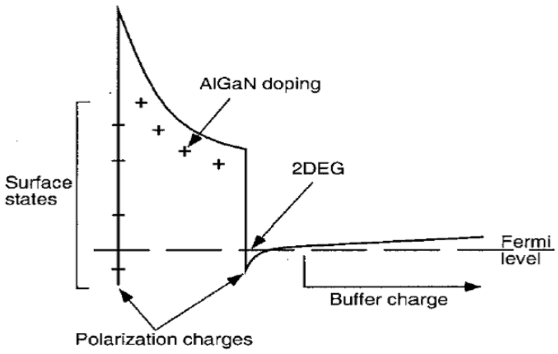


Fig 2: Energy band diagram showing 2DEG formation.

2.1. Current- Voltage Characteristics

The Current-Voltage is related to the density variation for the 2DEG density under the influence of a gate-source voltage applied of the component. In fact, any action on the gate voltage Vgs has the effect to modify the electronic population of the channel which varies the electrons density ns. Several authors have developed models in order to account for the $I_{DS}(V_{DS})$ characteristics electrical behavior of HEMTs [9][6]. First, we started to introduce conventional expression of the drain-source current I_{DS} according to the voltage drain-source V_{DS} in order to determine ideal characteristics $I_{DS}(V_{DS})$ for differ-ent values of Vgs. The current I_{DS} is proportional to the density of electrons in the channel ns which is expressed as follows [7][5]:

$$\boldsymbol{I_{DS}(x) = W\,\mu_n\, q n_s E(x)} \qquad (1)$$

where W is the channel width and μ_n is the mobility of carriers.

Since the current is constant throughout the channel, integrating the above equation from source -to -drain gives:

$$I_{DS} = W\,\mu_n\, C_0/L\left[(V_G - V_{th})V_{DS} - \frac{V_{DS}^2}{2}\right] \qquad (2)$$

The output characteristics for an enhancement -mode HEMT are shown in Fig 3. In the linear region where $V_{DS} \ll (V_G-V_{th})$, Eq (2) is reduced to an ohmic expression:

$$I_{lin} = \frac{W\,\mu_n\, C_0(V_G - V_{th})V_{DS}}{L} \qquad (3)$$

from the equation (3), the transconductance can be obtained as follow :

$$g_{m,lin} \equiv \frac{dI_{lin}}{dV_G} = \frac{W\,\mu_n\,C_0 V_{DS}}{L} \qquad (4)$$

At high V_{DS}, n_s at the drain is reduced to zero, corresponding to the pinch-off condition an current saturates with V_{DS}.

3. Results

3.1. simulation model

In this model, we use SiC as a substrate for HEMT structures AlGaN/GaN .The fig 3 shows a schematic representation of the HEMT structure in two dimensions.The channel is based not intentionally doped GaN (nid). The doping concentration in this layer is $N_{D1}= 10^{15}$ cm^{-3} of type N. the channel width is 10 nm. The channel is inserted between two spacer layers of thickness 55 nm with a doping $N_{D2} = 10^{17}$ cm^{-3} in which is inserted a δ doping layer with $N_{D2} = 2 \times 10^{18}$ cm^{-3}. The device at a gate length of 0.6 microns and a source-drain spacing is 1 micron.

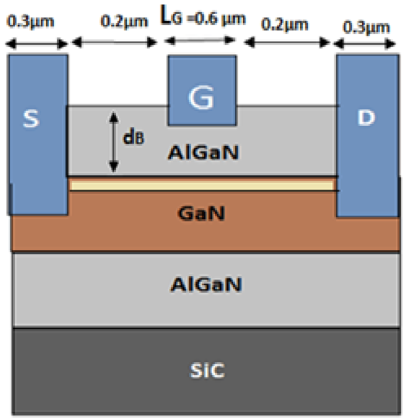


Fig 3: A scheme simulating an HEMT AlGaN / GaN two-dimensional

3.2. I_{DS} (V_{DS}) Characteristics for different values of molar fraction (x)

The current-voltage characteristics of a HEMT transistor based heterostructure AlGaN/GaN are shown in figure 4 . These results are obtained by varying the drain voltage for different values of the voltage Vgs applied to the gate and the two values of "x" molar fraction.

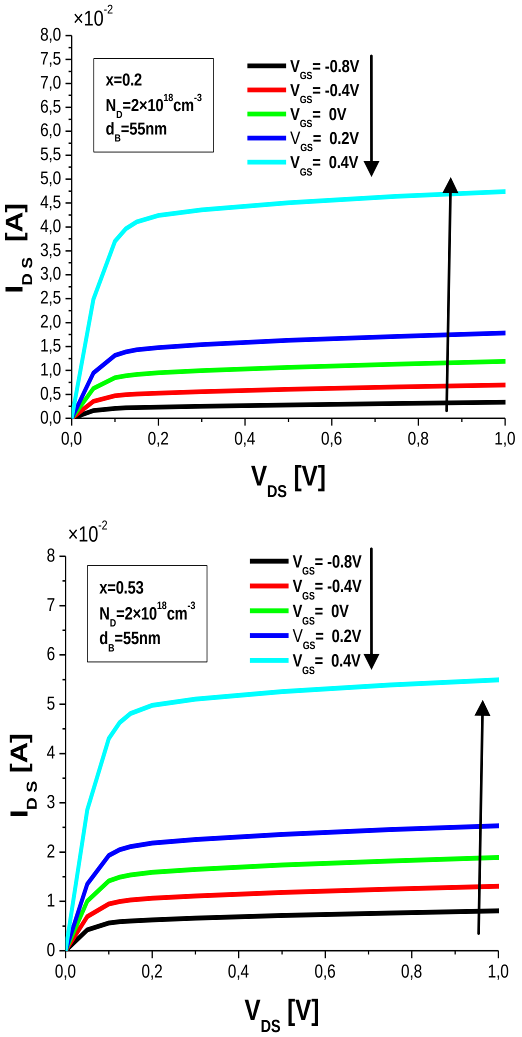


Fig 4: Evolution of the drain-source "IDS" depending on the drain voltage "VDS" for different values of the gate voltage in the effect of x.

3.3. I_{DS} (V_{DS}) *Characteristics for different values of barrier thickness* (d_B)

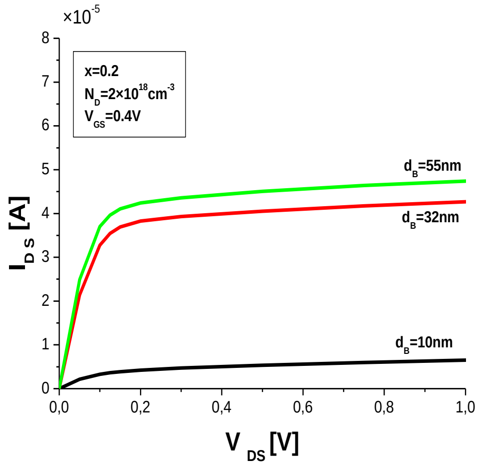


Fig 5: Evolution of the drain-source "IDS" depending on the drain voltage "VDS" for different values of the thickness "dB".

3.4. IDS (VDS) Characteristics for different values of gate width (LG) at VGS = 0.4V

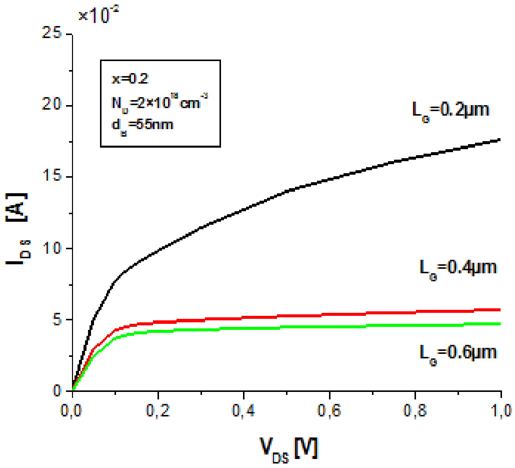
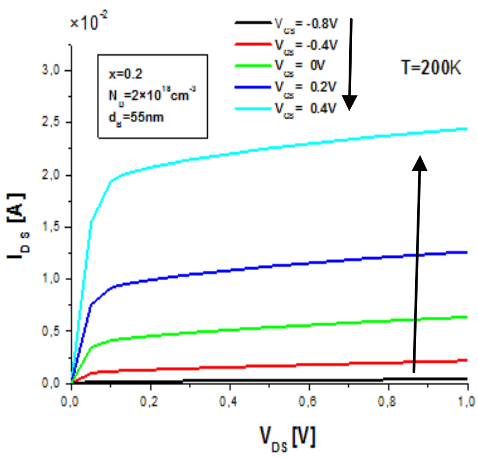


Fig 6 : Evolution of the drain-source "I_{DS}" depending on the drain voltage "V_{DS}" for different values of the gate width "L_G".

3.5. I_{DS} (V_{DS}) characteristics for different values of temperature (T)



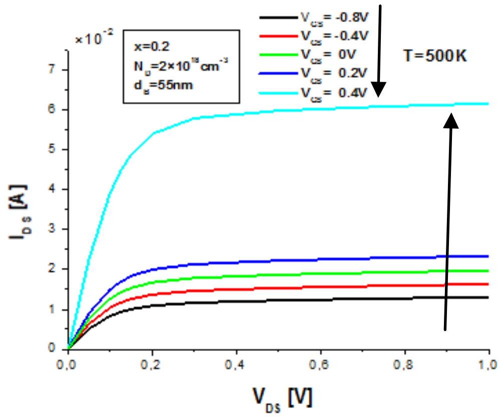
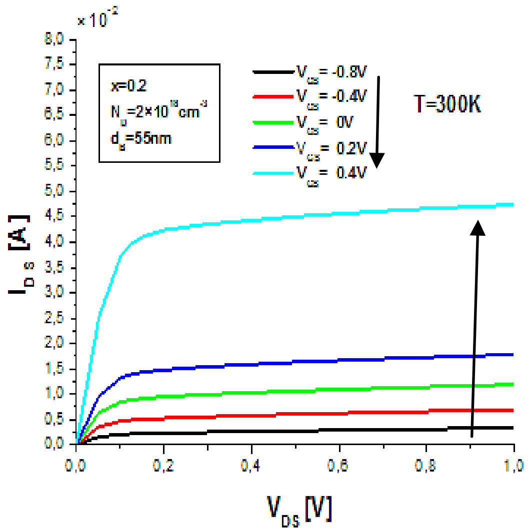


Fig 8: I_{DS}(V_{DS}) characteristics for different V_{GS} with thermal effect



4. Conclusion

we have presented the results of I_{DS}(V_{DS}) characteristic of HEMT AlGaN/GaN 2D with Silvaco ATLAS software and concerns that the effect of some physical parameters and geometry to improve the performance of transistor among them (the aluminum content (x), the gate width (L_G) ... etc.).

It was found that the intensity of drain-source current value to I_{DS} = 0.065A. But we note that the effect of languor grid is very important compared with other parameters to increase the current value for L_G = 0.2 µm intensity rises to I_{DS} = 0.16A.

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