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# Modeling the Transport of Charge Carriers in the Active Devices MESFET, Based of GaInP by the Monte Carlo Method

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***Abstract*—**The progress of industry integrated circuits in recent years has been pushed by continuous miniaturization of transistors. With the reduction of dimensions of components at 0.1 micron and below, new physical effects come into play as the standard simulators of two dimensions (2D) do not consider. In fact the third dimension comes into play because the transverse and longitudinal dimensions of the components are of the same order of magnitude. To describe the operation of such components with greater fidelity, we must refine simulation tools and adapted to take into account these phenomena. After an analytical study of the static characteristics of the component, according to the different operating modes, a numerical simulation is performed of field-effect transistor with submicron gate MESFET GaInP. The influence of the dimensions of the gate length is studied. The results are used to determine the optimal geometric and physical parameters of the component for their specific applications and uses.

***Keywords*—**Monte Carlo simulation, transient electron transport, MESFET device.

## I. Introduction

SINCE the introduction of the field-effect transistors, MESFET technology has seen a tremendous increase in processing capability due to scaling. The scaling trend Predicted by Gordon Moore has been accurate for more than 30 years [1]. The formidable progress of semiconductor technology in the last decade has allowed transistors such as the MESFET to operate in the regime where diffusive transport and quantum effects start playing a significant role in determining device and circuit performance [2]. The main advantage of III-V's is their high intrinsic mobility, which amounts to high speed and lower delay [3]. The effective mass of electrons is much lower in III-V's as compared to Si, which results in a high injection velocity. This low effective mass, however, also result in a low density-of-states, which affects the semiconductor capacitance and drive current [4]. This is frequently referred to as the density of-states bottleneck [5].

Several other issues need to be resolved for III-V's to contend as commercially viable technology. The diffusion model is used to study the role of phonon scattering on the on-state characteristics of MESFET channel devices [6]. Finally, the role of the Surface roughness scattering and its implementation within Monte Carlo discussed [7].

Recent progress in electron beam lithography and molecular beam epitaxial growth technology has brought critical dimensions of a field-effect transistor down to 100 nm [8]. The enhanced DC and microwave characteristics of GaInP Metal-Semiconductor Field Effect Transistors (MESFETs) are direct consequences of efforts to decrease the gate length [9]. In this study, we describe how the device characteristics of sub-100 nm gate GaInP Metal-Semiconductor Field Effect Transistors (MESFETs) are affected by short channel effect (gate aspect ratio effect) due to very low gate aspect ratio [10], by velocity overshoot due to near ballistic electrons, and by overshoot degradation due to short-channel tunneling of carriers [11].

## II. Model Details

Several simulations of MESFET's have been presented after the work of BRU, C, from the physical point of view, the various simulations can be divided into two groups, depending on the GaInP model used (two or three valley model, or the full band diagram) [13]. The scattering mechanisms are also taken from these models, and include non-equivalent intervalley (Γ↔X or L for the two valley model, Γ↔L, L↔X, Γ↔X for the three valley model), equivalent intervalley (L↔L in the first case, L↔L, and X↔X in the second), polar optic and acoustic phonon scatterings [14]. For traditional semiconductor device modeling, the predominant model corresponds to solutions of the so-called drift-diffusion equations [15], which are 'local' in terms of the driving forces (electric fields and spatial gradients in the carrier density), i.e. the current at a particular point in space only depends on the instantaneous electric fields and concentration gradient at that point [15]. The complete drift-diffusion model is based on the following set of equations [16]:

Current equations:

$$J_n = qn(x)\mu_n E(x) + qD_n\, dn/dx$$
$$J_p = qn(x)\mu_p E(x) - qD_p\, dn/dx$$

Continuity equations:

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla . J_n + U_n$$
$$\frac{\partial p}{\partial t} = \frac{1}{q}\nabla . J_p + U_p$$

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Poisson's equation:

$$\nabla.(\varepsilon\nabla V) = -(p - n + N_D^+ + N_A^-)$$

where $U_n$ and $U_p$ are the generation-recombination rates.
The continuity equations are the conservation laws for the carriers. A numerical scheme which solves the continuity equations should [17]

- Conserve the total number of particles inside the device being simulated.
- Respect local positive definite nature of carrier density. Negative density is unphysical [18].
- Respect monotony of the solution (i.e. it should not introduce spurious space oscillations) [19].

## III. Calculated Results

The MESFET GaInP Fig. 1 was taken as a prototype for devices Monte Carlo simulator illustration. The choice was suggested by the fact that the physical model is quite simple. Applied bias voltages are VG = -0.1v, VD = 0.25V. For the drain doping concentration is identical to that of the source $n^+ = N_D = N_S = 3.\ 10^{23} m^{-3}$ against the grid is $n = 10^{23} m^{-3}$.

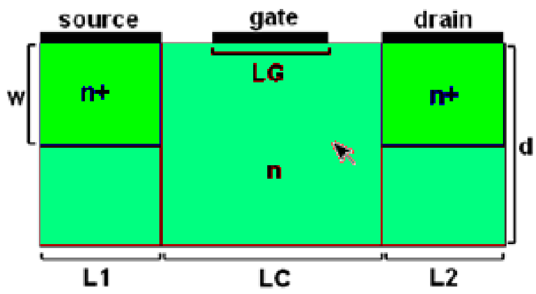


Fig. 1 MESFET (GaInP)

For the first aspect of Fig. 2, which shows the electron density in the MESFET, we formally observe a depletion region under the gate due to the application of the drain voltage source and strong electric fields which push the charge carriers of this region.

In Fig. 3 we see the longitudinal component of the electron drift velocity (in the x direction), which increases to a value of about $10^7$ cm / sec. The following reduction is due when the electric field is increased above the threshold value-. This effect is due to the transfer of electrons from the central valley Γ with a low energy state and high mobility at a high valley with high energy state and a low mobility.

When tension is applied to the structure Fig. 4, the potential decreases within the active region and then rises sharply until it reaches the value of the applied voltage.

MESFET GaInP does not have an integrated electric field within the source region. It is clearly shown in Fig. 5, and the electron density in the present case is increased because of the carrier transport that is slow and therefore the accumulation of carriers.

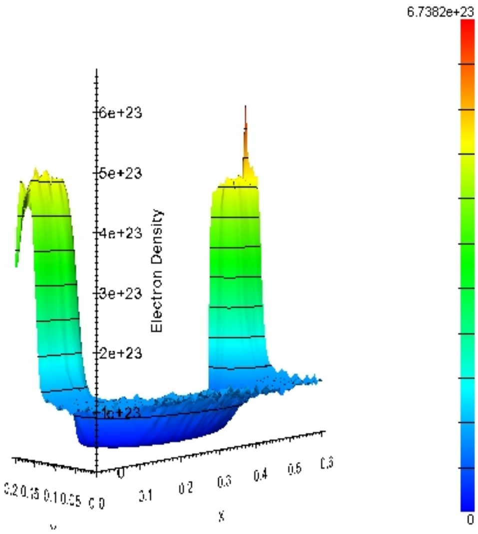


Fig. 2 Electron density in 3D as a function of distance x

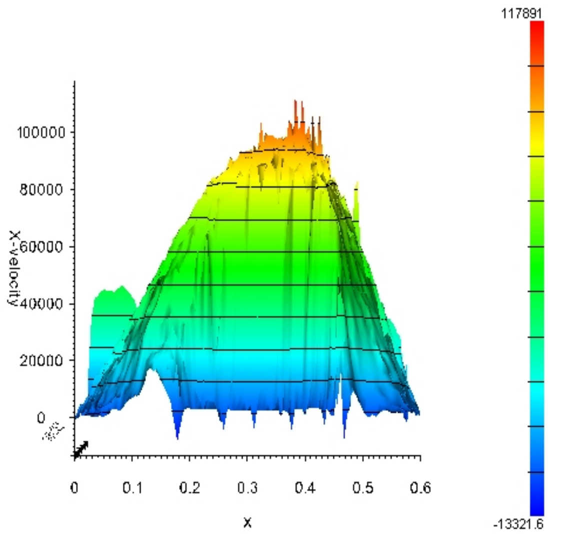


Fig. 3 The electrons drift velocity as a function of the distance x

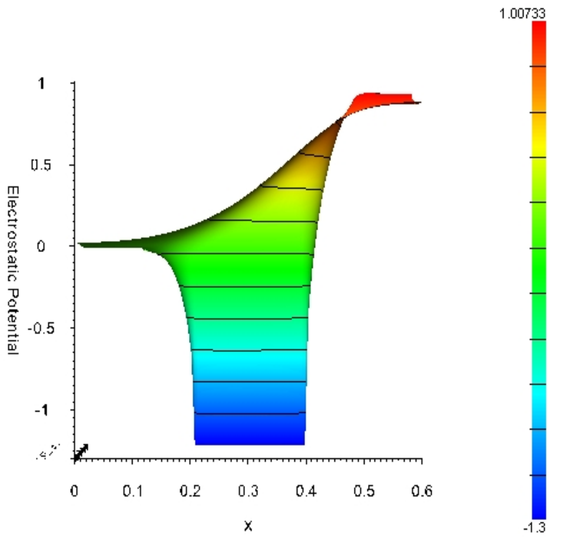


Fig. 4 Electrostatic potential as a function of the distance x

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In the active region of Fig. 6, the electrons are accelerated by the strong electric fields and gain energy, leading its electrons to the n-n$^+$ drain interface at maximum energy. In contact with the drain, the average energy continues to decline. This is caused by the fact that the electrons lose their energies due to several phenomena of diffusion.

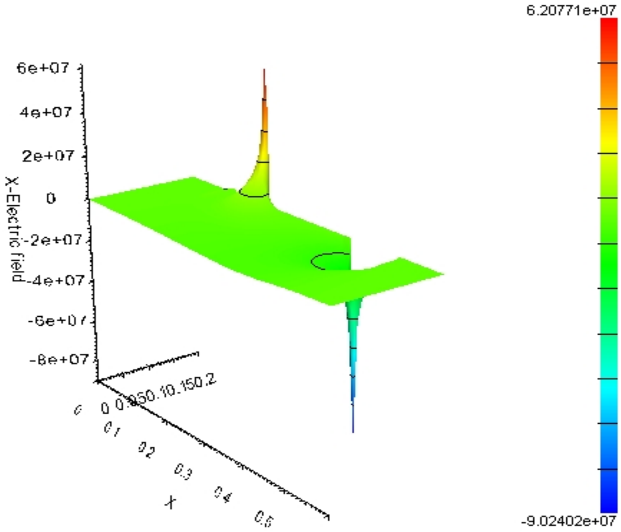


Fig. 5 Electric field as a function of the distance x

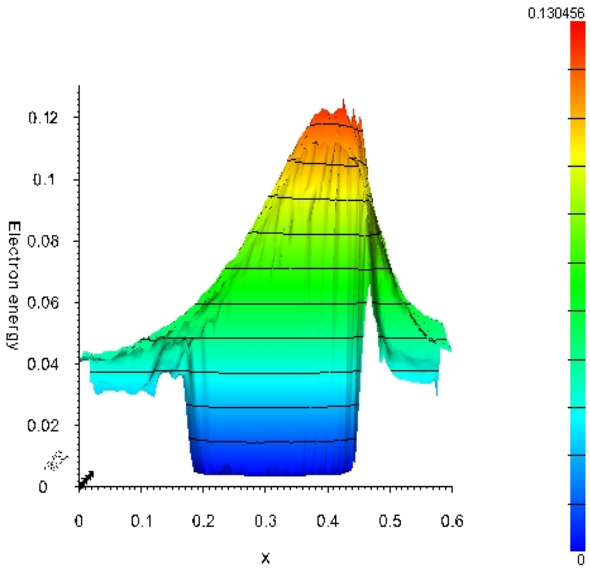


Fig. 6 Electron energy as a function of the distance x

Fig. 7 indicates two rapidly varying concentration regions. The first is between the source and gate and the second is between the gate and drain. It is also observed that, the electron density reduces to zero along the gate. There is a barrier region near the source end of the channel. This barrier determines the amount of electrons entering the channel. Its height is modulated according to the grid.

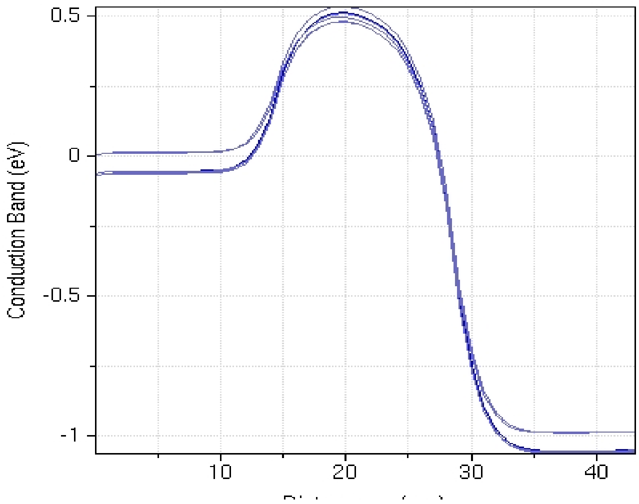


Fig. 7 Conduction band diagram along the transport direction obtained from drift diffusion simulations of a GaInP channel MESFET

## IV. Conclusion

As we have emphasized throughout of this article, all methods are based on the Boltzmann transport equation. The Monte Carlo method is on an ever higher level because it provides (even in non-homogeneous conditions, non-stationary) an exact solution of the Boltzmann equation. It correctly describes the non-local effects [20]. Unfortunately, the complexity and the cost of each approach is inversely related to the improvement of the physical model in which it is based. The use of an approach or another depends on the specific device under consideration [21].

The simulators using three models of the valley are certainly preferable, although the differences between the two models are important only in the presence of high electric fields (≥10 kV / cm). Probably more important are the values of the coupling constants and the separation of the valley, which strongly influence the GaInP transport properties and the results of the simulation [22].

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