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Physics and Simulation of Diffusive Transport in Nanoscale Transistors MESFET Device $Ga_{0.49}$ $In_{0.51}P$ Using Monte Carlo Method of Electronic Transport

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ABSTRACT
The field of microelectronics has made surprising advances in the last decade, mainly pushed by the enormous progress in semiconductor technology. Such a reduction of dimensions allows the fabrication of chips with more than one million components. In addition, it opens the way to new physical phenomena, which were not present in traditional structures. In this context, the Monte Carlo simulation has particular significance. This approach allowed conceiving applicable model for GaInP MESFET operating in the turn-one or pinch-off region, and valid for the short-channel and the long-channel GaInP MESFET, in which the two-dimensional potential distribution contributed by the depletion layer under the gate is obtained by conventional 1D approximation
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.

The main advantage of III-V's over SI is their high intrinsic mobility, which amounts to high speed and lower delay [2]. The effective mass of electrons in 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. This is frequently referred to as the density of-states bottleneck [3].
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. Finally, the role of the Surface roughness scattering and its implementation within Monte Carlo discussed [4].

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. The enhanced DC and microwave characteristics of GaInP Metal-Semiconductor Field Effect Transistors (MESFETs) are direct consequences of efforts to decrease the gate length [5]. 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, by velocity overshoot due to near ballistic electrons, and by overshoot degradation due to short-channel tunneling of carriers[6]

II. MATHEMATICAL MODEL

Several simulations of MESFET's have been presented after the work of Hockney's et al. [7]. 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). 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 [8]. For traditional semiconductor device

modeling, the predominant model corresponds to solutions of the so-called drift-diffusion equations, 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. The complete drift-diffusion model is based on the following set of equations [9]:

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:

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

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

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

• Conserve the total number of particles inside the device being simulated.

• Respect local positive definite nature of carrier density. Negative density is unphysical.

• Respect monotony of the solution (i.e. it should not introduce spurious space oscillations).

III. Resultats and Discussions

The properties of channel MESFET were studied using (Gate Length L_G=25nm, Source/Drain length $L_{S/D}$=25nm, Thickness Channel T_C=20nm). There the source and drain regions are heavily doped, and the gate is self-aligned (channel length equal to gate length 25nm in this case). The Transport model used in simulation is diffusive. The profiles of electric field E, average lateral velocity V and concentration N as a function of distance x from the source are presented in figure (1~ 5).

Fig1: shows the conduction band diagram for the device InGaP MESFET with Source/Drain doping 2×10^{25}/cm3 and LG=25nm for various gate biases (VG = -1~0V), obtained with drift-diffusion simulations. The lowest plot shows the onset of source exhaustion, where the top-of-the-barrier is pushed close to the source conduction band edge. The source cannot supply more charge if the gate voltage is further increased.

On the other hand, GaInP Mesfet has not a built-in electric field within the emitter region this is clearly shown in Fig 2, and the electron density in this case is increased due to slow transport of carriers and thus carrier accumulation.

Fig3: 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 by the gate bias

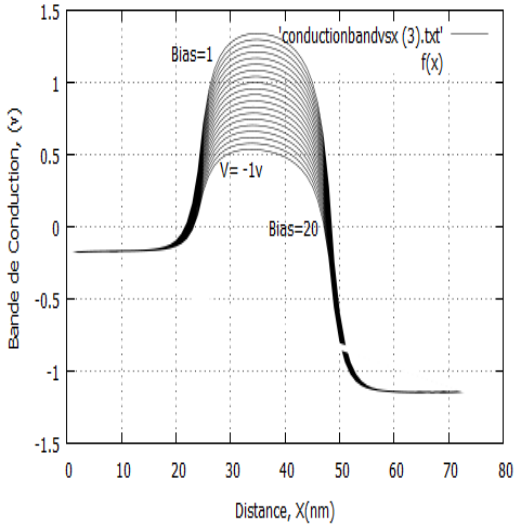


Figure 1 - Conduction band diagram along the transport direction obtained from drift diffusion simulations of a GaInP channel MESFET at high drain bias and various gate bias for source/drain doping of $N_{S/D} = 2\times10^{25}$ /cm3 **.**

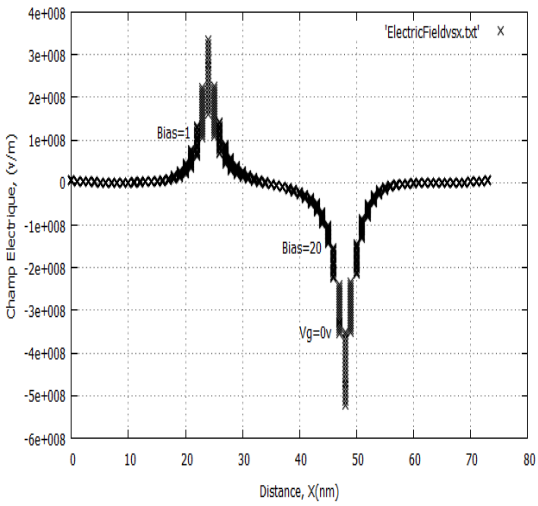


Figure 2 - Average electrical fields along the axis.

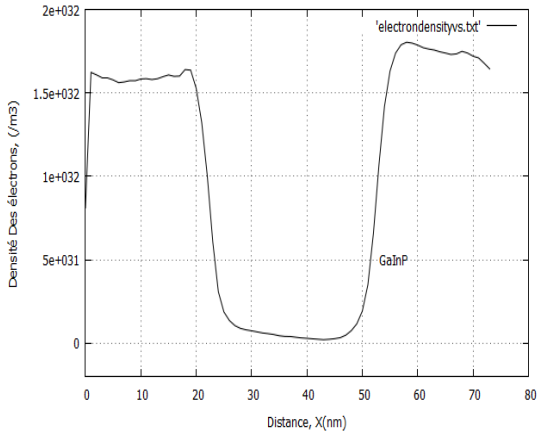


Figure 3 - electron density versus distance profiles for Mesfet

In the Fig4: no electric field is present in the emitter of the conventional design. The corresponding electron density is therefore dramatically decreased due to the presence of a drift velocity component in this region of the emitter. Near the drain the velocity exhibits a sharp decrease, due to the accumulation of L-valley slow electrons in that region. A large electron accumulation is also present near the source, caused by the electron Spillover from the doped region. Such high concentration balances the rather small electron velocity to sustain the large drain current of the device.

Fig5: exhibits the transient response of electrons in GaInP alloy, so it's noted that the velocity overshoot initially increases faster with increasing electric field due to the low effective mass of the gamma valley. For an electric field below the critical field (<10 kV / cm), the effect of overshoot is very little or not quite observable in the alloy GaInP

From 15 kV / cm to 50 kV / cm, the velocities begin to exhibit a peak. This peak for the 15kV/cm field is $1.7x10^7 cms^{-1}$ for a time 315fs. Whereas that for 50kV/cm field, the maximum speed is $2.45x10^7$ cms^{-1} for a time of 108fs

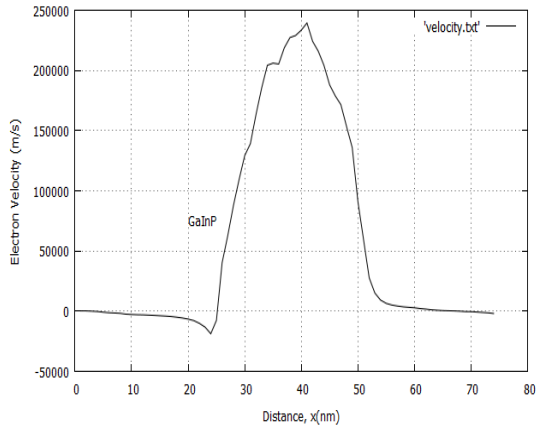
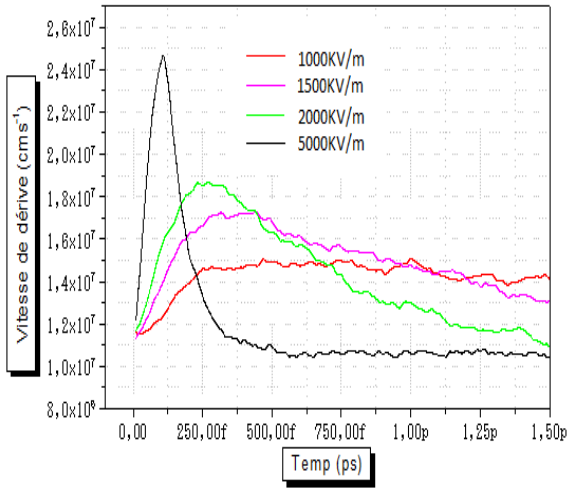


Figure 4 - Electron drift velocity as a function of distance



Figures 5 - Electrons drift velocity as a function of time for various field values

IV. Conclusion

In conclusion of the previous discussion, we would say that simulators using 3 valley models are certainly to be preferred, even if the differences between the two models are only important in the presence of very high electric fields (≥10 KV/cm). Probably more important are the values of the coupling constants and valley separation, which strongly influence the transport properties of GaInP and the results of the simulation.

It has also been possible to analyze the current control mechanisms. In particular, by switching-off the intervalley transfer in the simulation, it has been found that the gate voltage controls the current through the modulation of the depletion layer depth as well as of the electron velocity. Details of this particular work and of other interesting papers can be found in the References

References

[1] Zhibin Ren, Nanoscale Mosfets Physics Simulation and Design, Purdue University, p211, 2001.

[2] Himadri Sekhar Pal, Device Physics Studies Of III-V and Silicon Mosfet For Digital Logic, Purdue University West Lafayette, Indiana Graduate School Form 20 (Revised 6/09), 127, December 2010.

[3] Farzin Assad, Computational and Experimental Study of Transport In Advanced Silicon Devices, Purdue University, 174, December 1999.

[4] Jung-Hoon Rhew, physics and simulation of Quasi-Ballistic Transport in Nanoscale Transistors, Purdue University, p144, 2003.

[5] Gerhard Klimeck, Electron-Phonon and Electron-Electron Interactions in Quantum

Transport, January, 1994 School of Electrical Engineering Purdue University West Lafayette, Indiana 47907-1285.

[6] Supriyo Datta, Nanoscale device modeling the Green's function method School of Electrical and Computer Engineering, Purdue University, West Lafayette, In 47907-1285, U.S.A.(Received 24 July 2000), Superlattices and Microstructures, Vol. 28, No. 4, 2000.

[7] Haiyan Jiang, Boundary treatments in non-equilibrium Green's function (NEGF) methods for quantum transport in nano-MOSFETs, received and revised form 10 March 2008 Peking University, Beijing 100871, China.

[8] Ruud V. lutters, Hot-electron transport in the spin-valve transistor 2001 Twente University Press.

[9] Monte Carlo Device Simulations Dragica Vasileska Arizona State University, Tempe AZ 2010, Volume 44, no. 2.

[10] Jung-Hui Tsai, InGaP/InGaAs Doped-Channel Direct-Coupled Field-Effect tansistors Logic with Low Supply Voltage National Kaohsiung Normal University, Kaohsiung 802, Taiwan.

[11] Jacoboni, Carlo, Lugli, Paolo, The Monte Carlo Methode for Semiconducteur Device Simulation, p356, 1989.

[12] M. Levinshtein, S. Rumyantsev, M. Shur, Handbook Series On Semiconductor Parameters, 205p, (1999).