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An Enhanced Two Dimensional Hydrodynamic Energy Model for Transient Time Simulation of Complex Heterostructure Field Effect Transistors

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Abstract

In this work we present an enhanced two dimensional hydrodynamic energy model used for the simulation of complex heterostructure field effect transistors. We highlight its capabilities and potential performance using the state of art computational technologies. The major modifications are presented and discussed; then typical obtained results are presented.

1. Introduction

The interest in complex heterostructure field effect transistors has grown in the past years. The attention was particulary drawn towards pseudomorphic channel AlGaAs\InGaAs because of their particularly unprecedented performance in microwave power applications. Yet their performance falls at 60 GHz mainly due to non-optimised structures.

The optimisation of such devices passes by the investigation of different structural parameters and studying their effect upon the device performance.

From the numerous parameters emerges the necessity of a reliable simulation tool that should satisfy two major criterea : Accuracy and Rapidity. The two dimensional hydrodynamic energy models satisfy these criterea.

Based upon a simpler model used for conventional HEMT simulation, our model was modified to permit the simulation of the more complex pseudomorphic HFETs.

In the following section we will be presenting the features of our enhanced model and the computational technics employed to increase its efficiency. Then we will present typical results obtained.

2. The enhanced model

The enhanced 2D model is based upon the three transport equations driven through the integration of Boltzmann Transport Equation for heavily doped multivalley semiconductors [1]. This model was then modified by including the effect of minority carriers (holes) into Poisson's equation, adding the holes current continuity equation and the holes current density equation.

Carrier generation by impact ionisation was included in the two charge conservation equations. Quantization effects were accounted for by assuming that the electrons start with an energy equivalent to that of the first sub-band and not the bottom of conduction band as was done before.

Another modification made was that we included the screen effect. This effect was noticed experimentaly, and was introduced based upon an emperical formula $\mu(Ns)$.

The final set of equations composing our model then reads :

Poisson Equation :

$$\nabla^2 V = \frac{q}{\epsilon}(n - Nd - p) \tag{1}$$

Electrons current continuity :

$$\frac{\partial n}{\partial t} = -\nabla n\vec{v}_n + \alpha_n \frac{J_n}{q} + \alpha_p \frac{J_p}{q} \tag{2}$$

Holes current continuity :

$$\frac{\partial p}{\partial t} = \nabla p\vec{v}_p + \alpha_p \frac{J_p}{q} + \alpha_n \frac{J_n}{q} \tag{3}$$

Average electron energy balance :

$$\frac{\partial \varepsilon}{\partial t} + \vec{v} \cdot \nabla \varepsilon = \frac{\vec{v}^2}{\mu(\varepsilon)} - KT(\varepsilon)\nabla \cdot \vec{v} - \frac{\varepsilon + \delta\varepsilon}{\tau(\varepsilon)} \tag{4}$$

And the current density J calculated by :

$$J_n = \mu(\varepsilon)nE - \nabla \cdot (\mu(\varepsilon)nKT) \tag{5}$$

$$J_p = -\mu(E)pE \tag{6}$$

The dependance of the different physical parameters upon energy or field is driven from the steady-state Monte-Carlo simulations. The ionisation coefficient α, is taken as a function of the average total energy for electrons.

The whole system of equations is discretised using a finite difference scheme with a variable mesh size; linearised with respect to time using a dynamic time step that is controlled by the simulation program. The system of equations is decoupled based upon the relaxation time approximation. Poisson's equation is solved using the MDS technique [2] , the energy equation is linearised and solved, as well as the continuity equations, using an iterative scheme.

The decoupling of equations permitted the use of parallel execution techniques to solve the energy balance equation, and the two current continuity equations in the same elapsed time.

The whole system of equations was written, in the discretised form, in a vectorial formulation. This allowed the use of the inherently fast vector processors resulting in a significant reduction in the execution time.

3. Computational performance

The simulations were done using an IBM-3090-600E equiped with parallel vector processors of which we used at least 4. A typical execution time recorded was 1 cpu minute for 1 psec of simulation time, keeping in mind that we need 3-4 picosecond to reach the steady state. This time however increased as the complexity of the structure increases; for a 0.1 μ gate,δ-doped, double plan, pseudomorphic transistor we were at 10 cpu min for 1 psec real time. The simulation of dual-gate conventional HFET came up with a time performance of about 40 cpu min for 1 psec real time. It is important to note that the mesh size varies typically from 91x42 uptill 120x49, which is considered relatively large mesh.

4. Examples of obtained results

Figure 1 shows the effect of 2DEG screening, where we notice considerable reduction in the maximum intrinsic current gain cut-off frequency F_{ci}. The obtained values are in good agreement with those obtained experimentaly (* points).

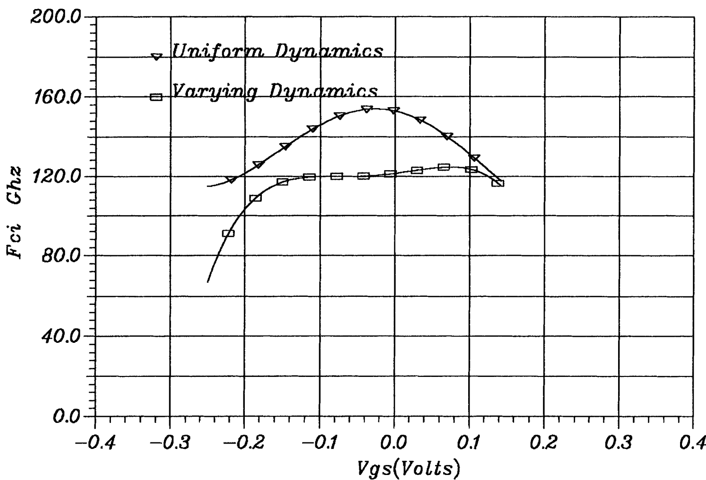

Figure 1: Effect of 2DEG screening on F_{ci} in .3μ gate, δ-doped HFET

Our model is quite capable of simulating the HFET under breakdown conditions. In figure 2 we can see such an effect occuring in a 0.3μ gate uniformely doped HFET.

To our knowledge this is the only model that is capable of simulating the avalanche breakdown in HFETs in transient time

Another feature of this model is that it gives a good insight of the device physics through isolines of different quantities. Figure 3 shows such isolines of electrons density, energy and potential contours.

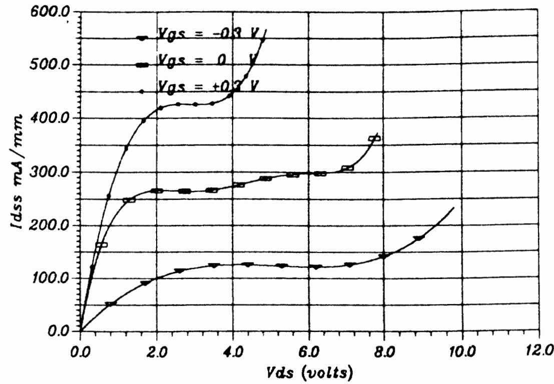

Figure 2: I-V characterstics of $.3\mu$ gate HFET including avalanche multiplication

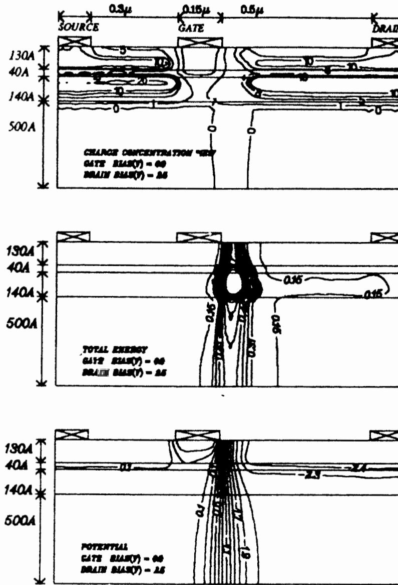

Figure 3: Isolines of physical quantities in a 0.15μ gate, δ-doped pseudomorphic HFET with AlGaAs buffer

5. Conclusion

We have developped an enhanced two dimensional hydrodynamic energy model that serves as a powerfull tool in the simulation and optimisation of largerly submicronic gate pseudomorphic δ - doped HFET. The model is capable of predicting transient time as well as steady state DC characteristics.

References

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