Quasi One Dimensional Simulation of Heterojunction FET

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The carrier dynamics in 2D gas of HEMT hetero-structure remained very complex until now because of the importance of quantum terms in addition to the usual classical terms.

In quantum well structure, we need to resolve not only the Schrödinger and Poisson equations, but also the Boltzmann equation, in two separate steps.

In our work, we present a quasi 1- dimensional model, which is based on a numerical solution of the Boltzmann equation rewritten using the relaxation constants, the "conservation equations of energy and momentum", which permits us to take into account stationary transport in addition to the Poisson and drift current equations [1].

We need so to solve the following system of equations:

Poisson equation

$$\frac{d\xi_x}{dx} = \frac{q}{eps}(n_{ch} - n)$$

Drift current equation

$$I_{ds} = q\ n\ v\ b\ W = q\ n\ v\ (a_1 + d_{2Deg} - d_{sc})$$

Relaxation energy equation

$$d\varepsilon = q\ \xi_x\ dx - \frac{\varepsilon - \varepsilon_0}{\tau_\varepsilon(\varepsilon)} dt$$

Relaxation moment equation

$$\frac{d\,(m^*(\varepsilon)v)}{dt} = q\,\xi_x - \frac{m^*(\varepsilon)v}{\tau_m(\varepsilon)}$$

where $dt = \frac{dx}{v}$, and n is the actual electron density anywhere in the channel layer, b is the thickness of the 2D channel, n_{ch} the electron concentration in the 2D channel region, ξ the middle electrical field, τ_m, τ_ε are the relaxation times of momentum and energy, respectively, v the middle velocity, m^* the effective mass, ε the middle energy, ε_0 the middle energy of thermal agitation, d_{sc} the extension of the space charge region, d_{2Deg} the effective width of the gas 2D , W grid's width, a_1 donor and spacer layer's depth, *eps* the dielectric constant, and I_{ds} the Drain- Source current.

The principal method is to follow carriers from source to drain taking into a count the evolution of physical quantities, which characterize the dynamics of carriers by dividing the structure into small segments of length, Δx , in the direction of current follow. The bias conditions are given by applying a Gate-Source voltage and feeding a certain drain current I_{ds} into the transistor. This method needs the discretization of the system of equations given before and that is done using finite difference method.

The simulation has allowed us to extract physical quantities which characterize the dynamics of carriers that are the middle values of the electrical field, energy and velocity, in additions to the $I_{DS}(V_{gs}, V_{ds})$ characteristics and the evolution of the basic elements of the equivalent schema in small signal as the conductance and the capacitance [2].

Figs. 1 - 3 present the evolution of three principal physical quantities $\xi_x(x), v(x), \varepsilon(x)$, respectively:

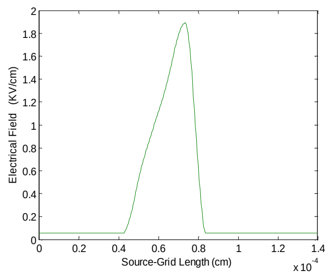

Fig.1: Electrical field variation in the channel.

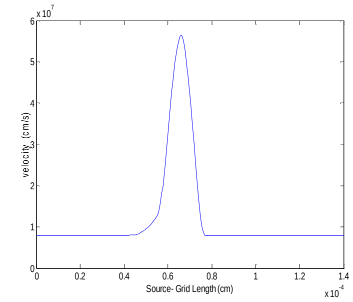

Fig.2: Carrier's velocity variation.

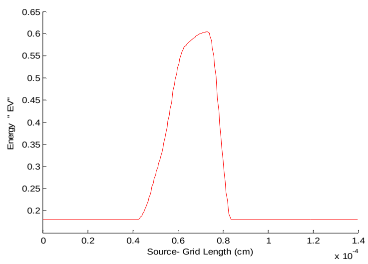

Fig.3: Carrier's energy variation.

Fig. 4 shows the static characteristics of the HEMT. The variation of the conductance and the capacitance are present in Fig. 5 and Fig. 6, respectively.

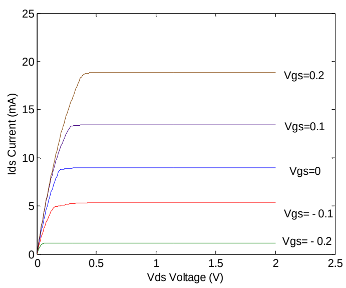

Fig.4: $I_{ds}(V_{ds}, V_{gs})$ characteristics.

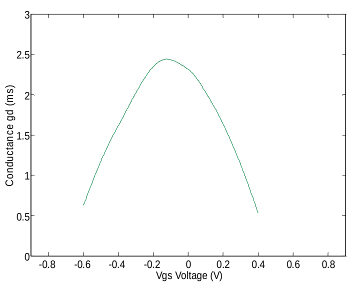

Fig.5: Conductance variation.

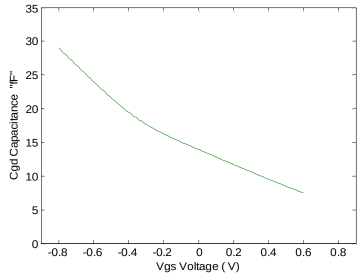

Fig.6: C_{gd} variation.

To validate the model, we present comparison between the simulated model and the experimental results [1, 3] as shown in Figs 7 -9.

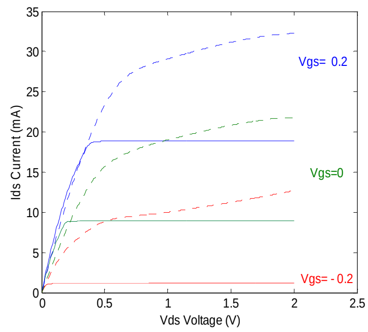

Fig.7: Experimental-theoretical comparison for $I_{ds}(V_{ds}, V_{gs})$ characteristics.

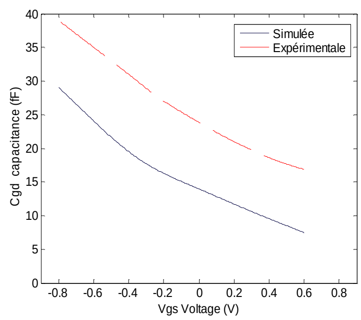

Fig.8: Experimental-theoretical comparison for conductance.

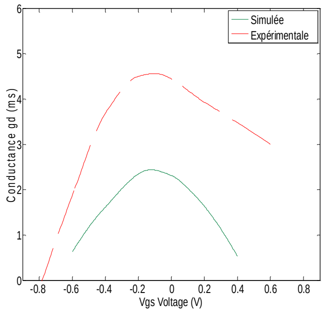

Fig.9: Experimental-theoretical comparison for C_{gd} .

References

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[3] P. Godts, D. Depeeuv, E. Constant and J. Zimmermann, Revue Phys. Appl. **24**, 151 (1989).