TWO-DIMENSIONAL HYDRODYNAMIC SIMULATION OF HIGH ELECTRON MOBILITY TRANSISTORS USING A BLOCK ITERATIVE SCHEME IN COMBINATION WITH FULL NEWTON METHOD

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ABSTRACT

Pseudomorphic submicron High Electron Mobility Transistors (HEMT) have conquered a broad field of application because of their high-frequency performance. The DC characteristics of a $0.23\mu m$ gate length transistor have been calculated by our recently developed device simulator using a hydrodynamic model (HD) which accounts for carrier heating effects in the short channel region. A block iterative scheme combined with a full Newton method is applied to improve the convergence performance, robustness and stability of the HD model. Furthermore, an extended Scharfetter-Gummel scheme was used to account for the spatial variation of material properties such as band edge energy and effective density of states.

HETEROJUNCTIONS

The multi-layer structure of HEMTs requires a special treatment of heterojunctions. As a result of an idealization process an abrupt variation of parameters on interfaces is assumed and is modeled by special interface conditions. This leads to a better condition of the linearized system compared to a method which simply reduces grid spacing in the vicinity of heterojunctions. The HD equations are discretized by an extended Scharfetter-Gummel scheme ([1][2]) which additionally accounts for a spatial variation of material proper-ties such as effective density of states and band edge energy.

ITERATION SCHEME

The well known moderate convergence performance of the HD model has been improved by a block iterative scheme. Considering the partial differential equations

$$\text{div}(\varepsilon\,\text{grad}\psi) = -\rho \tag{1}$$

$$\text{div}\,J_n = +q\frac{\partial n}{\partial t} + qR_n^{eff} \tag{2}$$

$$\text{div}\,J_p = -q\frac{\partial p}{\partial t} - qR_p^{eff} \tag{3}$$

$$\text{div}\,S_n = -\frac{3k}{2}\frac{\partial(nT_n)}{\partial t} + \text{grad}\left(\frac{E_C}{q} - \psi\right)J_n - n\frac{3k}{2}\frac{T_n - T_L}{\tau_{wn}} - nR_n^{eff} \tag{4}$$

$$\text{div}\,S_p = -\frac{3k}{2}\frac{\partial(pT_p)}{\partial t} + \text{grad}\left(\frac{E_V}{q} - \psi\right)J_p - p\frac{3k}{2}\frac{T_p - T_L}{\tau_{wp}} - pR_p^{eff} \tag{5}$$

where

$$J_n = q\mu_n n \operatorname{grad}\left(\frac{E_C}{q} - \psi\right) + \mu_n k N_C \operatorname{grad}\left(\frac{nT_n}{N_C}\right) \tag{6}$$

$$J_p = q\mu_p p \operatorname{grad}\left(\frac{E_V}{q} - \psi\right) - \mu_p k N_V \operatorname{grad}\left(\frac{pT_p}{N_V}\right) \tag{7}$$

and

$$S_n = -\kappa_n \operatorname{grad}T_n - \frac{5kT_n}{2q}J_n \qquad S_p = -\kappa_p \operatorname{grad}T_p + \frac{5kT_p}{2q}J_p, \tag{8}$$

the set of Possion's equation and continuity equations (1)(2)(3) is solved alternately with the set of continuity equations and energy balance equations (2)(3)(4)(5). Each set is solved iteratively using Newton's method until the norm of the updates remains under a certain value. At last, for the full equation set Newton's method ([3]) is invoked to obtain the desired final accuracy. Therefore, this method combines both a block iterative scheme for effectiveness and a full Newton method for accuracy. After about 60 iterations the norm has decrceased by a factor of $\approx 10^{-3}$ and the scheme can be switched to full Newton. It is remarkable that, even for high bias conditions convergence is achieved from an initial equilibrium state without stepping the applied voltages, whereas with a full-Newton only strategy convergence is possible only for a small initial bias.

RESULTS

The simulated characteristics obtained by the HD model are fairly similar to the results of a drift-diffusion model, even though the velocities along the channel differ significantly (Fig. 1, the gate starts at $x = 0.585\mu m$ and ends at $x = 0.815\mu m$). This is explained by the fact that the channel charge is nearly identical for both models, since it is mainly determined by the gate voltage, whereas the carrier concentration varies along the channel according to the carrier velocity. For a $0.23\mu m$-gate-length pseudomorphic HEMT, simulation results are compared with measured data and are found to be in good agreement (Fig. 2).

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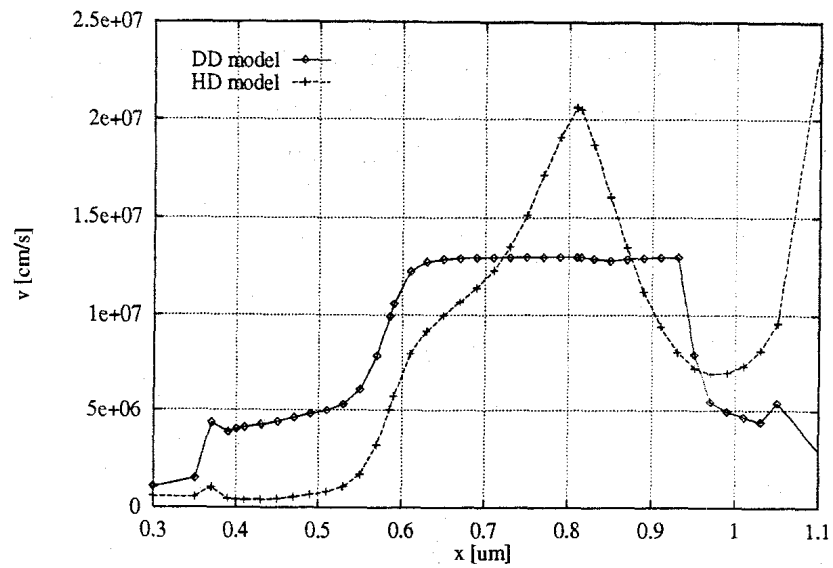
Figure 1: Comparison of electron velocities along the channel for the drift-diffusion and the hydrodynamic models.
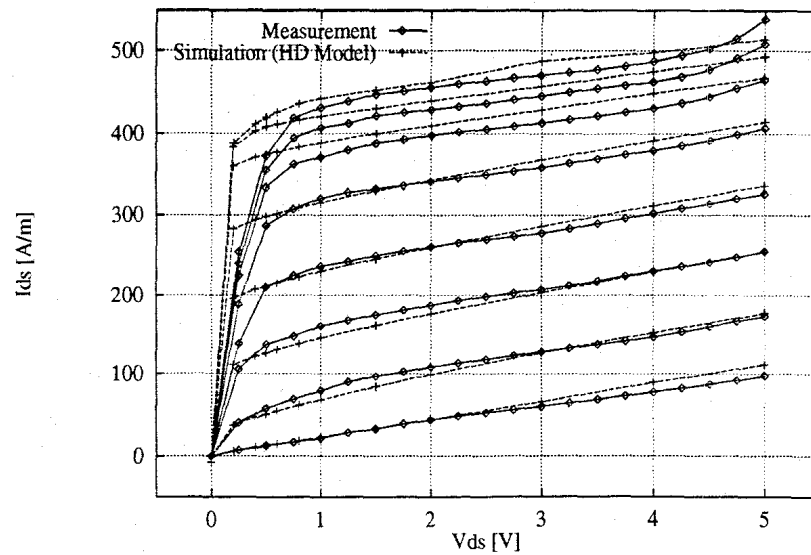

Figure 2: IV-characteristics simulated with a hydrodynamic model, compared to measured data.