DEVELOPMENT AND VERIFICATION OF AN ACCURATE GaAs MESFET MODEL

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A finite element model of Gallium Arsenide MESFETs is presented. The model employs a steady-state, semi-classical description of current flow. For accurate results the model uses physical data appropriate to the device being simulated. This data includes channel geometry, doping profile and surface charge density as well as carrier transport coefficients. It is particularly important in MESFET modelling to avoid spurious mobility degradation due to electric fields perpendicular to current flow. Comparison of the model with an experimental device shows that the predicted terminal characteristics are within 10% of the typical measured values.

INTRODUCTION

In the search for high speed digital integrated circuit technologies, the higher electron mobility in GaAs gives rise to faster devices while the availability of semi-insulating material makes it more suitable for closely packed circuits. State of the art digital GaAs circuits use ion-implanted planar MESFETs. Accurate numerical models are needed to help the design of these devices, which is increasingly difficult as gate lengths reduce below one micron. To achieve accurate numerical models, it is essential to use physical data appropriate to the process on which the device is fabricated and to use numerical techniques which enable efficient solution of the resulting model equations.

MODEL DESCRIPTION

The model employs a steady state, semi classical description of current flow. The distribution of electrostatic potential and electron concentration is

The resulting discretised equations are very non-linear. They are solved simultaneously using Newton's method. The Newton-Richardson variant of the algorithm is employed to reduce the overall cost of matrix factorisations. A good initial approximation is achieved at each bias point by linear extrapolation of the results from previous solutions. The solution at zero bias is found using an off-state model.

The drain current is evaluated using a power integral method which smooths over local errors in current density. This method improves the accuracy of current estimates close to pinch-off.

ONE MICRON MESFET SIMULATION

The accuracy of the model has been verified by using it to simulate a one micron gate length planar GaAs MESFET. This low pinch-off voltage device has an ion-implanted channel with a total dose of 2E12/cm^2 and a peak at 0.07 micron, as shown in figure 1. The gate to drain and gate to source distances are 1.0 and 2.0 microns, respectively. In the simulations, a low field mobility of 3000 cm^2/Vs was used, corresponding to the average of the depth dependant measured mobility. Measurements of sheet resistance indicated a surface charge density of 7E11/cm^2. The measured built-in voltage at the schottky barrier gate is 0.7 volt.

The simulated I-V curve for the device is shown in figure 2. Rather than comparing this curve with measurements from a single device, it is more appropriate to compare the curve with measurements for a large set of fabricated devices. As shown in table 1, the predicted transconductance, pinch-off voltage and saturated drain current are within 10% of the typical measured values. The largest error is in the pinch-off voltage, but even here the 0.125 Volt discrepancy is less than the measured standard deviation of 0.23 Volt.

In an effort to improve the agreement with the measured characteristics, the model was tuned. The pinch-off voltage was reduced by moving 10% of the surface charge to the channel to substrate interface. As this reduced the drain current, the saturated electron velocity was increased to 1.2E7 cm/s. The resulting improve terminal characteristics are shown in table 1. Table 1 also shows the simulated terminal characteristics found when both vertical and horizontal components are included in the carrier heating. The very poor agreement is due to spurious carrier heating, as explained above.

described by Poisson's equation and the electron current continuity equation, which using the usual notation are written:

$$\nabla . \varepsilon \nabla \psi = q(n-N_d) \tag{1}$$

$$\nabla . (D \nabla n - n \mu \nabla \psi) = 0 \tag{2}$$

The fixed charge term, Nd, includes ionised impurities and trapped charges along the surface of the device. The electron mobility and diffusivity are both strongly dependant on electric field. For these simulations, the diffusivity follows the Einstein relation at low fields but saturates to a minimum of 20 cm^2/s at high fields. The mobility is related to the electric field by the fitting equation:

$$\mu E = \frac{\mu_{\circ} E + V_{sat}(E/E_{\circ})^{\psi}}{1 + (E/E)^{\circ}} \tag{3}$$

For the simulations presented here, the saturation velocity is vsat= 1.1 x 10^7 cm/s and the threshold electric field 3.0 kV/cm. The low field mobility is process specific and for accurate simulations should be based on measured data. The use of equation (3) implies that the carrier heating depends on the local electric field. This approximation can give rise to error in short gate devices, particularly near built-in electric fields where it results in a spurious carrier heating. However, in ion implanted MESFETs, the current flow is predominantly in the lateral source to drain direction while the built-in fields are vertical, across the current path. Thus, spurious carrier heating can be avoided by considering only the lateral field components in equation (3). As will be seen later, this simple modification has a striking effect in improving simulation accuracy.

NUMERICAL FORMULATION

Numerical considerations play an important role in achieving accurate device simulations [1]. The finite element discretisation method is chosen because its triangular elements allow the simulation of recessed gate devices (which do not have a rectangular geometry) and allow easy refinement of the mesh in the high field regions near the gate. The equations are discretised with potential and electron concentration as basic variables. Linear elements are used, with added dissipation [2] introduced into the current continuity equation to give a Scharfetter-Gummel like optimal upwinding. This improves the accuracy of the discretisation and so allows simulation of devices with high channel carrier densities.

Parameter	V pinch-off Volt	Idss mA/mm	gm mS/mm
Measured	-1.125	59.35	77.55
Simulated	-1.25	57.38	77.15
Tuned Simulation	-1.1	56.35	77.95
Isotropic Simulation	-2.1	34.97	28.5

TABLE I Comparison of terminal characteristics

CLOSURE

A finite element model for the simulation of GaAs MESFETs has been presented. Through the use of measured physical data appropriate to the device under study combined with effective numerical techniques, an accurate simulation has been achieved. The close agreement between the simulated and measured characteristics indicates that the underlying physical model is sufficent for the simulation of state of the art digital GaAs MESFETs.

ACKNOWLEDGEMENTS

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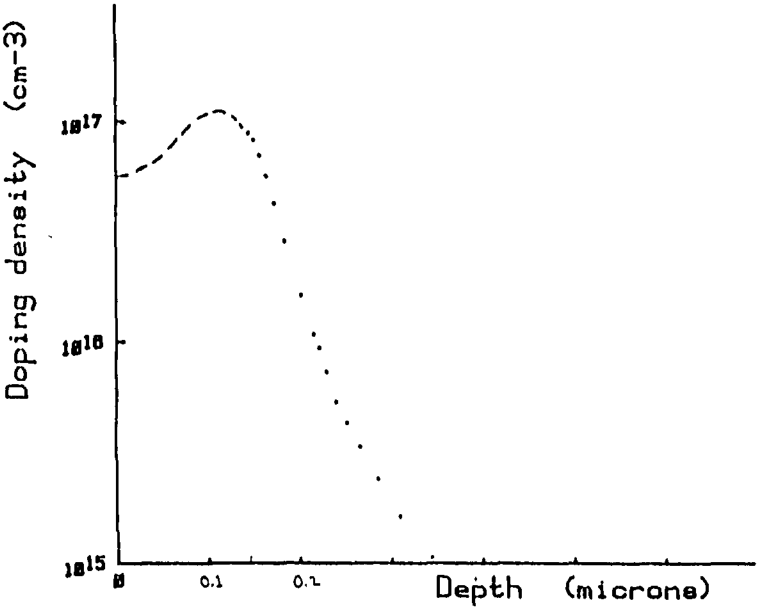

FIGURE 1 Channel Impurity Profile

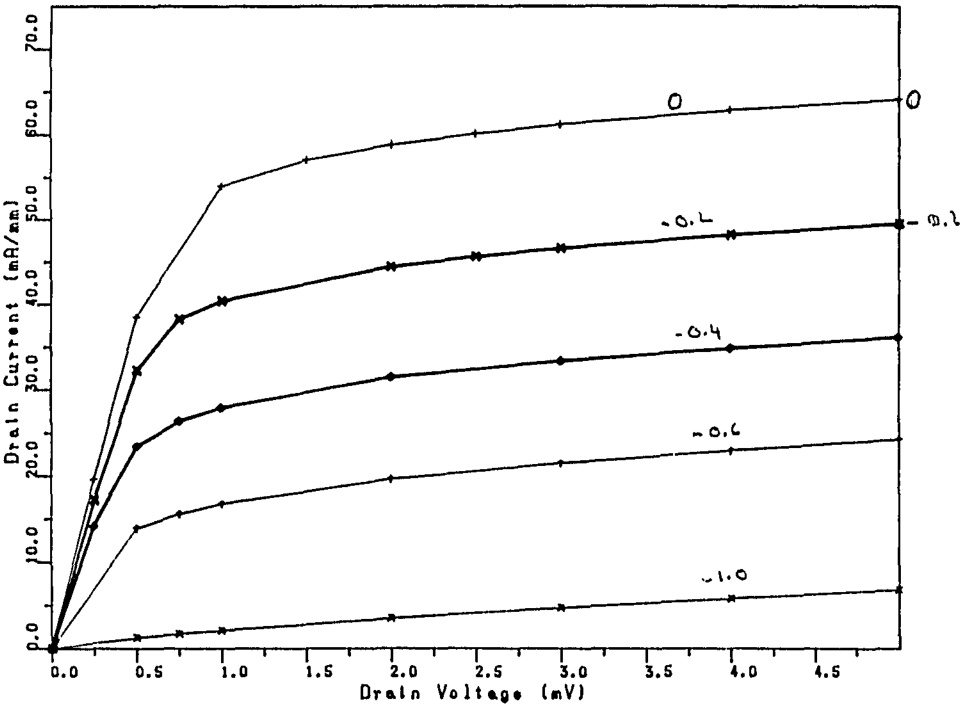

FIGURE 2 Simulated I-V Curve