THE INFLUENCE OF VARIOUS MOBILITY MODELS ON THE ITERATION PROCESS AND SOLUTION OF THE BASIC SEMICONDUCTOR EQUATIONS

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Abstract

A comparison of various ways of modeling the carrier mobilities is presented. Using an already developed two-dimensional semiconductor simulation program we investigate non linear field- and carrier- dependend models. The impact on the discretization of the continuity equations and the calculation of the iteration matrix is discussed. We present simulation results of three different mobility models for a GaAs MESFET. The iteration process and the resulting electron densities are compared. Only with constant mobility convergence is quadratical. The nonlinear models show linear convergence behaviour. Considering the electron distributions the differences between the models become more evident. The results obtained by the constant mobility model must be completely rejected. A field-dependend model which is appropriate for silicon devices gives better but not quantitatively reliable results. For accurate physically asserted calculations a negative differential mobility has to be used.

1. Introduction

The basic semiconductor equations contain several types of physical parameters, eg. the carrier mobilities which influence the continuity equations directly. Since the nonlinear PDE system is solved by iterative numerical methods the mobilities have to be calculated at each step. Therefore one is interested in simple parameter models to save computer time. But to obtain physically asserted results it is necessary to describe nonlinear field- and carrier- dependend mobility models. This paper investigates the influence of such complex models on the iteration process. An already devellopped two-dimensional semiconductor device simulation system SCDSS /1/ which handles externally defined mobilities is applied using various mobility models. In section 2 we describe the discretization of the continuity equations with respect to the mobilities. The effects of three different models are presented for a GaAs MESFET. Section 3 contains the device geometry and the parameters. We compare the convergence properties and the different physical results in section 4.

2. Discretization of the continuity equations

For the discretization of the continuity equations one has to calculate the current densities depending on the carrier mobilities. We have used the well-known Scharfetter - Gummel discretization in "Finite Boxes" formulation /1/, /2/, presuming constant densities between grid points. There the values of the mobilities must be calculated. They are implemented as external functions in order to change the models easily such that a high degree of flexibility is achieved. To compute even complex parameter models it is necessary to provide the grid point coordinates, the carrier concentrations, the doping concentration and the components of the electric field and of the current densities in x- and y- direction. For the implemented discretization scheme they must be calculated at the center of the line between two neighboured grid points which is computationally rather time consuming. Since the solution of the nonlinear system of equations is obtained by a Newton type method, the Jacobian contains the partial derivatives of the mobilities with respect to the unknowns, namely potential and carrier densities. We have investigated the influence of neglecting these partial derivatives. The results have shown no significant loss in the rate of convergence. This fact can save a large amount of computer time because the derivatives have to be calculated numerically.

3. Device geometry and parameter models

We used the different mobility models for the computation of a GaAs MESFET. The geometry is shown in Fig. 1. The gate has been recessed into the active layer. The calculations have been done at an operating point of VG = 0V and VD = 2V. We investigated three kinds of mobility models. Model 1 describes a typical mobility model for GaAs devices. Model 2 results from an average value of model 1. Model 3 is a mobility model commonly used in simulations of silicon devices.

Model 1 : $$\mu = \frac{\mu_0 + v_s . E^3/E_0{}^4}{1+(E/E_0)^4}$$

$\mu_0 = 5600\ cm^2/Vs$ $\quad v_s = 10^7\ cm/s$ $\quad$ /4/

$E_0 = 3.5\ kV/cm$ $\quad E = \vec{J}_n . \vec{E}$

Model 2 : $\mu = const = 2000\ cm^2/Vs$

Model 3 : $$\mu = ((\mu_0 . a + \mu_{min}(1-a))^\beta + (\frac{v_s}{E_p})^\beta)^{1/\beta}$$

$$a = \frac{1}{1+(\frac{0.67.N+0.33.n}{N_0})^{0.73}}$$

$$E_p = \max\left(0, \frac{\vec{E}.\vec{J}_n}{|\vec{J}_n|}\right)$$

$\mu_0 = 1429\ cm^2/Vs$

$\mu_{min} = 55.2\ cm^2/Vs$ $\quad$ /3/

$N = N_D^+ + N_A^-$

$N_0 = 10^{17}\ cm^{-3}$

$v_s = 9.10^6 cm/s$

$\beta = -2$

The resulting v(E) characteristics are plotted in Fig. 2.

4. Results

We investigated the numerical behaviour and the physical impact of the different mobilities. Fig. 3 shows the series of iterations for the three mobility models. Only with constant mobility (model 2) convergence is quadratical. If the part of the residual norm originating from Poisson´s equation dominates the overall residual norm also model 1 and 3 converge quadratically. Otherwise the convergence is only linear with no significant differencies between the models 1 and 3. Fig. 3 represents the iterations on the initial grid with 354 mesh points, which is identical for all simulations. After automatic grid refinement according to the local discretization error which of course depends on the parameter models the rate of convergence is always quadratical. Small changes of drain- and gate- voltages show no significant effect on the behaviour of the iterations. But if the device reaches pinch off voltage the continuity equations loose their dominance. Then quadratical convergence has been observed with all three models.

Considering the electron distributions (Fig. 4-6) the influence of the models on the qualitative results becomes more evident. In Fig. 4 the electron density using constant mobility is plotted. The electron channel is pinched off homogenously in a wide region under the gate. Using model 3 (Fig. 5) the channel is also pinched off and the typical silicon accumulation- and depletion- zone can be seen. In Fig. 6 (negative differential mobility model) a stationary dipole is formed by an excess electron density and a positive donor charge. The electron channel is also pinched off. The electric field reaches its maximum at the edge of the gate contact.

5. Conlusion

We have investigated the influence of three different mobility models on the iteration process and the internal distributions. From the computational point of view it would be much easier to perform the simulations with constant mobility, but from the physical point of view those results are physically unreliable. Only complex mobility models which include carrier-carrier-, surface- and impurity- scattering and field dependend velocity saturation yield correct results.

Acknowledgement

Helpful discussions with Prof.Dr.H.W.Pötzl who also critically read the manuscript and Dr.A.Schütz were highly appreciated. We should also like to thank the Interuniversitäre Rechenzentrum for the excellent computer access.

Sponsored by the Fonds zur Förderung der wissenschaftlichen Forschung, Projekt Nr. S22/11 and by the Research Lab. of Siemens AG Munich.

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$l = d =$ 10 µm
$l_s = l_d =$ 2.5 µm
$w =$ 1.8 µm
$r = r_1 = r_2 =$ 0.1 µm
$e =$ 0.35 µm

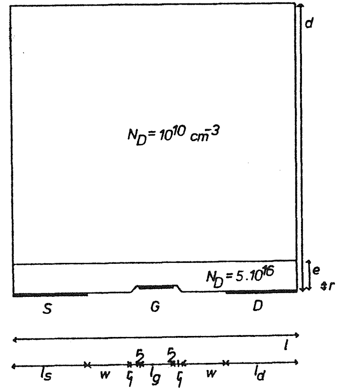

Fig. 1 : Device geometry of the GaAs MESFET

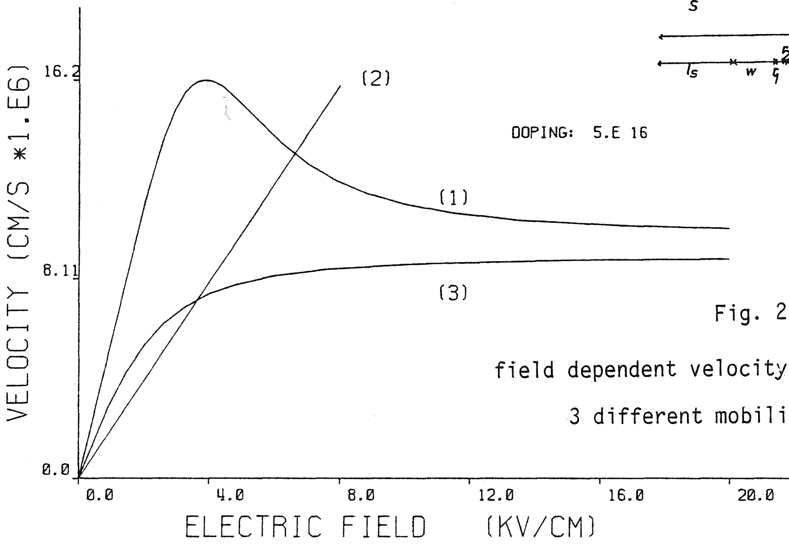

Fig. 2 :

field dependent velocity characteristic of 3 different mobility models

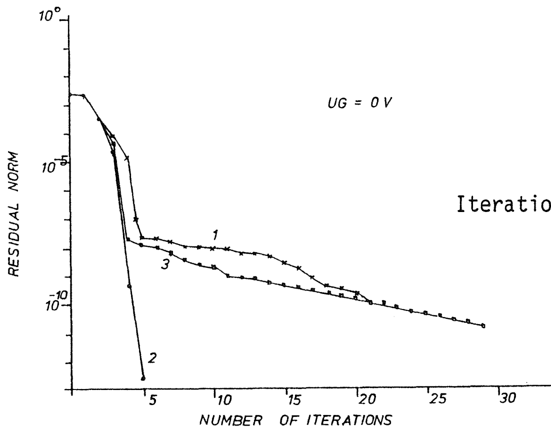

Fig. 3 :

Iteration process for VD = 2V and VG = 0V

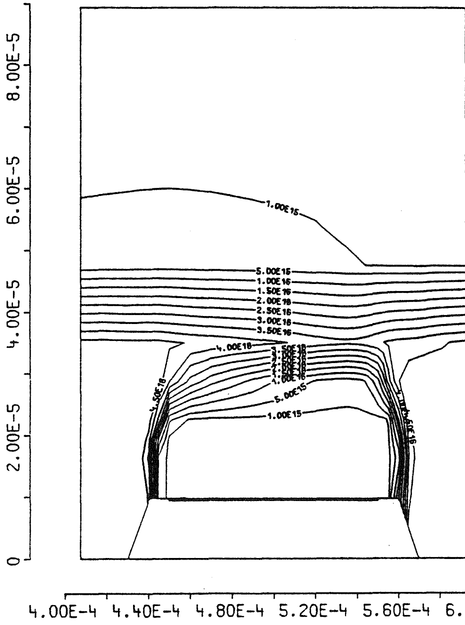

Fig. 4 :

Electron density for constant mobility

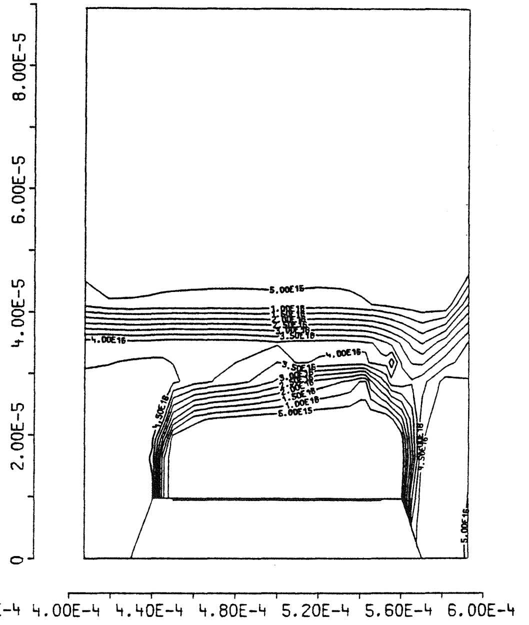

Fig. 5 :

Electron density for silicon mobility

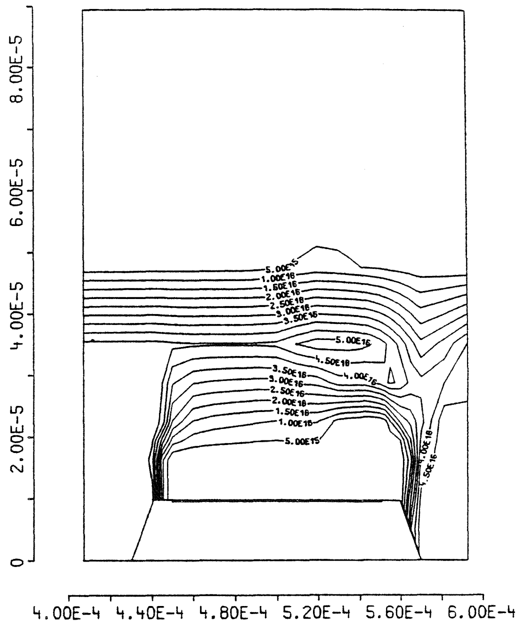

Fig. 6 : Electron density for negative differential mobility