TWO-DIMENSIONAL SIMULATIONS OF HETEROJUNCTION DEVICES

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abstract

Simulations of compound semiconductor devices suffer from poor numerical stability due to the wide number range for concentrations in the different materials. We discuss a new scaling method which circumvents this stability problem. An example shows the strength of the method.

1. Introduction

Intrinsic concentrations can vary over many orders of magnitude for the various materials which are present in a compound semiconductor device. Moreover, although heterojunction high electron mobility transistors (HEMT's) are majority carrier (electrons) devices, they are often constructed on a p-type buffer GaAs layer, such that an accurate simulation is only possible if both carriers are taken into account. Combining minority and majority carriers as well as large variations in the intrinsic concentrations into a single simulation run can cause serious problems. This is due to the fact, that a numerical implementation of the semiconductor equations requires a global scaling transformation (De Mari scaling) with respect to some concentration n^*_i .The precise value is not relevant but in general, if materials are present with high intrinsic concentrations then n^*_i will also be large. Now, since all concentrations will be scaled with respect to n^*_i, the minority carrier concentrations in the materials with low n^*_i, will become extremely small. In fact, these numbers may drop below the machine accuracy limit, which results into convergence problems.

Abrupt heterojunctions

Recently, we have presented a scheme for 2D simulations of abrupt heterojunctions [1]. In Fig.2 a schematic view of such a junction is shown.The electrostatic potential is defined at the middle of the bandgap. Consequently, since the bands are discontinuous at the interface, the electrostatic potential will also be discontinuous. Poisson's equation is solved using the familiar Finite Element Method (FEM). Only one value of the electrostatic potential at the interface is stored in the computer memory, whereas the other one is calculated, if needed, during the assembling procedure.
Let us now consider the continuity equations. Using the Box Integration Method (Controlled Volume Method), we obtain the following equation for the node i.

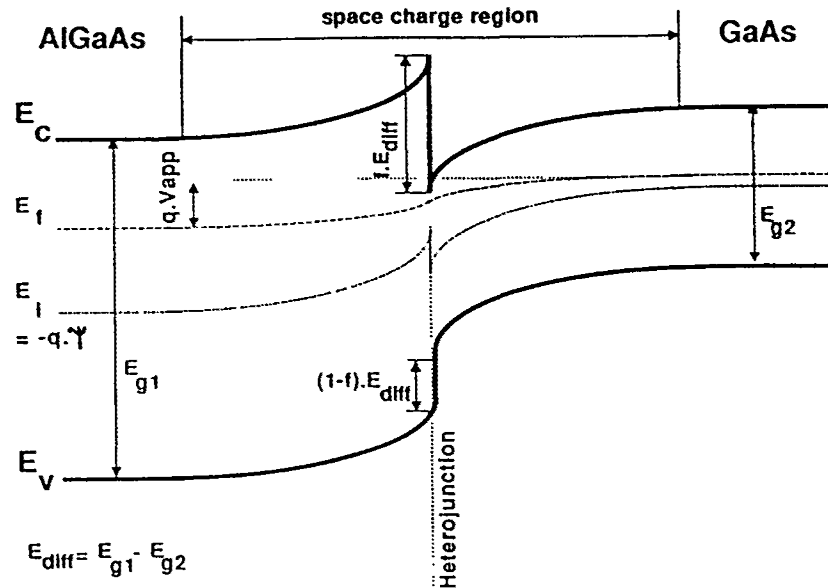

Fig.1 Schematic view of an abrupt heterojuction.

$$\sum_{j=1}^{N} J_{ij}\, d_{ij} + sq\,(R\text{-}G)_i = 0$$

where the sum is over all neighbouring nodes of node i and J_{ij} is the Scharfetter-Gummel-Tang current possibly extended with terms for tunneling and thermionic emission. For each node i, this equation has to be scaled with n^*_i. However, if want to solve the current continuity equations for both carriers, it becomes necessary to bring all equations into the same numerical range. This can be accomplished by scaling each nodal equation with respect to its nodal charge. At the abrupt heterojunction, the charge is also discontinuous, therefore we scale with respect to the geometrical average,

$$c_{av} = \sqrt{c_{up}\, c_{down}}$$

where c_{up} and c_{down} are the nodal charges above and below the heterojunction. Together with the following formule for the global scaling concentration

$$n^*_i = \exp\left(\sum_{j=1}^{N_{mat}} \frac{\log n^{*(j)}_i}{N_{mat}} \right)$$

we arrive at a stable numerical implementation.
For the energy balance equations the same procedure has been applied.

Simulation of a HEMT structure.

In order to demonstrate the applicability of the scaling method, consider the HEMT device, which is shown in Fig.2 This device was processed by the CSP group at IMEC, such that a comparison with experiments could be made.

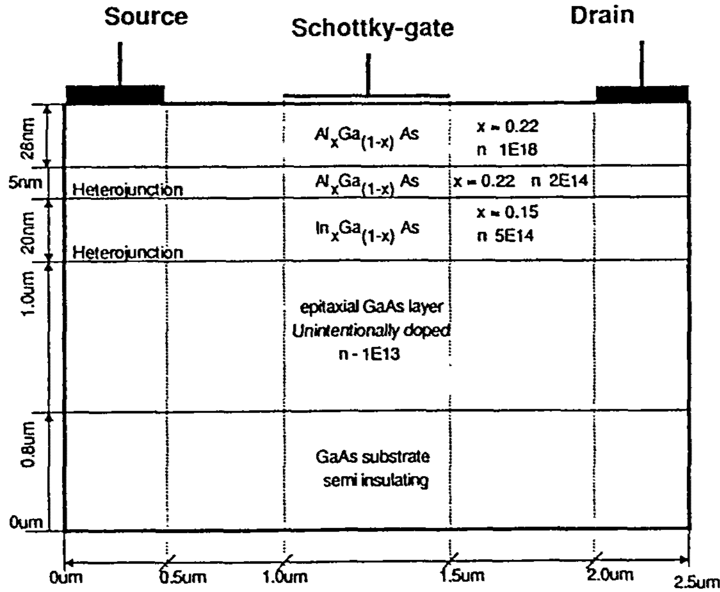

Fig.2 Lay-out of the processed HEMT structure.

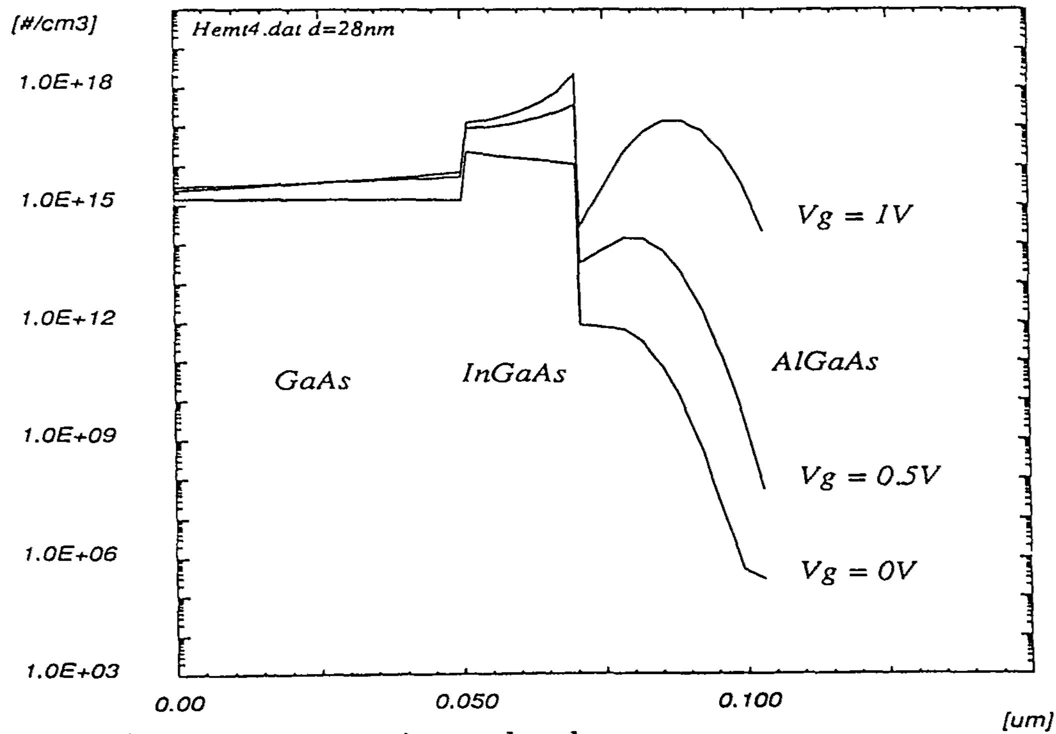

Fig.3 Electron concentration under the gate.

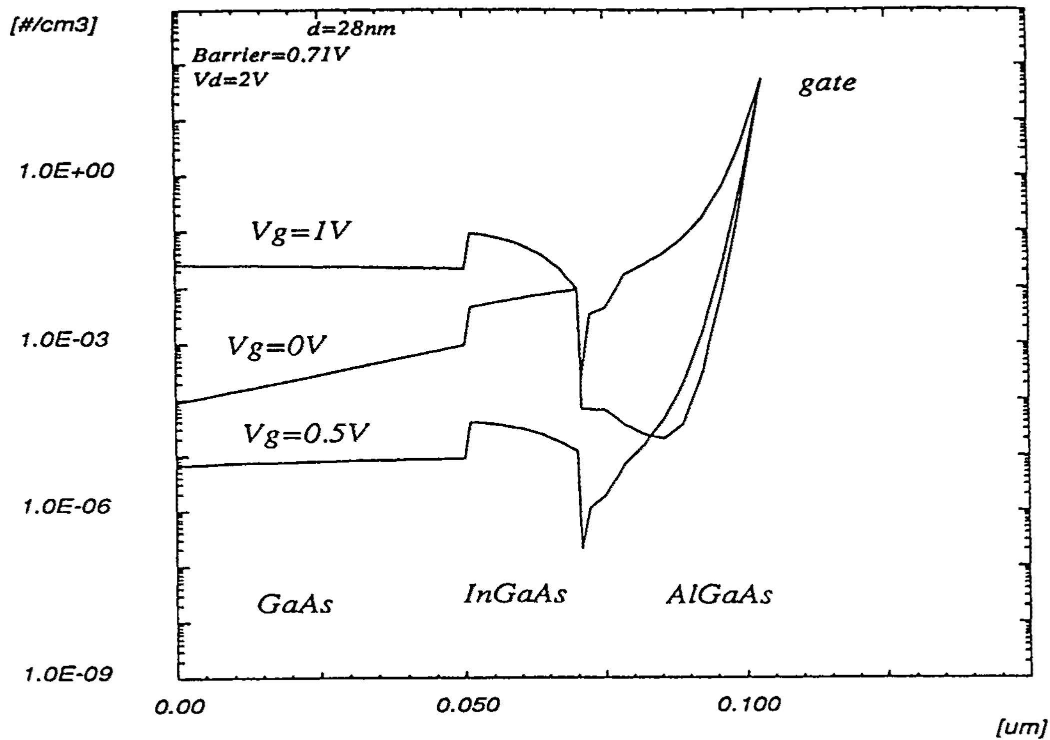

Fig.4 Hole concentration under the gate.

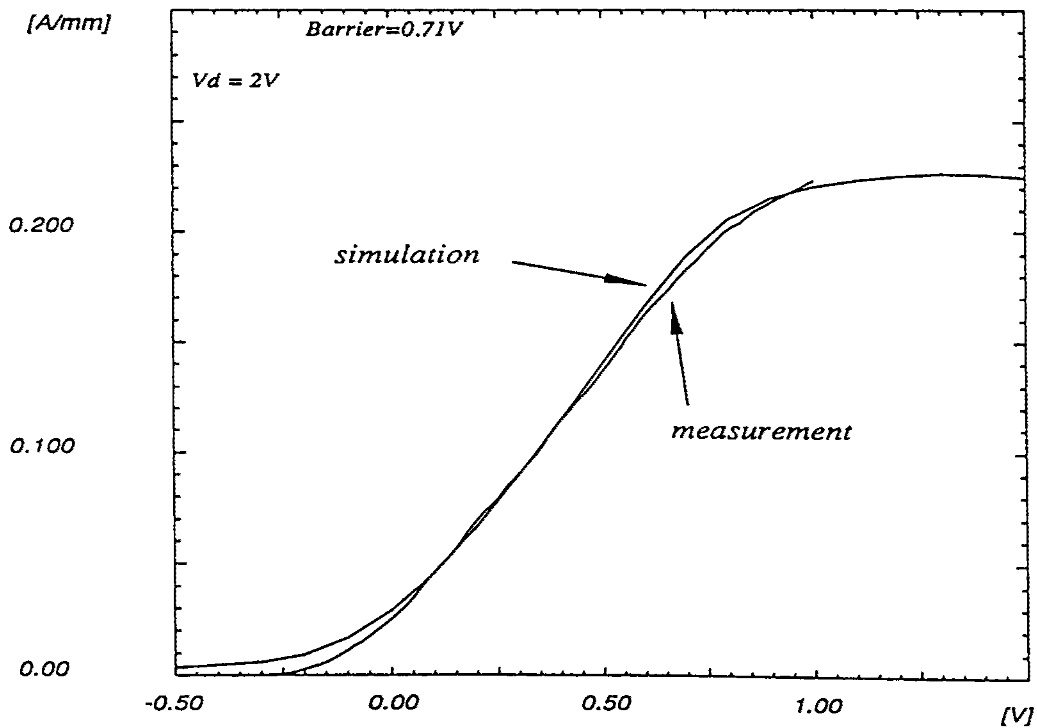

Fig.6 Total drain current, I_D vs. Gate Bias V_G

References.

[1] R. Vankemmel, W.Schoenmaker, R. Cartuyvels, K. Appeltans and K. De Meyer *Solid-State Electronics* Vol. 35, No. 4 pp. 571-578,1992