A Stable Two-dimensional Device Simulator for GaAs MESFET

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Abstract

Two dimensional semiconductor device simulators are indispensable for state-of-the-art small-geometry device design. In the case of GaAs device simulation, the inclusion of negative differential mobility is essential to physically model the device behavior. However, this introduces numerical convergence stability problems. In this paper, we apply the stream function formulation to develop a stable 2D device simulator for GaAs devices. The coupled Poisson and stream equations are solved by the Gummel algorithm. Preconditioned conjugate gradient acceleration methods are used to solve the linearized equations. An application of this simulator to a self-aligned ion-implanted planar MESFET is demonstrated.

Summary

As devices are scaled down, two dimensional device simulators become crucial tools for device design and optimization. Modern GaAs devices are characterized by small gate-lengths (< 1um), ion-implanted active layers, and/or recessed gate structures, thus, the physical modeling of GaAs MESFET's should include all of these features. We have developed a stable 2D simulator for realistic GaAs devices based on Mock's stream function formulation[1]. The C language is used to implement the simulator since its dynamic memory allocation facility provides for an efficient use of the computer's memory. Fig. 1 shows the simulation algorithm. The program accepts a grid specification from the input and automatically generates two non-uniform grid systems (Fig. 2). Poisson's equation is discretized on the potential grid and the stream equation is discretized on the dual stream grid. The resulting matrix equations from Poisson's and the stream equations are solved by conjugate gradient and bi-conjugate gradient iterative acceleration methods separately, with preconditionings achieved by Choleski and LU incomplete decompositions[2]. These algorithms provide efficient handling of sparse matrices and do not require iteration parameters and thus, unlike other iterative solvers no optimization is needed. As a consequence of the use of stream variables, the calculation of the current is a built-in process and no postprocessing is required. This can be compared with formulations using other fundamental variables which need to perfrom a path integration around the contact to obtain terminal currents. In these formulations the change of the boundary conditions from Dirichlet to Neumann type at the end points of a contact, causes a singularity to appear in the derivatives of the fundamental variables and this decreases the accuracy of the current calculated with the path integral.

A planar ion-implanted MESFET with a 1 um gate length has been studied (see Fig.3). The gate-source / gate-drain distance is 0.2 um. The active channel region is formed by a Se implantation with an energy of 120 keV and a dose of 2.3e12 cm^{-2}. The activation efficiency was determined to be 80% by comparing C-V measurements with SUPREM 3.5 simulation data. Ti/Pt/Au is used as the gate metal with a 0.73 eV Schottky barrier height. Fig. 3 shows the 2D potential distribution, potential contours, and current flow stream lines. Simulation results up to Vds equal to 2.0 V are exercised. These values cover the typical ranges of GaAs digital IC circuit operation.

The electron mobility is modeled by the following expression

$$\mu = \frac{\mu_0 + v_s/E(E/E_{th})^4}{1.0+(E/E_{th})^4}$$

where μ_0 is the low field mobility, v_s is the saturation velocity, E_{th} is the threshold voltage, and E is the magnitude of the electric field. The low field mobility μ_0 is modeled by Hilsum's[3] relation. However, as can be seen from Fig. 4, a small discrepancy still exists in the low-field characteristics. To accurately model the low field mobility, the active layer and substrate interaction must be taken into account. A more accurate mobility model is under development.

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References

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2. I. Efrat and B. Bachelis, "New Numerical Tools for Fielday, A Semiconductor Device Simulator", Tech. report 88.218, IBM Israel Science and Technology and Science Center, March 1987.

3. C. Hilsum, "Simple Empirical Relationship between Mobility and Carrier Concentration", *Electron. Lett.*, Vol. 10, 1974, pp. 259-260.

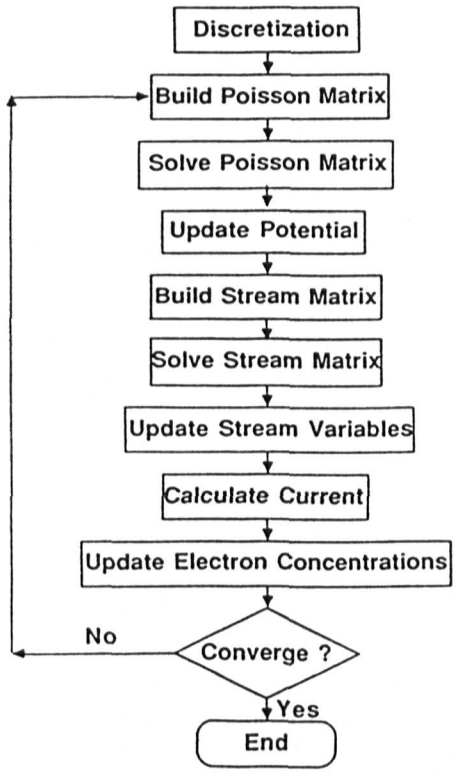


Figure 1: The simulation algorithm

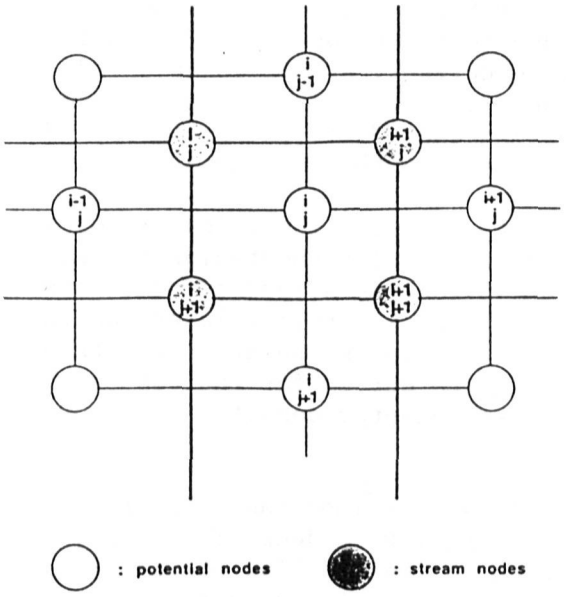
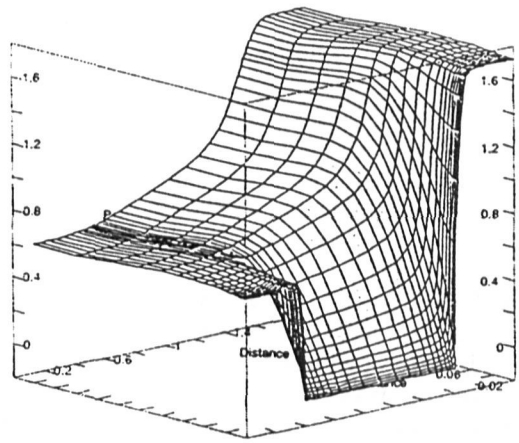
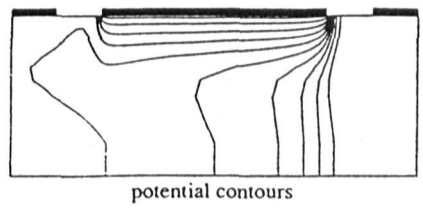


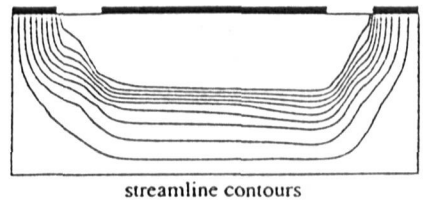
Figure 2: The dual grid systems used for discretization



potential distribution



potential contours



streamline contours

Figure 3: Potential distribution, contour lines and current flow streamlines for Vds = 1.0 V, Vgs = 0.0 V.

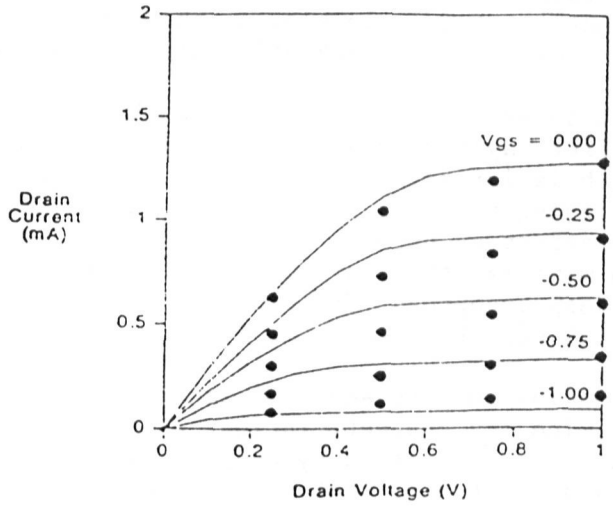


Figure 4: Drain I-V characteristics for the simulated structure. Solid lines represent the simulation results. Dots are the experimental data.