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Finite Element Simulation of Recess Gate MESFETs and HEMTs: The Simulator H2F

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Abstract

In this paper we present a new 2D finite element compound semiconductor device simulator H2F suited for simulation of the parasitic effects in recess gate MESFETs and HEMTS. Several simulation examples of real devices fabricated in the Nanoelectronics Research Centre at the University of Glasgow illustrates the usefulness of the adopted finite element approach.

1. Introduction

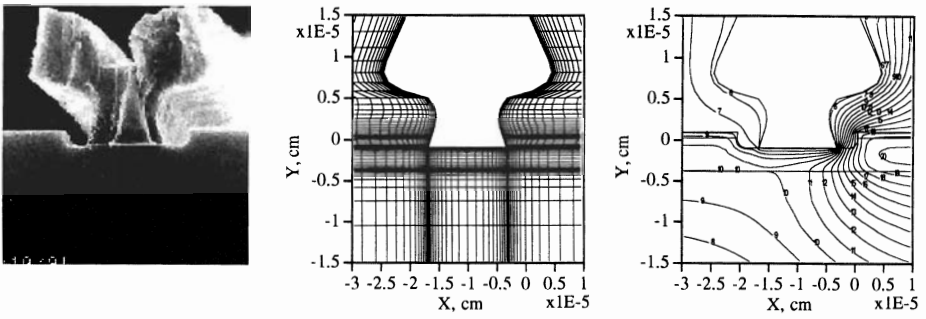
When dimensions of the modern MESFETs and HEMTs scale down to a few tenths of a micron, the device performance becomes strongly affected by device parasitics such as coupling capacitances and access resistances [1]. In recess gate devices these parasitics are critically affected by the shape and surface condition of the recess region. In addition the T-gate process designed to reduce the gate series resistance [2] may also reinforce the parasitic capacitances. Although Hydrodynamic [3] and Monte Carlo [4] simulation programs are making significant progress in properly describing the non equilibrium transport phenomena in compound FETs, the real shape of the gate recess is generally poorly modelled, assuming planar or rectangular simulation domains. Surface effects are also either neglected or modelled by fixing the surface potential or by increasing the surface doping [5]. Yet it is well known that these effects in many cases have a more profound impact on device DC characteristics and high frequency performance than the transport details in the 'intrinsic' region under the gate.

In this paper we report on a new Heterojunction 2D Finite element (H2F) device simulator which focuses on a precise description of the device's geometry and a realistic handling of surface effects and their influence on the device performance.

2. The program H2F

The program H2F is a 'classical' steady-state simulator, which self-consistently solves Poisson's and the current continuity equations in a drift-diffusion approximation. While this approach is unable to describe precisely the device's transport, in many cases it is justified by the need to accurately predict the device's parasitics. A great deal of attention has been paid to the proper handling of the surface effects in the simulation. For

Poisson's equation, the simulation domain includes the space above the semiconductor surface providing a proper interaction between the charge on the surface states and the spreading surface potential. A generalised surface trap model includes acceptor and donor like traps with an arbitrary energy position whose occupation depends on the quasi-Fermi level and the surface potential variation.



(a) (b) (c)

Figure 1. Finite element simulation of a 200 nm gate length MESFET. (a) SEM picture of the device cross sectional view (b) the corresponding H2F grid (c) Potential distribution at VG=-0.4 V and VD=2.5 V.

Quadrilateral finite elements have been used for discretization. The flexibility of the quadrilateral grid is illustrated in Fig. 1 where the cross sectional photograph of a 200 nm gate-length state of the art MESFET, fabricated in the Nanoelectronics Research Centre at the University of Glasgow [6], is compared with the corresponding H2F simulation domain. The grid is generated by appropriate deformation of originally rectangular sub domains. The Galerkin finite element method with a linear isoparametric mapping has been adapted to solve Poisson's equation. A control volume method has been developed for the discretization of the current-continuity equation [7]. In this approach each quadrilateral element is divided into four subelements and the discretization is carried out balancing the current flowing in and out of the subelements attached to a given condensation point. The current density is approximated by the standard Gummel-type expression. The growth functions involved in the derivation of this expression are also used for interpolation of the electron concentration along the sides of the element. It has been found that this discretization is stable for arbitrary shapes of the quadrilateral elements and do not leads to the spikes typical for obtuse triangles.

The grid generation preserves the number of grid points in lateral and vertical directions and leads to a regular nine diagonal matrix of the discretized equations. A Fast Incomplete LU factorisation Biconjugate Gradients (ILUBCG) solver is used for the numerically intensive iterations. The solution of the Poisson's equation involves only a few biconjugate gradient steps per Newton iteration that significantly reduces the total computation time. The convergence problems related to the strongly localised, potential dependent interface charge have been resolved by appropriate dumping. ILUBCG also solves without complication the discretized current continuity equation.

Although H2F is a 'serial' code, an universal pipeline fileserver have been developed to run the program on MIMD mashines like Parsytec Model 64 transputer system. Using this approach multiple copies of the program can calculate in parallel a separate set of input device data. This extends dramatically the capability of the simulator for real design work such as structure optimisation, sensitivity analysis and yield prediction where several hundred simulations are often carried out for a single investigation.

3. Simulation Examples

A set of examples illustrate the application of H2F simulating compound FETs with complex recess shapes. The influence of the position and the density of these surface states on the device's I_D-V_G characteristics for the 200nm MESFET shown in Fig. 1 is given in the Fig. 2 (a, b). The doping concentration in the 60 nm thick MESFET channel is $5x10^{17}$ cm^{-3}. A p-type buffer suppresses the electron penetration in the substrate. The experimental measurements are in good agreement with the expected position and states density Ps=0.6 eV and Nit=$2x10^{12}$ cm^{-2} (Fig 5 (c)). The reduction of the drain current for gate voltages above 0 V and the presence of deep surface states is mainly due to the increase in the series resistance of the unprotected recess region.

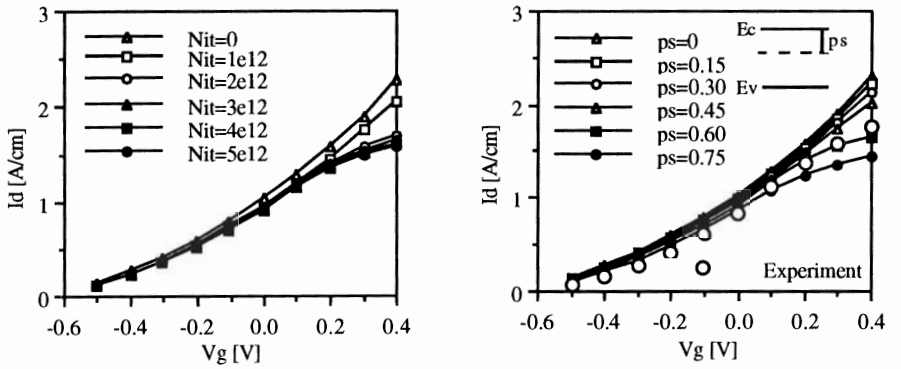


Figure 2. Simulated and measured ID-VG curves for the 200 nm gate length MESFET illustrated in Fig. 1. (a) influence of the acceptor type surface states position P_S (b) influence of the surface state density N_{it}.

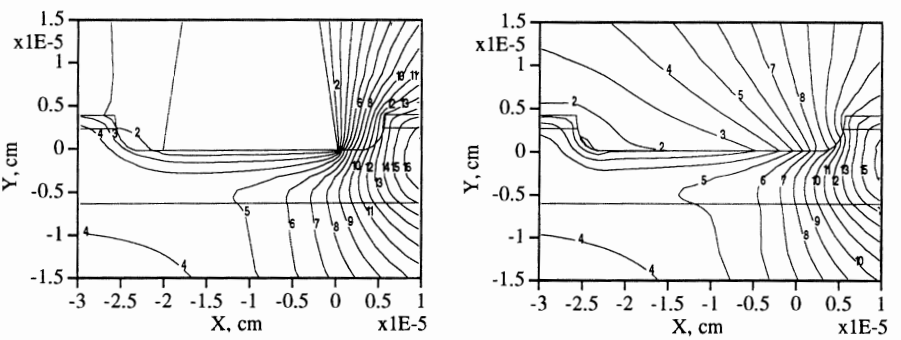


Figure 3. Potential distribution (a) in a gated MESFET (same as in Fig. 1) at V_G=0 V and V_D=3.5 V and (b) in the corresponding gate-less structure at V_D=2.5 V. In the both cases acceptor type surface states with density $4x10^{12}$ cm^{-2} and position 0.6 eV below the conducting band are assumed.

A practical technological problem is addressed in Fig 3 (a, b) where the potential distribution in gated and gate-less transistor structures are investigated. This reflect a part of the technology cycle as recess etching is often controlled by measuring the saturation current in the gate-less structure. The gateless structure shows approximately 160% more current than that of the gated transistor with zero gate bias. This is due to the change in the

surface conditions and to the lateral penetration of the drain potential and the corresponding shortening of the effective channel length.

H2F is also suited to simulating parasitic effects in HEMTs and the results for a delta-doped pseudomorphic HEMT structure significantly influenced by the series resistances are presented in Fig. 4 (a, b). Although the drift diffusion approach underestimates the current, it has been found that by adjusting the saturation velocity in the mobility model (to 1.4×10^7 cm/s in this case) the measured characteristics can be acceptably matched.

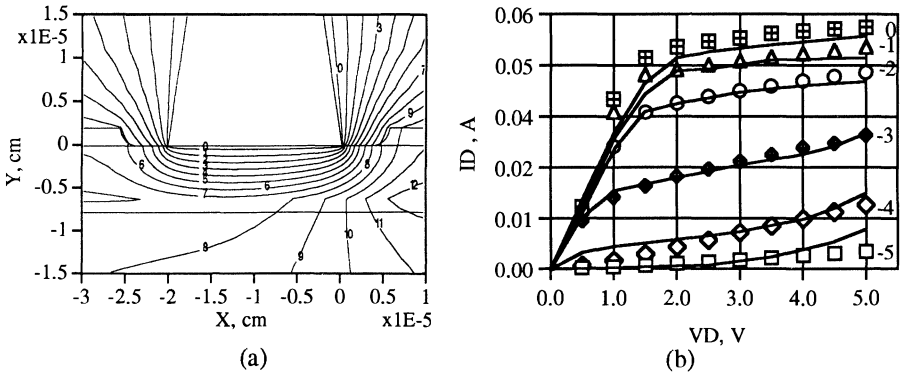


Figure 4. Simulation of pseudomorphic HEMT. (a) device structure and potential distribution at V_G=-3.5 V and V_D=2.5 V (b) measured and calculated I_D-V_G characteristics

Conclusions

A new finite element 2D simulator H2F has been developed. The quadrilateral elements used in the simulator provide the necessary flexibility for realistic description and proper estimation of the parasitic effects in recess gate structures. In many cases, when device parasitics play an important role, the implemented drift-diffusion approach leads to a reasonable prediction of the dc device behaviour even in the submicrometer gate range

References

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