

MINIMOS - A PROGRAM PACKAGE TO FACILITATE MOS DEVICE
DESIGN AND ANALYSIS

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Abstract

We describe a program package for the two-dimensional numerical exact simulation of planar MOS structures. The model is based upon the fundamental semiconductor equations (Poisson's equation, continuity equations and current relations for electrons and holes). To ensure maximum flexibility and low computing costs sophisticated programming methods have been used. Dynamic memory management feasibility has been included to adjust automatically the memory requirements to the number of grid points. Large parts of the solution routines are assembly coded and allow a very fast execution. The input processor syntax is easy to read and is shown to be fully compatible with a recently published proposal for a unified input syntax for CAD programs.

For one operating point typical execution times have been found to be between 15 and 60 seconds on a CDC Cyber 74 computer depending on bias values. The calculation of the current-voltage characteristics of a planar MOS transistor (10 operation points) in the subthreshold region can be performed in about 120 seconds CPU time.

The program has been successfully tested for widely varying devices, geometries and bias conditions. Reasonable agreement between theory and experiment has been obtained in almost all cases.

1. Introduction

During the past decade the use of MOS circuits in digital and analog systems has seen a real breakthrough. As experimental investigations are either unfeasible, too expensive or too time-consuming, computer-aided simulation has become essential for MOS circuits. Thus, MOS device modelling has proved a valuable tool to characterize or even to predict transistor behaviour. Nearly all of the analytic models published show a limited predictability of MOS performance due to too restrictive assumptions or regional approximations. As the structures have become smaller and more complex, the applicability of those simple models turned out to be insufficient. Especially the wider application of scaled devices prohibits the use of one-dimensional models due to important physical

constraints. To get a reasonable device characterization, the designer is urged to apply higher order numerical models. As up to now computer programs based on two-dimensional exact models have either not been available or necessitated a large amount of computing time, they have not been widely used.

In this contribution we describe a program package for the two-dimensional numerical exact simulation of planar MOS structures. The following sections describe:

- 1) some specific results
- 2) the basic model and the main approximations and
- 3) the program structure.

2. Results

Due to the lack of space only some specific results for planar MOS transistors are given to illustrate the variety of results which can be calculated with the program. Fig. 1 shows subthreshold characteristics for a planar MOS structure with a channel length of 2.4 microns. For this case excellent agreement between theory and experiment is achieved.

It can also be shown that the program is very valuable in device design, as it allows to fully investigate the internal behaviour of the devices. The behaviour of internal variables such as potential, field or carrier densities can provide the designer more physical insight and does also allow predictioning. A typical example is given in Fig. 2 where the equipotential lines for a very short channel MOS transistor (channel length .35 micron) are drawn. Note the nearly punch effect between the source and drain depletion layers.

3. Model description

The model is based upon the fundamental semiconductor equations in two dimensions:

- a) Poisson equation
- b) Continuity equations for electrons and holes and
- c) Current relations for electrons and holes.

To calculate the two-dimensional doping profiles the user can choose among two different possibilities: i) the drain-source diffusions are calculated after Kennedy and Murley /1/ and the implanted profiles after LSS theory /2/ or ii) the Stanford process modelling program SUPREM II is used to determine the vertical profile and a fit is performed in the second, lateral direction.

The main assumptions which are incorporated in the model are:

- the impurities are assumed to be completely ionized;
- Maxwell-Boltzmann statistics and validity of the Einstein relation;
- the carrier mobilities in the channel are assumed to be dependent on the doping and on both the normal and lateral electric field. The dependence on the doping is treated according to /3/ and the treatment of the dependence of the mobilities on the electric fields follows the works of Hess /4/.
- the recombination is assumed to be a Shockley-Read-Hall process with traps in the middle of the band gap.

4. Numerical treatment and program structure

The basic equations are normalized into a dimensionless form. This gives three coupled differential equations for the potential and the carrier densities. As it is impossible to solve this set of coupled equations analytically, numerical methods are used. The equations are discretized with a two-dimensional finite difference method. To achieve minimum memory requirements a nonuniform mesh is automatically generated depending on bias conditions and geometry. Each equation is treated separately and solved with iterative techniques. Here Stone's SIP method /5/ and overrelaxation methods are used. The overall solution is easily found with a Newtonian iteration process.

To ensure maximum flexibility and low computing costs very sophisticated programming methods have been used. Dynamic memory management routines have been included to adjust automatically the memory requirements to the present number of grid points. Main parts of the solution routines are assembly coded and allow a very fast program execution. The input processor syntax is easy to read and is fully compatible with a recently published proposal for a unified input syntax for CAD programs /6/. One example of input data for the simulation of a planar MOS transistor in a typical operating point is shown in Fig. 3.

For one operating point typical execution times have been found to be between 15 and 60 seconds on a CDC Cyber 74 computer depending on bias values. The calculation of the current-voltage characteristics of a MOS transistor in the subthreshold region (10 operating points) can be performed in about 120 seconds CPU time.

More data on used physical models and obtained numerical results can be found in /7/.

5. Conclusion

In this contribution we describe a user-oriented program package for the two-dimensional numerical exact simulation of planar MOS structures. Sophisticated programming and optimal numerical algorithms allow very low execution times. The driving forces for the development of this package were twofold:

- to bridge the gap between technology modelling and circuit design and
- to provide both designers and technologists with an easily usable but yet exact MOS simulation program.

6. References

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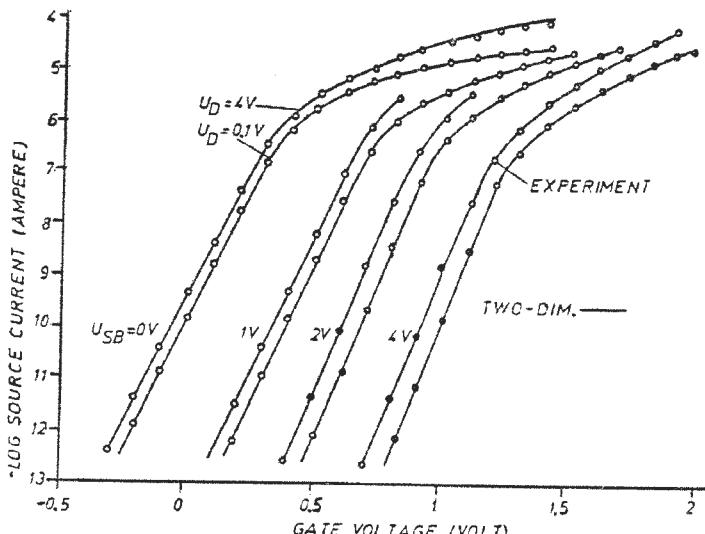


Fig. 1

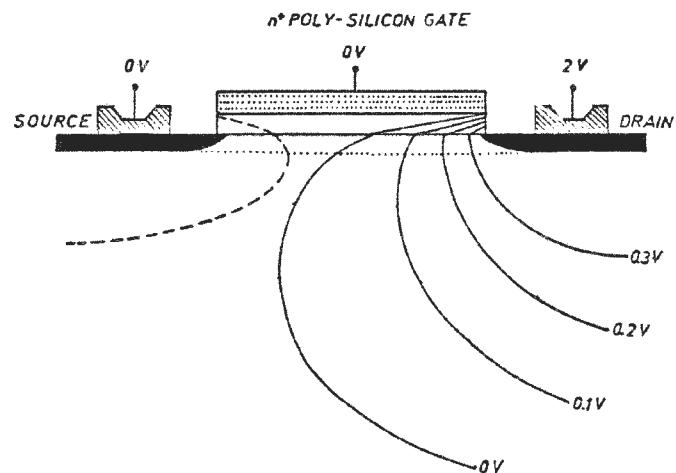


Fig. 2

MINIMOS 1.0
4 MICRON TEST

TU VIENNA

10.39.03. 79/02/23

DEV CHANNEL=N, GATE=AL, TOX=500.E-8, L=4.E-4, W=10.E-4
BIAS UD=5, UG=2, UB=-3
PROF NB=1.5E16, NS=1.E20, TEMP=1000, TIME=3000

Fig. 3

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