A QUASI THREE DIMENSIONAL SEMICONDUCTOR DEVICE SIMULATION USING CYLINDRICAL COORDINATES

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Abstract

A quasi three dimensional simulation of devices with cylindrical symmetric structure is presented. The basic semiconductor equations have been discretized for cylindrical coordinates. Taking advantage of the symmetries it was possible to adapt a recently developed two-dimensional numerical device simulation system without loosing its features of automatic grid generation and refinement. The method is demonstrated by simulating the on-characteristic of power thyristors. We compare and discuss the convergence properties and the physical results for planar and cylindrical discretization. The simulations show no significant differences in the number of iterations and grid updates. The influence of the cylindrical symmetry depends on the location of the emitter contact and results in different transfer currents. The highest values have been calculated with a circle ring emitter.

1 Introduction

A considerable number of discrete semiconductor devices have a cylindrical symmetric structure. Taking advantage of this property the two-dimensional numerical simulation of these devices using cylindrical coordinates exhibits complete information on their electrical behaviour. A previous treatment /1/ outlines only shortly the possibility of formulating Poisson´s equation with circular symmetry. Our approach is based on a recently developed two-dimensional numerical device simulation system SCDSS /2/. The reformulation of the system of partial differential equations in cylindric coordinates is presented in Section 2. We investigate the convergence properties and computation times. As a typical example the on-characteristic of a power thyristor has been simulated using both planar and cylindrical discretization and the effect of the different approaches is discussed.

2. Discretization in cylindrical coordinates

The basic semiconductor equations contain three differential operators: grad, div, div grad. As it is well known their formulation in cylindrical coordinates contains additional terms compared to cartesian coordinates. The partial derivatives with respect to ϕ vanish assuming that the functions are cylindrically symmetric. Therefore the threedimensional device behaviour can be described by only two coordinates. (1) and (2) give the mentioned additional terms.

$$\text{div } \vec{J} : \quad \frac{1}{r} J_r \tag{1}$$

$$\text{div grad } U : \quad \frac{1}{r} \frac{\partial U}{\partial r} \tag{2}$$

A two dimensional device simulation system can be adapted to cylindrical coordinates by inserting the discretized terms (1) and (2). We have developed such a simulation program /2/ using a "Finite Boxes" discretization scheme. Now the "div" operator reads

$$\text{div } \vec{J} = J_{i+0.5j} \cdot \frac{2}{\Delta r_i + \Delta r_{i-1}} \cdot \left(1 + \frac{\Delta r_{i-1}}{2r_i}\right) - J_{i-0.5j} \cdot \frac{2}{\Delta r_i + \Delta r_{i-1}} \cdot \left(1 - \frac{r_i}{\Delta r_i}\right) + \frac{\partial J_z}{\partial z} \tag{3}$$

Compared to cartesian coordinates the coefficients of the function values in r-direction are multiplied by the factors (4), (5)

$$1 + \frac{r_i - r_{i-1}}{2r_i} \quad (4) \qquad\qquad 1 - \frac{r_{i+1} - r_i}{2r_i} \quad (5)$$

(5) may vanish if $r_{i+1} = 3r_i$ and the iteration matrix becomes illconditioned. This can be avoided by checking the distances between the grid points. The formulation of the system of equations in cylindrical coordinates has no other influence on the solution methods. Therefore we use all the facilities of the two-dimensional program such as automatic grid generation, adaption and the flexibility of the device geometry.

3. Thyristor Geometry

We applied the quasi three dimensional device simulation to two power thyristors with identical emitter contact areas. The basic geometry is shown in Fig. 1. Device A has a circular emitter contact, the emitter in device B is a circle ring with the same contact area of $2.84 \cdot 10^{-4}$ cm^2. For comparison purposes we also simulated a planar device with an emitter stripe. The impurity concentration of device A is shown in Fig.2. Its parameters are the same for all three devices. We simulated voltages between 0.8 and 3V at the anode contact. The thyristors have been assumed to operate on the on-characteristics. The parameter models for the recombination include Shokley-Read-Hall-recombination and the Auger-recombination /3/. The carrier lifetimes depend on the impurity doping. The model of the carrier mobilities takes into account carrier-carrier- as well as impurity scattering /4/, /5/. The amount of band gap narrowing is taken from /6/.

4. Results

The simulation of the devices shows no significant differences in the number of iterations. The iterations have always been started on the same initial grid. We need between 15 to 20 cycles for convergence. The number of grid updates depends on the applied voltage and the desired final accuracy but there was no unique differenc between cylindrical and planar devices. Fig. 3 shows calculated current - voltage curves for all three devices. For the calculation of the contact currents the current densities have been integrated along grid lines around both contacts. The cylindrically symmetric devices allow a direct calculation of the current.

$$I = \int \{ (J_{n_z} + J_{p_z}).2r\pi .dr + (J_{n_r} + J_{p_r}).dz\} \qquad (6)$$

A significant difference in the calculated values of the three devices can be observed. The high transfer current value of the ring emitter device is due to the plasma spread from the contact towards the axis. This diminishes the on-resistance and increases the active area of the anode compared to the circular emitter device A. The level of the current densities is nearly the same for both devices. Therefore a thyristor element with a ring emitter structure is preferablefor the design if low forward voltage drop shall be achieved. The influence of neglecting band gap narrowing is also shown in the IV plot. A constant intrinsic number decreases the current by more than 10%. As an example for the internal distributions Fig. 4 and 5 show the electron and hole current density for device A at an anode voltage of 2V. The current is crowding underneath the emitter contact and it is spreading across the whole device. Nevertheless the value int the center of the device is always much higher than that at the outer edges as far as the highly doped anode region. In Fig. 6 and 7 the corresponding distributions are plotted for the planar device C. The value of the current densities at the anode exceeds that of the circular device by nearly a factor of 2. In spite of that increase the total current is less than half the value of device A (cf. Fig. 3).

5. Conclusion

A consistent method for exact cylindrically symmetric semiconductor device simulation has been presented. The approach is based on the "Finite Boxes" discretization scheme developed in /2/. The method has been successfully applied to power thyristors Three types of devices have been investigated with equal emitter contact areas for comparison of the results. The discussion has shown that the internal distributions and the terminal currents of axial symmetric devices are accurately calculated only by the cylindrically coordinate approach.

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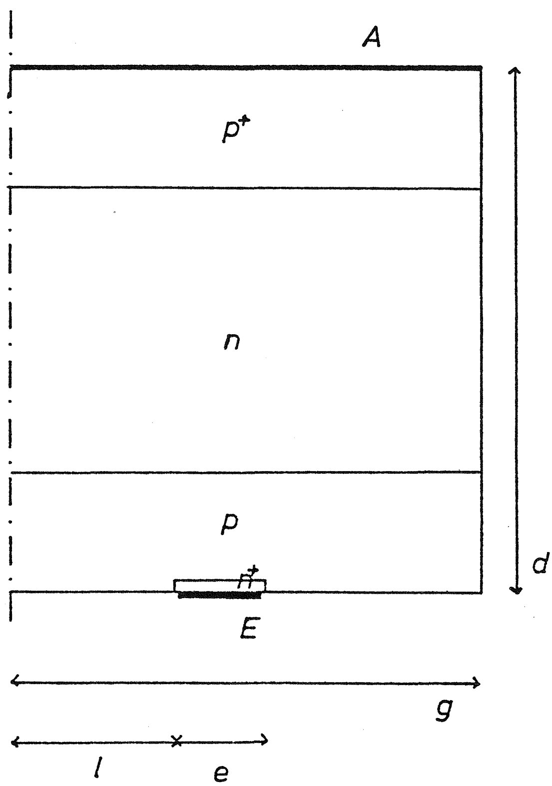

	A	B	C
g	500 um	500 um	500 um
d	450 um	450 um	450 um
l	0	200 um	0
e	95 umn	21.4 um	95 um

Fig. 1 : Basic device geometry

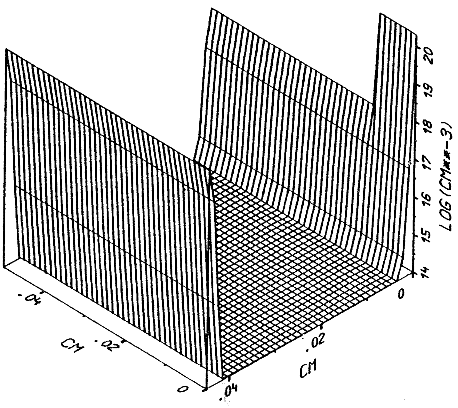

Fig. 2 :

Concentration of impurities ($|N_D|+|N_A|$)

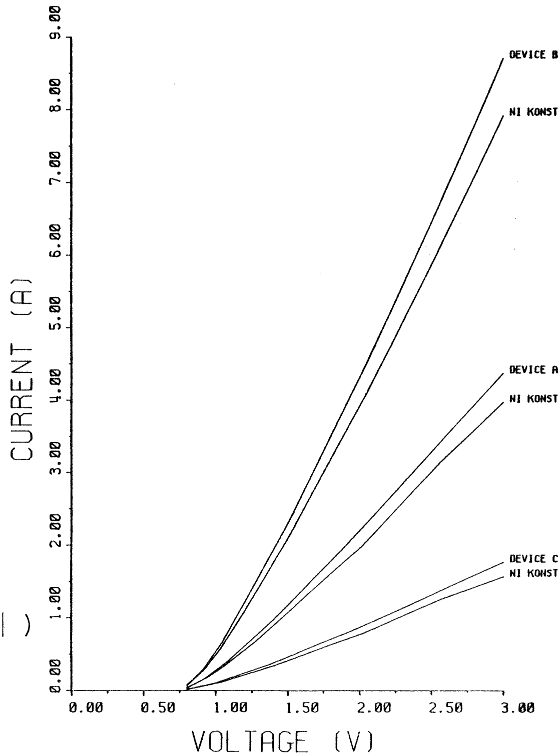

Fig. 3 : Current - Voltage - Characteristic

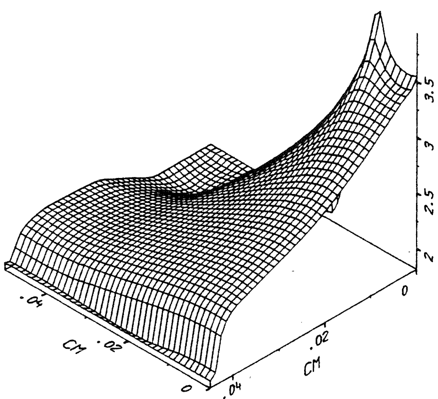

Fig. 4 :

Electron current density - device A

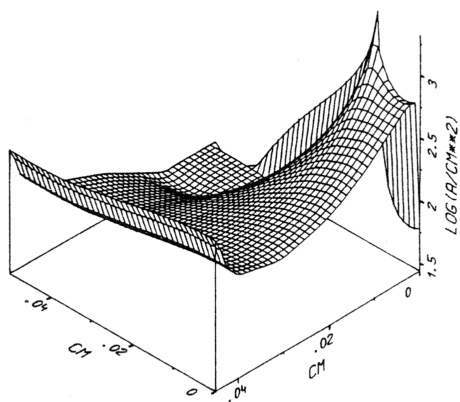

Fig. 5 :

Hole current density - device A

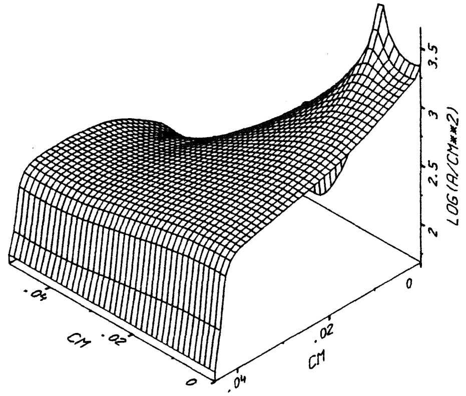

Fig. 6 :

Electron current density - device C

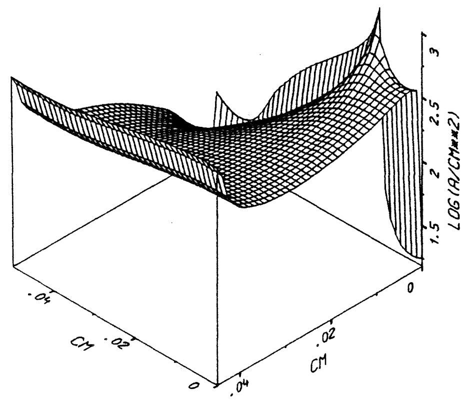

Fig. 7 :

Hole current density - device C