

**CALCULATING CURRENT DENSITY IN TWO-DIMENSIONAL
 SEMICONDUCTOR PIN STRUCTURES**

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ABSTRACT - Starting from the model for a two-dimensional analysis of semiconductor devices /1/, /2/, /3/, a method for calculating current density, if we know the potential distribution and the carriers concentration, is presented in this paper. It consists of some approximation and assumption, but it is more sufficient and efficient than others. In this paper we present a two-dimensional distribution of parameters in a PIN structure. The results are presented graphically and the comparison with earlier methods is given.

1. INTRODUCTION

The physical and mathematical analysis of the behaviour of a PIN diode is generally a very difficult task due to the two dimensional nature of the device. The PIN structure plotted on Fig. 1. is the topic of the analysis of the present paper.

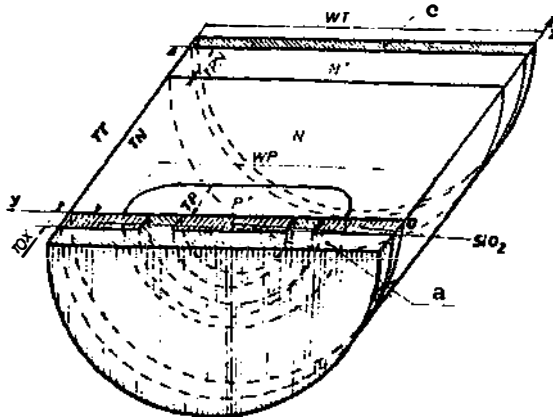


Figure 1. The geometry of a PIN diode in a simple form

The set of equations in the normalized form giving the current density, the continuity of carriers flow and Poisson's equation are, on the two-dimensional model for Fig.1./1/, /4/, /5/, /6/

$$\vec{J}_n = q[D_n \text{grad}(n) - \mu_n n \cdot \text{grad}(\Psi)] \quad (1)$$

$$\vec{J}_p = -q[D_p \text{grad}(p) + \mu_p p \cdot \text{grad}(\Psi)] \quad (2)$$

$$\text{div } \vec{J}_n - R(\Psi, n, p) = \frac{\partial n}{\partial t} \quad (3)$$

$$\text{div } \vec{J}_p - R(\Psi, n, p) = \frac{\partial p}{\partial t} \quad (4)$$

$$\text{div } \text{grad}(\Psi) - \frac{q}{\epsilon}(n-p-c) = 0 \quad (5)$$

In the most general case the solution for the carrier's concentrations n and p , potential Ψ and current densities J_n and J_p is reached by a numerical procedure of solving the upper system of equations.

2. MATHEMATICAL-PHYSICAL MODEL AND RESULTS FOR CURRENT DENSITIES

At the end of the simulation program the potential and the carrier's concentration are known. Then it is theoretically possible to compute the current densities.

Equations (1,2) can be rewritten in the following form:

$$\vec{J}_p = -\mu_p \cdot e^{-\Psi} \cdot \text{grad } \nu \quad (6)$$

$$\vec{J}_n = \mu_n \cdot e^{-\Psi} \cdot \text{grad } \nu \quad (7)$$

where ν is a quasi Fermi potential.

Such formulations are not easily used because of the great inaccuracy met in a numerical differentiation. It is better to use an integral form /4/. From (6,7) we can easily show that:

$$\int_x^{x+h} \frac{1}{\mu_p} X_p e^{\Psi} dt = p(x, y) e^{\Psi(x, y)} - p(x+h, y) e^{\Psi(x+h, y)} \quad (8)$$

where X_p is the longitudinal component of the hole current density. The equation for the electron current is similar.

Using the method for solving equation (8) presented in Ref./2/, after discretization we finally obtain the equation for longitudinal component of the current density which is convenient for computer simulation:

$$X_p(i+1) = X_p(i) \cdot \exp \left[- \left[1 + e^{\Psi_i - \Psi_{i+1}} \right] \right] - \frac{2\mu_p}{h_i} \frac{p_i \cdot e^{\Psi_i - \Psi_{i+1}} - p_{i+1}}{1 + e^{\Psi_i - \Psi_{i+1}}} \cdot \left\{ 1 - \exp \left[- \left[1 + e^{\Psi_i - \Psi_{i+1}} \right] \right] \right\} \quad (9)$$

The two-dimensional analysis for the PIN diode (Fig.1), taking that the distribution of impurities is of Gaussian type, was carried out in 2450 points (net 49x50). The parameters of the analyzed structure were: $TT=7.44\mu\text{m}$, $TN=6.94\mu\text{m}$, $TP=TNP=0.5\mu\text{m}$, $WT=7.84\mu\text{m}$, $WP=2\mu\text{m}$, $N_A=4 \cdot 10^{18}=\text{cm}^{-3}$, $N_D=N_{DSB}=8 \cdot 10^{13}=\text{cm}^{-3}$.

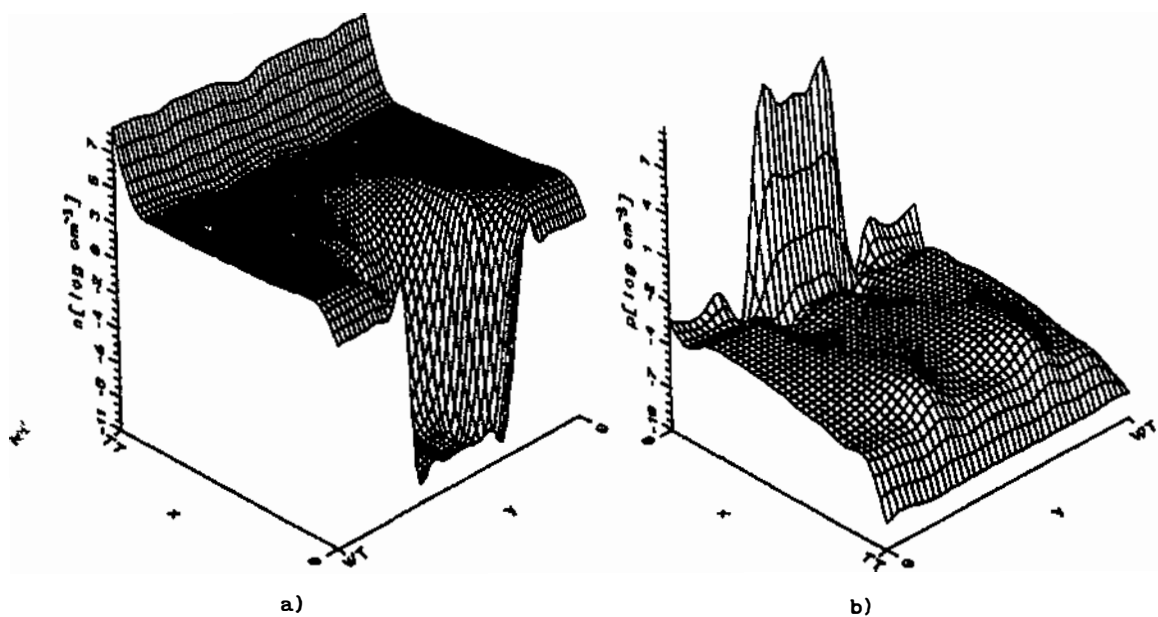


Fig.2 Distribution of carriers: a) electron; b) hole

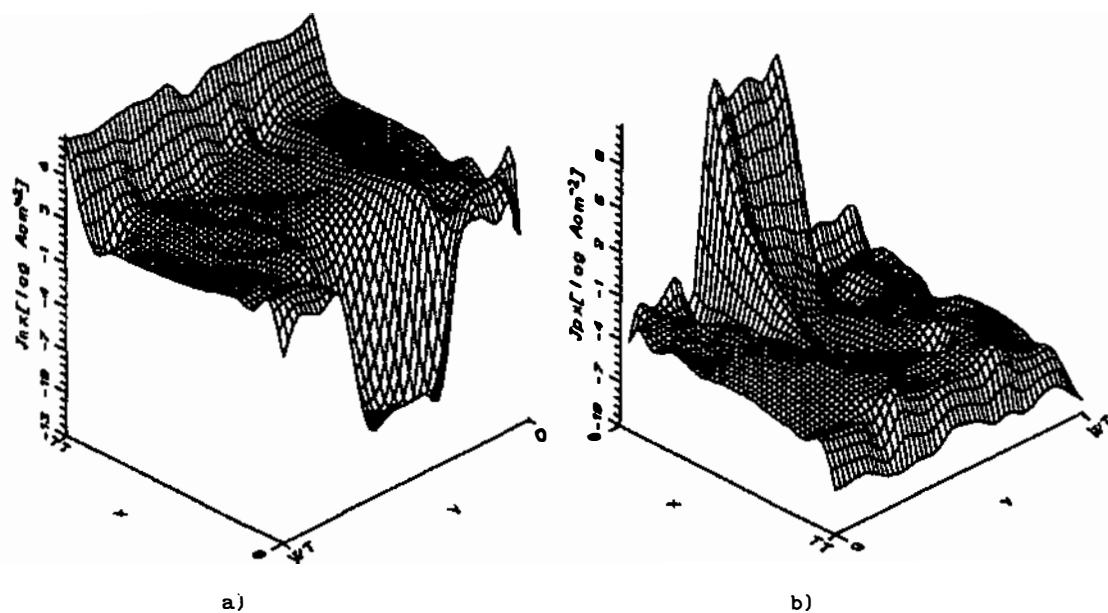


Fig.3 Longitudinal components of electron (a) and hole (b) current densities

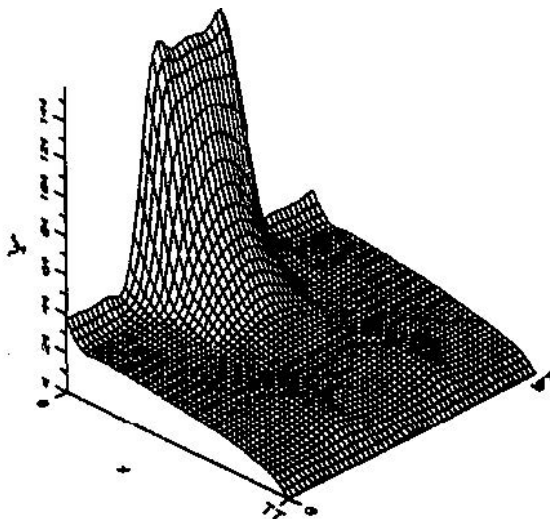


Fig.4 Distribution of potential

3. CONCLUSION

The PIN structures are in a wide use, but we can hardly find any results with the two-dimensional analysis in literature. The method and the calculation algorithms developed in this paper are of generally use for various structures. Such computer programs are of general interest in device technology for optimization, electrical modelling and physical understanding of the behaviour of devices. The presented method provides a possibility to simulate the transient current-voltage characteristics for the PIN diode.

REFERENCES

- /1/ W.L. Engl, "Process and Device Modeling", North-Holland, New York, 1986.
- /2/ Z. Ristovski, R. Ramović, D. Stojanović, D. Stojanović, D. Tjapkin, "New Method for Calculating Current Density in Semiconductor Devices", conf. MIEL, Zagreb, 1988.
- /3/ D. Stojanović, D. Stojanović, R. Ramović, D. Tjapkin, "Calculation of Distribution of Current Density in Some Two-Dimensional Semiconductor Devices", conf. ETAN, pp.X 61-X 68, 1986.
- /4/ D. Vandorpe at all, "An Accurate Two-Dimensional Numerical Analysis of the MOS Transistor", Solid State Electronics, 1972, Vol.15, pp.547-557.
- /5/ S. Selberherr, "Analysis and Simulation of Semiconductor Devices", Springer-Verlag, Wien, 1984.
- /6/ D. Stojanović "Two-Dimensional Analysis of Electrical Parameters in the Semiconductor Structures", M.C. Thesis, Faculty of Electrical Engineering, Beograd.