SIMULATION OF SEMICONDUCTOR DEVICES AND PROCESSES Vol. 5
Edited by S. Selberherr, H. Stippel, E. Strasser – September 1993

Determination of EBIC Response by Two-Dimensional Device Simulation

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Abstract

The carrier generation as a result of electron beam irradiation of semiconductor devices has been incorporated into the device simulator ToSCA. The simulator extended with this new capability makes feasible the investigation of complex device structures under conditions which are equivalent to those of EBIC measurements. Simulation results are compared with experimental data.

1. Introduction

Computer simulations of processes and devices have become significant in the design of novel device structures and manufacturing processes. Better approaches for simulation embeded in process and device development are created. Investigations of device behavior, analysis of sensitivity to different process or design parameters and vizualisation of non-measurable parameters are well-known. In the following we describe an extension and new application which aim at supporting the development of new high-tech measurement methods.
The parameters of microelectronic devices are defined by dopant profiles. Therefore the lateral extension of profiles gains importance. Extensive investigations are necessary providing methods for lateral features like effective channel length and channel asymmetry. The use of electron beam induced current (EBIC) [1] for quantitative determination of two-dimensional profiles appear to be possible. This method needs extensive interpretation and numerical treatment.
In the present work the carrier generation as a result of electron beam irradiation is incorporated into a general purpose device simulator. Simulation has been done with and without electron beam incidence during EBIC measurement for calculation of two-dimensional electric field and carrier distributions. These results are applied for a better interpretation of EBIC images, where the comparison of simulated and measured EBIC profiles gives information about the lateral dopant distribution.

2. Principles of the EBIC method

The electron beam of a scanning electron microscope (SEM) generates electron-hole pairs in a semiconductor sample. If the mobile excess minority carriers reach by diffusion an electric field (e. g. of a pn-junction), they give an external current in a low impedance amplifier connected to both sides of the pn-junction. The electric field can be caused by dopant gradients, external voltages and Schottky barriers. One can obtain EBIC images or profiles (line scans) by scanning the focused beam over the sample. In the past, analytical calcula-

tions of the EBIC signal have been performed. Most of the models divide the sample in a space charge region (SCR) and a field free diffusion region. The EBIC signal is calculated by using the collection probability of the excess carriers at a given distance of the SCR. One-dimensional numerical calculations of the EBIC signal have been published [2,3].
In modern semiconductor devices the SCR width, the depth of doped regions and the generation volume have comparable dimensions. In this case a numerical simulation of the EBIC signal using the real two-dimensional dopant distribution of the device is necessary.

3. Two-Dimensional Simulation of EBIC Profiles

The EBIC is determined by introducing an additional generation rate for electrons and holes into the continuity equations which is due to the primary electrons entering the semiconductor. The entire system of semiconductor equations takes into account the extended continuity equation and is solved with the advanced two-dimensional device simulation program ToSCA[1)]. The generation rate is described by a gaussian function [4] characterized by the standard deviations σ_x, σ_y and the depth of the generation centre y_0 in the following manner:

$$G(x,y) = G_0 \cdot \exp(-(x-x_0)^2/(2 \cdot \sigma_x^2)) \cdot \exp(-(y-y_0)^2/(2 \cdot \sigma_y^2)) \quad (1)$$

where

$$G_0 = \frac{(1-f) \cdot W_e}{E_{eh} \cdot 2 \cdot \pi \cdot \sigma_x \cdot \sigma_y}.$$

W_e is the power of the electron beam, f characterizes the rescattering of electrons, E_{eh} is the energy required to produce an electron hole pair and x_0 is the location of the electron beam on the x-axis.
Essential effects influencing the EBIC signal are surface recombination velocity, additional surface charges, electron and hole life times and mobilities. The surface recombination velocity is increased by perturbations caused by surface treatment. Therefore the diffusion length of electrons and holes decreases near the surface. The bulk life time of the semiconductor material, the dopant profile and trap density distribution have a comparatively smaller influence on the diffusion length of electrons and holes. Careful determination of the parameters of generation and recombination processes mentioned above has to be carried out in order to obtain accurate simulation results.

4. Results

This new simulation method is applied for EBIC signal calculation of an 1.2 µm n-channel MOS transistor. All process steps influencing the dopant profile and the substrate surface contours are simulated with high accuracy. This is important for the accurate calculation of electric field.
To calculate the EBIC profile the electron beam is scanned over the device surface with a

[1)] development of the Institute of Applied Analysis and Stochastics Berlin step width of 100 nm. For each distinct irradiation step the EBIC signal is calculated by solving the non-stationary problem from the beginning of electron irradiation to stationary conditions achieved after about 10^{-7}s. Figure 3 shows the electron density distribution in the n-channel transistor during stationary electron irradiation. The generation rate produced by an electron beam (3 keV and 120 pA) is assumed to have a depth of the generation centre of 60 nm and standard deviations of 90 - 150 nm. The EBIC profile represents the sum of drain and source current for each irradiation position.

If the electron irradiation causes a small perturbation of the electric field only, there is a strong correlation between pn-junctions, undisturbed field strength distribution (fig. 2) and the EBIC image (fig. 1). Figure 4 shows that the maximum of the EBIC signal is located at the same position as the maximum of the electric field and the pn-junction. The influence of the dopant profile asymmetry and the surface inversion in the channel region can be clearly seen in the simulation data. The EBIC profiles in figure 4 (obtained at a depth of 50nm) show the good agreement between measurement and simulation. Differences occured in the tails of the profile are caused by deviations in the life time near surface of high doping areas. The EBIC plateau in the channel region found in measurements of short n-channel transistors is reproduced by the simulation too.

The special sample treatment (e.g. beveled sample) influences the surface recombination velocity and surface charge density strongly and thus the electrical properties. The surface charge density can produce an inversion layer and an additional electric field in the transistor channel enhancing the collection of electrons for the EBIC signal. For our calculations we use a surface recombination velocity of 10^6 - 10^7 cm/s and a surface charge density of 10^{12} e/cm^{-2}. The width of the EBIC peak is found to decrease by increasing of surface recombination. Very high values of recombination velocity can even provide two maxima in the EBIC profile instead of a plateau. It is possible to distinguish the several space charge regions of a n-channel transistor in these cases.

Acknowledgments

The authors would like to thank Prof. H. Gajewski for providing of the code ToSCA, Dr. H. Kück for helpful discussion and F. Richter for the technical assistance.

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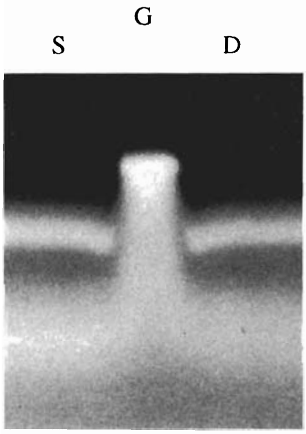

Fig. 1. EBIC image of an 1.2 µm n-channel transistor

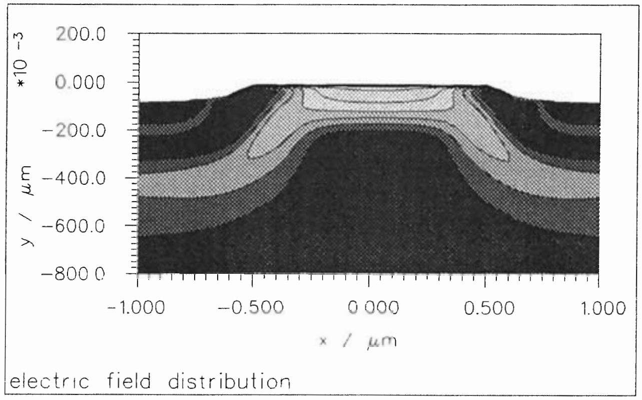

Fig. 2. Distribution of electric field strength in the n-channel transistor without electron beam irradiation

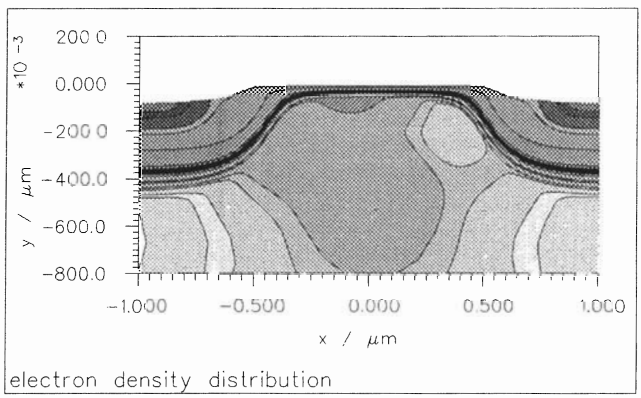

Fig. 3. Electron density distribution in the n-channel transistor during stationary electron irradiation

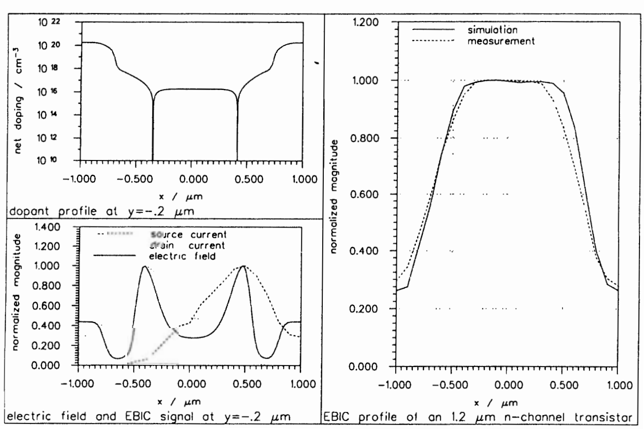

Fig. 4. Simulated lateral doping profile, electric field and EBIC signal and comparison of measured and simulated EBIC profile