A NUMERICAL ANALYSIS OF BULK-BARRIER DIODES

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Abstract

A selfconsistent numerical analysis of Bulk-Barrier Diodes (BBD), which have been patented only recently, is presented. The principal way of operation of a BBD is explained. A computer program which can accurately model second order effects is used to illustrate the internal electric behaviour of a BBD. The distributions of the relevant physical quantities in the interior of a BBD are discussed. Measured and simulated characteristics which show good agreement are compared. Investigations of the sensitivity to minute variations of the doping profile are presented. The advantages and disadvantages of a BBD compared to a standard silicon diode and a Schottky diode are discussed.

1. Introduction

Bulk-Barrier Diodes are relatively new devices which promise to have impact on integrated circuits henceforth. Current flow in BBD's is essentially accomplished by majority carriers and controlled by a 'Bulk-Barrier' which is adjustable with standard technological steps. At first glance the BBD is comparable to a Schottky diode which is also a majority carrier device. As a remarkable difference the barrier of a Schottky diode is located at the metal-semiconductor interface and not in the bulk, and is not controllable by technological steps.

This paper deals with a numerical analysis of the BBD, which has been performed by a computer program. The physical model this program is based on consists of the well-known fundamental semiconductor equations (Poisson's equation, continuity equations, current relations and heat flow equation). Great efforts have been made in modeling the physical parameters (e.g. intrinsic number dependent on doping and temperature; carrier mobilities temperature-dependent because of lattice-, ionized impurity-, free carrier-scattering, and velocity saturation; thermal- and Auger-recombination and avalanche generation /8/). Owing to lack of space, the models cannot be discussed here in detail; neither is it the objective of this paper to describe the numerical solution. This fact is especially to state because our analysis is just performed one-dimensionally - this type of analysis for diodes has already been published in 1968 /6, 7/ - and recently published papers already deal with two-dimensional transient analysis (e.g. /2, 3, 5, 11/) or even three-dimensional analysis /4/. However, our one-dimensional semiconductor simulation program is just as good for some practical applications since the physical parameters have been modeled extremely carefully.

2. The internal behaviour of Bulk-Barrier Diodes

For our investigations we used a BBD with a p^+np-doping profile. The fundamental idea of the operation of a BBD is the following: The n-layer is relatively thin, so that without an applied voltage the complete n-layer is depleted of free electrons - the p^+np-diode is 'punched through' /12/. If one applies a positive voltage between the p- and p^+-layer, the p^+n-junction - henceforth called the first junction - is reverse biased and the np-junction - the second junction - is forward biased. As the doping in the p^+-layer is higher than in the n-layer, the depletion region of this reverse biased diode extends mainly into the n-layer. As result of punch through a hole current flows from the p- to the p^+-layer at relatively low voltages; the BBD is forward biased. The knee voltage of the BBD can be controlled by the doping level and the thickness of the n-layer alone; i.e. by technological steps.

If one applies a negative voltage between the p- and p^+-layer, the second junction is reverse biased. This junction is, owing to the low substrate doping, able to block, because the depletion region extends mainly into the substrate; the BBD is reverse biased. Analytic investigations of the above mentioned effects can be found in /9, 10/.

As the doping profile determines the behaviour of the BBD in an extremely critical way, the modeling of the doping profile was performed carefully. We compared two versions of SUPREM, the **S**tanford **U**niversity **PR**ocess **E**ngineering **M**odels program /1/, for these investigations. Fig. 1 shows the doping profiles obtained by SUPREM-03 and SUPREM-05, respectively. In the newer version of SUPREM (05) the shape of the boron implantation has been changed so that no n-layer exists at all. As we knew that our fabrication process for the BBD produces a thin n-layer we used SUPREM-03 results as input for our device simulation program and performed an analysis to demonstrate the sensitivity of the electric properties of the BBD on uncertainties of the doping profile.

Fig. 2 shows the potential distribution in the interior of the BBD at various operating points. One can easily extract from this figure that the barrier is vanishing with increasing bias. It is to note at this point that the blocking barrier at reverse bias conditions tends to become smaller too which will certainly lead to an increase in current. The quantitative amount of the barrier lowering, however, does not affect the blocking capability at moderate reverse bias conditions.

Fig. 3 shows the carrier density distributions for a forward bias of 0.8 Volts. The magnitude of the hole density is larger in the whole device than the electron density which is, owing to the punch through effect, depleted in the n-layer.

Fig. 4 shows the carrier density distributions for a reverse bias of -1.0 Volts. One can see the depletion region of the second junction. The magnitude of the hole density, although it is depleted, increases with higher reverse bias which leads to the already mentioned increase in saturation current.

3. Comparison with measurement

Fig. 5 shows a comparison of the simulated and the measured characteristics of the BBD. The predicted diode behaviour is totally confirmed. The knee voltage is distinctly lower than for a standard silicon diode. The offset one can identify for forward bias between simulation and measurement is based on the uncertainty of the doping profile as confirmed by Figs. 6, 7.

Fig. 6 shows the forward characteristics of the BBD drawn in a logarithmic scale. The shift of the characteristics, owing to small changes of the doping parameters, is quite pronounced, so that there is no reason to worry about the offset of measurement and simulation as an error of the latter.

Fig. 7 shows the blocking characteristics of the BBD in similar presentation as Fig. 6. One has an approximately exponential dependence of the saturation current on the bias. Small technological changes result in similar offsets as for forward bias.

4. Conclusion

When summarizing all advantages and disadvantages of a BBD there is certainly a wide field of applications. BBD's are majority carrier devices with diode like characteristics. The knee voltage of BBD's can be controlled by standard technological steps which is a big advantage compared to silicon diodes. The switching speed of BBD's can be expected as very high since the relevant time constant, the dielectric relaxation time, is in the order of picoseconds. Additionally the capacity characteristics and the differential resistance could be tuned with technological steps for special purpose applications.

Our computer program for simulating any type of silicon diodes is able to predict and analyse satisfactorily the behaviour of the BBD. This application is in fact much more complicated than the analysis of a standard silicon diode, because the BBD reacts extremely sensitively to a number of parameters. It is nevertheless possible to obtain good quantitative aggreement of simulation results and measurements, because much emphasis has been laid on the adequate modeling of second order effects. The analysis of the thermal behaviour can be performed with this program too, although it has not been demonstrated in this paper, because it is a third order effect for the BBD. The computer program is available from the authors for just the handling fees.

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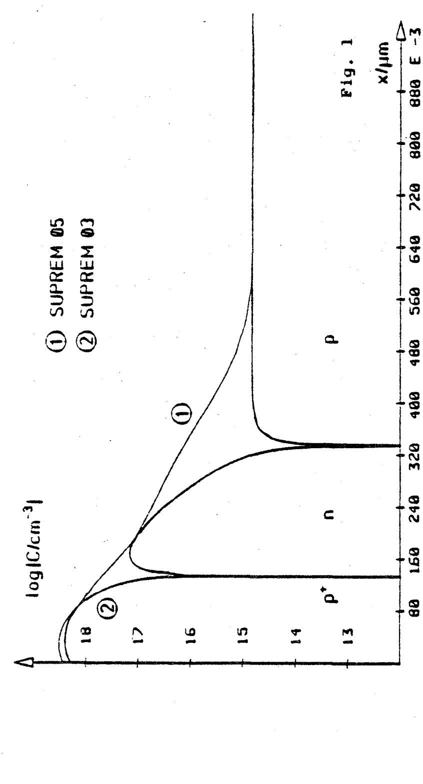

Fig. 1

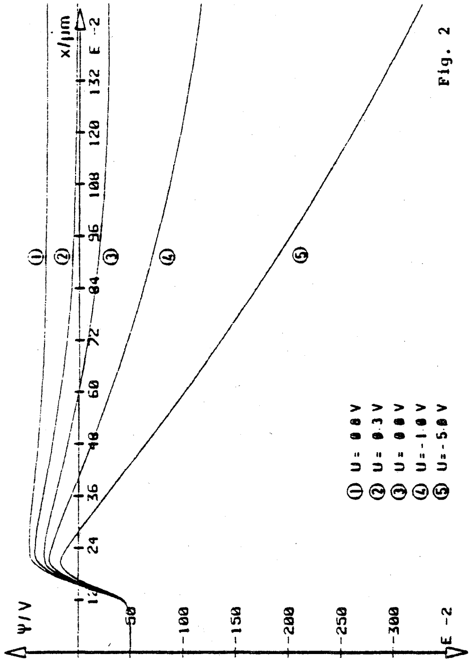

Fig. 2

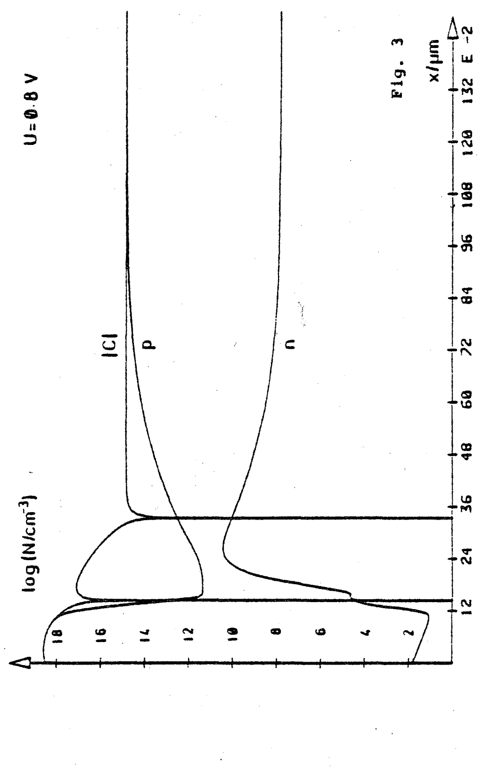

Fig. 3

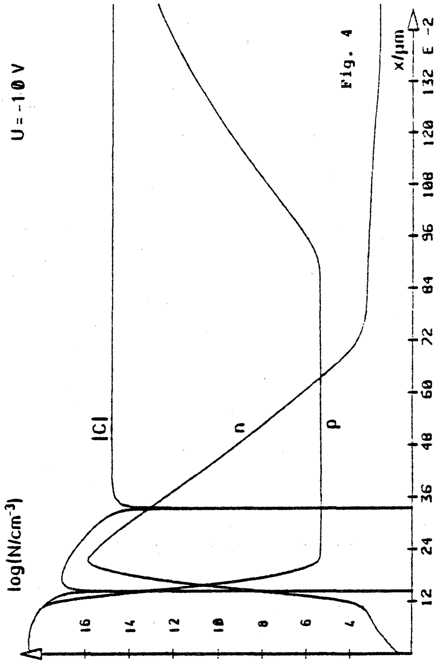

Fig. 4

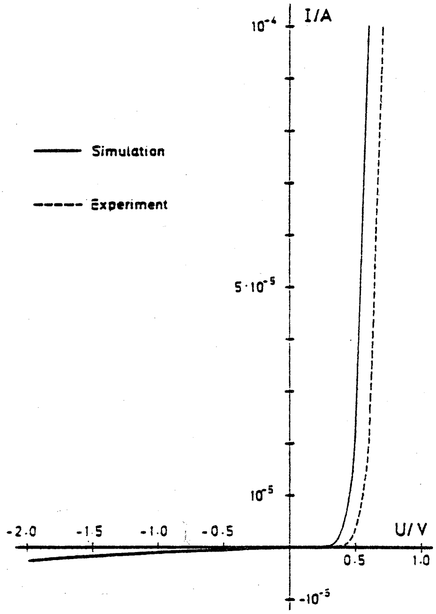

Fig. 5

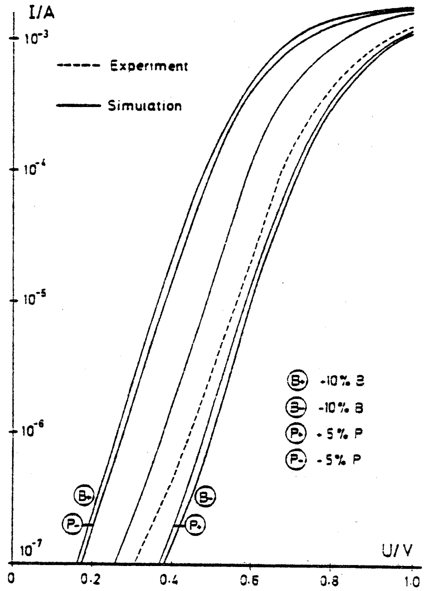

Fig. 6

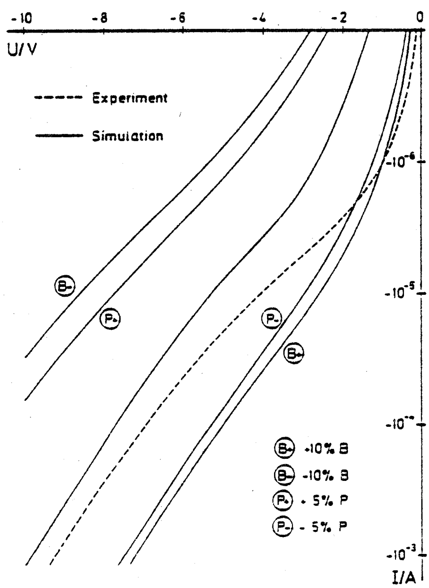

Fig. 7

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