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3D-Simulation of Single Event Upsets in a High Voltage Diode

ABSTRACT - We present the first totally self-consistent 3D-simulation of ionizing radiation caused by single event upsets in a cylindrically symmetric high voltage diode. The effects of ions entering along the symmetry axis in a moderately reverse biased operation condition are analyzed. The results of the simulations are based on a totally self-consistent solution of the three basic semiconductor equations by the transient device simulator BAMBI. The applicability of 2D-simulations as well as the influence of impact ionization are investigated.

1. Introduction

The influence of single event upsets (SEU) and radiation in semiconductor devices becomes of more and more interest especially if the devices are to operate under extreme conditions such as those in space or in nuclear plants.

SEUs occur when high energetic ions pass through sensitive parts of digital integrated circuits. By generating charge they alter the electrical behaviour of these circuits. To gain knowledge about the microscopic behaviour of single semiconductor devices measurements and experiments like laser simulations have been performed (e.g. [1]). Two-dimensional simulations (e.g. [2]) are *not* sufficient because SEUs provide inherently three-dimensional effects.

Fig. 1 shows the cross section of our cylindrically symmetric silicon diode including the doping profile which is approximated by Gaussian distribution functions. The device is capable of about 75V in backward direction. We assume the ions to enter the device along the symmetry axis generating a plasma filament of cylindrical shape. The results of the simulations are based on a totally self-consistent solution of the three basic semiconductor equations by the transient device simulator BAMBI [3].

In particular we present the time dependent generation term which is caused by the entering ion, the transient response of the device including the carrier distributions at selected moments.

2. Physical Models

A bias of 5V in backward direction is assumed for all simulations. The ions are assumed to be slowed down within 15µm depth from the surface of the device. The distribution of the plasma filament generated by the ion is assumed to be of Gaussian shape along the coordinate x perpendicular to the trace:

$$R_{Ion} = R_0 \cdot \exp\left(-\left(\frac{x}{x_0}\right)^2\right) ,$$

where x_0=5nm denotes the standard deviation, x the distance from the symmetry axis and $R_0=10^{18}s^{-1}cm^{-3}$ the "amplitude". The additional time dependent term $G(t)$ is of the following form:

$$G(t) = \frac{R_{Ion}}{\tau_a} \cdot \exp\left(\frac{t}{\tau_a}\right)$$

with τ_a=3ps. t denotes the time starting at the slow down of the ion. $G(t)$ is added to the conventional net generation which accounts for Shockley-Read-Hall generation, Auger recombination and impact ionization according to [4].

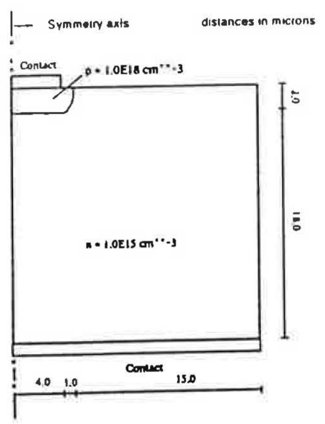

Fig. 1 Geometry of diode

3. Numerical Results

For our simulations we use a fixed space grid which is determined *a-priori* ("worst case"). The time step control is done manually since all automatic strategies will fail. Time steps are limited by 0.1ps (used within the first 20ps) and 50µs. All simulations are performed once accounting for impact ionization once neglecting it. The results are the same.

Two different calculations are performed. Once we assume that multiple ions enter the diode, suddenly this "flow"stops. This means that in the beginning of the simulation the plasma filament already exists. There is almost no space charge region at this moment since the *pn*-junction is filled with holes (short-circuit). The other simulation accounts for the effects of *one* entering ion (including the entry). The results differ from the previous simulation because additional effects occur resulting from the "switch on" of the short-circuit caused by the ion.

In Fig. 2a,b the hole concentration at t=0s with the existing electron/hole plasma (a) and the hole concentration in the undisturbed diode (b) can be seen. In Fig. 3a,b the transient responses of the diode are shown for both simulations. (a) provides a result as it is expected, but in (b) multiple changes of the sign of the current can be observed. This "oscillation" is *no* numerical artefact, this effect is caused by the peak at 1ps which stems from the maximum generation rate when the single ion stops at a depth of 15μm.

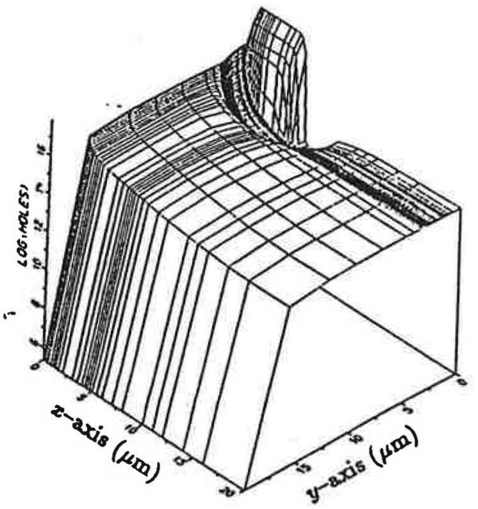

Fig. 2a Hole concentration at t=0 with plasma

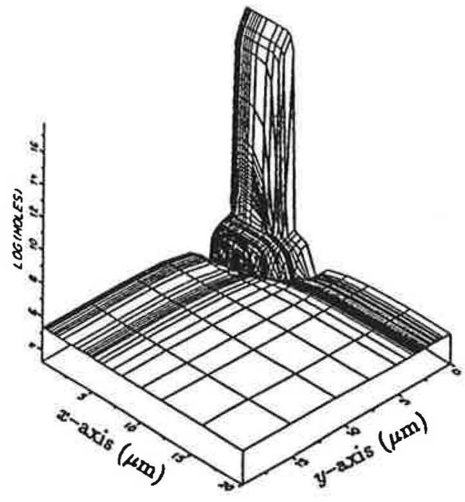

Fig. 2b Hole concentration at t=0 without plasma

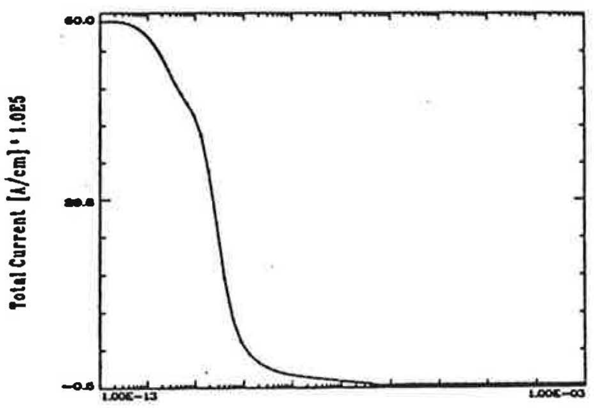

Fig. 3a Transient response of diode starting with plasma

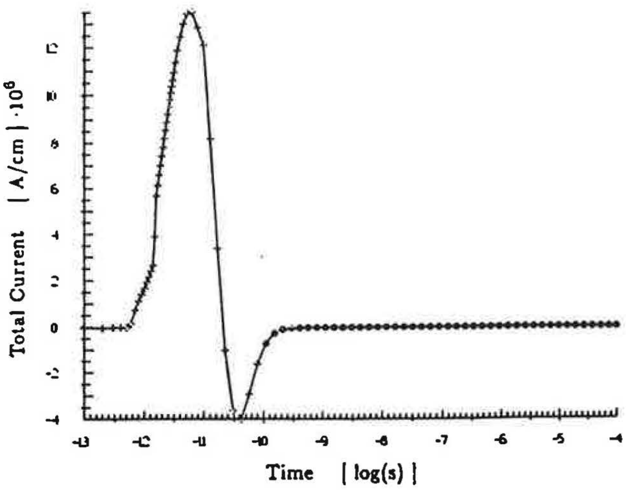

Fig. 3b Transient response of diode for single ion

Fig. 4a,b shows the hole concentrations after about 445ps ((a), multiple ions) and 325ps ((b), single ion), respectively. For the entry of multiple ions it takes about 16μs until the undisturbed condition of the diode is reestablished. If only one ion enters it takes about 6μs. The difference results from the different amount of electrons and holes which have to recombine. The longest lasting part of the current consists of hole current. It cannot be seen in Fig. 4 due to the large scale.

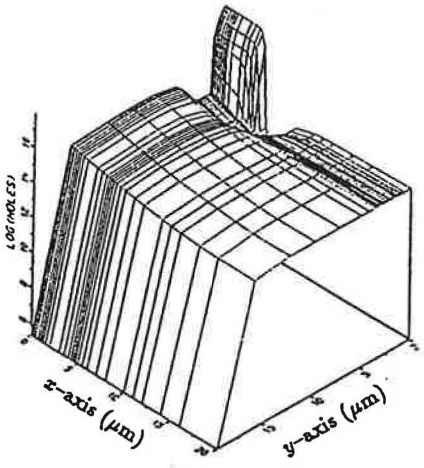

Fig. 4a Hole concentration after 445ps starting with plasma

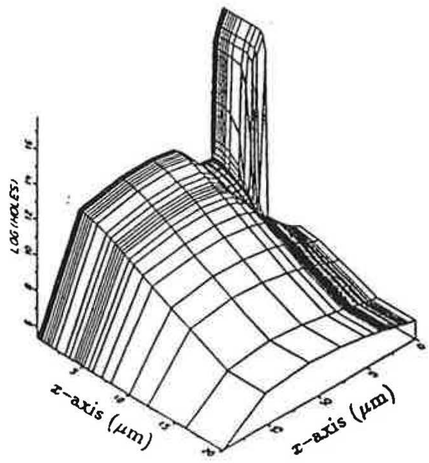

Fig. 4b Hole concentration after 325ps for single ion

4. Conclusion

By our simulations we point out that 3D-simulations are absolutely necessary and that the neglection of one dimension gives not only quantitatively but also qualitatively completely different results. Furthermore it can be shown that the influence of impact ionization is negligible. For the investigation of radiation effects caused by SEUs the simulation results must be judged very carefully since the numerical methods come very close to their limits and new physical effects must be taken into account which are not *a-priori* included in today's state-of-the-art approaches.

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References

[1] Buchner, S.P. et al.; "Laser simulation of SEUs", *IEEE Trans. Nuclear Science*, NS-34, No. 6, pp. 1228-1233 (1987)

[2] Anderson, W.T. et al.; "Experimental and theoretical study of alpha particle induced charge collection in GaAs FETs", *IEEE Trans. Nuclear Science*, NS-34, No. 6, pp. 1326-1331 (1987)

[3] Franz, A.F. et al.; *BAMBI 21. User's Guide*,Technical University Vienna, 1989

[4] van Overstraeten, R. et al; "Measurement of the ionisation rates in diffused silicon p-n junctions", *Solid-State Electronics*,Vol. 13, pp. 583-608 (1970)