Edge Effects and Tilt Dependency of Heavy Ion SEE Characterization In PN junctions

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Abstract—**Tilted irradiations are commonly used during Single Event Effect (SEE) characterization, since this method generally gives reliable results. However, recent works have shown an unexpected behavior for some devices: instead of increasing, the cross section decreases when the device is tilted for a given ion and energy. This phenomenon has been observed for digital as well as for analog circuits. This paper tries to understand the phenomena and link simulation results with experimental data obtained on PN junctions.**

I. Introduction

During Single Event Effect (SEE) characterization using heavy ions, a standard way to increase the number of data point is to tilt the device under test at different angles with respect to the beam axis. For some devices, this method leads to unexpected behavior; instead of increasing the cross section decreases when the device is tilted for a given ion and energy.

This phenomenon has been observed for digital as well as for analog circuits (cf. e.g. recent ESA test results on LM139, UC17073, UC1848 and RH1078 among others) [1].

This paper tries to understand this phenomenon and compare computer simulations with heavy ion beam irradiation data obtained on PN junctions.

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II. Test Structures

Since the unexpected SEE tilt effects were reported for components produced with recent IC processes, we focused our work on the charge collection in silicon devices with rather low junction depth and high substrate doping.

Simple PN test structures are best suited to determine the beam deposited charge under different test conditions and incident beam angles (i.e. tilt parameters). This data is required for reference and data correction purposes on actual device types.

For that purpose, a set of diode based test structures has been defined consisting in an array of diodes with different known topologies, i.e. areas, perimeters and junction depths, in order to allow a clear separation of the impacts in bottom and sidewall areas on the irradiation results.

Minimum dimension has been chosen equal to 6 µm, maximum equal to 100 µm and the junction depths equal to about 1 µm.

A number of technological simulations have been carried out with Silvaco ATHENA/ATLAS two-dimensional simulators, in order to optimize the simplest and most adequate complete process definition for our purpose. Schematically, the process consists in the following steps.

1 - Initial P type wafer ($N_A = 10^{15}$ cm^{-3}).
- Wet oxide growth (4500 Å).

2. - Open windows in implantation zones.
- Implant N+. Dose = 10^{15} cm^{-2}. Energy ≈ 100 keV in function of desired junction depth.

3. - Open windows for contacts to implanted zones.
- Aluminum deposition.

4. - Aluminum etch for interconnect definitions.
- Oxide deposition for passivation.
- Open PAD contacts (for bonding) and back contact metallization.

The layout of the diode photolithographic masks has been designed on CADENCE. To obtain the dependence of charge recollection on the diode topological shape, the mask consists in an array of rectangular diodes with different lengths and widths as shown in figure 1. 16 different diode sizes were designed, ranging form 6 X 6 μm up to 100 X 100 μm. This array was repeated 49 times per wafer.

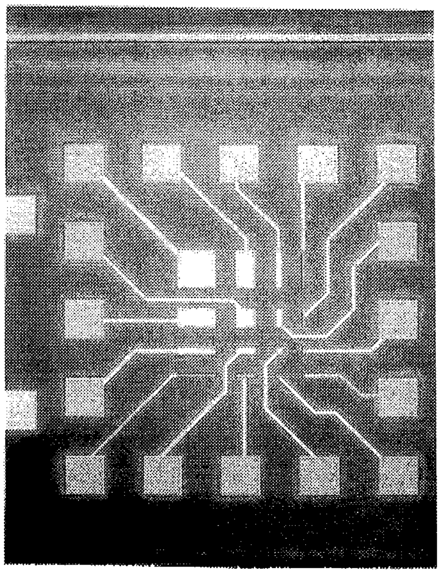

Fig 1 Fabricated diode array photography

III. Simulation Results

A complete set of simulations using ATLAS has been made for the 8 μm wide structure.

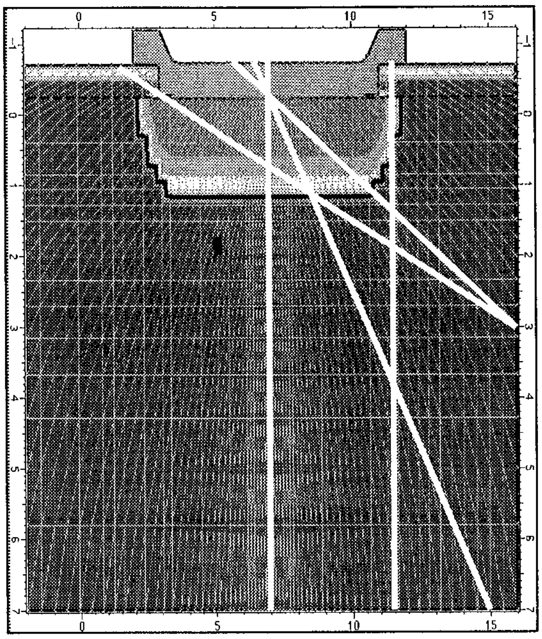

Fig 2 Meshing for the 8 X 2 μm and ion tracks

Figure 2 presents the structure meshing and the different ion tracks. The lateral extension of the Si substrate on the sides of the device edge is limited to mimic the effect of now conventional deep trench isolation. As can be seen, we have chosen to strike the diode in the middle, on the edge and at three different angles (30°, 50° and 60°).

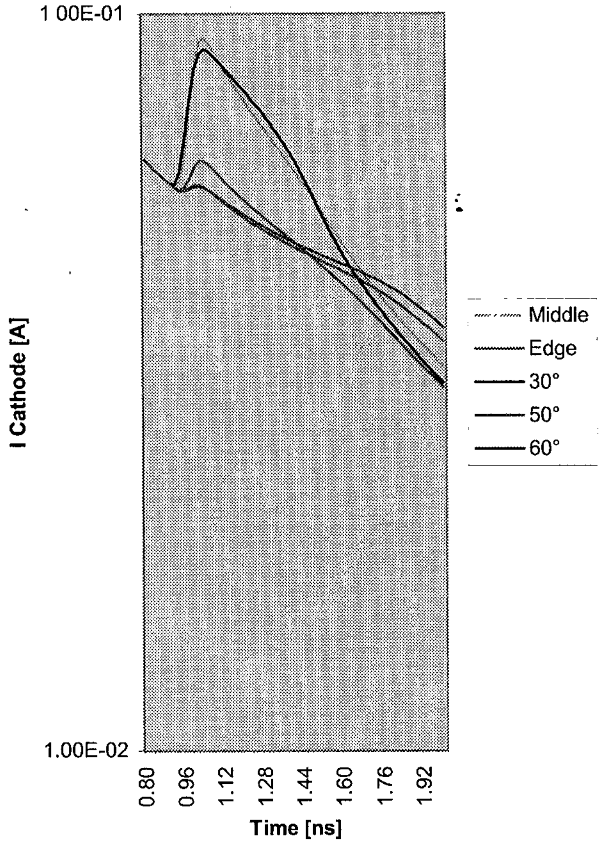

Fig 3 Angular effect on the cathode current

Figure 3 presents the simulation results using a Xe beam with the same energy as planned for the experiment, i.e. equal to 459 MeV. These simulations were performed for a 3V reverse bias. Entry points can be seen on figure2. It is clearly shown that the current peak is much higher in the middle of the diode more than on the edge. Furthermore, for tilted irradiation conditions, the peak value decreases for increasing angle.

Figure 4 presents simulation results for a normal incidence ion strike and zero bias. Impacts start in the middle of the diode (X = 7 μm) and are shifted toward the edge. The peak current amplitude is maximum and remains almost constant in the central part of the diode, then decreases below half of the maximum value when the strike enters a peripheral zone at 2 μm from the edge, still shows an amplitude of about 20% of the maximum even at 2 μm beyond the device edge and finally shows a shifted time dependence as the strike leaves the device area.

Several simulations were also carried out for a constant tilted angle but for different entry points in the structure. It was observed that the peak cathode current was much higher for an ion strike in the middle of the structure than on the edge. As it can be seen, on Fig. 5 for a 60° irradiation with entry points from left to right of the diode, the impacts present very different time characteristics. While tilted, the cathode current modification extends over a longer period of time when compared to a normal incidence impact. This may be linked to the fact that for normal incidence strikes, the pairs are generated in the same direction as the current flow, and may have a faster contribution on the cathode current; whereas when the incidence is tilted, the pairs are created at remote locations from the device main electrical field and take more time to be collected.

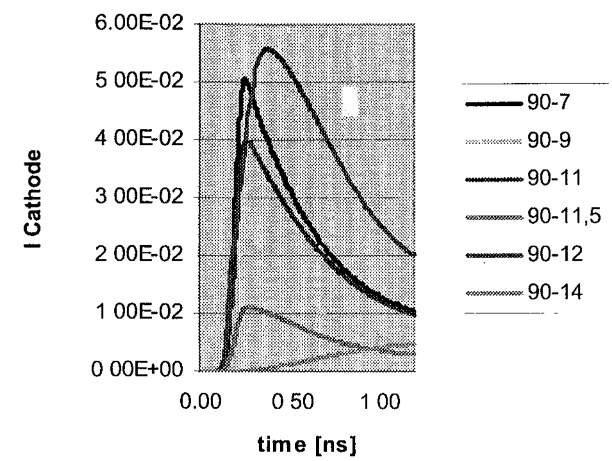

Fig 4 0° Ion strike localization effect on the cathode current
90- means a normal incidence strike,
the second vaue is the entry point localization in μm
(i.e7 in the middle and increasing values to the right)

The other consequence of the time characteristics shift is that the current peak value is lower for the tilted conditions than it is for a normal incidence.

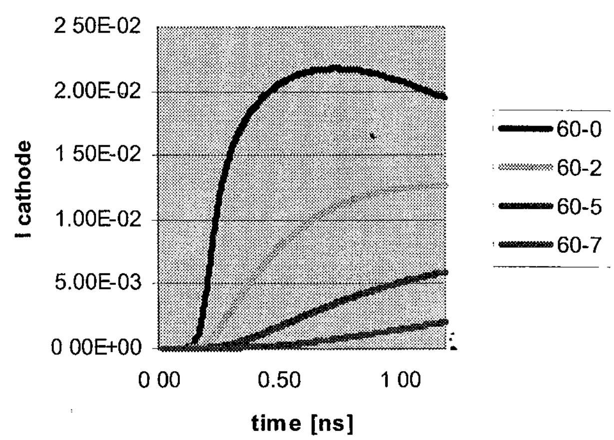

Fig 5 60° Ion strike localization effect on the cathode current
60- means a 60° impact,
the second vaue is the entry point localization in μm
(i.e. 0 on the left, 7 in the middle and
increasing values to the righ)

IV. IRRADIATION DATA

The experimental data presented here were obtained with a Xe 459 MeV beam provided by the Louvain la Neuve cyclotron and the Heavy Ion Irradiation Facility (HIF) [2,3]. During irradiation, diodes were reverse biased at 3V and connected to a charge preamplifier. A spectroscopy amplifier was used to have a suitable signal for the measure.

As can be seen on the figure 6, the oscilloscope trace of consecutive strike signals presents a large distribution of amplitudes. To monitor these amplitudes separately and have a histogram of their distribution, the amplifier output was injected in an octal discriminator with preset thresholds. The different bins have further been calibrated using a pulse generator to derive the equivalent charge.

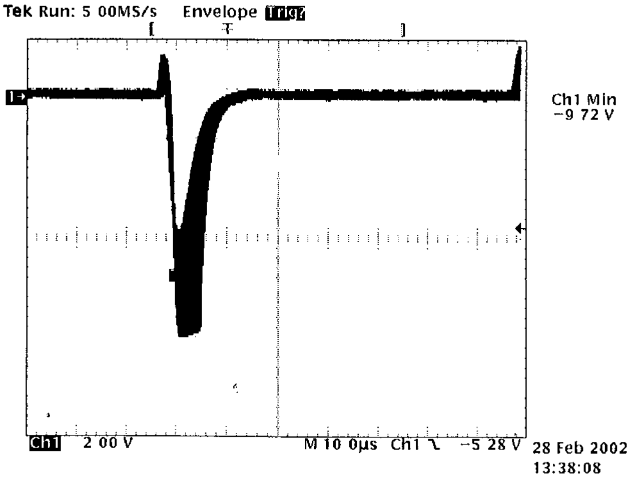

Fig 6 Amplifier output for a 100 X 100 µm diode with Xe beam at 0°.

The next two figures represent the collected charge distribution for the same structure but at different angles. Sigma values represent the number of event per bin normalized to the total number of event in all the bins.

At normal incidence (Fig. 7), most of the events occur for a collected charge of about 1 pC, which is in fair correlation with the charge computed using a 1D model and for an ion strike in the central part of the device. The number of occurrence for charges below half of the peak value accounts for less than 10 % of the total number of events, also in qualitative agreement with the area ratio, for a 100 µm x 100 µm device, between the central device zone and its peripheral zone starting at about 3 µm of the device edge, as observed in our simulations.

Furthermore, the collected charge amplitude also lowers with increasing angle while its distribution widens (fig. 8). It is also in fair agreement with simulations.

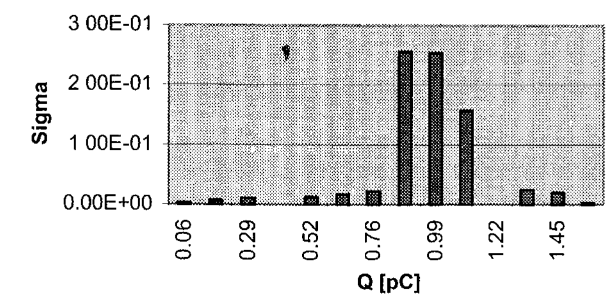

Fig 7 Amplifier output for a 100 X 100 µm diode with Xe beam at 0°

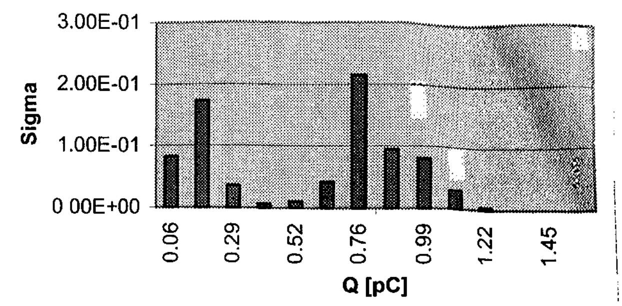

Fig 8. Amplifier output for a 100 X 100 µm diode with Xe beam at 60°

During the next irradiation period, additional data will be taken for these structures as well as other diode size. In the final paper, additional data will be presented and the simulation correlation will be more developed.

V. Conclusion

From simulations and experiments, we have demonstrated that the charge collection in PN diodes with CMOS-like low junction depth and high substrate doping decreases in amplitude and shows longer time constants when the ion strike is tilted or on the periphery of the device. We believe that these observations may intuitively explain the SEE cross-section decrease observed in recent components when tilted.

VI References

[1] R. Harboe-Sorensen, F.X. Guerre, H. Constant, J ; van Dooren, G. Berger, W. Hajdas "Single Event Transient Characterisation of Analog IC's for ESA's Satellites" 1999 RADECS proceedings, pp. 573-581

[2] G. Berger, G. Ryckewaert, R. Harboe-Sorensen, L. Adams " The Heavy Ion Irradiation Facility at CYCLONE - a dedicated SEE beam line " 1996 IEEE NSREC Workshop.

[3] G. Berger, G. Ryckewaert, R Harboe-Sorensen " CYCLONE – A Multipurpose Heavy Ion, Proton and Neutron SEE Test Site " 1997 RADECS Workshop, pp. 51-55.