Charge collection with a Microbeam : Prospect for determination of ion track profile

T. Colladant[1,2], [1]GPS Université Paris 6 – 7 (France), [2]CEA-DIF (France)
O. Musseau, V. Ferlet-Cavrois, CEA-DIF (France)
A. B. Campbell, NRL (USA)
B. Fischer, M. Schlögl, GSI (Germany)

Introduction

Single event effects (SEE's) induced by heavy-ions from cosmic-rays are a major problem for the reliability of microelectronic devices in space environment. The energy deposited by a heavy-ion through the sensitive structure of a device produces, in a very short time, a dense concentration of electron-hole pairs along the ion trajectory. Generated carriers are collected by drift (if there is a local electric field) or by diffusion over hundreds of picoseconds. Previous works showed that differences in charge collection depend on the initial ion track structure [1][2].

Codes proposed by atomic physicists for ion tracks as TRKRAD [3] or TRIPOS [4] calculate a track profile which does not take into account the carrier thermalization and the recombination in the core of the track. For actual and future device generations, the knowledge of the ion track structure becomes necessary to correctly simulate the interaction within a device which has dimensions smaller than the ion track radius.

Test structures were fabricated in order to determine experimentally the effective size of an ion track and the carrier density profile [5][6]. They consist either of Schottky-barrier junctions or PN junctions on a silicon line.

Experiments

Following this way, Schottky-barrier junction microstrips are investigated here. They are made up of three lines (0.5 µm width with a 1.5 µm pitch) connected together. Schottky-barrier junctions were processed on a Silicon On Insulator (SOI) substrate to avoid long-distance charge collection, with a 0.6 µm thick silicon film (figure 1-a).

The devices were irradiated using the GSI scanning ion microprobe with 99.6 MeV carbon ions (LET=1.44 $MeV.cm^2.mg^{-1}$ [7]). The microbeam spot diameter was 0.5 µm. All the electrodes were grounded during experiments including the metal lines via the charge preamplifier input impedance. When an ion strikes one of the lines, a charge is generated and detected by the amplifier chain. This collected charge and the coordinate of the ion strike are recorded by a multiparameter data taking system. The resulting charge collection image is shown (figure 1-b) after correction by an offset angle with respect to X and Y axis.

a) b)

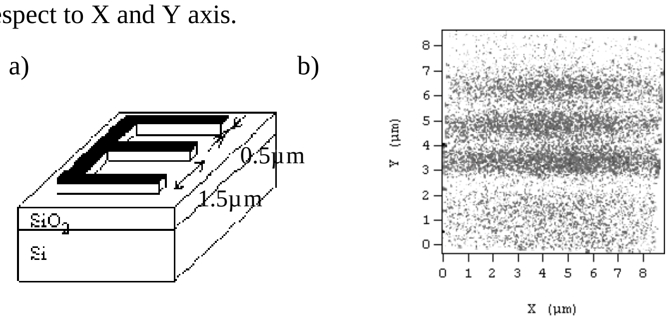

Figure 1: (a) Cross section of the tested devices,
(b) charge collection image from experimental data
(the dark area correspond to large collected charges).

Charges are collected in the Schottky-barrier junctions by drift due to the local electric field in the depletion region (thickness of about 0.13 µm) and by funneling effect. Charges collected from ion strikes outside the lines could be due to a capacitive coupling between silicon film and the substrate, and to a local electric field in the silicon near the oxide interface caused by trapped charge in the oxide from previous scanning.

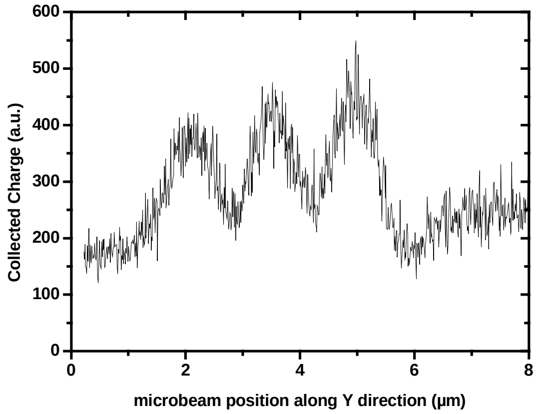

Figure 2: collected charge profile along Y direction.

An experimental charge collection profile is extracted from the charge collection image by integrating data over the X direction (figure 2).

Note that the ratio between the charge collected when the ion strikes a line and the bare SOI substrate is only 2. Thus, only the microbeam allows to extract the charge collected by lines, by rejecting the SOI substrate signal thanks to its small probing surface. This would indeed not be possible with a standard heavy ion beam.

Conclusion

The ion microbeam is the only technique which allows us to spatially measure the collected charge on Schottky-barrier junctions with a good signal to noise ratio.

With a complete understanding of the charge collection mechanisms by drift-diffusion simulations, it may be possible to correlate the charge collection on the strip with the ion track profile.

References

[1] H. Dussault et al., IEEE Trans. Nucl. Sci. NS-40, pp. 1926-1933 (1993)
[2] W. J. Stapor et al., IEEE Trans. Nucl. Sci. NS-35, 1585-1590 (1988).
[3] W. J. Stapor et al., J. Appl. Phys. 64, pp. 4430-4434 (1988).
[4] R. C. Martin et al., Physica Status Solidi A 104, pp. 743-754 (1987).
[5] J. W. Howard et al., IEEE Trans. Nucl. Sci. NS-41, pp. 2077-2084 (1994).
[6] O. Musseau et al., IEEE Trans. Nucl. Sci. NS-45, pp. 2563-2570 (1998).
[7] J.F. Ziegler et al, SRIM-2000.10, 1999 IBM Co.