Impact of Heavy Ions Singular Effects on Electronic Components Embarked in a Spatial Environment

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Abstract:
The electronics devices functioning in hostile surroundings can undergo, besides failing owed to the normal ageing of components deteriorations provoked by the environment in which they are used. The interaction of particles met in irradiative environment with the constituent materials of a integrated circuit can mislead failing disrupting the functionality of this one, or even driving to its destruction. The survey of radiation effects on the integrated circuits and in particular the effect of latchup has therefore for stake the electronic system reliability submitted to an irradiation. The objective of this work will be focalised on the survey of the induced latchup phenomenon in the embarked components.

Keywords: *ionizing radiations, heavy ions, singular events, SEL (Single Event Latchup), Integrated circuits.*

I. INTRODUCTION

Systems embarked in the space, electronics close to nuclear explosions or bundles in accelerators of particles, robots of intervention in the nuclear power stations and in nuclear garbage processing plants are submitted to radiations. Radiance interacts with materials constituting the electronic components, provoking defects whose nature depends on the particle type present in their environment.

Radiations effects on the electronic components can be diffuse, the most often owed to the integrated dose created by the light particles (protons, electrons) either localized, due to singular effects produced by the heavy particles of strong energy.

In its whole this survey aims, for a given system and environment, to determine the possible failing mechanisms, to value their probability and, so necessary, to propose solutions permitting to guarantee a certain level of reliability of the system in question. The integrated circuit test is an essential phase to each of these stages.

II. THE SPATIAL RADIATIING ENVIRONMENT

In a radiating middle the behavior of an electronic component depends notably on the nature and the flux of the incidental radiance. The spatial domain is certainly most complex and most coercive concerning integrated circuit reliability. The large variety of particles and the almost inaccessibility of systems during their mission contributes to make of the specification a crucial stage. The complexity of the spatial environment occurs because it includes four components that interact between themselves and with the earth magnetosphere [1].

Belts of radiations: They are constituted of light loaded particles trapped in the terrestrial magnetosphere. One essentially distinguishes an internal belt and an external belt of protons and electrons. Their energy is between a few score of KeV and several hundreds of MeV, with fluxes localized in the belt reaching 109/protons/m^2/s. Among particles trapped in the magnetosphere the weakly ionized heavy ions have been also discovered.

The cosmic radiance: the cosmic rays are the very energizing loaded particles coming from outside of the solar system. They are constituted mainly of protons, particles and all elements having an atomic number between 1 and 92. Their flux is very weak but being constituted of highly energizing particles (several hundred of GeV). They have important courses in the matter; they can cross armors and even satellites.

The solar wind: composed mainly of protons and electrons of low energy (few KeV). These particles are not susceptible to mislead disruptions in the embarked components, they can be however the origin of working anomalies of the electronic systems when some electrostatic discharges occur at the level of coatings of satellites thermal control [2].

The solar eruptions: they can be two types. The rich in protons eruptions that have a spectrum of energy reaching about hundred MeV and the heavy ions solar eruptions that have a spectrum in energy from a few hundreds of MeV. If the spectrum is less hard here than for the cosmic rays, the flux of ions can be on the other hand 100 to 1000 times more important.

III. SEMI CONDUCTOR INTERACTION PARTICLES

Natural particles interacting with the integrated circuits are essentially photons, electrons, protons and the heavy ions. We propose to briefly describe the way how these particles act on materials composing the integrated circuits.

a) Interaction with loaded particles

It is about protons; alpha particles and ions. The more the particles have a mass and an important energy, the more they provoke damages. The protons are proved to have an insufficient ionizing power to cause some direct effects but they can produce some nuclear interactions while interacting with the met cores. The charged particles (ions and α particles are most dangerous; they are responsible for single event phenomenon (SEP) such as latch-up (SEL) and the single event upset (SEU).

b) Interaction with neutrons

The neutrons don't produce in a direct way SEP because they are electrically neutral. However, they have some important indirect effects. The neutron is a particle having a mass, but no electrical charge it can be neither decelerated or stopped except during a collision, some different phenomena can occur; phenomena whose consequence are the distortion of the material network with atoms that leave the crystalline stitch, secondary emission of rays or alpha particles according to the incidental energy of the neutron [3]. It was only in 1992 that the first SEP owed to neutrons has been observed in the SRAM memories.

IV. RADIATION EFFECTS ON THE ELECTRONIC COMPONENTS

The exposition of integrated circuits to radiations provokes different phenomena, can drag anomalies whose gravity depends on the type of incidental radiance and the type of exposed circuit and conception technology (bipolar, CMOS,…). Among radiations those having a high energy can act on atoms or molecules constituting the matter of equipment embarked on board of spatial vehicles [4]. This action appears, in the case of the integrated circuits, by two types of phenomena: accumulated dose effects owed mainly to the light particles and singular events by a local deposit of energy due to the ionization all along the course of a heavy ion (creation of electron – hole pairs).

a) The dose effect

The dose effect owed to the weakly energizing light particles is an accumulation of charges at the level of oxides and interfaces in the components. It results some effects as the reduction of the carrier mobility and the creation of a parasitic electric field. In the case of MOS technology it results in displacements of the threshold voltages, leakage currents and a less good immunity to the noise. The analogical components are not or are rarely used in an irradiative environment, because a weak energy deposit can roughly modify their behavior. Hence in the case of the numeric components, dose effects lead to permanent parametric drifts that limit the life duration of the component or sometimes the systems of the component. These effects can be minimized by armor (protection by a leaf of aluminum) and by the suitable technology (Hardening). In the case of devices in a spatial environment, we make sure that the components life duration is superior to the mission life. Dose effects are not then critical for its entire success.

b) The singular events :

The singular effects, regrouped under the SEP acronym (Single Event Phenomena), correspond to phenomena triggered by the passage of unique particle. The most often, it is about charged and greatly energizing particles, as the heavy ions or the energizing protons. One can distinguish two singular effect classes, the transient shortcomings defects or software errors (SEU) and the permanent deteriorations or material errors (SALT).

1) The phenomenon of single event Upset (SEU) corresponds to the change of logical state of a memory point following the passage of a unique particle. This accidental change of logical level in a memory is reversible (the point memory will be able to be corrected by the normal writing process) and doesn't lead to the destruction of the component. In a general manner all electronic component processing points of memorization is sensitive to the SEU [5].

2) The phenomenon of Single Event Latchup (SEL) is due to the stake in involuntary conduction of a succession of PNPN junctions forming a parasitic thyristor between the supply and the ground. The parasitic thyristor starting point causes a short circuit between the supply and the ground of the integrated circuit that can be destructive. Its survey is the object of this article [6]

V. LATCHUP PHENOMENON

A Single Event Latchup is the stake in conduction of a parasitic thyristor (PNPN structure) present in all CMOS integrated circuits [1] [7] [8], as shown on the figure 1.

A transient current impulse produced by the impact of heavy particle can start the stake in conduction of such a parasitic thyristor that is inactive in normal condition. The latchup creates a path of a direct parasitic conduction between the ground and the supply and therefore, causes an important supplementary warming-up in the circuit and drags a strong increase in the power consumption. The generated short circuit can lead to the circuit damage if the supply current is not controlled. The disabling of this effect generally passes by a power cut and leads to the circuit reset [9].

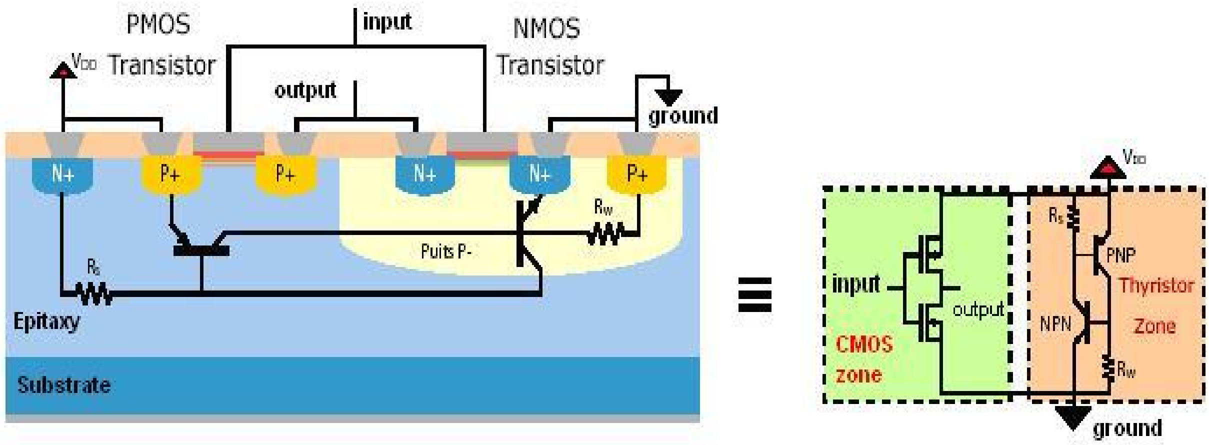

Fig. 1 : Phenomenon of latchup in the integrated circuits.

The latchup phenomenon plays a very important role especially for the spatial systems. The technological evolution increases the sensitivity to the latchup in the future integrated circuits and the phenomenon proves to be more and more bothersome in weak supply and consumption circuits.

Sometimes, the latchup phenomenon can entail weak change of current consumption in circuits. Then, the logical tests or the I_{DDQ} tests cannot detect them because the circuit presents neither errors nor detectable errors in a current test.

VI. MEANS OF ACTION FACING PARTICLE EFFECTS

A means to face radiations risks consists in minimizing the probability of effect apparition. Considering the gravity of heavy ion effects on electronics, means of action facing radiations prove to be necessary. We distinguish the means of prevention and the means of forecasting.

a) Means of prevention

Numerous techniques have been developed to limit the sensitivity of components to the different effects of radiations or to attenuate the impact of failings on the global working of a system. One can distinguish techniques of "hardening" according to the level to which they intervene.

At an initial level, the semiconductor technologies on insulator (Silicon On Insulator: SOI) permit to limit the volume of particle-semiconductor interaction, and therefore the quantity of collected charges. In the GaAs technologies, the low temperature growth (Low temperature GaAs: LTGaAs) permits to limit the life generated carriers duration.

“At the level of the mask drawing (layout), one can mention rings notably issued from protections to the Latchup, as well as closed transistors "edgeless ".

“At the circuit level, numerous original solutions have been proposed, notably for the hardening static or dynamic memories cells.

“At last, at the level system, we noted the presence of control circuits devoted to current supply where the processor data flow (watchdogs) and embarked error detection and correction codes permit to a certain extent, to re-establish the corrupted data [10].

b) Means of Forecasting

All means of prevention previously quoted don't permit a total immunity to face the SEP and in particular latchups. A means to assure an optimal working and life duration in a spatial mission is to take the maximal protective precautions. For this purpose, tests on soil and a prediction calculation are necessary. Once a component characterized, it is then possible to eliminate it if it is too appreciable or to foresee the adequate actions (watchdog timer, periodic reset) in order to decrease risks in orbit.

A statistical survey on integrated circuits failings, caused by radiations, permits to clear up information concerning the circuit reliability in a determined irradiative environment. However, predictive assessment of reliability (i.e the specification) of a system requires the knowledge of the indicatory parameters of the sensitivity to the SEE of used circuits. The experimental characterization has for objective to define and to measure these parameters.

The cost of SEL experimental tests is extremely high and is to be added to the non negligible cost of the manufacture test components. Besides, the commercial applications cannot allow a very elevated cost of conception and technological processes. Other precautions must be therefore taken in account at the system level. Therefore, it is necessary to be able to value the sensitivity of a circuit to the system and to decide the necessary protective level not to increase the cost of the unjustified way. For that, to make simulations of the impact of an energizing particle with prediction calculations are necessary. Once a circuit or a component is characterized, it becomes possible either to eliminate it, or foresee the adequate actions to decrease risks when these systems work in the space or in risky environments.

c) Means of latchup simulation

The latchup simulation on soil, also called “heavy ion tests” consists in exposing the circuit to characterize to a radiance that may be as representative as possible to the one that it will meet during its final use (spatial mission). The assessment under irradiative ambiance of the integrated circuit behavior raises different problems. The first is the reproduction of the spatial environment by a bundle of particles (heavy ions, electrons, protons) similar to the one met in the space. It is also necessary to develop an electronic environment making the interface between the circuit under test and the outside world during its irradiation and collecting the results, it is about the test system. Finally, a test strategy intended to value the component sensitivity must be developed [11].

The goal of such tests is to get the sensitivity characterization of facing latchups of the studied circuits and this for different LET values, in order to determine the efficient section curve.

The measure of the efficient section is worked out while controlling the parameters of experience that are conditions of irradiation and the electric parameters of the circuit. The LET is the only parameter of the ion conditioning the answer of the circuit [12]. We measure the efficient section therefore for several values of the LET, obtained while changing the energy and the type of ions (as well as the incidence angle) [3].

The experimental points are generally adjusted by a Weibull distribution of the shape:

$$\sigma(LET) = \sigma_0 \left(1 - Exp\left((LET - L_0)/W\right)^S\right)$$

The figure.2 shows the latchup section efficient according to the LET for the LCA200K Gâte Array.

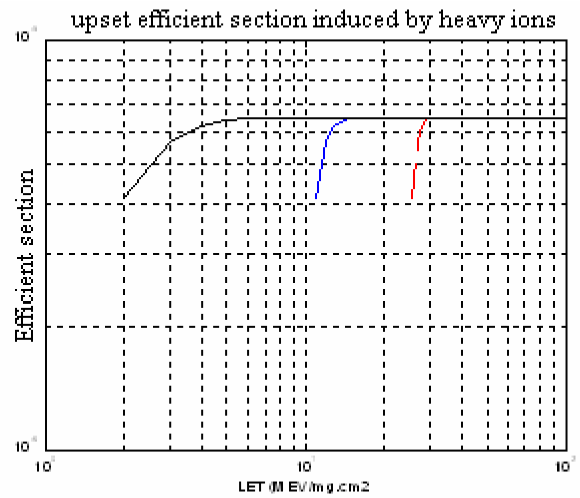

Fig.2: the efficient section of latchup according to the LET for the LCA200K Gate Array

The generated charge by an ion to normal impact (incidence) in a volume of d depth is given by: $Q_n = L \cdot d$ (1)

Where L is the LET and is expressed in charge by unit of length. In the general case of an incidental ion with an angle α, the ion deposits a charge. In order to get a shape similar to (1), we define the efficient LET:

$$L_{eff} = L/\cos\theta \quad (2)$$

Such as:

$$Q_n = L_{eff} \cdot d \quad (3)$$

Thus, if we suppose that the sensitivity of a circuit is only function of the quantity of load generated on a certain depth, we can increase the LET "seen" by the circuit while inclining it with respect to the incidental bundle. This method is frequently used to increase the number of accessible LET values without increasing the number of used ion - energy couples (Z_i, E_i). The used angles spread fluently until 60°.

The use of efficient LET to plot the curve σ (LET) appears hazardous. However, according to Koga, [13] this practice should be proscribed for the greatly integrated circuits. Some numeric simulations showed indeed that the dependence of the LET threshold according to the angle could not be resumed to a simple law in 1/cosθ for the angles superior to 30°. The obtained points for too important angles can introduce discontinuities in the efficient section curve. They must then be corrected via an advanced modeling, or to be estimated at the time of the curve exploitation process. The increase of the crossed superior layer thickness withy the impact (incidence) angle constitutes a supplementary source of uncertainty associated to use the efficient LET.

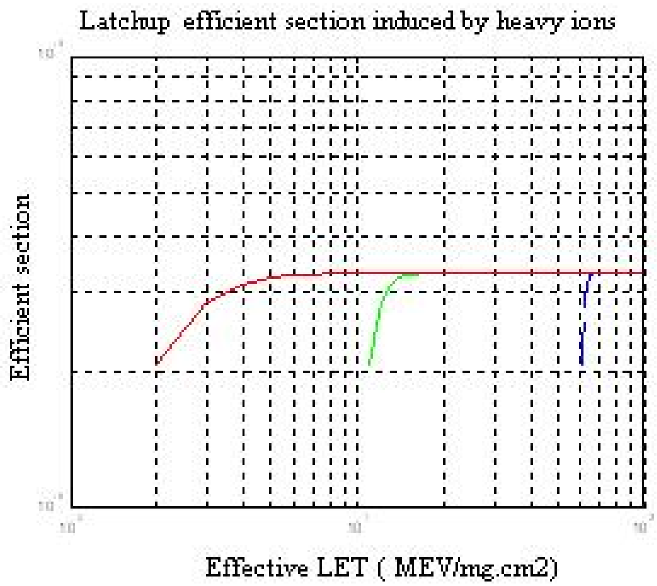

Fig.3: Latch-up efficient section according to the effective LET for the 128 Mb SDRAM Samsung

Besides the efficient LET method, the survey of the angular dependence of a circuit sensitivity permits a finer modeling of failing mechanisms.

VII. CONCLUSION

Radiations are present in the spatial environment and are essentially owed to two types of particles: the heavy particles and the light particles. They interact with the embarked electronic components and can lead, under some conditions, to their functional failings. They result particularly from the accumulated dose and from the singular effects of the heavy ions and can be catastrophic on the whole system, notably if the part of the system effected by particles is vital (control system for example).They require to study the different means of actions, at the level of components or at the system level, permitting to face radiance effects.

Two techniques are used, the prevention and the forecasting, the first consists to minimize the probability of apparition of these effects while the second consists in calculating the errors rate of satellite components in spatial missions, from a simulation on soil (test to the heavy ions) and of a means of prediction calculation. Tests to the heavy ions require handling means of irradiative environment simulation, test systems permitting to interface the circuit under test as well as the intended test strategies to determine its sensitivity.

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