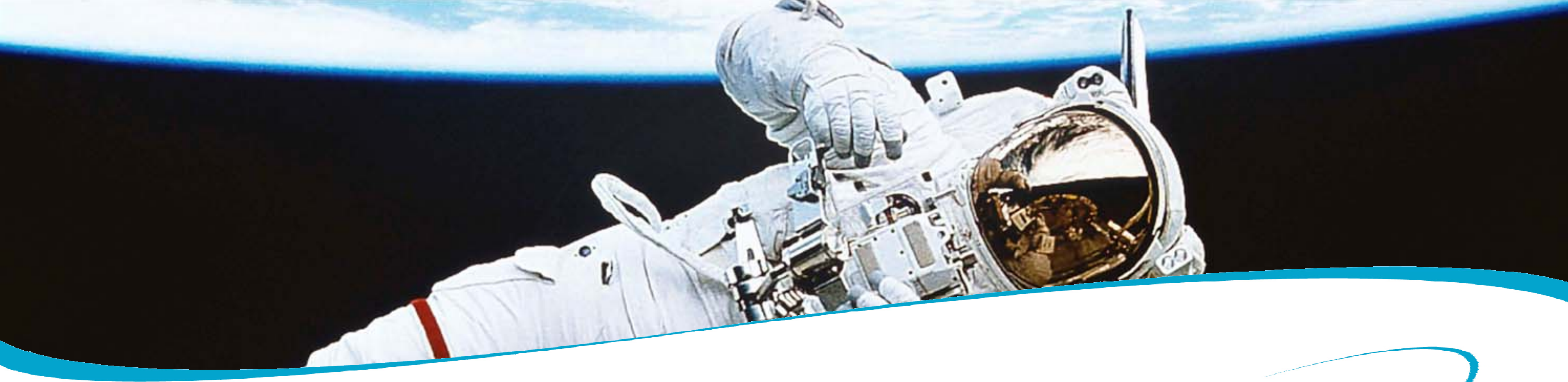


Methodology to predict the SEE rate in Vertical MOSFET with Deep Charge Collection

QCA days – January 28th 2009 – PSI – Villigen

Ronan Marec, Philippe Calvel and Michel Mélotte

Outline

1. Introduction
2. How to explain surprising experimental results . . . !
3. A proposal for a reliability calculation method
4. Equivalent LET module available in OMERE
5. Conclusion

Introduction

- This work has been done under CNES Contract :
  - R&T CNES 2006 MT3-024

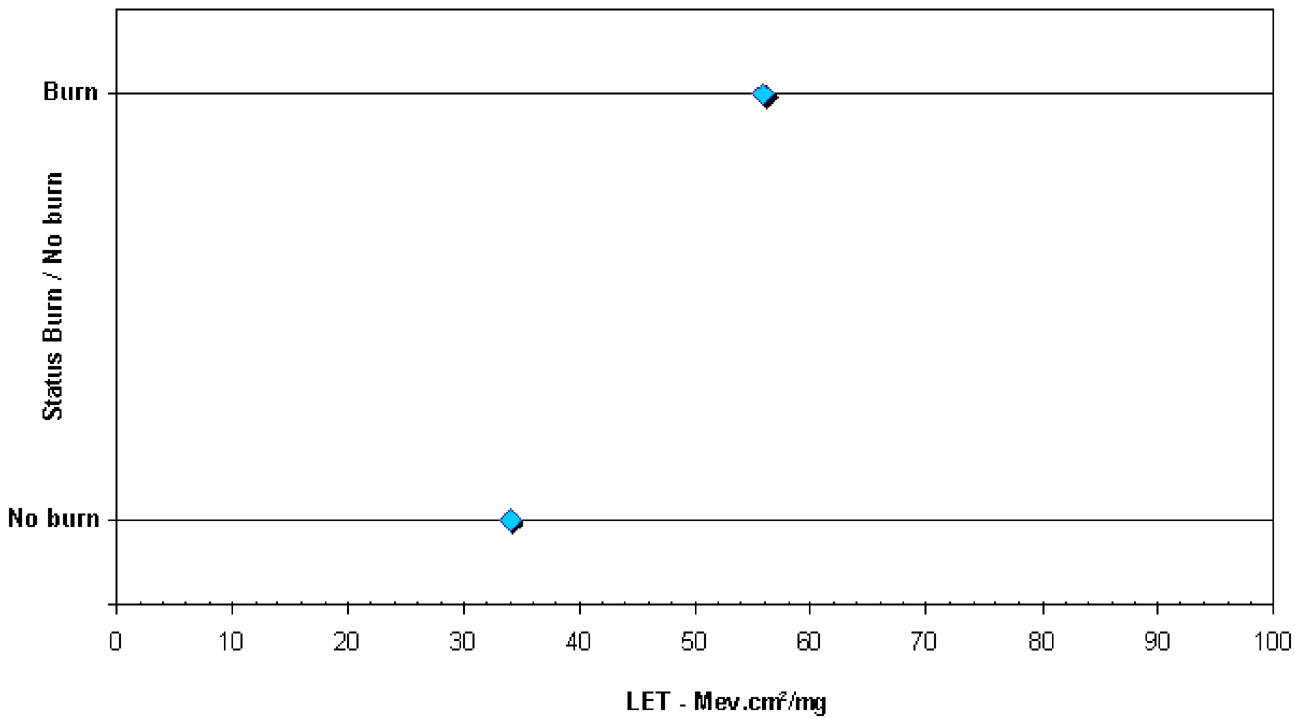
- Continuation of the work presented by Michel Mélotte at Worshop in 2007
  - “Lesson Learned in MOSFET Burn-out Test”

The result & the surprise

Heavy ions Testing performed on IRFC360 from International Rectifier

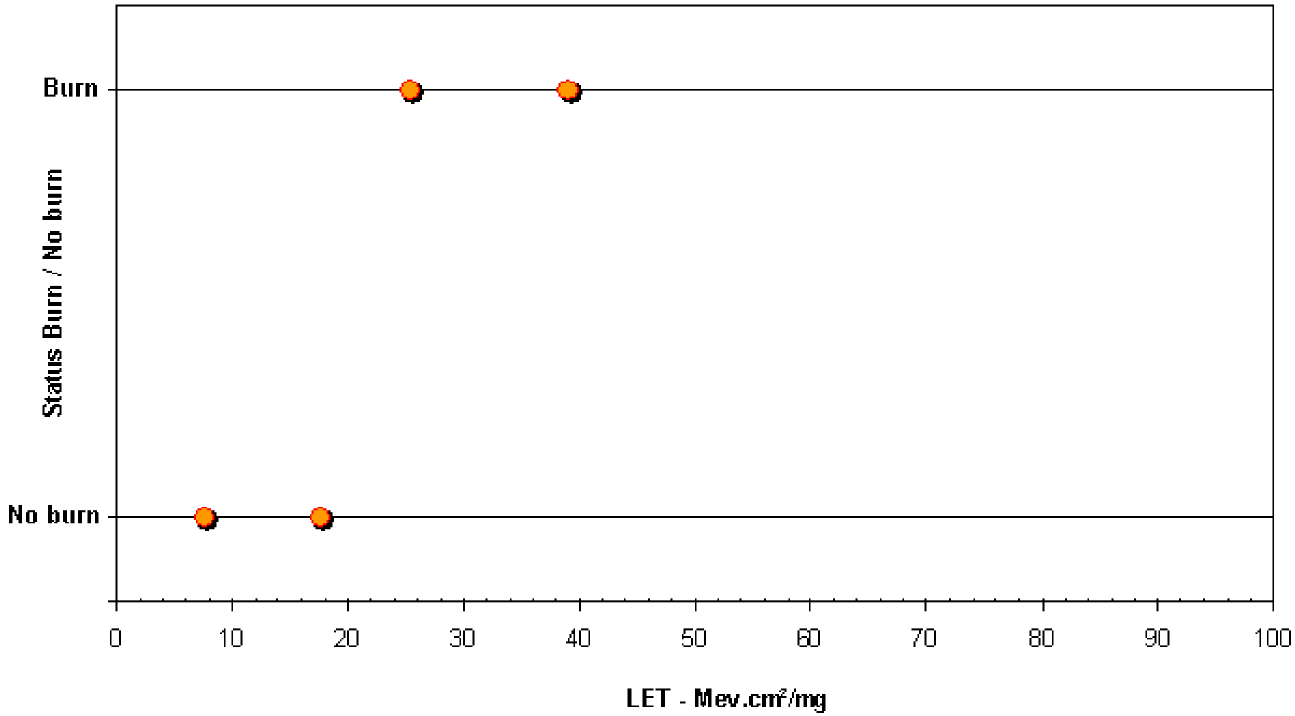
- Sensitive to SEB

A first campaign done at HIF facility . . .



The result & the surprise

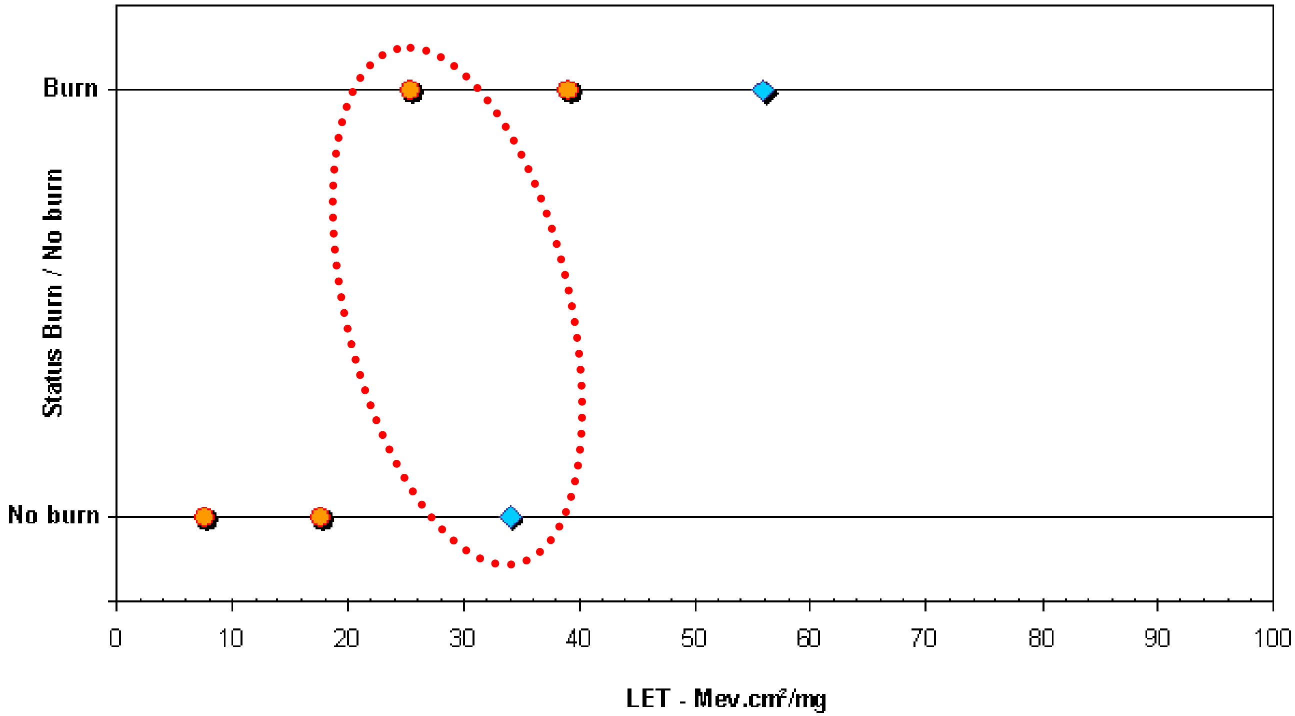
A second campaign done at TAMU facility . . .



Ref : SEE rate prediction

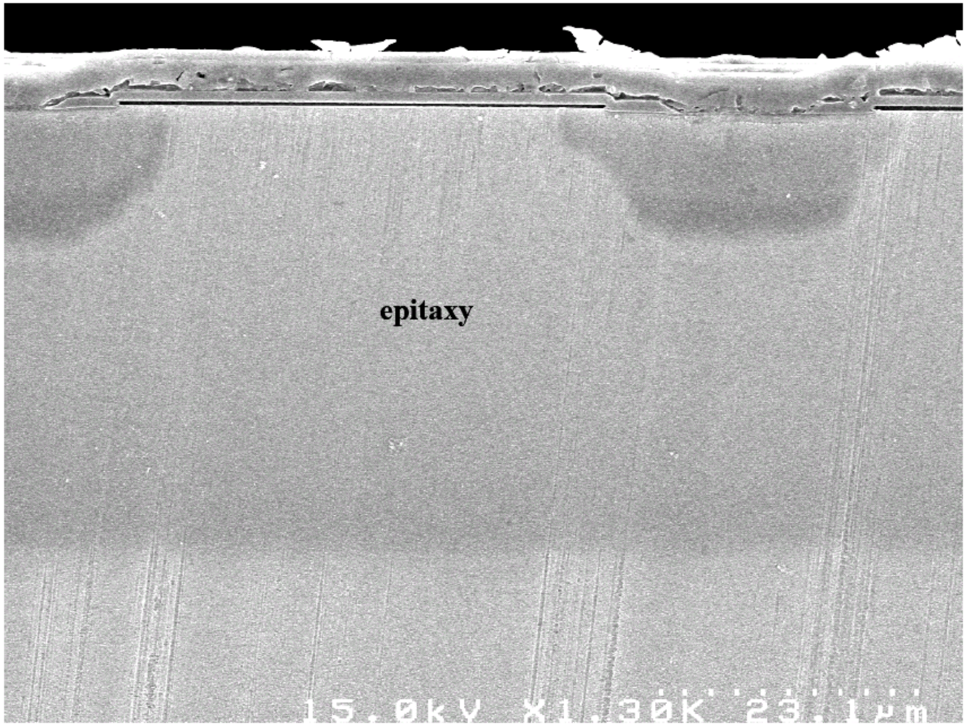
Date : January, 28th 2009.

The global results seems illogical !



The key : The active zone is deep !

- 5 µm for SiO2 and Al
- 39 µm for epitaxial Si
  (n doped)
- Then let consider the LET evolution within the active zone as previously published in IEEE TNS (Stassinopoulos, Titus, Wheatley…)



How to Explain . . . !

1 – LET provided by cyclotron administrator at the device surface is not appropriate parameter to express the level of sensitivity

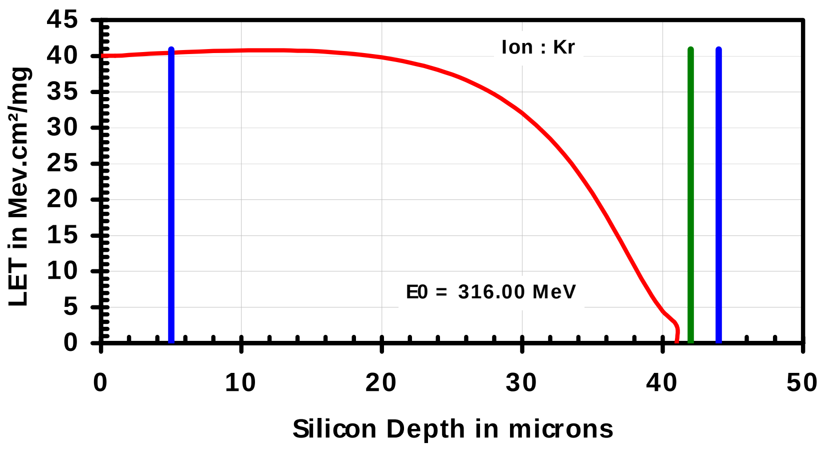
2 – SEB/SEGR sensitivity depends on :

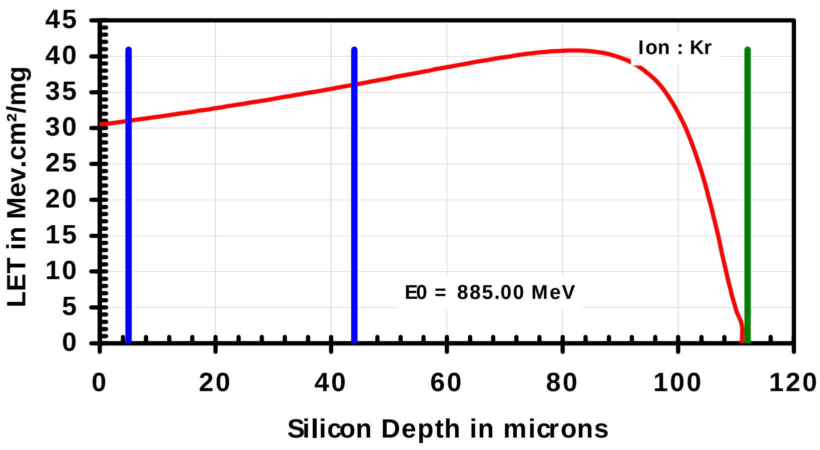
- ion beam energy (type of ion, energy)
- depth and the thickness of the sensitive area (need technological information on the device under test)
- total charge deposited (collected would be better) in the “sensitive” area

=> Need to calculate the deposited charge

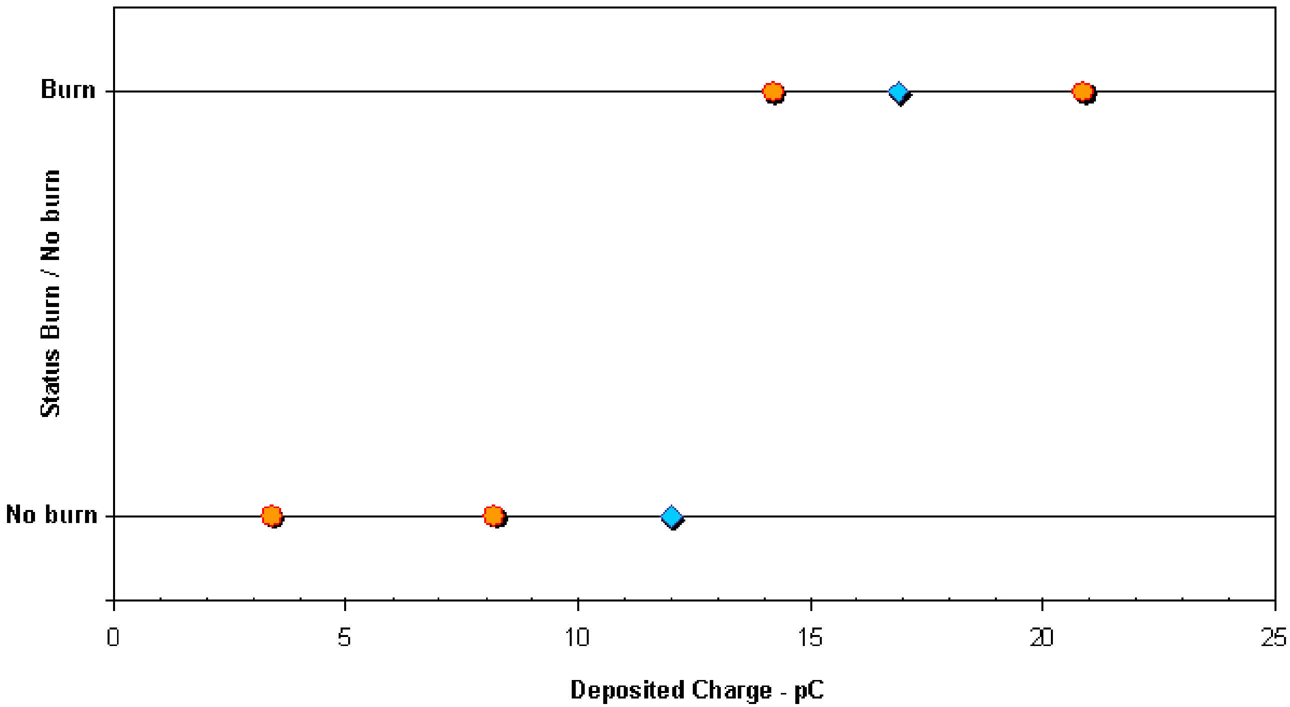
Calculation of the charge deposited

- Cyclotron : UCL vs TAMU
- Energy : Kr 316 MeV vs Kr 885 MeV
- LET : 40 MeV.cm²/mg vs 30.6 MeV.cm²/mg
- Deposited charge : 12.0 pC vs 13.1 pC

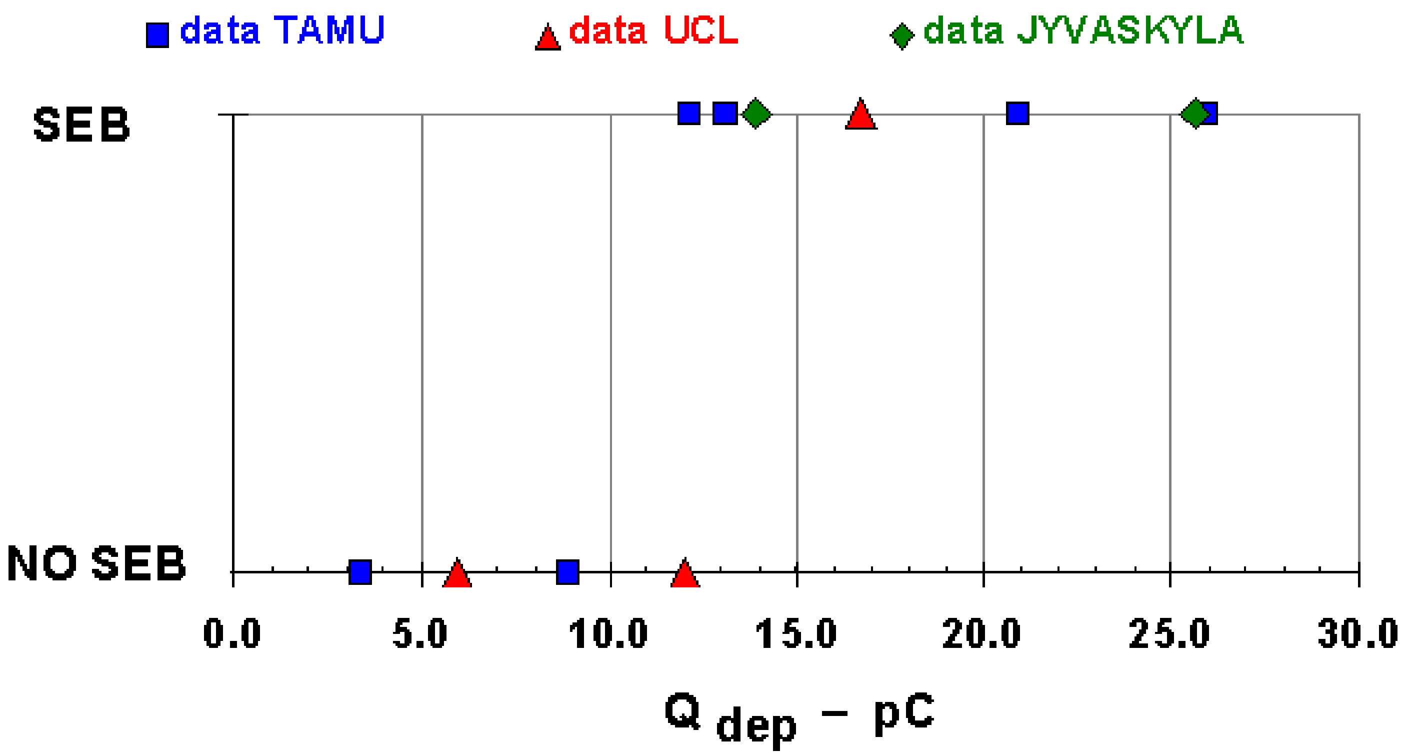




Everything is now logical !



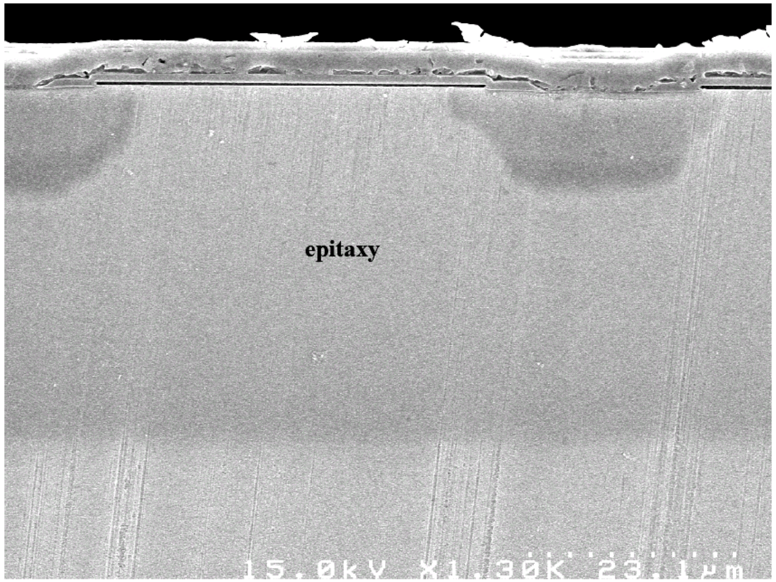
And confirmation with a third machine and an other device



Step 1 : To identify the depth and thickness of the sensitive area

To identify the nature of material and thicknesses of the different layers. In particular, the width of the epitaxial layer.

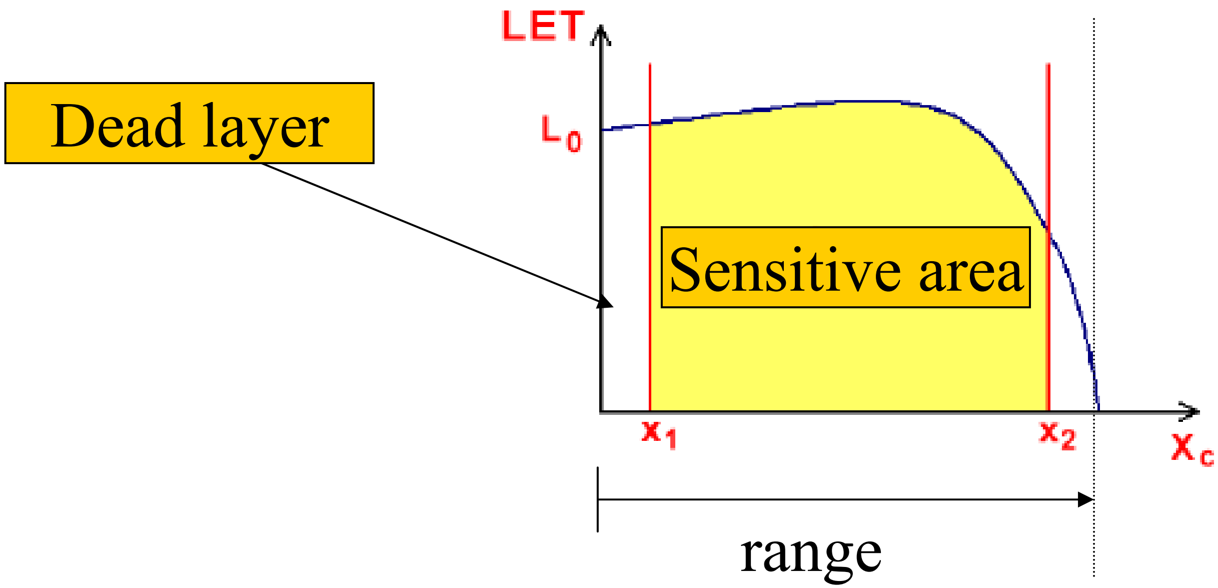
But also the number of sensitive cells and the die size.



- For IRFC360
  - Made of 42000 elementary cells
  - Die size is 0.558 cm^2
- Thickness of dead layer :
  - 5 µm for SiO2 and Al
  - 39 µm for epitaxial Si (n doped) Epitaxi
- The sensitive volume is parallelepipedal
  - Dimension 5 µm x 5 µm x 39 µm for IRF360

Step 2 : To calculate stopping power

For each type of ion and as function of its energy, the stopping power or LET evolution through the different layers of the MOSFET can be calculated with a computer code (as SRIM/TRIM). Range can be also determined.



Proposal for Reliability Calculation

Step 3 : Selection and validation of beam characteristics the heavy ion test facility

- ***For data already available***

3.1 At minimum, the energy of the test ion used shall assure a complete penetration of the sensitive region (epitaxy and transition/buffer layers). If it’s not the case, the heavy ion test data are not valid.

- **To select a beam cocktail for the heavy ion facility**

3.2 In order to select the appropriate heavy ion beam, there are two different ways to identify the worst conditions in terms of Energy for one type of ion :

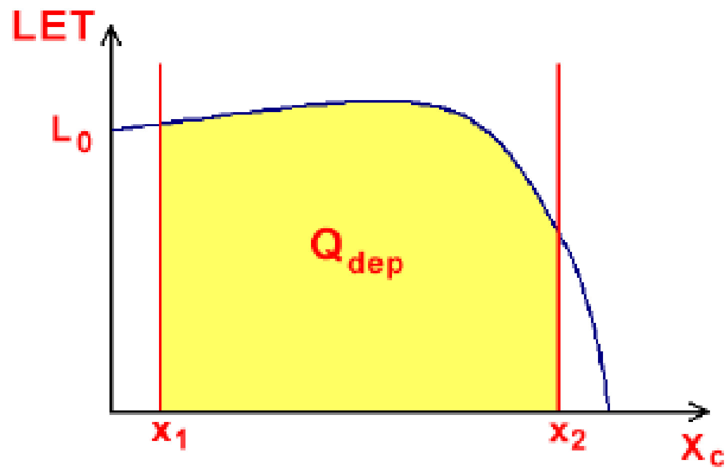
1. **To calculate Worst case Energy of the ion beam with the expression defined by Titus in “SEE Characterization of Vertical DMOSFETs : An Updated Test Protocol” Jeffrey L. Titus and C. Frank Wheatley, IEEE Transaction on Nuclear Science, Vol. 50, N°. 6, Dec. 2003**

$$E_{DIE}(surf) = \left(\frac{(Z^{1.333}).BV_{DSS}}{176} + \frac{382.Z}{(112 - Z)} \right) \sqrt{\frac{V_{DS}}{BV_{DSS}}}$$

2. **To use the computation results of LET profile over the sensitive area of the MOSFET for different energies in order to determine which energy value places the Bragg Peak at the interface of the epitaxial area (or eventually the transition layer) and the highly doped substrate.**

Step 4 : To calculate deposited charge

Using the computed code results obtained in step 2, the amount charge deposition in the epitaxy area (and with the transition layer when used) is determined.

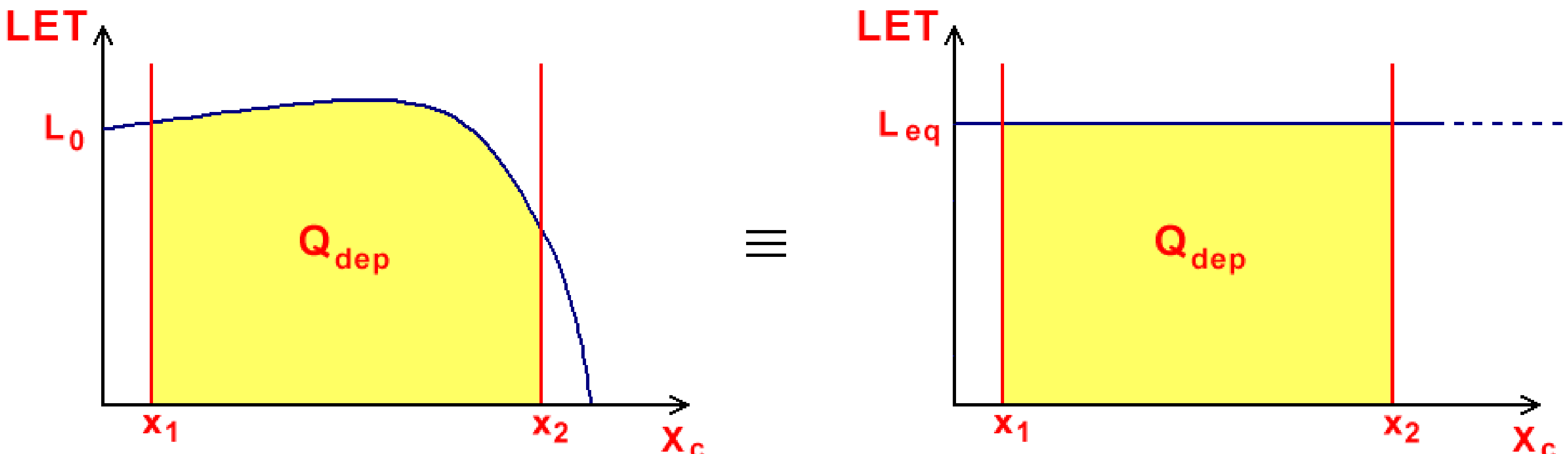


$$Q_{DEP} = \int_{x_1}^{x_2} k * LET(x) * dx$$

Step 5 : To calculate equivalent LET

If the amount of ionization along each ion's path in the sensitive area is considered as constant then this value can be converted back in terms of equivalent LET.

NB : this is not physically correct but just an approximation

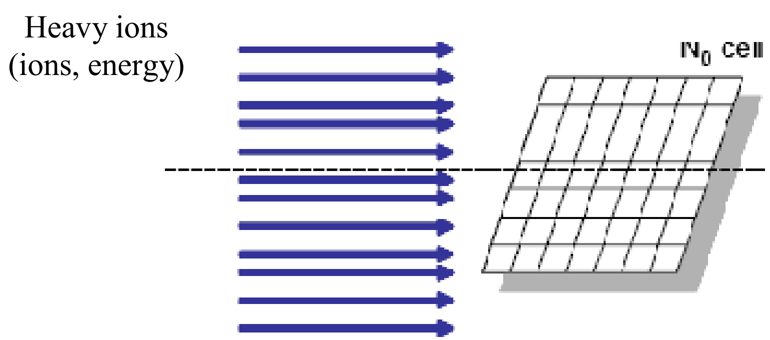


$$Q_{DEP} = \int_{x_1}^{x_2} k * LET(x) * dx = LET_{EQ} * (x_2 - x_1) * k$$

Step 6 : Heavy ions testing

The SEE cross section versus equivalent LET is determined using the equivalent LET in place of the LET at the surface of the irradiated device.

- During the heavy ion test, the normal test procedure is to expose the device to different mono-energetic and mono-directional ions in order to define the SEE cross section versus equivalent LET : $\Sigma = f(LET_{eq})$. For each couple of (ion, energy), the device is usually irradiated up to a certain level of fluence.



- For each value of equivalent LET of the ion test, the cross section (where N_{SEE} is the total number of SEE measured one run up to the fluence F).

$$\Sigma = \frac{N_{SEB}}{\Phi}$$

Proposal for Reliability Calculation

Step 7 : SEE Rate Calculations

Two different ways to calculate the SEE rate

Method 1 : If detailed heavy ion data are not available (ie cross section versus equivalent LET) but only LETthreshold

By assuming :

- The solid angle of sensitivity is a cone 60° open
  - (ref : D.L. Oberg and all – First Destructive Measurement of Power MOSFET SEB Cross-Section – IEEE Vol NS-34, N° 6, December 1987 PP 1736 – Fig 11)

- The σ vs LET a step function
- σ_{sat} (saturated cross section) is estimated to be 25% of the die size

We can compute the reliability . . .

$$FIT = Flux(@LET_{Th}) \times \sigma \times 6.048 \times 10^{8}$$

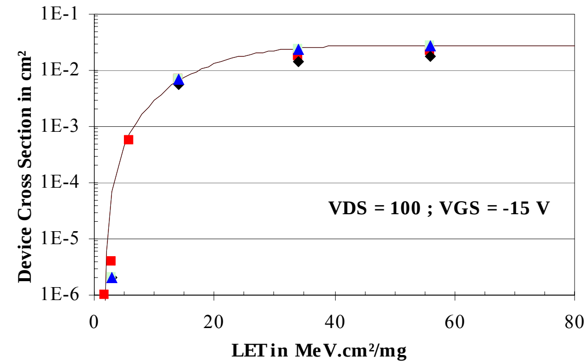
- FIT : 1 failure / 10^9 h = 1 failure / 114 077 years
- Flux : Flux at the LET_{th} in ion/m^2.sr.s

Step 7 : SEE Rate Calculations

Method 2 : with detailed cross section versus equivalent LET

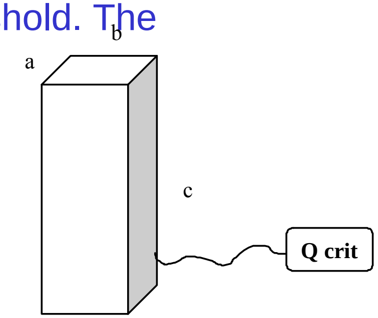
- Fit of the data with a Weibull curve :

$$\Sigma = \Sigma_{sat}\left[1-\exp\left(-\left(\frac{L-L_{th}}{W}\right)^{S}\right)\right]$$



  - L_{th} is the equivalent LET threshold,
  - W is one parameter corresponding to the width of the Weibull fit,
  - S is one parameter corresponding to the the power of the Weibull fit,
  - Σ_{sat} is saturated cross section

- Assuming that all elementary cells have the same surface, but different LET threshold. The number of cells having a LET threshold lower or equal to L is expressed by:



$$N(\leq L) = N0\left[1-\exp\left(-\left(\frac{L-L_{th}}{W}\right)^{S}\right)\right]$$

where N0 is total the number of elementary cells.

- The LET distribution function is calculated as follow :

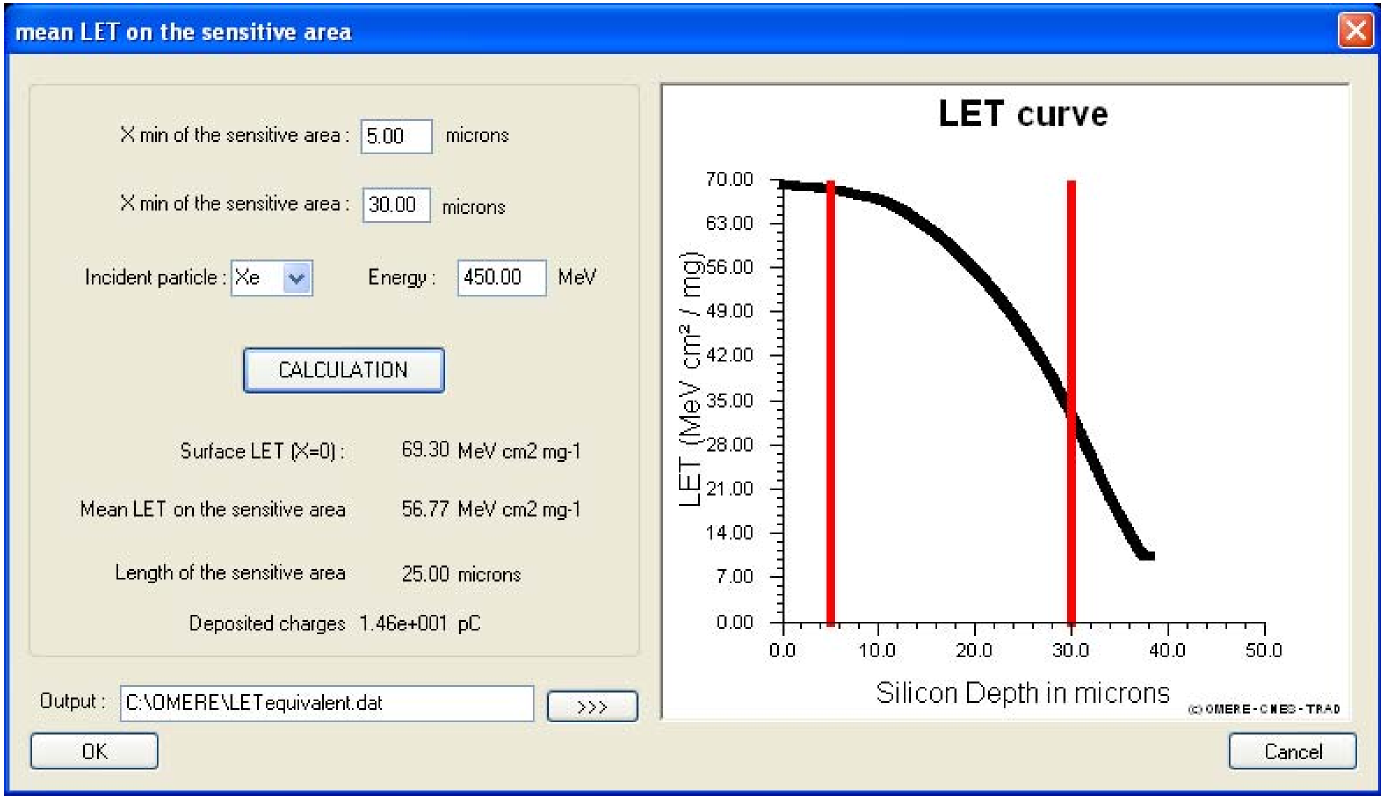
$$\xi(L) = \frac{dN(\leq L)}{dL}$$

- Using CREME and taking into account the sensitive volume size, (a, b & c), the SEE rate t(L) is calculated for various LET threshold, using the CREME suite of programs, SEE rate is

$$\tau = \int_{L_{th}}^{\infty} \tau(L).\xi(L).dL$$

Equivalent LET in OMERE

For information, an equivalent LET calculation module is available on OMERE v3.2



Ref : SEE rate prediction

Date : January, 28th 2009.

Conclusion

- LET is not the key parameter for some SEB and SEGR assessment (but also on SEL and SET), it is the collected charge (or more practically, the deposited charge)
  - For devices with deep active zone, the use of LET as a key parameter can end to a failure !
- A method, based on deposited charge and on equivalent LET for reliability calculation is proposed

We agree that . . .

- It is a *raw / pragmatic / industrial* approach !
- This method need still to be *validated / tested and compared with in flight data*
- Warning : Sensitive area is different depending on the type of SEE and on technology
  - ***SEB, SEGR***
    - *today sensitive area is considered as depleted region (epi + buffer layer) on space qualified IR technology (R3, R4, R5, R6 and R7) based on published data*
    - *on other technology should be different*
  - ***SEL***
  - ***SET** : different type of transistor (lateral or vertical, NPN or PNP) used inside the IC*

For the future :

- Could be interesting to develop an experimental methodology to determine the sensitive area