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# BASICS & STATE OF THE ART OF SINGLE-PHOTON LASER TESTING METHODOLOGIES

Montpellier University, 9th of October 2017

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# CONTEXT & OUTLINES

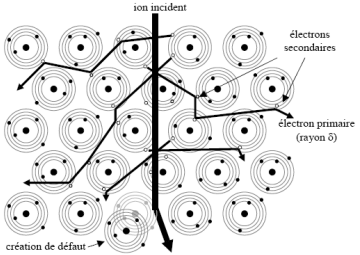
- Laser has demonstrated to be a very interesting tool, complementary to accelerators for the radiation sensitivity assessment

- Over the past years :
  - Many papers featuring laser tests
  - More groups developing their own facilities
  - Initiatives to compare laser facilities

- Main methodologies:
  - Worst case analysis
  - Parametric testing
  - Fault injection
  - Functional reverse engineering
  - Cross section estimation

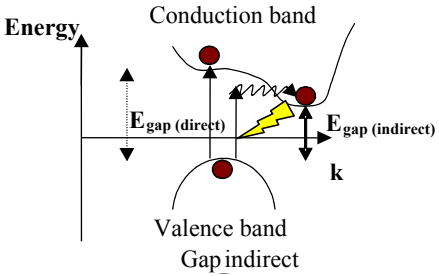
# BASIC MECHANISMS

## Ion/Si




V. Pouget - 2000

## SPA Laser/Si




Both ions and laser (with an appropriate wavelength) can interact with silicon and generate charges

- Coulombian Interaction ➔ Ionization
- LET (pC/µm) : $\frac{\partial E}{\partial z}$
- <u>Ionization track</u>
  - Track radius
    - ➢Function of the energy
    - ➢Range in Silicon : function of the energy

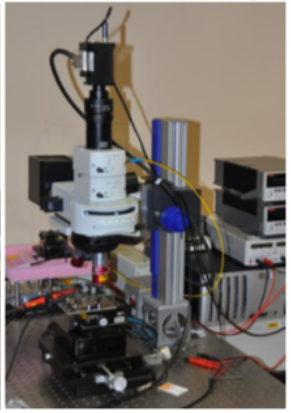
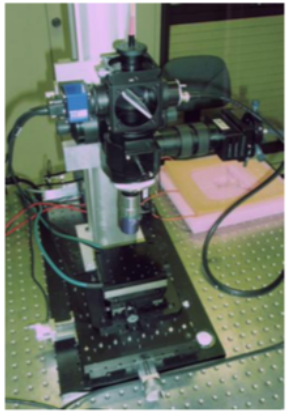
- Photoelectric effect ($\lambda$ <1,1µm)
- <u>Ionization track</u>
  - Track radius
    - ➢Limited by diffraction laws (≈ 1µm for $\lambda$=1,06µm)
  - Range in Silicon : function of the wavelength - >700µm for 1,06µm

Laser ⇔ Ions : not the same basic mechanism
BUT : same consequence, that is, a localized charge generation

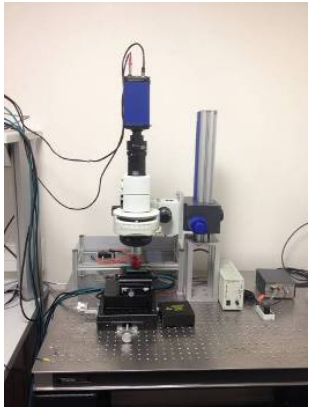
# FACILITIES

## AIRBUS LASER FACILITIES



## NUCLETUDES LASER FACILITY



- Single Photon laser
- Designed for backside irradiation
- Pulsed Laser
- X100 Objective
- Motorized energy attenuator
- Optical fibers
- Camera
- Compact
- XYZ motorized stages (50nm resolution)
- Computer driven

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# 01

# A LASER TO PERFORM …

# WORST CASE ANALYSIS

# WORST CASE SET

## Mechanisms:

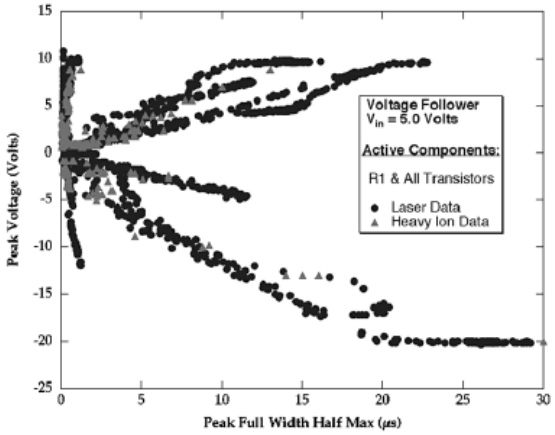
- Combination of a deposited charge & electrical behavior of the device

## Conditions:

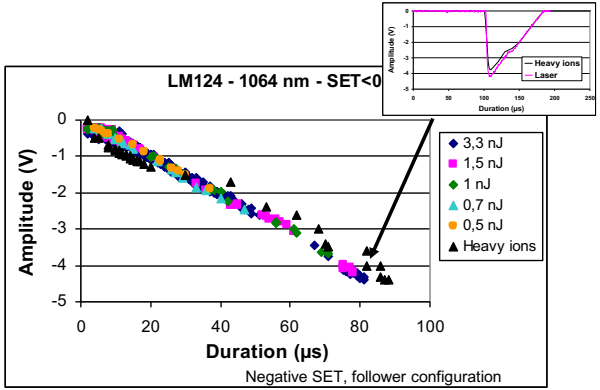
- Various laser energies (shape can change with the energy)

## Remarks:

- Maximum laser energy can deposit much more charges than High LET heavy ions ➔ HI test at one LET recommended




SET in LM124 triggered by laser (from [1])








[1] Comparison of single-event transients induced in an operational amplifier (LM124) by pulsed laser light and a broad beam of heavy ions, IEEE Transactions on Nuclear Science ( Volume: 51, Issue: 5, Oct. 2004 ), S. Buchner et al.

# LATCHUP SCREENING

## Mechanisms:

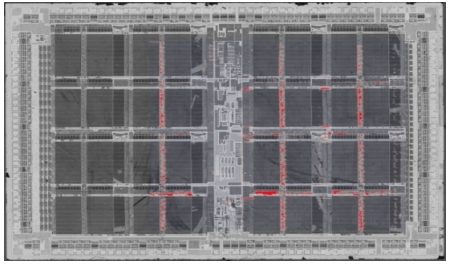
- Combination of a deposited charge to trigger a bipolar parasitic structure & Regenerative feedback

## Conditions:

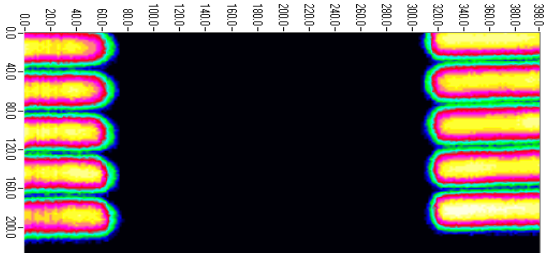
- High laser energy

## Remarks:

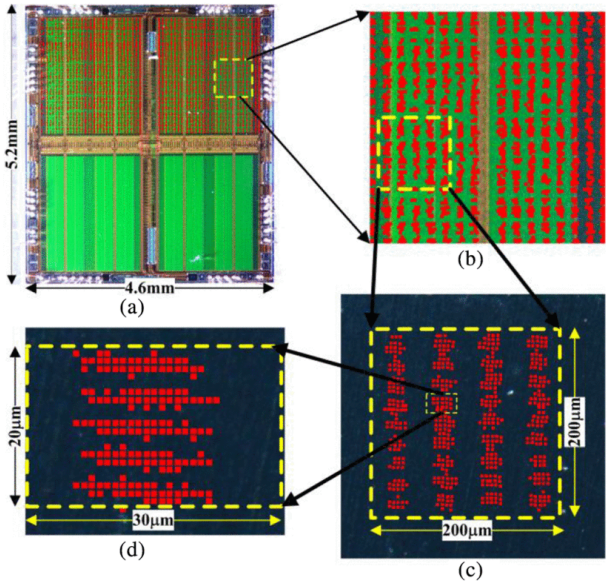
- Sort SEL sensitive device & validate the selected one(s) under beam



Latchup mapping of a MRAM



Latchup mapping of a SRAM




Latchup mapping of a SRAM [1]





[1] Correction of Single Event Latchup Rate Prediction Using Pulsed Laser Mapping Test IEEE Transactions on Nuclear Science ( Volume: 62, Issue: 2, April 2015 ), Y.-T. Yu et al.

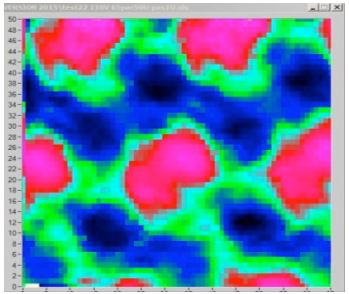
# SOA DETERMINATION FOR POWER DEVICES

## Mechanisms:

- Combination of a deposited charge to trigger a bipolar parasitic structure & Regenerative feedback

## Conditions:

- High laser energy



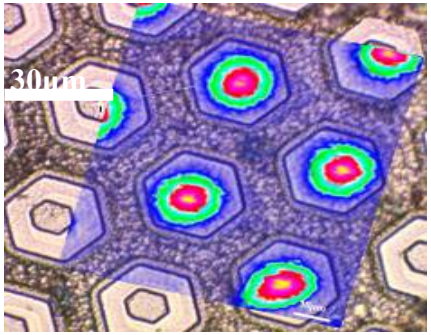
More sensitive

Less sensitive

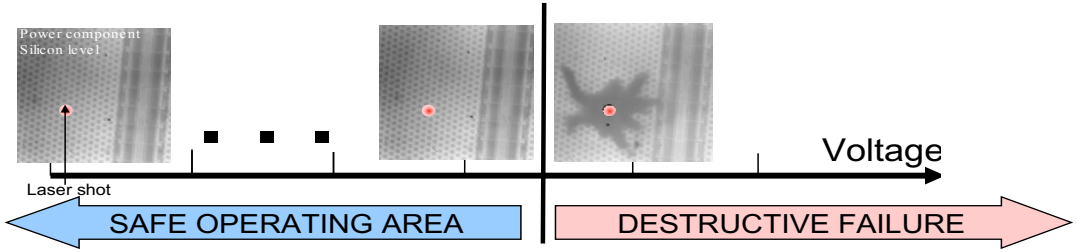
Laser mapping of a power MOSFET

Laser Spot

480V
400V
320V
240V
160V
80V




Laser mapping of a power MOS



# 02

# A LASER TO PERFORM …
# PARAMETRIC TESTING

# AS A FUNCTION OF THE BIASING CONFIGURATION

## Mechanisms:

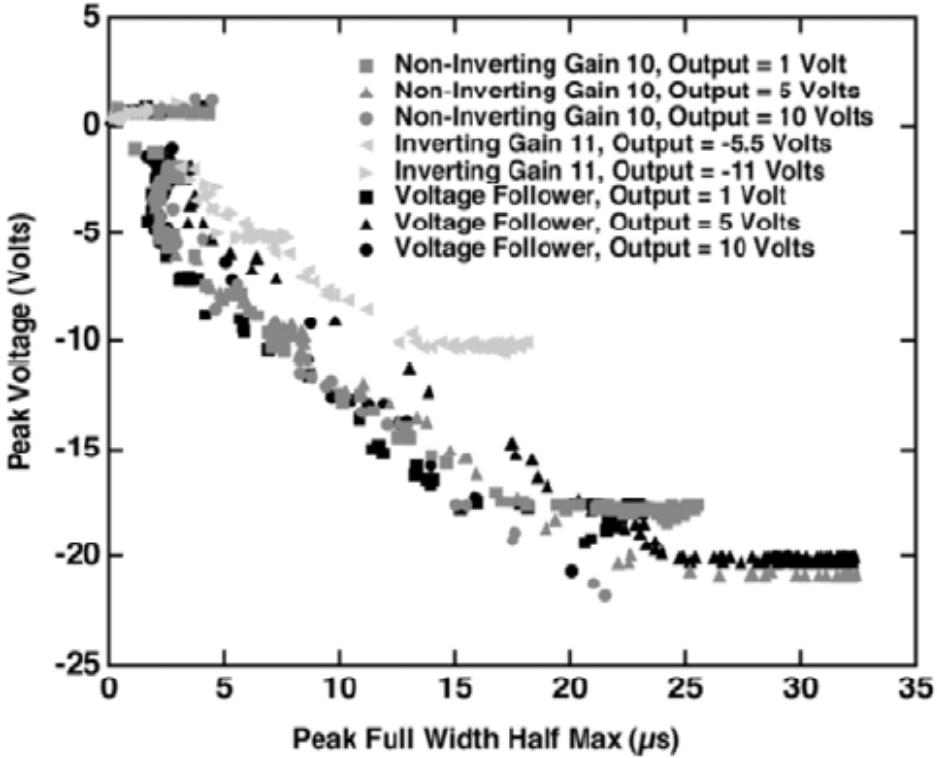
- Combination of a deposited charge & electrical behavior of the device

## Conditions:

- Various laser energies (shape can change with the energy)
- Various biasing conditions

## Recommendations

- Test at one heavy ion LET to set the laser energies in the range of interest




SET in LM124 as a function of the biasing configuration (from [1])

[1] Comparison of single-event transients induced in an operational amplifier (LM124) by pulsed laser light and a broad beam of heavy ions, IEEE Transactions on Nuclear Science ( Volume: 51, Issue: 5, Oct. 2004 ), S. Buchner et al.

# AS A FUNCTION OF THE TID LEVEL (SYNERGETIC EFFECT)

## Mechanisms:

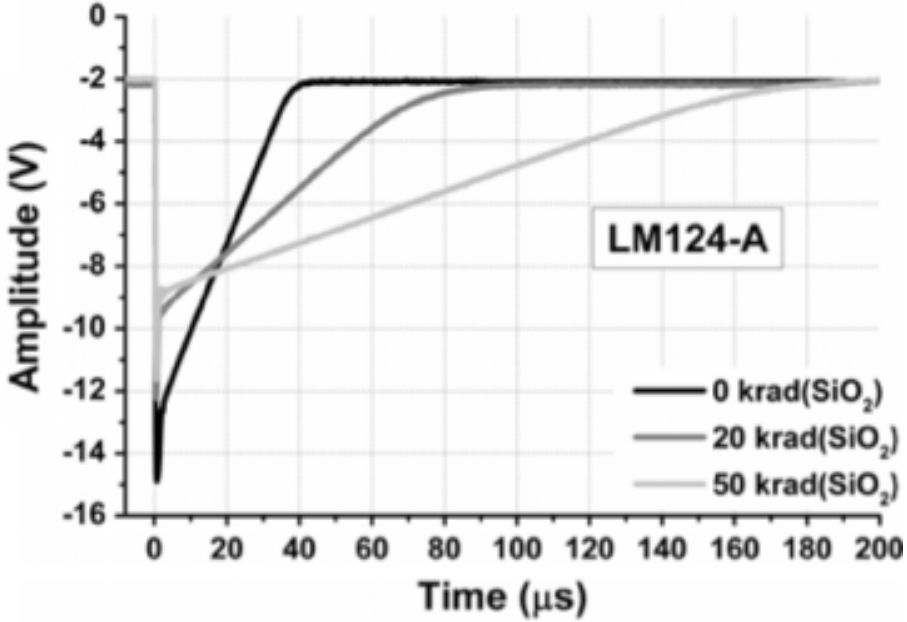
- Combination of a deposited charge & electrical behavior of the device

## Conditions:

- Various laser energies (shape can change with the energy)
- Various TID levels

## Recommendations

- Test at one heavy ion LET to set the laser energies in the range of interest




Experimental ASETs obtained on Q9 for LM124-A opamps in IWG configuration for pristine and irradiated devices [1].





[1] Modeling and Investigations on TID-ASETs Synergistic Effect in LM124 Operational Amplifier From Three Different Manufacturers, IEEE Transactions on Nuclear Science ( Volume: 60, Issue: 6, Dec. 2013 ), F. Roig et al.

# AS A FUNCTION OF THE RELIABILITY (AGEING)

## Mechanisms:

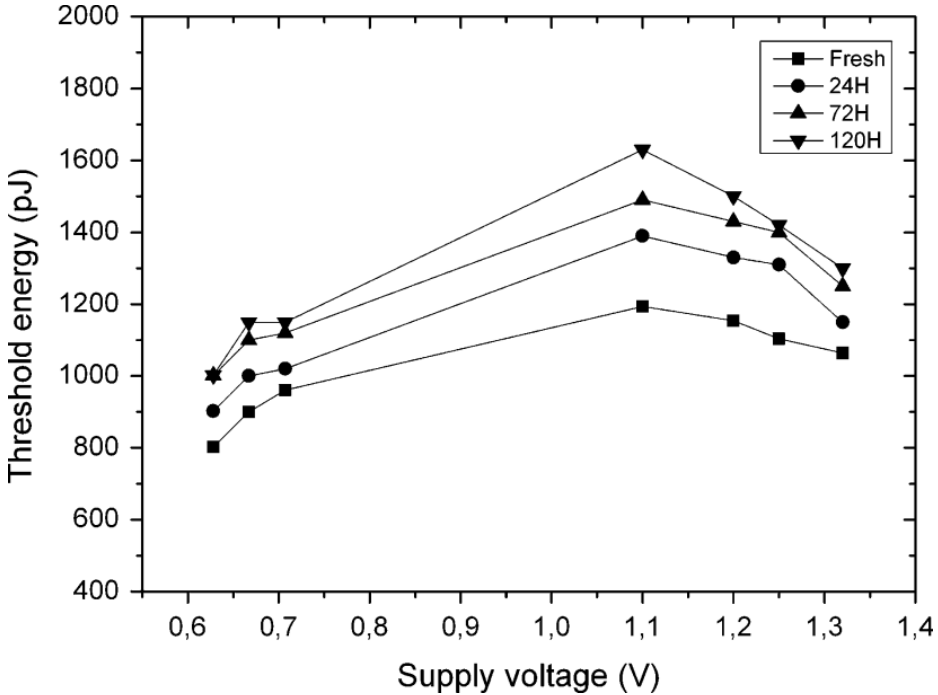
- Combination of a deposited charge & electrical behavior of the device

## Conditions:

- Various laser energies
- Different ageing levels

## Recommendations

- Test at one heavy ion LET to set the laser energies in the range of interest




SET sensitivity of gates chain before and after aging [1] (NBTI)





[1] Negative Bias Temperature Instability Effect on the Single Event Transient Sensitivity of a 65 nm CMOS Technology IEEE Transactions on Nuclear Science ( Volume: 60, Issue: 4, Aug. 2013 ), I. El Moukhtari et al.

# AS A FUNCTION OF TEMPERATURE?

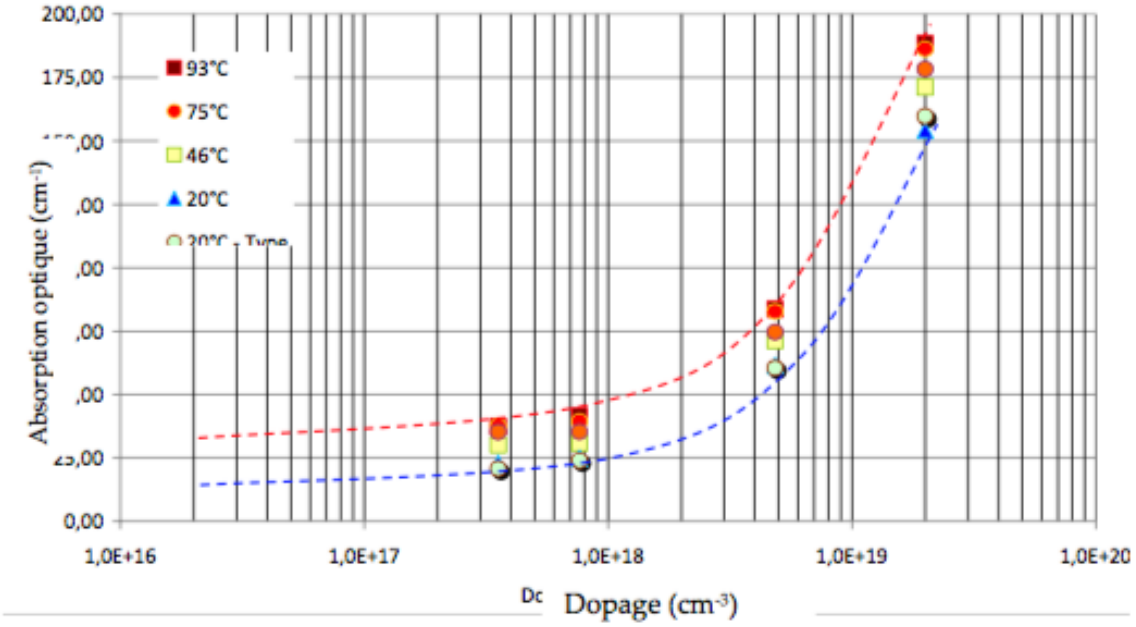
## Mechanisms:

- Parametric testing is not as straightforward for some parameters such as T° because of their specific influence on the laser charge deposition

## Recommendations

- Test at one heavy ion LET to set the laser energies in the range of interest

**BE CAREFUL!!**



# 03

# A LASER TO PERFORM …

# FAULT INJECTION

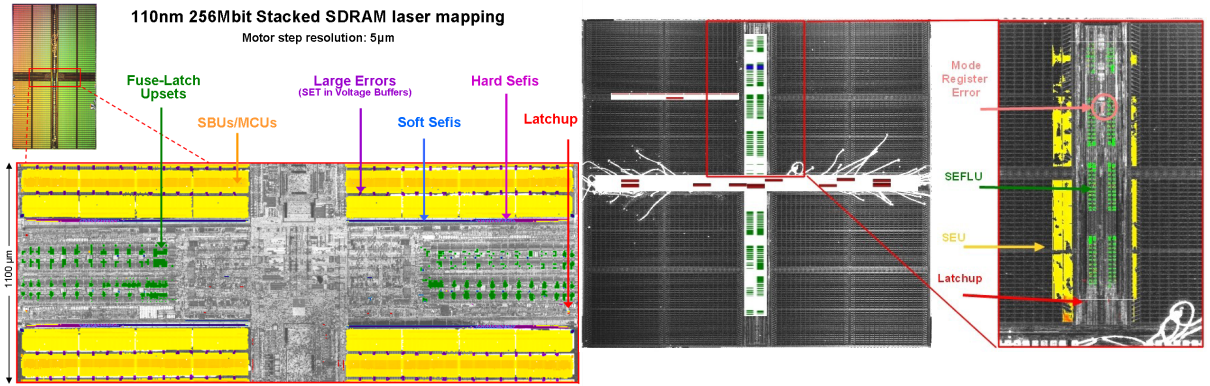
# IDENTIFY, SORT SEE & IDENTIFY MITIGATIONS

## Conditions:

- Various laser energies (threshold energy mapping)

## Remarks

- It is of particular interest prior to an accelerator testing in order to improve and validate the test setup




| | |
|---|---|
| ▪ SEU/MBU | Rewrite |
| ▪ SET in voltage reference | Rewrite |
| ▪ Fuse latch upset | Recover with Mode Register Set |
| ▪ Hard SEFI | Recover with power cycle |
| ▪ Latchup | Recover with power cycle |

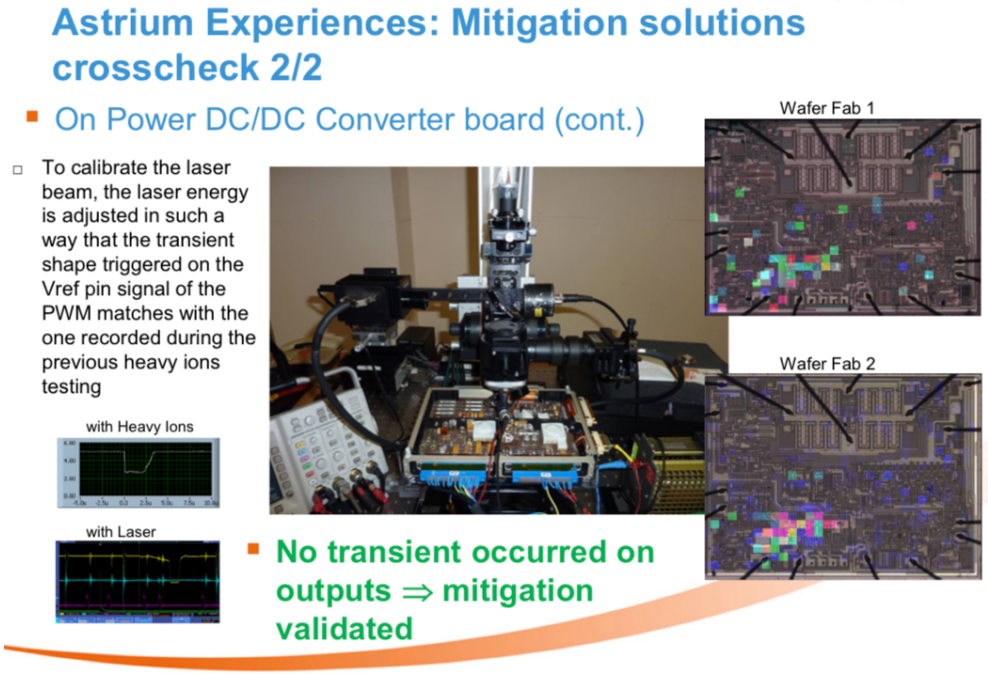
# VALIDATE MITIGATIONS

## Conditions:

- Various laser energies

## Recommendations

- It is of particular interest prior to an accelerator testing in order to improve and validate the test setup
- One heavy ion LET test to set the laser energies in the range of interest




Mitigation validation of a DC/DC converter [1]

[1] http://www.ies.univ-montp2.fr/radlas2013/slides/RADLAS2013_10_Salvaterra.pdf

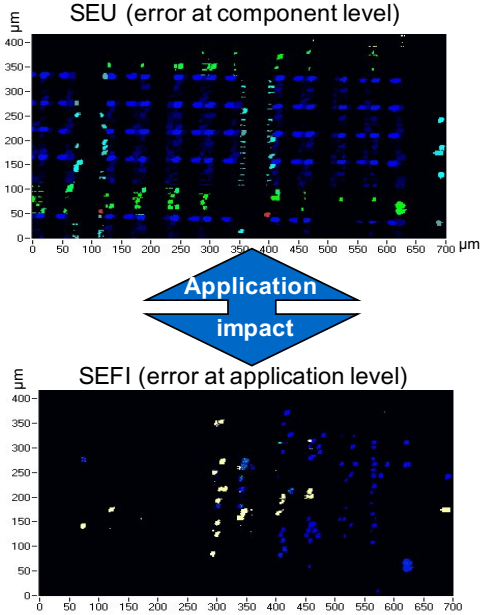
# ASSESS IMPACT AT APPLICATION LEVEL

## Conditions:

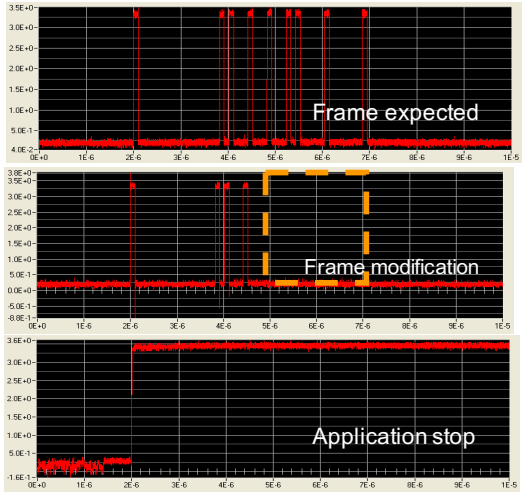
- Laser energies for which errors are triggered at component level

## Remarks

- As for a test under beam, it may be difficult to be exhaustive depending on the complexity of the application layer




180nm FPGA running a communication application
(color scale ⇔ kind of resource impacted)



# 04

# A LASER TO PERFORM …

# FUNCTIONAL REVERSE ENGINEERING

# REVEAL ARCHITECTURE OF DIGITAL ICs

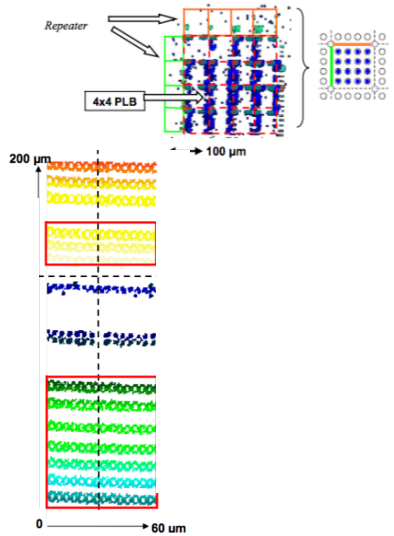
## Conditions:

- Laser threshold mapping

## Remarks

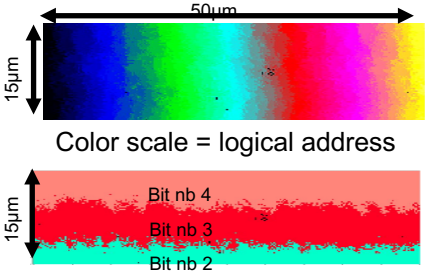
- Key parameters for the MBU prediction & ECC efficiency evaluation

### 130nm FPGA



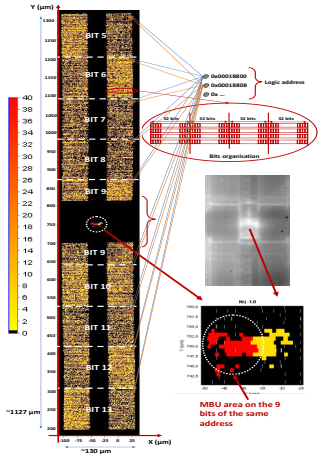

130nm FPGA CRAM laser mapping

### 90nm SRAM




High probability to have MBUs (less than 10µm between bits of the same word)

### 40 nm FPGA




40nm FPGA BRAM laser mapping

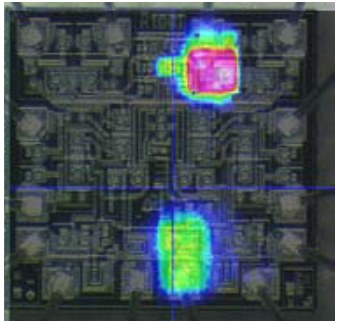
# LOCATE & ESTIMATE THE NUMBER OF SENSITIVE VOLUMES

## Conditions:

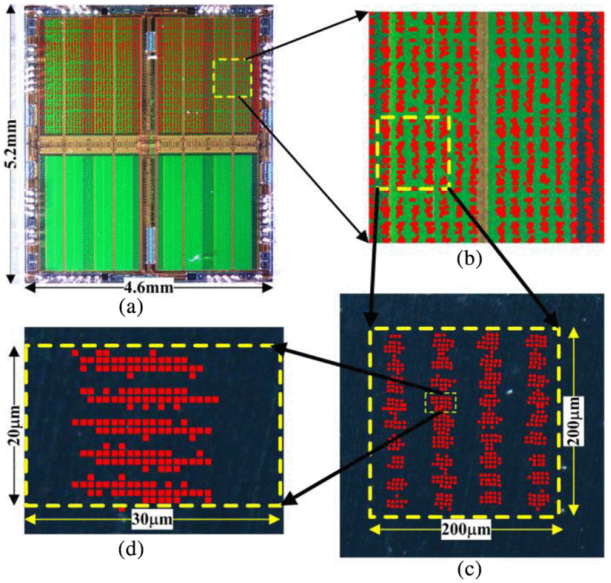
- High laser energy

## Remarks

- The location of sensitive areas is a valuable information for IC designers and the number of sensitive volumes may be useful for prediction approaches



Latchup mapping of a comparator




Latchup mapping of a SRAM [1]





[1] Correction of Single Event Latchup Rate Prediction Using Pulsed Laser Mapping Test IEEE Transactions on Nuclear Science ( Volume: 62, Issue: 2, April 2015 ), Y.-T. Yu et al.

# 04

# A LASER TO PERFORM …
# CROSS SECTION EVALUATION

# EQUIVALENT HEAVY ION CROSS SECTION?

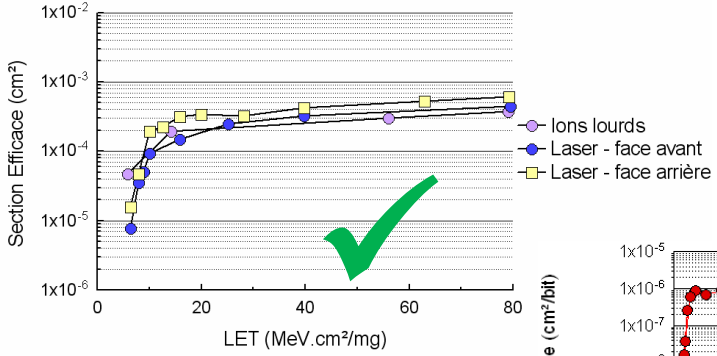
## Conditions:

- Various laser energies (threshold energy mapping)

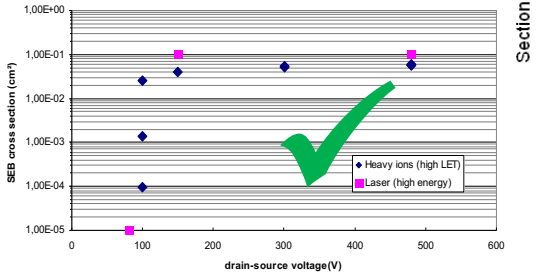
## Remarks

- Due to the spot size effects, direct XS correlation between laser and heavy ions should be handled carefully for integrated devices

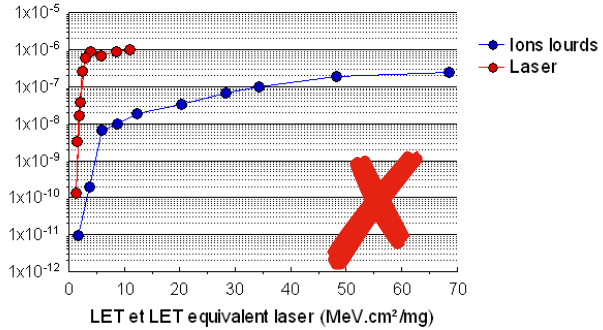
**BE CAREFUL!!**




Laser and heavy ion XS for a LM139




Laser and heavy ion XS for a 500V powerMOSFET



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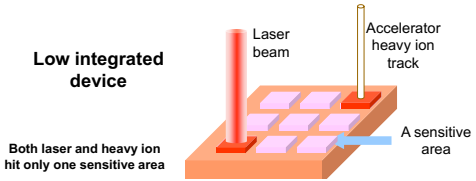
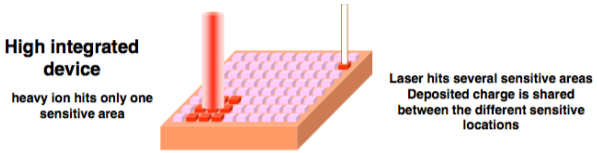
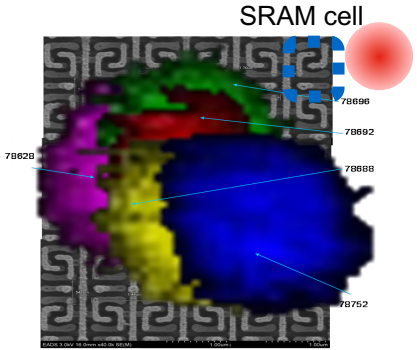
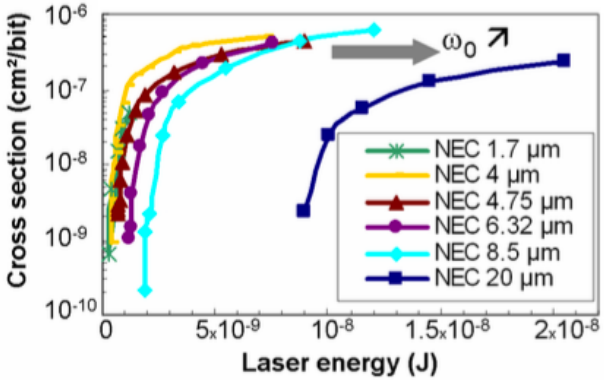



**90nm SRAM**



# 05
# CONCLUSIONS

# Conclusions

- Review of the main SPA laser test methodologies
- Not exhaustive, many more methodologies studied
- Not limited to silicon, applicability to SPA in wide band gap
- Laser should be considered as a complementary tool to accelerators ➔ may require a HI test at one LET to set the energy range

# Be aware of

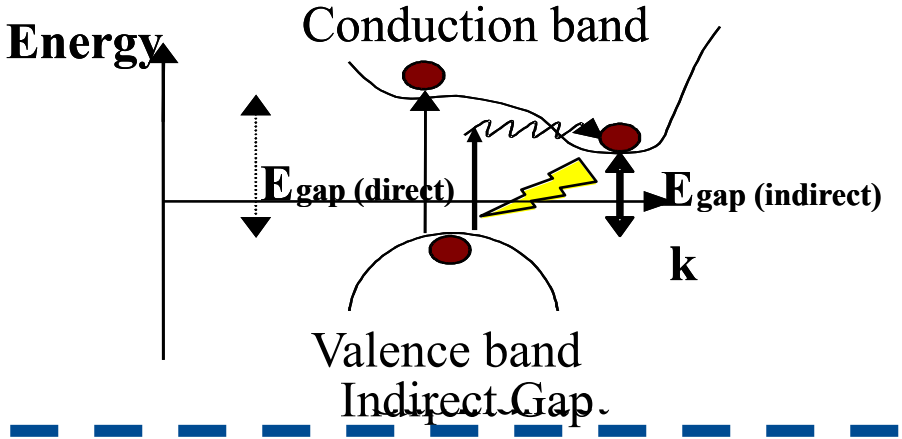
- Temperature
- Comparison of devices with different feature sizes

| | |
|---|---|
| **Worst case** | SET |
| | SEL |
| | SEB |
| **Parametric** | Biasing configurations |
| | TID |
| | Ageing |
| | Temperature |
| **Fault injection** | Identification of SEE |
| | Identification of mitigations |
| | Validation of mitigations |
| | Application impact |
| **Functional reverse** | Architecture of digital ICs |
| | Sensitive volume localization |
| **Cross section** | Low integration level |
| | High integration level |

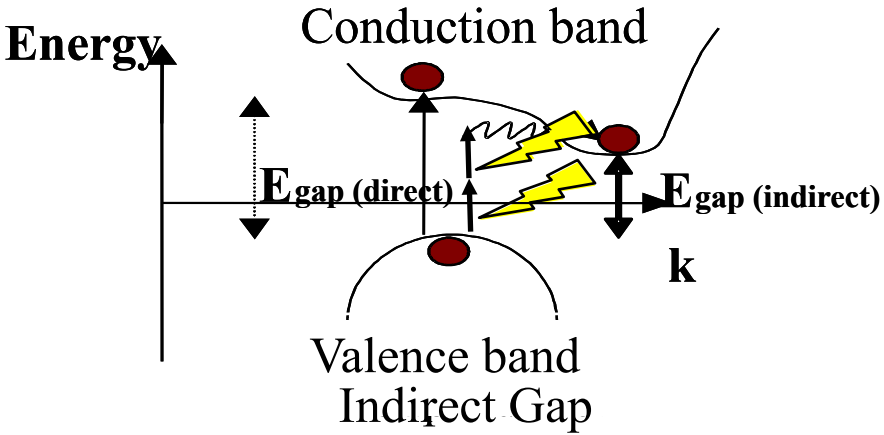
# 06
# BACKUP

# SPA VS TPA

## Single Photon Absorption

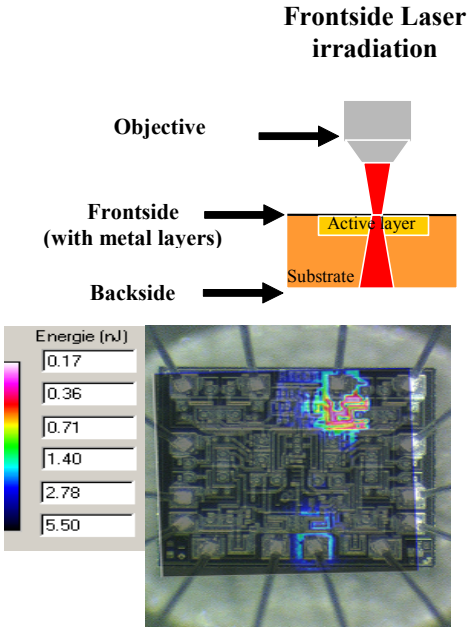


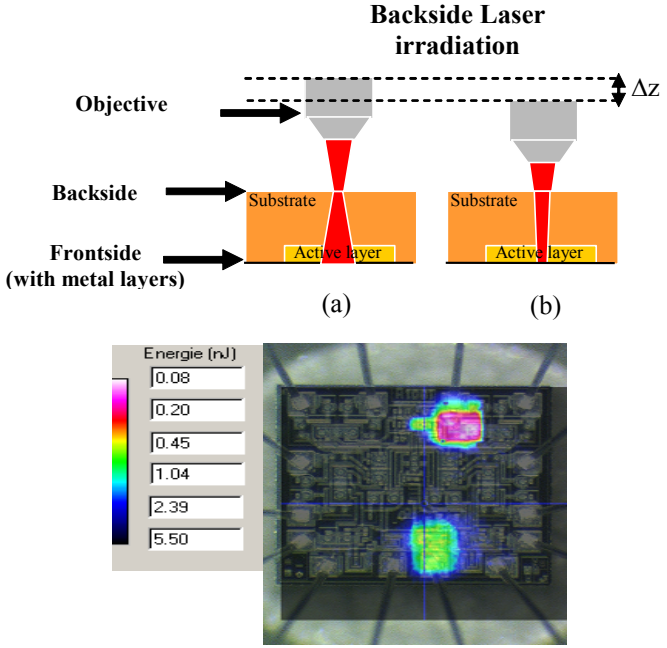

## Two Photon Absorption




| | Single Photon Absorption | Two Photon Absorption |
|---|---|---|
| Stability | | |
| Minimum spot size | | |
| Sensitive thickness probing | | |
| Cost | | |
| Ease to use | | |
| Theoretical modelling | | |

# Backside irradiation




- Laser can't cross metal layers :
  Problem due to metal opacity
  Part of the sensitive areas are not revealed

- No problem due to metal opacity
- Need a backside opening (but now, flip chipped devices)

**Backside laser testing reveals all the sensitive areas**