SEE Laser testing at ESA

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ESA ESTEC

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Summary

ESA Labs equipped since mid-2021

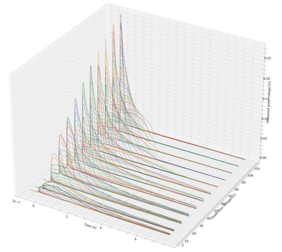
Several classical tests performed (Screening, cross section assessment, …)

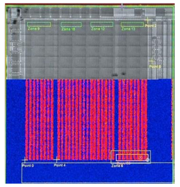
Non-Routine test cases:

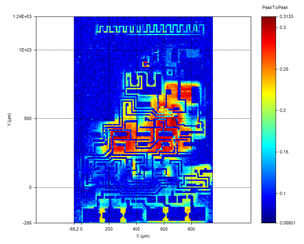
- <u>Comparison SEE Laser vs Heavy Ions</u>
    - Pin diode: Analysis of Pulse profile
    - SRAM: Comparison with SEL in-Flight Data
    - Voltage Reference: Assessment of Worst-Case SET

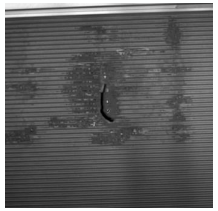
- <u>Failure Analysis:</u>
    - Point of Load: Localisation of SEFI and SEB

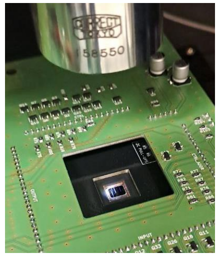
- <u>Fault Injection</u>
    - µP STM32: Test of Software Protection Technics to SEU











Comparison Heavy Ion / Laser

Case of a PIN Diode

Pin Diode – Photo diode

DUT: Pin Diode

Background:

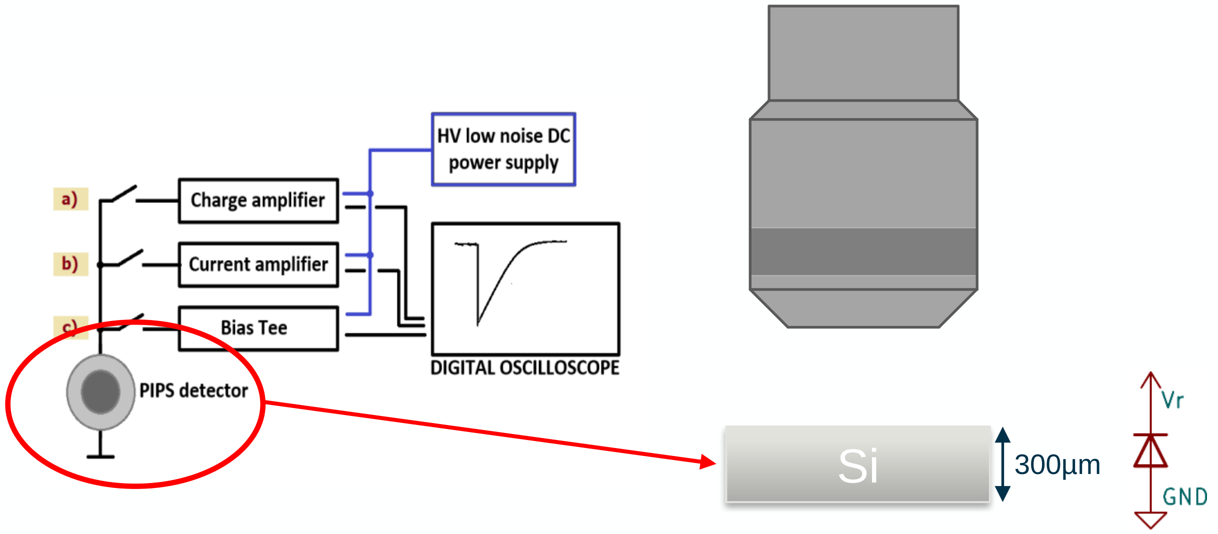
- System used by ESA for spectral characterisations of beam

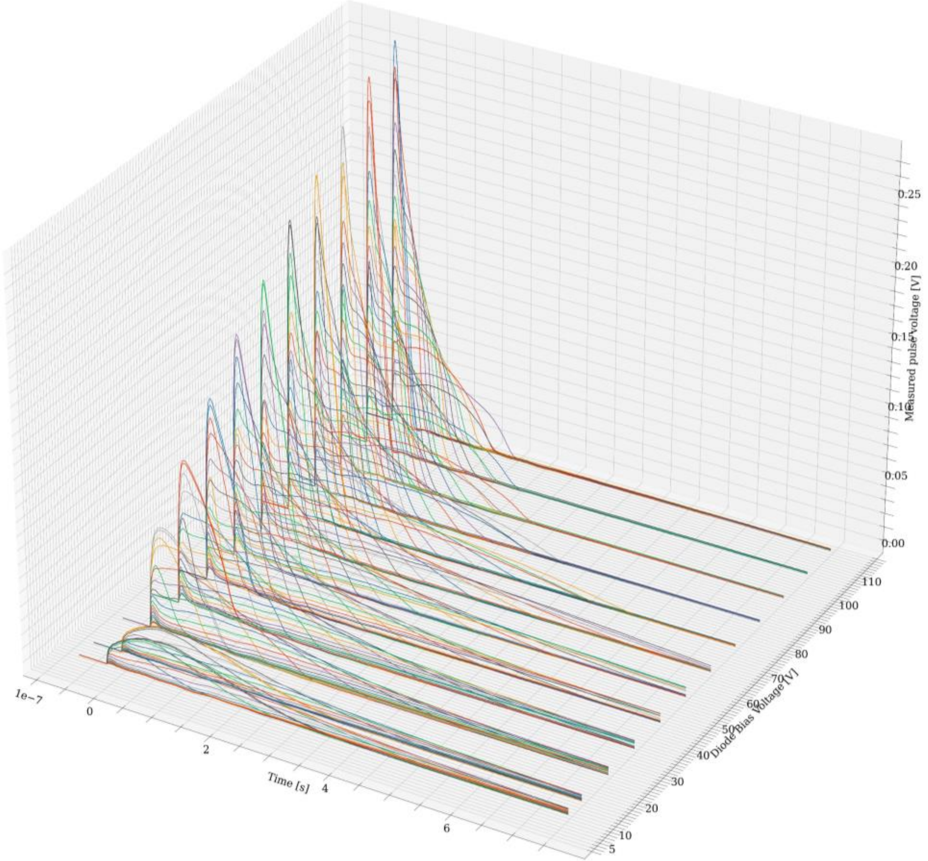
T. Borel et al., "PIPS Diode Test Setup for Heavy Ion Beam Spectral Characterization," in IEEE Transactions on Nuclear Science, vol. 70, no. 8, pp. 1732-1739, Aug. 2023

RADECS 2022
Venice, 3-7 October

Objective:

- Understanding better the charge deposition mechanism by analysing pulse shapes

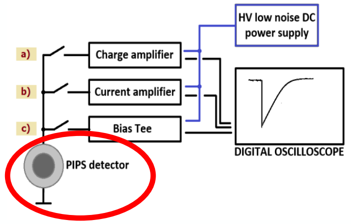


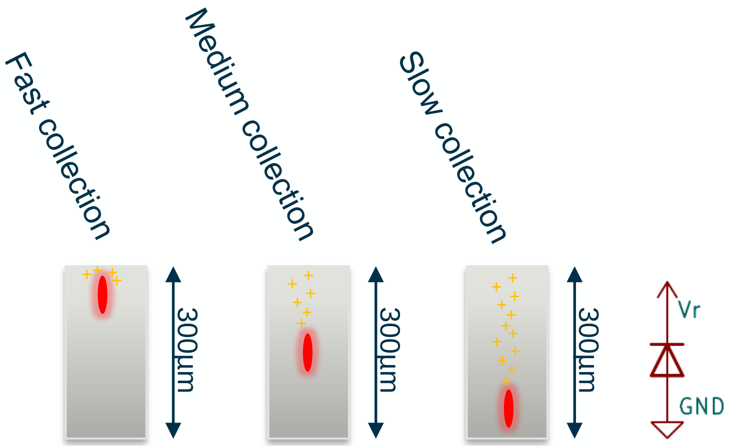


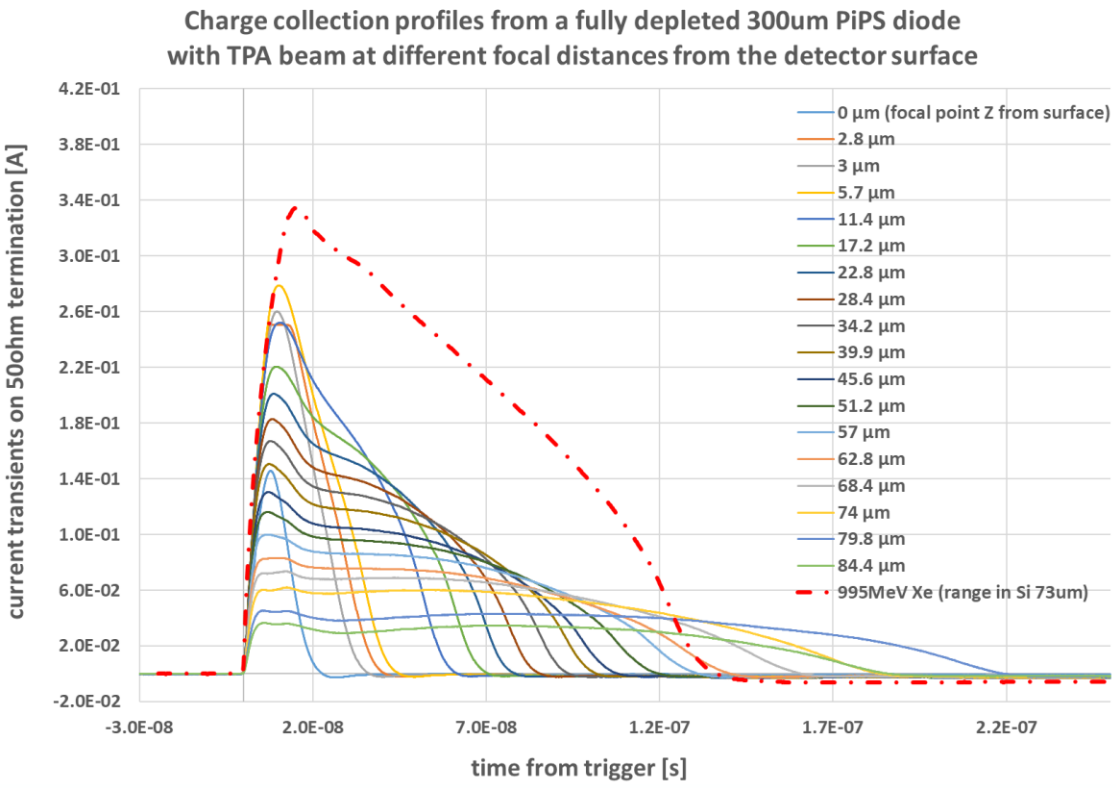
Measured pulses of the biassing voltage of the diode with depth in the diode

→ THE EUROPEAN SPACE AGENCY

Pin Diode – Photo diode







Minority carriers takes more time to travel to the negative pole

Result:

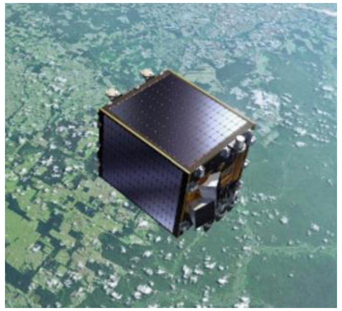
- Shape can help determining z position of generation
- Could be used to determine location of Brag Peak
- Ion signature

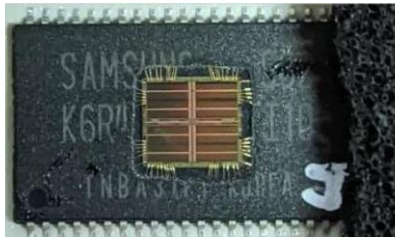
Comparison Heavy Ion / Laser

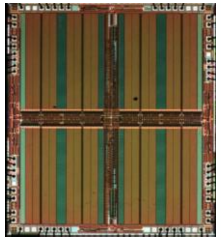
Case of an SRAM - Samsung 4Mbit K6R4016V1C

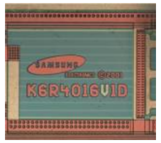
SRAM – Samsung 4Mbit K6R4016V1C

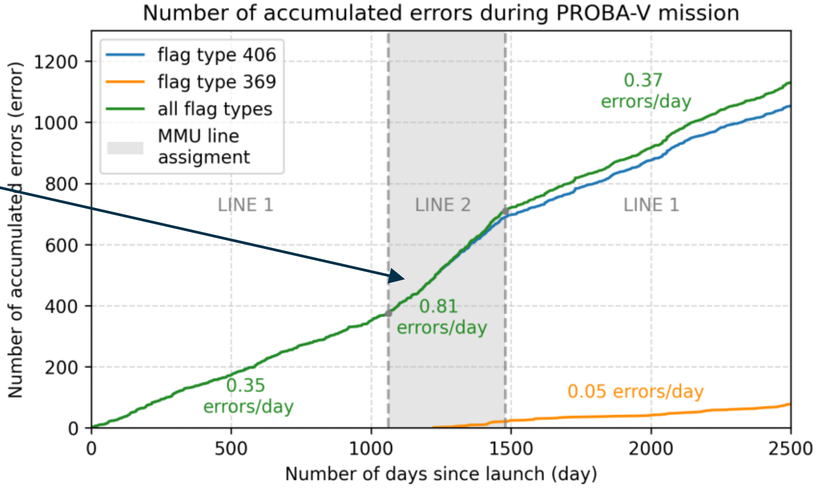
DUT: K6R4016V1C-TI10 with a die SEL sensitive







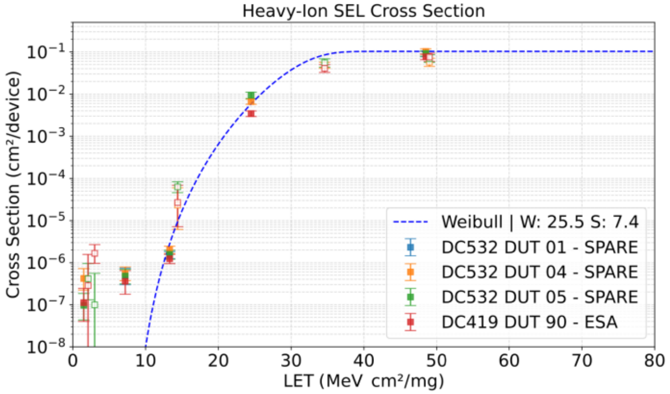


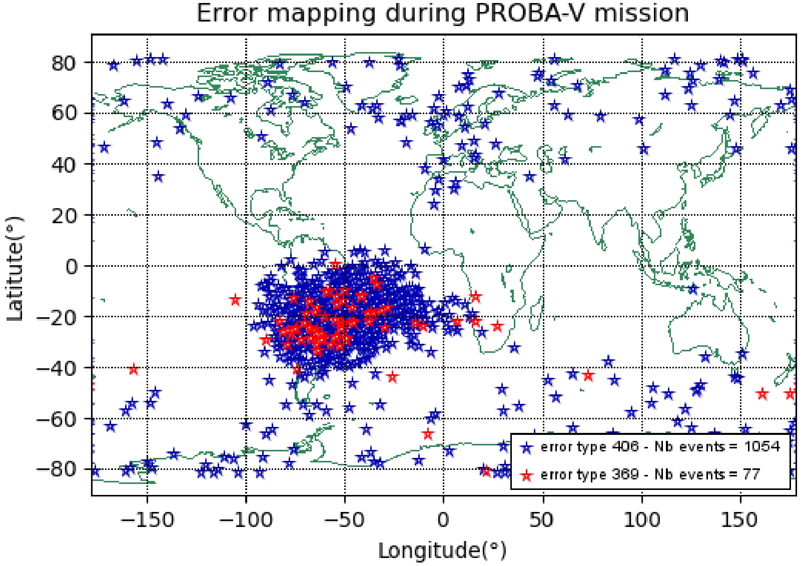


Goal: Internal investigation to understand the cause(s) of the ~1 year average SEL error rate during operations

Study:

- Heavy-ion data showed that part-to-part variability (from flight "lot") cannot explain this increase
- Alternative causes could be:
  - Temperature – not assessed during heavy-ion testing
  - Shielding difference between main & redundant unit
- Also unexpected increase of XS at low LET



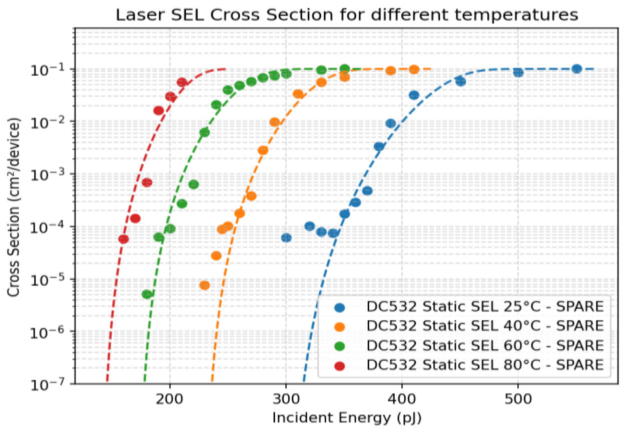


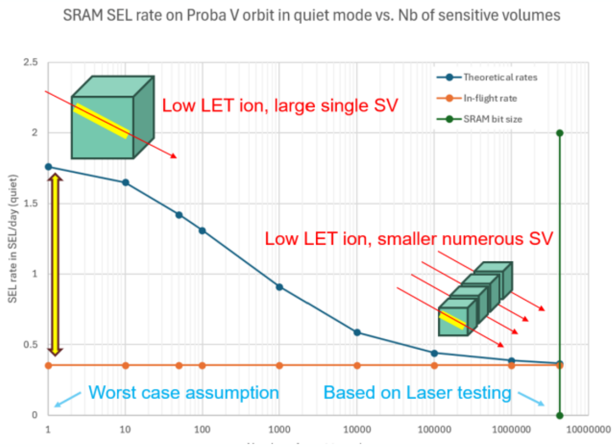
M. P. Mattos, D. A. Santos, L. M. Luza, V. Gupta, T. Borel and L. Dilillo, "Investigation on Radiation-Induced Latch-Ups in COTS SRAM Memories Onboard PROBA-V," in IEEE TNS, vol. 71, no. 8, pp. 1614-1622, Aug. 2024

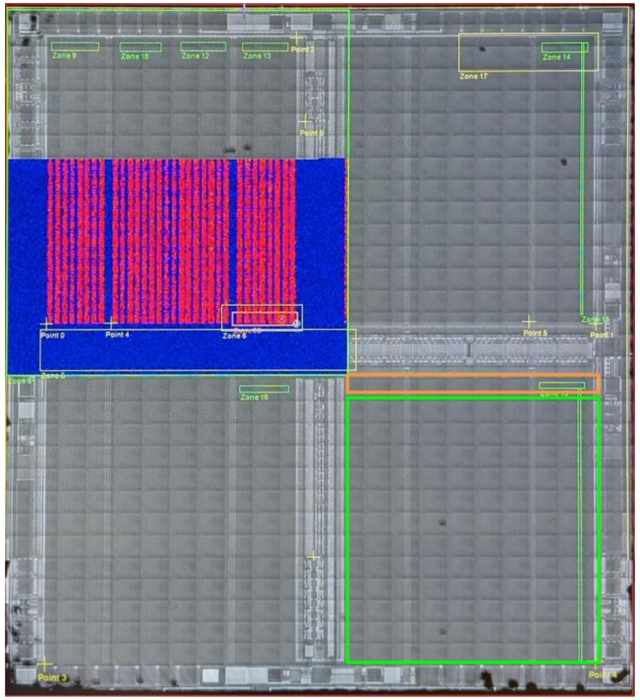
SRAM – Samsung 4Mbit K6R4016V1C

Laser testing was useful in this study to:

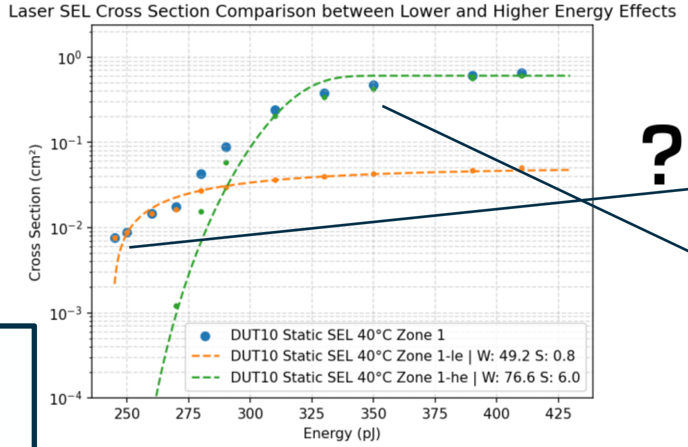
1. **Confirm** the assumption of a large number of Sensitive Volumes to match in-flight error rate with theoretical calculations
2. **Investigate** SRAM SEL sensitivity with temperature

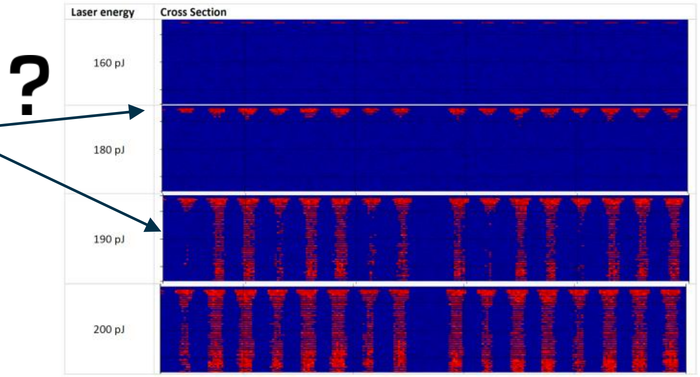






3. **Provide more insights** into the possible cause of the low LET cross-section behaviour: areas near the central periphery appear at lower LET & quickly saturates: perhaps another parasite path?





Laser tests here allowed to deepened investigations easily (low cost) & complement heavy-ion data

M. P. Mattos, D. A. Santos, L. M. Luza, V. Gupta, T. Borel and L. Dilillo, "Investigation on Radiation-Induced Latch-Ups in COTS SRAM Memories Onboard PROBA-V," in IEEE TNS, vol. 71, no. 8, pp. 1614-1622, Aug. 2024

Comparison Heavy Ion / Laser

Case of a Voltage Reference – SET Worst Case on TL1431

SET worst case - TL1431

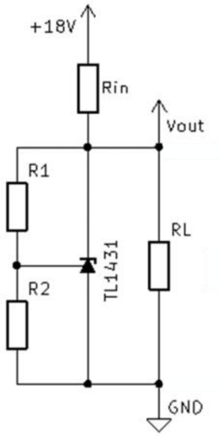
DUT: Voltage Reference – TL1431-SP

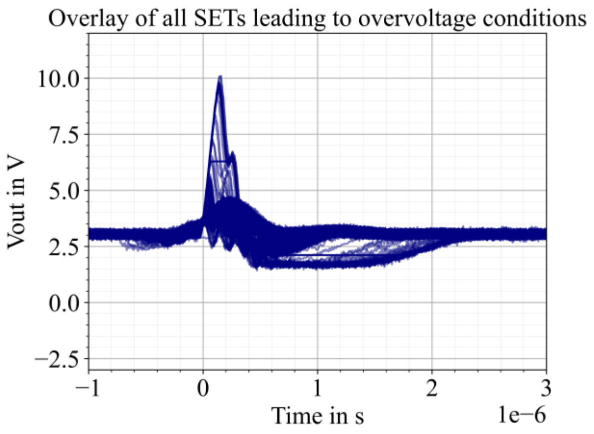
Objective:

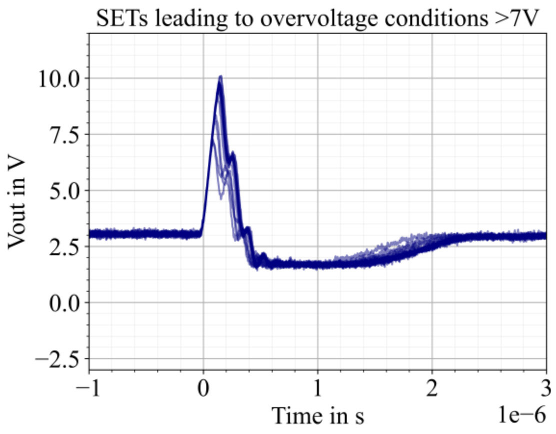
- Crosscheck some data on the maximum duration of an SET
- Verification with Laser, then with HI

Results with Heavy Ion:

- HI tests performed to obtain the WC transient (Xe: LET 62.5 $MeV.cm^2.mg^{-1}$)







- WC Transient: 10V and ~2µs

TEXAS INSTRUMENTS

TL1431-SP

SLVSB44C – JULY 2012 – REVISED NOVEMBER 2020

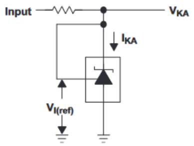
TL1431-SP Class V, Precision Programmable Reference

1 Features

- QMLV qualified to 100-krad(Si) RHA, 5962R99620
- 0.4% initial voltage tolerance
- 0.2-Ω typical output impedance
- Fast turnon: 500 ns
- Sink current capability: 1 mA to 100 mA
- Low reference current (REF)
- Adjustable output voltage: $V_{I(ref)}$ to 36 V

2 Applications

- Adjustable voltage and current referencing
- Secondary side regulation in flyback SMPSs
- Zener replacement
- Voltage monitoring
- Comparator with integrated reference
- Command and data handling (C&DH)
- Optical imaging payload
- Radar imaging payload
- Satellite electrical power system (EPS)



Simplified Schematic

3 Description

The TL1431 is a precision programmable reference with specified thermal stability over automotive, commercial, and military temperature ranges. The output voltage can be set to any value between $V_{I(ref)}$ (approximately 2.5 V) and 36 V with two external resistors. This device has a typical output impedance of 0.2 Ω. Active output circuitry provides a very sharp turnon characteristic, making the device an excellent replacement for Zener diodes and other types of references in applications such as onboard regulation, adjustable power supplies, and switching power supplies.

The TL1431 is characterized for operation over the full military temperature range of –55°C to 125°C.

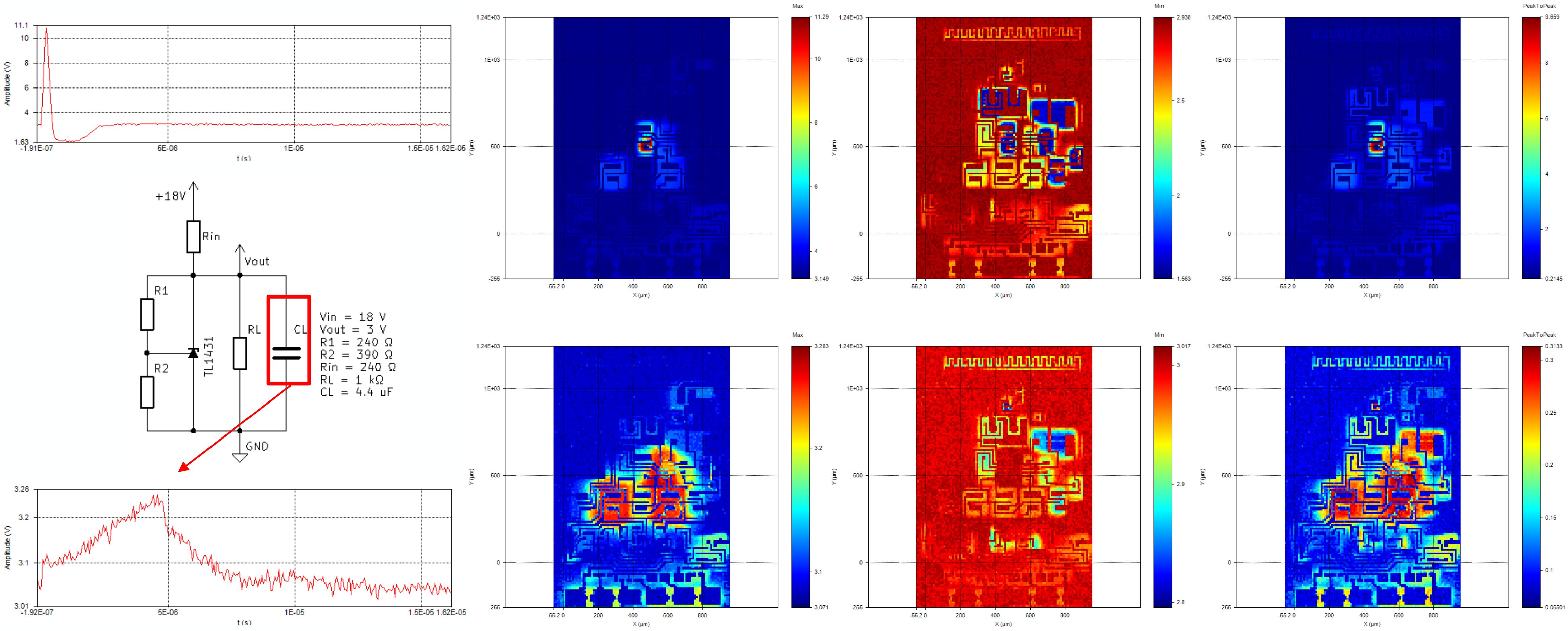
Device Information

PART NUMBER(1)	GRADE	PACKAGE
5962R9962001VPA	Flight grade RHA 100 krad(Si)	8-pin JG Weight 0.87 g(2)
5962-9962001VPA	Flight grade class V	
5962R9962001VHA	Flight grade RHA 100 krad(Si)	10-pin U Weight 0.2 g(2)
TL1431U/EM	Engineering samples(3)	EVM

(1) For all available packages, see the orderable addendum at the end of the data sheet.
(2) Weight is accurate to ±10%.
(3) These units are intended for engineering evaluation only. They are processed to a noncompliant flow (that is, no burn in, and so forth) and are tested to a temperature rating of 25°C only. These units are not suitable for qualification, production, radiation testing or flight use. Parts are not warranted for performance over the full MIL specified temperature range of –55°C to 125°C or operating life.

SET worst case SET. TL1431

Results with Laser:



Failure analysis

Case of a Point of Load

Failure analysis - PoL

DUT: Point of Load

Operator: Marta Rizzo

Background:

- Developed in a frame of an ESA activity ➔ POL-RH
- HI test showed a sensitivity to SEFI and SEB at high load

Objective:

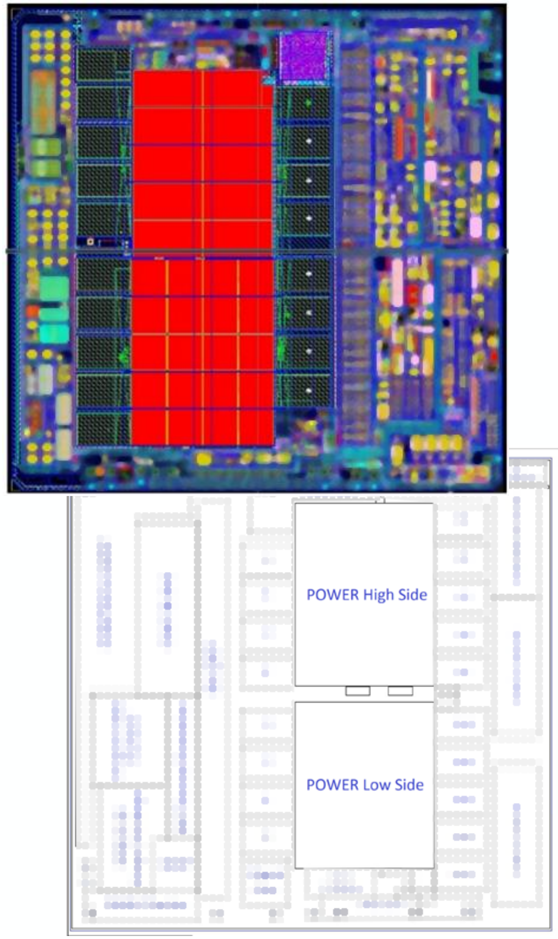
- Detect the SEFI sensitivity region
- Detect SEB sensitivity area

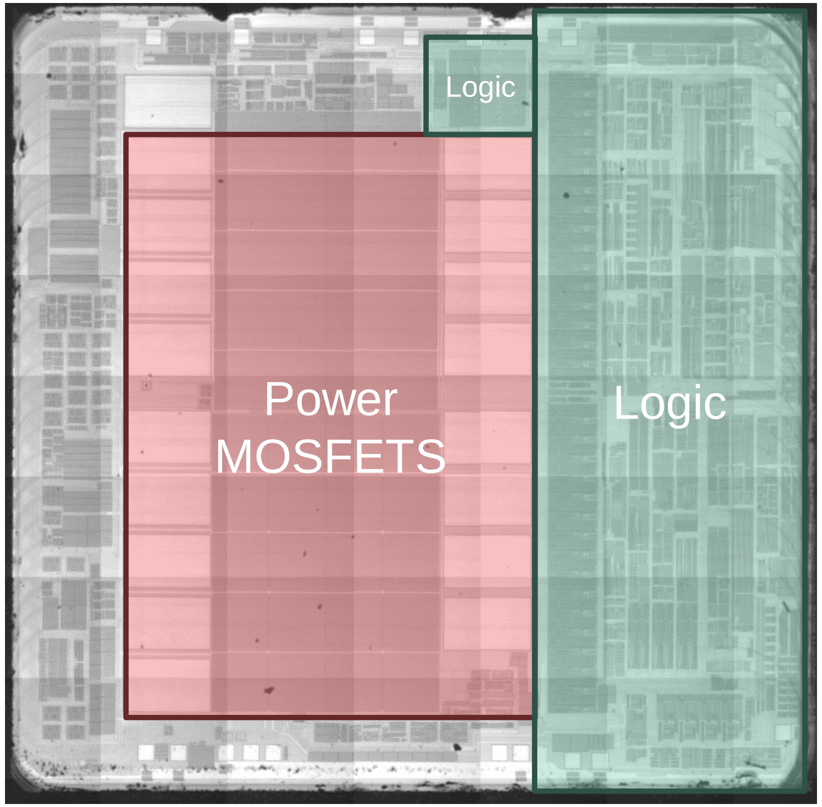
Material:

- Design layout
- Contact with Manufacturer

Suspects:

- None





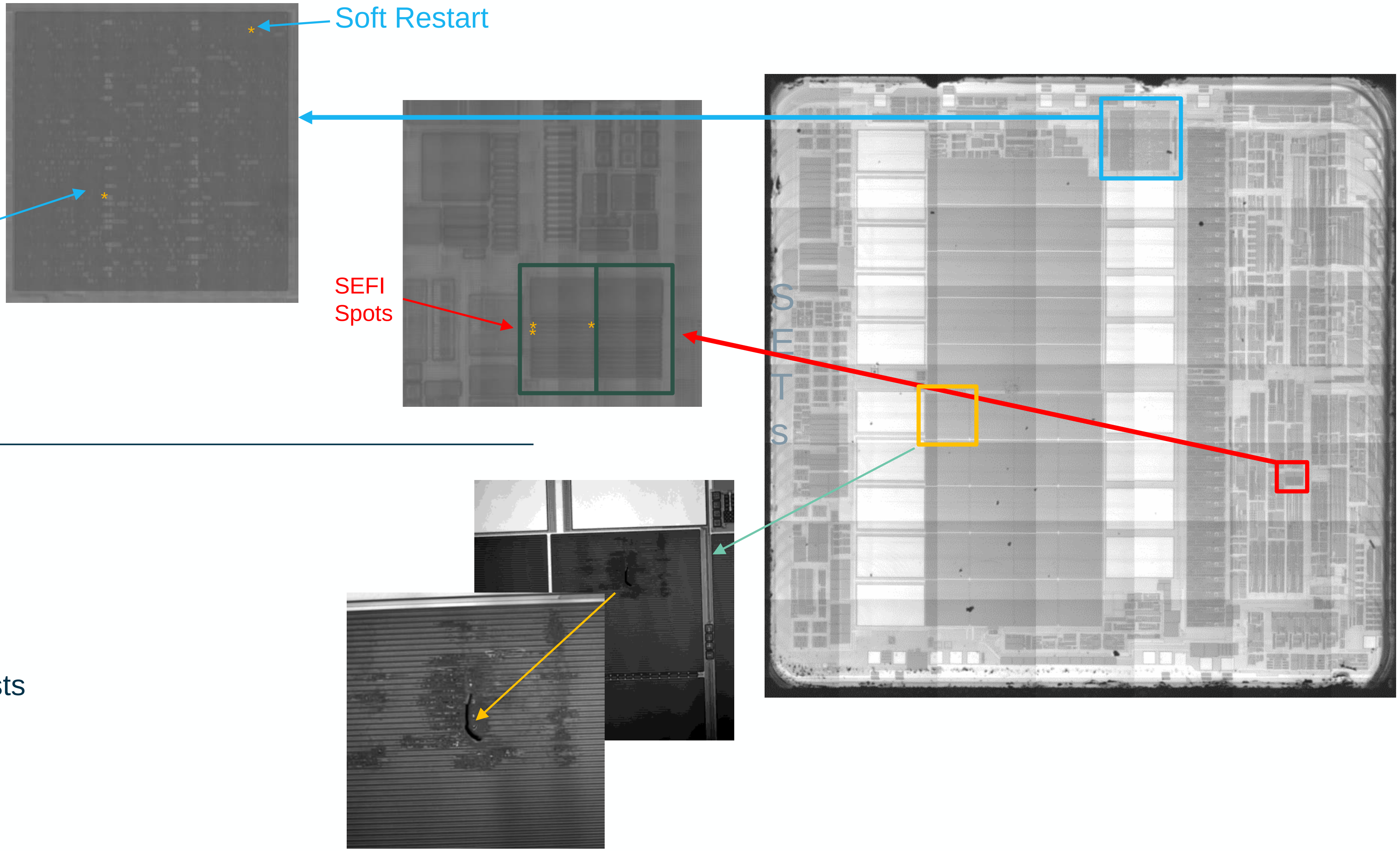
Failure analysis - PoL

SEFI:

- Several SEFI spot located
- Different Failure mechanism
- Trigger repeatable

SEB:

- Sensitive area detected
- Event Triggered with several DUT
- SPA and TPA used
- Failure mechanism same as HI tests

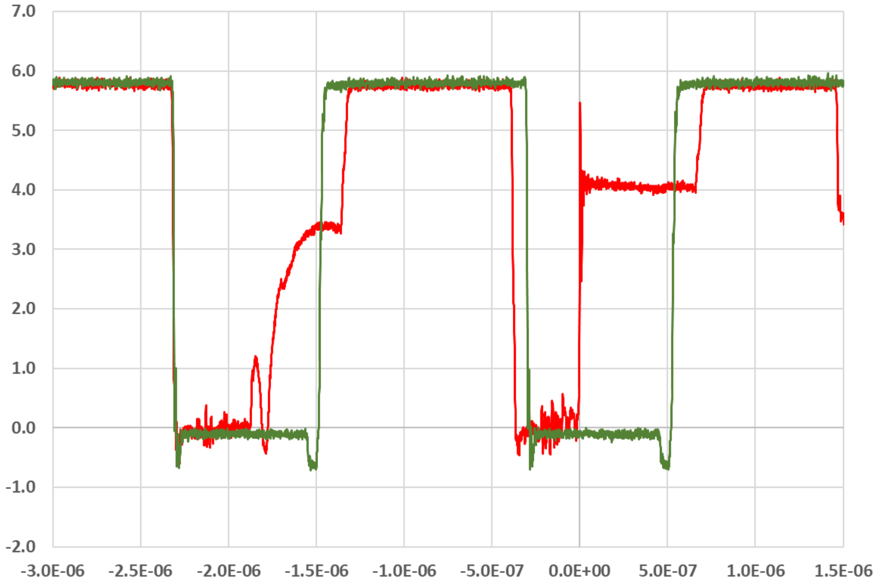


POWER High Side

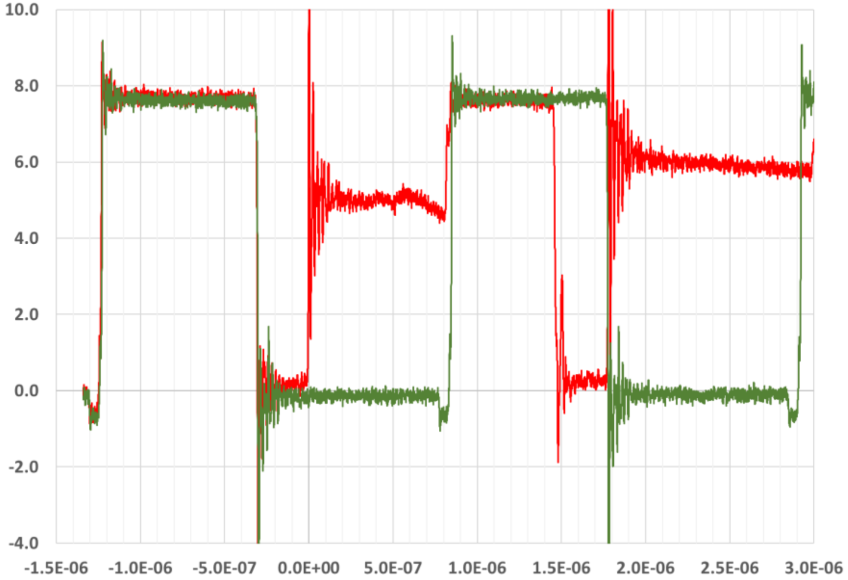
Failure analysis - PoL

Failure mode of PoL Output Power MOSFET's

Output waveforms before filtering



995MeV $^{124}Xe^{35+}$ Heavy Ion beam
(LET 62 MeV/mg/cm2 LET)



SPA 1064nm Laser 1nJ

Burn-out triggered

Fault Injection

Case of an STM32

Laser testing of software mitigation approaches

DUT: STM32F407

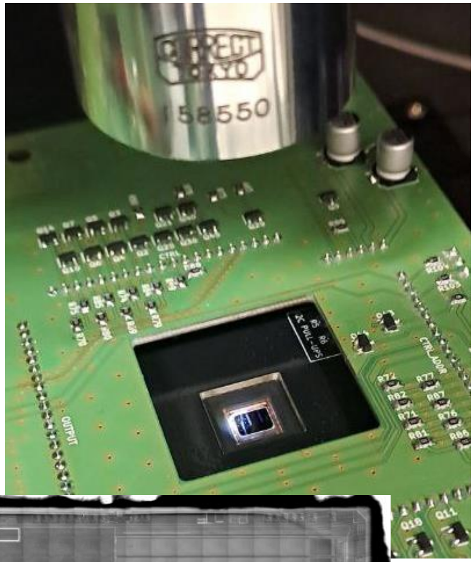
Operator: Federico Reghenzani (Politecnico di Milano, IT)

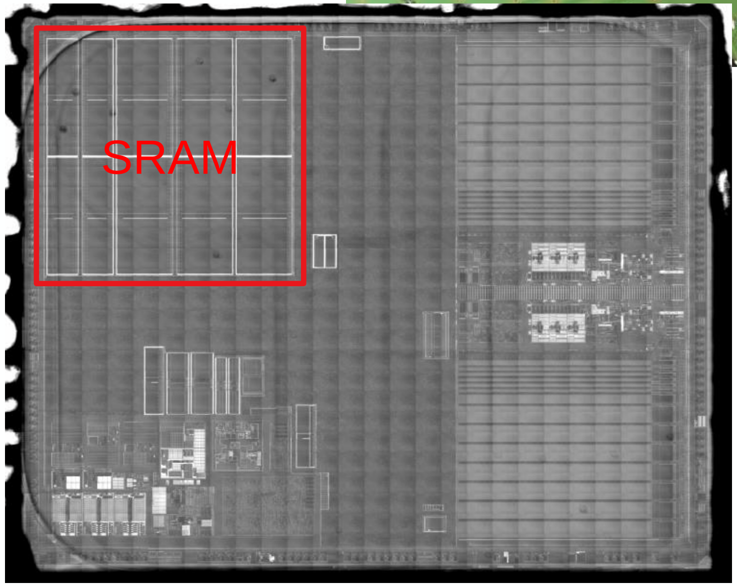
Objective:

- **Software-Implemented Hardware Fault Tolerance (SIHFT)** techniques via laser-based SEU injection
- Test the capability of SIHFT techniques to detect and recover from SEUs by injecting faults without breaking timing metrics

Experimental results:

- COTS automotive **STM32** microcontroller running FreeRTOS with some benchmarks
- The results are promising and showed that when SIHFT is employed, **less than 0.05%** of the effective faults result in a **Silent Data Corruption (SDC)** compared to an unprotected version that exhibits 30%-99% SDC rate (depending on the benchmark)





Die of the STM32F407

Conclusion

Conclusion

Non-Routine test cases presented:

- Comparison SEE Laser vs Heavy Ions
    - Pin diode: Mechanism understood, more tests to be performed
    - SRAM: allowed to deepened investigations on SEL sensitivity & complement heavy-ion data
    - Voltage Reference: Worst-Case SET found, and other configurations tested

- Failure Analysis:
    - Point of Load: Localisation of SEFI and SEB and underwent redesign

- Fault Injection
    - µP STM32: Positive results on the SHIFT technics tested with laser