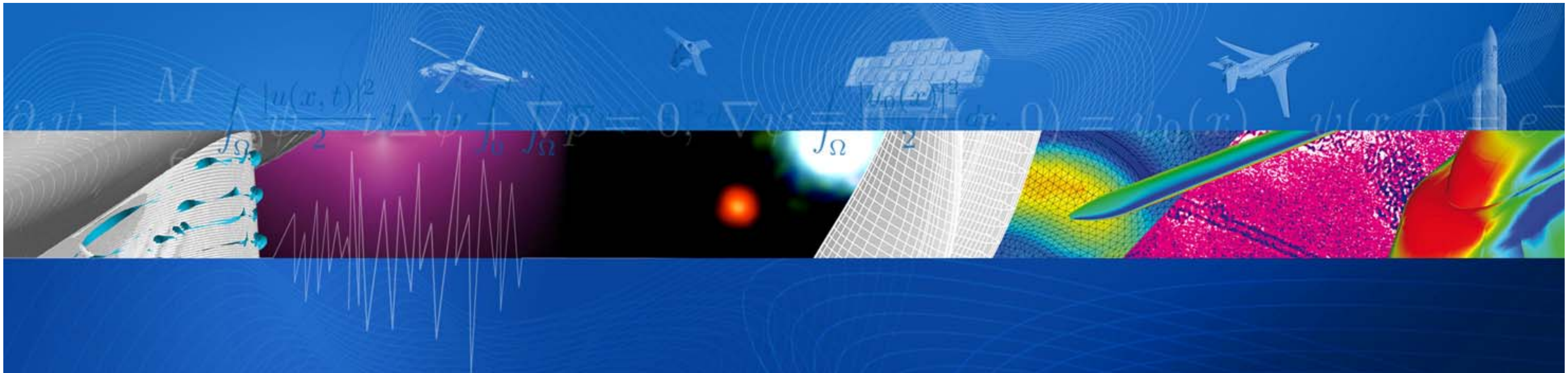

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Recent R&T activity on optoelectronics: bulk defects generation in photodiodes and dose rate/bias effect on CCDs degradation

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Outline

- Overview of recent R&T activity on optoelectronics
  - Identification of defects generated by displacement damages
  - Evaluation of imagers degradation
- Some DLTS results on defect generation
- Dose rate and bias effect on CCDs degradation
  - Context of the study
  - Experimental setup
    - Presentation of the device
    - Measurement conditions
    - Irradiation conditions
  - Total dose results
    - Bias effect
    - Dose rate effect
    - annealings
  - Proton results
  - Comparison with in-flight data
  - Summary of the main results
- Perspectives

Overview of recent R&T activity on optoelectronics

Evaluation of imagers degradation

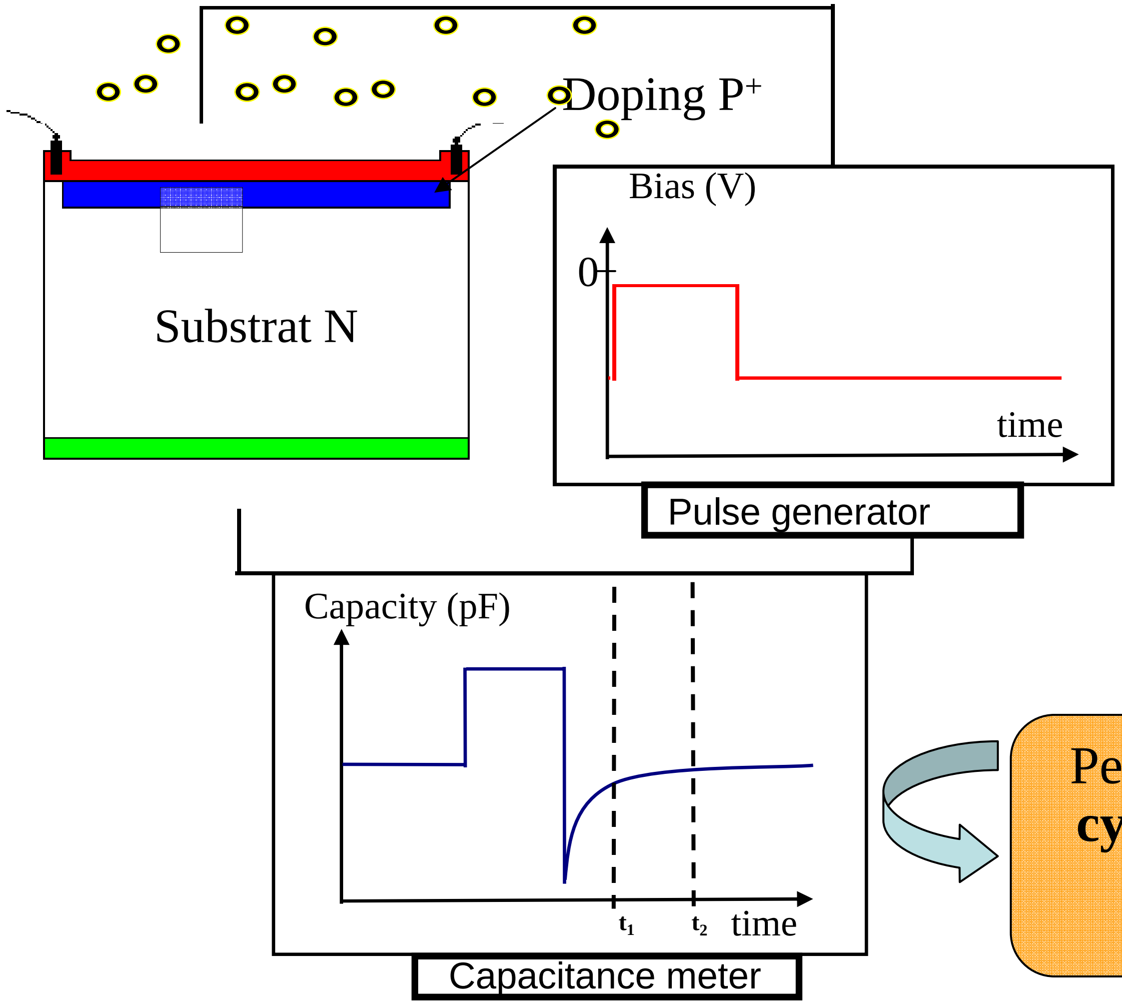
- Influence of test conditions on the final degradation
  - Goal : refine the final degradation evaluation
  - Part of a CNES/Onera PhD study (Emma Martin)
  - Example of results in next part
- Inputs for DSNU estimation
  - Monoenergetic and spectrum proton irradiation with normal incidence
  - Evaluation of the spectrum DSNU from monoenergetic irradiation thank to a fit method proposed by CNES

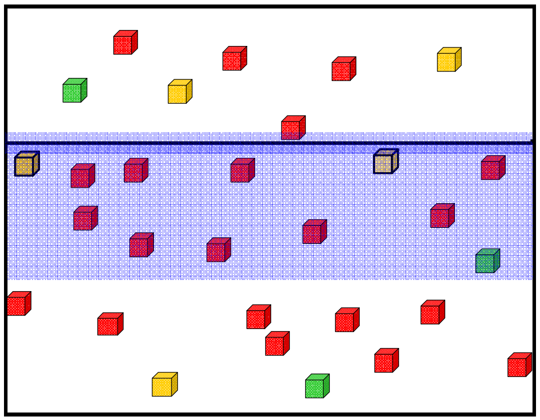
Identification of defects generated by displacement damages

- Goal : understand and estimate the origin of the electrical degradation in electronic devices
  - NIEL calculations
  - From bulk defects to electrical effect
  - Influence of doping type and level
  - High energy deviations
- Method
  - Use of Deep Level Transient Spectroscopy (DLTS) on irradiated photodiodes
  - Extraction of defects nature and concentration
  - Comparison with NIEL calculations
  - Part of an Onera PhD study (Pierre Arnolda)

Identification of defects generated by displacement damages

Description of the DLTS method



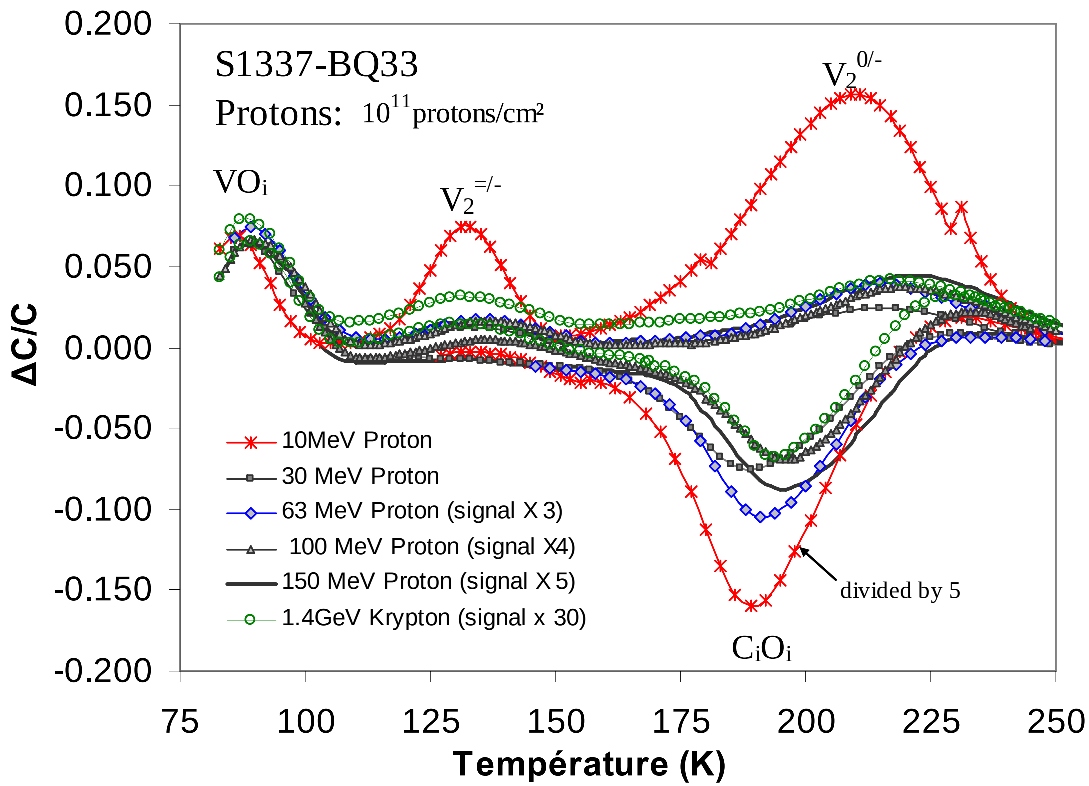


1. Inverted bias
2. Voltage pulse → filling of defects
3. Initial bias → progressive emptying of defects→ transient of capacity

Perform several **filling-emptying cycles** of defects by carriers with different **temperatures**

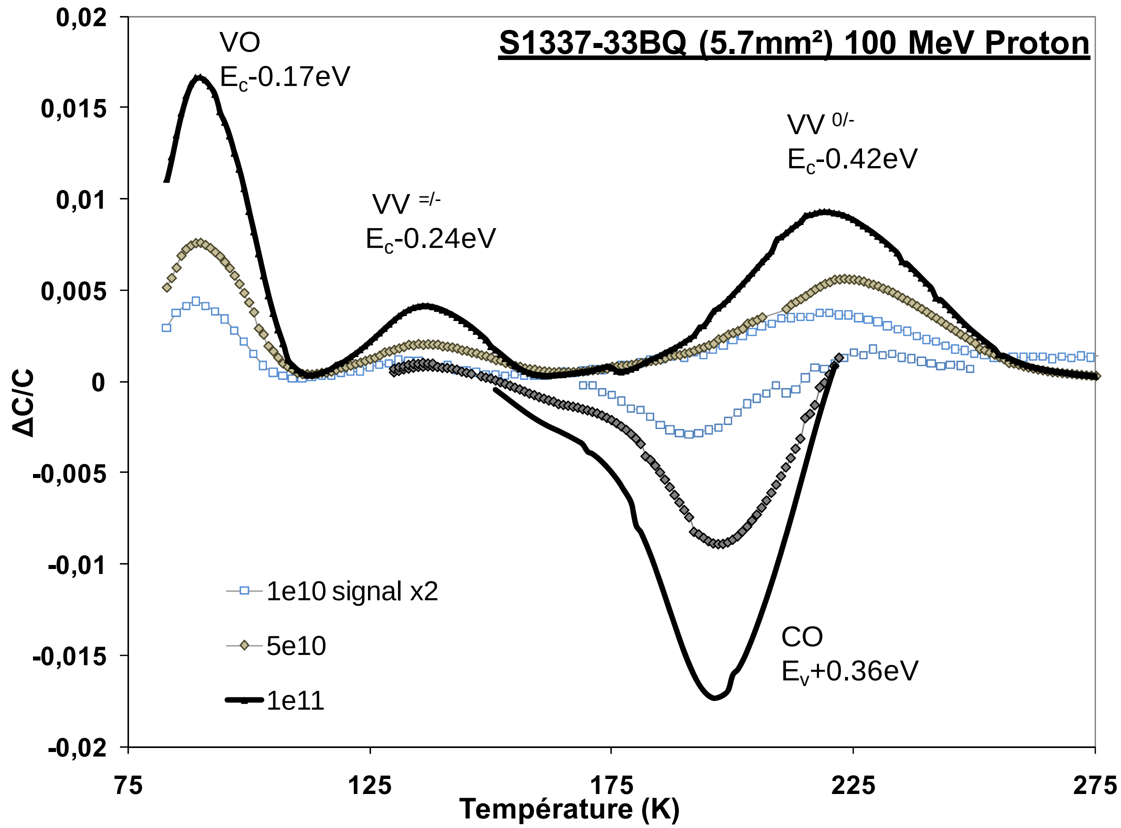
Spectra examples for photodiodes

- Extract parameters for each defect type
  - Concentration
  - Activation energy
  - Capture cross section



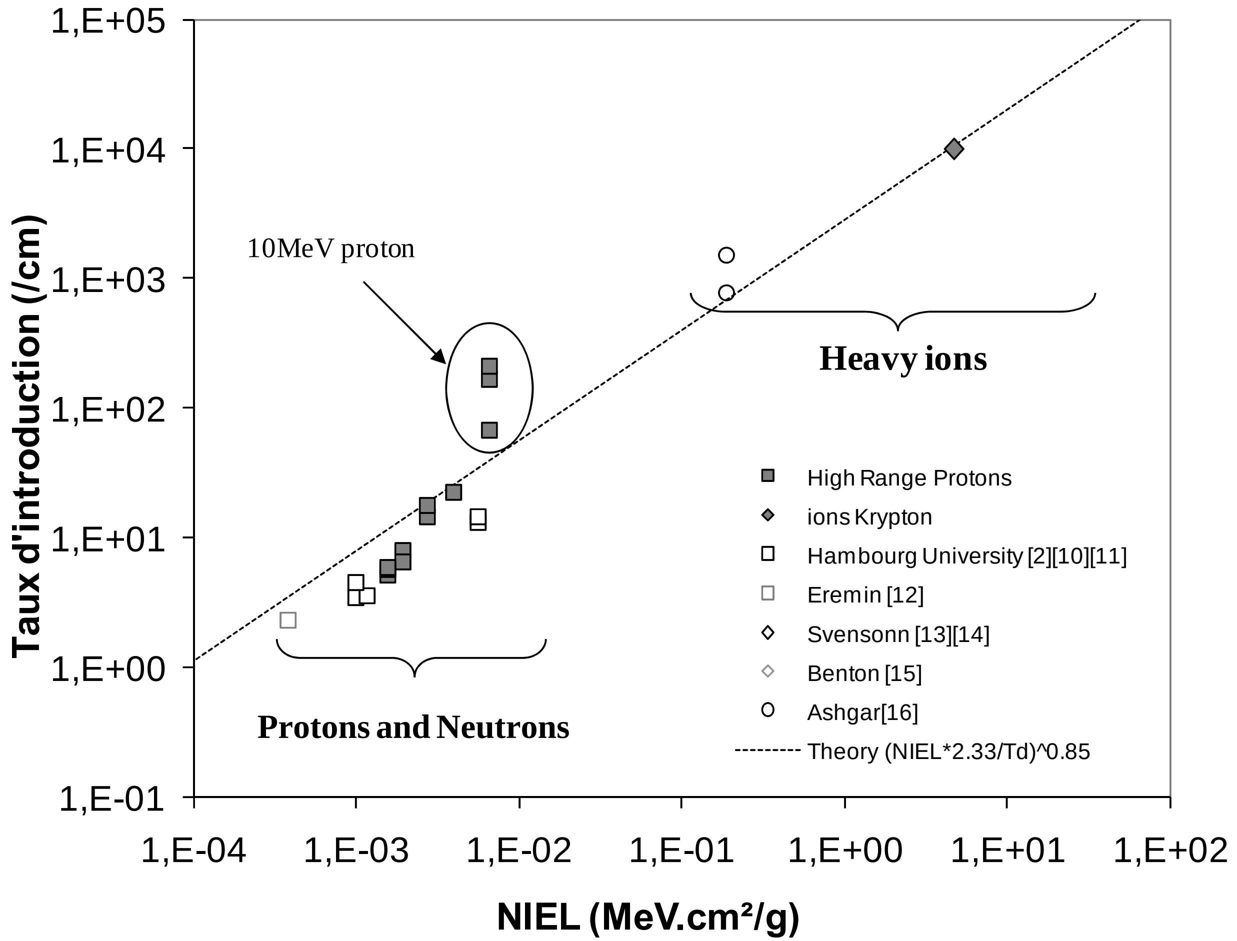
The fraction of each defect type depends on the incident particle type and energy

100 MeV proton spectra with fluence



The defect concentration is proportionnal to the fluence

Defect introduction rate compared to NIEL (concentration/fluence)



Introduction rate proportional to NIEL

Input results for effective NIEL validation (Christophe Inguimbert's presentation)

Dose Rate And Static/Dynamic Bias Effect On CCDs Degradation: context

- <u>CCDs are key components for space missions</u>
  - Heart of the payload for space and Earth observation
  - Generally need of high electro optical performances
  - Need to meet the radiation requirements
  - Limited number of manufacturers

    => reduced number of possible candidates
  - Expensive devices

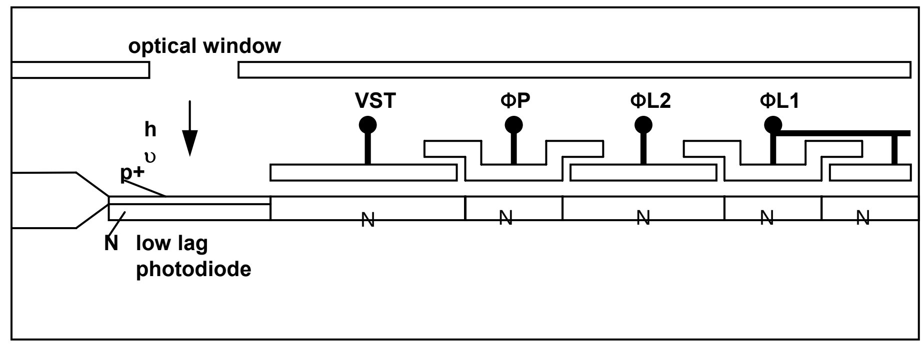
    => reduced number of samples for radiation tests
  - MIL-STD-883G or ESA-SCC 22900 test methods look for the worst case of degradation

- <u>Case of SPOT 5 mission</u>
  - In flight degradation of a CCD is much lower than ground testing results (factor of twelve on dark current density). Device operates 7% of time
  - Would it be possible to reduce the margins and still be conservative?

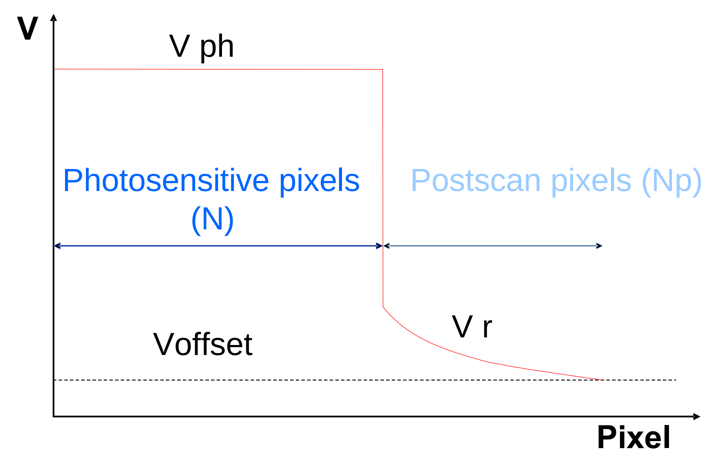
- <u>Test campaign on CCDs with the same reference as SPOT 5 devices</u>
  - Investigate dose rate and bias condition effect
  - Compare results with in-flight data

Experimental Setup

- Device TH7834 e2v
  - 12000 pixels linear CCD, optical size $(6.5\mu m)^2$
  - Two registers, 4 outputs
  - Multi spectral detector of SPOT 5
  - 7% active during the mission (rest = off) => reproduce this duty cycle with 100s period



- Measurement conditions
  - Dark current at 26°C with a dedicated test bench
  - Result converted in nA/cm^2 assuming the optical window area
  - CTI measured thank to postscan signal



Irradiation test plan

7 Devices

5 CCDS for ^{60}Co (UCL GIF)

		Bias		
		OFF	7% ON	100% ON
Dose rate Gy(Si)/h	20		CCD 8	
	3.1		CCD 9	
	0.36	CCD 12	CCD 10	CCD 11

- Irradiations begin at the same time
- On state = activated in dynamic mode (1MHz)
- CCD 8 and 9 maintained biased untill the end of other irradiations (all 20 Gy(Si))

24h RT devices biased like irradiated

168h 100°C biased like irradiated

168h 100°C 100% activated in dynamic mode

2 CCDS for protons unbiased

	Proton energy [Mev]	**Fluence [p+/cm²]**	**Dose (Si) [Gy] SRIM**	**NIEL(Si) [MeV.g.cm^{-2}] NEMO 1.1**	**Displacement damage [MeV/g]**
CCD 6	62 (UCL)	8.3x10^{9}	11.5	3.3x10^{-3}	2.7x10^{7}
CCD 7	Spectrum [8;114] MeV (KVI)	SPOT5 mission (5 years)	11.2		1.7x10^{7}

proton irradiation

Long time unbiased storage

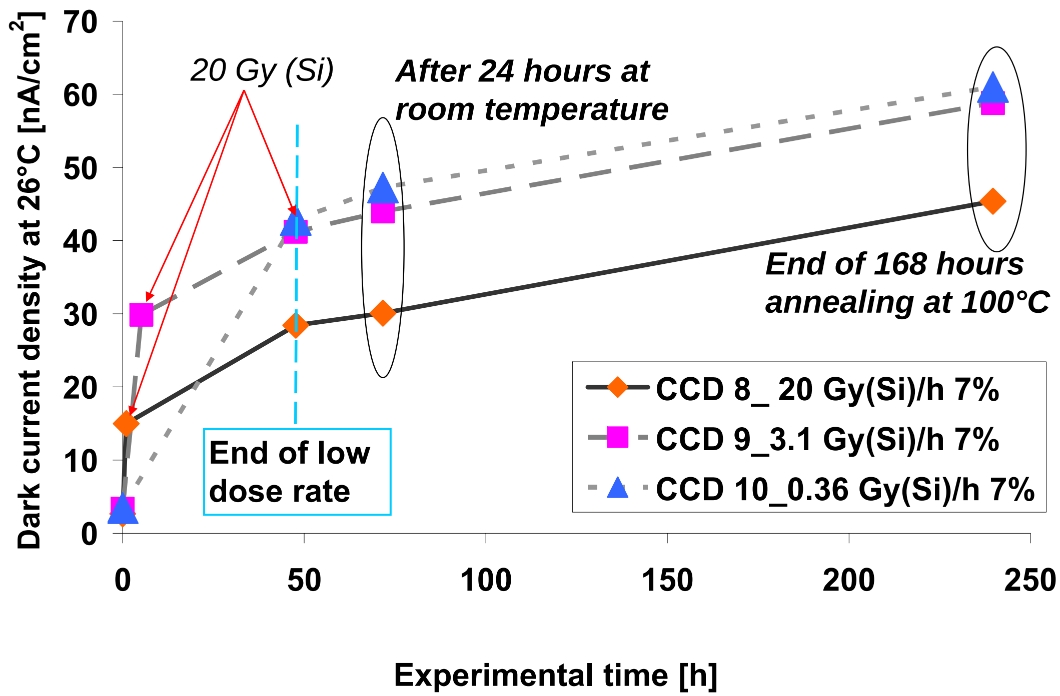
168h 100°C unbiased

168h 100°C 100% activated in dynamic mode

Dose rate effect

- More degradation at lower dose rate at the end of the irradiation
  - Device 7% biased
  - 50% higher degradation
  - Still verified after first annealing (7% biased)

Time dependent and ELDRS-like effect

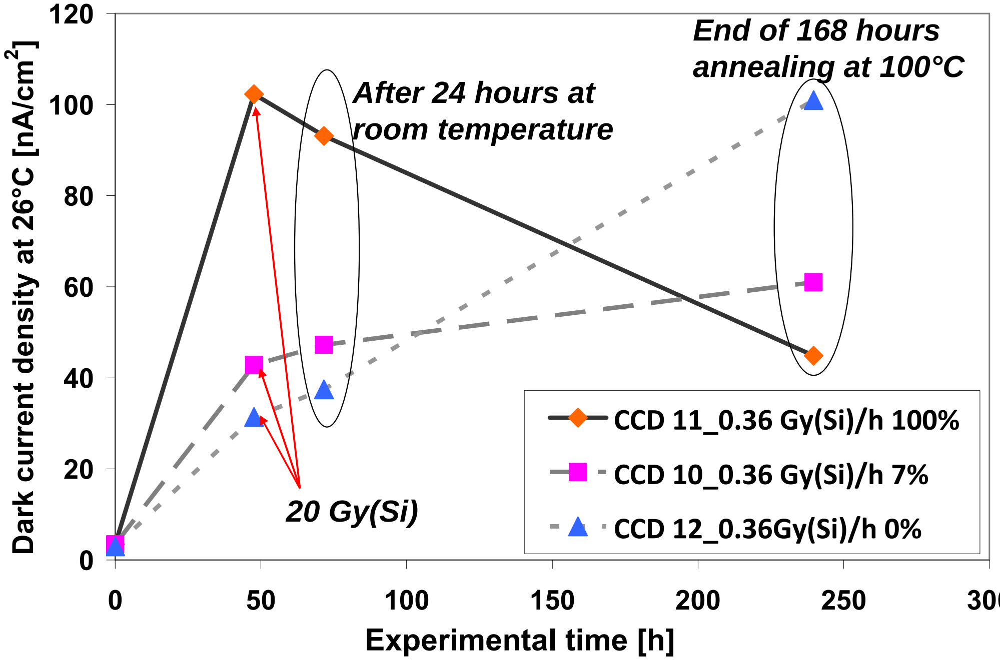


- <u>Possible reasons</u>
  - High electron-hole recombinaison rate in « off » and High Dose Rate
  - Slow charge transport in insulating oxydes

Bias effect on total dose

- More degradation on biased devices at the end of the irradiation => Factor of 3 from device to device : typical MOS behaviour

- Possible reasons: different recombinaison rate because of bias

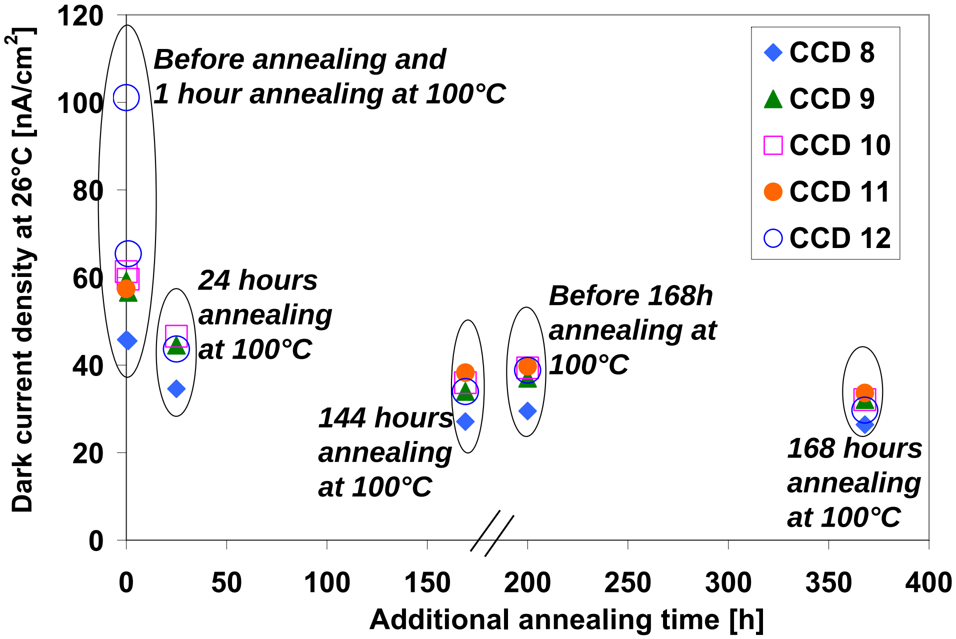


- Different behaviour for first annealing (same bias as irradiation)
  - Decrease of dark current 100% On device
  - Increase for 7% and Off devices

Further annealing with devices biased

- Decrease of dark current
- Almost the same final result for all devices

➡ Importance of oxide charge on dark current degradation



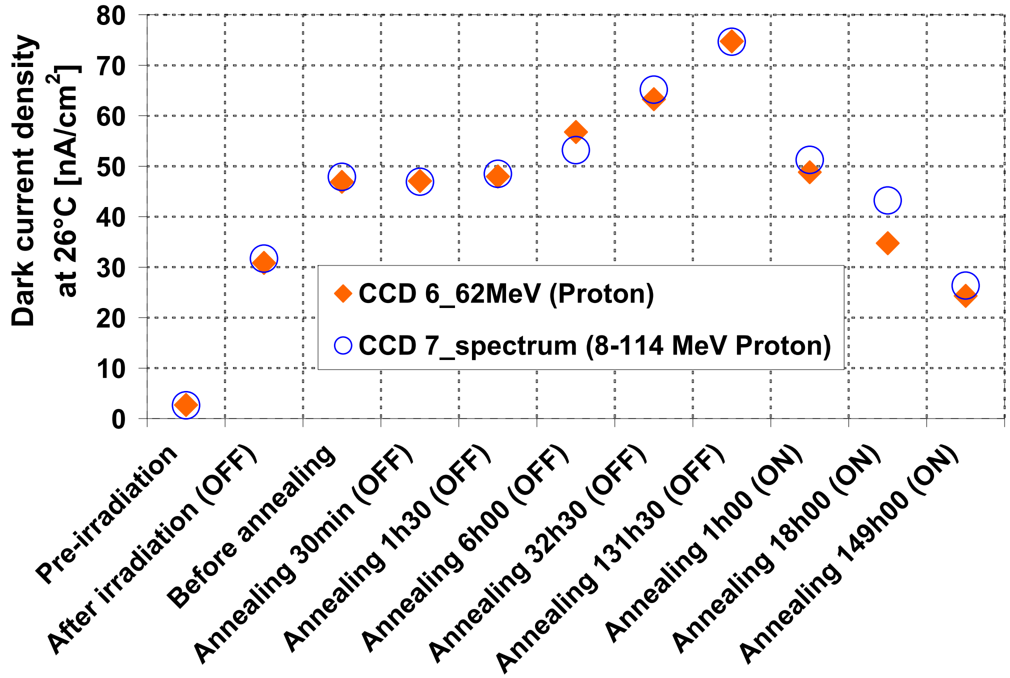
- <u>Possible degradation modes</u>
  - Creation of leakage paths
  - Extention of depleted area at the Si/SiO_2 interface combined with the creation of interface generation states

Proton results 1/2

- Comparison with total dose unbiased
  - Higher dose rate and lower charge yield
  - Same dark current for half total dose => effect of bulk damage

	Dark current density at 26°C [nA/cm²]	
	Before irradiation	After irradiation
CCD 6	2.7	30.8 at 11.5 Gy(si)
CCD 7	2.6	31.7 at 10.6 Gy(Si)
CCD 12	3.0	31.4 at 20.0 Gy(Si)

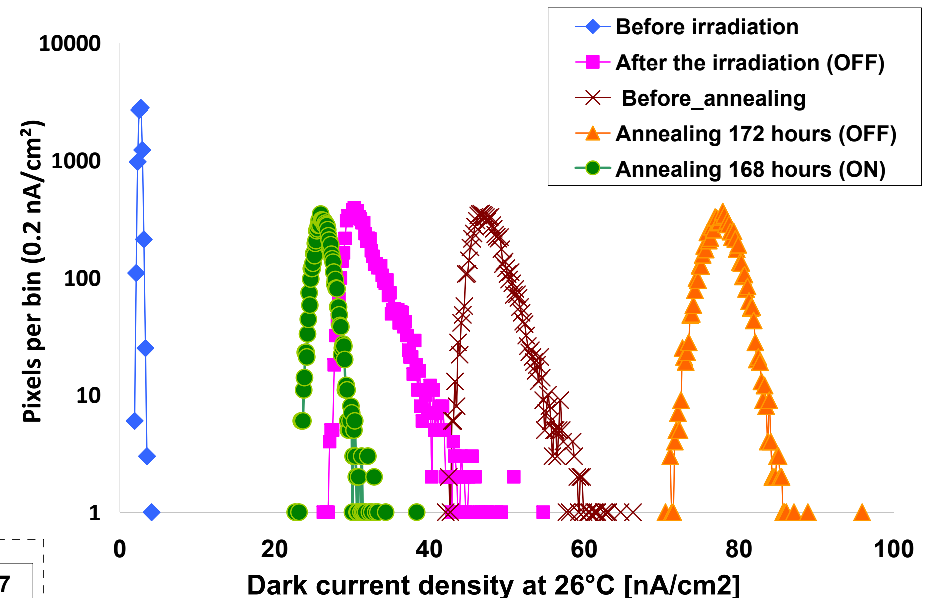
- Annealing effect
  - Effect of long time RT storage
  - Same behaviour than with CCD 12
  - Competition between total dose effect (increase) and bulk defect annealing

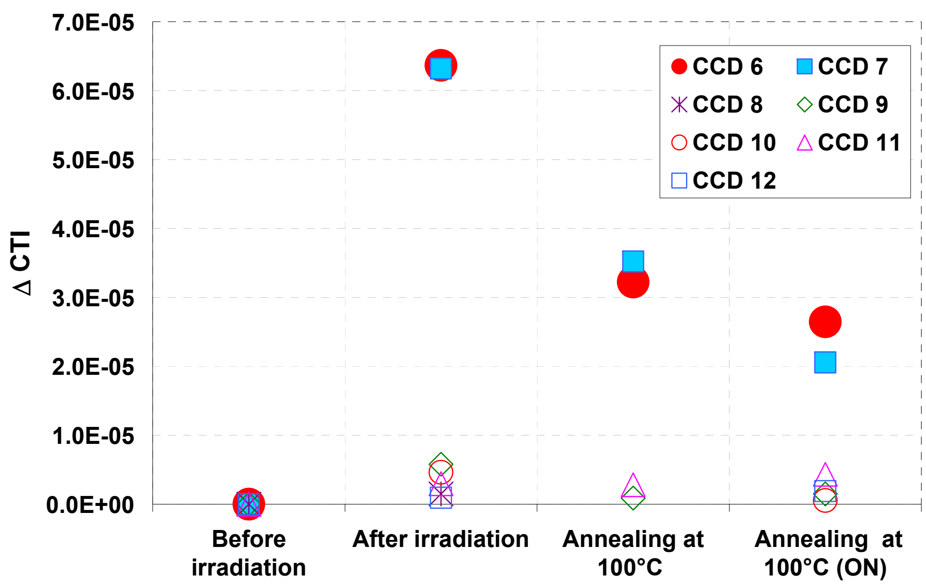


Proton results 2/2
Annealing of bulk damage

- Shape of the dark current distribution CCD 7

  => The tail disapears with annealing

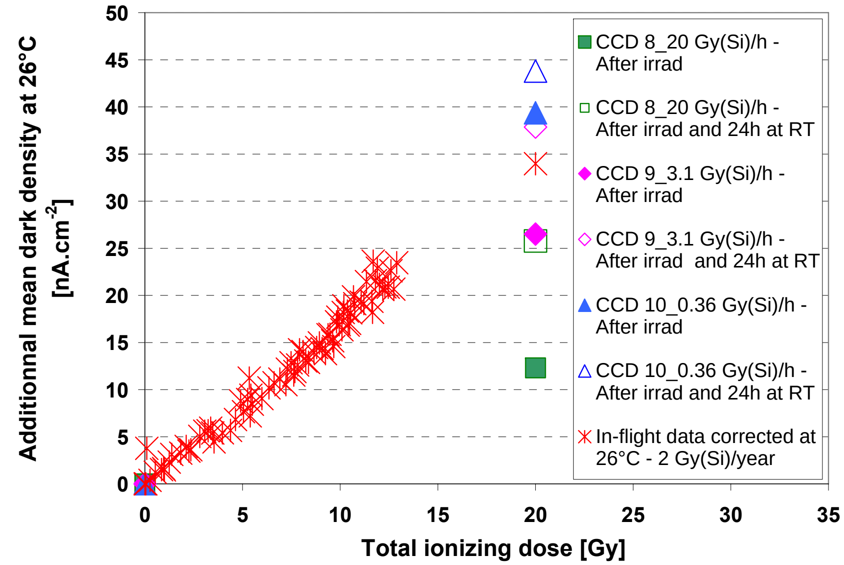


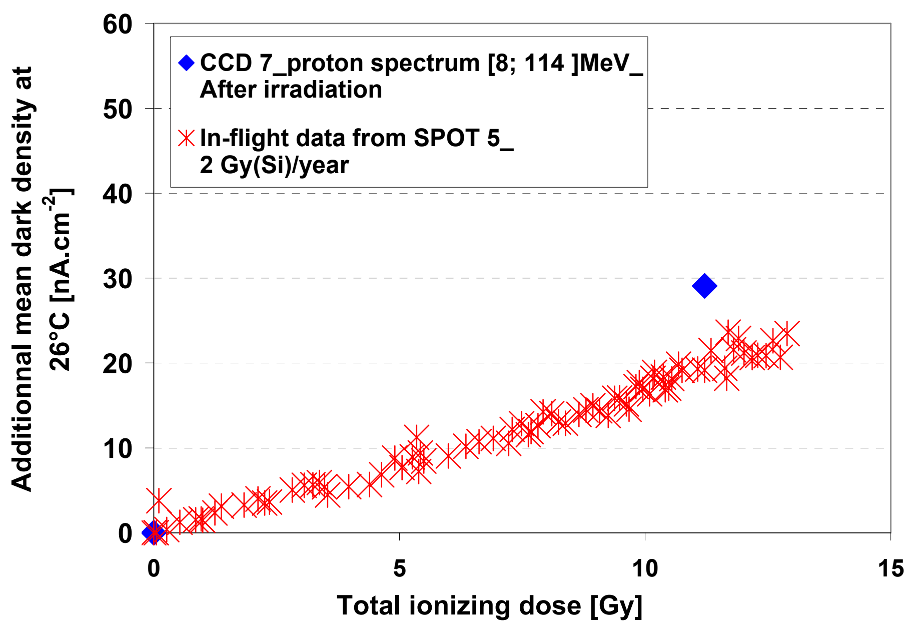


- CTI evolution
  - No total dose effect
  - No bias effect
  - Large annealing of bulk damage

Comparison with in-flight data

- <u>Assumptions - approximations</u>
  - Not the same device batch between tested parts and flight model
  - Uncertainty on the in-flight total dose
  - Data at 10°C modified to 26°C
  - Linear extrapolation to 20 Gy(Si)





- <u>Total dose</u>
  - Close to low dose rate and 7% biased
  - Bulk damage not taken into account
- <u>Protons</u>
  - Not the same bias and dose rate
- Results in the same order of magnitude - no strong overestimation

Summary

Main results

- Device sensitive to both ionization and displacements
- Strong dose rate and bias effects
- Important contribution of oxide charge in the dark current increase
- Large part of annealing of bulk damages after 168h 100°C

Implication on hardness assurance testing

- Worst case given by the standards (ON bias)
- Interest to test the device in the same bias conditions as in-flight, especially when those conditions strongly differ from worst case
- A way to approach the real degradation but:
  - Possible ERDLS-like effect: be carefull on dose rate
  - No assurance we have a worst case
  - Problem to generalize those results
  - Look at influence of other parameters (accleration rate of activation frequency, temperature, …)

Perspectives

Estimation of the total dose degradation

- Experimental study of APS devices
- Effect of bias (activation) and dose rate
- Gamma vs proton irradiation
- Part of Emma Martin PhD study

Estimation of the DSNU

- Modelisation of the DSNU after proton irradiation
- Develop a Monte Carlo code based on GEANT 4 simulations
- Take into account:
  - the fraction of energy deposited in a pixel and its neighbours
  - The pixel dimensions
- Different steps:
  - Monoenergetic protons with normal incidence => spectrum
  - Energy distribution => electrical effect (DSNU)