RTS MEASUREMENTS TECHNIQUES IN CCDs IRRADIATED WITH PROTONS OR NEUTRONS AND APPLICATIONS

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Outline

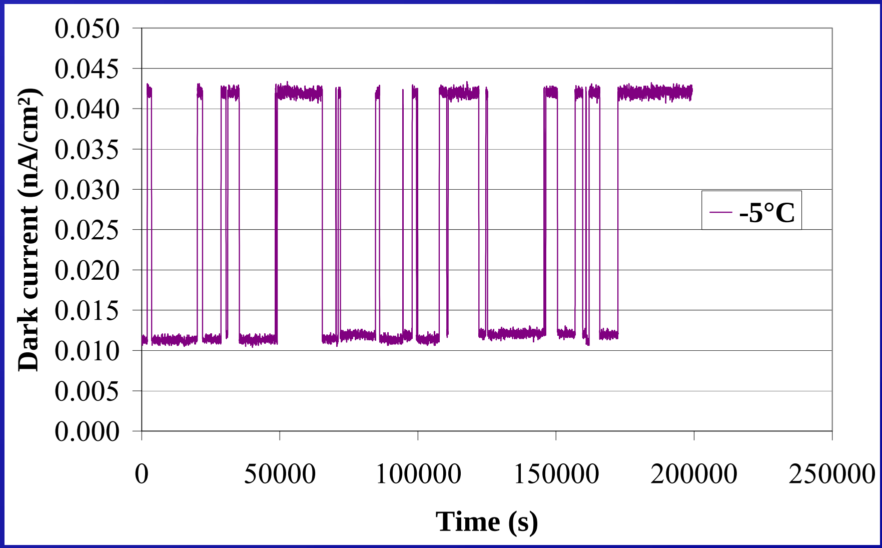
- Context of the study
- RTS Detection in CCDs
  => Detection through variance measurement
- Applications
  - Effect of proton energy
  - RTS annealing survey
  - RTS detection for projects
- Following studies: CNES transportable test bench
- Conclusion

Context

- Motivation: develop a methodology to evaluate CCDs sensitivity to RTS

- What is RTS ?
  - Fluctuation of dark current between discrete values with random time intervals
  - Associated to defects in the bulk of the semiconductor
  - Observed in different semiconductor types (Si, InGaAs)

- RTS is a problem for space missions
  - Degradation of the imager performances
  - In-flight calibrations (and thus post treatment corrections) difficult because of random variations



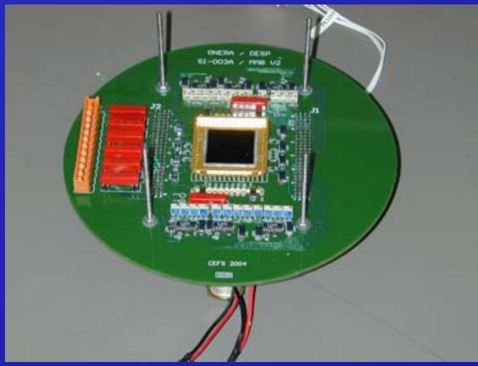
RTS detection 1/2

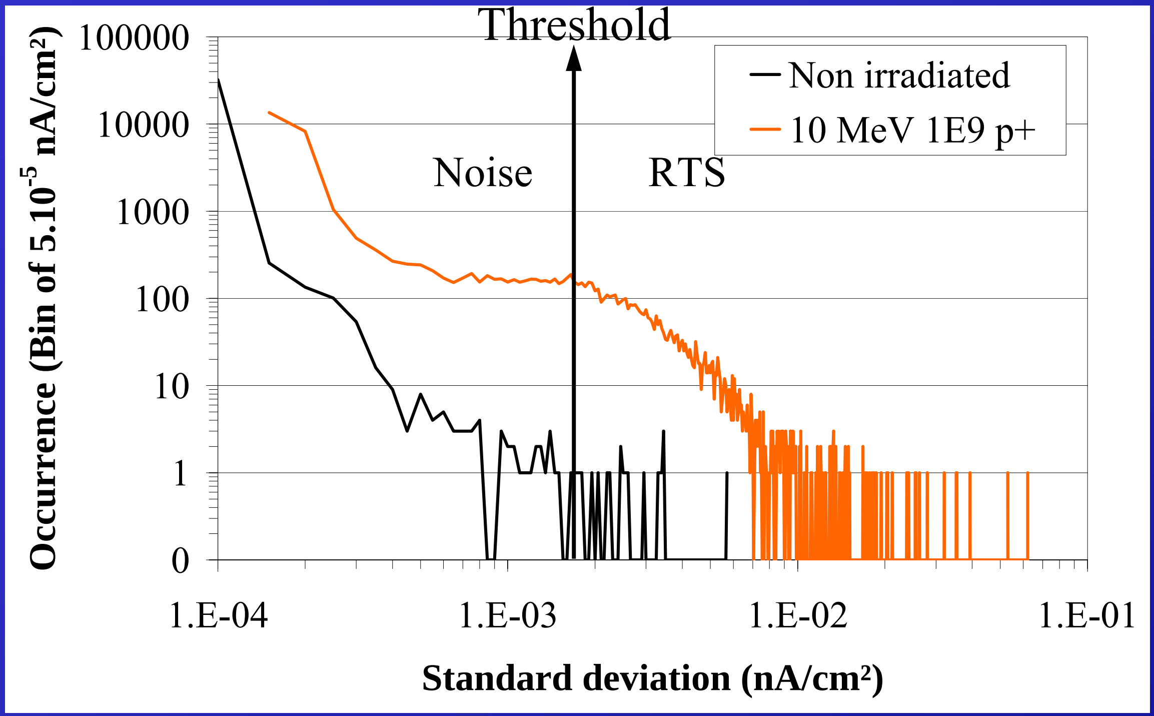
- Record the variance of each pixel dark current (or response)
  - Some thousands of repetitive measurements (same temperature and integration time)
  - Plot of the standard deviation histogram for all the pixels
- Different noise sources that contribute to global variance
  - Inside the device
    - Thermal generation assuming a Poissonien process (square root of the number of charge per pixel): one of the main contribution
    - Transfer of charges for CCDs (trap of charges and release): depend on test conditions (transfer frequency, temperature)
    - Output amplifier
  - Analog to digital conversion
    - Converter resolution and accuracy
    - Linearity
  - Environmental consideration
    - Stability of the phase generation (timing and level accuracy)
    - Thermal stability (direct impact on dark current)
- + RTS

Quantitative Estimation
⇒ Maximum
⇒ threshold

RTS detection 2/2

- Application: Device SITe SI-003A
  - 1024 x 1024 pixels, 24 x 24 µm, equivalent to 4 x 512 x 512 (4 outputs)
  - 14 µm Silicon substrate (back thinned), back illuminated
  - MPP, 3-phases operation





Standard deviation histogram of 32,760 pixels, 5,000 measurements Ti = 20s, -10°C

⇒ Threshold "selection" compatible with estimated noise level

- Probability of pixel with RTS

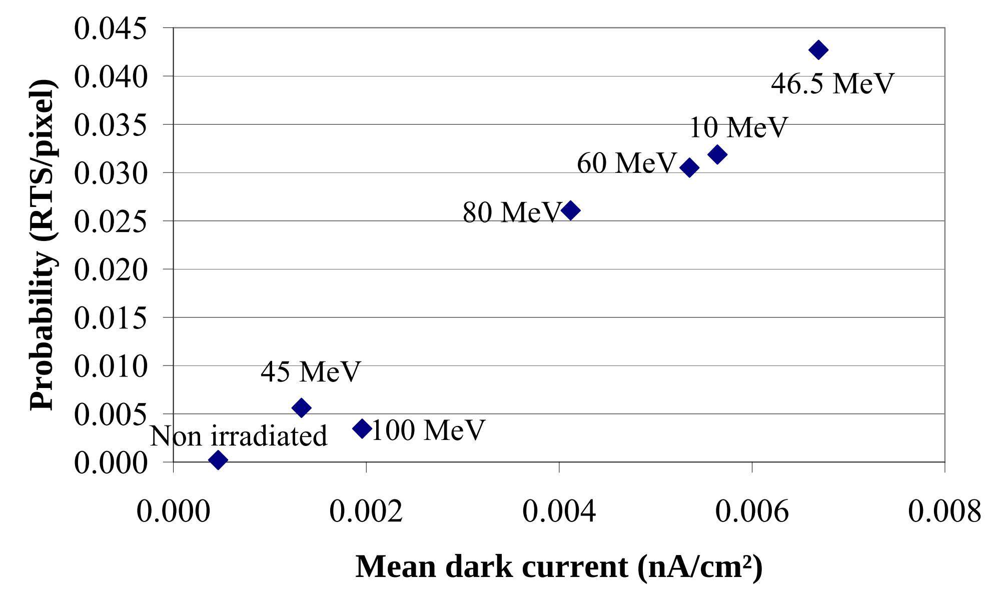
$$\text{Probability} = \frac{Nb_{\sigma_{pixel} > threshold}}{Nb_{total.pixels}}$$

Effect of Proton energy

RADECS 2005

- Results over energies

Irradiation	Number of pixels > 3 pA/cm²	Probability (RTS/pixel)
N.I.	7	$2.14\ 10^{-4}$
10 MeV p^+ (10^9/cm²)	1044	$3.19\ 10^{-2}$
46.5 MeV p^+ (2 10^9 /cm²)	1399	$4.27\ 10^{-2}$
60 MeV p^+ (10^9/cm²)	999	$3.05\ 10^{-2}$
80 MeV p^+ (10^9/cm²)	854	$2.41\ 10^{-2}$
100 MeV p^+ (10^9/cm²)	114	$3.48\ 10^{-3}$
45 MeV n° (10^9/cm²)	184	$5.62\ 10^{-3}$



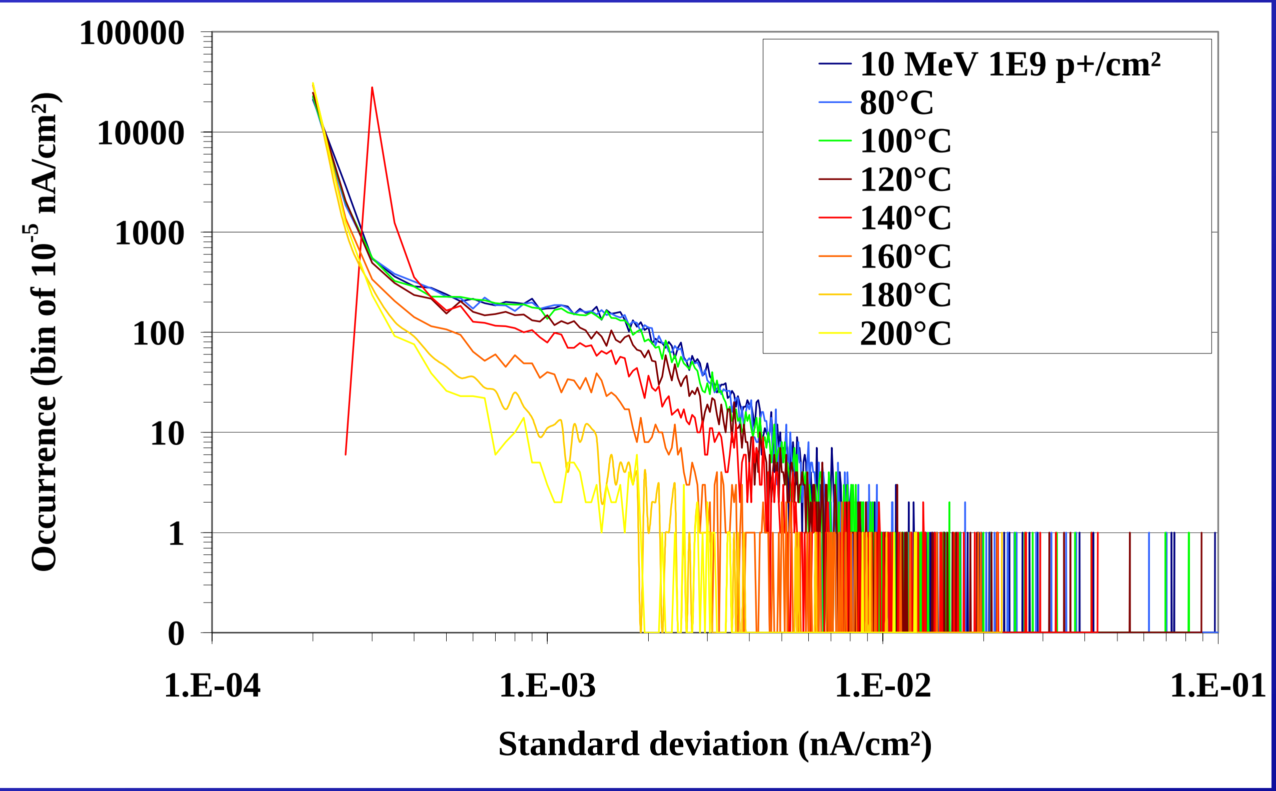
3 pA/cm² Threshold, -10°C

- Comparison between mean dark current and RTS probability
  - Proportionality
  - Verified for threshold between 1 and 5 pA/cm²
  - Extraction of the RTS probability per pixel per proton (neutron) at a given energy

RTS stability: Annealing results 1/2

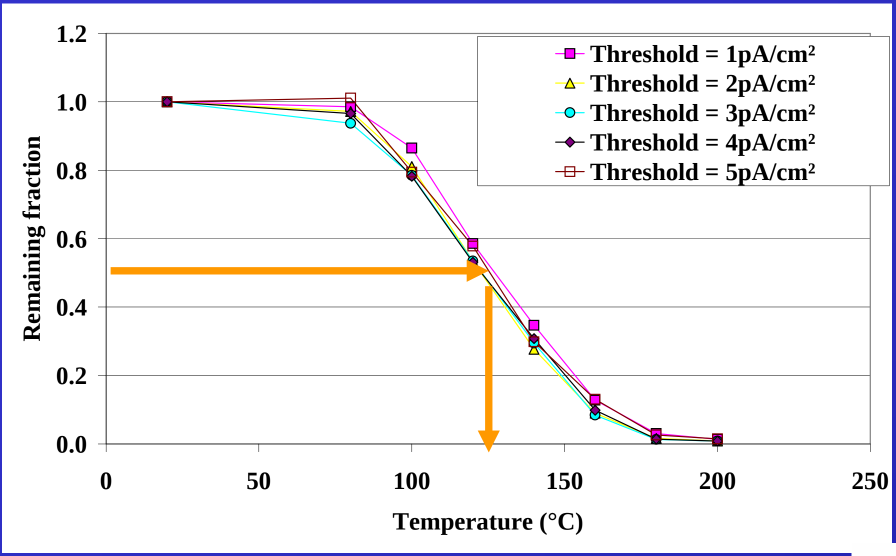
RADECS 2006

- 30 min. Isochronal annealing every 20°C

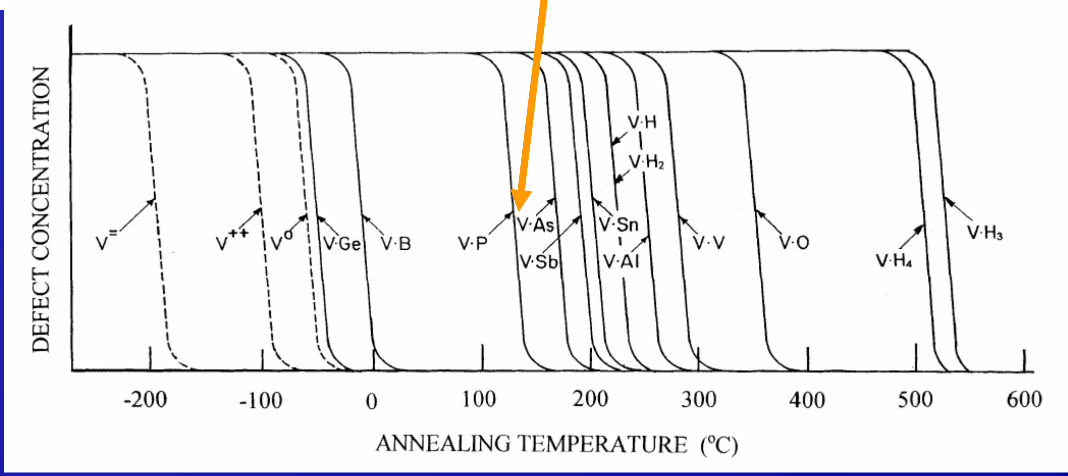


Standard deviation histogram evolution after different annealing temperatures, Ti = 20s, -10°C 32,760 pixels

RTS stability: Annealing results 2/2



- Preferential annealing temperature close to 125°C
- Compatible with P-V center [Wat]
- Strengthens [Hpk] hypothesis



[Wat] G. D. Watkins “Intrinsic defects in silicon", Material Science in semiconductor processing, vol. 3, 2000

[Hpk] I. H. Hopkins and G. R. Hopkinson, “Further measurements of andom telegraph signals in proton irradiated CCDs", IEEE Transaction On Nuclear Science, vol. NS-46, n°6 1995

Hints of use in a project application

- Irradiation conditions
  - Choice of energy and fluence ?
    - Linearity observed on this device between mean dark current increase and RTS probability
    - NIEL scaling ? to be confirmed
  - Temperature considerations for cold applications
    - Many irradiations performed at room temperature
    - Representativity of displacements organization into stable defects at low temperatures ?
    - Possibility of stable defects contributing to RTS at low temperature annealed at room temperature ?
- Choice of measurement conditions
  - Integration time (definition of the maximum switching frequency): Better close to final application
  - Measurement duration (definition of the minimum switching frequency): Compatible to calibration period
  - Measurement cadence: Limit of the number of measurement to some thousands
  - Temperature close to application
  - Threshold determined by the global acquisition accuracy and project specification

Transportable Test Bench for CCD Characterization on Site

- Development in progress at CNES (end of the validation phase in June 2007)
- Measured performance
  - Dark current (mean and DSNU)
  - Transfer efficiency
  - Conversion factor
  - Spectral response
  - Pixel response non-uniformity
  - Linearity
  - Saturation voltage
  - Leakage current (gate to substrate and inter-pin)

Conclusion

- Detection of RTS
  - Proposition of a quantitative detection technique through variance measurement
  - Applications to RTS comprehension on a CCD irradiated at room temperature
    - Tentative of NIEL scaling => reduce sensitivity measurement to one experimental data (energy and fluence)
    - Characteristic annealing temperature
- Application to device characterization for a space project

  => Test should be adapted to the mission requirements and conditions
- Further studies of CCDs and APS degradation under protons and heavy ions
  - Development of a transportable test bench by CNES
  - Possible applications for spike study and fast post irradiation changes in device response