Radiation Induced Leakage Current and Electric Field Enhancement in CMOS Image Sensor Sense Node Floating Diffusions

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DE LA RECHERCHE À L'INDUSTRIE

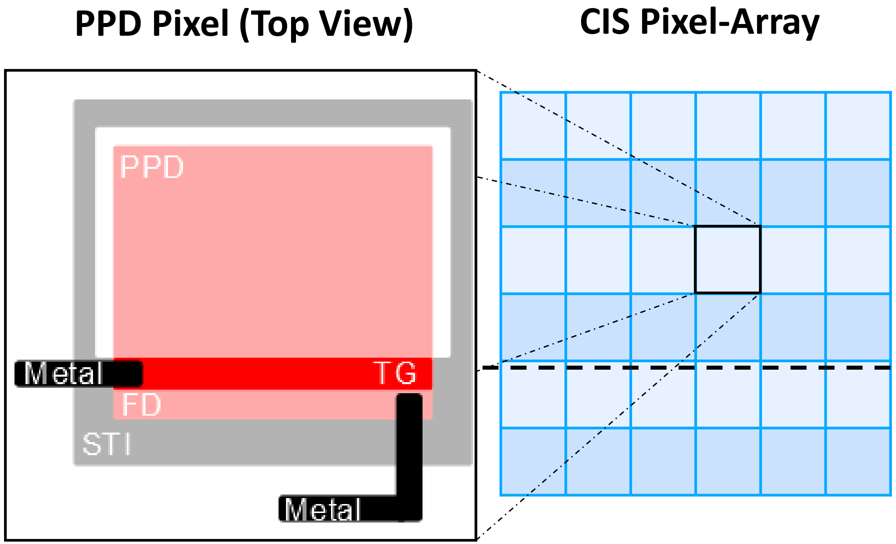
Context and Motivation

- CMOS Image Sensor (**CIS**):

Pixel-array where transistors are integrated in the pixel.

- Pinned-PhotoDiode (**PPD**) CIS are more and more considered for visible imaging in radiative environments.

- Leakage current sources have been extensively studied in the PPDs.

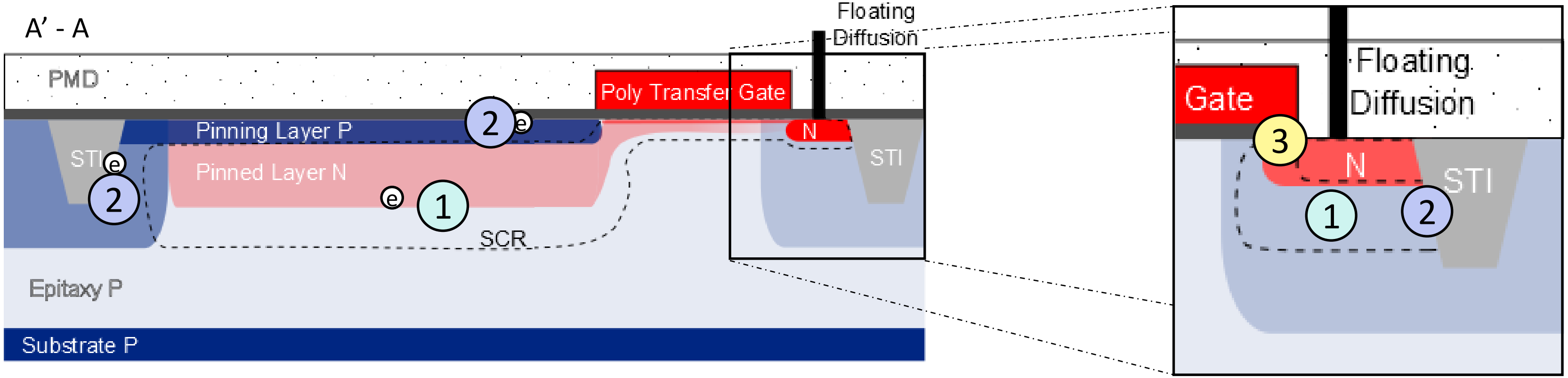


No study dedicated to the <u>Floating Diffusions</u> (FD) leakage current after irradiation.

Context and motivation: The role of the Floating Diffusion

Integration → Transfer → Idle Time → Readout

PPD Pixel (Top View)



- The same leakage current sources are expected to be found in both structures:

(1) Bulk defects (2) Si/SiO_2 interface defects (3) Gate Induced Leakage (GIL)

- The FD leakage current is more influent when long storage times are concerned.

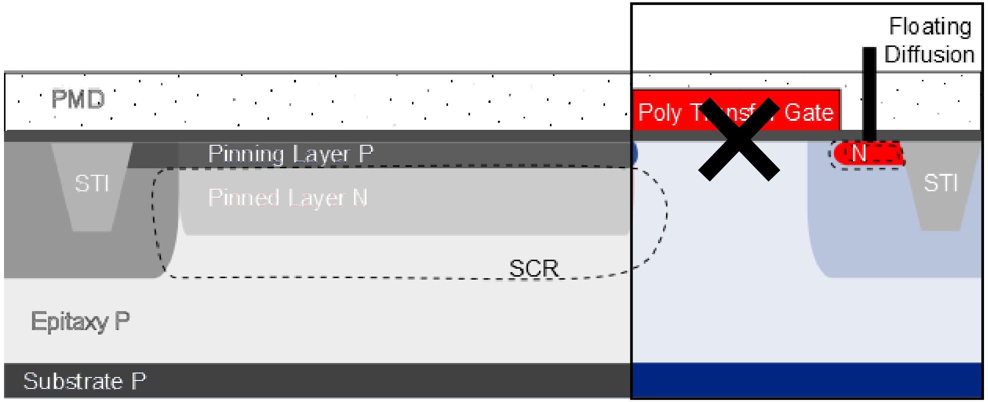
Global Shutter CIS must consider the FD leakage current in radiative environments.

Experimental Details: Comparison PPD Vs FD

CIS under test:

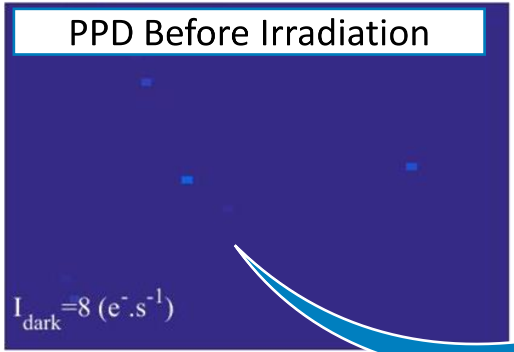
- 4T PPD
- Custom Imager designed at ISAE-SUPAERO
- Standard 0.18 µm deep micron technology
- 512 x 512 pixels
- 7µm pitch
- PPD depleted volume 23 µm3
- FD depleted volume 6 µm3

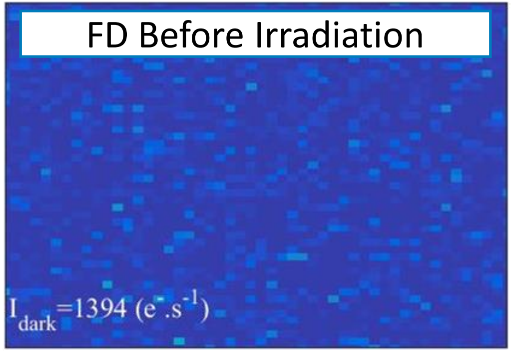
FD structure

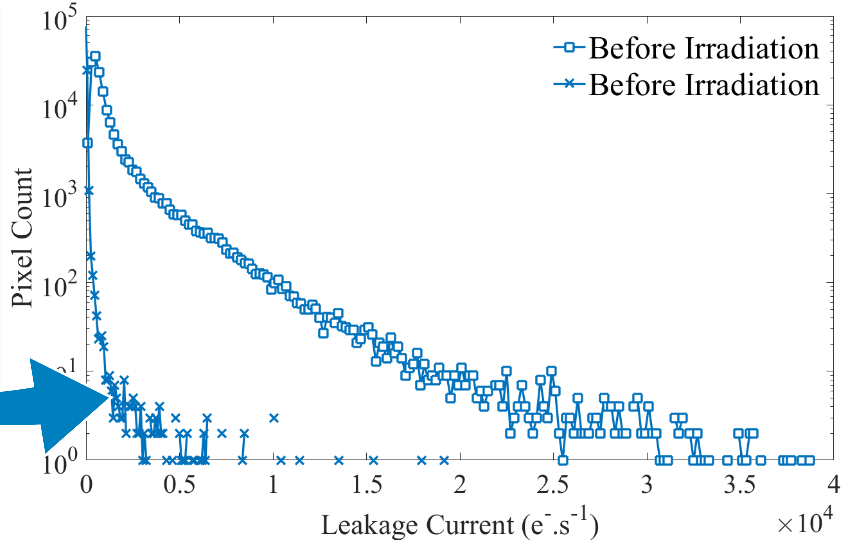


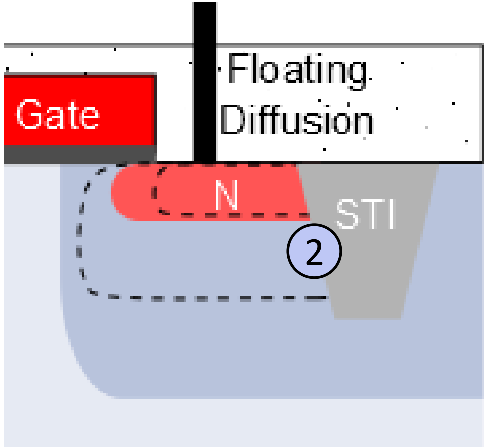
FD study: Operated as a conventional 3T PD by closing the transfer gate.

Results: Before Irradiation







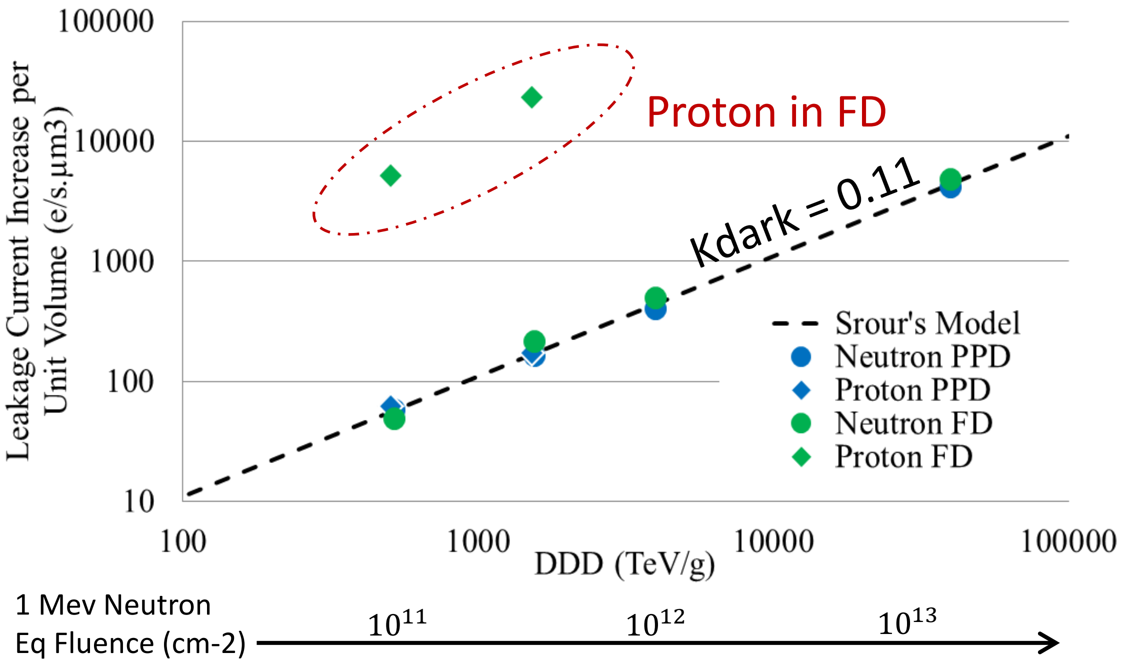


② Si/SiO_2 interface defects

- No bulk defect neither in PPD nor in FD before irradiation.
- Huge leakage current in the FD before irradiation coming from Si/SiO_2 interface defects.

Results: After Neutron (22 Mev) and Proton (50 MeV) Irradiation

Prediction of the mean leakage current increase: Universal Dammage Factor (UDF).



PPD:

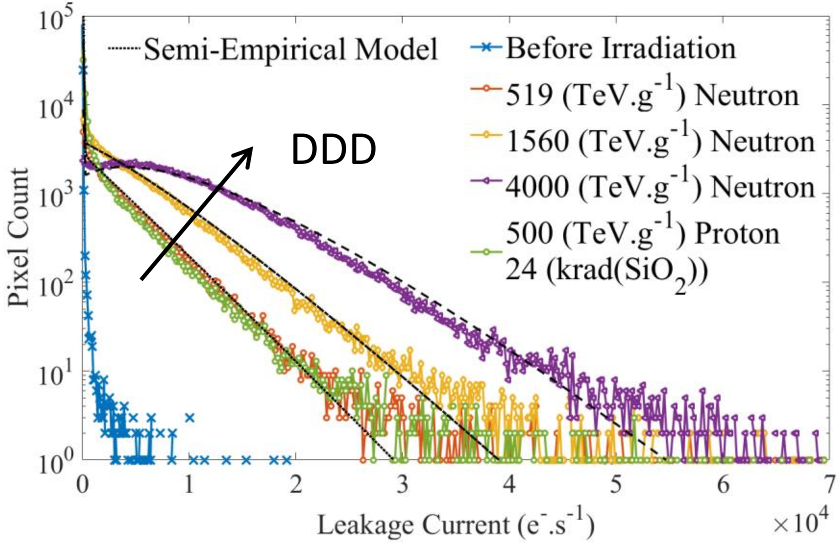
- UDF model works for neutron and proton irradiations.
- PPD not sensitive to TID induced by protons (24 krad(SiO2)).

FD:

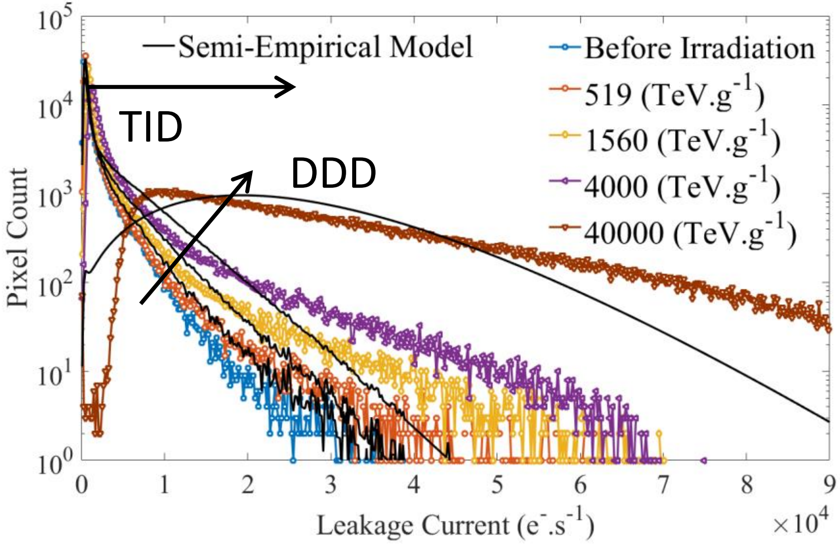
- UDF model works for neutron
  - The FD structure has no influence on the model.
- UDF model does not work for proton irradiations.
  - FD is sensitive to TID induced by protons.

Results: After Neutron (22 Mev) and Proton (50 MeV) Irradiation

PPD



FD

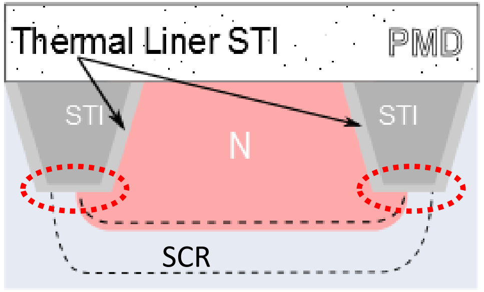


- Leakage current increase with the DDD.
- No impact of the TID induced by proton.
- Empirical exponential prediction (Belloir 2017) in agreement with the data.

- Strong impact of the TID (proton / X-ray).
- Leakage current increase with the DDD.
- Empirical exponential prediction does not work.

What makes the Floating Diffusion Different from 3T PD & 4T PPD

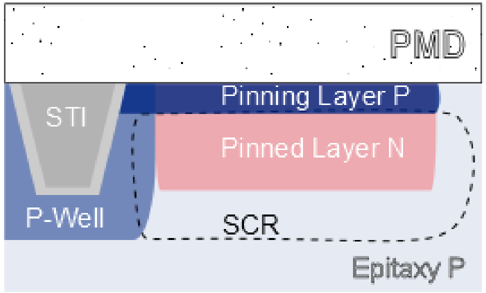
3T PD



*Space Charge Region (SCR)

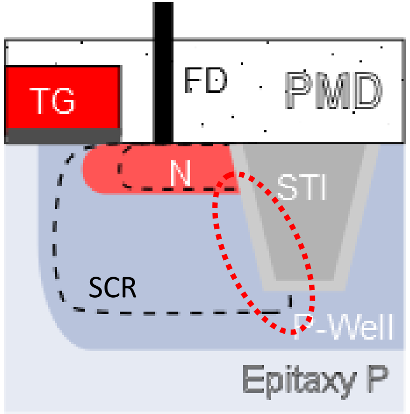
- Small STI / SCR contact area.
- Good interface quality.
- Low doping level / Low electric field.

4T PDD



- No STI / SCR contact area.
- Low doping level / Low electric field.

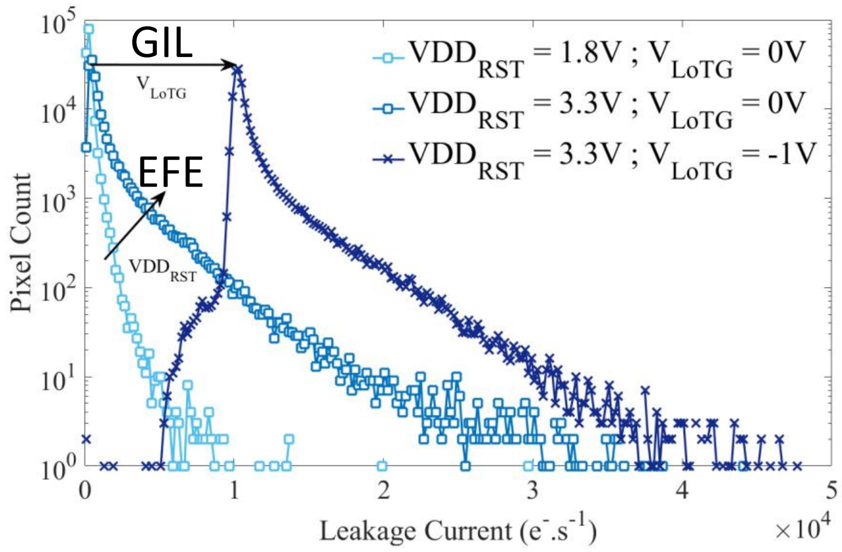
FD

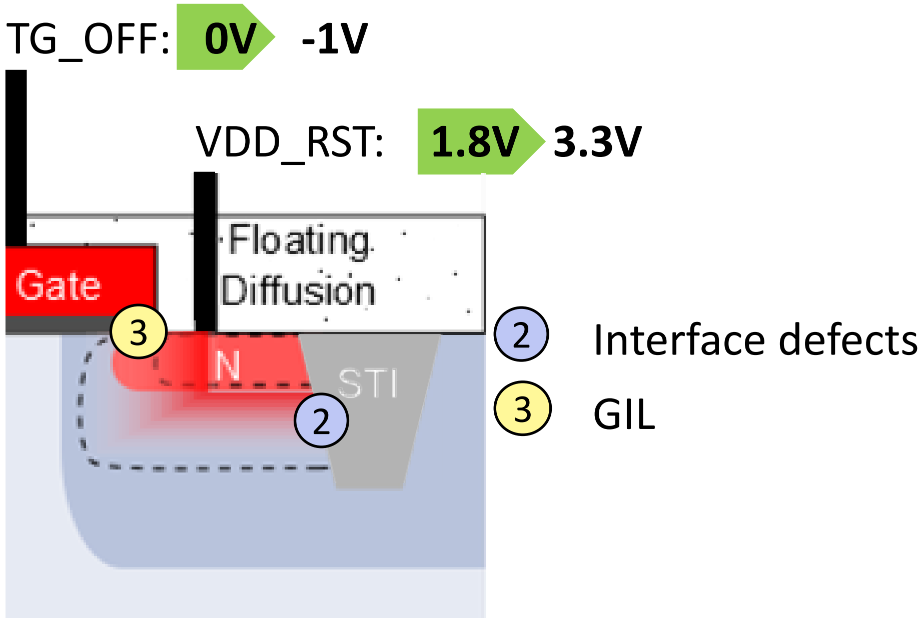


- Large STI / SCR contact area.
- Bad interface quality at the STI sidewalls.
- High doping level / High electric field.
- Contact with the STI corner ?

Results: Leakage Current Distribution & Electric Field

Before Irradiation in FD

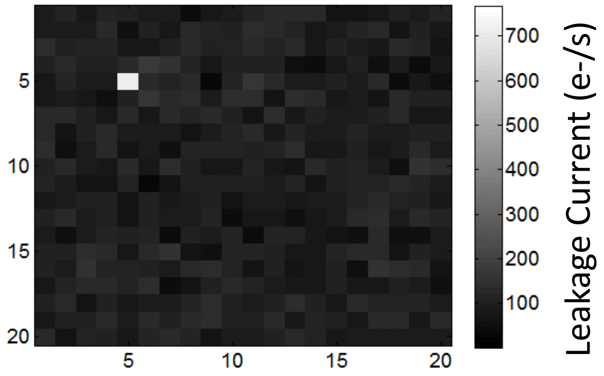




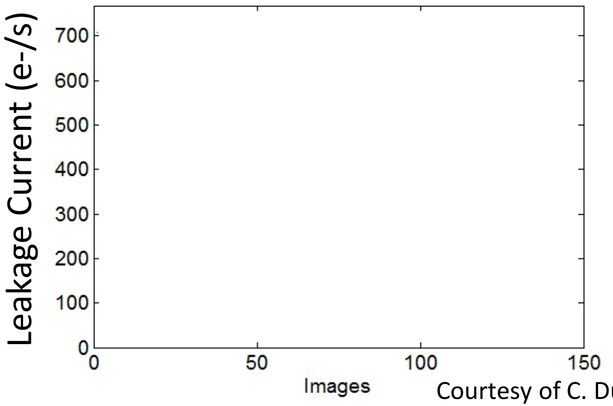
- Electric Field Enhancement (EFE) of defects generation rates with the reset voltage.
  - Interface defects before irradiation.
- Gate Induced Leakage (GIL) current below the transfer gate.

RTS Leakage Current: Definition

Leakage Current:
- Constant leakage current when no photon hits the CIS.



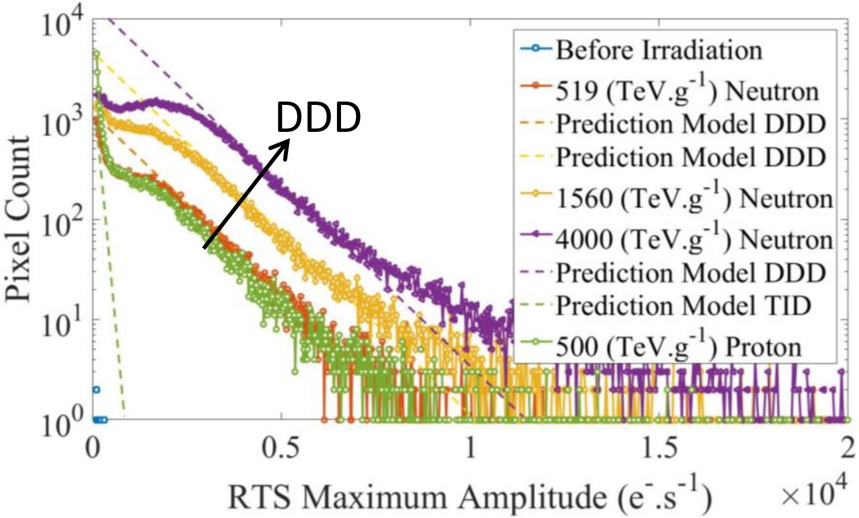
Leakage Current Random Telegraph Signal
- Leakage current which switches randomly between two or more discrete levels with time.
- Looks like a blinking pixel.
- Calibration troubles.
- Typical maximum transition amplitude distribution



Courtesy of C. Durnez

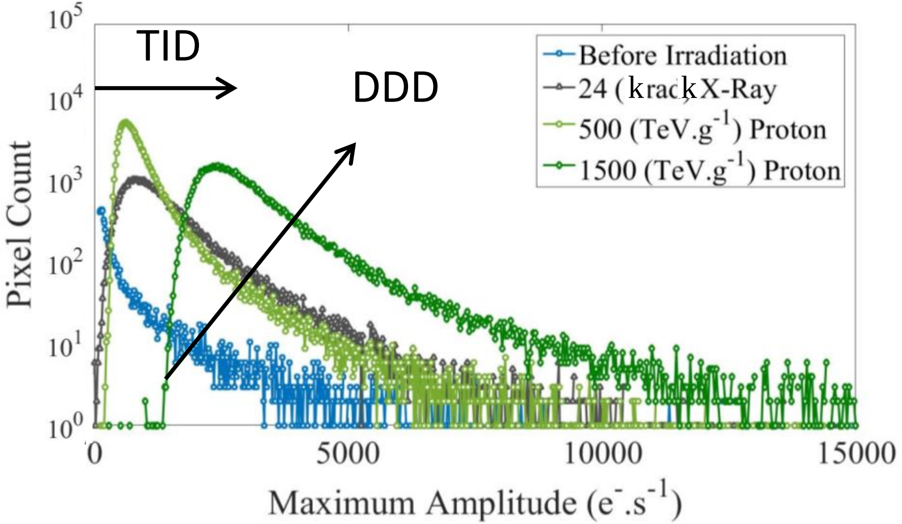
Results: RTS Leakage Current

PPD



- RTS Leakage current increase with the DDD.
- RTS prediction model works.
- Small impact of the TID induced by protons.

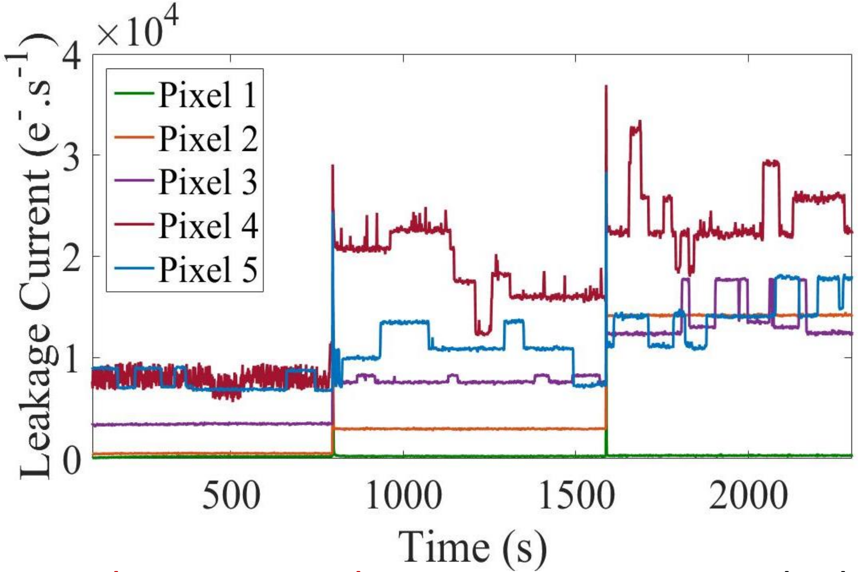
FD



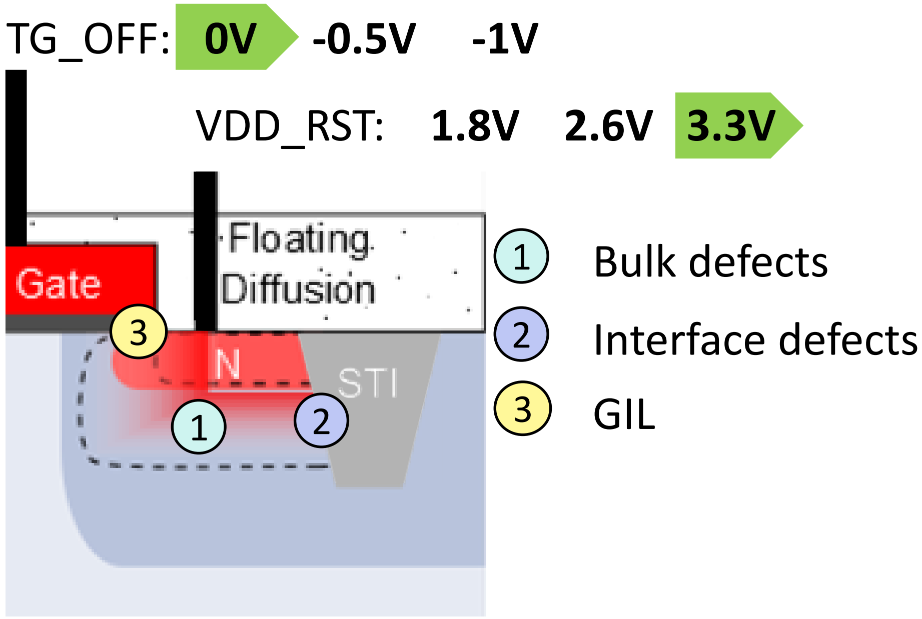
- RTS Leakage current increase with the DDD.
- RTS prediction model does not work .
- Strong impact of the TID (proton / X-ray).

Results: RTS Leakage Current & Electric Field

Neutron in FD



- The GIL reveals some RTS centers which maximum transition amplitudes are enhanced by the induced electric field under the gate.



- The electric field into the FD junction enhances the defects maximum transition amplitudes.
- Pre-irradition: only Interface defects.

Conclusion: Radiation Effects on CIS Floating Diffusions

Before irradiation:

- Interface defects coming from STI sidewalls dominate the FD leakage current.
- Some of them act as RTS centers.

After Irradiation:

- FD leakage current is dominated by the TID induced defects (proton & X-ray).
- FD leakage current distributions reveal a population of pixels impacted by an Electric Field Ehancement (EFE).
- RTS centers are also impacted by the FD electric field.

Consequences:

- The radiation induced FD leakage current has to be taken into account in Global Shutter CIS. It can prevent the use of global shutter image sensor in radiation environments.
- The conventional TID hardening techniques of PN junctions can be considered:
  Enclosed layout FD / buried channel FD

Thank you for your attention!

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