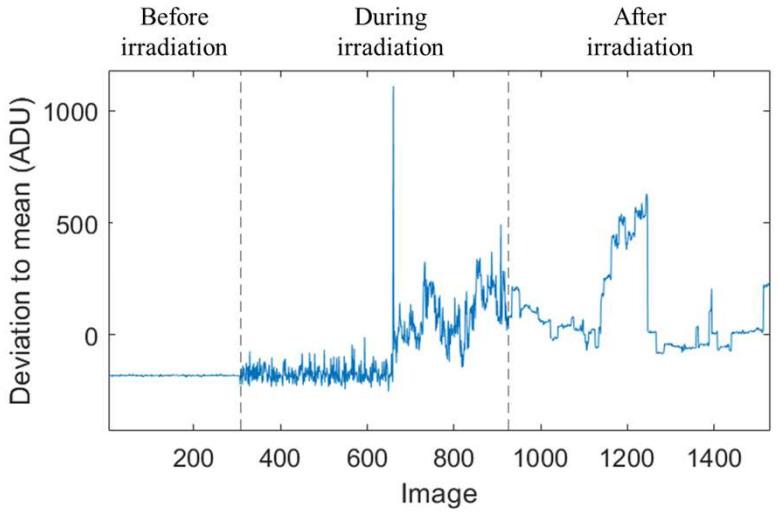

Study of damages caused by proton irradiation on MCT n/p focal plane cooled arrays

Ségolène Dinan [a b c], Eric Deborniol [a], Nicolas Baier [a], Florent Rochette [a], Serena Rizzolo [c], Vincent Goiffon [b], Olivier Gravrand [a]

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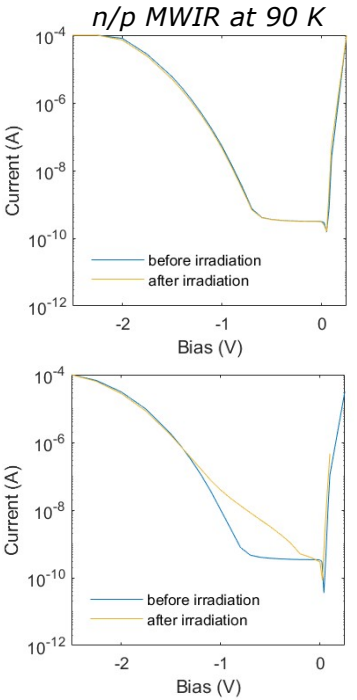
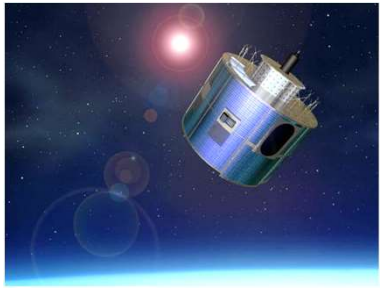
[c] Airbus Defense and Space

Radiation effects on HgCdTe image sensors

- **Single Event Effect (SEE)** → No permanent damage.
  Out of the scope of the study
- **Total ionizing dose (TID)** → Gamma Tests
  → No degradation on HgCdTe was visible @ 80kard(Si)
- **Displacement Damage Dose (DDD)** → Proton Tests
  → Induced degradation on HgCdTe
  → **Main proton induced degradation on HgCdTe photodiodes linked to DDD**



Current - Voltage characteristics of n/p MWIR HgCdTe photodiodes at 90 K



Typical Earth Observation space mission

~ 10^{10} p/cm² EOL

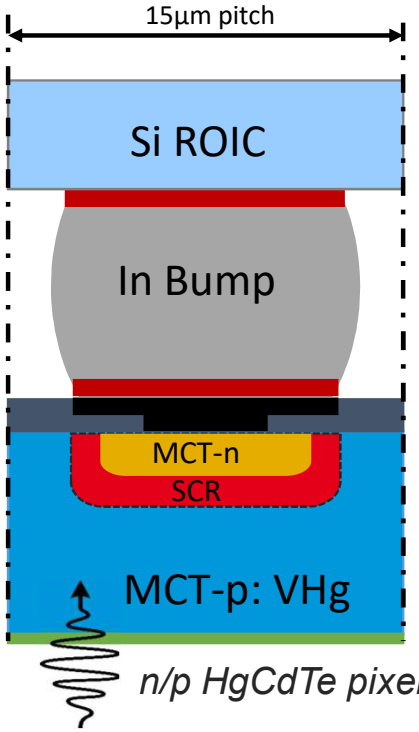
X10-100

Proton source 63 MeV
Max. fluence **8 10^{11}p/cm²**
⇔ TID 130 krad(Si)

⇔ **2 Mp / pixel$_{15\mu m}$**

Outlook

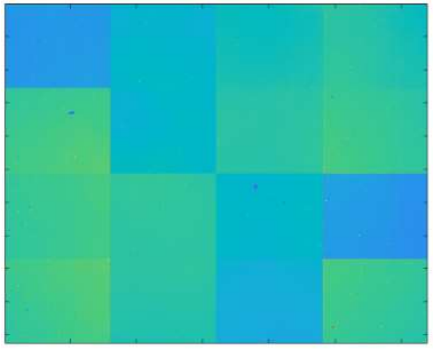
1. **Introduction**
2. **Single diode damage**
   - Dark current
   - Response
3. **FPA damage**
   - Hot pixels distribution
   - RTS pixels
4. **Focus on RTS pixels**
   - Annealing
   - Dynamic
5. **Conclusion**



n/p HgCdTe pixel

- HgCdTe
- MWIR (5.2 µm at 78K)
- n/p VHg doped
- CEA-Leti made

CEA focal plane array (FPA)

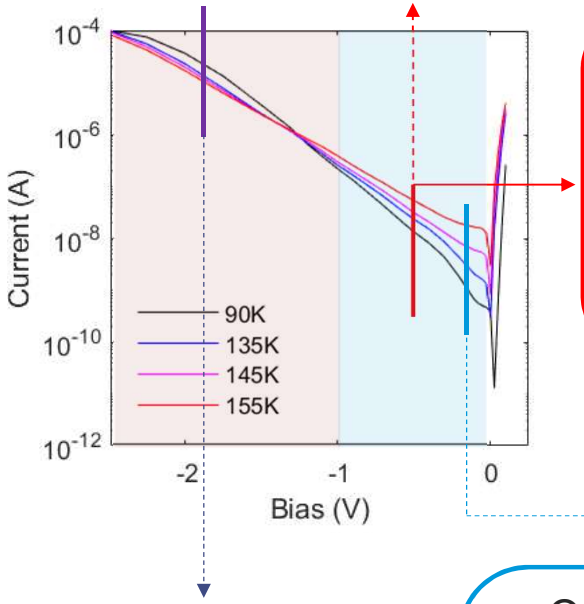


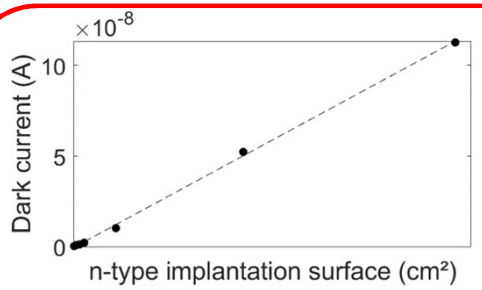
- Variable areas single diodes
- 15µm pitch FPAs
  - DI
  - 8 diodes flavors

First assessment on variable area single diodes

8 10^{11} p/cm², 90K **After RT Thermal cycle**

Activation Energy (-0.5V) = 73 meV → **Decreased dark current activation energy** indicates dark current is no longer dominated by diffusion

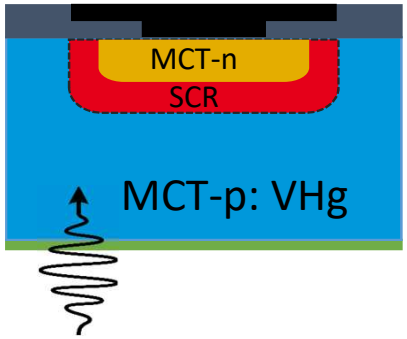




Dark current after RT thermal cycle (-0.5 V bias at 155 K)

→ Dark current ∝ to the photodiode surface

→ Suggests defects responsible for dark current are located **in the Space Charge Region**



Activation Energy ~Gap
→ diffusion current

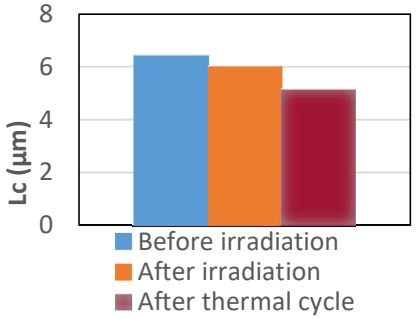
Activation Energy <0
→ Tunnel currents

- Optical response loss

→ Lateral collection length contraction

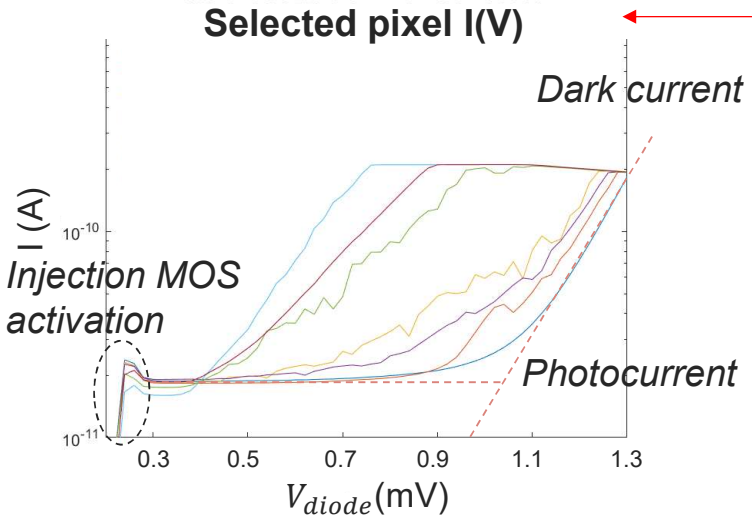
- Small dark current diffusion increase

➔ Degraded minority carrier lifetime?

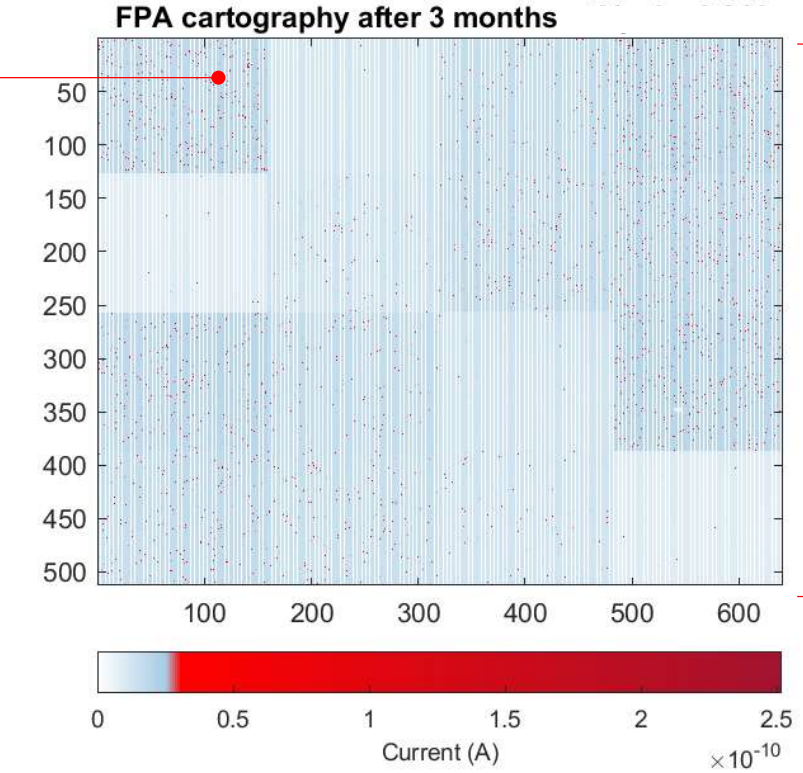


Irradiation impact on FPA current mapping

f/8 78K operation, 15µm pitch

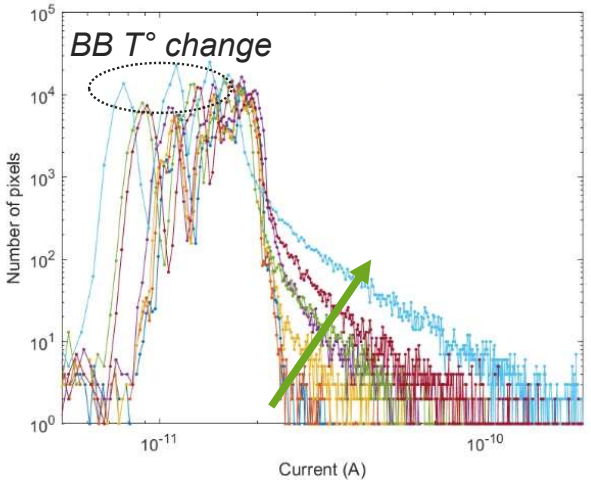


IV change consistent with single diodes



FPA current distribution at

$V_{diode} = 0.5V$



HOT pixels tail increase
- Fluence
- RT thermal cycle

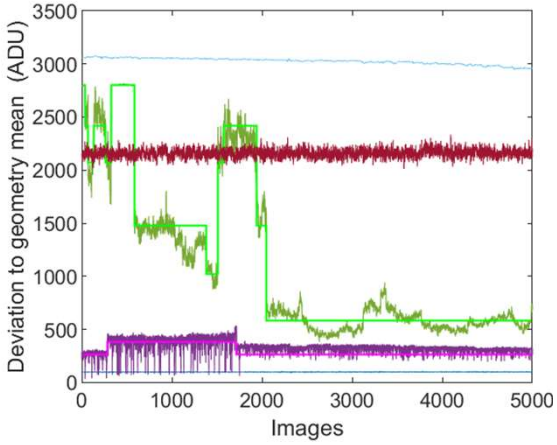
Self healing at RT

Before irradiation → After 1E+10 p/cm² → After 1E+11 p/cm² → After 3E+11 p/cm² → After 8E+11 p/cm² → After thermal cycle → After 3 months

Irradiation impact on Random Telegraph Signal (RTS)

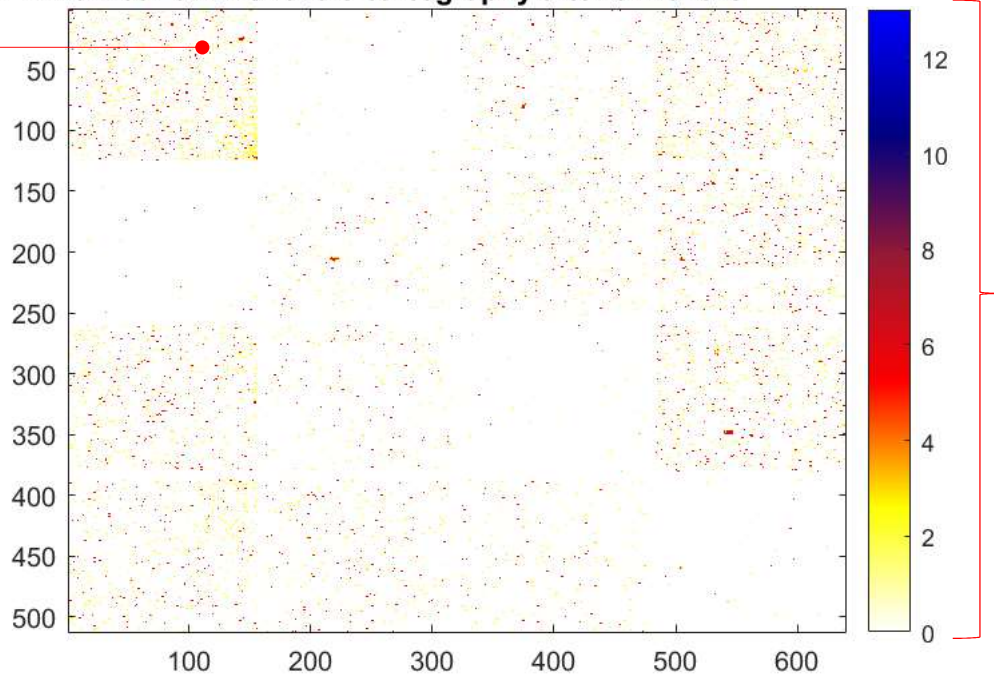
f/8 78K operation, 15µm pitch

Selected pixel RTS behaviour

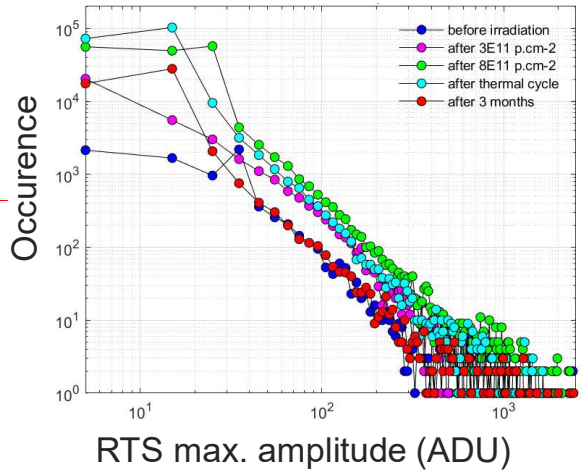


FPA number of RTS levels cartography after 3 months

$V_{diode} = 0.5V$



FPA RTS max amplitudes

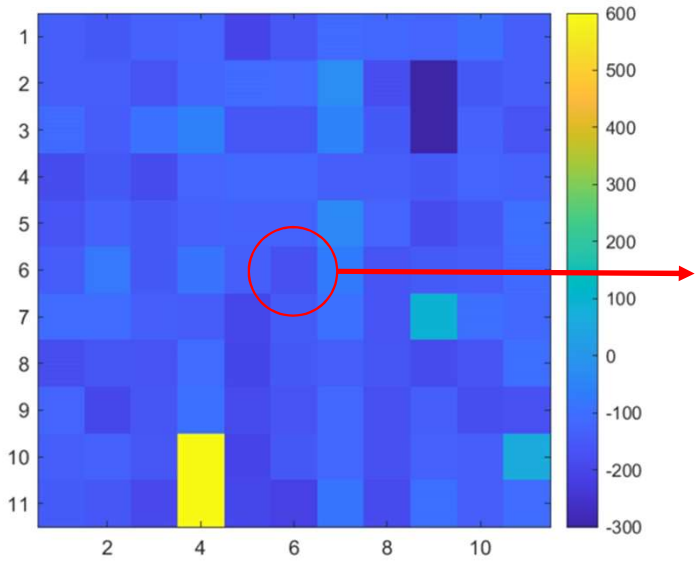


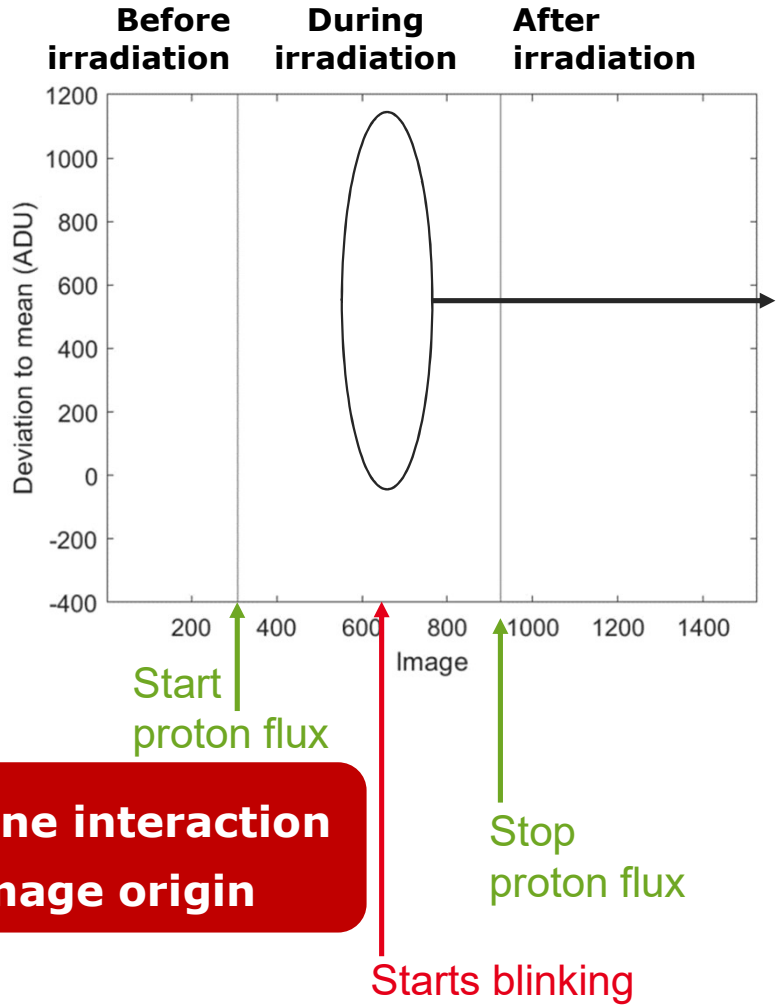
Partial recovery after RT thermal cycle

Before irradiation → After 1E+10 p/cm² → After 1E+11 p/cm² → After 3E+11 p/cm² → After 8E+11 p/cm² → After thermal cycle → After 3 months

Formation and Dynamics of Proton Induced RTS

f/8 90K operation, 15µm pitch





Dark current spike and ionisation

PKA

SKA

3KA

Frenkel Pair

©A.Jay

Single Particle Displacement Damage Event

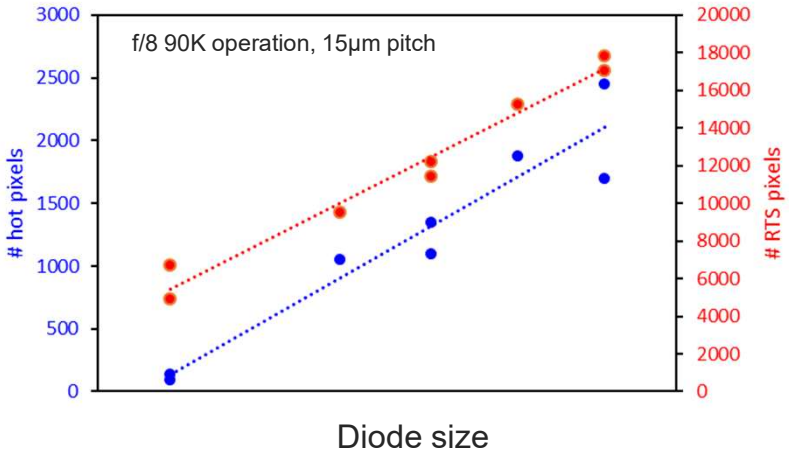
→ RTS seems to be linked to one interaction

→ Suggests Displacement Damage origin

Discussion on FPA proton damage
Same defects for HOT and RTS pixels?

- **Evolution with diode size** (in a 15µm pitch)
  - Hot pixel count ∝ RTS pixel count
  - Consistent with single diode measurements
- RTS thermally activated ~ mid gap

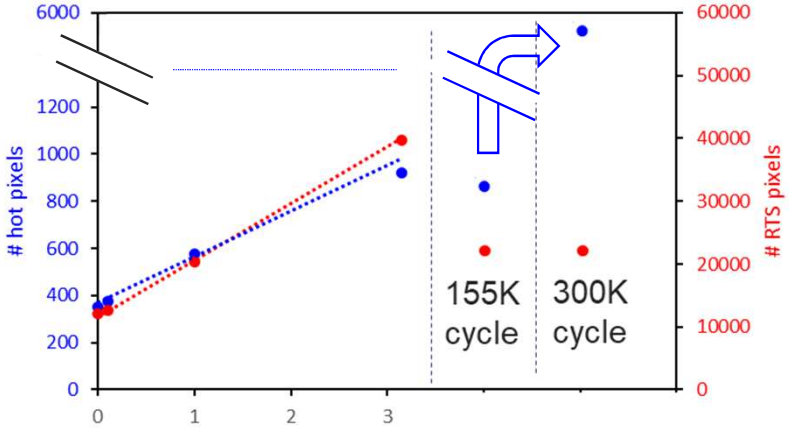
➔ ***Depletion related defect for HOT & RTS pixels***



Diode size

- **Evolution with fluence**
  - Hot pixel count ∝ RTS pixel count
  - @ 155K RTS count decreases, not hot pixels
  - @ 300K Strong increase hot pixels count

➔ ***Different annealing behaviour***



Fluence ($10^{11} p/cm^2$)

Discussion on FPA proton damage
Field enhancement?

- **Evolution with electrical field, ie Bias**

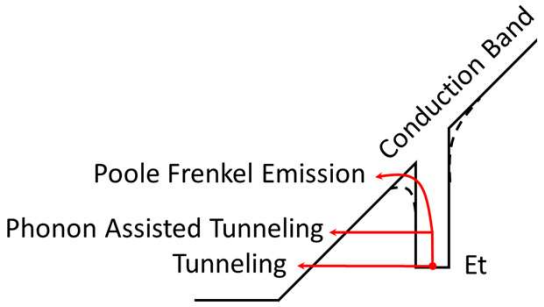
➔ ***Larger electrical field enhancement ?***

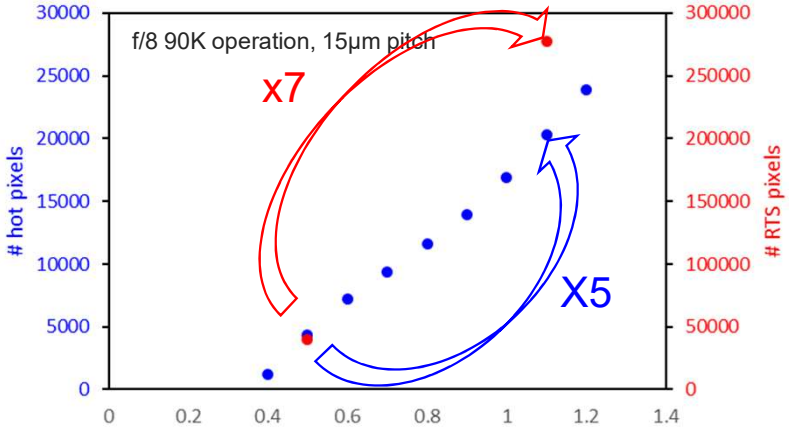
for RTS than hot pixels

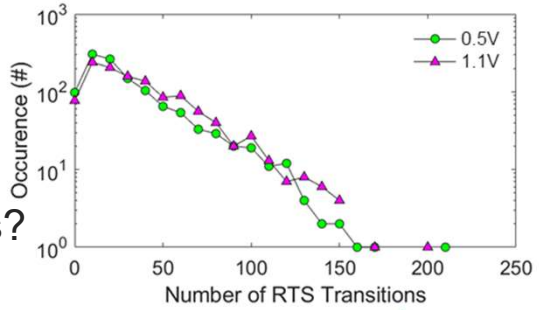
- Evolution of detected RTS pixels at 0.5V up to 1.1V
  - Same stat in jump frequencies, #levels ,
  - Higher amplitudes

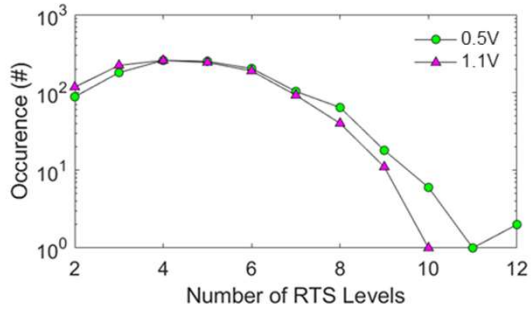
➔ Same switch, larger leakage

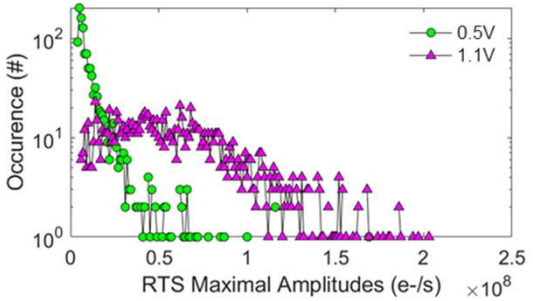
➔ Pool Frenkel emission from proton induced defects?









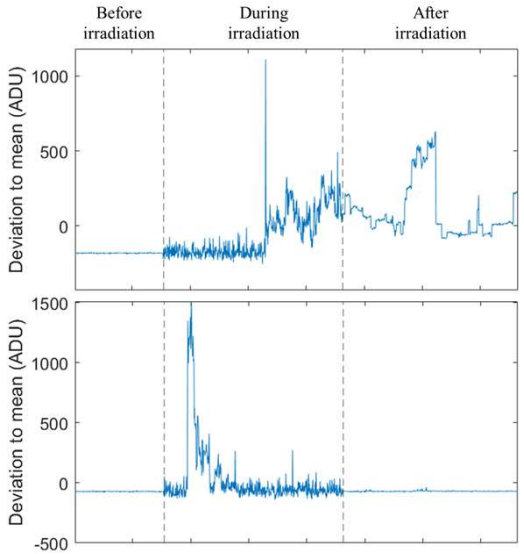


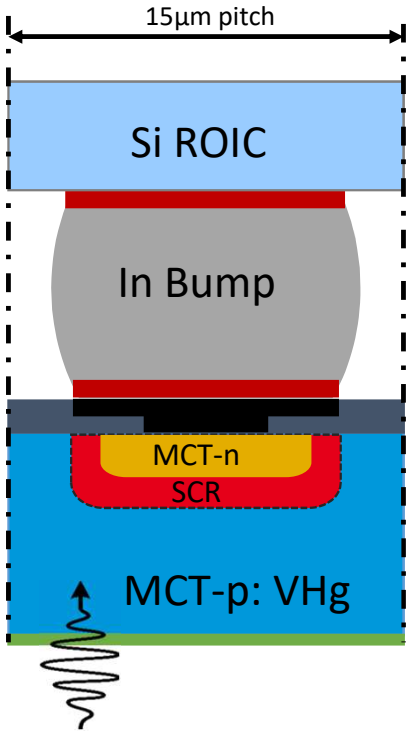
Conclusion

- Diffusion dark/photo current → Weak degradation of carrier lifetime? = diffusion region defects
- For dark and RTS
  - Mid-gap activation
  - Degradation ∝ fluence / diode size
- Field enhancement FX an RTS
  - Only affects jump amplitudes, not the switch

→ Depletion located defects

- RTS trigger might involve a single interaction





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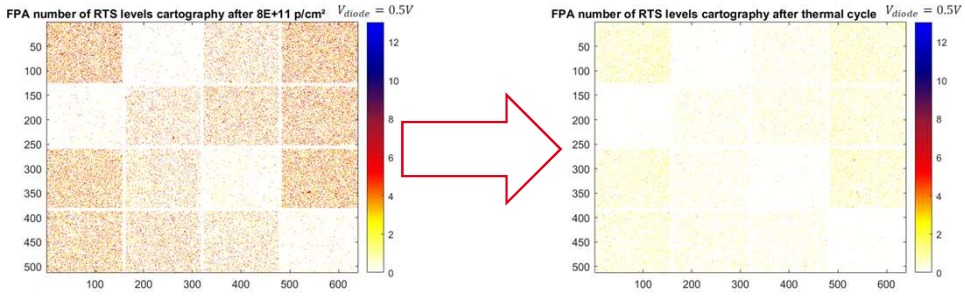


- RTS trigger might involve a single interaction

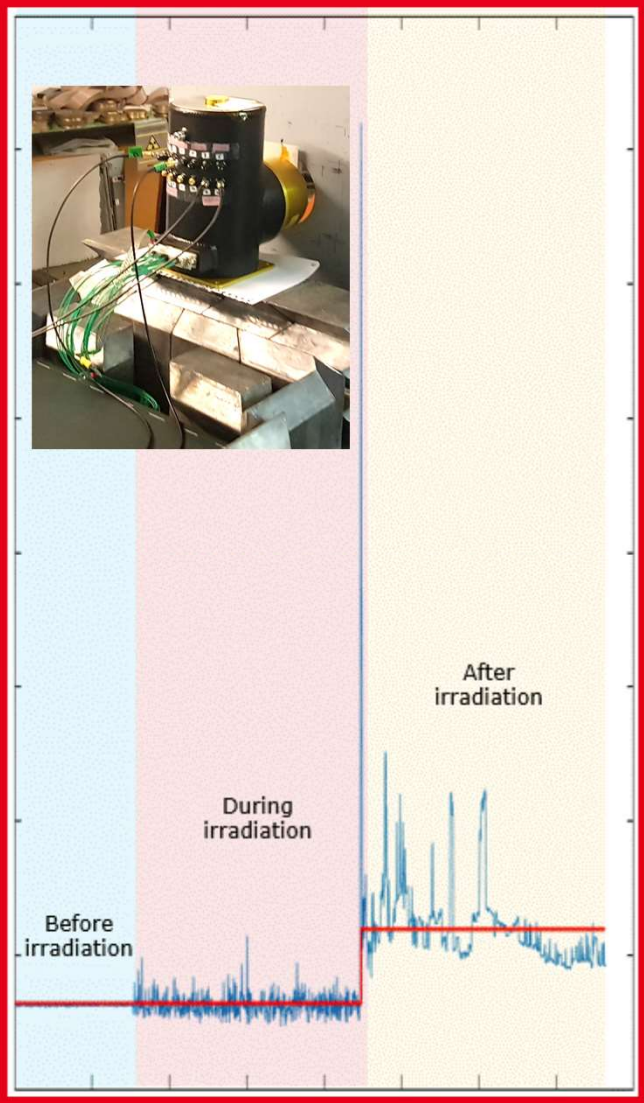
- RT thermal cycle degrades further the dark current,
- But not RTS
  - Partial recovery of RTS for 155K thermal cycle

- **Full recovery of the FPA after >80°C annealing ! (hot pixels and RTS)**

Frozen defect configuration at cryo T°
Defect reorg. @ low T° (155K) or RT (300K)

RTS defects ≠ dark current defect

Defect healing @ higher T° (80°C)



Acknowledgments

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