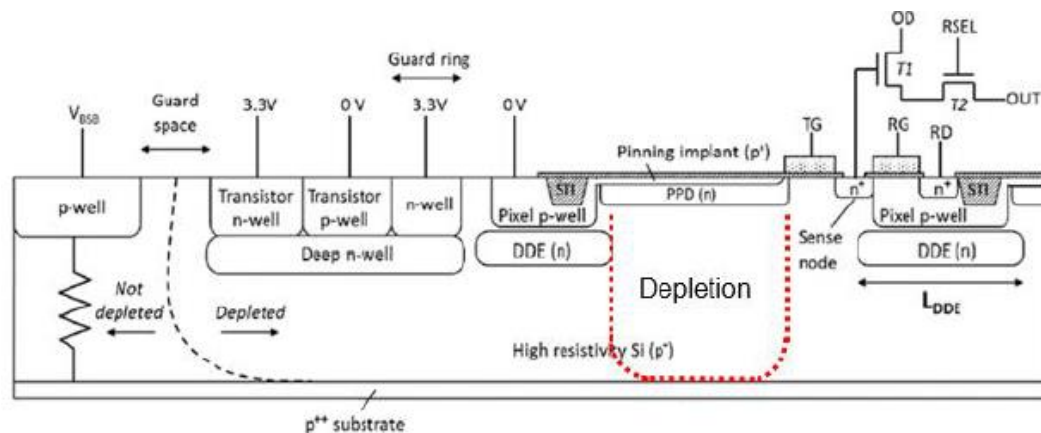
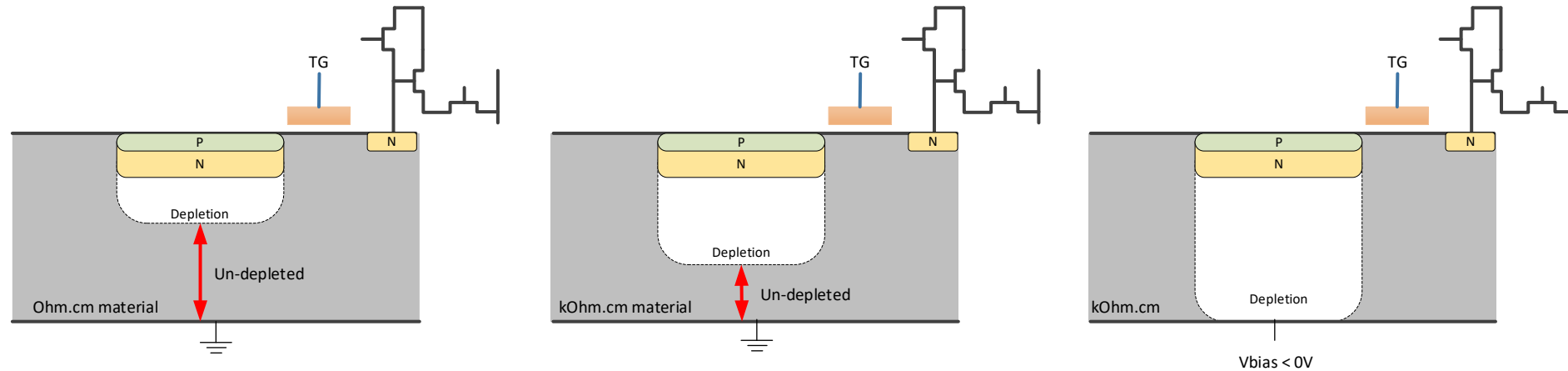


CMOS HIRHO – Radiation results

- J. Pratlong, R. Mackie, R. Gil-Otero and A. Baldock -

RADOPT Workshop 29th – 30th November 2023

Context



J. Pratlong "CMOS detector Radiation synthesis" RADOPT 17th November 2021.

- Depletion for CMOS technology is limited especially compare to CCD.
- To have good response in NIR thick material is needed.
- With limited depletion MTF becomes quickly poor with thick material.
- A first improvement is the use of hi-resistivity material.
- Ultimate solution is HiRho applying a reverse bias to increase and control the depletion.
- As the reverse bias is applied to prevent the transistors to leak a special implant named DDE is used.

BSI results



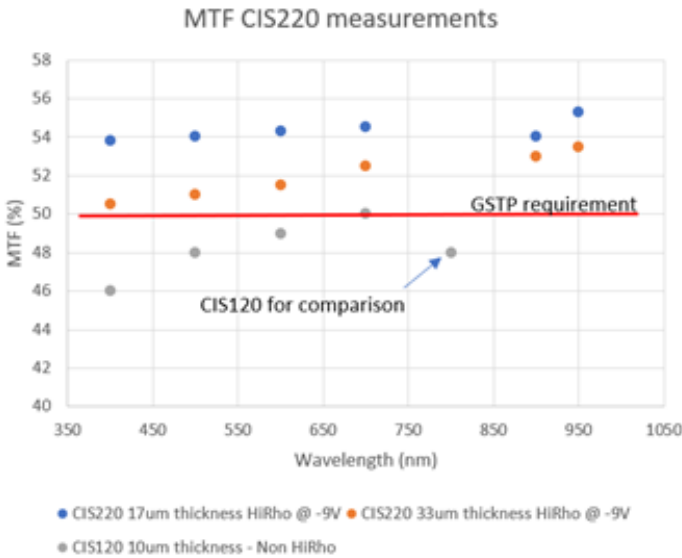
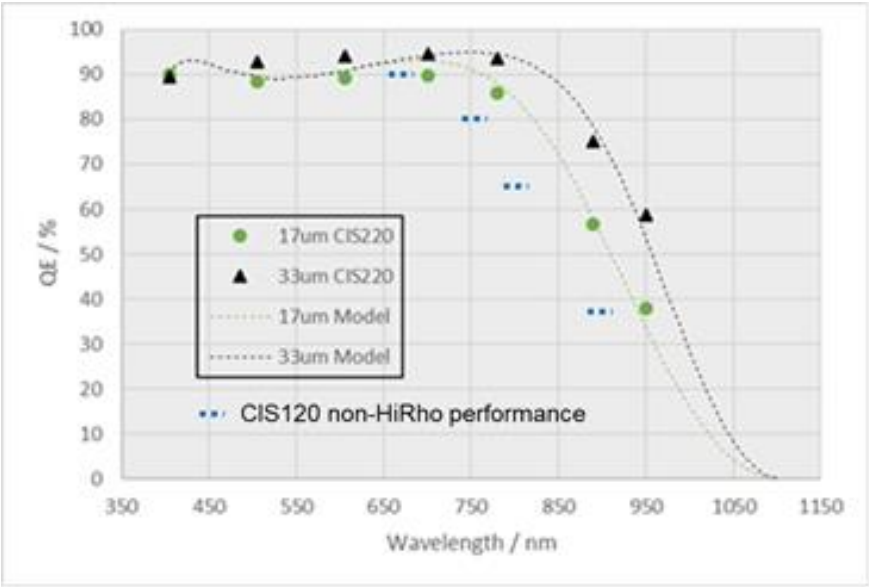
CIS220 thinned to:
17µm
and 33µm



ESA GSTP



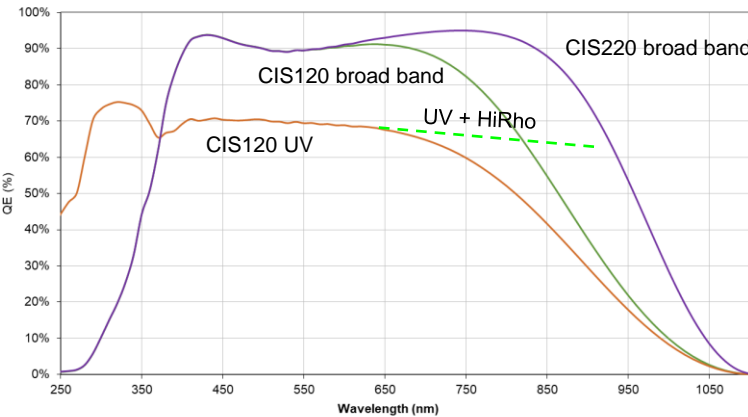
HiRho applied to
standard product CIS120



Parameters	Unit	CIS120	CIS220	Comments
HiRho (DDE added)		No	Yes	
Pixel type		5T	5T	
Pixel pitch	µm	10	10	Same layout just DDE added
Format		2k x 2k	2k x2k	
FWC	ke ⁻	100	100	Re-targeted
Noise	e ⁻ _{RMS}	19	19	Changes due to new FWC
Dark current	e ⁻ /pix/s	50	90	



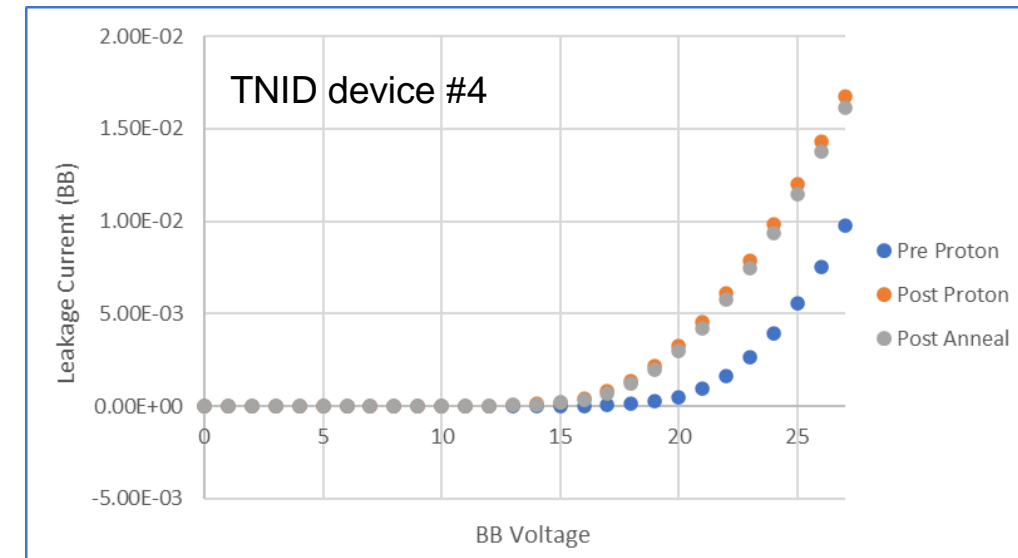
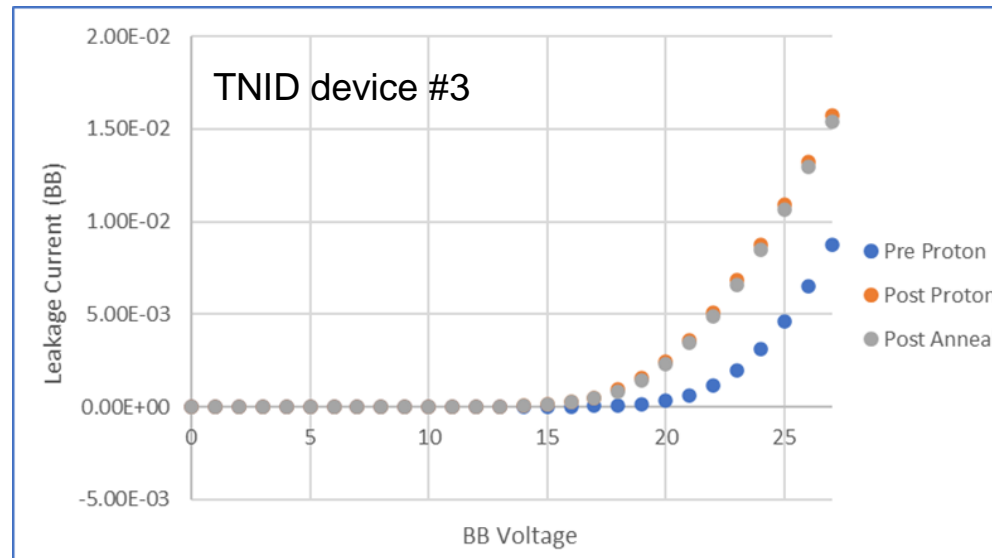
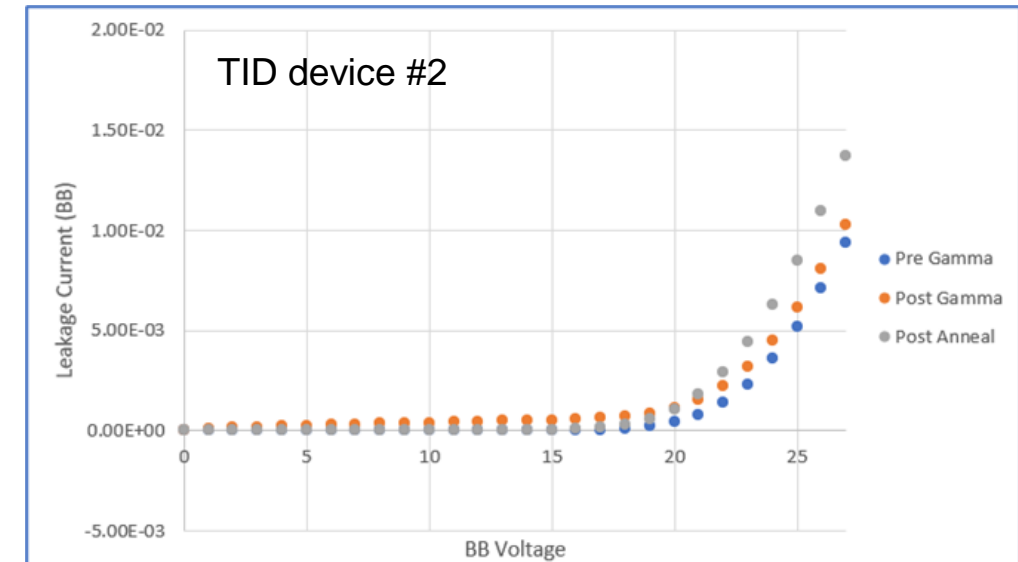
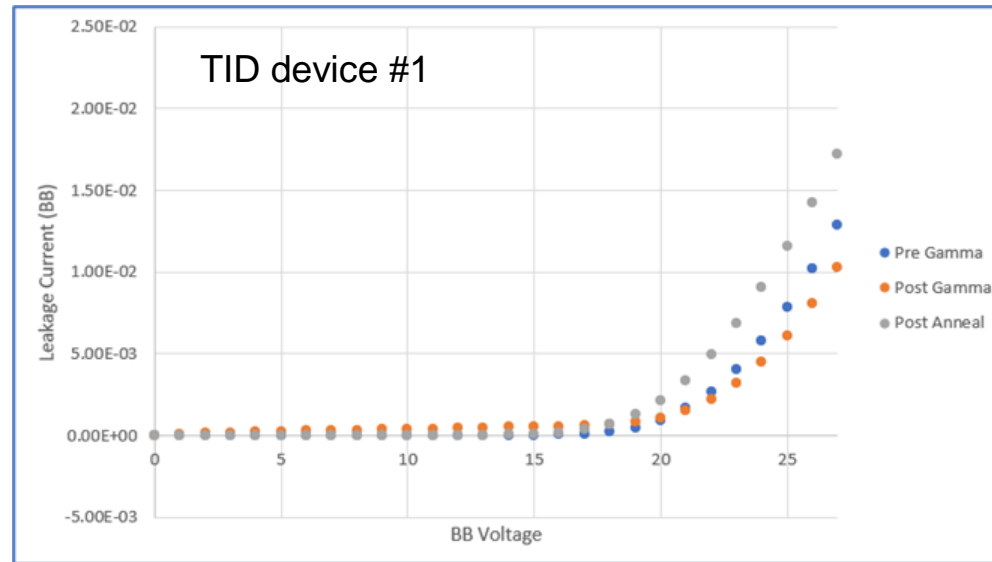
High QE on a large spectrum
with one silicon



Radiation condition

TID	TNID	Heavy Ion
Irradiation: <ul style="list-style-type: none"> ➤ Radiation source: 60Co ➤ Radiation dose: 50kRads ➤ Radiation rate: about 10kRad/hour ➤ Reverse bias -20V ➤ Rolling shutter 12 bits Anneal: <ul style="list-style-type: none"> ➤ Duration: 168 HOURS ➤ Temperature: 100oC ➤ Reverse bias -20V 	Irradiation: <ul style="list-style-type: none"> ➤ Radiation source: OPTIS Theraphie Proton Bean ➤ Radiation dose: 5×10^{10} protons/cm² at 60MeV ➤ Radiation rate: about 1×10^7 protons/cm²/s ➤ Unbiased Anneal: <ul style="list-style-type: none"> ➤ Duration: 168 HOURS ➤ Temperature: 100oC ➤ Unbiased 	Irradiation: <ul style="list-style-type: none"> ➤ Radiation source: LINAC at the Radiation Effects Facility (RADEF), University of Jyvaskyla, Finland. ➤ Radiation rate: 62.5 MeV/cm²/mg ➤ Reverse bias -20V ➤ Rolling shutter 12 bits
<div> <div>↓</div> <div>HiRho vs non-HiRho</div> <div>↓</div> <div>↓</div> </div>		
<ul style="list-style-type: none"> ➤ No difference expected ➤ Depletion deeper ➤ Depletion not wider 	<ul style="list-style-type: none"> ➤ DC expected to increase ➤ Due to deeper depletion 	<ul style="list-style-type: none"> ➤ No difference expected ➤ Can only be better

Reverse bias

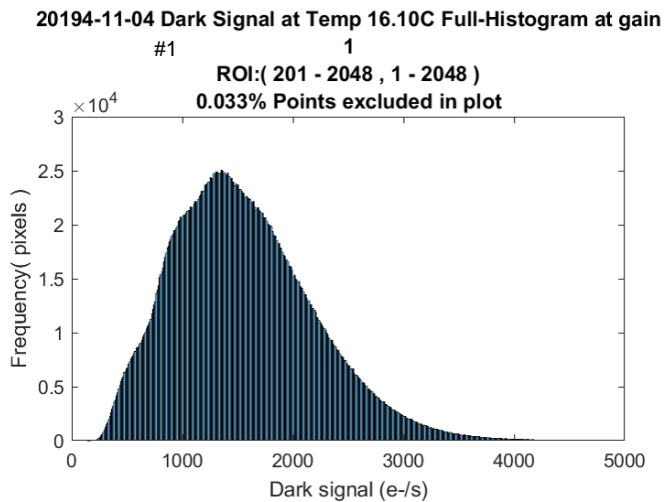


TID - Rolling shutter mode

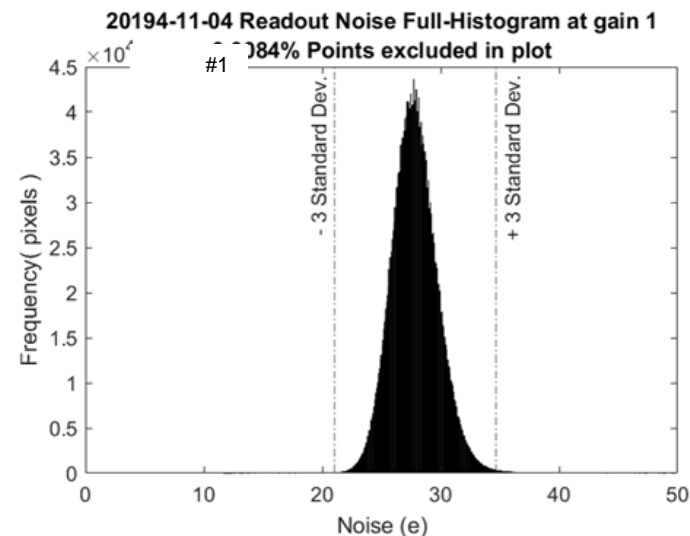
Device Number	Parameter	TID (20°C, Rolling Shutter)		Units
		Pre radiation	Post radiation	
#1	DC	83.9	1261	e-/pix/s
#2		86.2	1486	e-/pix/s
#1	Noise	23.2	25.5	
#2		23.0	25.9	

Device Number	Parameter	TID (3.5°C, Rolling Shutter)		Units
		Pre radiation	Post radiation	
#1	DC	31.2	214	e-/pix/s
#2		39.9	251	e-/pix/s
#1	Noise	23.2	26.8	
#2		23.0	27.9	

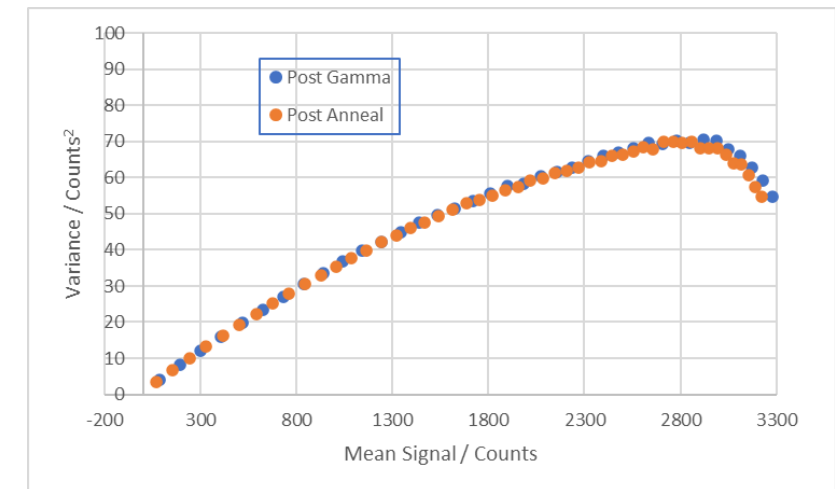
DC post-radiation



Noise post-radiation



CCF and QSAT



TID: Comparison with CIS120 – Non-HiRho

- Dark current at 20°C
 - CIS120
 - Pre radiation was 60 e⁻/pix/s, post radiation was 1000 e⁻/pix/s
 - ~16 times increase
 - CIS220
 - Pre radiation was 85 e⁻/pix/s and post radiation was 400 e⁻/pix/s
 - ~14 times increase

- Noise at 20°C
 - CIS120 (Comparison with a slightly lower Q_{SAT} hence noise)
 - Pre radiation was 18e⁻, post radiation was 24 e⁻
 - ~33% increase
 - CIS220
 - Pre radiation was 23 e⁻ and post radiation was 26 e⁻
 - ~13% increase

TNID - Rolling shutter mode

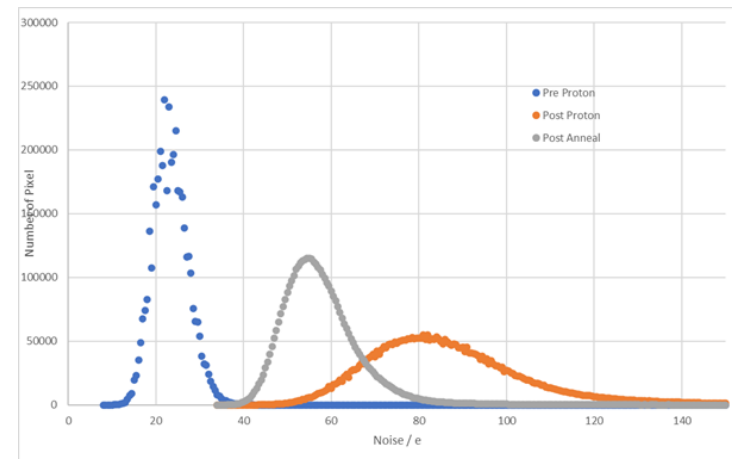
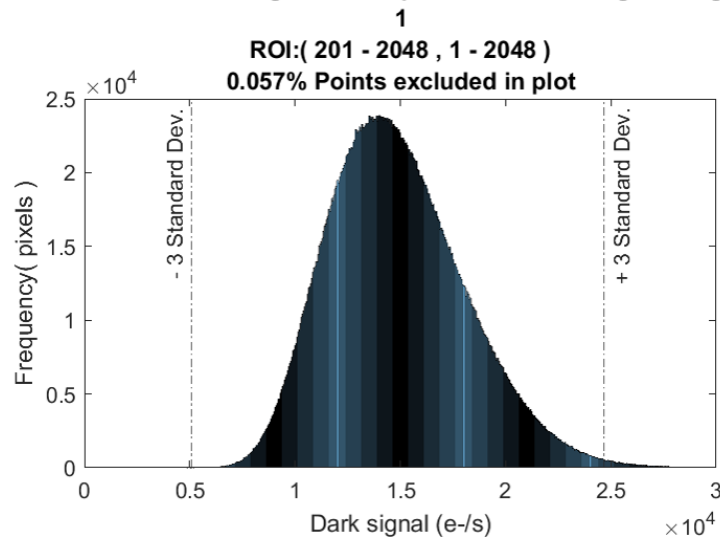
Parameter	Pre Proton	Post Proton	Post Anneal	Units
Noise	23.2	84.1	56.3	e-
Dark Signal @ +20°C	86.1	38711	14576	e-/pix/s
Dark Signal @ +3.5°C	Not tested	6352	2171	e-/pix/s

DC post-radiation

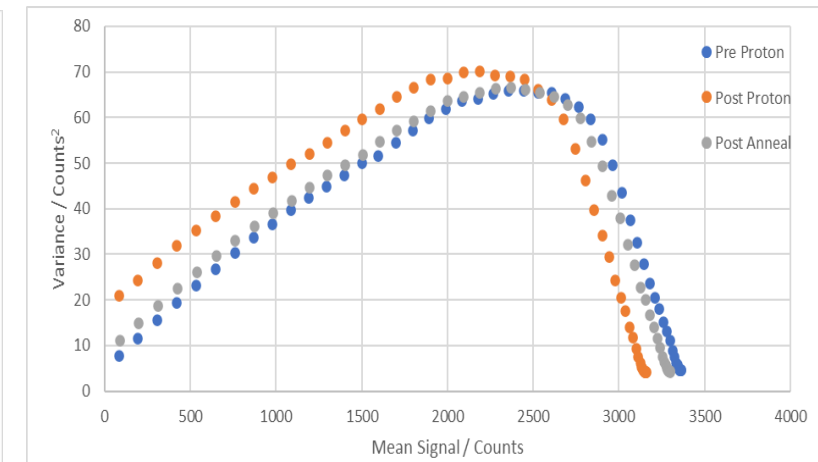
Noise

CCF and QSAT

201 #1 ark Signal at Temp 16.10C Full-Histogram at gain



Noise increase due to DC increase



TNID - RTS

- RTS does show an increase at +20C (~7.5% of array)
- Reducing temperature improves the number of RTS greatly

Device Number	RTS at 20°C			Units
	Pre Proton	Post Proton	Post Anneal	
20194-11-05	108	391591	13603	Pixels
20194-11-08	415	324549	16191	Pixels

Device Number	RTS at 3.5°C			Units
	Pre Proton	Post Proton	Post Anneal	
20194-11-05	72	2021	1015	Pixels
20194-11-08	50	1624	1825	Pixels

TNID: Comparison with CIS120 – Non-HiRho

➤ Dark current around 20°C

➤ CIS120

- Pre radiation was 42 e⁻/pix/s, post radiation was 971 e⁻/pix/s
- ~24 times increase

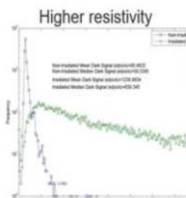
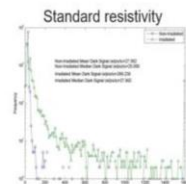
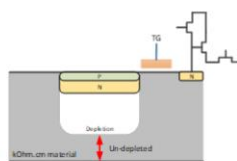
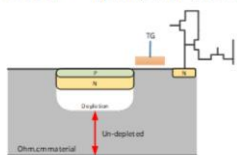
➤ CIS220

- Pre radiation was 81 e⁻/pix/s and post radiation was 14576 e⁻/pix/s
- ~180 times increase

For same DDD we observe an increase proportional to the depletion of about a factor 8

Proton – Depletion contribution

CIS107 – 7μm pixel pitch



RADOPT Workshop – 17th November 2021

9

- Same DDD
- Same pixel pitch 7μm
- Depletion is 4 times bigger
- Mean DC is 4 times higher

— Pre proton
— Post proton

Proportionality already reported between standard resistivity and high resistivity materials.

Heavy Ion

No latch-up							Normal Imaging Mode	Digital Scan (readout of SPI shadow register)		
Device Number	Test	Kapton thickness / μm	LET / $\text{MeV.mg}^{-1}.\text{cm}^{-2}$	Fluence ions/ cm^2	Flux ions/ cm^2/s	Test Duration	Latch Up	SEE (total)	0 to 1	1 to 0
20194-11-11	Latchup	75	69	1.00E+07	5058	1977	0	N/A	N/A	N/A
20194-11-11	Digital Scan	75	69	1.00E+07	4904	2039	N/A	0	0	0
20194-11-20	Latchup	75	69	1.00E+07	4437	2254	0	N/A	N/A	N/A
20194-11-20	Digital Scan	75	69	1.00E+07	3931	2544	N/A	1	1	0
20194-11-20	Digital Scan	50	65	1.00E+07	6072	1647	N/A	0	0	0
20194-11-20	Digital Scan	0	58	1.00E+07	6177	1619	N/A	0	0	0

Conclusions

The CIS220 HiRho version of CIS120 a generic purpose detector has been:

- Designed and tested back illuminated – And that in a single revision A.
- Going through a radiation campaign including TID, TNDI and Heavy Ion

The results:

- Confirmed a drastic increase of the figure of merit QExMTF in the Near infra-red
- QE as high as 60% at 950nm while maintaining a MTF above 50% was demonstrated despite a small pixel pitch of 10µm.
- TID and Heavy Ion test campaign shown not impact of the HiRho technology on the detector performance
- TNID shown an increase of dark current proportional to the increase of the depletion volume within expectation.
- CIS220 and HiRho technology have successfully reach TRL6

Possible next step:

- Validation of such technology using bulk material
- Test at cryogenic temperature

Acknowledgement

- We gratefully acknowledge support and funding from ESA
- This work has also benefited of the exceptional work of the Teledyne e2v team and OU. The design and results presented in this paper were carried out at Teledyne e2v Chelmsford UK.