First productions of large area Silicon Drift Detectors for the eXTP Wide Field Monitor instrument: test results and yield assessment.

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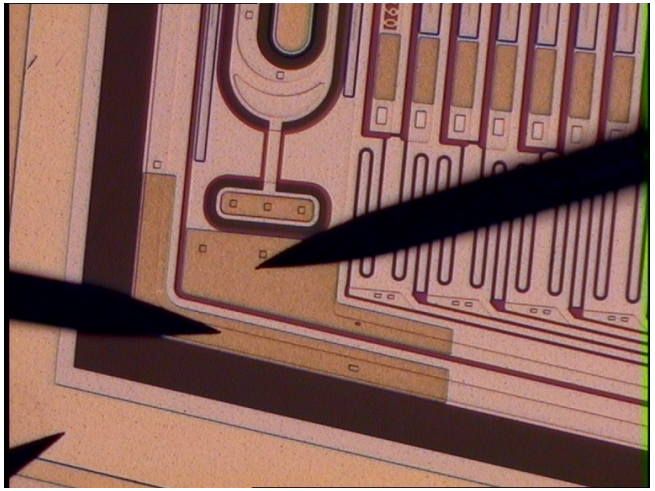


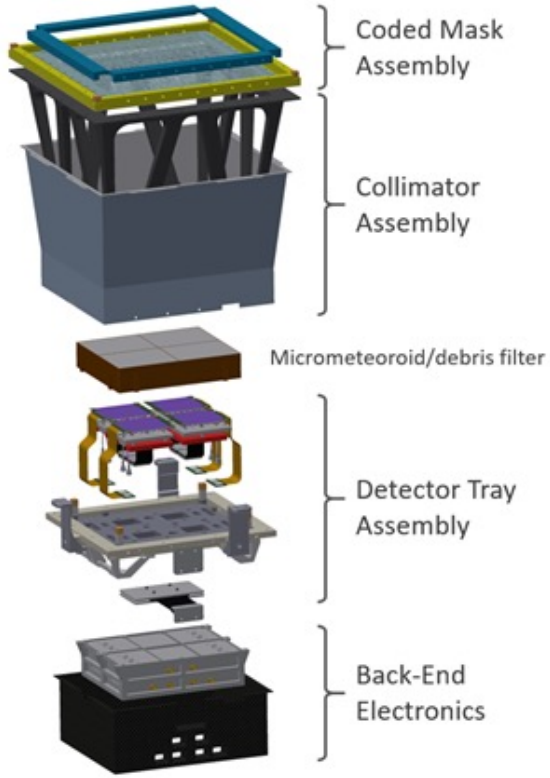
The enhanced X-ray Timing and Polarimetry Mission (eXTP)

The enhanced X-ray Timing and Polarimetry Mission is a scientific space program that will look at X-rays coming from targets such as neutron stars, and black holes to study the state of matter in extreme conditions of density, gravity and magnetism.

The enhanced X-ray Timing and Polarimetry mission will cost around three billion yuan (£340m) and is set to launch by 2025 (courtesy: Institute of High Energy Physics)

The scientific payload of the mission consists of four main instruments, among which the **Wide Field Monitor** will observe the X-ray sky with

- a large field of view **of 90°x30°**
- FWHM **angular** resolution better than 4.3 arcmin
- an **energy resolution** better than 500 eV FWHM at 6keV.



WFM consists of **6** coded-mask cameras, each made up of **4 Detector** Assemblies (DAs), for a total of **24 Large-area Silicon Drift Sensors**

* See also Poster of Antonelli Matias

Other proposed missions STROBE-X and LEM-X

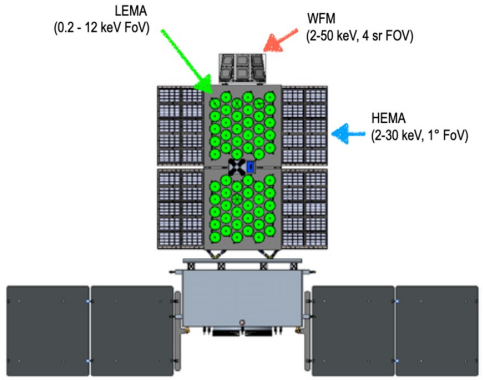
These sensors we are developing for eXTP have been adopted by other two proposed missions: Strobe-X, which was proposed to NASA for its probe class mission call, and the Italian LEM-X observatory on dark side of the moon.

STROBE-X Mission

STROBE-X is a probe-class **observatory** designed for X-ray timing and spectroscopy in the 0.2–30 keV band

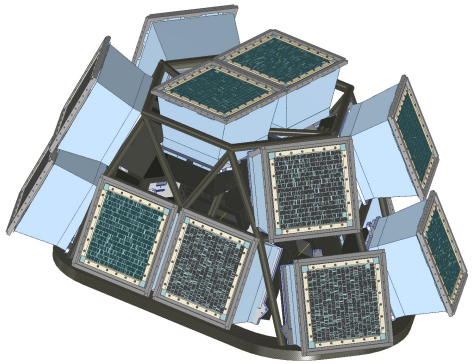
TIME-DOMAIN ASTROPHYSICS

Continuously surveying the dynamic X-ray sky with large duty cycle and high spectral and time resolution to characterize source behaviour over a vast range of time scales.

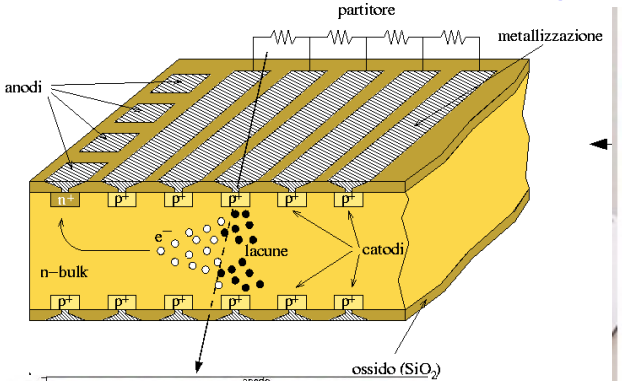


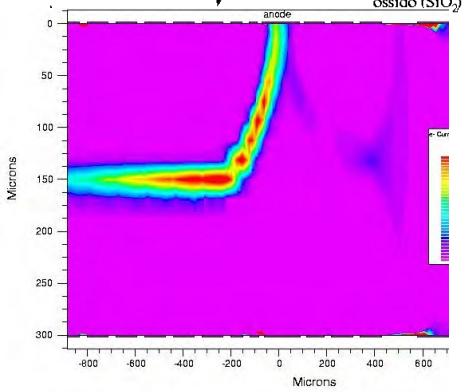
LEM-X

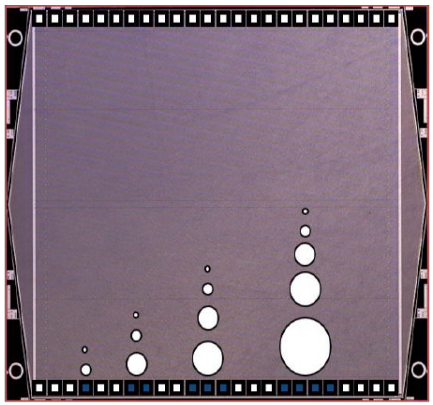
The **Lunar Electromagnetic Monitor in X-rays** (LEM-X) is a proposed **observatory** on the Moon surface for the detection of transients and the long-term monitoring of astrophysical sources across the whole observable sky in the 2 – 50 keV band.

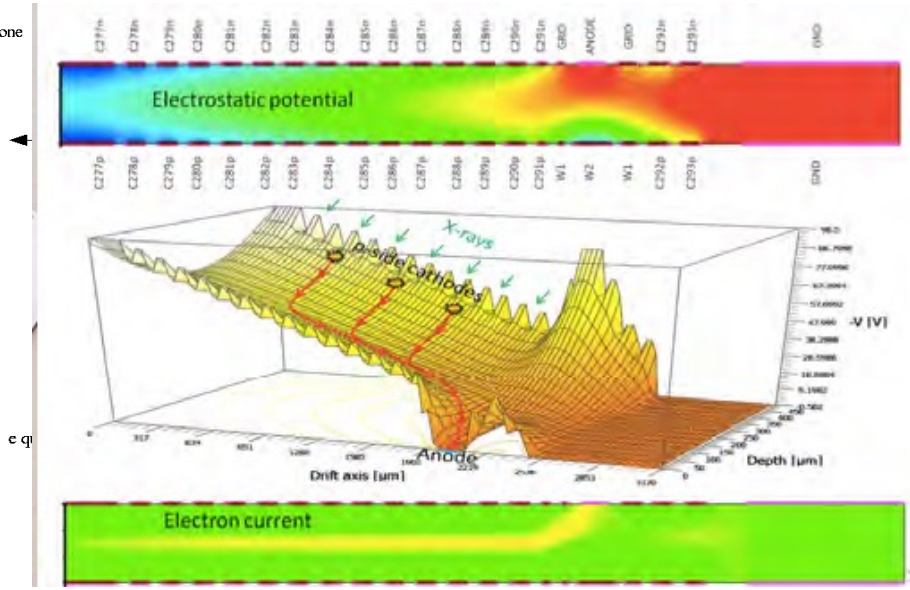


Linear Silicon Drift Detector





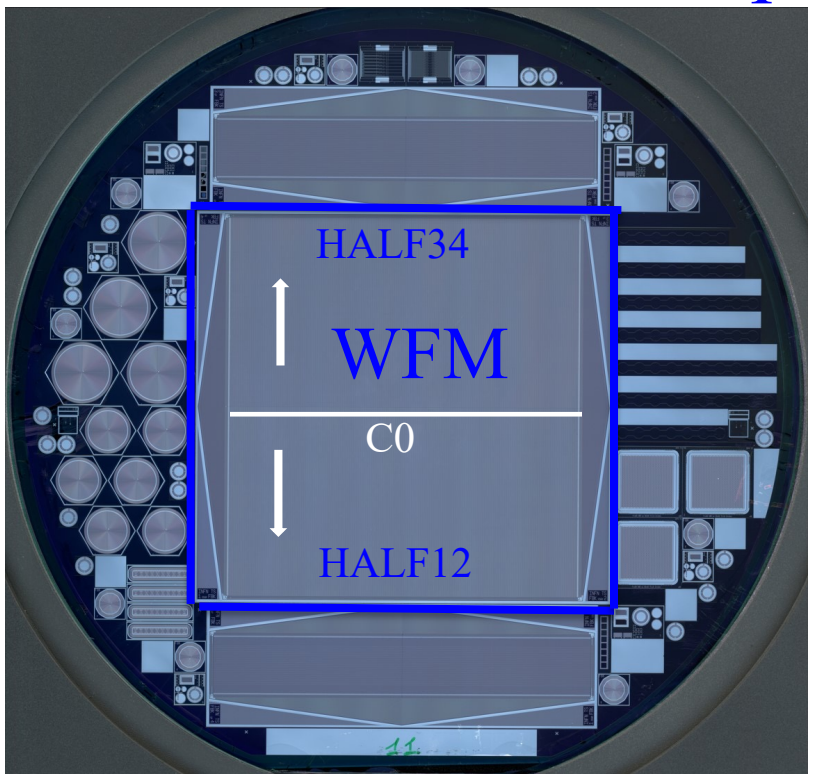




- p-type implants on both side of silicon with integrated voltage divider
- linear electric field from a high voltage at the central cathode to low voltage at the edges of the detector
- the line of n-type readout anodes
- electron cloud, created by charge particle, drifts and diffuses laterally
- The central anode gives us the x coordinate
- the width of the cloud gives as the y coordinate

  - large sensitive area
  - small redout anodes with low capacitance
  - reduced number of readout channels.

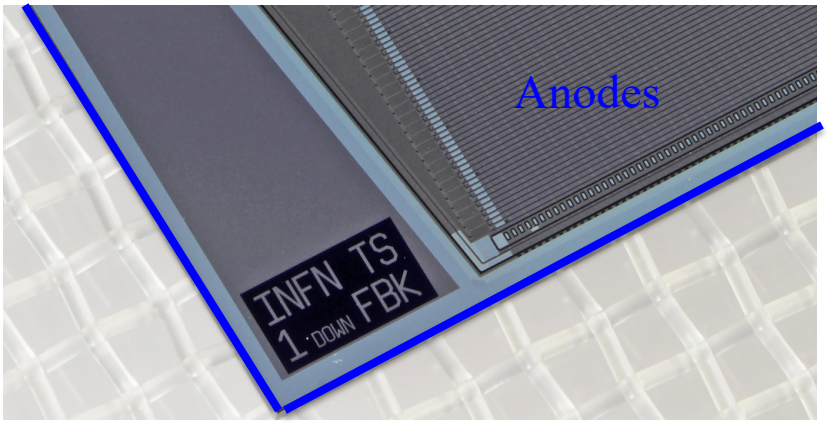
Sensor production



WFM layout

- **two symmetrical drift regions HALF12 and HALF34 with one high voltage cathode C0,** each one defined by 292 p-type cathodes implanted on both sides of the wafer
- **the readout n-type anodes, organized in two arrays along opposite ends of the detector**.

The challenge is to produce large area sensors with low leakage current and good yield



FBK Production

- Si wafer: 6", 450 um thick, float-zone, n-type
- Resistivity: 6.5-10 kΩcm
- Processing: double-sided, FBK proprietary **leakage reduction steps (gettering)**
- Batch : WFM221 15 wafer – 15 sensors
  WFM231 20 wafer – 20 sensors

Sensors Parameters

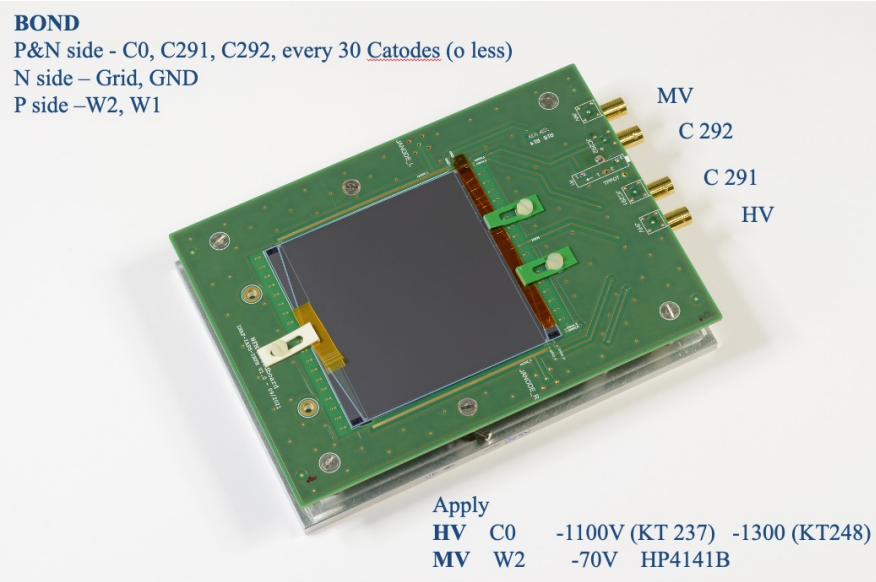
Geometrical dimensions	77.08 × 72.42 mm^2
Active volume	64.90 mm × 70.18 mm × 450 µm
Number of anodes	**384 per half**
Anode pitch	**169 µm**
Anode capacitance	≈ 90 fF
Drift field	360 V/cm (Bias of 1.3 kV)
Drift speed	5x10^5 cm/s @ 20 C, 7.6x10^5 cm/s @ -26 C
Leakage current (BOL)	< 36 pA/anode (600 pA/cm^2)
Spatial resolution	< 25 µm (anode) < 6mm (drift)
Operative temperature	- 26C

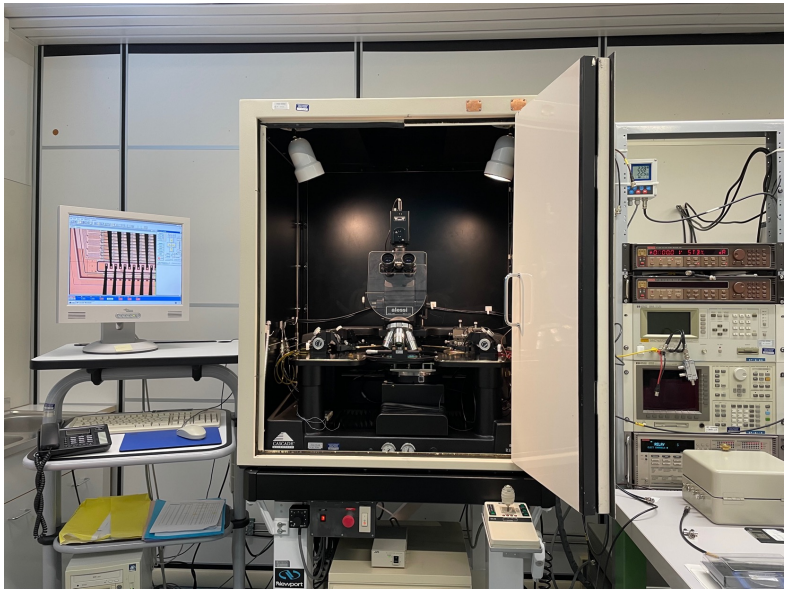
Specifications

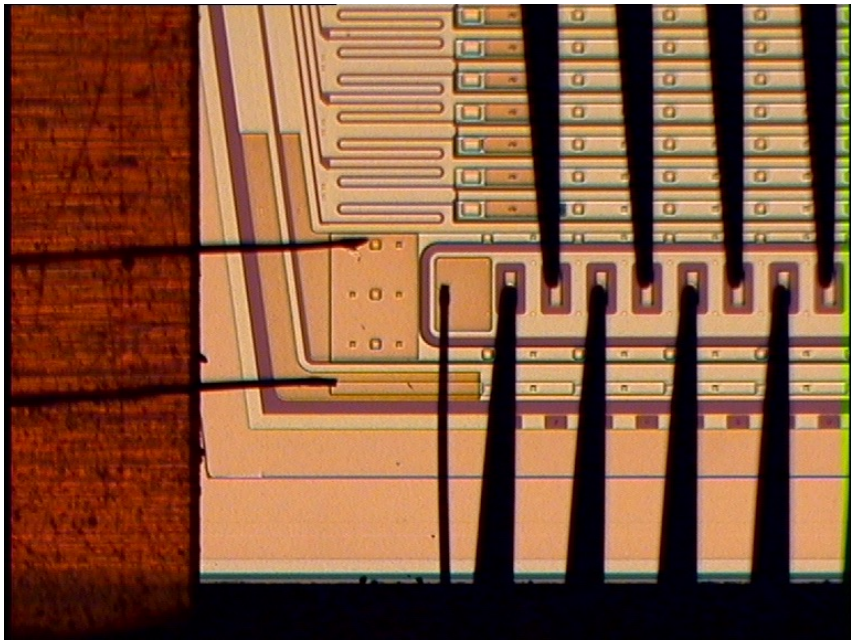
- I lim 600 pA/cm^2 36 pA/ anode @ 20C
- Less than 2% of defective anodes

Class **A**	>98% of Anodes in SPEC
Class **B**	one half of sensors with >98% of Anodes in SPEC another half of sensors with 72-97 % of Anodes in SPEC
Class **C**	with 72-97 % of Anodes in SPEC
Class **D**	very high cathode current

Test - PC Board Probe Station





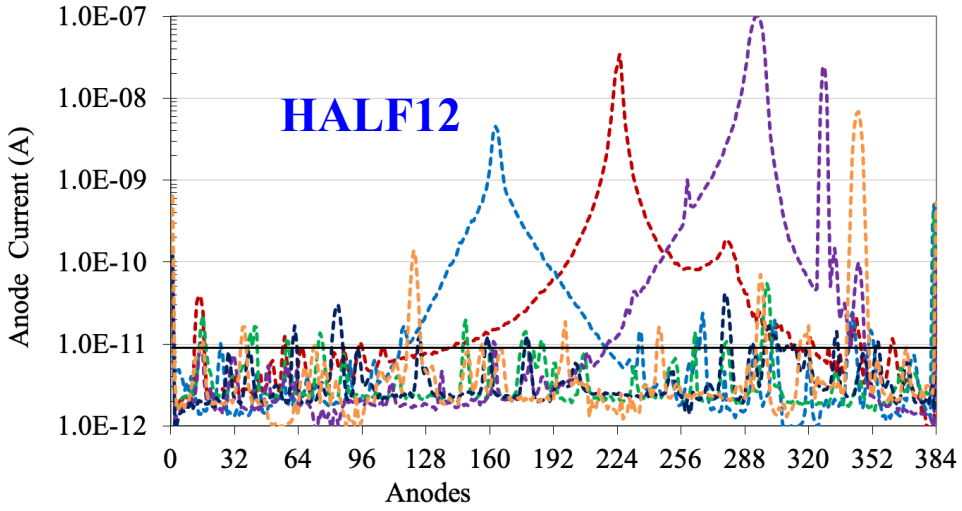


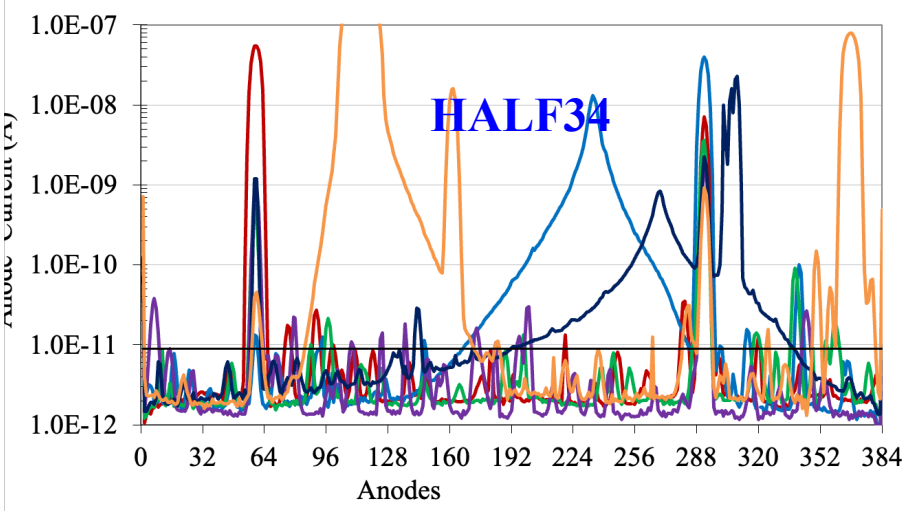
384 Anodes with 169 um pitch

The automatic scan is performed with the 50-needles ProbeCard. There are exactly 8 positions of the probecard for testing all the anodes. In the first position anodes 1-48 are measured with two last needles connected to GND. Then for 6 positions of the probecard **48 central anodes with two outer needles connected to GND** are measured. In the last position the last 48 anodes are tested with two first needles connected to GND.

Scans are performed for two half-detectors **HALF12** and **HALF34**.

Sensors Production - WFM 221 (2022) 15 sensors





Class **A**	**0** sensors
Class **B**	**2** sensors
Class **C**	**4** sensors
Class **D**	**9** sensors

For the next WFM231 Batch FBK applied

- special procedure of handling
- increased robustness (more processing steps) and surface protection of the side not under processing

Sensors Production – Batch WFM 231 (2023) 20 sensors

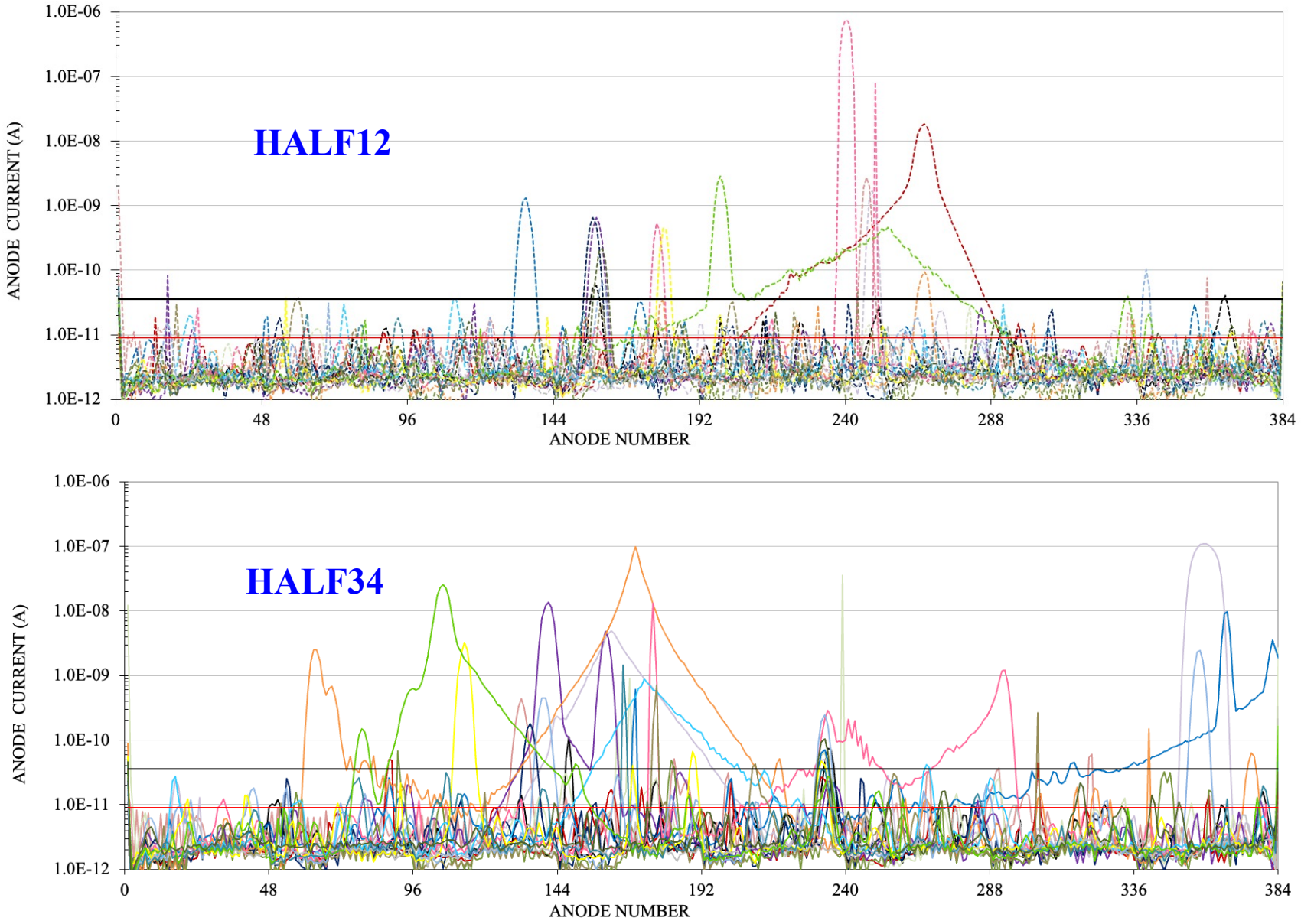
	WFM			
		pA	A	pA/cm2
	I limits	35.82	3.58E-11	600.0

	LOT	WAFER		I min	I limits	Imax	< I Anodes >, I Anodes < I limits			GOOD	BAD	Yield	A	B	C	Mec	TOT
				A	A	A	A	pA	pA/ cm2	N	N	%	8	9	2	1	20
							20C	20C	20C								
1	WFM231	1	DOWN12	4.78E-13	3.58E-11	5.84E-11	3.77E-12	3.8	63	378	6	98%	1				
	23/10/2023		UP34	7.58E-14	3.58E-11	1.14E-10	3.26E-12	3.3	55	377	7	98%					
			TOT	7.58E-14	3.58E-11	1.14E-10	3.51E-12	3.5	59	755	13	98%					
2	WFM231	2	DOWN12	1.60E-12	3.58E-11	2.73E-09	4.52E-12	4.5	76	375	9	98%		1			
	23/10/2023		UP34	1.20E-12	3.58E-11	4.34E-10	4.56E-12	4.6	76	371	13	97%					
			TOT	1.20E-12	3.58E-11	2.73E-09	4.54E-12	4.5	76	746	22	97%					
3	WFM231	3	DOWN12	8.25E-13	3.58E-11	1.73E-09	3.26E-12	3.3	55	378	6	98%		1			
	23/10/2023		UP34	8.04E-13	3.58E-11	1.10E-07	4.54E-12	4.5	76	304	80	79%					
			TOT	8.04E-13	3.58E-11	1.10E-07	3.83E-12	3.8	64	682	86	89%					
4	WFM231	4	DOWN12	1.08E-12	3.58E-11	4.97E-11	3.15E-12	3.1	53	382	2	99%	1				
	23/10/2023		UP34	1.06E-12	3.58E-11	3.55E-08	4.44E-12	4.4	74	376	8	98%					
			TOT	1.06E-12	3.58E-11	3.55E-08	3.79E-12	3.8	63	758	10	99%					
5	WFM231	5	DOWN12	5.80E-13	3.58E-11	1.83E-08	4.40E-12	4.4	74	314	70	82%		1			
	25/10/2023		UP34	4.13E-13	3.58E-11	4.98E-11	3.22E-12	3.2	54	380	4	99%					
			TOT	4.13E-13	3.58E-11	1.83E-08	3.76E-12	3.8	63	694	74	90%					

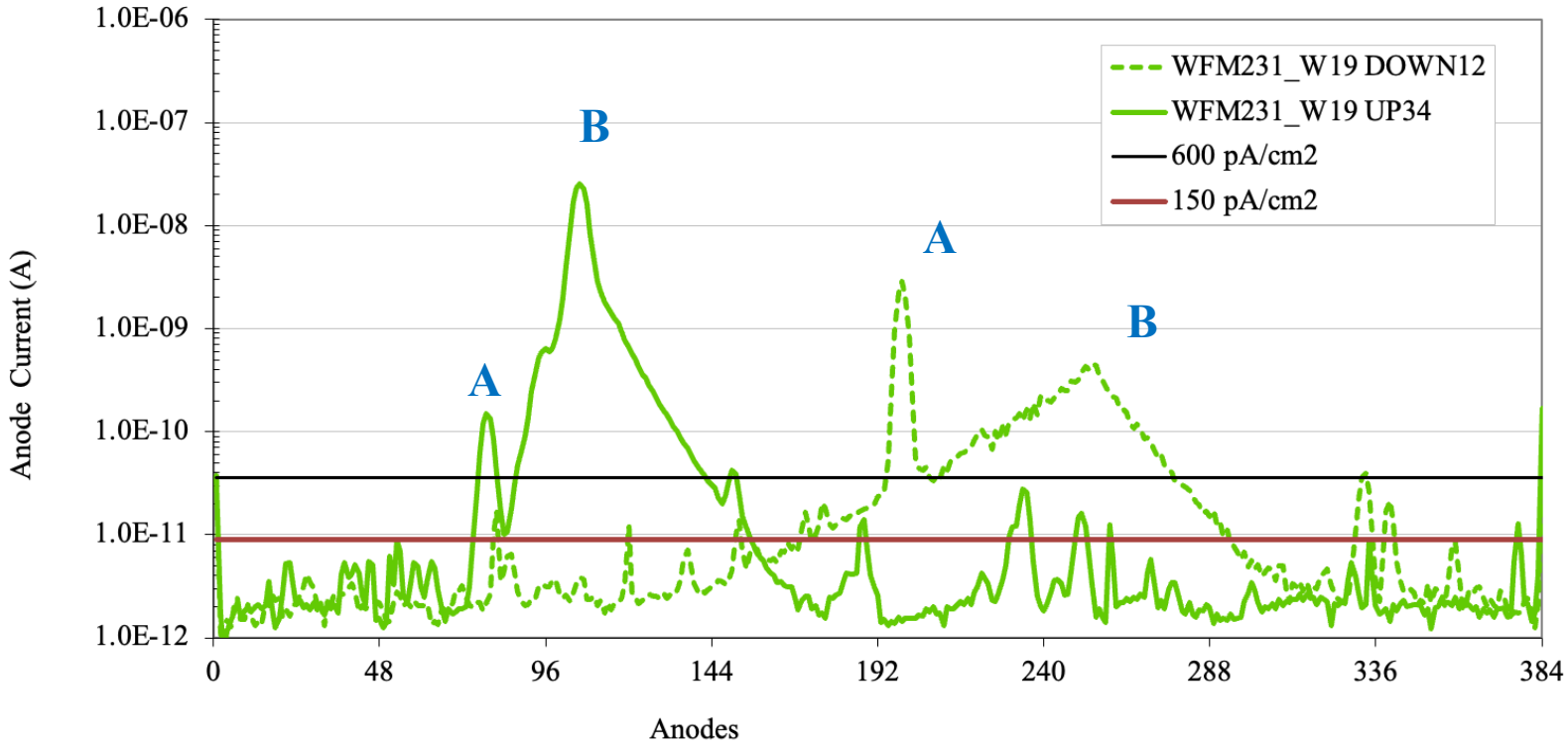
$< I > = 50 - 70$ pA/cm^2 (3 - 5 pA/anode)

Class **A** **8** sensors (**yield 40%**)
Class **B** **9** sensors
Class **C** **2** sensors
Class **D** **1** sensor

WFM 231 Anode Scan of 19 Sensors



WFM 231 W19



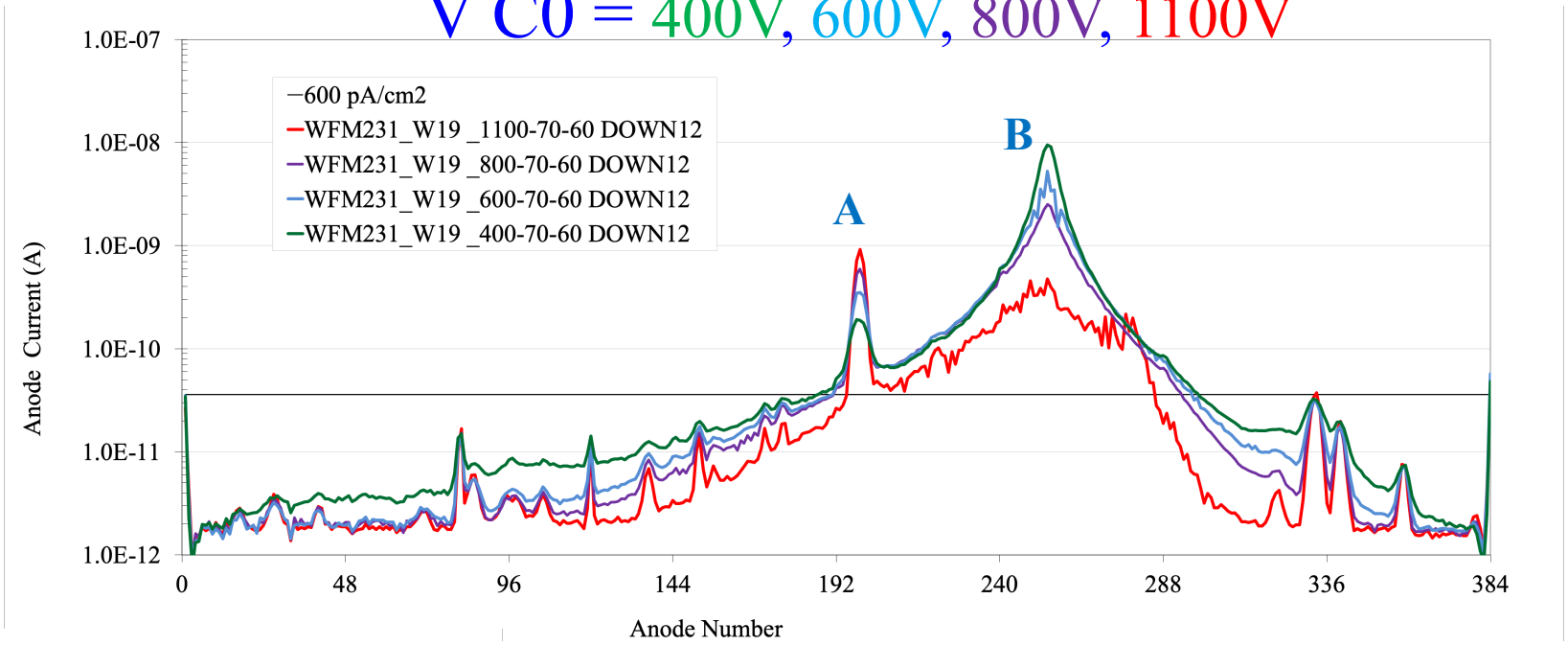
Two types of defects

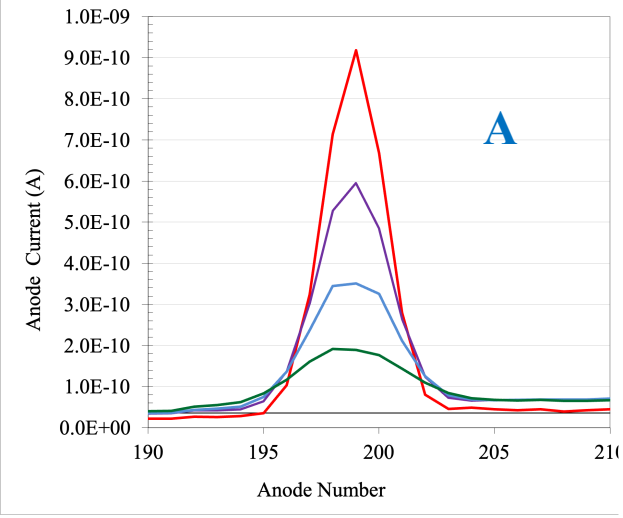
- **A** "Normal" peak, involving 8-10 Anodes
- **B** "Triangle" peak, involving 80-150 Anodes

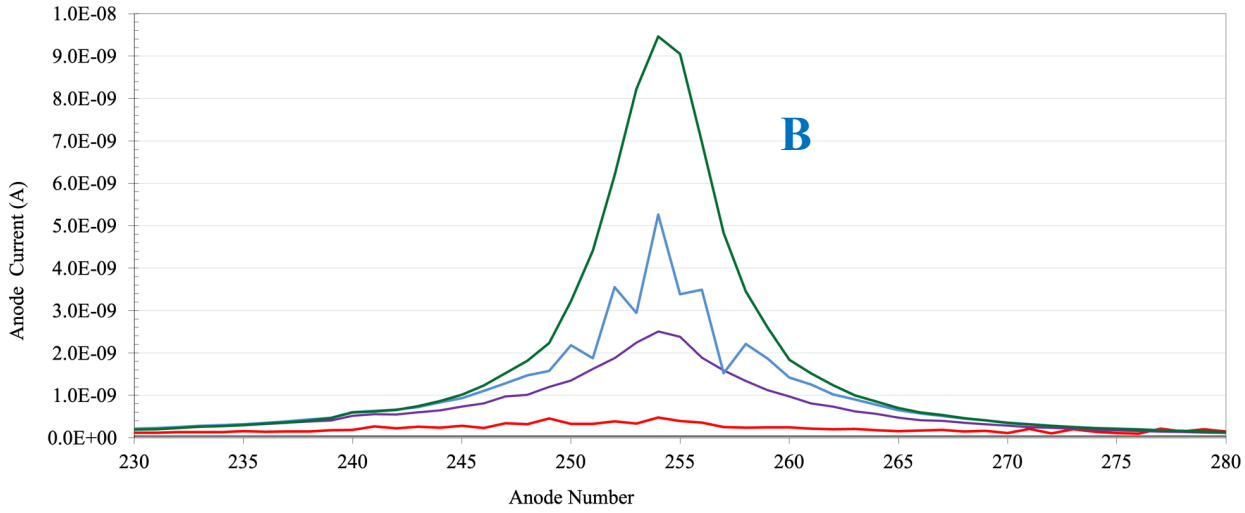
Defects of type A involve a limited number of anodes. The current generated by defects **A** diffuses while drifting toward the anodes the same way the signal charge does.

WFM 231 W19 SCAN

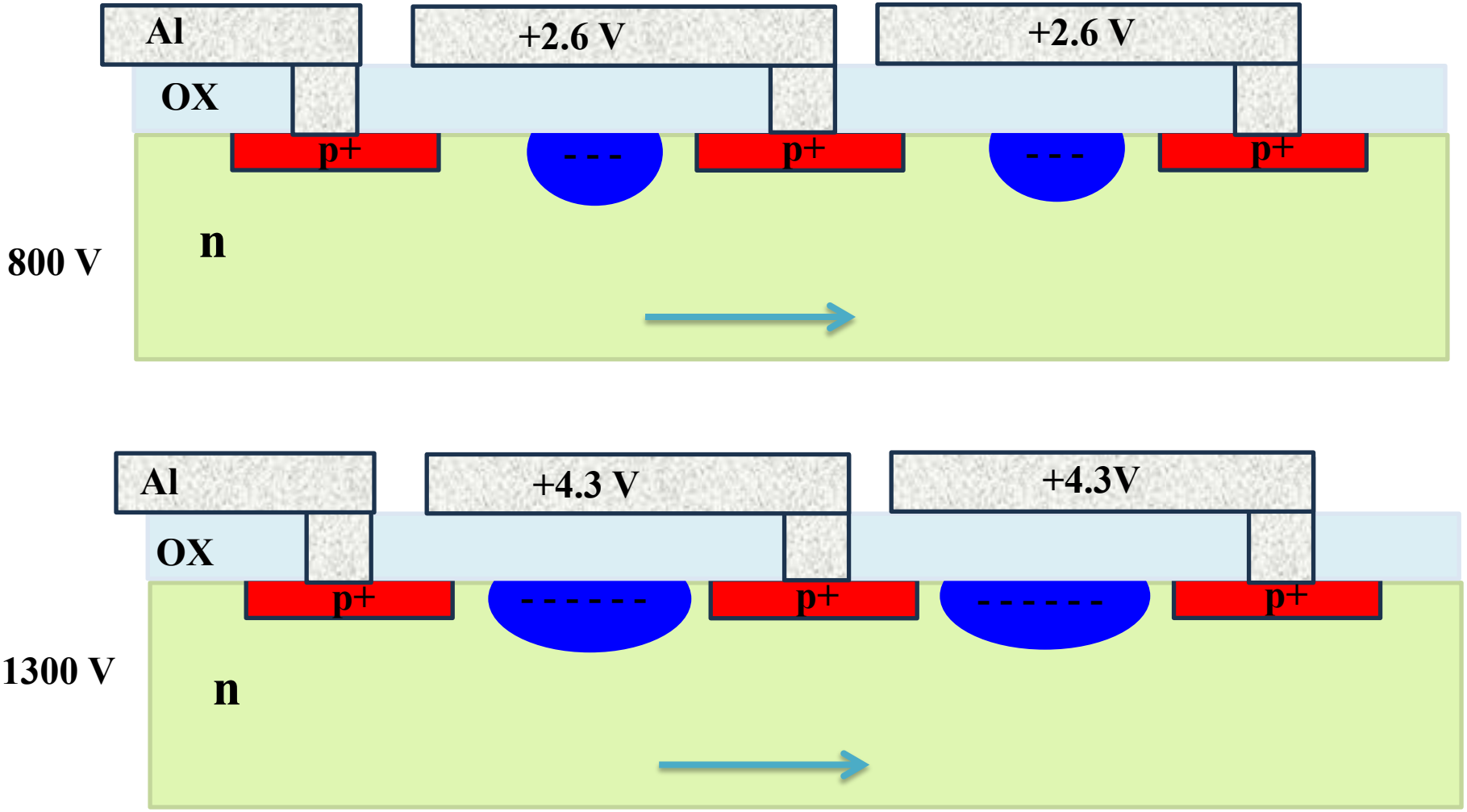
V C0 = 400V, 600V, 800V, 1100V





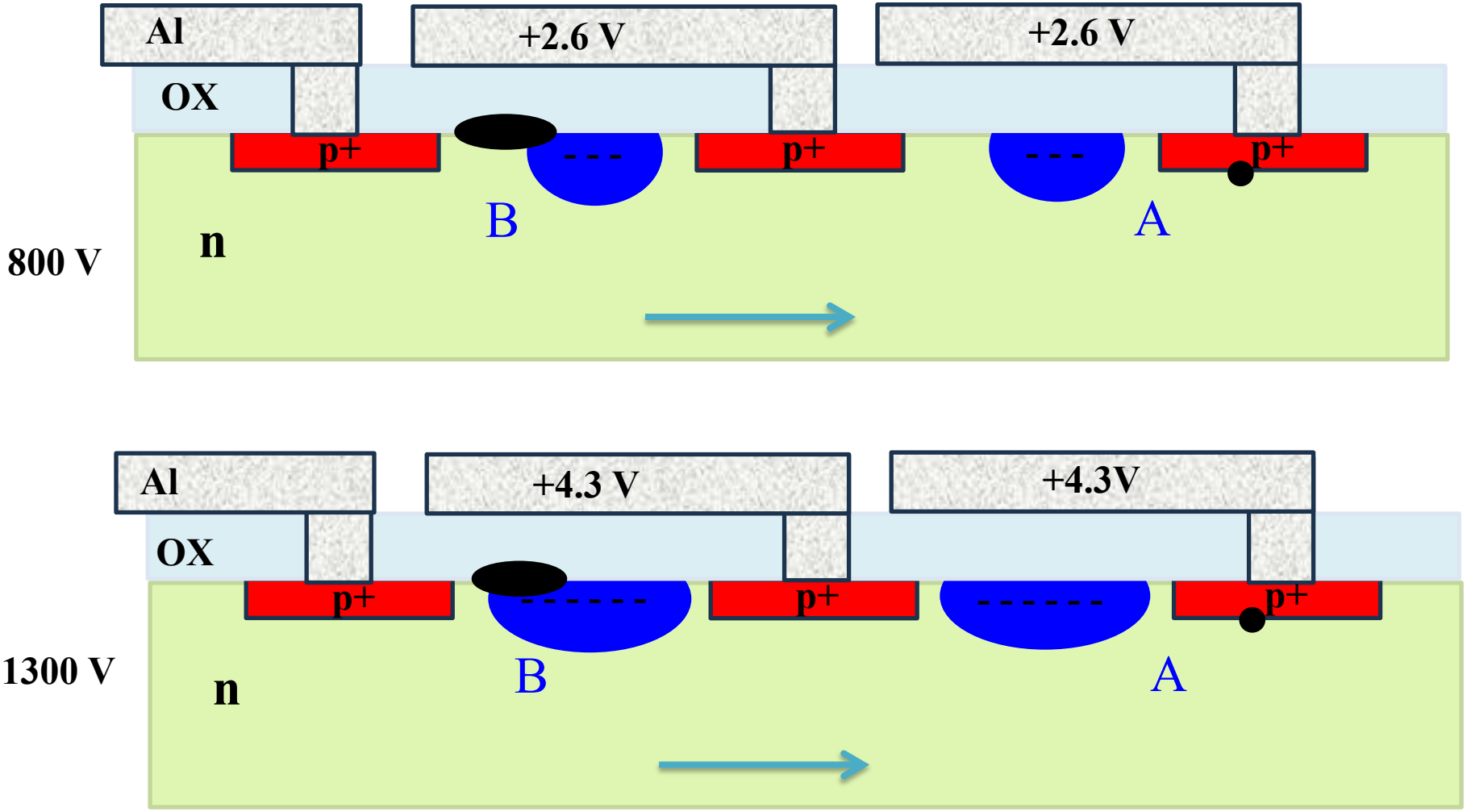


WFM 231 W19 Defects A and B



The positive field plate attracts more electrons in accumulated zone and extend laterally.

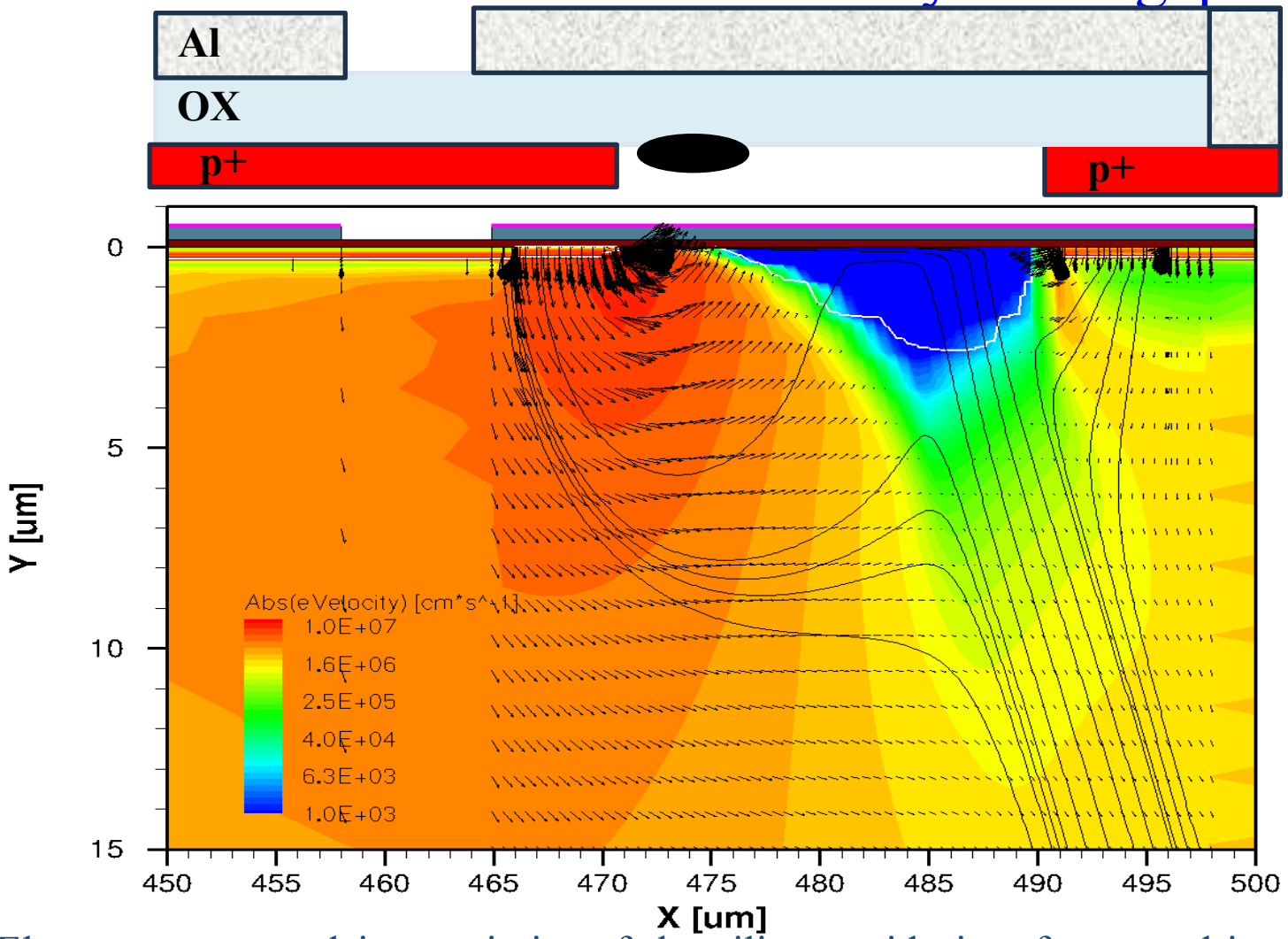
WFM 231 W19 Defects A and B



Defect **B:** extended defect in the Si-Oxide interface. Defect **B** enters gradually in the non depleted region so its efficiency at generating leakage current decreases.

Defect **A:** single-point defects in a Bulk.

Simulations. Electron Velocity in the gap region.



Electrons generated in proximity of the silicon-oxide interface are driven toward the non depleted blue region. Here they find a very low electric field and can freely diffuse along the cathodes over a long distance, even some centimeters.

Conclusions

98% of Anodes < 600 pA/cm2

WFM 8/20 40% Yield

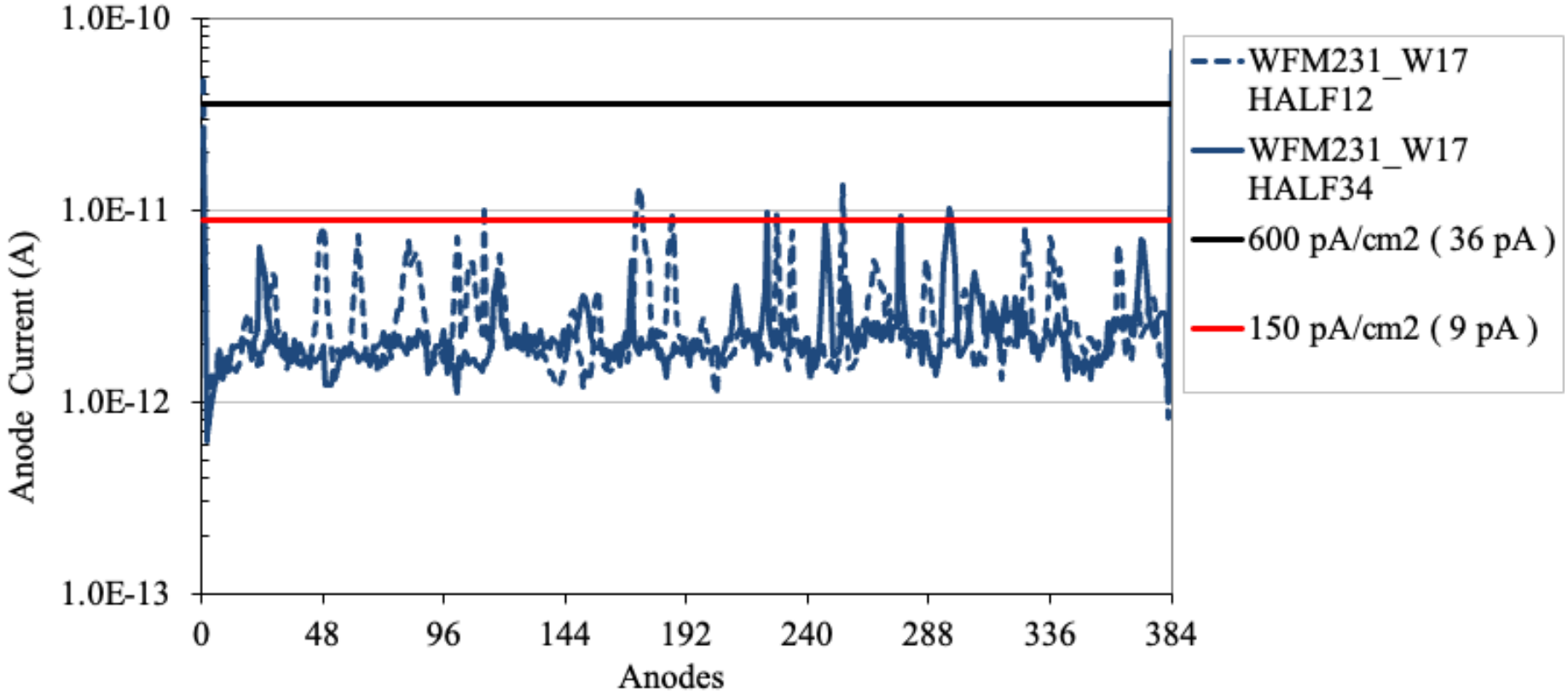
- We demonstrated the feasibility of producing large area SDDs with a reasonable yield for the eXTP WFM instrument.
- The fabrication process is able to produce the sensors with very low leakage currents
- We understand the factors limiting the yield and we plan to change the design to reduce effect of this factors.

Thank you

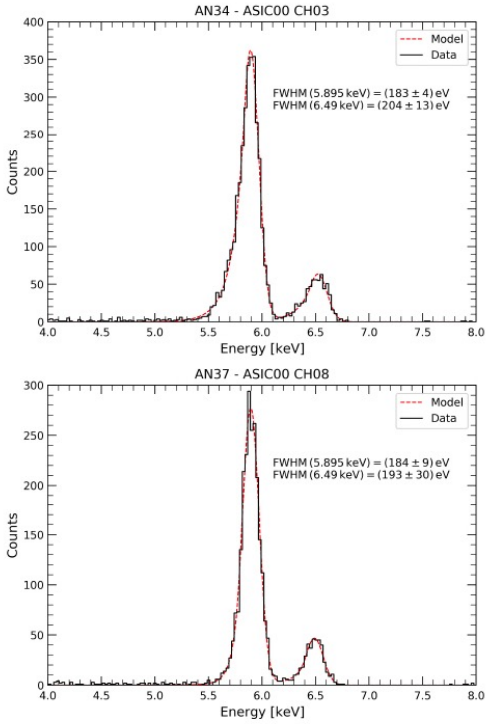
WFM 231 The best

< I > = 43 pA/cm^2 **(2.6 pA/anode)**

99.6% of Anodes in SPEC of 600 pA/cm^2
Only **3** lateral anodes are out of spec



Anode-wise spectral performance was evaluated by shielding the detector except for the anode region, and exposing it to X-rays from ^{55}Fe and ^{109}Cd. Tests were performed at 20 °C and 0°C in a climatic chamber, yielding a best resolution of **183 eV** and an average of 204 eV **at 5.9 keV at 0 °C**.



Sample single-anode spectra at 0 °C at 3.6 µs shaping time