

IV+CV Results for HGCAL Proto A Sensors

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CMS HGCAL Si Sensor Meeting

Outline

- 1 Introduction
- 2 IV Results
- 3 CV Results
- 4 Additional Measurements

Proto A sensors and their properties

- Have measured 43 sensors in about 6 months
- 120 um:
 - ▶ 19 HD Sensors: 5 oxide type B, 8 oxide type C (3 common p-stop), 6 oxide type D
- 200 um:
 - ▶ 12 LD Sensors: 2 oxide type A, 3 oxide type B, 5 oxide type C (3 common p-stop), 2 oxide type D
- 300 um:
 - ▶ 12 LD Sensors: 2 oxide type A, 3 oxide type B, 4 oxide type C (common p-stop), 5 oxide type D

Measurement Setup: PM8 and ALPS

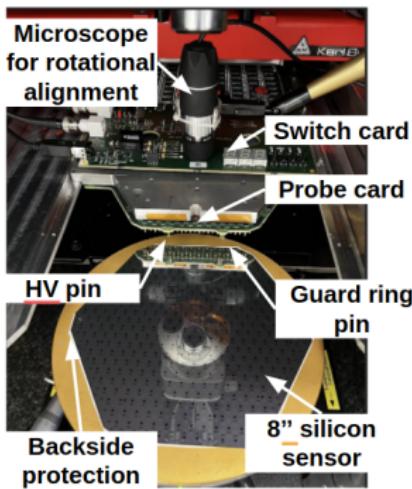


Figure: PM8

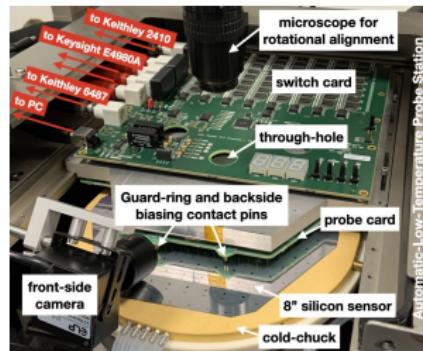


Figure: ALPS

- Pre-radiated sensors
 - ▶ Room temperature ref; humidity: 40% – 50% ; voltage up to -850V
 - ▶ Voltage provided through the HV pin to the backside
- LD sensor measured at ALPS; HD at PM8

General Remarks



Figure: picture of a discharge

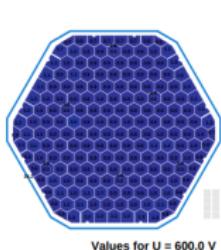
- Vulnerability to switch card breaks
- No discharges has been observed for proto A sensors
- Test throughput max. 20 per week

Proto-A: example IV+CV results



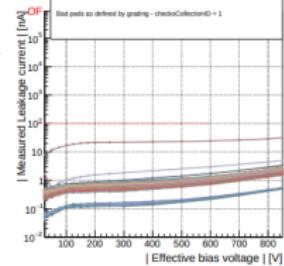
CERN IV
N4791_6

Cell current at 600 V

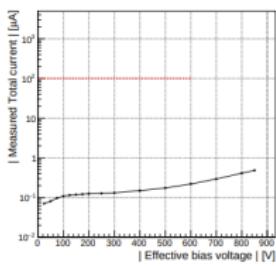


Values for $U = 600.0$ V

Channel IV curve

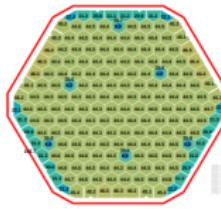


Total current curve



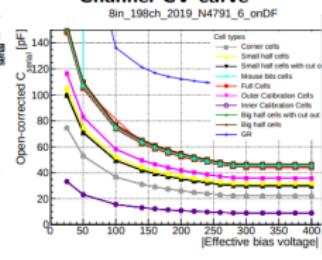
CERN CV
N4791_6

Capacitance at -400 V

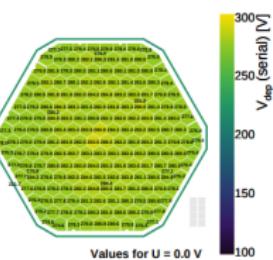


Values for $U = -400.0$ V

Channel CV curve



Depletion voltage

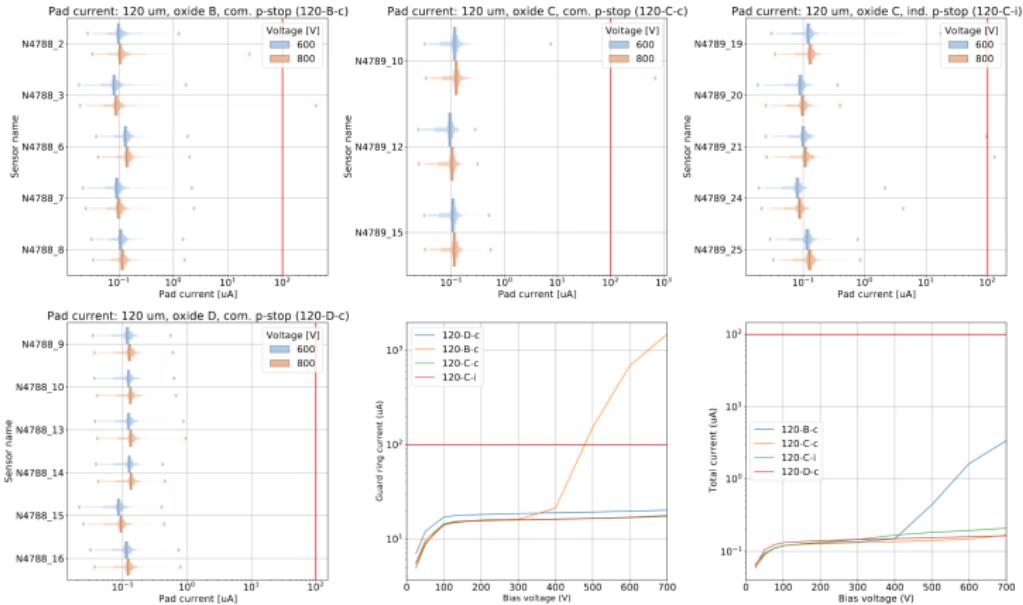


Values for $U = 0.0$ V

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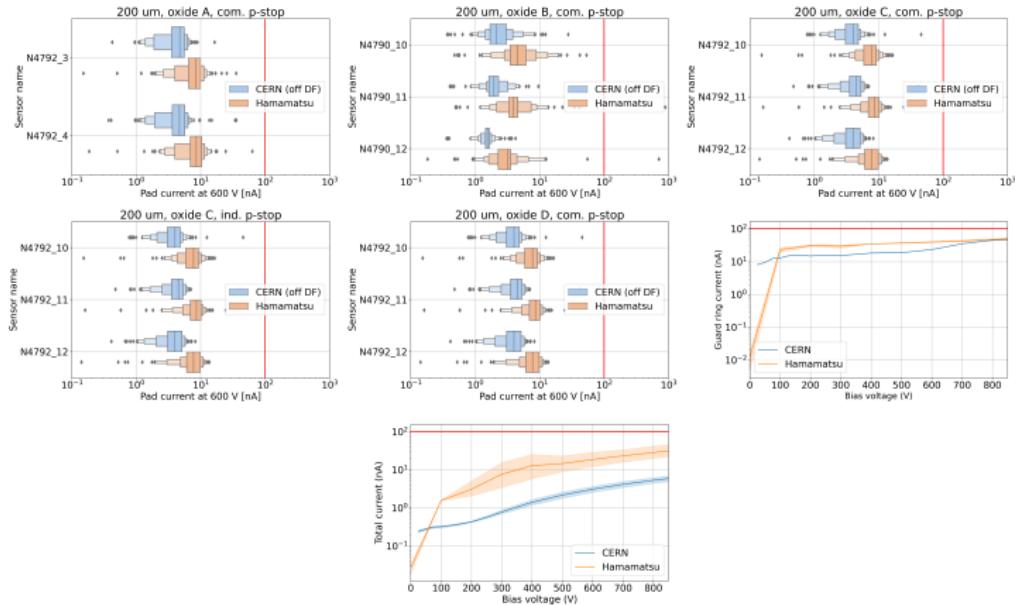
Proto-A, 120 um, IV results: HPK and CERN (on DF)



Proto-A, 120 um, IV grading comparison

tbd

Proto-A, 200 um, IV results: HPK and CERN (on DF)



Proto-A, 200 um, IV grading comparison

Proto-A: CERN IV grading, 12/12 passed



CMS full probe card (off dicing frame)									
Sensor ID	Thick-ness	P- Stop	Oxide type	I_tot_600V <100uA	I_tot_800V < 2.5* I_tot_600V	1) Ncell with I600 > 100nA	2) Ncell with I800 > 2.5 * threshold I800>25nA & I600<10nA	3) More than 8 bad cells: requirement, 1) and 2)	4) More than two neighbour cells, bad: requirement, 1) and 2)
N4792_3	200	com	A	Passed	Passed	0	0	Passed	Passed
N4792_4	200	com	A	Passed	Passed	0	0	Passed	Passed
N4790_10	200	com	B	Passed	Passed	0	1	Passed	Passed
N4790_11	200	com	B	Passed	Passed	0	0	Passed	Passed
N4790_12	200	com	B	Passed	Passed	0	0	Passed	Passed
N4792_10	200	com	C	Passed	Passed	0	0	Passed	Passed
N4792_11	200	com	C	Passed	Passed	0	0	Passed	Passed
N4792_12	200	com	C	Passed	Passed	0	0	Passed	Passed
N4792_22	200	ind	C	Passed	Passed	0	0	Passed	Passed
N4792_23	200	ind	C	Passed	Passed	0	0	Passed	Passed
N4790_22	200	com	D	Passed	Passed	0	0	Passed	Passed
N4790_23	200	com	D	Passed	Passed	0	0	Passed	Passed

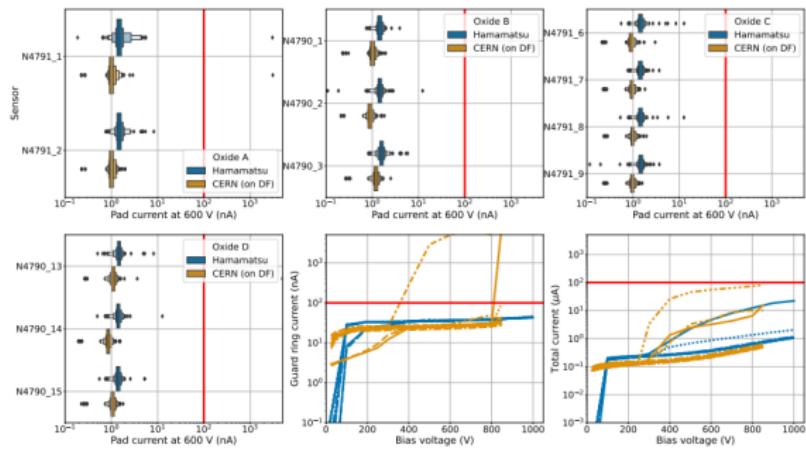
All sensors passed the grading at Hamamatsu as well

March 1, 2022

Marta Krawczyk, Low Density proto-A sensors

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Proto-A, 300 um, IV results: HPK and CERN (on DF)

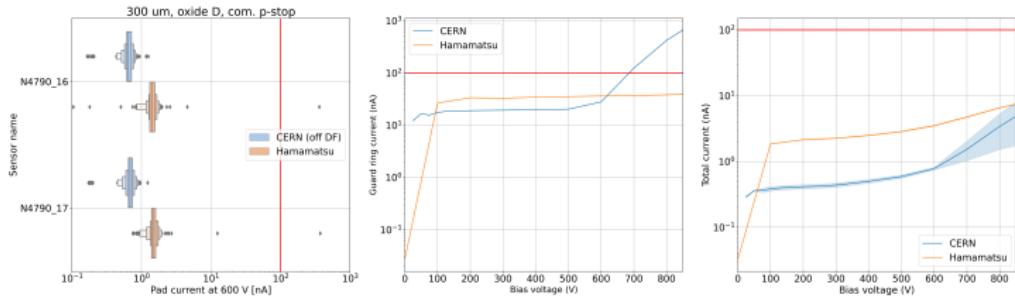


- ▶ N4791_1 (oxide type 'A') also fails at CERN. Other 11 sensors also pass IV criteria at CERN
- ▶ Guard ring current tends to be higher at CERN than at HPK

Proto-A, 300 um, IV grading comparison

Sensor ID	HPK full probe card				CMS full probe card (on dicing frame)				CMS full probe card (off dicing frame)			
	I_tot, 800V <100nA	I_tot, 800V <2.5°	I_tot, 600V	I_tot, 600V >100nA	I_tot, 800V <100nA	I_tot, 800V <2.5°	I_tot, 600V	I_tot, 600V >100nA	I_tot, 800V <100nA	I_tot, 800V <2.5°	I_tot, 600V	I_tot, 600V >100nA
N4791_1	Passed	Failed	1	0	Passed	Passed	Passed	Passed	2	0	Passed	Passed
N4791_2	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	1	Passed	Passed
N4790_1	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	1	Passed	Passed
N4790_2	Passed	Passed	0	0	Passed	Passed	Passed	Passed	1	0	Passed	Passed
N4790_3	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_4	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_5	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	1	Passed	Passed
N4791_6	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_7	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_8	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_9	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_10	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_11	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	1	Passed	Passed
N4791_20	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4791_21	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	1	Passed	Passed
N4791_22	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	1	Passed	Passed
N4790_13	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	1	Passed	Passed
N4790_14	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed
N4790_15	Passed	Passed	0	0	Passed	Passed	Passed	Passed	0	0	Passed	Passed

Proto-A Batch 2, 300 μm , IV results: HPK and CERN (on DF)



Proto-A Batch 2, 300 um, IV grading comparison

HPK full probe card									
Sensor ID	Thickness	P- Stop	Oxide type	I_tot_600V <100uA	I_tot_800V < 2.5* I_tot_600V	1) Ncell with I600 > 100nA	2) Ncell with I800 > 2.5 * I600 & I600>10nA threshold I800>25nA & I600<10nA	3) More than 8 bad cells: requirem. 1) and 2)	4) More than two neighbour cells bad: requirem. 1) and 2)
N4790_16	300	com	D	Passed	Passed	0	0	Passed	Passed
N4790_17	300	com	D	Passed	Passed	0	0	Passed	Passed

CMS full probe card (off dicing frame)									
Sensor ID	Thickness	P- Stop	Oxide type	I_tot_600V <100uA	I_tot_800V < 2.5* I_tot_600V	1) Ncell with I600 > 100nA	2) Ncell with I800 > 2.5 * I600 & I600>10nA threshold I800>25nA & I600<10nA	3) More than 8 bad cells: requirem. 1) and 2)	4) More than two neighbour cells bad: requirem. 1) and 2)
N4790_16	300	com	D	Passed	Failed	0	1	Passed	Passed
N4790_17	300	com	D	Passed	Passed	0	0	Passed	Passed

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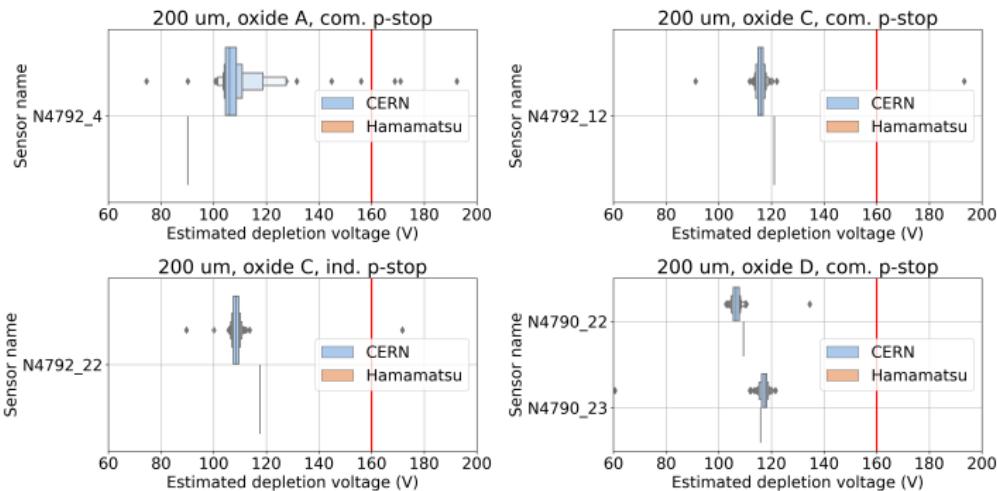
Proto-A, 120 um, CV results: HPK and CERN (on DF)

tbd

Proto-A, 120 um, CV grading comparison

tbd

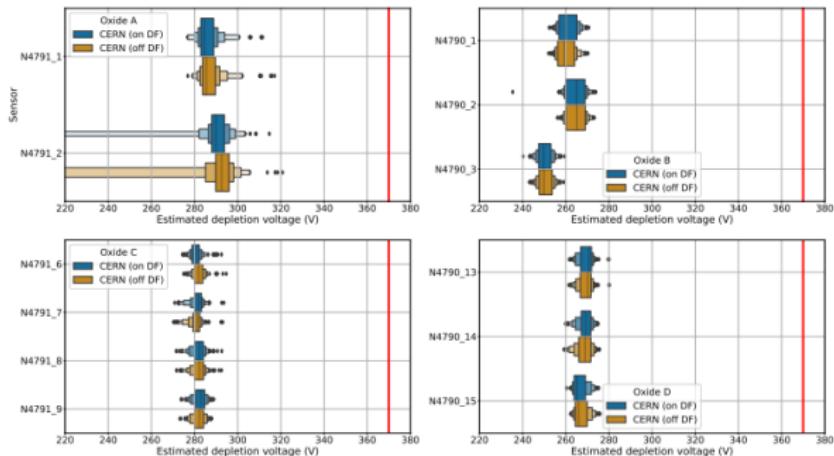
Proto-A, 200 um, CV results: HPK and CERN (on DF)



Proto-A, 200 um, CV grading comparison

CMS full probe card (off dicing frame)						
Sensor ID	Thick-ness	P- Stop	Oxide type	V dep corresponding to thickness	Maximum variation of Vdep across sensor of $\pm 10\%$	Thickness variation < 10 μm
N4792_4	200	com	A	passed: 94.5V < 160V	passed: 7.9%	passed: 0.5% = 1.0um
N4792_12	200	com	C	passed: 117.2V < 160V	passed: 0.9%	passed: 0.4% = 0.8um
N4792_22	200	ind	C	passed: 109.4V < 160V	passed: 0.8%	passed: 0.4% = 0.8um
N4790_22	200	com	D	passed: 106.9V < 160V	passed: 0.7%	passed: 0.6% = 1.2um
N4790_23	200	com	D	passed: 116.2V < 160V	passed: 0.5%	passed: 0.6% = 1.2um

Proto-A, 300 um, CV results: HPK and CERN (on DF)

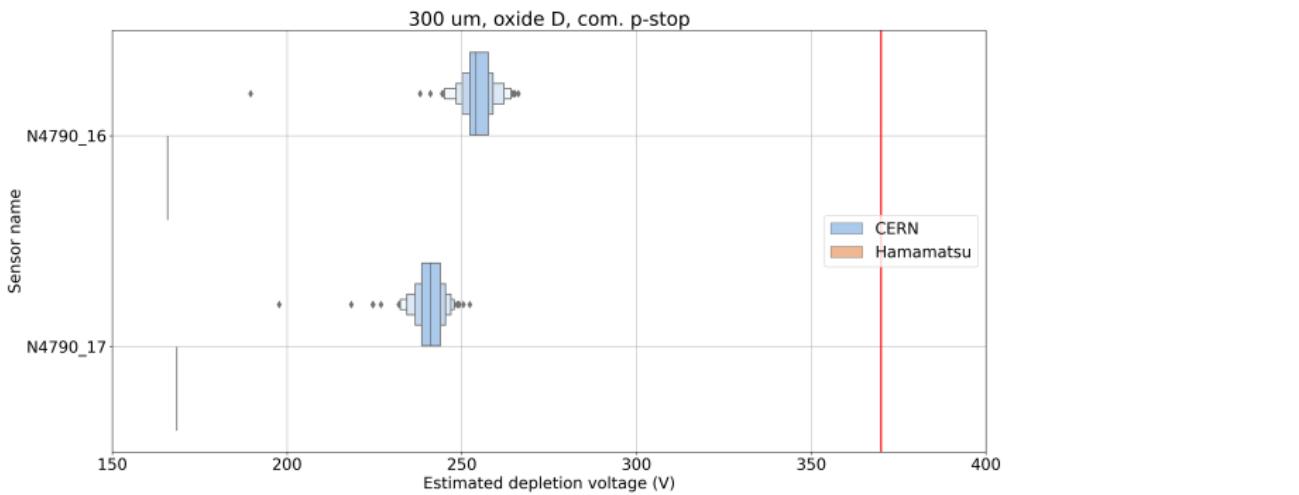


- ▶ Note difference in depletion voltage between oxide types
- ▶ Oxide types B-D pass CV criteria
- ▶ Oxide type A also pass CV criteria, but many pads with spurious C-readings

Proto-A, 300 um, CV grading comparison

CERN full probe card (on dicing frame)				CMS full probe card (off dicing frame)			
Sensor ID	V dep corresponding to thickness	Maximum variation of Vdep across sensor of ± 10%	Thickness variation < 10 µm	V dep corresponding to thickness	Maximum variation of Vdep across sensor of ± 10%	Thickness variation < 10 µm	
N4791_1	passed: 284.9V<370V	passed: 0.9%	passed: 0.8% = 2.4 um	passed: 285.8V<370V	passed: 0.9%	passed: 0.9% = 2.7 um	
N4791_2	passed: 280.3V<370V	passed: 0.7%	passed: 0.8% = 2.4 um	passed: 293.1V<370V	passed: 0.7%	passed: 0.8% = 2.4 um	
N4790_1	passed: 262.7V<370V	passed: 1.2%	passed: 0.4% = 1.2 um	passed: 261.8V<370V	passed: 1.2%	passed: 0.4% = 1.2 um	
N4790_2	passed: 267.7V<370V	passed: 1.1%	passed: 0.4% = 1.2 um	passed: 267.6V<370V	passed: 1.2%	passed: 0.4% = 1.2 um	
N4790_3	passed: 251.0V<370V	passed: 0.9%	passed: 0.6% = 1.8 um	passed: 251.2V<370V	passed: 0.9%	passed: 0.6% = 1.8 um	
N4791_6	passed: 281.2V<370V	passed: 0.4%	passed: 0.4% = 1.2 um	passed: 282.7V<370V	passed: 0.5%	passed: 0.4% = 1.2 um	
N4791_7	passed: 282.3V<370V	passed: 0.9%	passed: 0.3% = 0.9 um	passed: 281.6V<370V	passed: 0.9%	passed: 0.4% = 1.2 um	
N4791_8	passed: 283.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um	passed: 283.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um	
N4791_9	passed: 283.5V<370V	passed: 0.4%	passed: 0.4% = 1.2 um	passed: 283.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um	
N4791_18	Not available			passed: 281.1V<370V	passed: 0.2%	passed: 0.4% = 1.2 um	
N4791_19				passed: 281.2V<370V	passed: 0.3%	passed: 0.6% = 1.8 um	
N4791_20				passed: 281.5V<370V	passed: 0.4%	passed: 0.8% = 2.4 um	
N4791_21				passed: 276.2V<370V	passed: 0.5%	passed: 0.6% = 1.8 um	
N4790_13	passed: 271.3V<370V	passed: 0.4%	passed: 0.5% = 1.5 um	passed: 271.0V<370V	passed: 0.4%	passed: 0.5% = 1.5 um	
N4790_14	passed: 269.8V<370V	passed: 0.5%	passed: 0.4% = 1.2 um	passed: 269.6V<370V	passed: 0.7%	passed: 0.4% = 1.2 um	
N4790_15	passed: 266.8V<370V	passed: 0.9%	passed: 0.3% = 0.9 um	passed: 267.4V<370V	passed: 1.0%	passed: 0.3% = 0.9 um	
N4790_7				passed: 111.4V < 160V	passed: 2.9%	passed: 0.2% = 0.4um	
N4790_8	passed: 111.0V< 160V	passed: 1.7%	passed: 0.3% = 0.6um				
N4790_9	passed: 111.3V< 160V	passed: 1.7%	passed: 1.0% = 2.0um				
N4792_6				passed: 126.6V < 160V	passed: 2.2%	passed: 0.3% = 0.6um	
N4792_7				passed: 124.6V < 160V	passed: 2.7%	passed: 0.3% = 0.6um	
N4792_9	passed: 121.7V< 160V	passed: 2.4%	passed: 2.2% = 4.4um				
N4792_18				passed: 121.2V < 160V	passed: 2.7%	passed: 0.3% = 0.6um	
N4792_19				passed: 111.3V < 160V	passed: 2.7%	passed: 0.3% = 0.6um	
N4792_20				passed: 118.5V < 160V	passed: 2.9%	passed: 0.3% = 0.6um	
N4792_21				passed: 119.3V < 160V	passed: 2.4%	passed: 0.3% = 0.6um	
N4790_19				passed: 115.3V < 160V	passed: 1.9%	passed: 0.3% = 0.6um	
N4790_20	passed: 115.5V< 160V	passed: 2.0%	passed: 0.9% = 1.8um				
N4790_21	passed: 110.3V< 160V	passed: 2.6%	passed: 0.4% = 0.8um				

Proto-A Batch 2, 300 μm , CV results: HPK and CERN (on DF)



Proto-A, Batch 2, 300 um, CV grading comparison

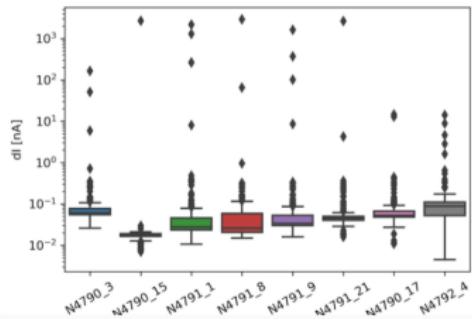
CMS full probe card (off dicing frame)						
Sensor ID	Thickness	P- Stop	Oxide type	V dep corresponding to thickness	Maximum variation of <u>Vdep</u> across sensor of $\pm 10\%$	Thickness variation < 10 μm
N4790_16	300	com	D	passed: 258.0V<370V	passed: 1.2%	passed: 0.4% = 1.2 μm
N4790_17	300	com	D	passed: 240.2V<370V	passed: 0.9%	passed: 0.4% = 1.2 μm

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Longterm Leakage current stability

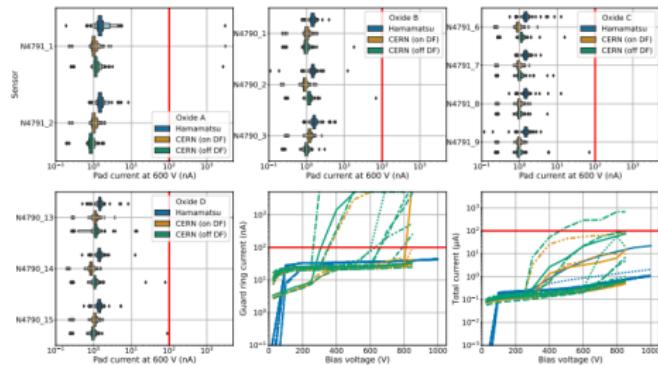
Ranges of current variations



Most channels show small variations. The outliers show current in the range of uA.

Dicing Frame removal at CERN

Proto-A: Our DF removal worsened IV



- ▶ 6/11 previously good sensors now fail at least one of the total current requirements
- ▶ Guard ring and total current (driven by guard ring) higher.

Summary

- Vulnerability to switch card breaks
- No discharges has been observed for proto A sensors
- Test throughput max. 20 per week

Backup

backup

Sensor list: HD

Sensor ID	P-stop	Flat band voltage voltage	Oxide quality	P-stop conc	Material	I-V	I-V remeasure	C-V
N4788_2	com	-2V	B	STD	epi	passed	-	Not conclusive
N4788_3	com	-2V	B	STD	epi	failed	failed	Not conclusive
N4788_6	com	-2V	B	STD	epi	passed	-	Not conclusive
N4788_7	com	-2V	B	STD	epi	passed	-	Not conclusive
N4788_8	com	-2V	B	STD	epi	failed	-	-
N4789_10	com	-2V	C	STD	epi	failed	passed	Not conclusive
N4789_12	com	-2V	C	STD	epi	passed	-	Not conclusive
N4789_15	com	-2V	C	STD	epi	passed	-	Not conclusive
N4789_19	ind	-2V	C	STD	epi	passed	-	-
N4789_20	ind	-2V	C	STD	epi	passed	-	Not conclusive
N4789_21	ind	-2V	C	STD	epi	passed	-	Not conclusive
N4789_24	ind	-2V	C	STD	epi	passed	-	-
N4789_25	ind	-2V	C	STD	epi	passed	-	-
N4788_9	com	-2V	D	STD	epi	passed	-	Not conclusive
N4788_10	com	-2V	D	STD	epi	passed	-	Not conclusive
N4788_13	com	-2V	D	STD	epi	passed	-	-
N4788_14	com	-2V	D	STD	epi	passed	-	-
N4788_15	com	-2V	D	STD	epi	passed	-	Not conclusive

Sensor list

ID	P- Stop	Thickness	Flat band voltage	P-stop concentration	Oxide quality	Material
N4792_3	com	200	-5V	STD	A	FZ
N4792_4	com	200	-5V	STD	A	FZ
N4790_10	com	200	-2V	STD	B	FZ
N4790_11	com	200	-2V	STD	B	FZ
N4790_12	com	200	-2V	STD	B	FZ
N4792_10	com	200	-2V	STD	C	FZ
N4792_11	com	200	-2V	STD	C	FZ
N4792_12	com	200	-2V	STD	C	FZ
N4792_22	ind	200	-2V	STD	C	FZ
N4792_23	ind	200	-2V	STD	C	FZ
N4790_22	com	200	-2V	STD	D	FZ
N4790_23	com	200	-2V	STD	D	FZ

Sensor list

Sensor ID	Scratch pad ID	Thick-ness	P-Stop	Oxide type	Flat band volt. (V)	P-Stop conc.	Proc.	Full-wafer
N4791_1	100088	300	com	A	-5	STD	FZ	CERN
N4791_2	100089	300	com	A	-5	STD	FZ	CERN
N4791_3	100090	300	com	A	-5	STD	FZ	HPK
N4791_4	100091	300	com	A	-5	STD	FZ	HPK
N4790_1	100076	300	com	B	-2	STD	FZ	CERN
N4790_2	100077	300	com	B	-2	STD	FZ	CERN
N4790_3	100078	300	com	B	-2	STD	FZ	CERN
N4790_4	100079	300	com	B	-2	STD	FZ	HPK
N4790_5	100080	300	com	B	-2	STD	FZ	HPK
N4790_6	100081	300	com	B	-2	STD	FZ	HPK
N4791_6	100093	300	com	C	-2	STD	FZ	CERN
N4791_7	100094	300	com	C	-2	STD	FZ	CERN
N4791_8	100095	300	com	C	-2	STD	FZ	CERN
N4791_9	100096	300	com	C	-2	STD	FZ	CERN
N4791_10	100097	300	com	C	-2	STD	FZ	HPK
N4791_11	100098	300	com	C	-2	STD	FZ	HPK
N4791_12	100099	300	com	C	-2	STD	FZ	HPK
N4791_13	100100	300	com	C	-2	STD	FZ	HPK
N4791_18	100105	300	ind	C	-2	STD	FZ	CERN
N4791_19	100106	300	ind	C	-2	STD	FZ	CERN
N4791_20	100107	300	ind	C	-2	STD	FZ	CERN
N4791_21	100108	300	ind	C	-2	STD	FZ	CERN
N4791_22	100109	300	ind	C	-2	STD	FZ	HPK
N4791_23	100110	300	ind	C	-2	STD	FZ	HPK
N4791_24	100111	300	ind	C	-2	STD	FZ	HPK
N4791_25	100112	300	ind	C	-2	STD	FZ	HPK
N4790_13	100082	300	com	D	-2	STD	FZ	CERN
N4790_14	100083	300	com	D	-2	STD	FZ	CERN
N4790_15	100084	300	com	D	-2	STD	FZ	CERN
N4790_16	100085	300	com	D	-2	STD	FZ	HPK
N4790_17	100086	300	com	D	-2	STD	FZ	HPK
N4790_18	100087	300	com	D	-2	STD	FZ	HPK

Sensor ID	Scratch pad ID	Thick-ness	P-Stop	Oxide type	Flat band volt. (V)	P-Stop conc.	Proc.	Full-wafer
N4792_2	200089	200	com	A	-5	STD	FZ	UCSB
N4792_3	200089	200	com	A	-5	STD	FZ	HPK
N4792_4	200089	200	com	A	-5	STD	FZ	HPK
N4790_7	200075	200	com	B	-2	STD	FZ	UCSB
N4790_8	200076	200	com	B	-2	STD	FZ	FSU
N4790_9	200077	200	com	B	-2	STD	FZ	FSU
N4790_10	200078	200	com	B	-2	STD	FZ	HPK
N4790_11	200079	200	com	B	-2	STD	FZ	HPK
N4790_12	200080	200	com	B	-2	STD	FZ	HPK
N4792_6	200092	200	com	C	-2	STD	FZ	UCSB
N4792_7	200093	200	com	C	-2	STD	FZ	UCSB
N4792_8	200094	200	com	C	-2	STD	FZ	FSU
N4792_9	200095	200	com	C	-2	STD	FZ	FSU
N4792_10	200096	200	com	C	-2	STD	FZ	HPK
N4792_11	200097	200	com	C	-2	STD	FZ	HPK
N4792_12	200098	200	com	C	-2	STD	FZ	HPK
N4792_13	200099	200	com	C	-2	STD	FZ	HPK
N4792_18	200104	200	ind	C	-2	STD	FZ	UCSB
N4792_19	200105	200	ind	C	-2	STD	FZ	UCSB
N4792_20	200106	200	ind	C	-2	STD	FZ	UCSB
N4792_21	200107	200	ind	C	-2	STD	FZ	UCSB
N4792_22	200108	200	ind	C	-2	STD	FZ	HPK
N4792_23	200109	200	ind	C	-2	STD	FZ	HPK
N4792_24	200110	200	ind	C	-2	STD	FZ	HPK
N4790_19	200081	200	com	D	-2	STD	FZ	UCSB
N4790_20	200082	200	com	D	-2	STD	FZ	FSU
N4790_21	200083	200	com	D	-2	STD	FZ	FSU
N4790_22	200084	200	com	D	-2	STD	FZ	HPK
N4790_23	200085	200	com	D	-2	STD	FZ	HPK
N4790_24	200086	200	com	D	-2	STD	FZ	HPK
N4790_25	200087	200	com	D	-2	STD	FZ	HPK

List of ProtoA Sensors

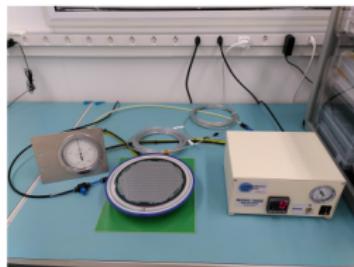
Dicing Frame removal at CERN

Backup

Dicing frame removal

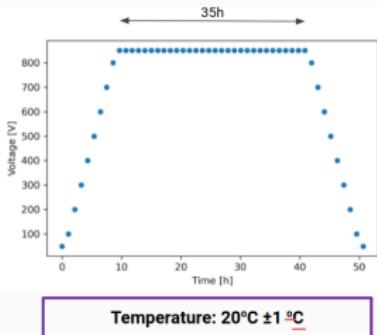
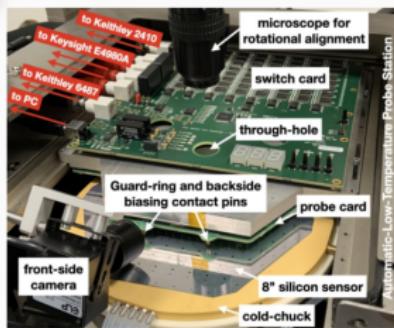


- ▶ UV illumination
- ▶ Heating up to 50°C
- ▶ 600 mbar vacuum



Longterm Leakage current stability

Measurement in ALPS probe station



Courtesy of T. Quast

February 1, 2022

Marta Krawczyk, 50 hours leakage current measurements

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