Update on SCP Slim Edges

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Acknowledgement:

1) Technical Guidance and Support by
Marc Christophersen*, Bernard F. Phlips*
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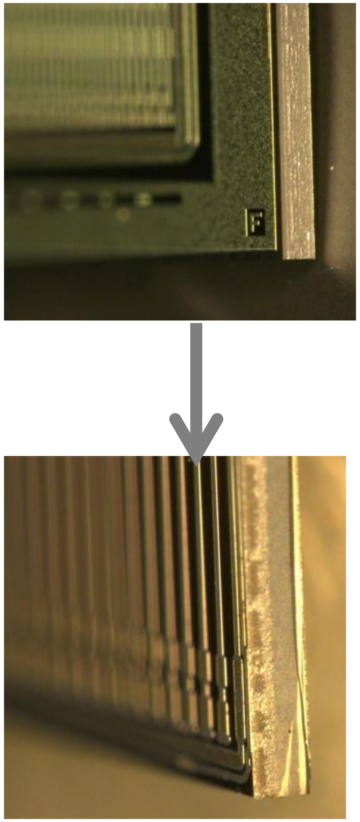
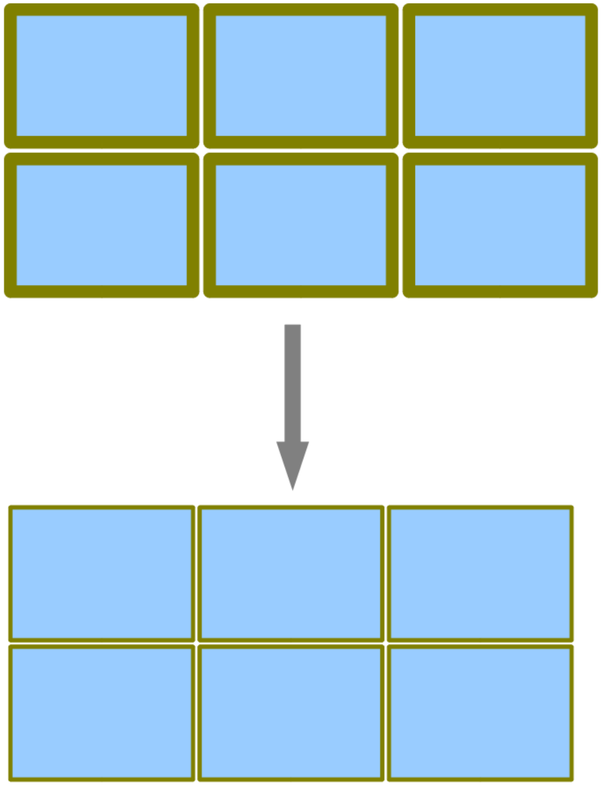
2) *Our numerous collaborators from ATLAS and RD50!*

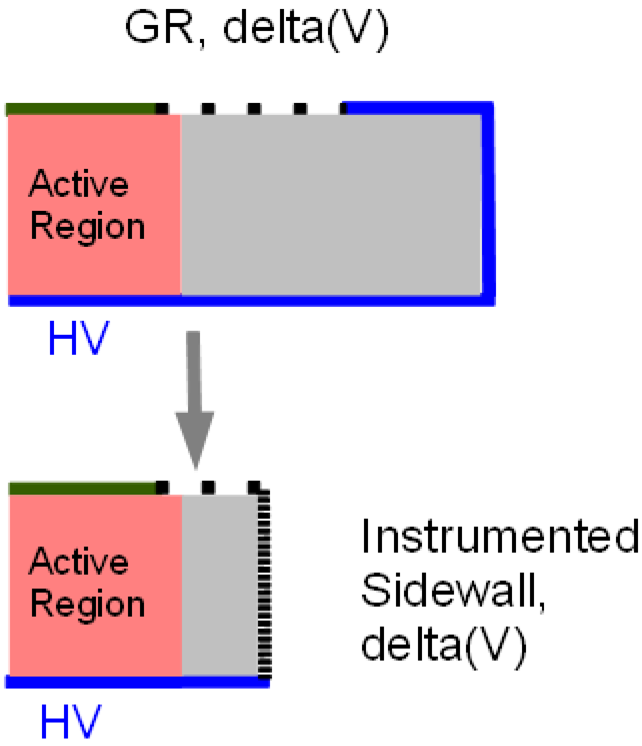
Slim Edges -- Motivation

<u>Basic Idea</u>: To minimize ~1 mm wide inactive peripheral region. This is relevant for “tiling” (as opposed to “shingling”) of large-area detector composed of small sensors.

<u>Basic Method</u>: To instrument the sidewall in a close proximity to active area, such that it’s <u>resistive</u>.

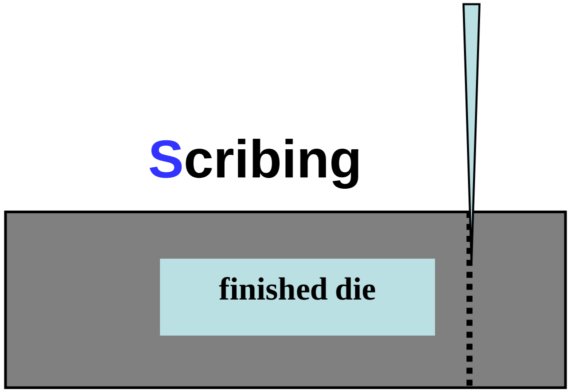






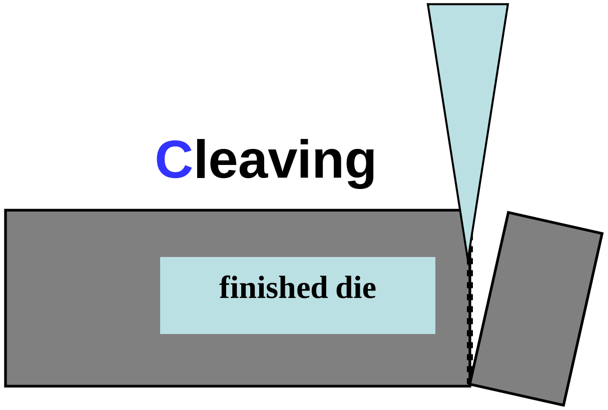
Method -- SCP Treatment

Scribing



- ➢ Diamond stylus
- ➢ Laser
- ➢ XeF_2 Etch
- ➢ DRIE Etch

Cleaving



- ➢ Tweezers (manual)
- ➢ Loomis Industries, LSD-100
- ➢ Dynatex, GTS-150

Passivation

Native Oxide
+ Radiation
or:

N-type	P-type
➢ Native SiO_2 + UV light or high T ➢ PECVD SiO_2 ➢ PECVD Si_3N_4 ➢ ALD “nanostack” of SiO_2 and Al_2O_3	➢ ALD of Al_2O_3

All Treatment is <u>post-processing & low-temp</u>
(Etch-scribing can be done during fabrication)

Basic requirement: 100 wafers (for rectangular side cleaving) with reasonably good alignment between sensor and lattice.

Current Efforts

We had a lot of technical development, with different fabrication options explored. For details, see recent publications:

- **M. Christophersen et al., "Alumina and Silicon Oxide/Nitride Sidewall Passivation for P- and N-Type Sensors", NIM A 699 (2013) 14**
- **M. Christophersen et al, “The effect of different dicing methods on the leakage currents of n-type silicon diodes and strip sensors”, Solid-State Electronics 81 (2013) 8.**
- **M. Christophersen et al, “Scribing-Cleaving-Passivation for High Energy Physics Silicon Sensors”, Proceedings of Science, accepted for publication.**
- **V. Fadeyev et al, “Scribe-cleave-passivate (SCP) slim edge technology for silicon sensors”, NIM A (2013) – in press. DOI: http://dx.doi.org/10.1016/j.nima.2013.03.046**

An interesting development is slim edge implementation as a part of low-R submission. → V. Benitez talk.

Recent work is focused on two aspects of device performance:

  - CCE near the edge
  - Radiation hardness

Asides:

- Application for proton tomography.
- Inter-strip with alumina passivation.

Charge Collection Testing

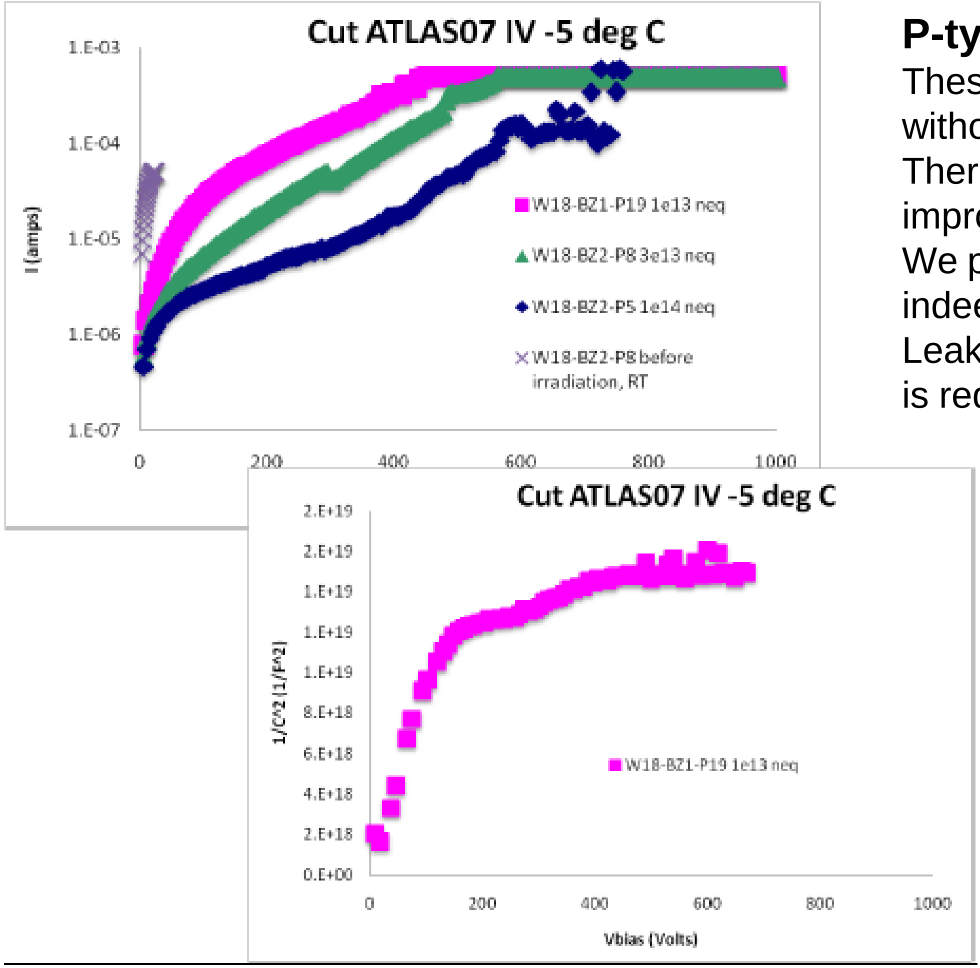
Sensor Type	Origin	Edge-Active area Distance [um]	Signal Readout	Beam	Ref
P-type strips	PPS (CIS)	~200	Binary (PTSM)	^{90}Sr	V. Fadeyev *et al* Pixel 2012, NIM A in press
N-type strips	GLAST (HPK)	~200	Analog (ALiBaVa)	^{90}Sr	R. Mori *et al*. 2012 JINST 7 P05002
P-type strips	PPS (CIS)	150	Analog (ALiBaVa)	Focused X-ray	R. Bates *et al.*, 2013 JINST 8 P01018
P-type 3D pixels	IBL (CNM)	50	FE-I3 & FE-I4	CERN Test Beam	S. Grinstein *et al.*, RESMDD12 G. Pellegrini *et al.*, Pixel 2012, NIM A in press
P-type strips	PPS (CIS)		Analog (ALiBaVa)	^{90}Sr	

In all cases CCE on the edge was within few % of CCE on other electrodes
→ BUT: all un-irradiated devices.

New development: MPI study has device irradiation in progress. See Anna Macchiolo's presentation on Wednesday.

1. 2010 Proton Irradiation Studies @LANL

S-C only: No Passivation



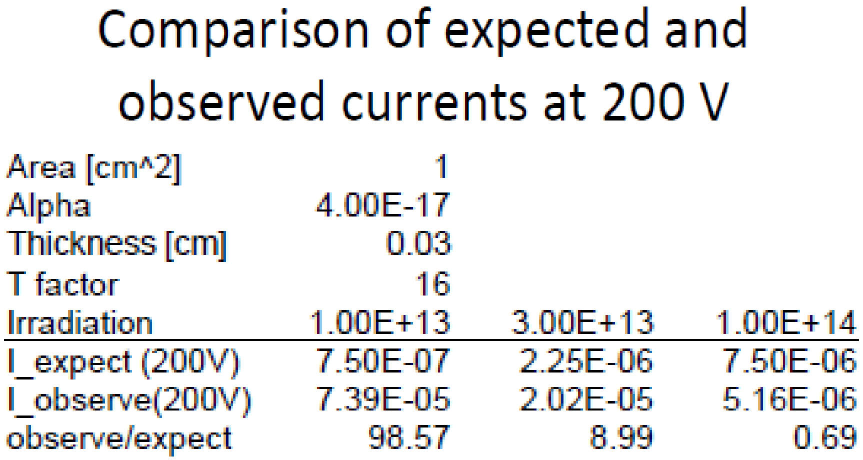
P-type HPK (ATLAS07)

These sensors did not work after cleaving (initial trial without sidewall passivation). Breakdown at ~few Volts.

There is an empirical evidence that the breakdown improves after irradiation.

We put these sensors in proton beam to see if they would indeed improve.

Leakage is initially dominated by the edge current, which is reduced with fluence. At 10^{14} neq, I(edge) < I(bulk).



Comparison of expected and observed currents at 200 V

Area [cm^2]	1		
Alpha	4.00E-17		
Thickness [cm]	0.03		
T factor	16		
Irradiation	1.00E+13	3.00E+13	1.00E+14
I_expect (200V)	7.50E-07	2.25E-06	7.50E-06
I_observe(200V)	7.39E-05	2.02E-05	5.16E-06
observe/expect	98.57	8.99	0.69

Observation #1 on S-C only p-type:

High fluence irradiation -> resistive edge!

2. 2011 Proton Irradiation @LANL

Irradiated 12 SCP processed p-type strip devices (CIS courtesy A. Macchiolo) at LANL (thanks S. Seidel). Results are in-conclusive:

+ Breakdown voltages extended post-rad

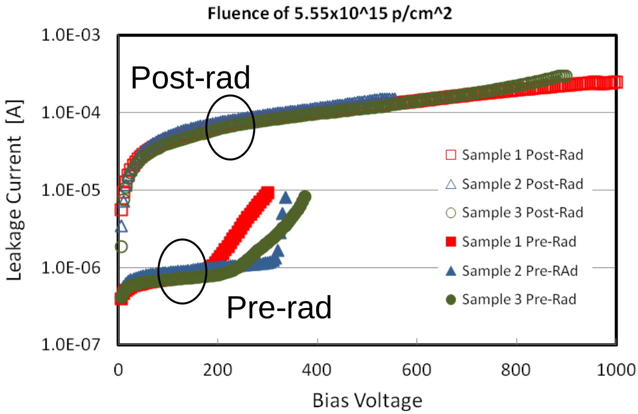
+ High fluence devices (3/3 for 1e16neq, 3/3 for 1e15neq) show expected post-rad leakage current

- Lower fluence devices (1/3 for 1e13neq and 1/3 for 1e14neq) show earlier breakdown!

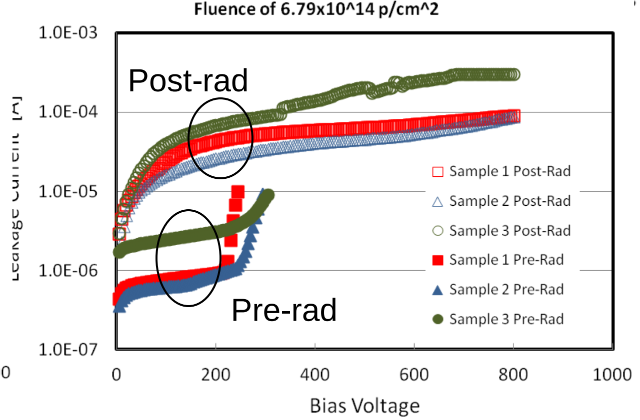
Sensor	**Before Irradiation** V(break) at ~10 uA	**After Irradiation** V(break) at ~100 uA	Fluence	No Guard Rings
B1 P5	30	460	10^13	1
B1 P6	290	165	10^13	1
B2 P1	410	80	10^13	3
B1 P8	15	90	10^14	5
B2 P10	310	80	10^14	5
B2 P6	390	100	10^14	1
B2 P8	300	>800	10^15	4
B2 P9	310	335	10^15	5
B2 P11	250	>800	10^15	2
B2 P2	305	390	10^16	1
B2 P3	340	330	10^16	3
B2 P4	380	425	10^16	3

A parallel investigation of the robustness of the passivation layer revealed a possible susceptibility to rough handling. There is no proof that this has skewed the irradiation results.

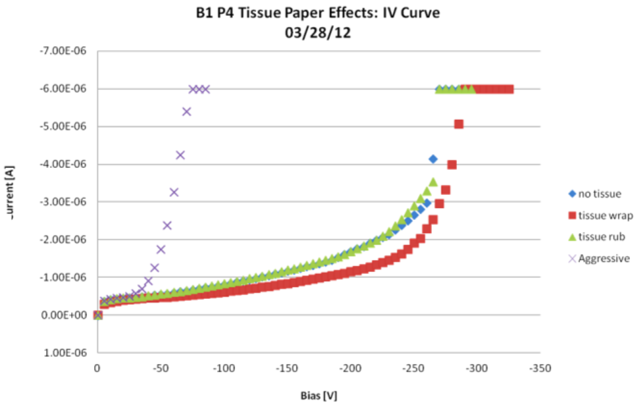
Fluence of 5.55x10^15 p/cm^2



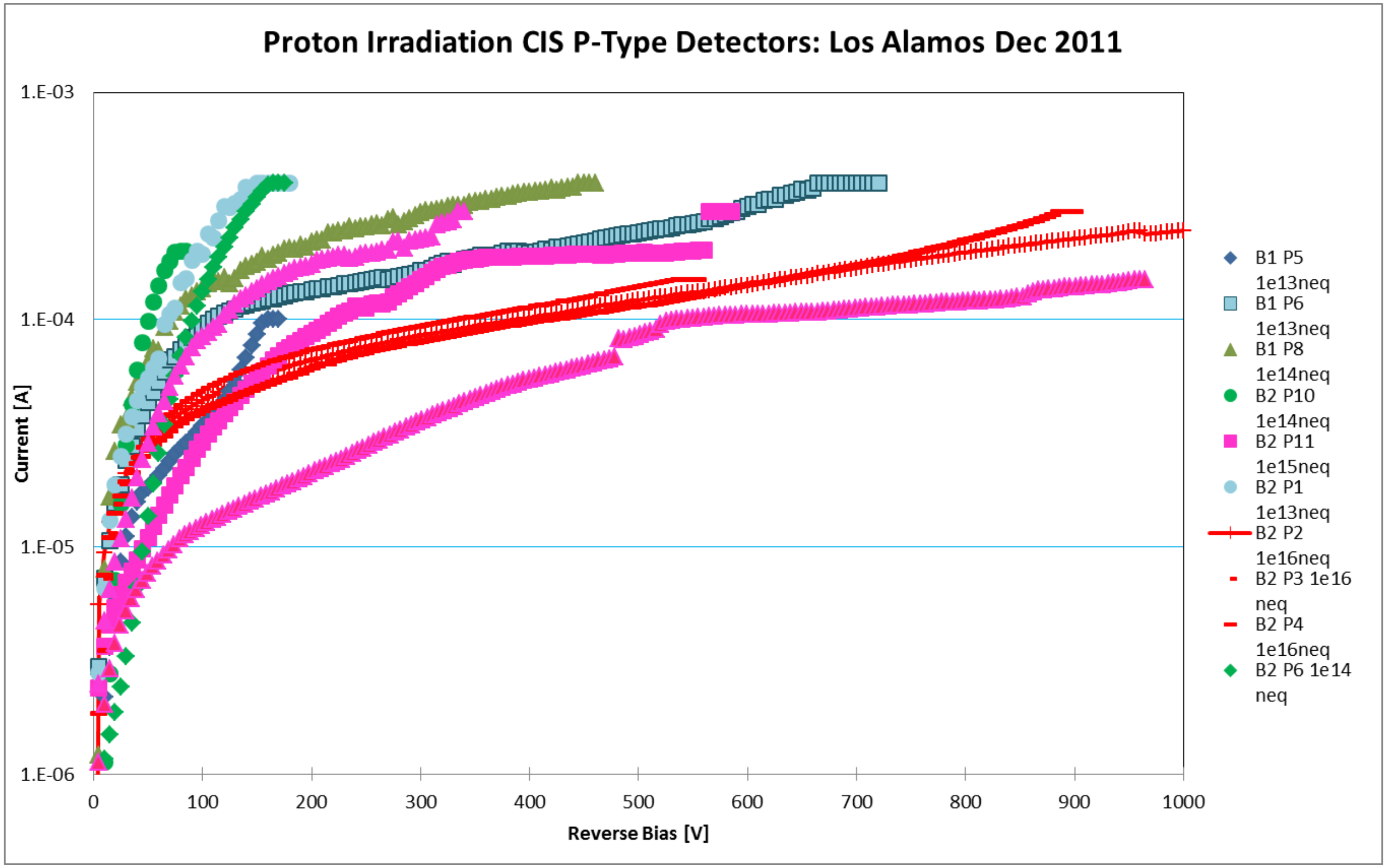
Fluence of 6.79x10^14 p/cm^2



B1 P4 Tissue Paper Effects: IV Curve
03/28/12



2. 2011 Proton Irradiation @LANL



Observation #2 on S-C-P p-type:

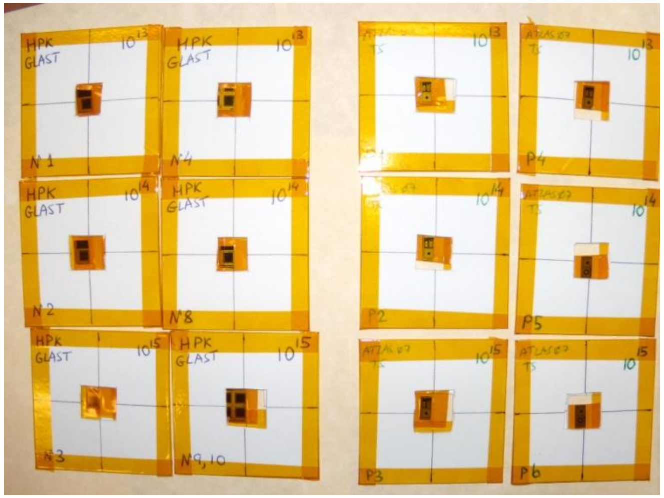
Low fluence (<= 1e14): high edge current

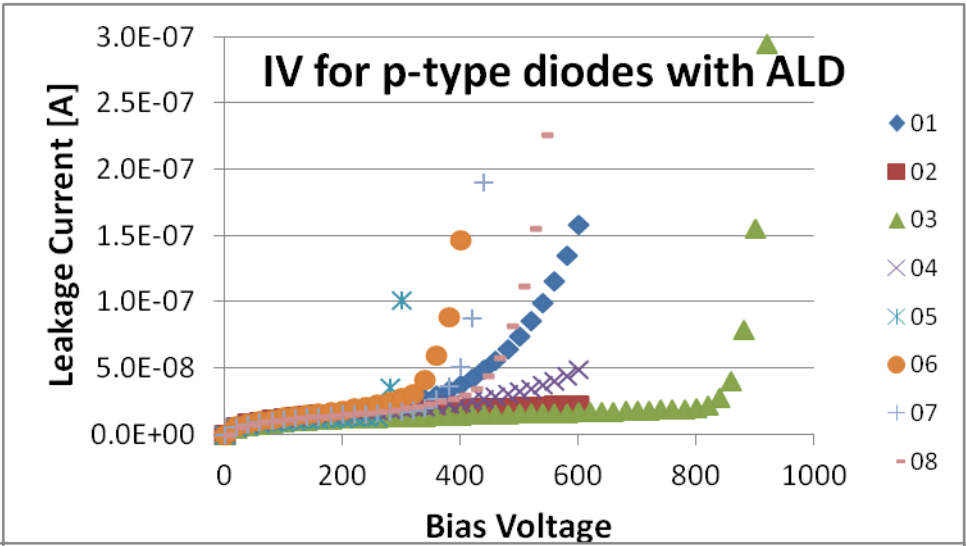
High fluence irradiation (>= 1e15): resistive edge!

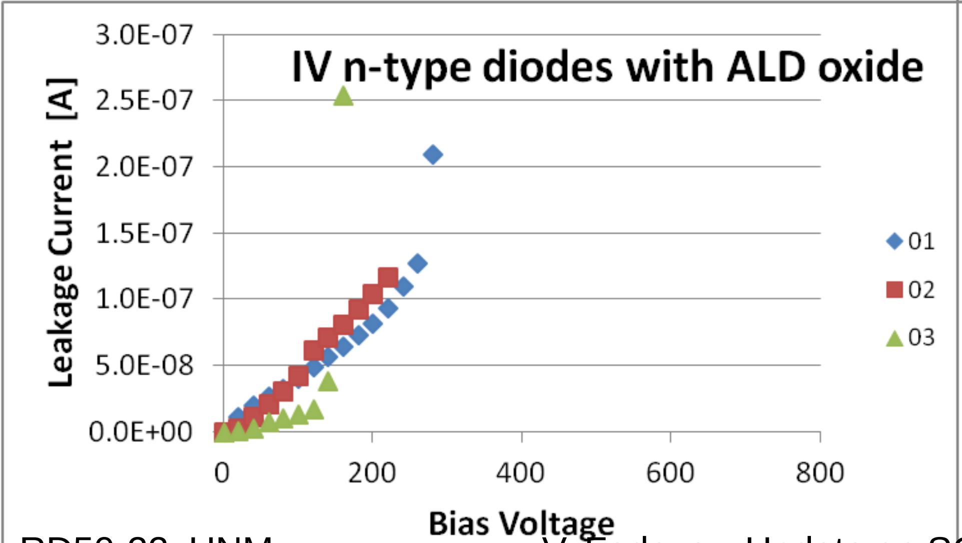
3. 2012 Proton Irradiation @CERN

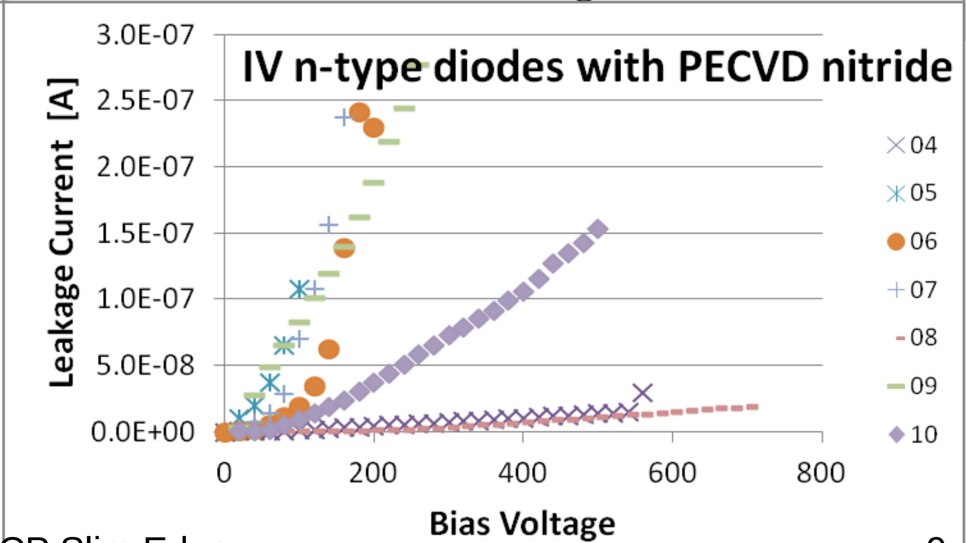
A round of irradiations at SPS (huge help from G. Casse & M. Glaser):

- p-type diodes from ATLAS07 Test Structures
- n-type diodes from Fermi/GLAST Test Structures, with both PECVD nitride and ALD oxide

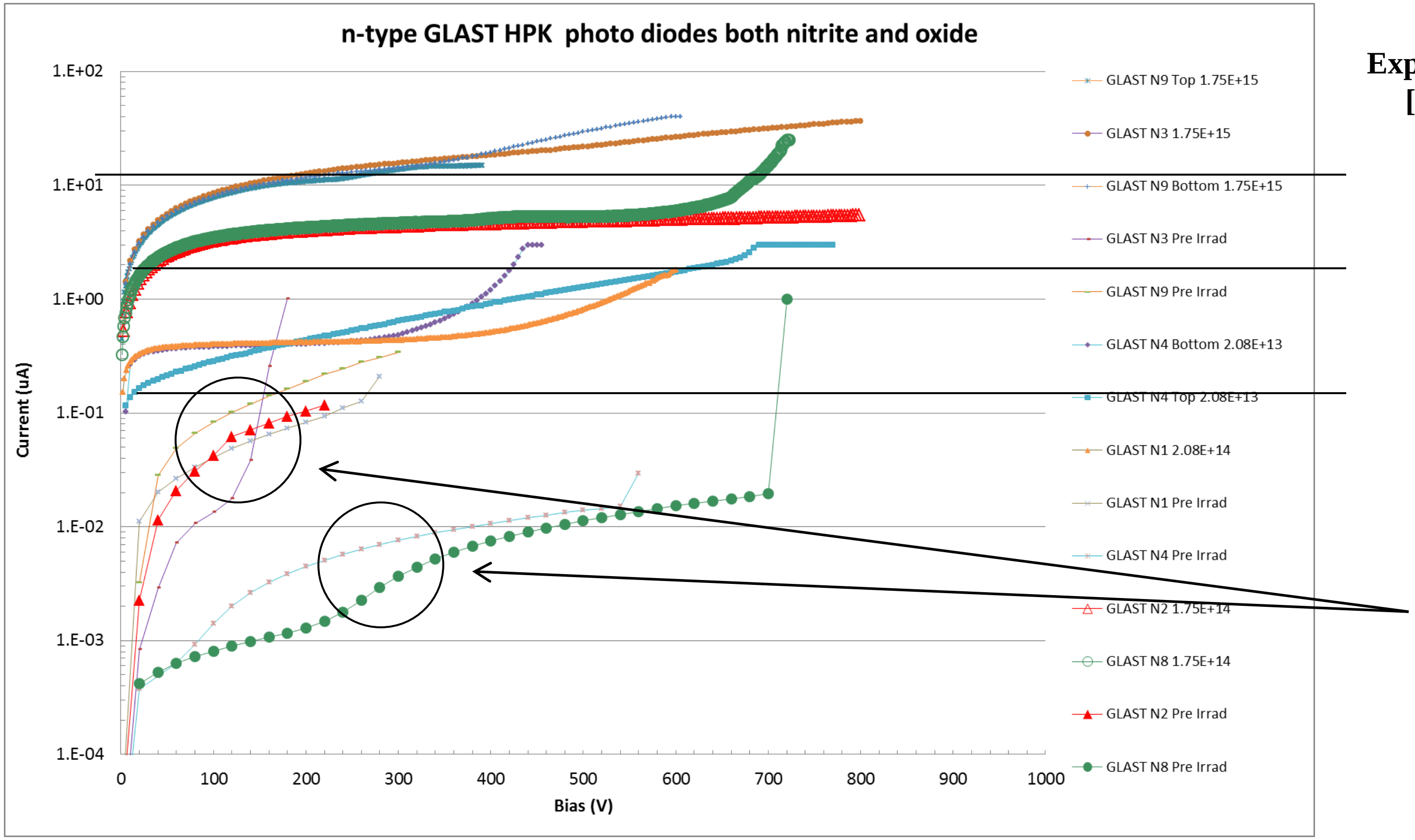








n-type GLAST HPK Photo Diodes both nitrite and oxide passivation



Expected current [uA] @ -5 C

13.3

1.33

0.16

Pre-rad

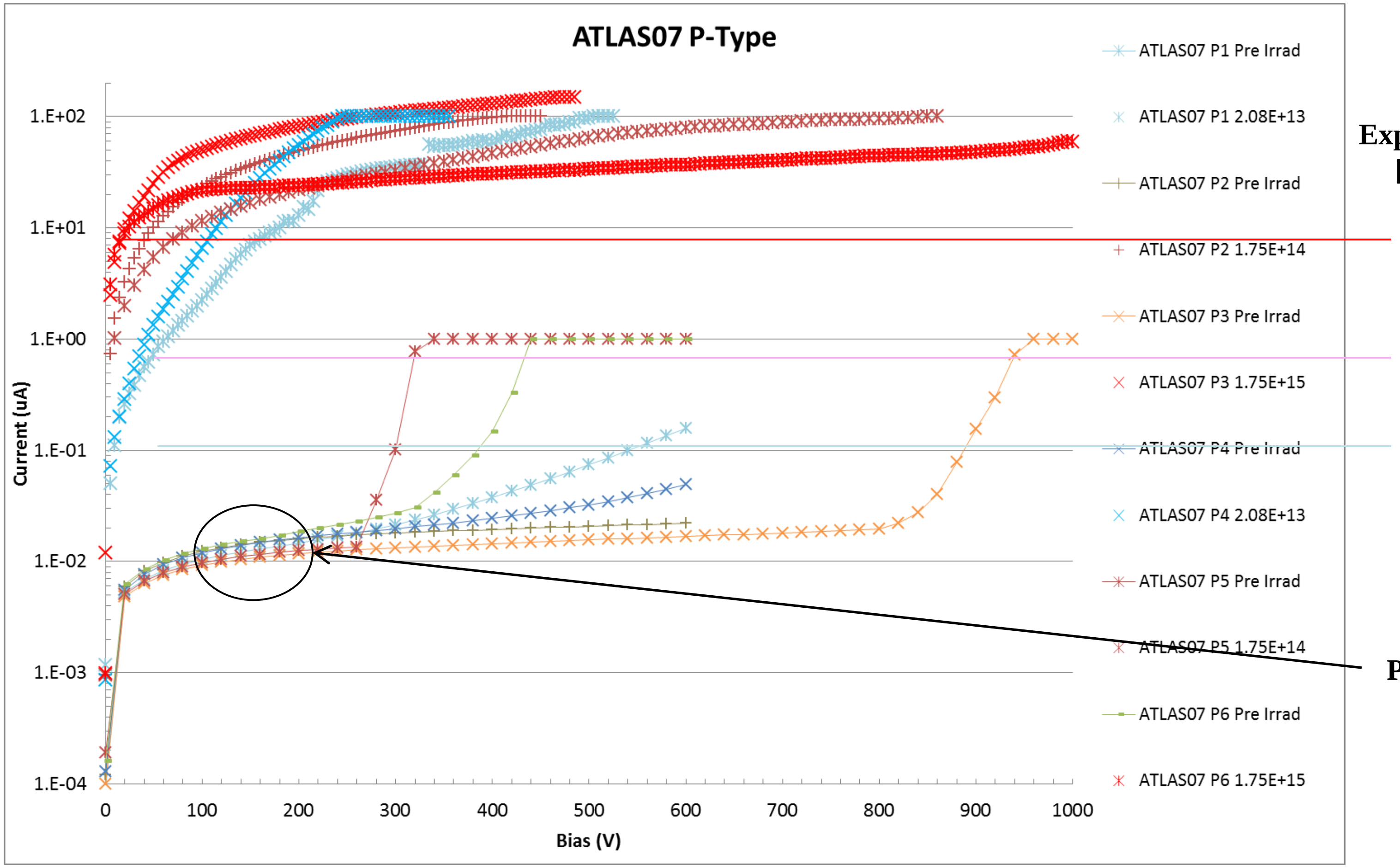
Observation #3 on S-C-P n-type:

low fluence (1e13, < inversion) edge isolation due to passivation (Nitrite/nanostack)

High fluence (>1e14, > inversion): resistive edge

…No dependence on type of passivation, leakage current close to bulk expectation

p-type ATLAS07 HPK Photo Diodes



Expected current [uA] @ -5 C

8

0.8

0.1

Pre-rad

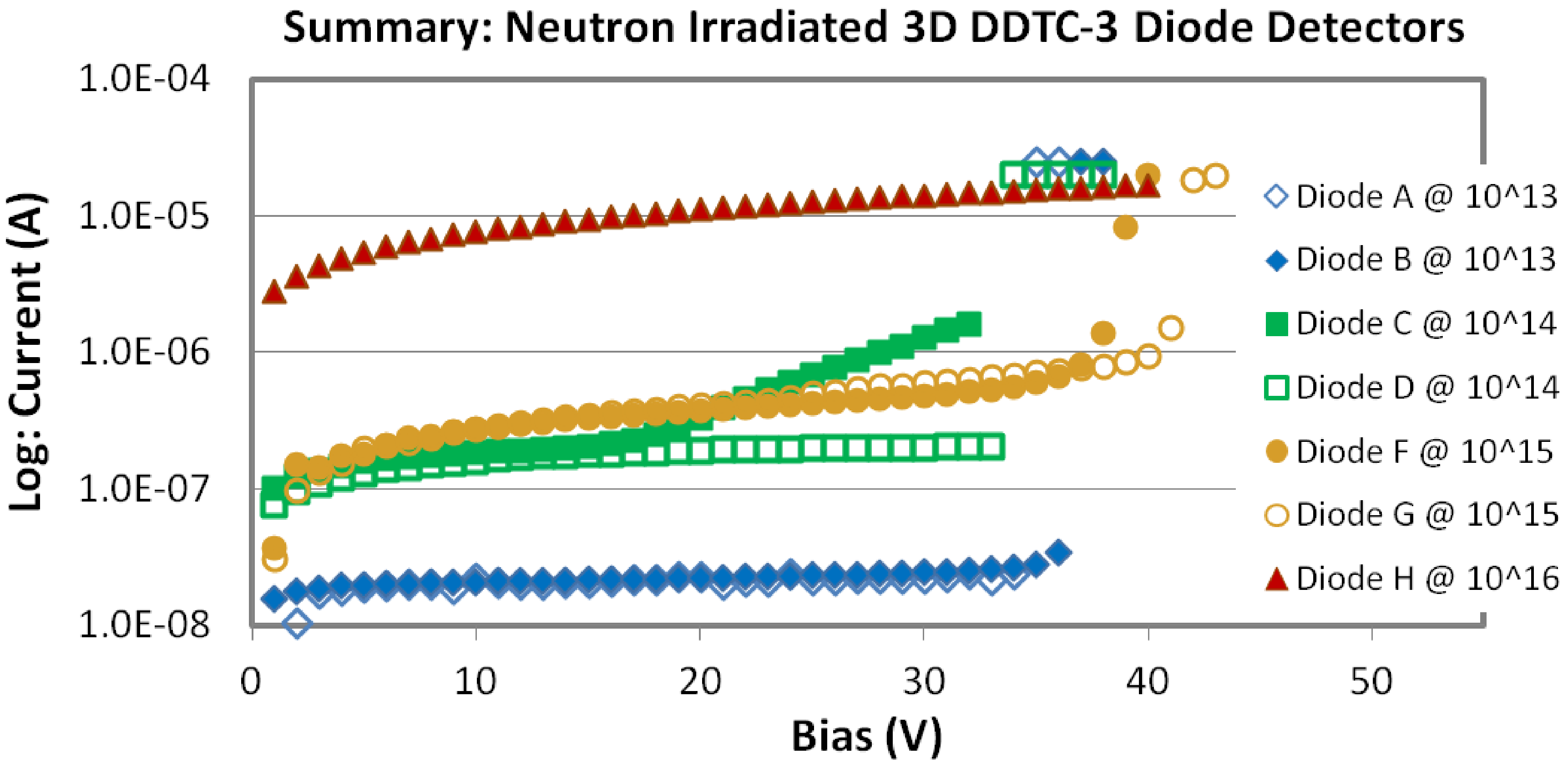
Observation #4 on S-C-P p-type:

Leakage currents do not scale with fluence

low fluence (< 1e14): reduced edge performance

high fluence (>1e14): resistive edge

p-type 3D sensors irradiated at Ljubljana, PI G.-F. Dalla Betta
VERY preliminary, data collection in progress

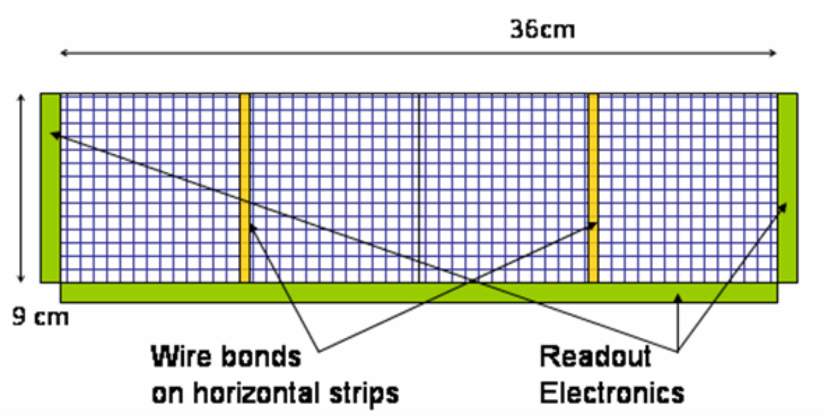


Observation #5 on S-C-P p-type:

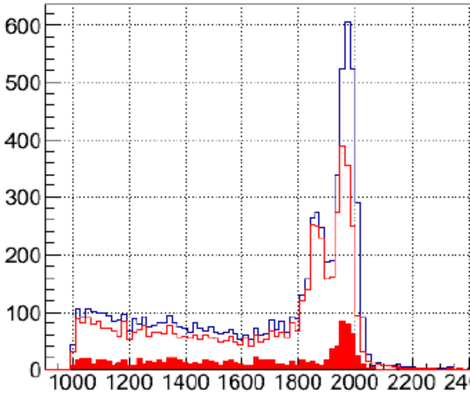
3D neutron-irradiate sensors show approximate scaling with fluences:
no high currents for low fluences !

S-C-P treated SSD in pCT Tracker

Large area coverage requires tiling of 4 sensors,
having ~ 1mm inactive edges which create image artifacts.



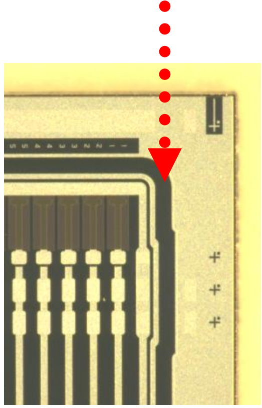
Overlapping sensors introduces artifacts requiring additional, non-uniform energy corrections



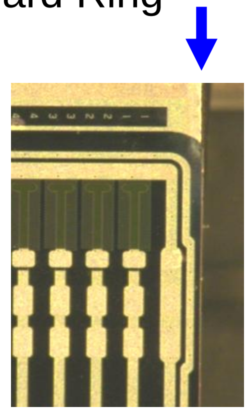
For Tiling with no Overlap: “Slim Edges”

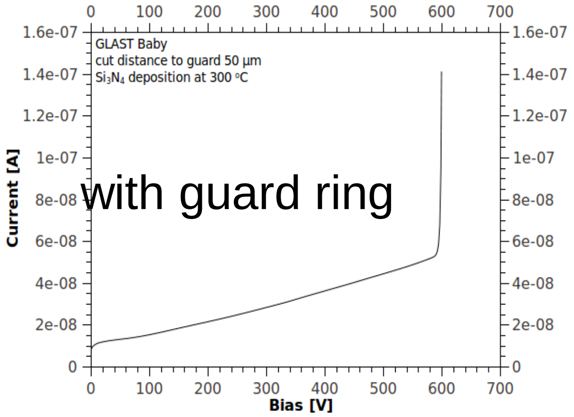
Si SSD with
900μm dead edge

Cut within 50 μm
of Guard Ring



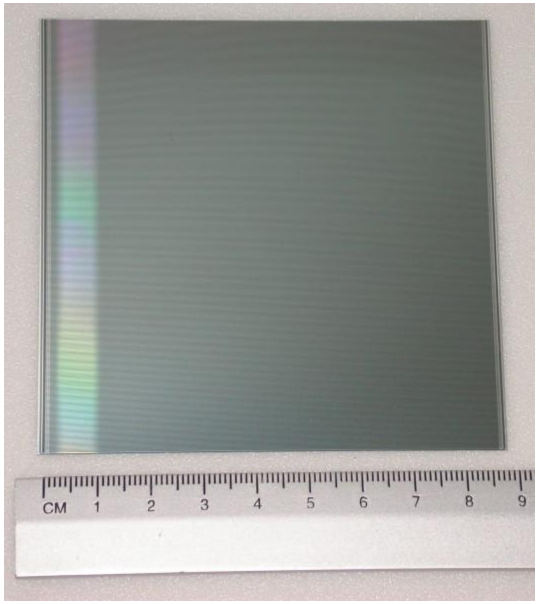
S-C-P:
Scribing (XeF_2)
+ Cleaving
+ Passivating
(N_2 PECVD)



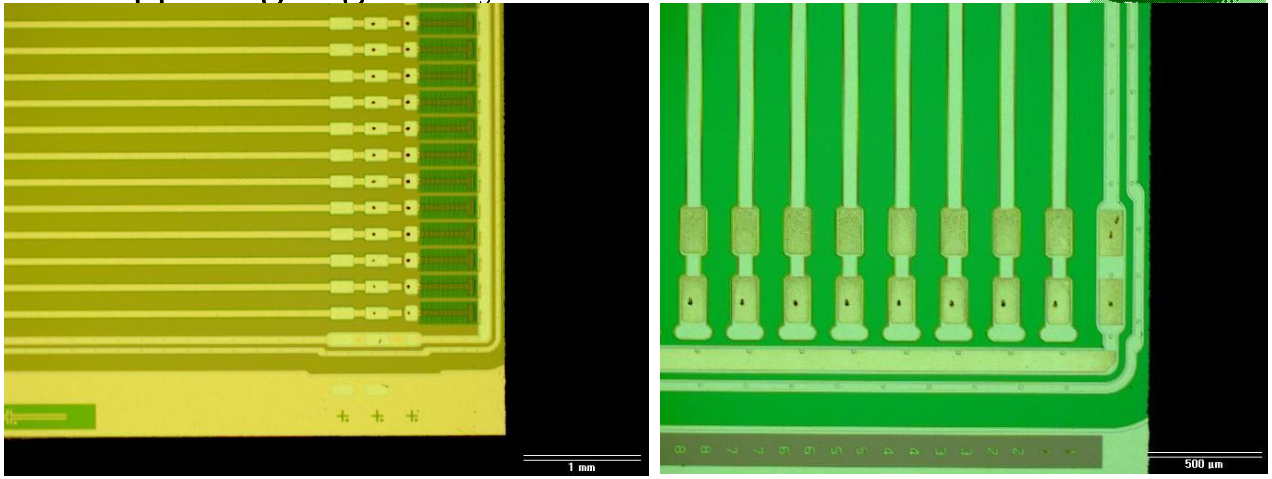


M. Christophersen et al.,
SSE 81, (2013) 8–12

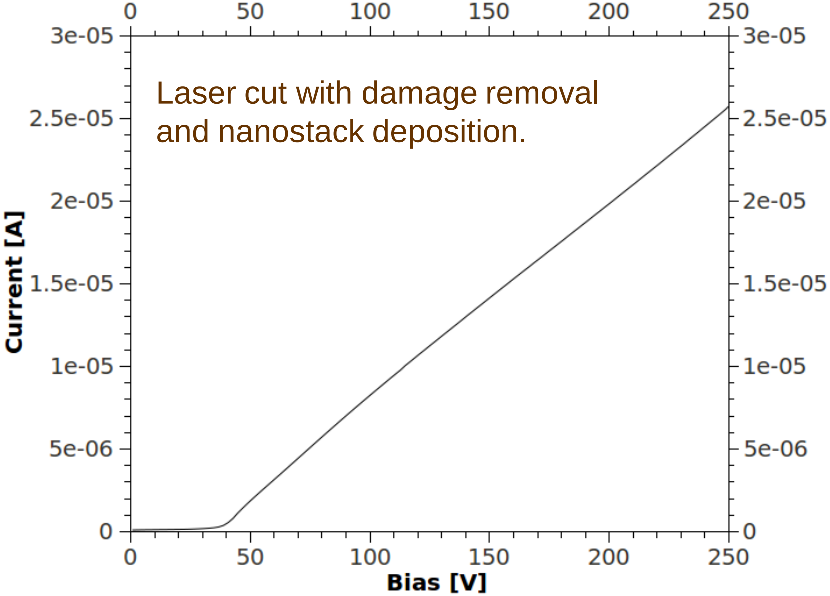
S-C-P treated 9 cm x 9 cm HPK SSD (ex GLAST)



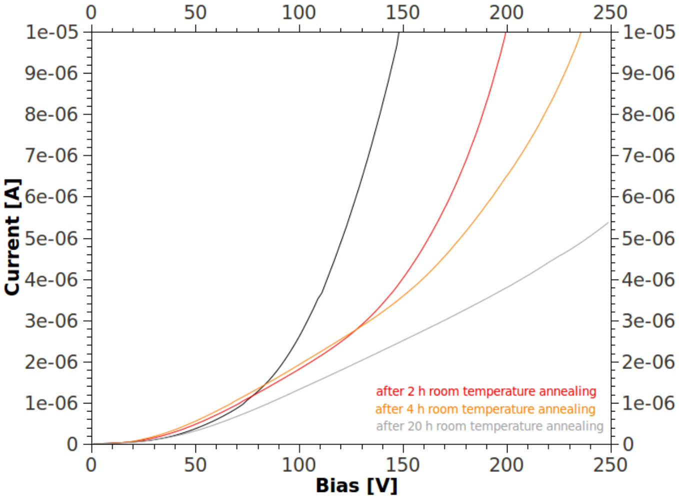
Cut 2 opposing edges only



Diced sensors => hard to cleave. But can tolerate higher currents. Can replace cleaving by laser cut. Current test (G. Pellegrini): dicing, etching, nitride.

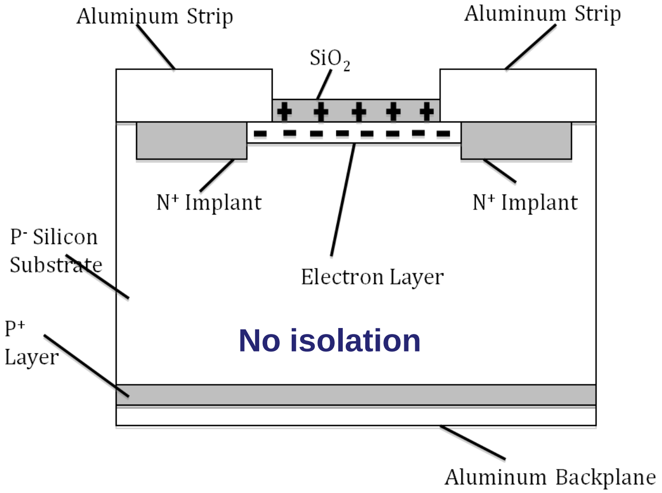

Laser cut with damage removal and nanostack deposition.

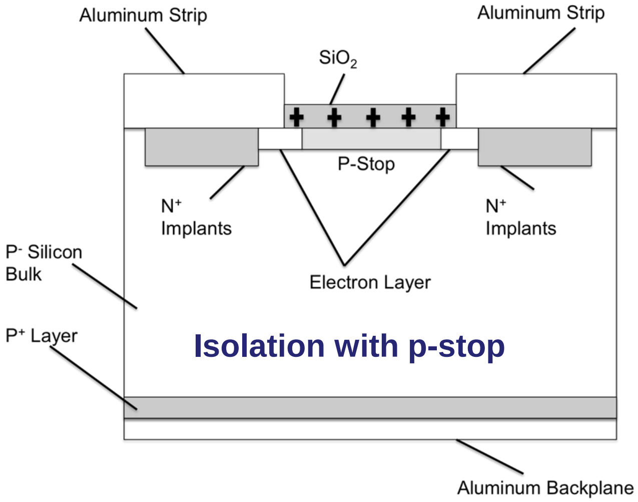
Observe considerable annealing effects!

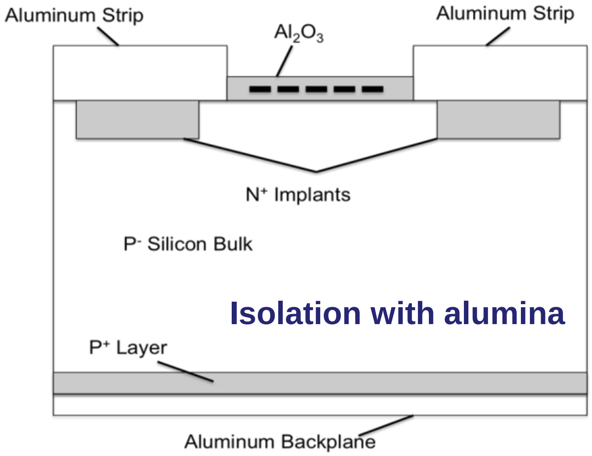


Inter-strip Isolation with Alumina Passivation

The idea is to use the *negative interface charge* formed on the boundary of **alumina** and silicon for interstrip isolation on **p-type** devices (NRL). This is quite analogous to isolation with *positive interface charge* formed by **Si oxide** with silicon for **n-type** devices.



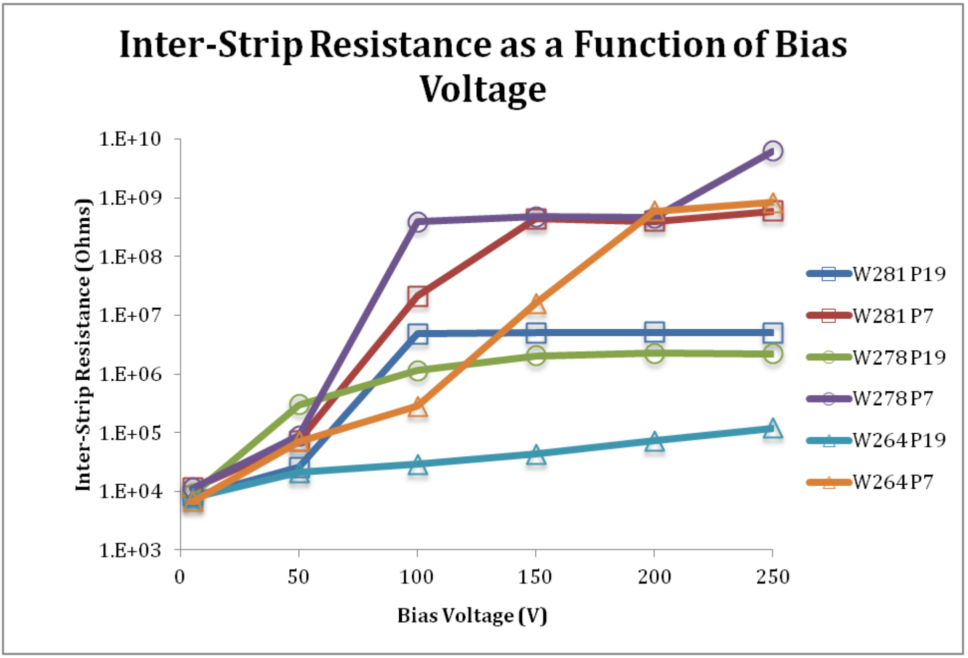




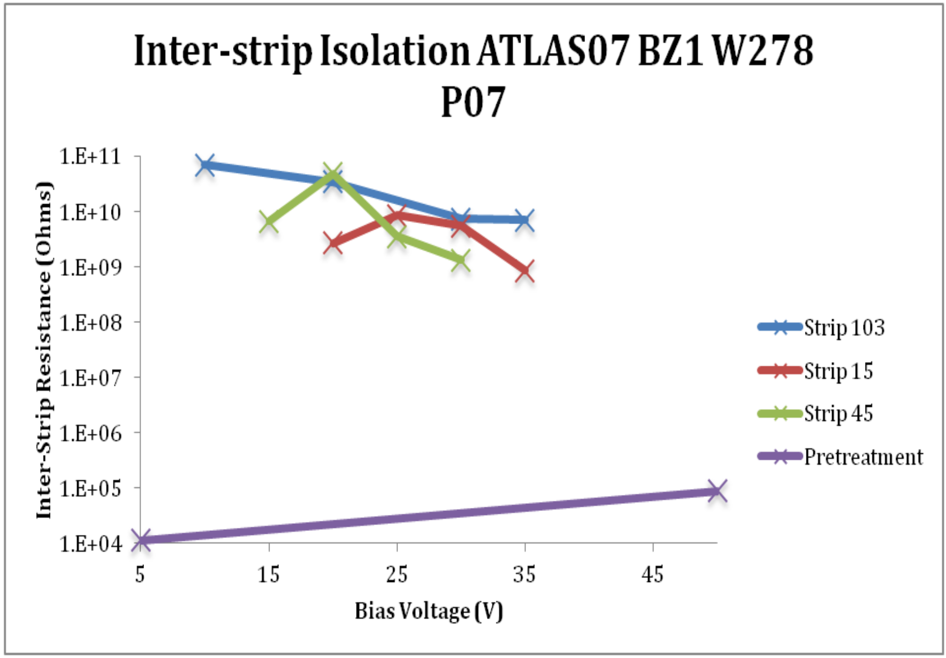
Test of IS with Alumina

ATLAS07 (p-type) without inter-strip isolation reprocessed at NRL:
-- stripped off the oxide layer
-- deposited of alumina.

Observe high IS resistivity at lower bias voltage, characteristic of intrinsic isolation.



before



after

Conclusions and Future Work

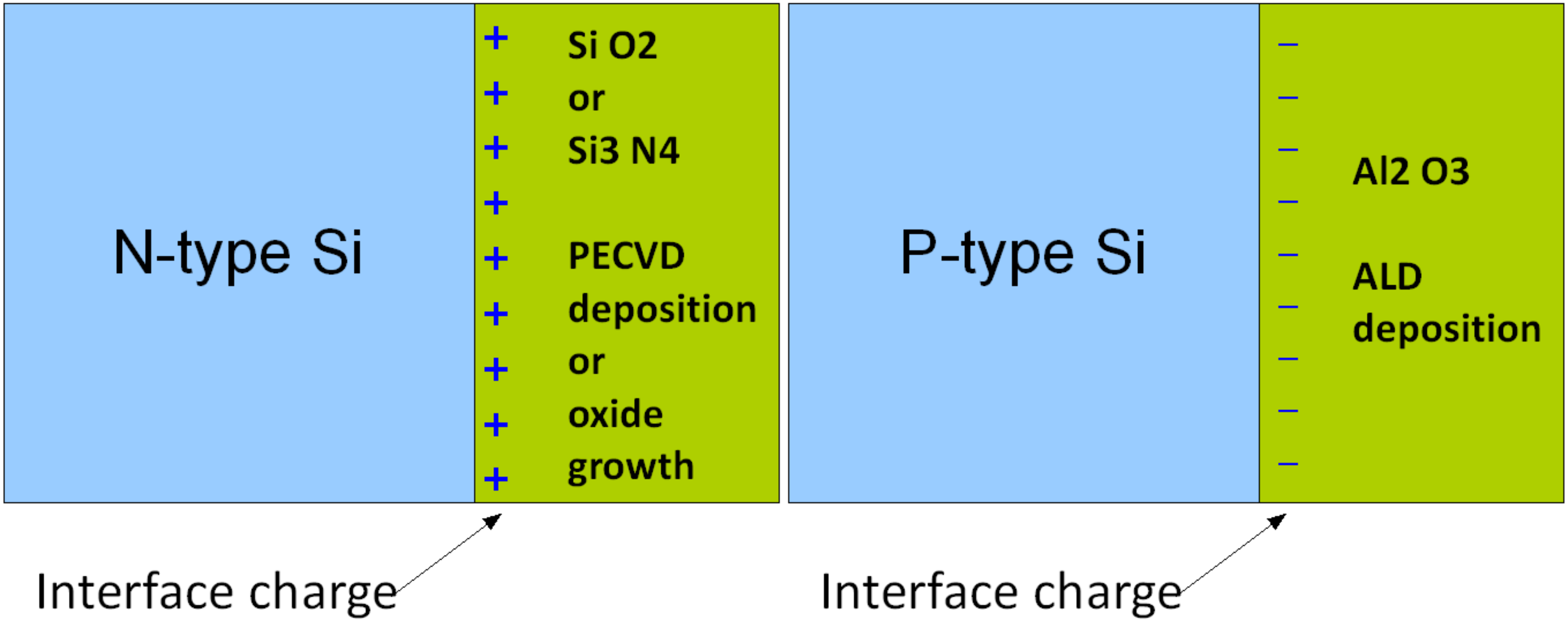
- Had multiple studies of CCE near the edge on un-irradiated sensors. So far no issues.
- Will be interesting to see results from MPI studies on irradiated devices.

- N-type devices seem to be rad-hard. This is expected, since the properties of the sidewall after irradiation should be similar to the case of top surface on conventional sensors. (Same passivation, similar surface properties.)
- There is an issue with rad hardness on p-type devices for fluences <10^14 neq/cm^2.
- This has to be related to properties of dielectric (alumina) after irradiation. There is a project, lead by G. Pellegrini (CNM) to fabricate MOS-like structures with alumina to find more details about it.
- Studies of neutron-irradiated p-type 3D sensors are in progress. Preliminary data indicate no issues. This is either due to different field geometry or non-ionizing dose.

- There is an on-going effort to make an instrument with SCP treated devices!
- Alumina passivation works as inter-strip isolation method for p-type devices.

Back-Up Slides

Passivation Options



N-type Si

+ + + + + + + + +

Si O2
or
Si3 N4

PECVD
deposition
or
oxide
growth

P-type Si

– – – – – – – – –

Al2 O3

ALD
deposition

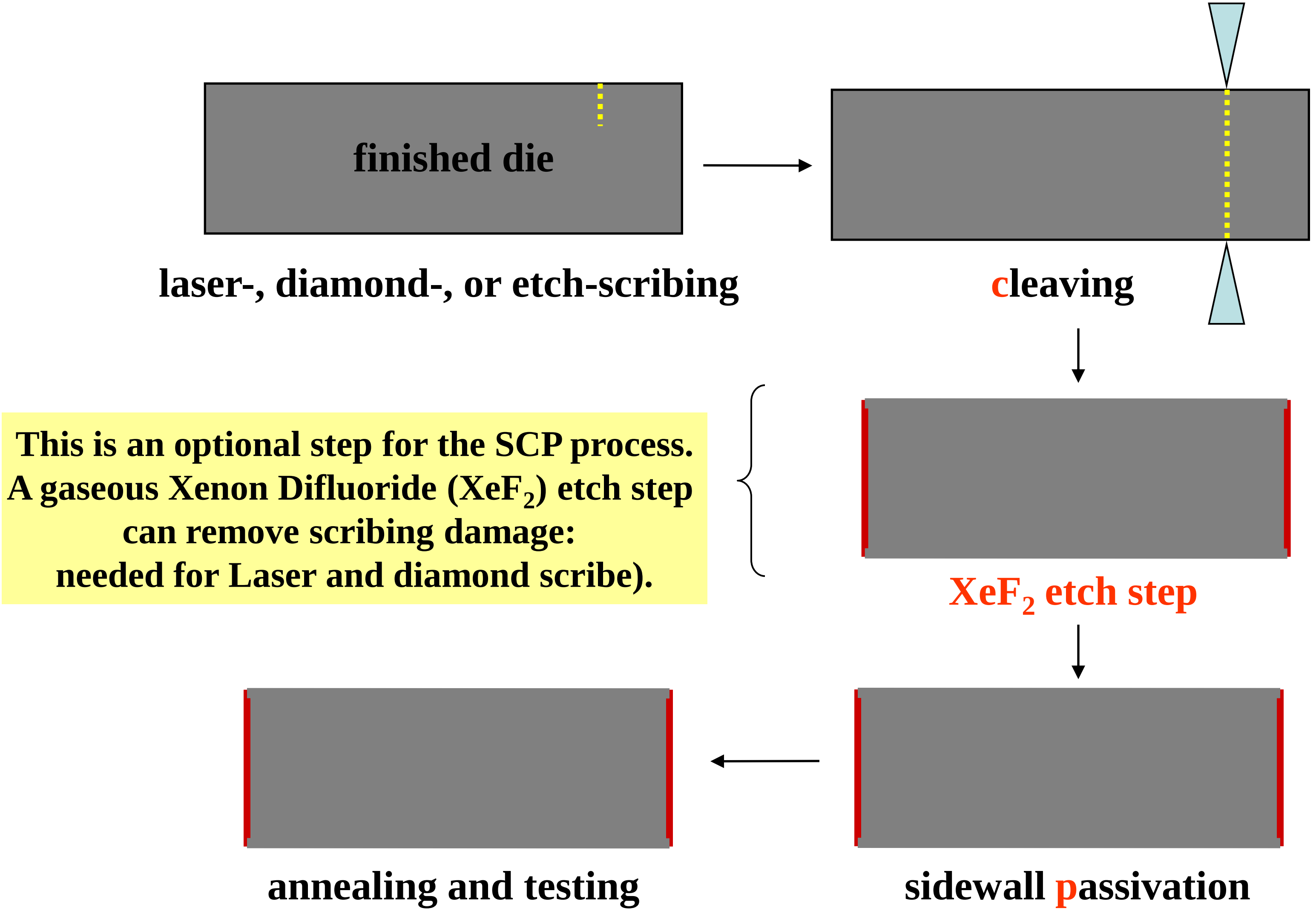
Interface charge

Interface charge

Surface passivation makes the sidewall resistive. N- and p-type devices require different technologies.

- For n-type devices one needs a passivation with *positive* interface charge. SiO_2 and Si_3N_4 layers works well.
- For p-type material a passivation with negative interface charge is necessary. We found that Al_2O_3 works in this case.

SCP Treatment (Cont)



finished die

laser-, diamond-, or etch-scribing

cleaving

This is an optional step for the SCP process.
A gaseous Xenon Difluoride (XeF_2) etch step
can remove scribing damage:
needed for Laser and diamond scribe).

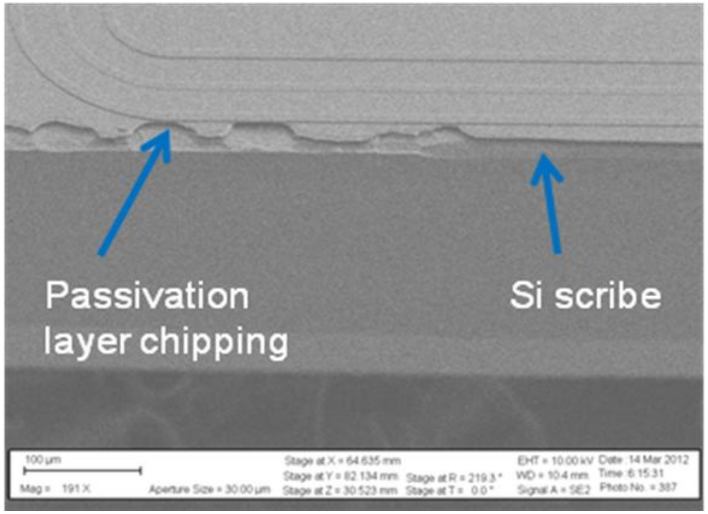
XeF_2 etch step

sidewall passivation

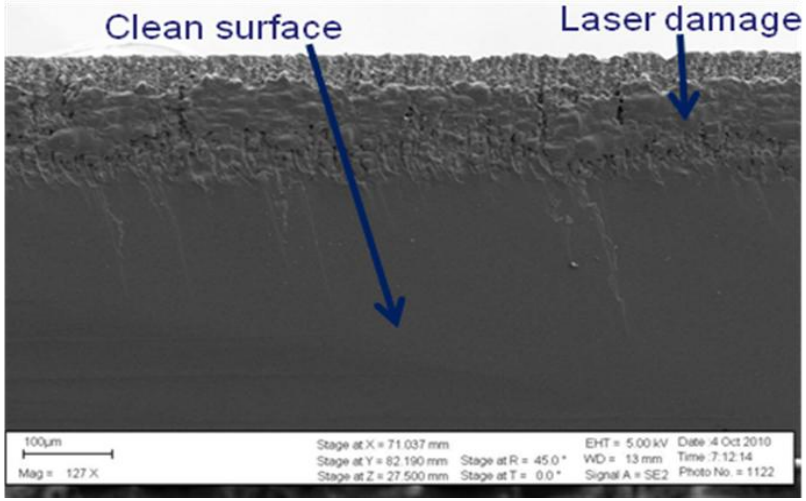
annealing and testing

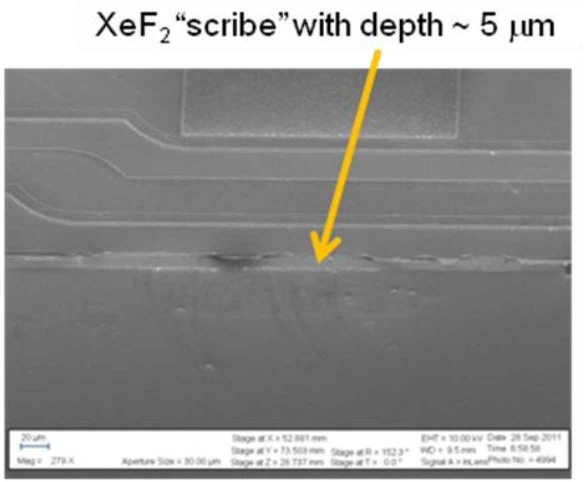
Scribing Technologies:
Diamond-, Laser-, and Etch-based

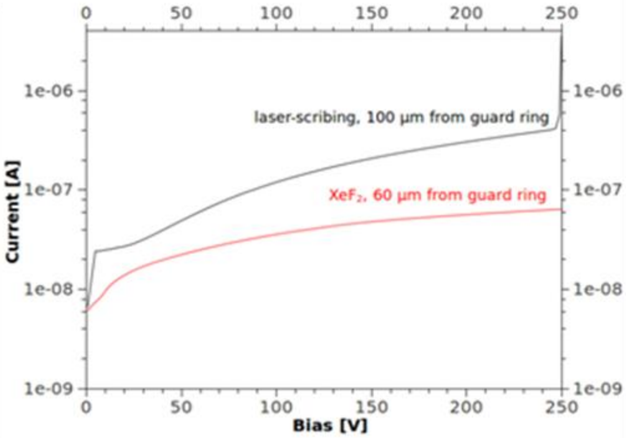
Diamond scribing



Laser scribing



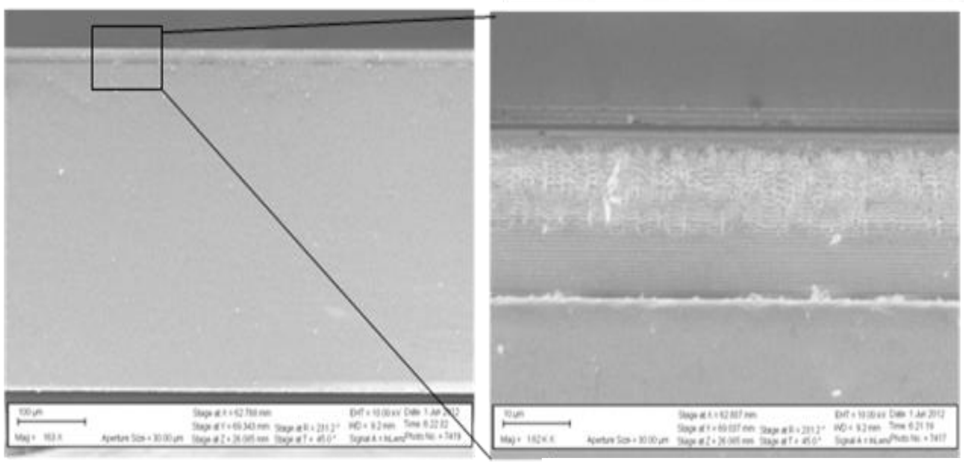


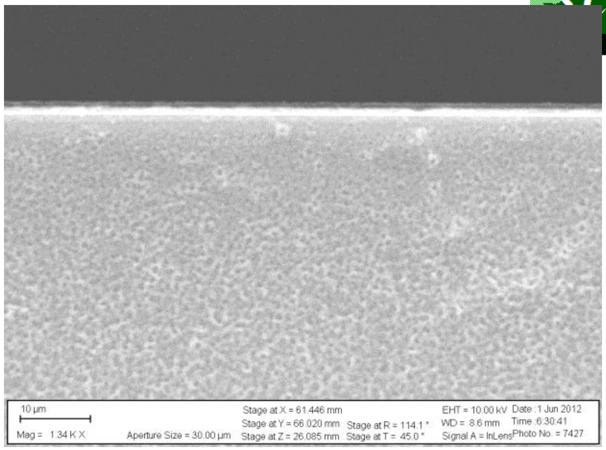


Issues:

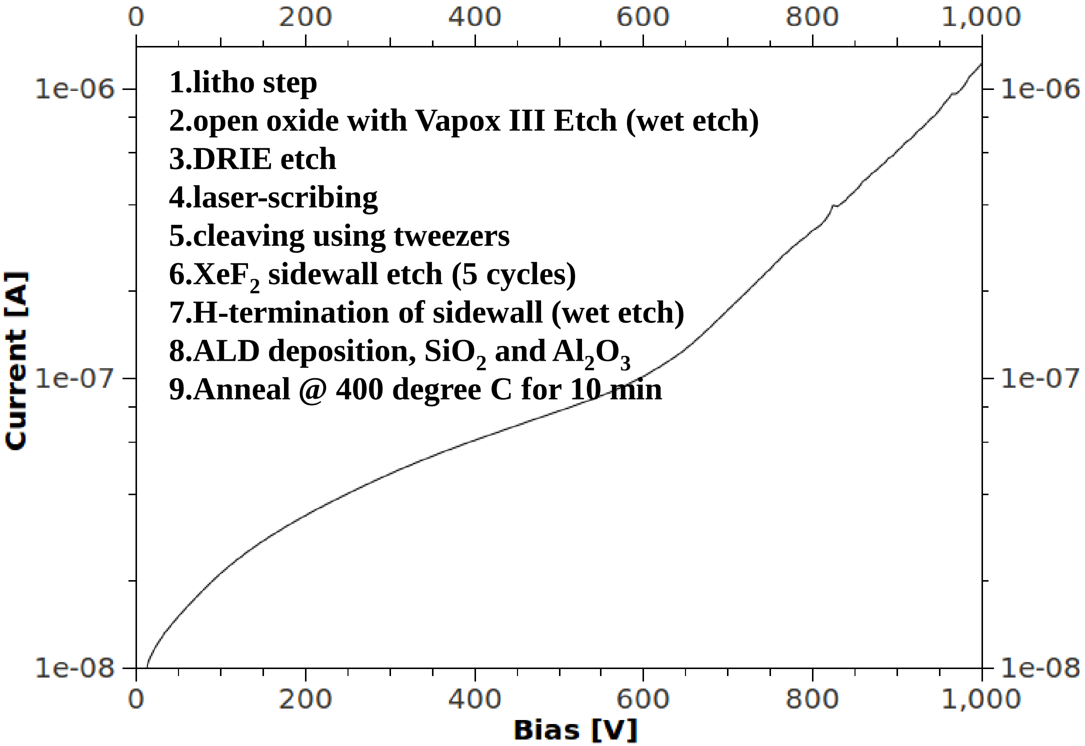
- ➢ Diamond scribing: surface chipping of <u>existing</u> passivation (=> to do again in future runs)
- ➢ Laser scribing: some degree of damage due to affected region of the sidewall
- ➢ XeF2 etching: cleaving by industrial machines is difficult

Scribing Technologies: DRIE



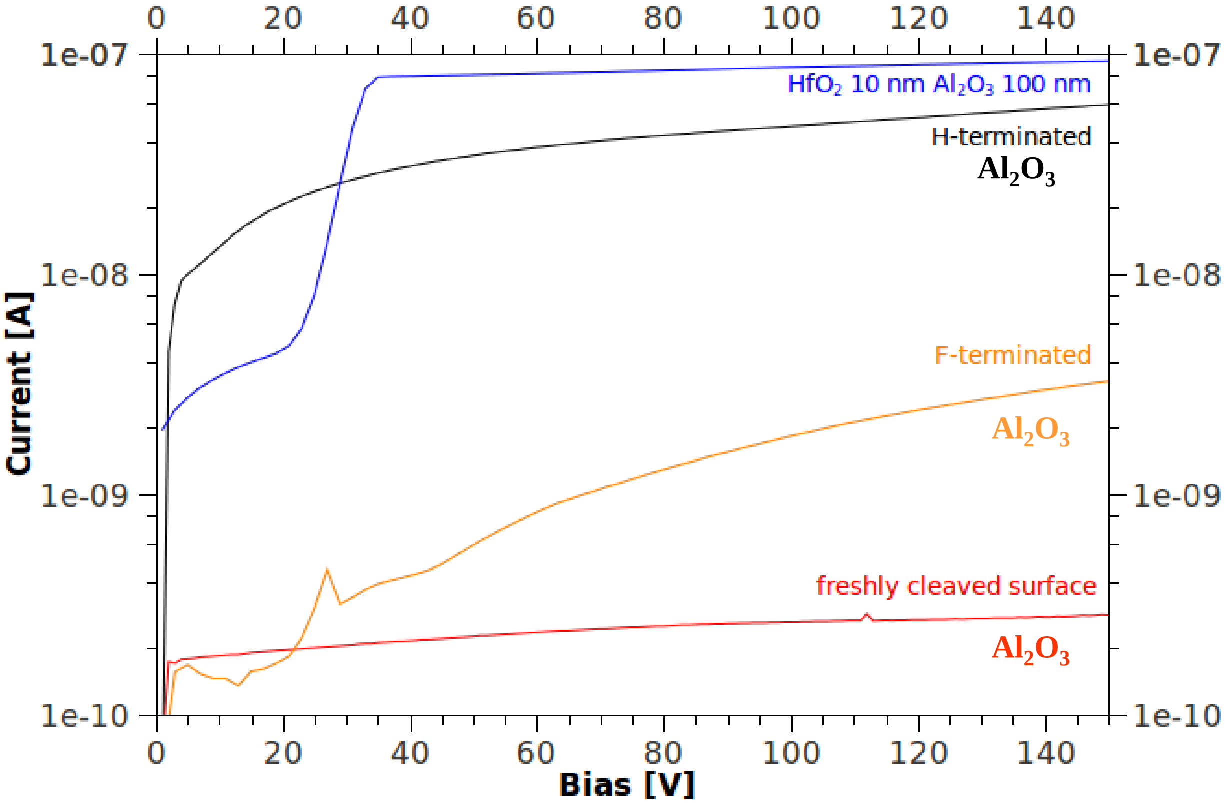


DRIE-based trenching as scribing has a promised of being a “universal” production solution without shortcomings of the other methods.



1. litho step
2. open oxide with Vapox III Etch (wet etch)
3. DRIE etch
4. laser-scribing
5. cleaving using tweezers
6. XeF_2 sidewall etch (5 cycles)
7. H-termination of sidewall (wet etch)
8. ALD deposition, SiO_2 and Al_2O_3
9. Anneal @ 400 degree C for 10 min

Effect of Surface Termination – P-Type Si

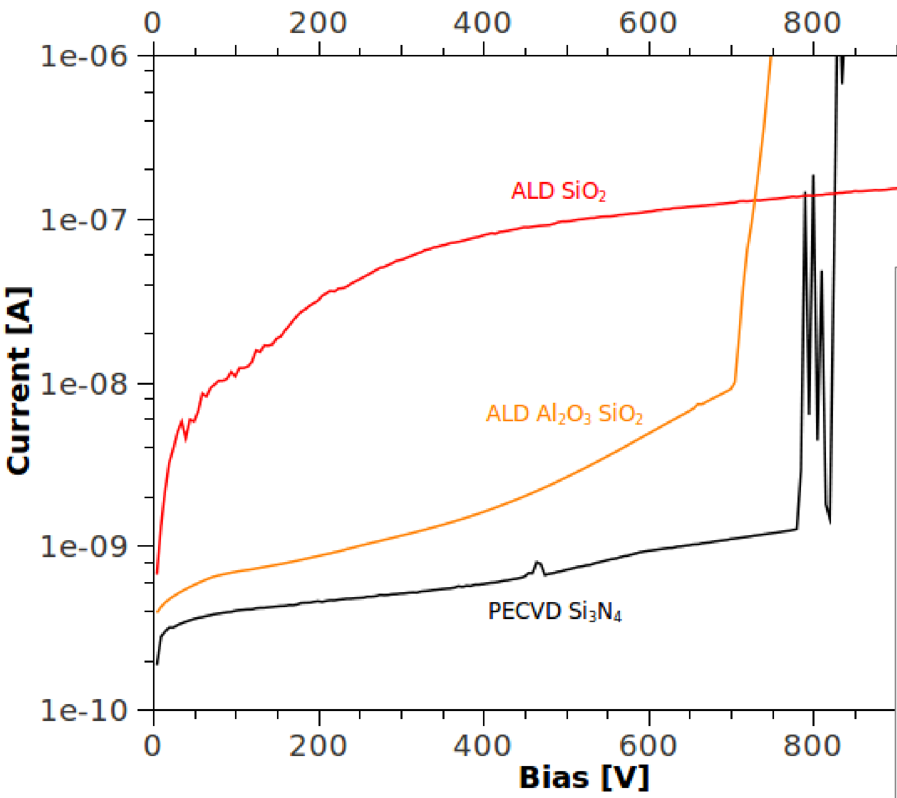


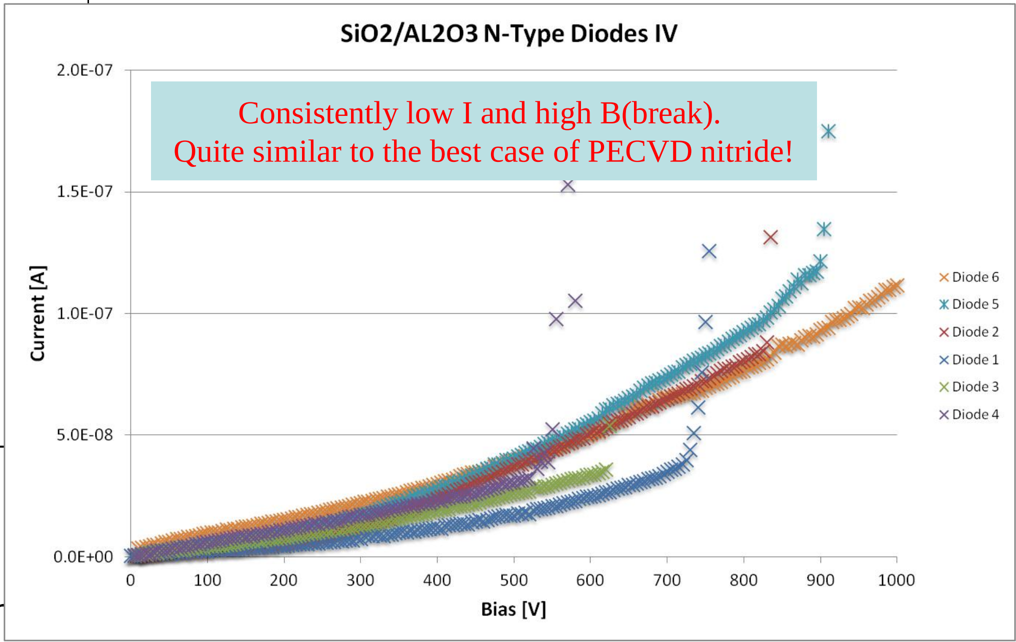
- After all the handling, we need to remove a native oxide. That is done w/ HF and leads to the “H-termination”, which can’t be passivated with alumina Al_2O_3.
- Need to covert the H-termination into F-termination which in combination with alumina ALD should work. Know they chemistry!
- The hunt for on ideal surface termination for p-type Si is still on.

Progress with Passivation (N-type Diodes)

PECVD process has been developed by industry as a wafer process => Small height of the chamber in a typical machine.
This worked well for small size samples, that could be positioned vertically, or slanted. For large sensors this is not quite applicable => replace by ALD method.

Study with HPK Fermi/GLAST diodes. The plain ALD SiO2 is worse than the best case of PECVD Si3N4.
But a “nanostack” of ALD SiO2 (10 nm) and Al2O3 (50 nm) works well.
Parameters are from G. Dingemans et al, J. Appl. Phys. 110, 093715 (2011); doi: 10.1063/1.3658246





Consistently low I and high B(break).
Quite similar to the best case of PECVD nitride!