Nineth International “**Hiroshima**” **Symposium** on the **Development** and **Application** of **Semiconductor Tracking Detectors**

International Conference Center
Hiroshima, Japan
Sep. 1 – Sept. 5, 2013
https://indico.cern.ch/conferenceDisplay.py?confId=228876

TOPICS:
- Simulations
- Technology
- Pixel and Strip Sensors
- Radiation Tolerant Materials
- ASICs
- Large Scale Applications
- Applications in Biology, Astro and CM
- New Ideas and Future Applications

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Scribe-Cleave-Passivate (SCP) Slim Edge Technology for Silicon Sensors

Scott Ely, Colin Parker, Jeffrey Ngo,
Vitaliy Fadeyev, Hartmut F.-W. Sadrozinski

Santa Cruz Institute for Particle Physics,
University of California Santa Cruz

Outline

- S-C-P of full-size sensors for proton CT

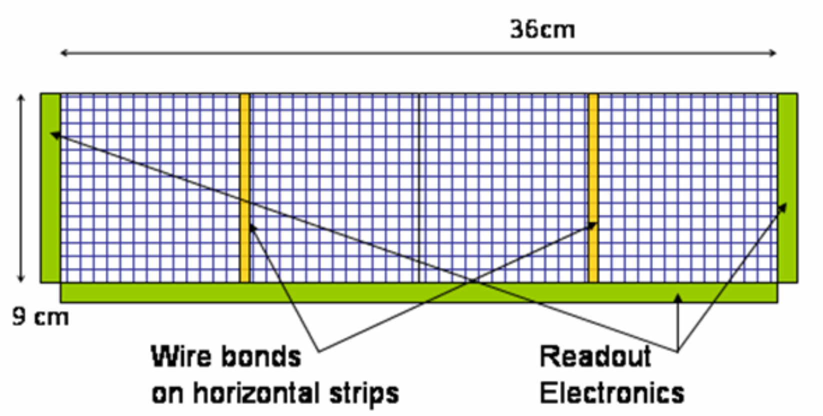
- S-C-P Slim Edges – p-type vs. n-type

- Irradiations with protons
  - S-C only: no passivation
  - S-C-P p-type CIS
  - S-C-P p-type and n-type HPK

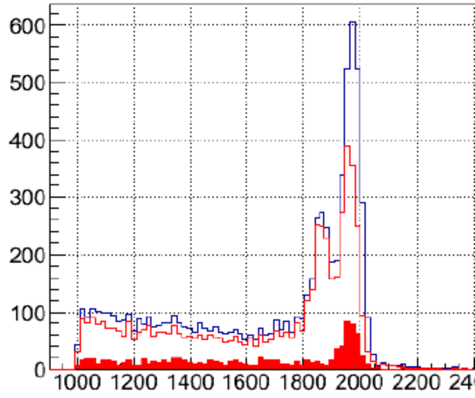
Guidance and Technical Support by
Marc Christophersen, Bernard F. Phlips
Code 7654, U.S. Naval Research Laboratory

S-C-P treated SSD in pCT Tracker

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



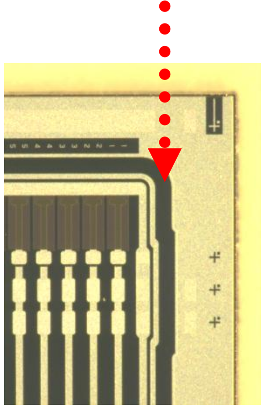
Overlapping sensors introduces artifacts requiring additional, non-uniform energy corrections



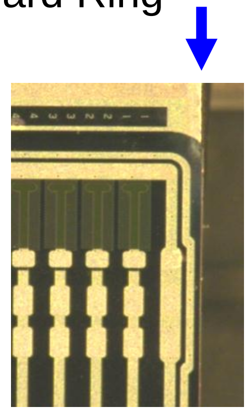
For Tiling with no Overlap: "Slim Edges"

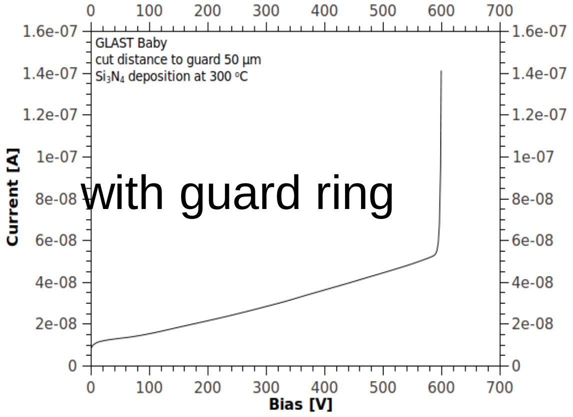
Si SSD with
900μm dead edge

Cut within 50 μm
of Guard Ring



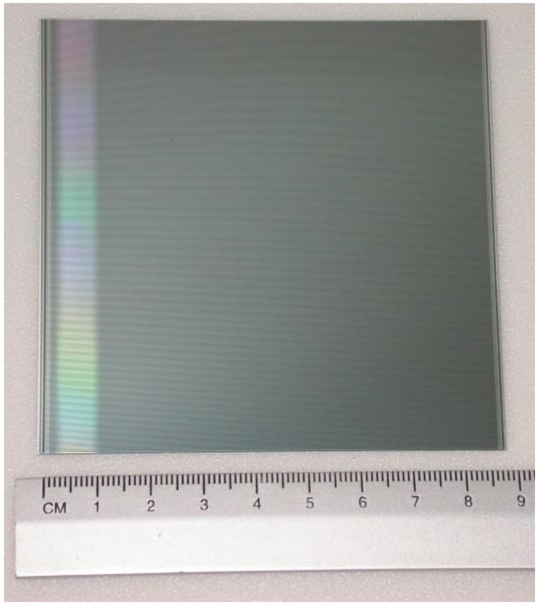
S-C-P:
Scribing (XeF_2)
+ Cleaving
+ Passivating
(N_2 PECVD)



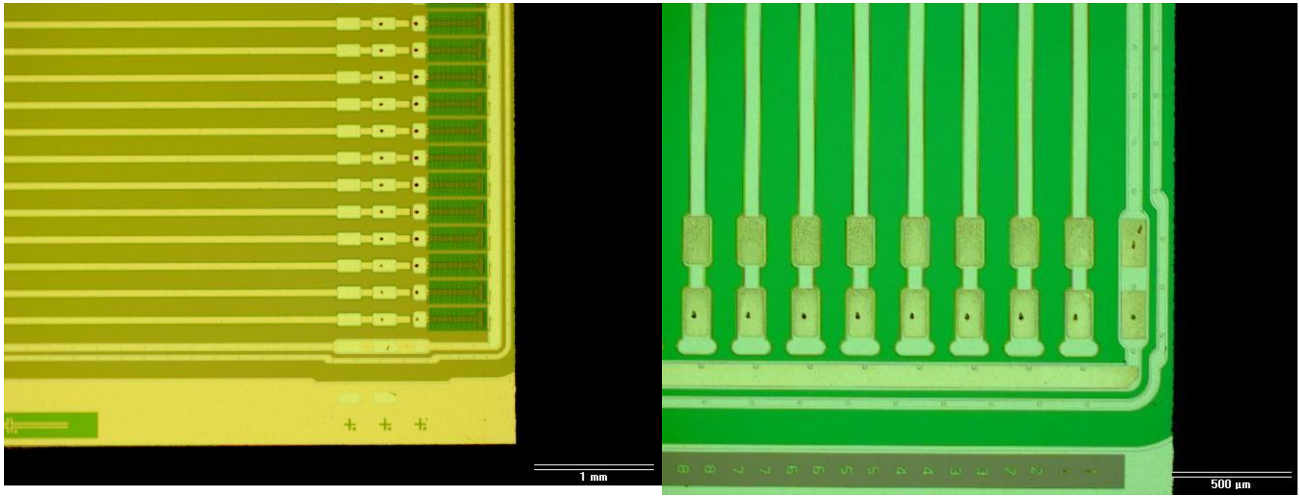


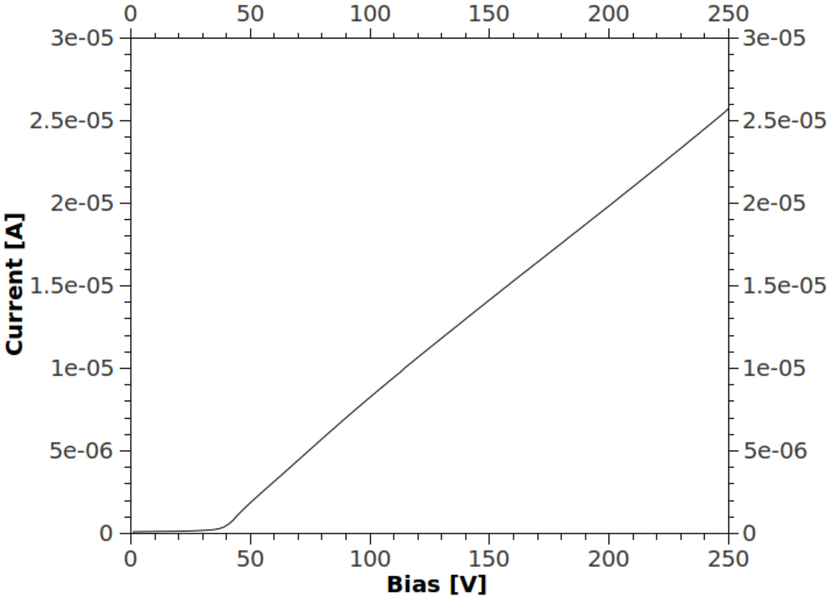
M. Christophersen et al.,
SSE 81, (2013) 8–12

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

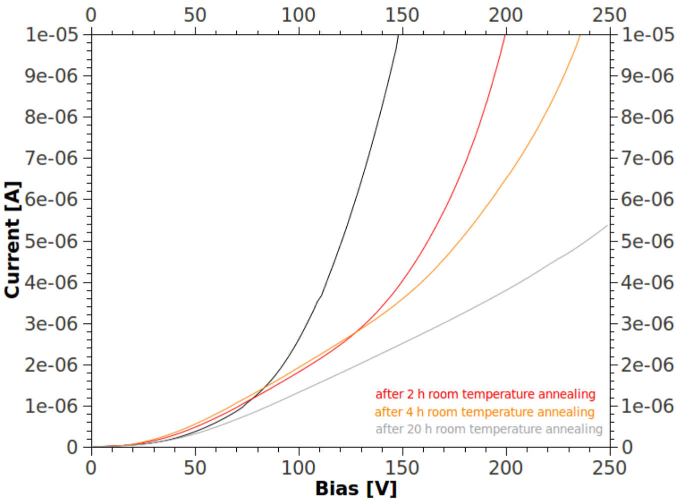


Cut 2 opposing edges only





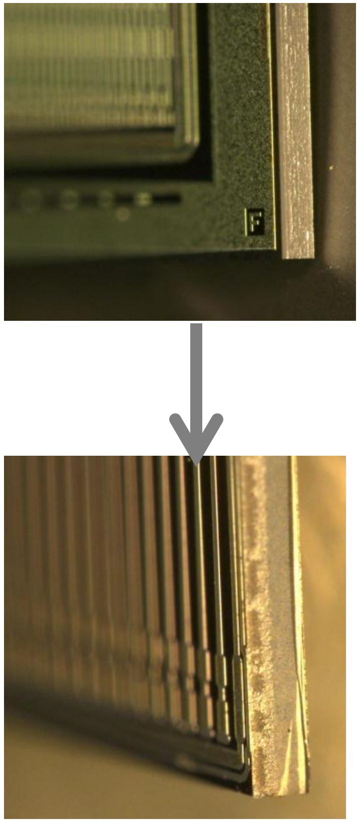
Observe considerable annealing effects!

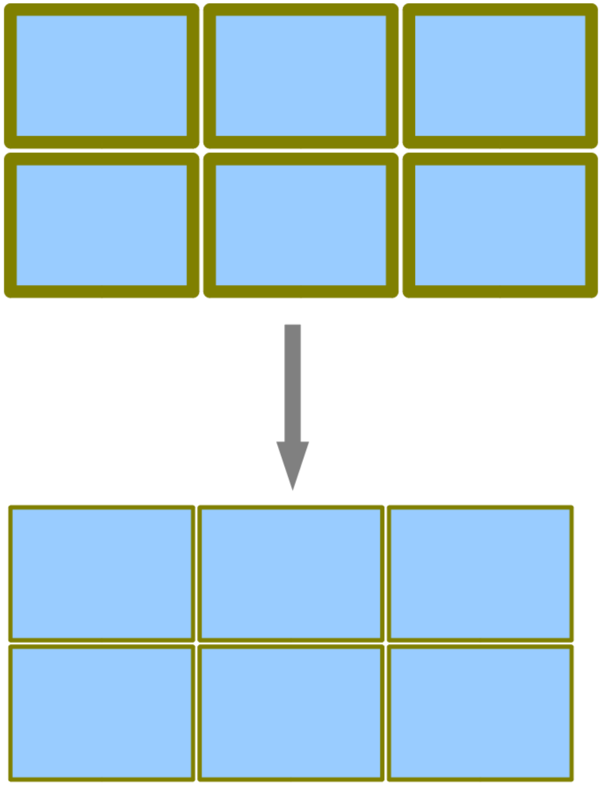


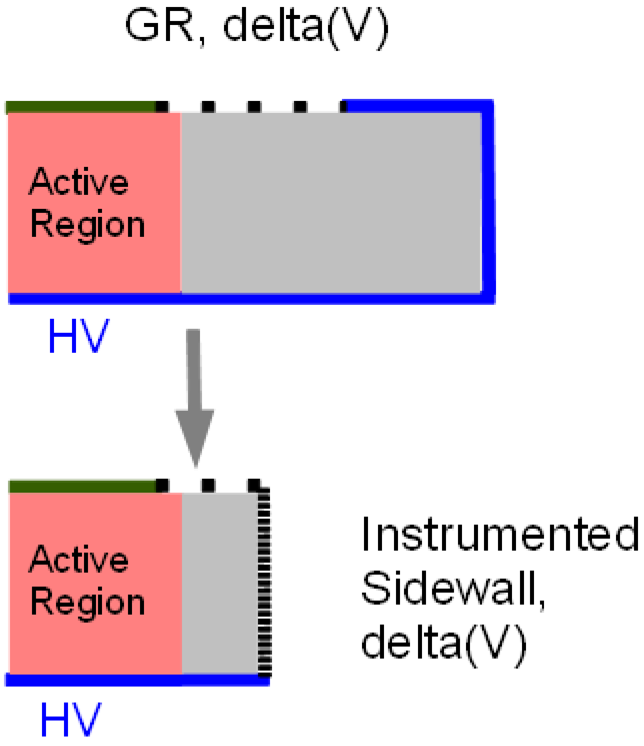
Slim Edges -- Motivation

Basic Idea: 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.

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

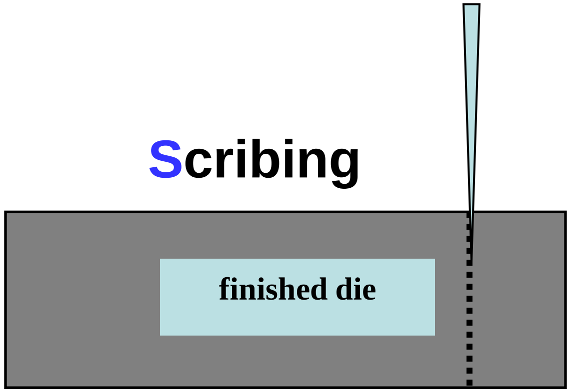






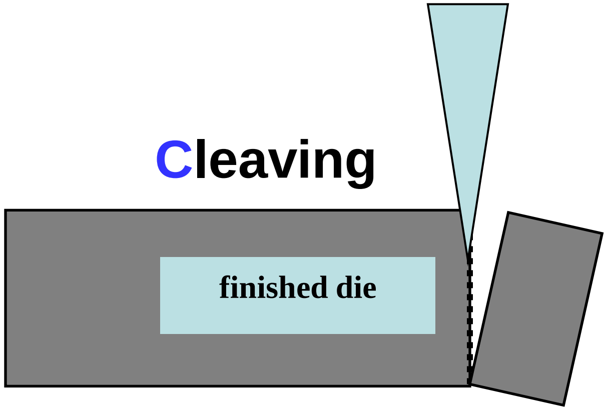
Method -- SCP Treatment

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

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

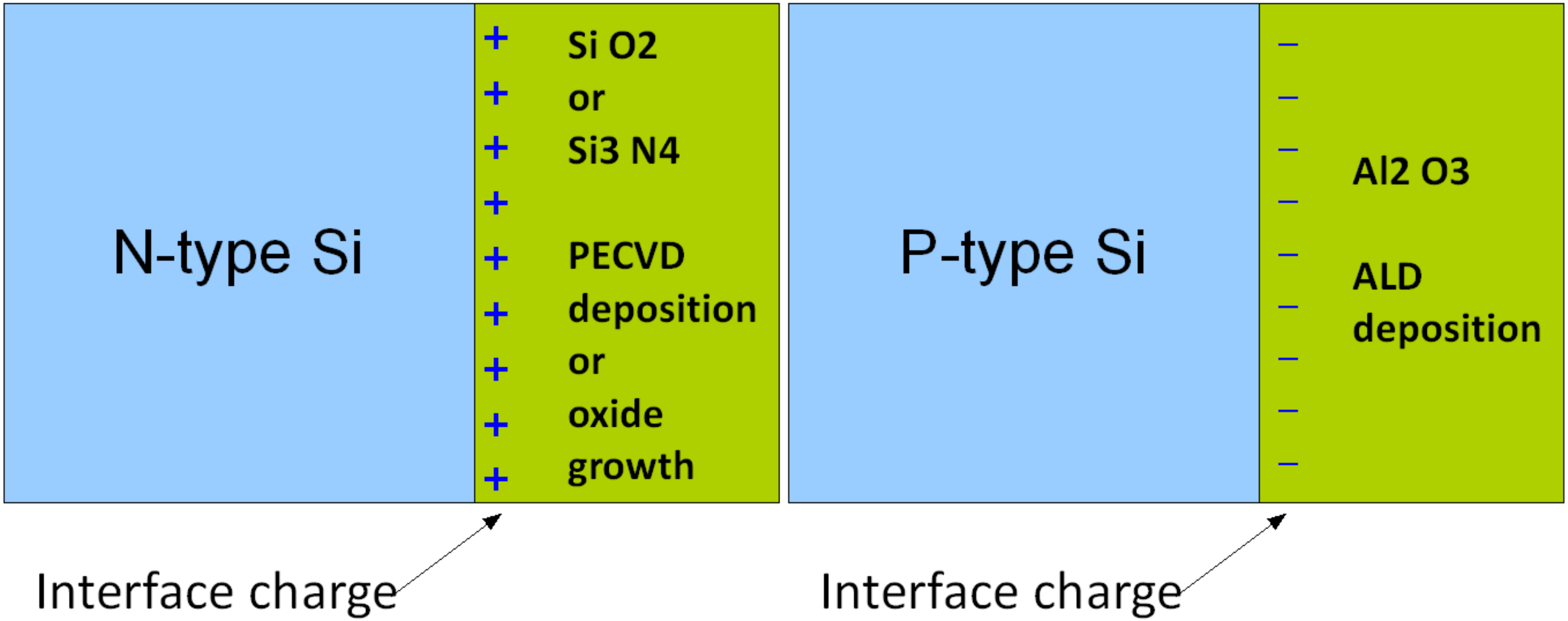
P-type

- ALD of Al_2O_3

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

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

Passivation Options



N-type Si

+ + + + + + + + +

Si O2
or
Si3 N4

PECVD
deposition
or
oxide
growth

Interface charge

P-type Si

– – – – – – – – –

Al2 O3

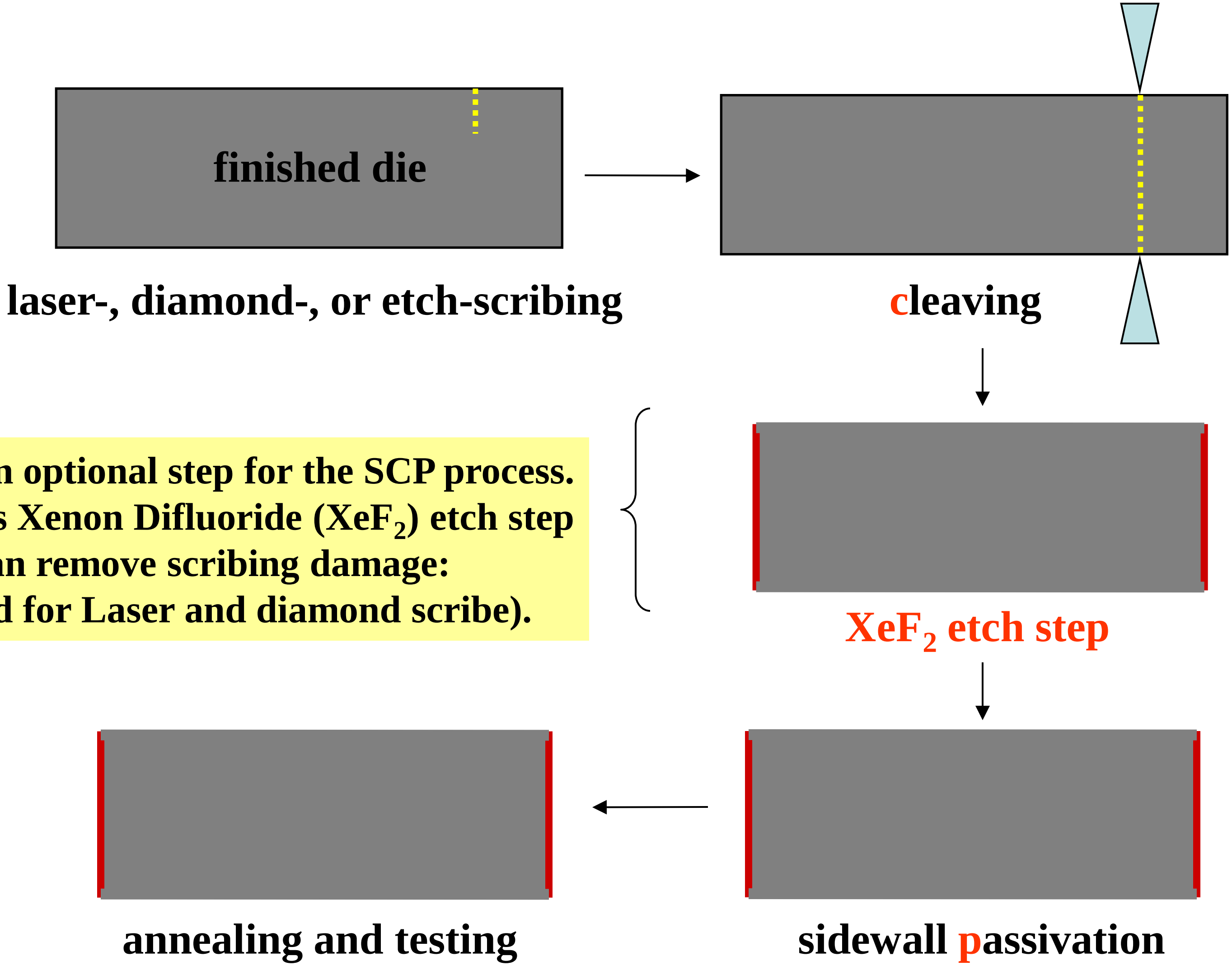
ALD
deposition

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).

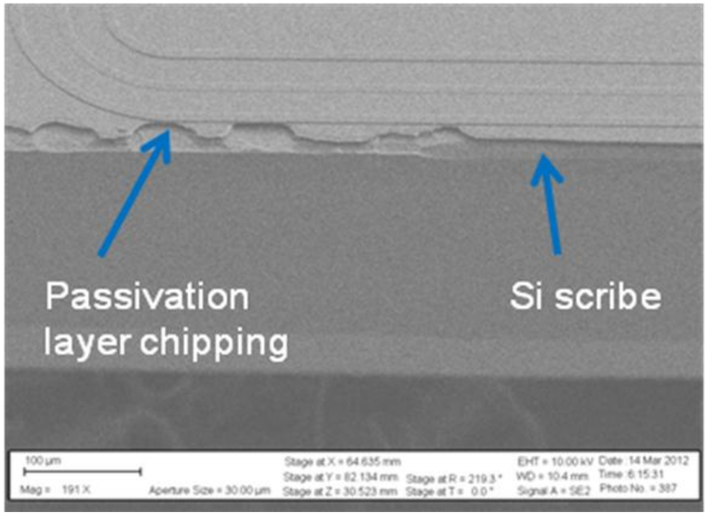
XeF_2 etch step

sidewall passivation

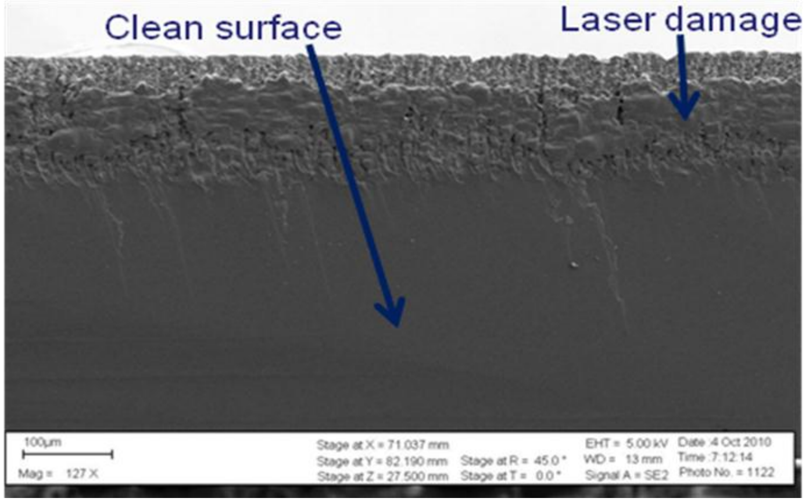
annealing and testing

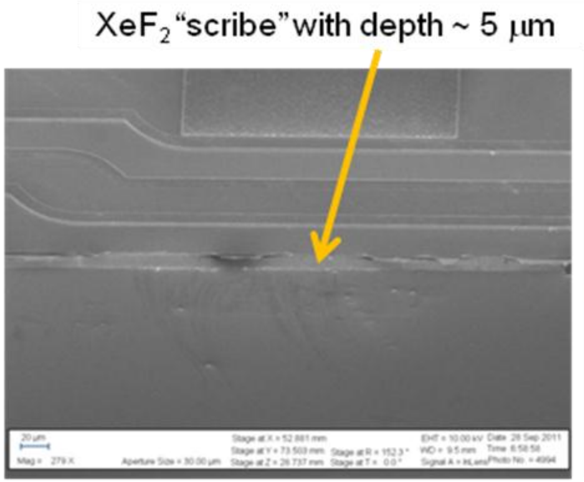
Scribing Technologies:
Diamond-, Laser-, and Etch-based

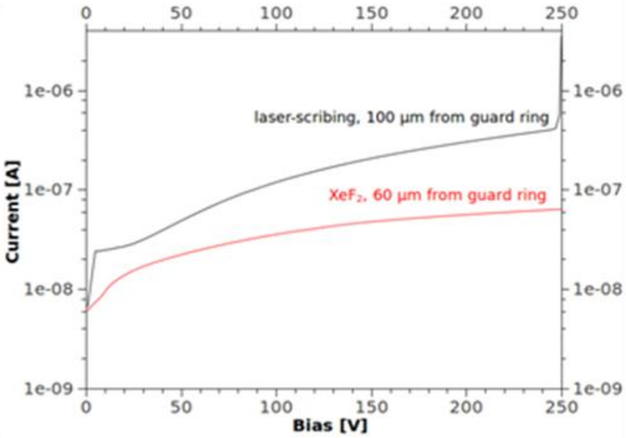
Diamond scribing



Laser scribing



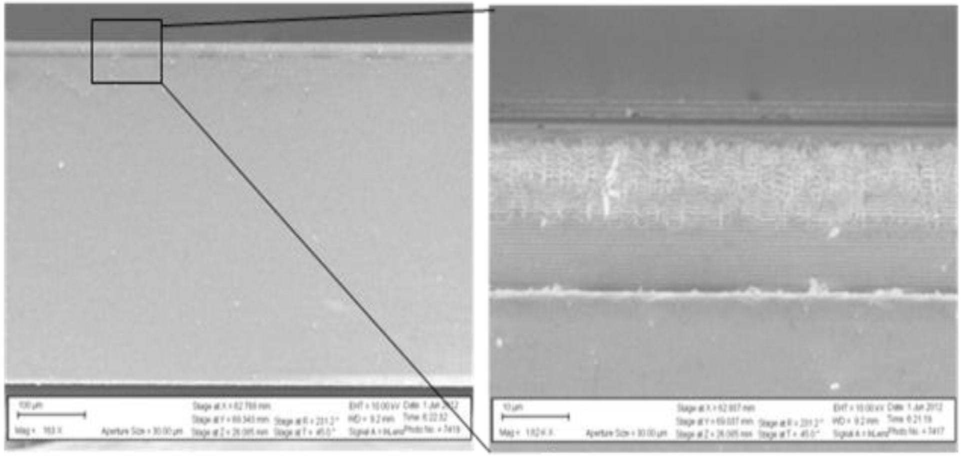


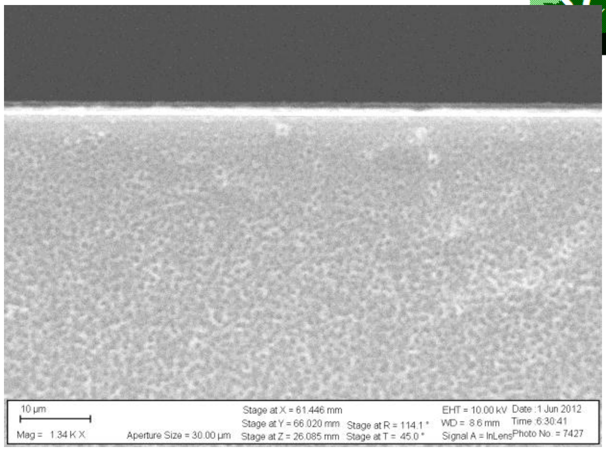


Issues:

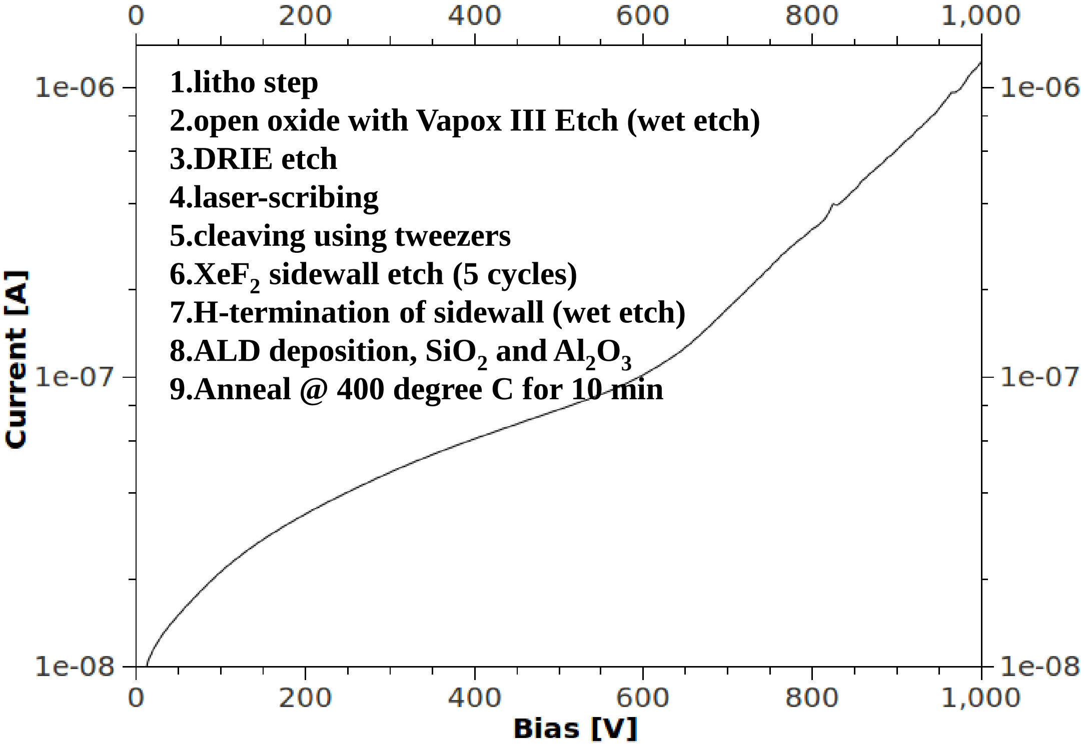
- ➢ Diamond scribing: surface chipping of <u>existing</u> passivation (=> to do again in future runs)
- ➢ Laser scribing: some degree of damage due to affected region of the sidewall
- ➢ XeF2 etching: cleaving by industrial machines is difficult

Scribing Technologies: DRIE



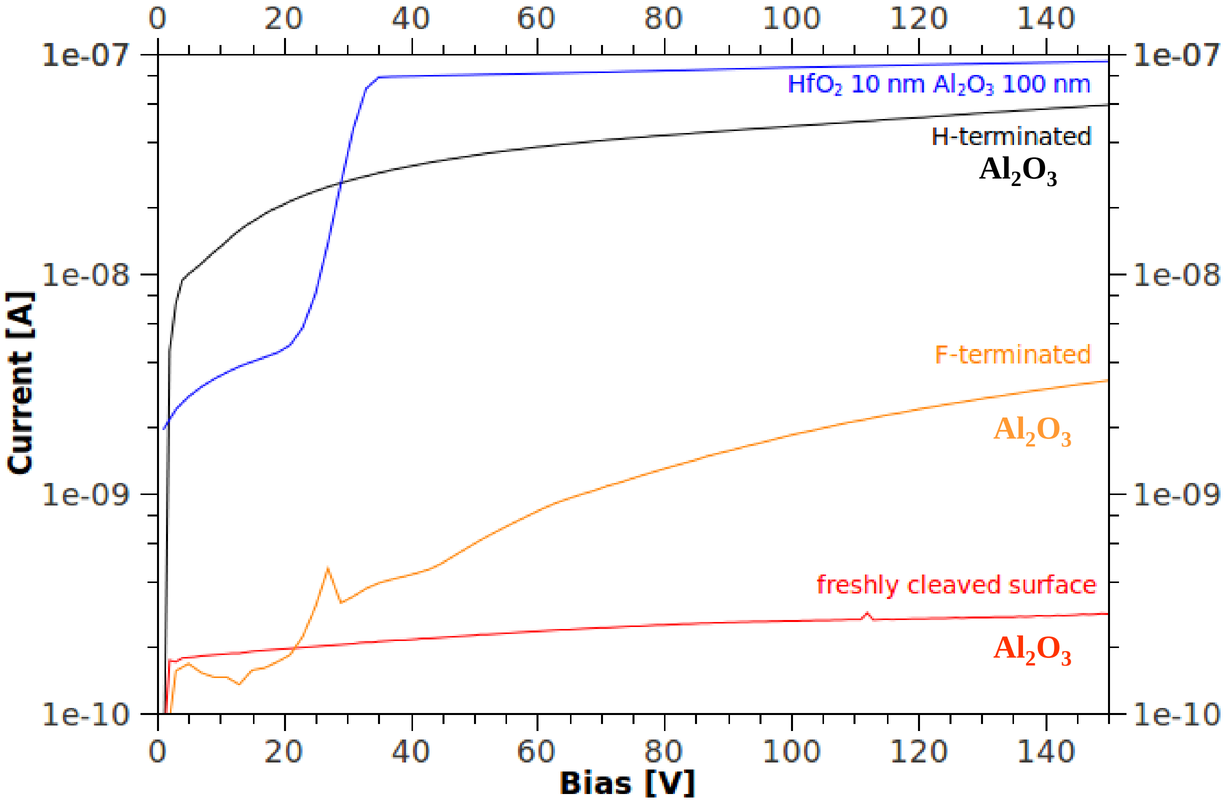


DRIE-based trenching as scribing has a promised of being a “universal” production solution without shortcomings of the other methods.



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**

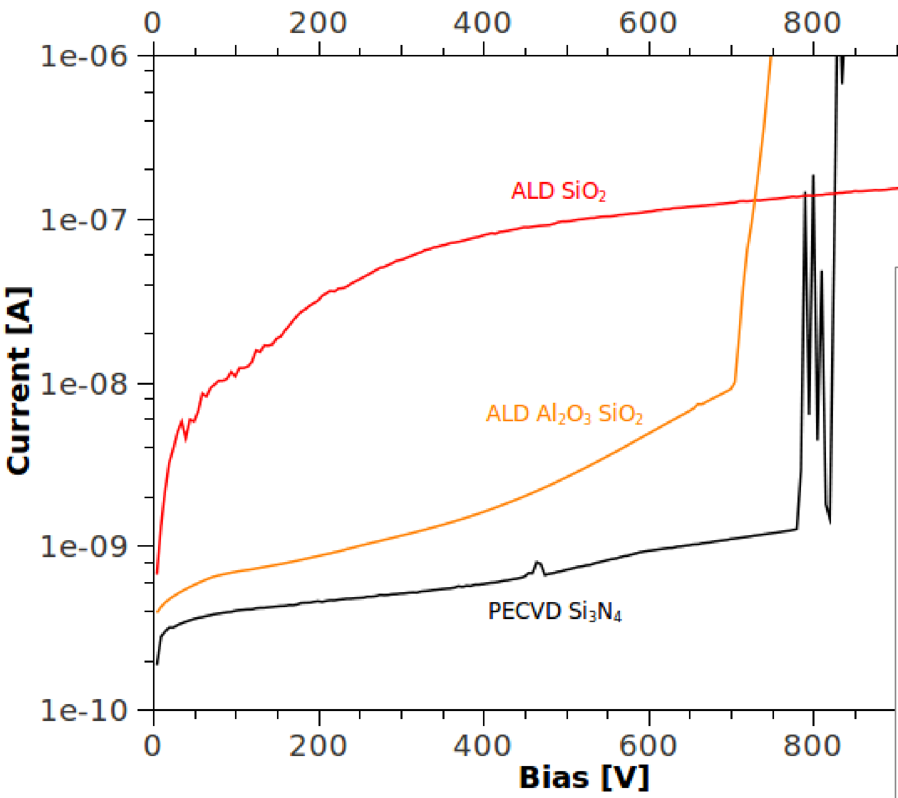
Effect of Surface Termination – P-Type Si



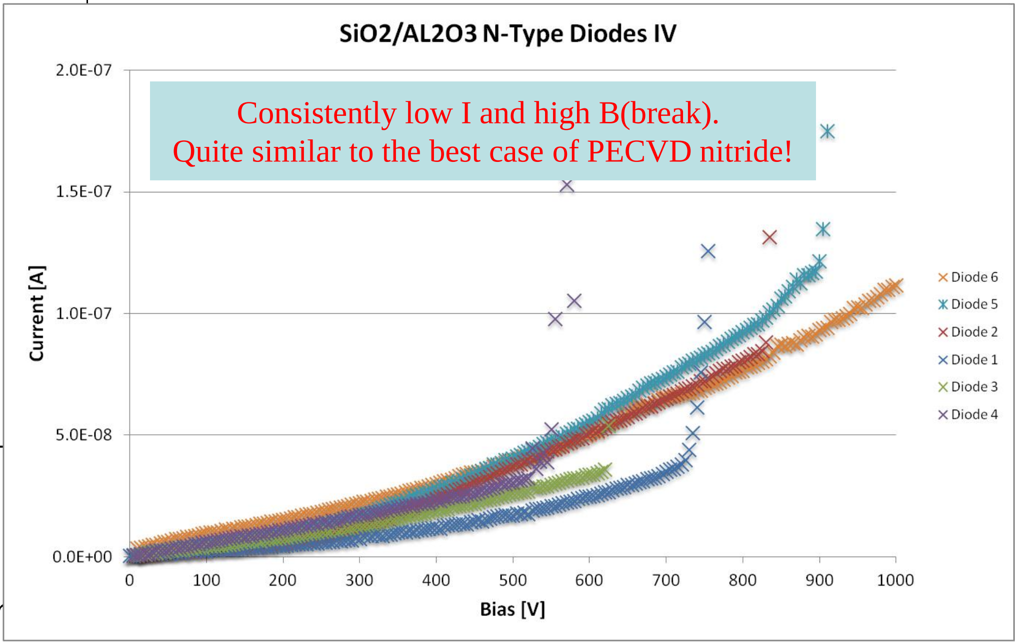
- After all the handling, we need to remove a native oxide. That is done w/ HF and leads to the "H-termination", which can't be passivated with alumina Al_2O_3.
- Need to covert the H-termination into F-termination which in combination with alumina ALD should work. Know they chemistry!
- The hunt for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



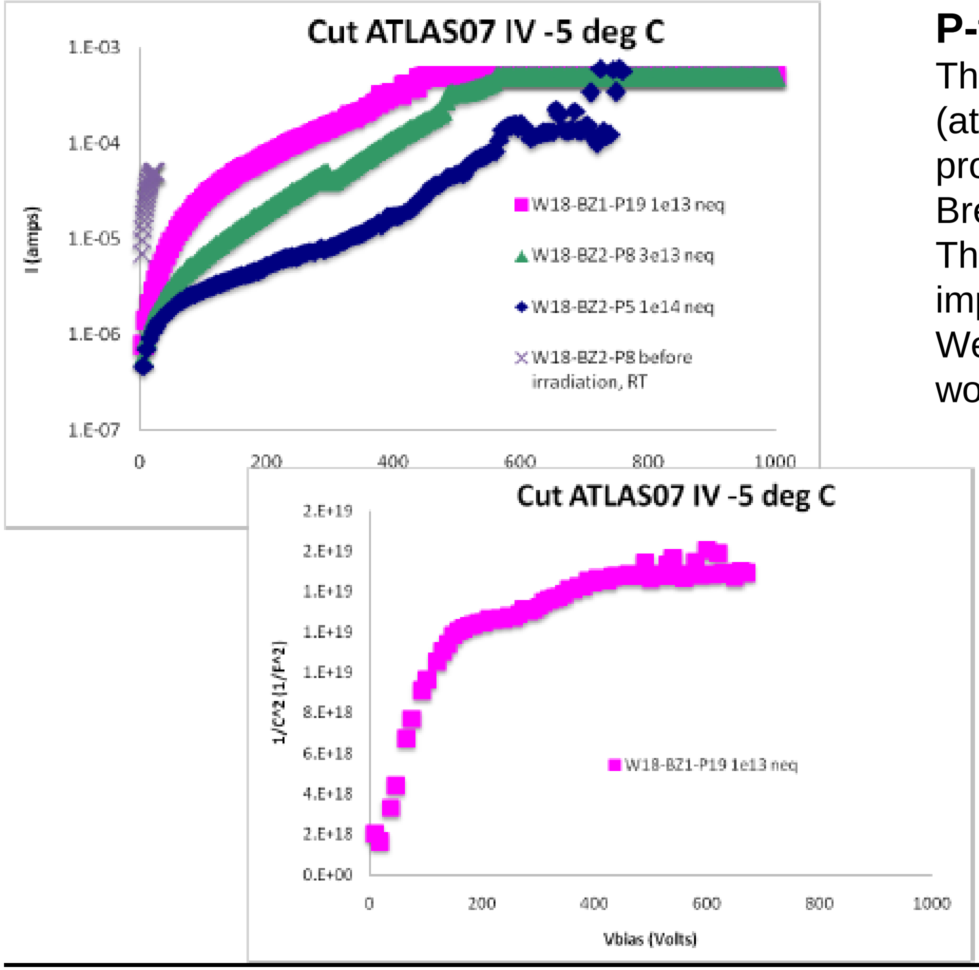
Study with HPK Fermi/GLAST diodes.
The plain ALD SiO2 is worse than the best case of PECVD Si3N4.
But a “nanostack” of ALD SiO2 (10 nm) and Al2O3 (50 nm) works well.
Parameters are from G. Dingemans et al, J. Appl. Phys. 110, 093715 (2011); doi: 10.1063/1.3658246



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

1. 2010 Proton Irradiation Studies @LANL

S-C only: No Passivation



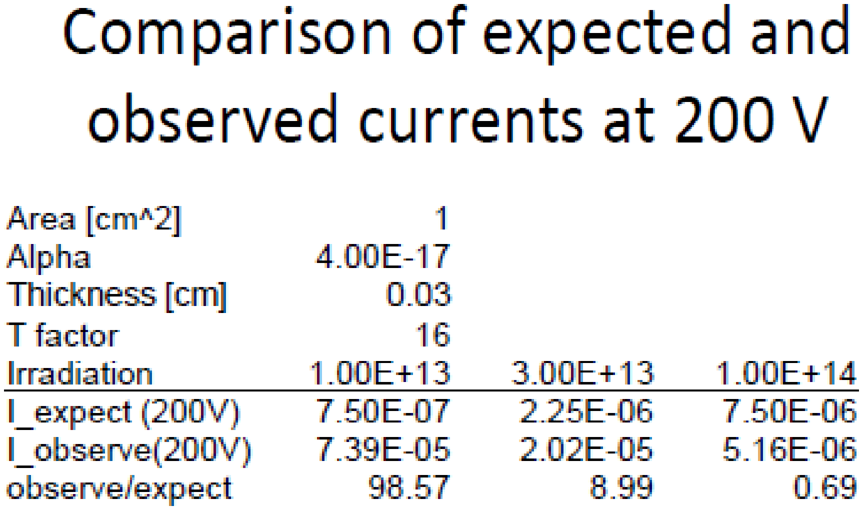
P-type HPK (ATLAS07)

These are sensors which did not work after cleaving (at the time we did not realize the importance of the proper surface charge).

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



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 -> high resistivity bulk -> edge isolation!

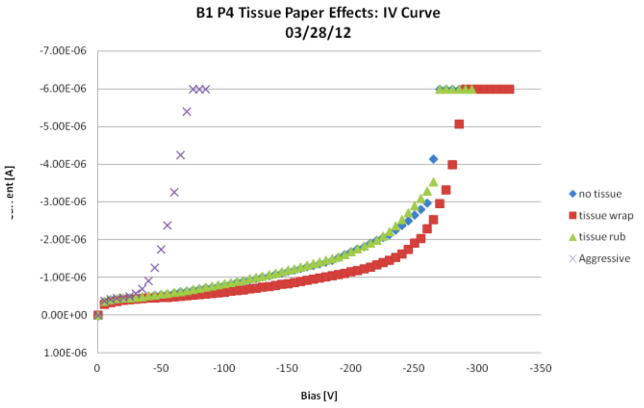
2. 2011 Proton Irradiation @LANL

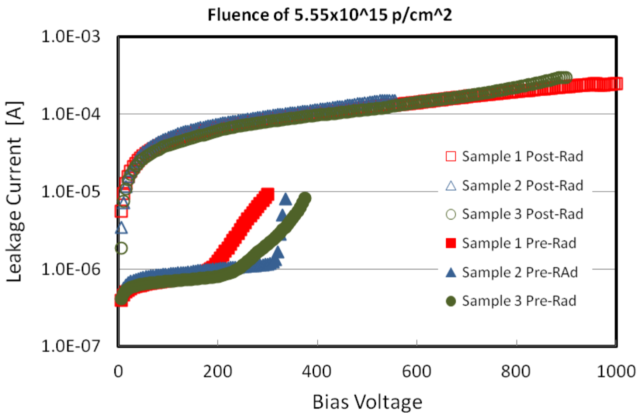
Irradiated 12 SCP processed p-type strip devices (CIS courtesy A. Macchiolo) at LANL (thanks S. Seidel)

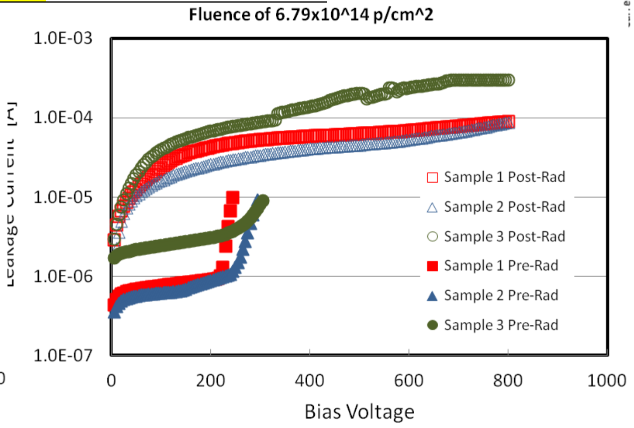
- **Results are in-conclusive:**
  - **+ Breakdown voltages extended post-rad**
  - **+ High fluence devices (3/3 for 1e16neq, 3/3 for 1e15neq) show expected post-rad leakage current**
  - **- Lower fluence devices (1/3 for 1e13neq and 1/3 for 1e14neq) show very early breakdown!!!**

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

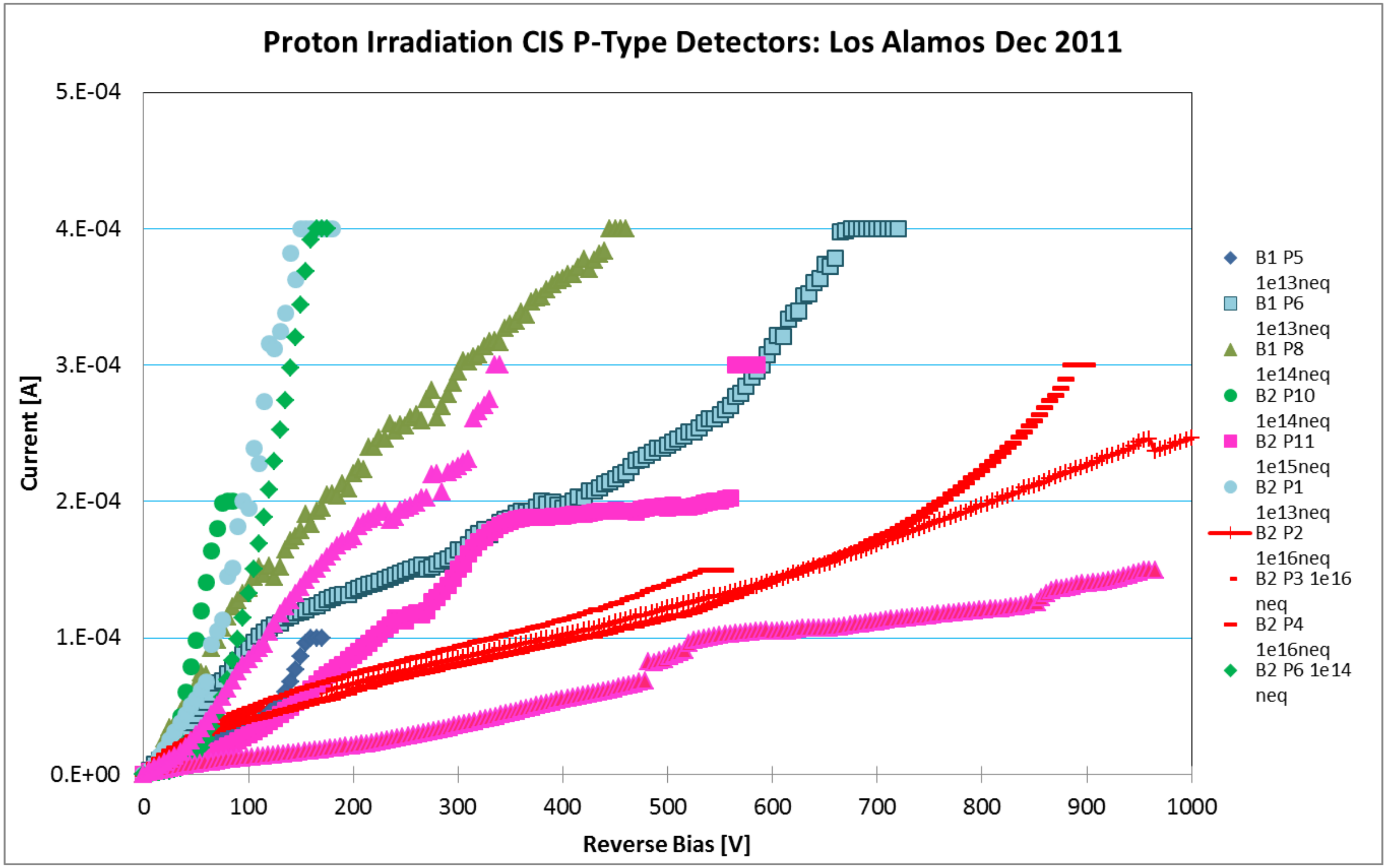
A parallel investigation of the robustness of the passivation layer revealed a possible susceptibility to rough handling. There is no proof that this has skewed the irradiation results.


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


Fluence of 5.55x10^15 p/cm^2


Fluence of 6.79x10^14 p/cm^2

2. 2011 Proton Irradiation @LANL



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

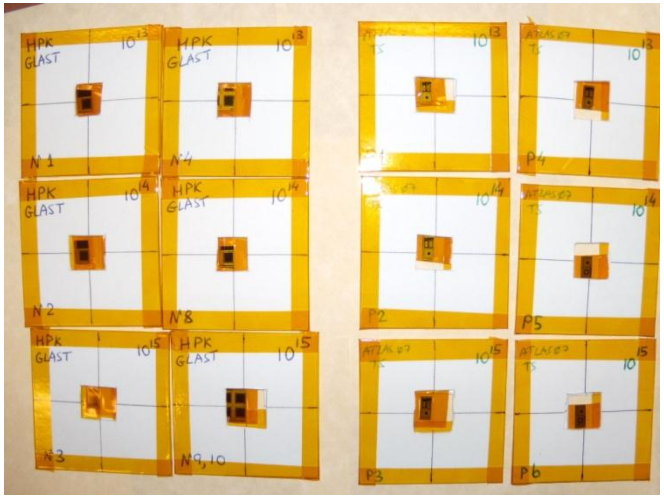
Low fluence (< 1e15): no edge-isolation

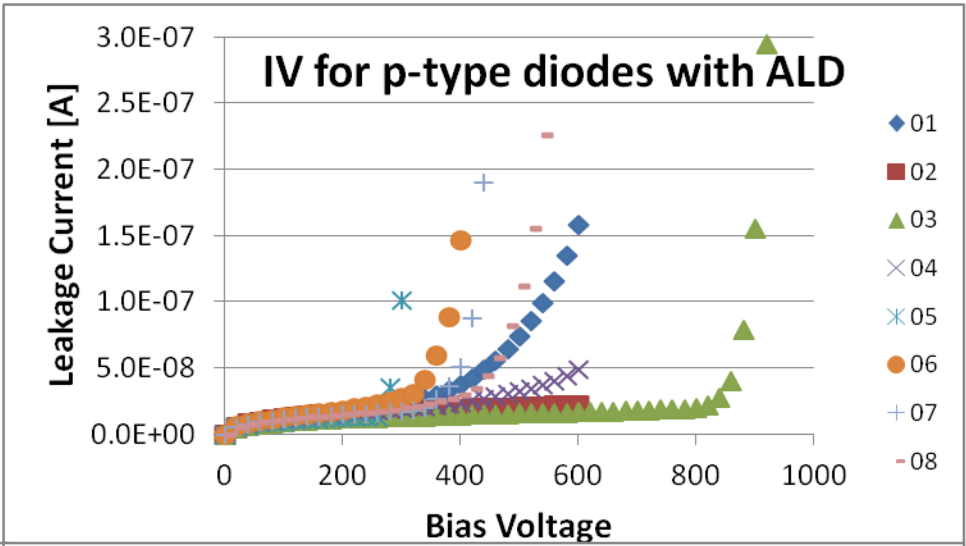
High fluence irradiation (< 1e15 ?): edge isolation!

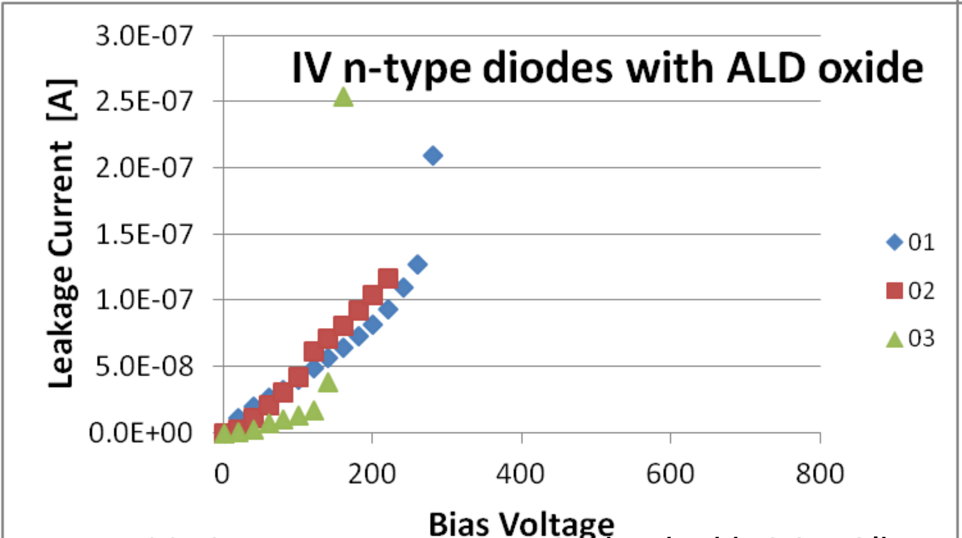
3. 2012 Proton Irradiation @CERN

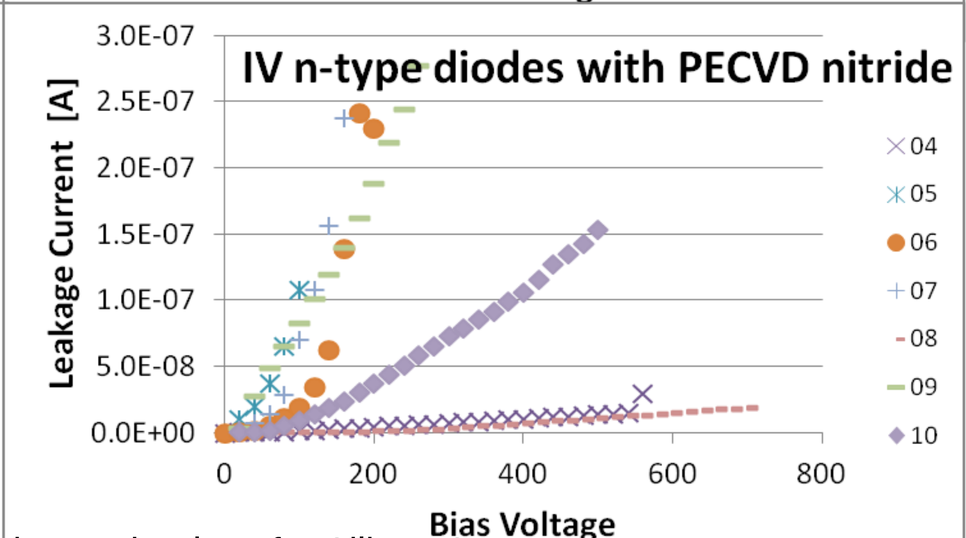
A round of irradiations at SPS (help from G. Casse & M. Glaser):

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





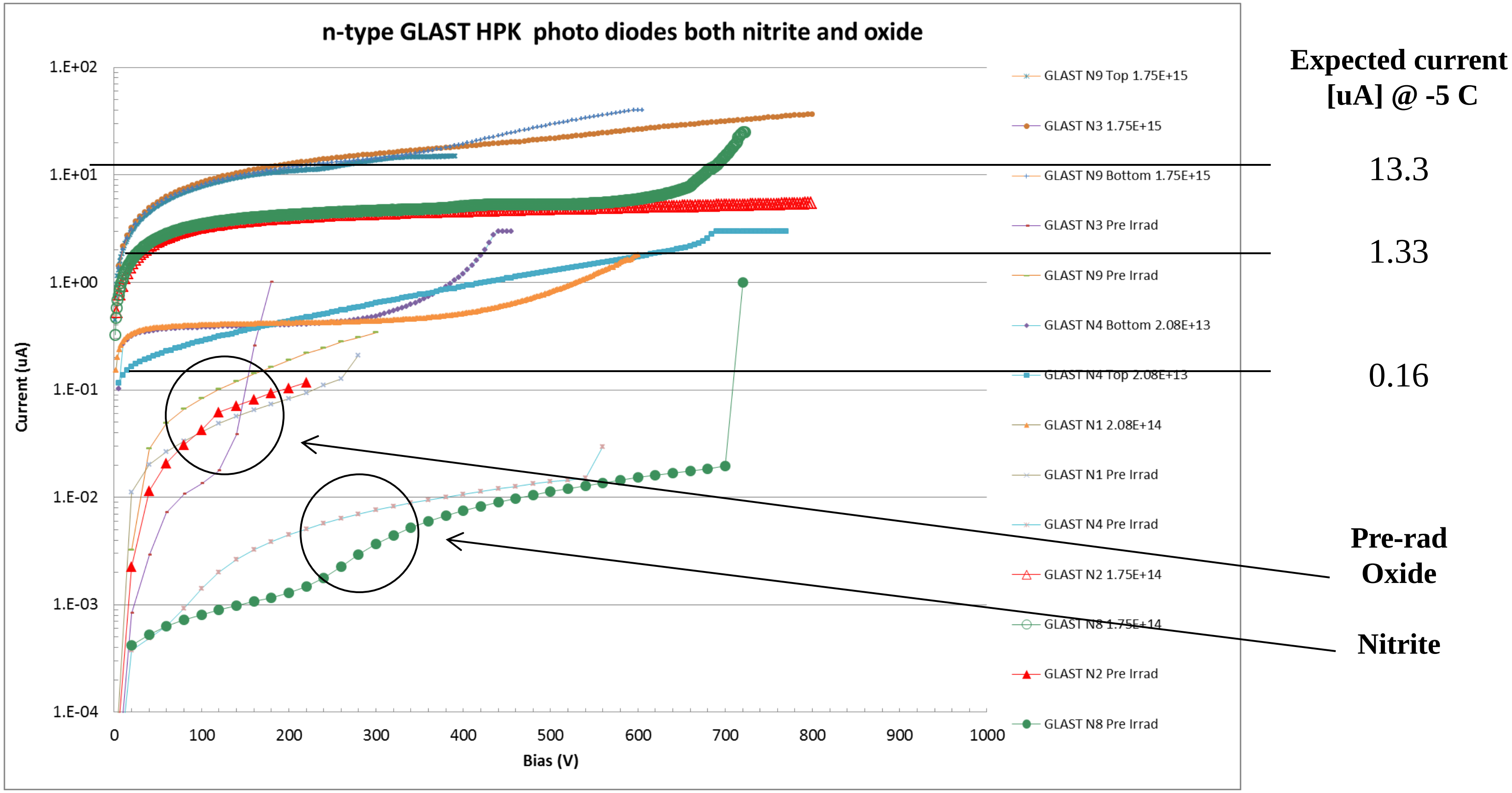




n-type GLAST HPK Photo Diodes

both nitrite and oxide passivation

PRELIMINARY



Expected current [uA] @ -5 C

13.3

1.33

0.16

Pre-rad Oxide

Nitrite

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

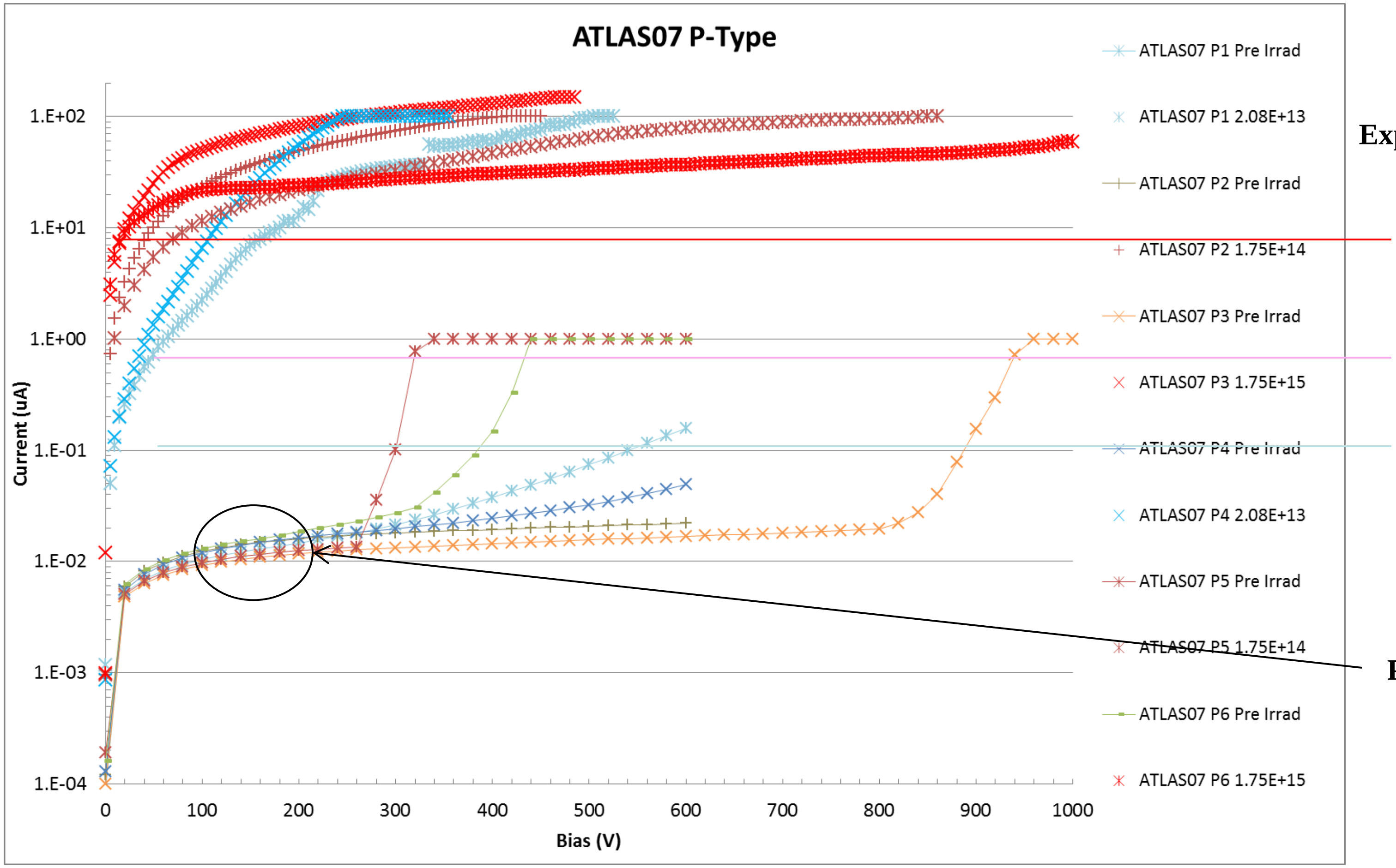
No dependence on type of passivation, leakage current close to bulk expectation

low fluence (1e13, below inversion) edge isolation due to Oxide/Nitrite

High fluence (>1e14, after inversion): edge isolation due to bulk resistivity

p-type ATLAS07 HPK Photo Diodes

PRELIMINARY



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 effect of Alumina ALD edge isolation

high fluence (>1e14): edge isolation works due to increased bulk resistivity

Conclusions and Future Work

- We have started S-C-P treatment of full-size 6” HPK n-type sensors

- After 3 irradiations we start to be able to interpret the observed post-radiation behaviour in terms of
  1. an increased bulk resistivity improving the edge isolation,
  2. and a potential reduction of the edge isolation created by the passivation due to type inversion (n-type) and an apparent growing in-effectiveness of the alumina ALD (p-type).

- In order to really understand the root cause for the performance, we will perform the following studies:
  - Annealing
  - Temperature dependence
  - Neutron irradiation (reduce the influence of interface charges, bulk effects only)
  - Gamma irradiation (reduce bulk effects, increase interface charge effects)

Acknowledgements

Members of RD50 and ATLAS Upgrade for supplying sensors.
Gianluigi Casse, Vladimir Cindro, Maurice Glasser, Sally Seidel for Irradiations.

Back-Up Slides

Charge Collection Testing

Sensor Type	Origin	Edge-Active area Distance [um]	Signal Read out	Beam	Ref
P-type strips	PPS (CIS)	~200	Binary (PTSM)	^{90}Sr	V. Fadeyev *et al* Pixel 2012, submitted to NIM A
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*., submitted to JINST
P-type 3D pixels	IBL (CNM)	50	FE-I3 & FE-I4	CERN Test Beam	S. Grinstein *et al*., RESMDD12