Punch through protection of heavily irradiated ATLAS07 mini- sensors.

Status report

Jan Bohm, Institute of Physics ASCR, Prague

Peter Kodys, Tomas Jindra, Zdenek Dolezal, Jan Scheirich,
Charles University in Prague

Petr Masek, Michael Solar, Institute of Experimental and Applied Physics of Czech Technical University in Prague

Outlook

The performance of the sample of 75 ***n*-in-*p*** HPK miniature 1cm*1cm sensors developed by ATLAS Collaboration for LHC upgrade [**Y. Unno, et.al., Nucl. Inst. Meth. A636 (2011) S24-30**] with different punch through structures, BZ4A-D, and with three different **ion concentrations of 2E12, 4E12 and 1E13 ion/cm^2** of the P-stop and P-stop + P-spray separation is studied before and after irradiation with the aim to select the most suitable P-stop ion concentration and punch through structure as a protection against beam splashes – protection of coupling capacitor
This report is a **preliminary** compilation of measured characteristics.

-**Irradiation of the sample of miniature sensors**

-**Bulk characteristics, IV & CV measurement**

-**Interstrip capacitance and Interstrip resistance**

-**Punch Through Protection and PT voltages**

The micro-strip silicon **miniature sensors of 1cmx1cm** (strip length 0.8cm) are ATLAS07 Series fabricated by Hamamatsu Photonics (HPK) using 6" (150 mm) process technology . The baseline is ***p-type*** float zone silicon with crystal orientation <100> and having **thickness of 320 µ**. Sensors are single-sided with **AC coupled readout *n-type* strips** which are biased through polysilicon resistors. One hundred readout strips with ***pitch 74.5 µ*** are electrically isolated by a common and floating p-implant (**'p-stop' isolation)**

Sample of HPK miniature sensors

	ATLAS07-pre-series-3rd								ATLAS07-series2								total
	Pspray(2E12)+Pstop(2E12)				Pstop(2E12)				Pstop(1E13) STD				Pstop(1E13) HPK_ex				
	W4	W5	W6	W10	W14	W17	W19	W31	W75	W78	W80	W81	W89	W91	W93	W97	
BZ4A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
BZ4B	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
BZ4C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
BZ4D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
total	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	63

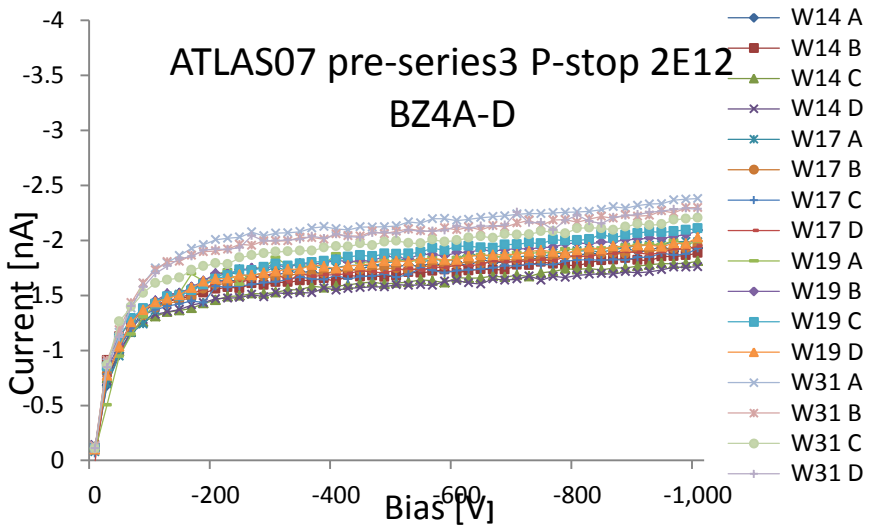
From Hamburg we received next 12 sensors BZ4A-D of **Series 3** (wafers 264,278 and 281) with P-stop ion concentration **4E12 ion/cm^2**. **Many thanks to colleagues from DESY**.

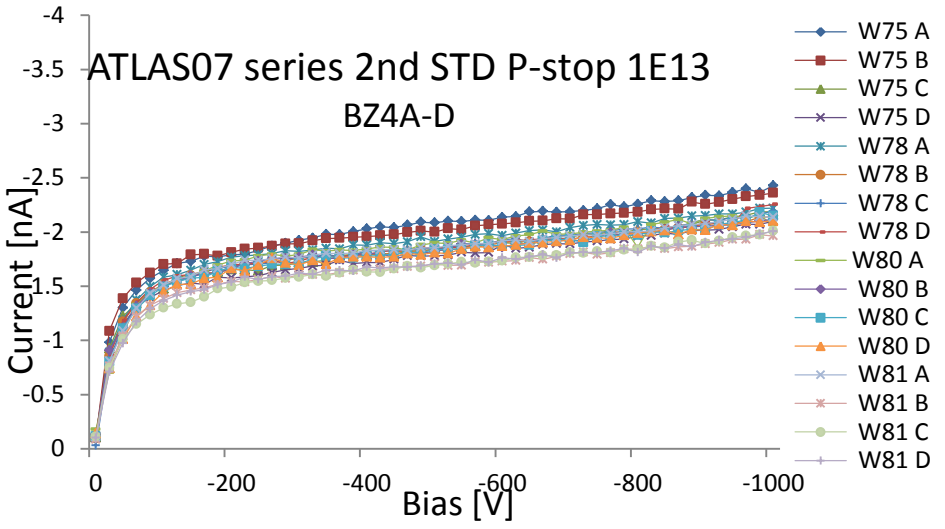
Irradiation of sensors BZ4A, B, C and D for each wafer

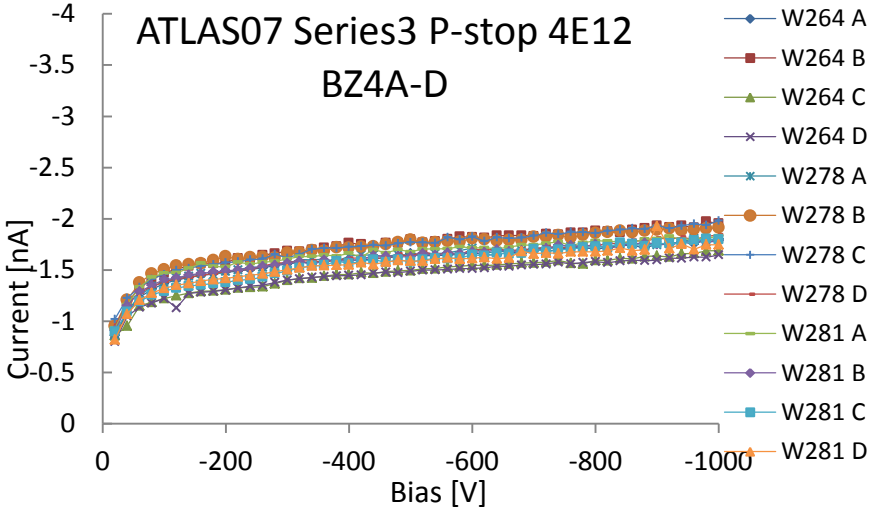
Wafer	Isolation	Ion/cm^2	Fluency neq/cm^2	Particles	Where	Annealing
W06	Pspr+Pstp	2E+12	4E+14	neutrons	Ljubljana	80min/60degC
W10	Pspr+Pstp	2E+12	2E+15	neutrons	Ljubljana	80min/60degC
W17	Pstop	2E+12	4E+14	neutrons	Ljubljana	80min/60degC
W19	Pstop	2E+12	2E+15	neutrons	Ljubljana	80min/60degC
W278	Pstop	4E+12	4E+14	neutrons	Ljubljana	80min/60degC
W281	Pstop	4E+12	2E+15	neutrons	Ljubljana	80min/60degC
W31	Pstop	2E+12	4E+14	p 23GeV/c	CERN	---
W91	Pstop	1E+13	4E+14	neutrons	Rez Prague	80min/60degC
W93	Pstop	1E+13	2E+15	neutrons	Rez Prague	80min/60degC
W97	Pstop	1E+13	1E+16	neutrons	Rez Prague	80min/60degC

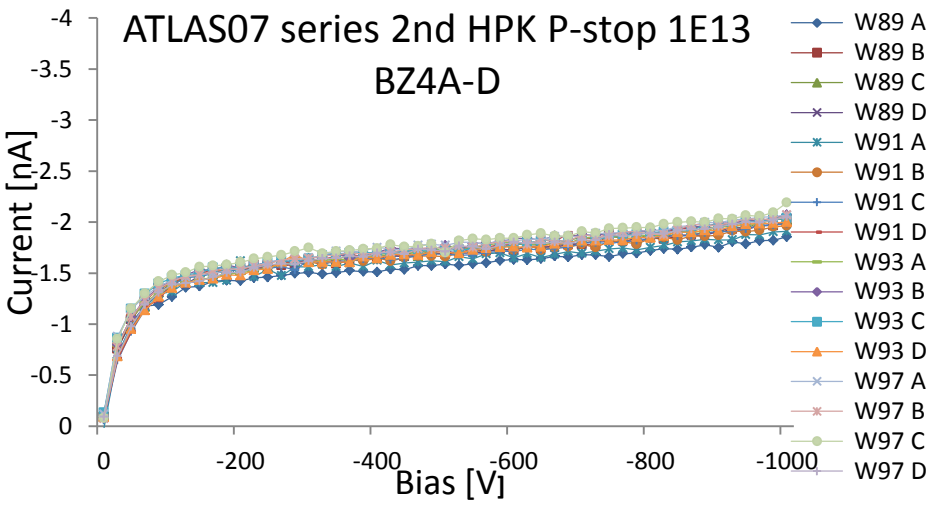
Many thanks to Vlado Cindro , Morris Glaser and Jan Kucera

IV characteristics – non-irradiated



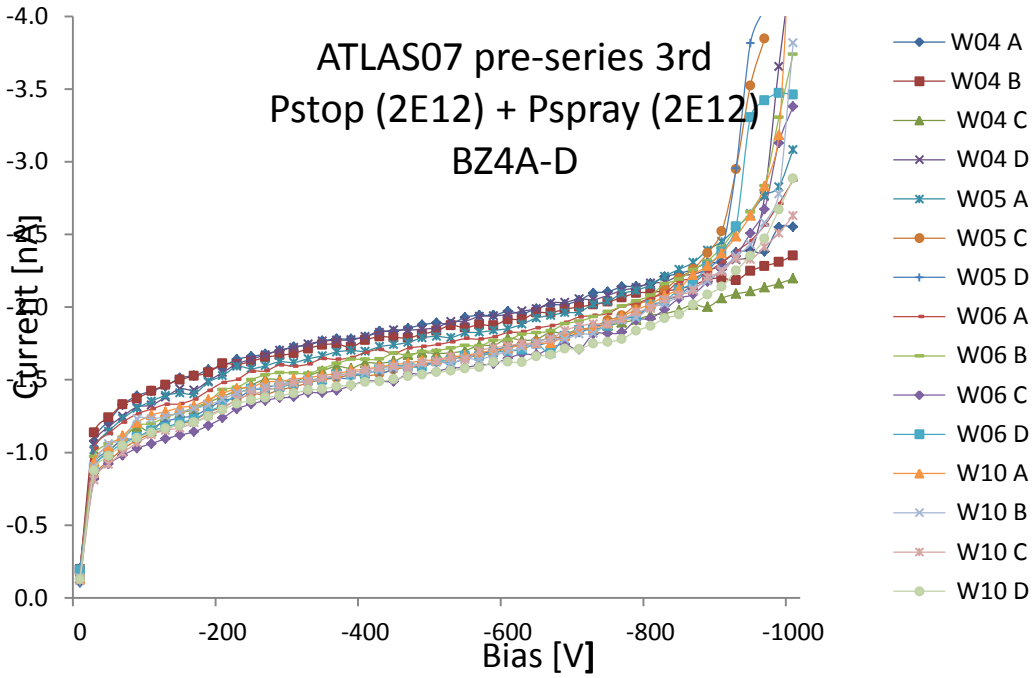




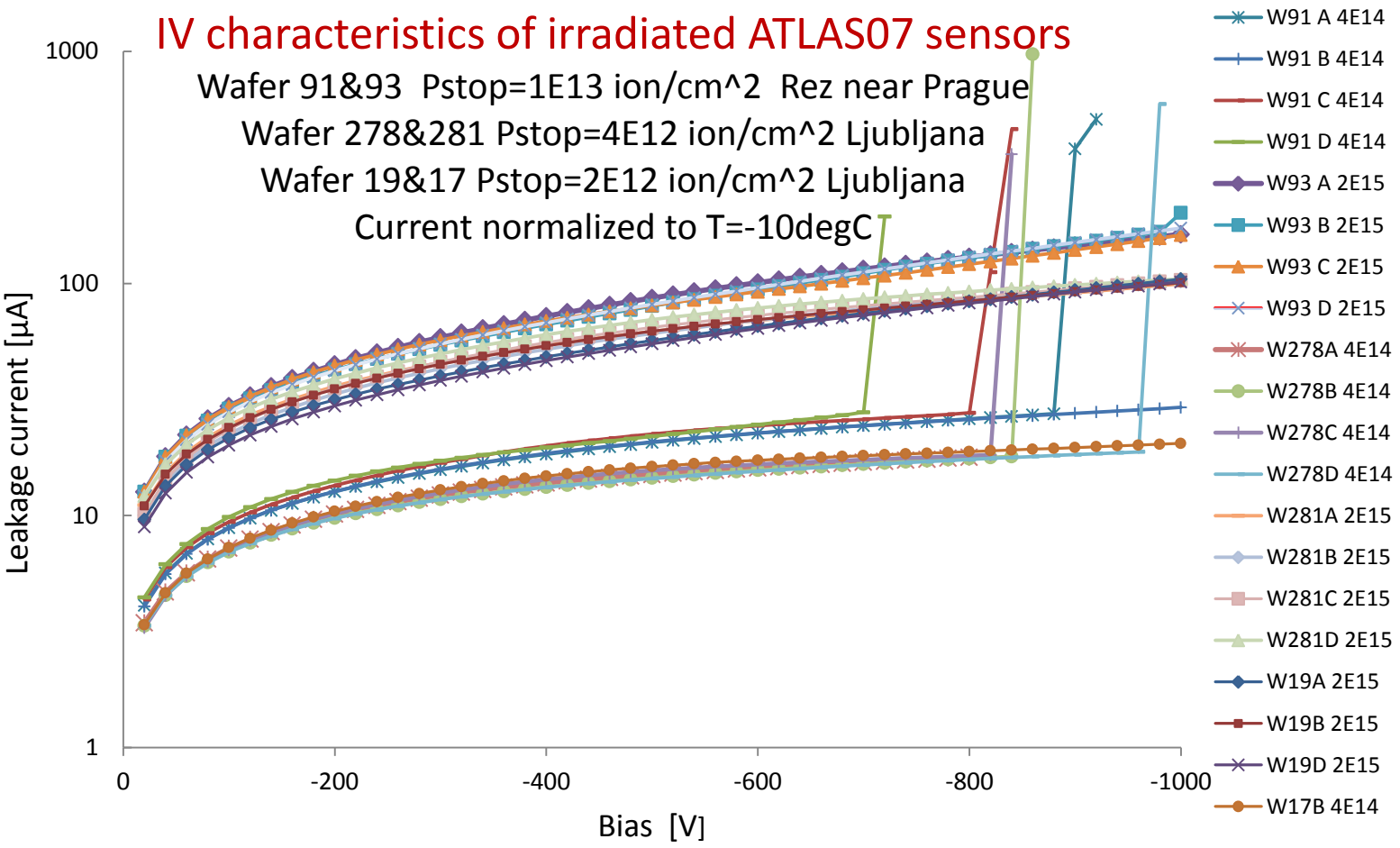


Measured sensors were placed on the table without vacuum chuck jig to avoid possible strong stresses which could cause breakdowns.

IV characteristics – non-irradiated

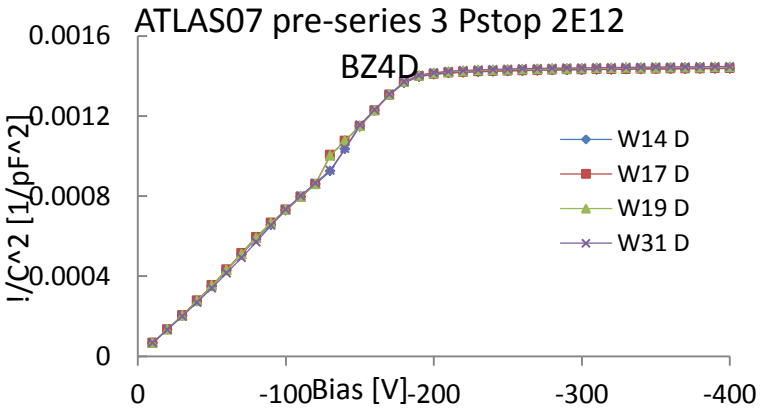


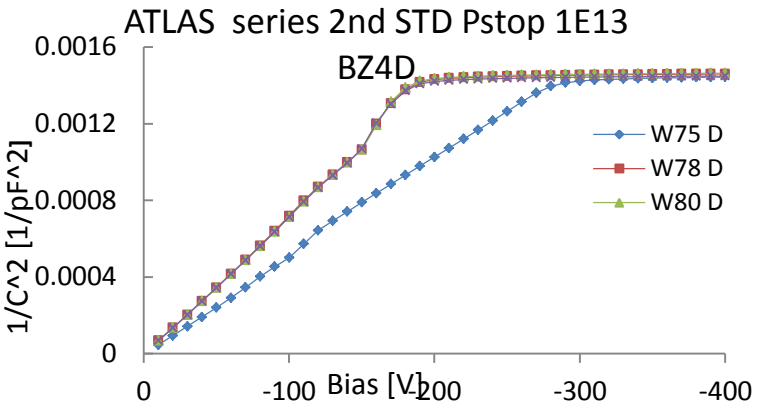
All sensors with p-stop isolation and with different ion concentrations were successfully operating up to 1000V, no onset of micro-discharges was observed.
On other side, sensors with P-stop + P-spray isolation behaves differently and an onset of breakdowns are above already Vbias=900V.

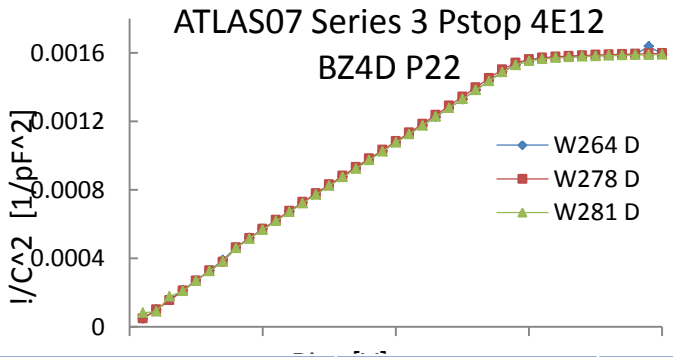


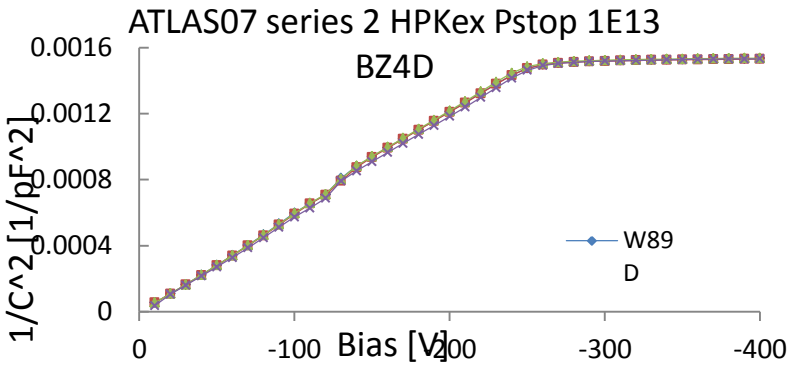
An onset of micro –discharges is observed for irradiated sensors to fluency 4E14 neq/cm^2 contrary to fluency 2E15 neq/cm^2 where no breakdowns are visible.
Higher current measured on wafers W91 and W93 is under study (irradiated in Rez).

CV Characteristics





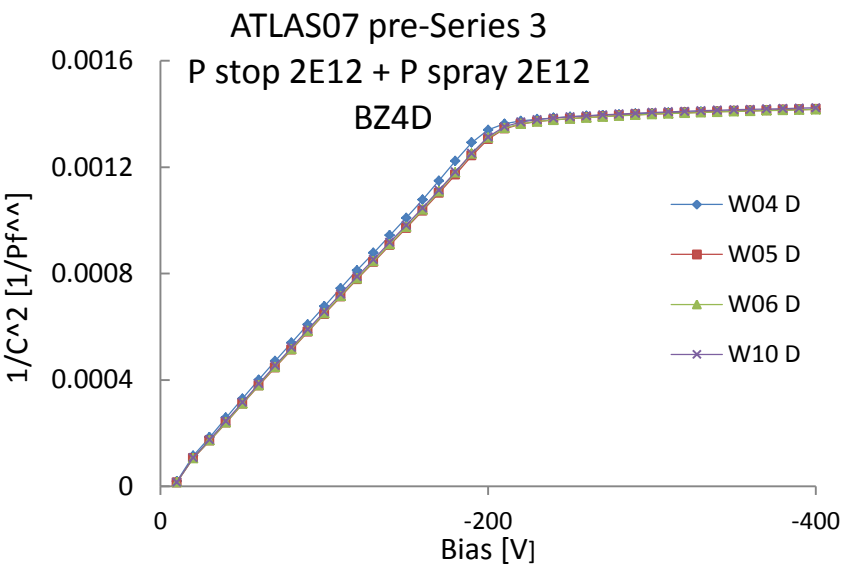


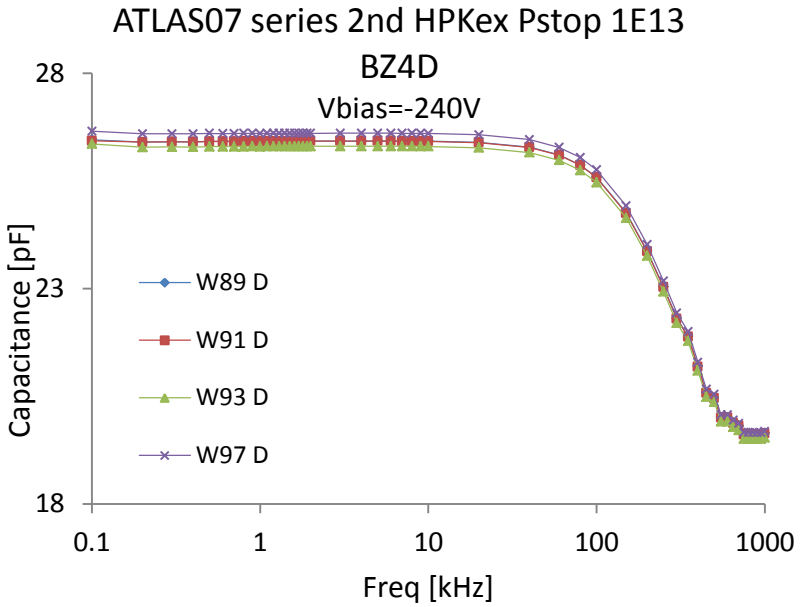


Series	Pre-Series3	Series 3	Series 2 STD	Series2 HPK	Pre-Series3
Concentration [ion/cm^2]	2E12	4E12	1E13	1E13	2E12 P stop 2E12 P spray
V full depletion	-183V	-292V	-186V	-252V	-204V

Bulk capacitance has been measured on sensors BZ4D at each wafers.

CV Characteristics



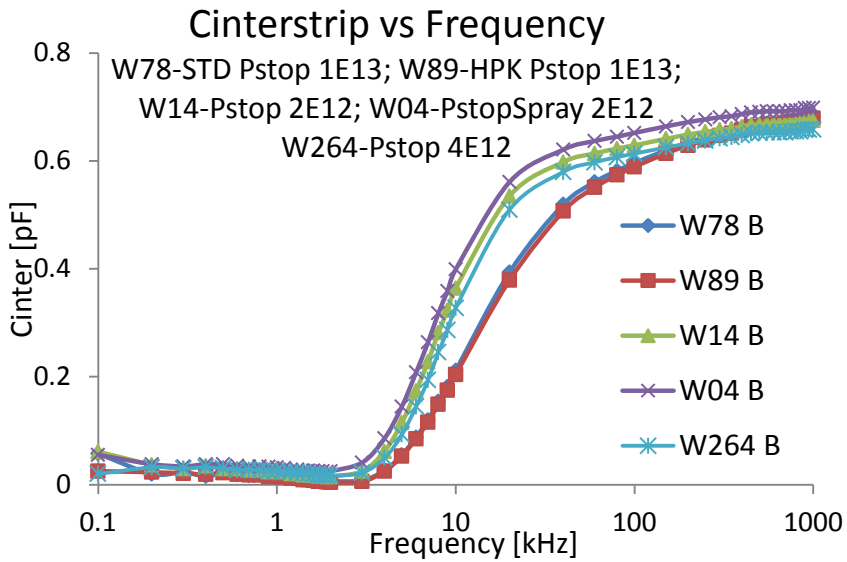


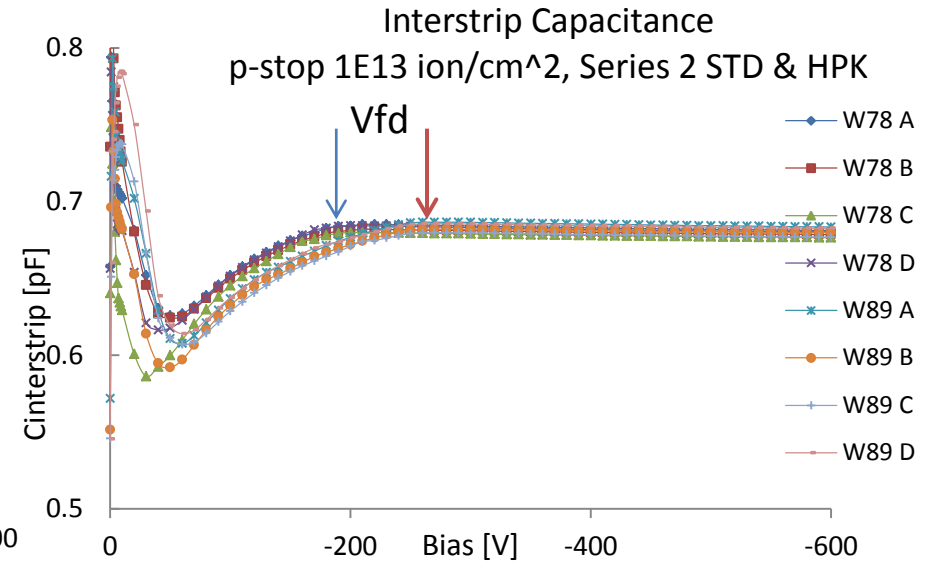
Bulk capacitance does not depend on testing frequency in range of 200Hz up to 20kHz

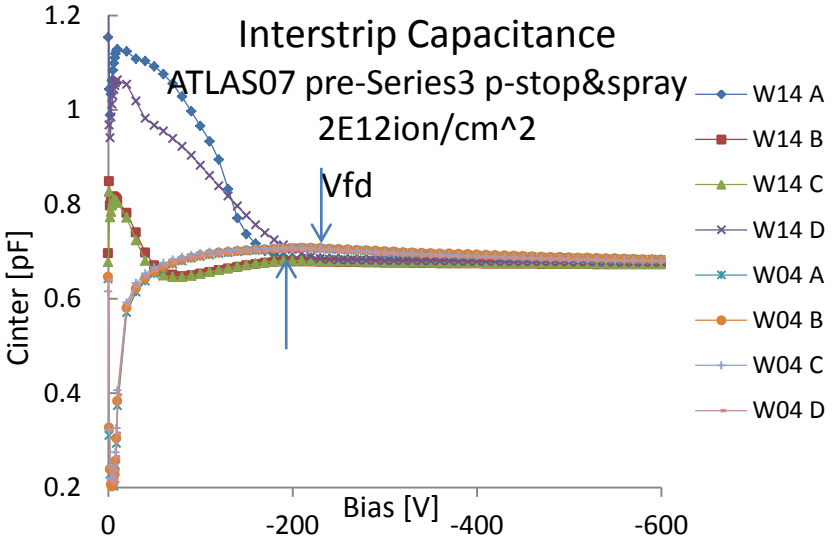
Series	Pre-Series3	Series 3	Series 2 STD	Series2 HPK	Pre-Series3
Concentration [ion/cm^2]	2E12	4E12	1E13	1E13	2E12 P stop 2E12 P spray
V full depletion	-183V	-292V	-186V *)	-252V	-204V

*) Sensors BZ4A-D from wafer W75 of Series 2 STD have higher full depletion voltage, Vfd=286V

Interstrip Capacitance – non-irradiated



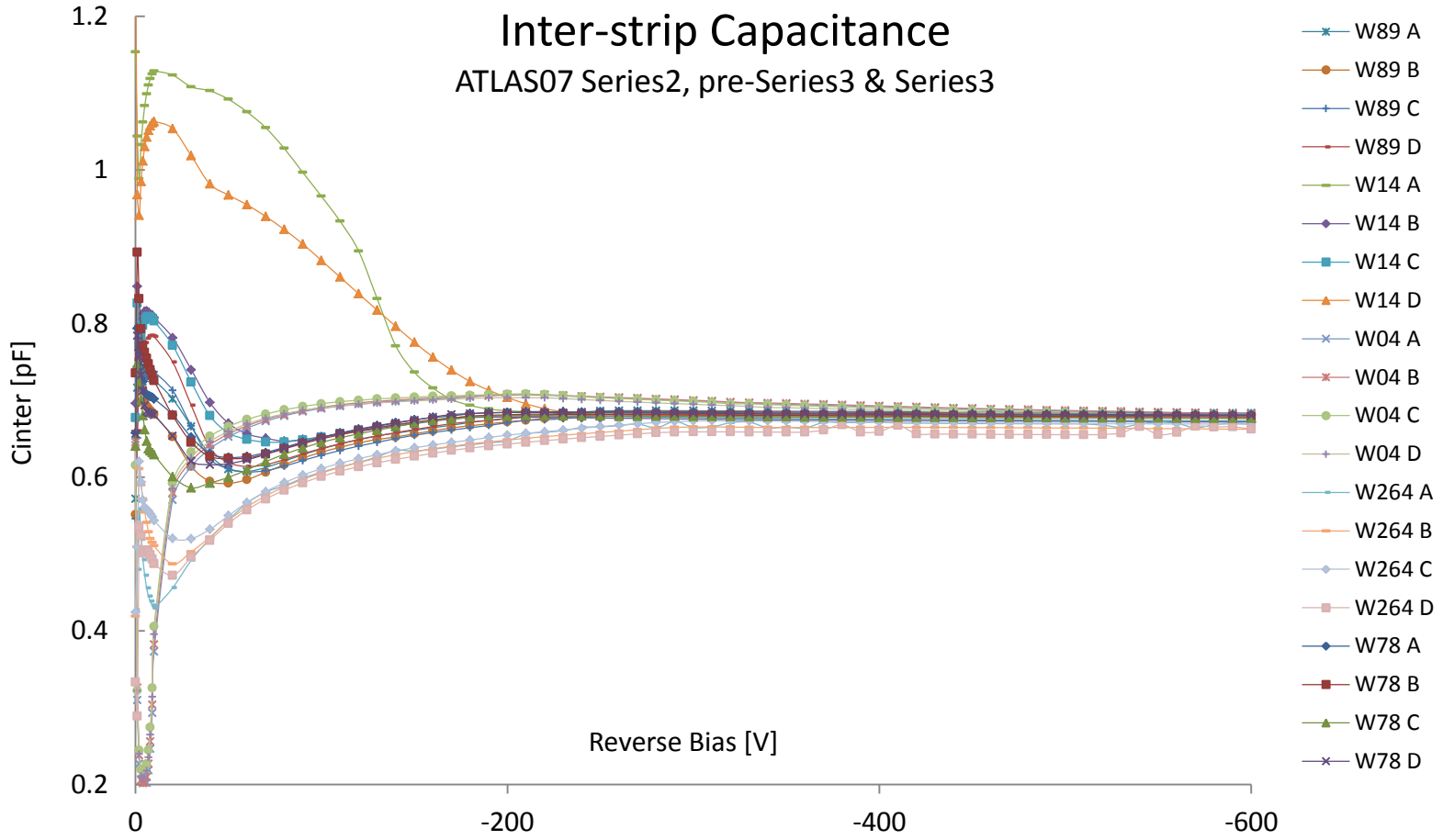




Interstrip capacitance is measured by 3 probes.

C interstrip depends strongly on frequency.
Capacitance is measured at 1MHz

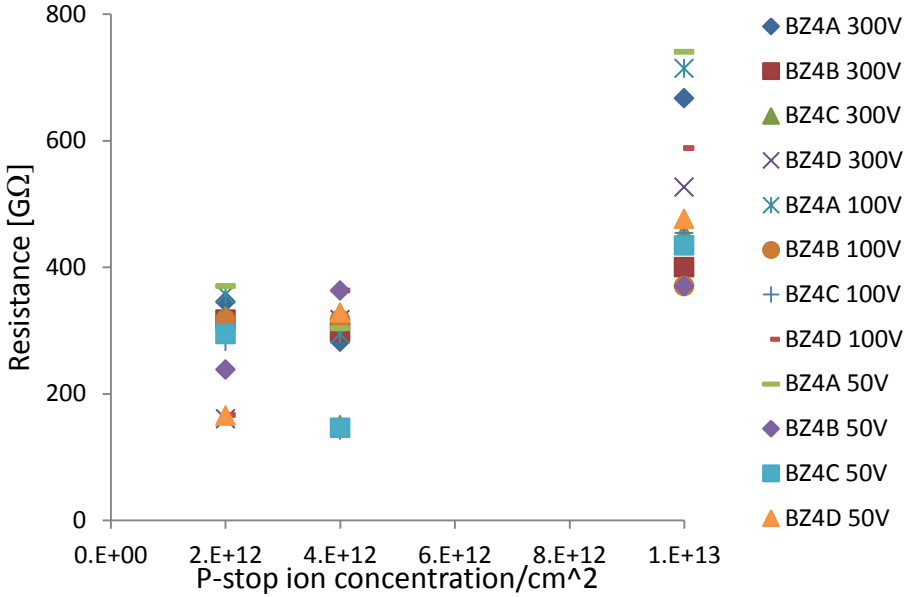
For Vbias<Vfd the values of C interstrip depend on the P-stop & P-spray ion concentration .
After irradiation Cinterstrip is a constant without any structure for low bias voltage.(J.B., RD50,Liverpool)
There is narrow deep minimum of Cint at Vbias =-4V for P-stop+P-spray isolation.

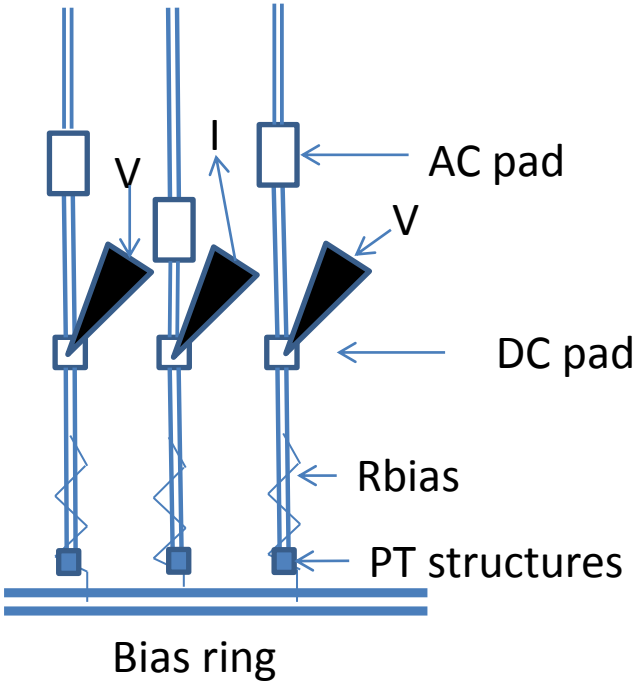


The inter-strip capacitance, Cint, is constant for bias voltages higher than respective full depletion voltages and Cint does not depend in this region on an ion concentration and the punch through protection structures within ±20fF.

Possible time dependence of Cint and an influence of relative humidity is in progress.

Interstrip Resistance - non-irradiated





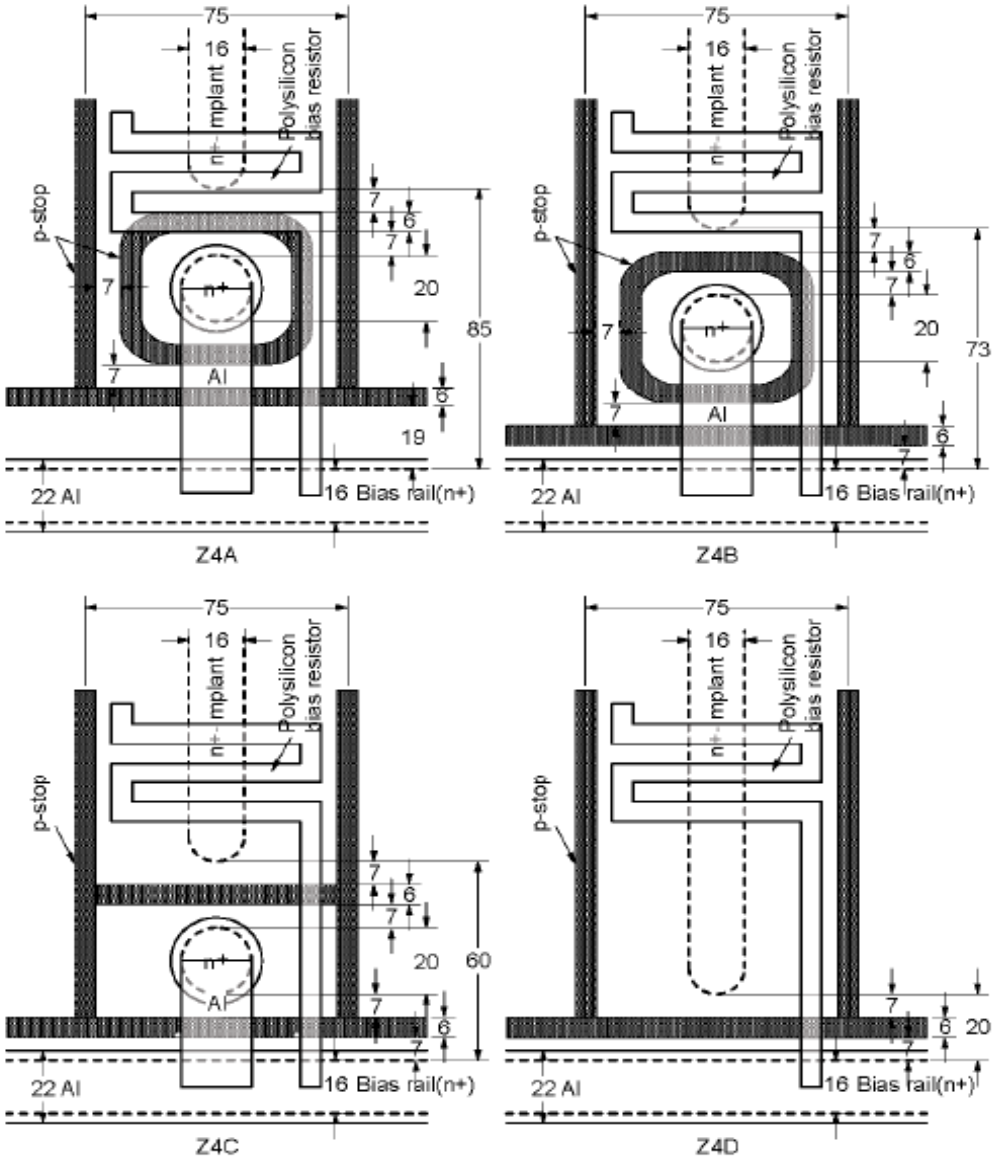
Rint = 2*dV/dI measured at Vbias=-50V, -100V and -300V

Interstrip resistance increases with P-stop ion concentration from 4E12ion/cm^2 up to 1E13 ion/cm^2

Interstrip resistance is decreasing with increasing fluency

K.Hara et al: Nucl.Instrum.Meth. A636 (2011) S83-S89

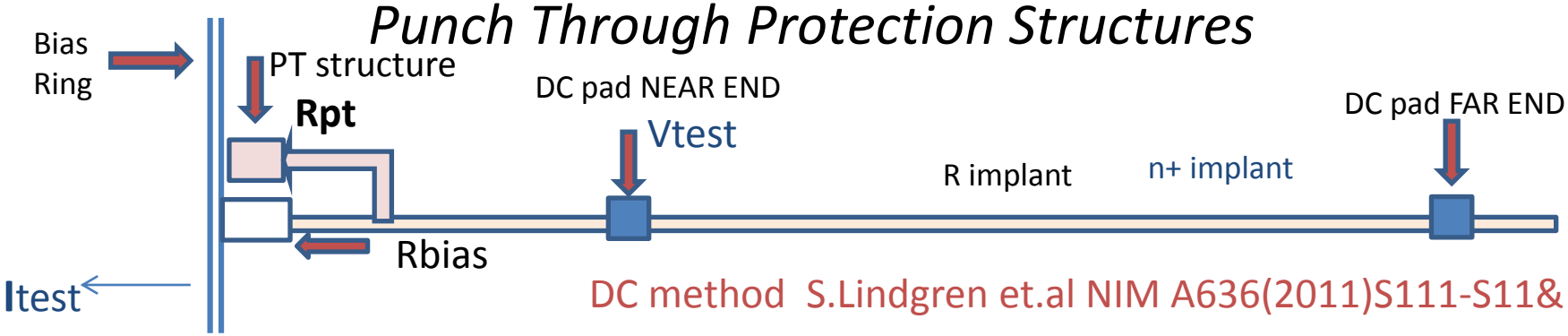
Punch Through Protection Structures



A protection of AC coupling capacitors against the beam splashes should ensure special structures, BZ4A,B,C on the HPK ATLAS07 mini-sensors.
A beam splash generates a spike of voltage across the AC coupling insulator. When the distance between the bias rail and the n-strip implants is appropriate, this voltage between the bias rail and the n-strip implant ends can be limited. This distance is 20 µ and is used in all special structures BZ4A,B,C and sensor BZ4D

Sensor BZ4D has no special structure and it is used for comparison with structures BZ4A, B and C.

Punch Through Protection Structures

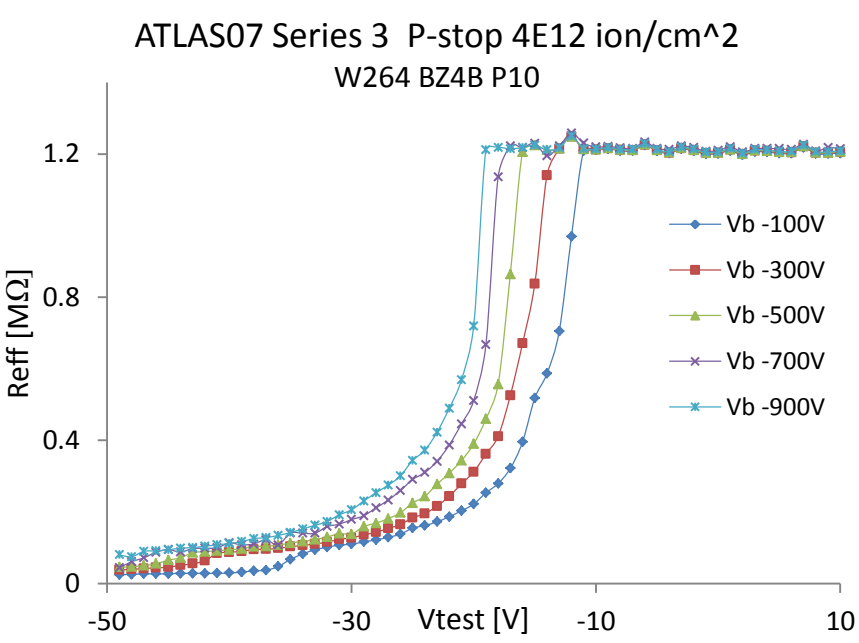


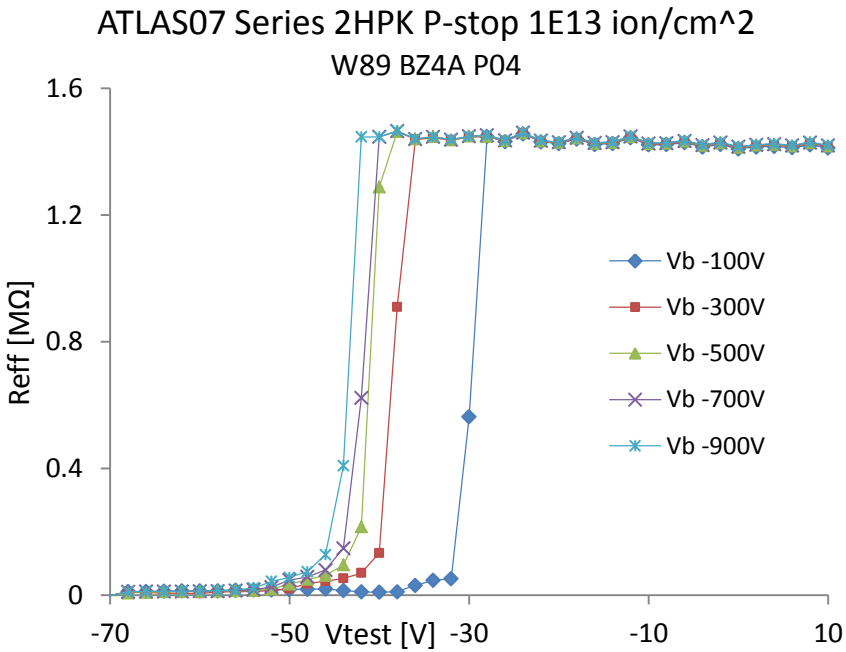
DC method S.Lindgren et.al NIM A636(2011)S111-S11&

Reff=dVtest/dItest, where Vtest is an applied voltage (Uappl) to DC pad and Itest is an current between DC pad and the bias ring**. Rpt** is supposed to be parallel to **Rbias: 1/Reff=1/Rbias+1/Rpt.**

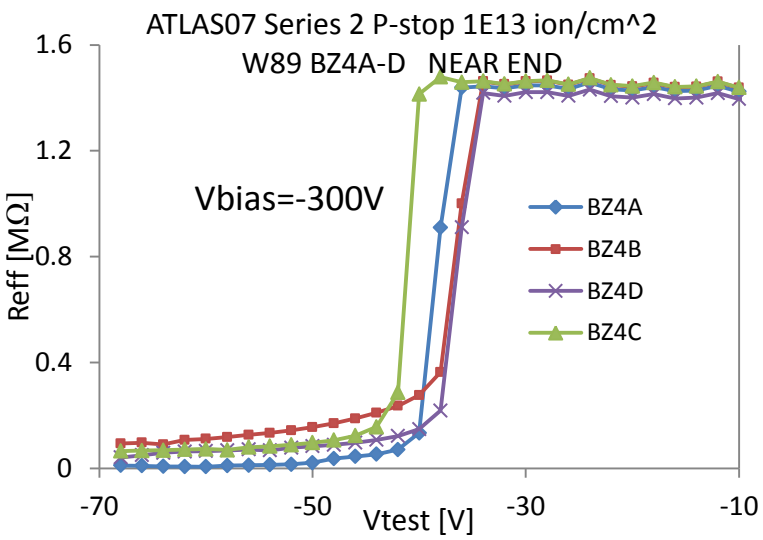
Punch-Through Voltage is the Test Voltage for **Rbias=Rpt**, i.e. for **Reff=Rbias/2.**

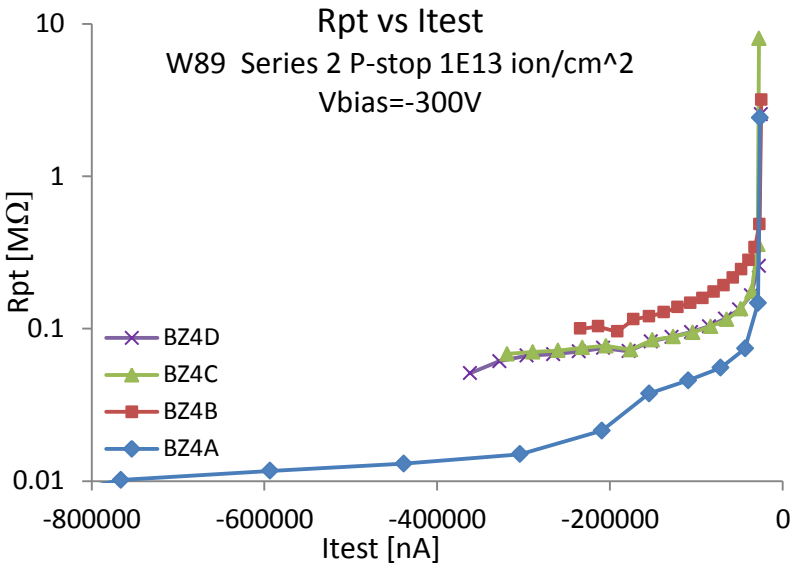
PT voltage is evaluated at bias voltages 100, 300, 500, 700 and 900V for PT structures Z4A-D

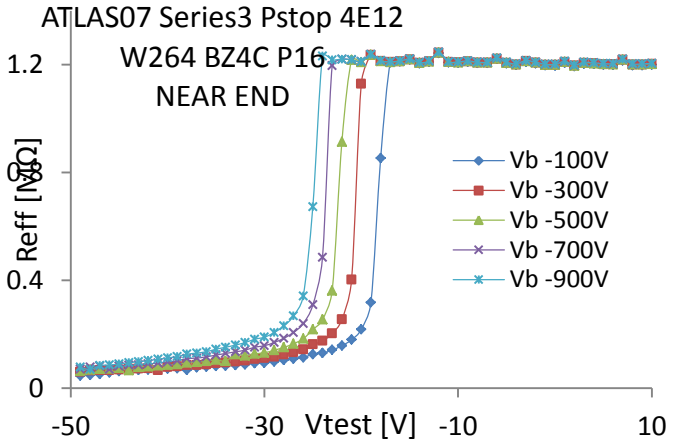


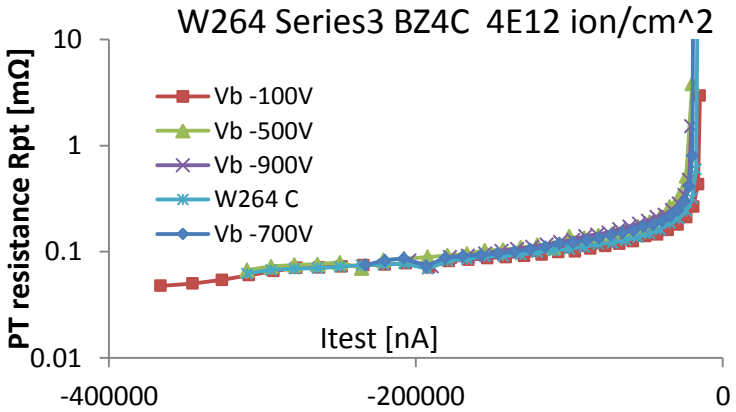


Punch Through Protection Structures - Rpt





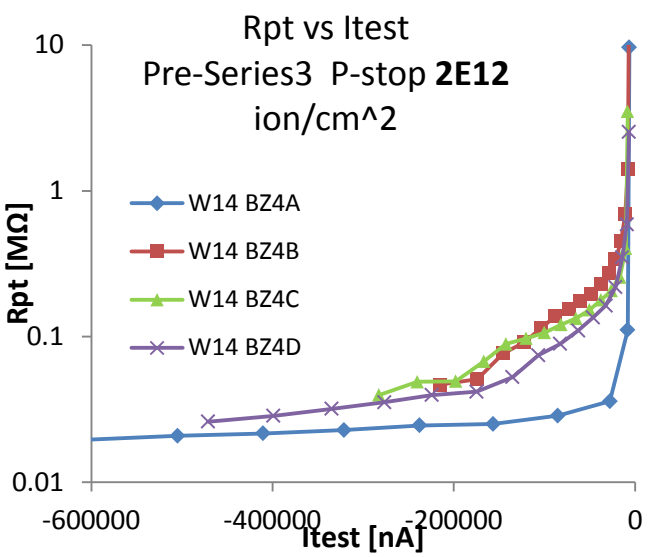


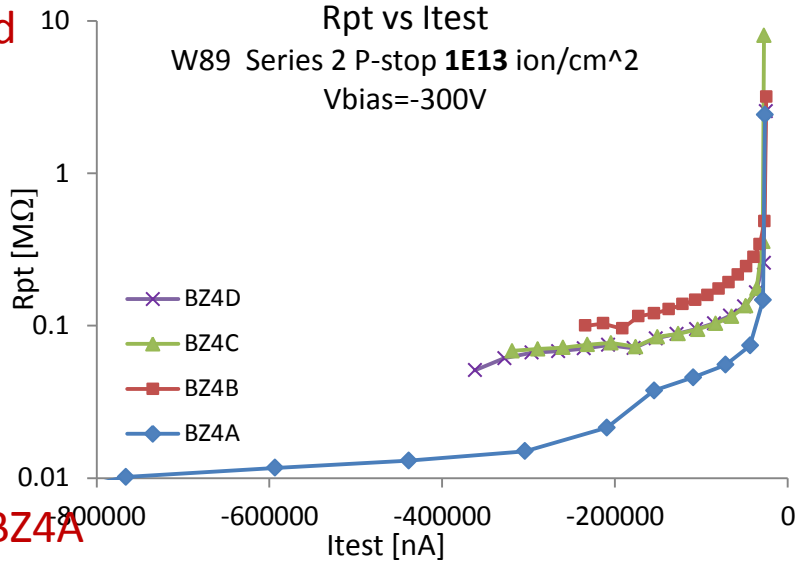


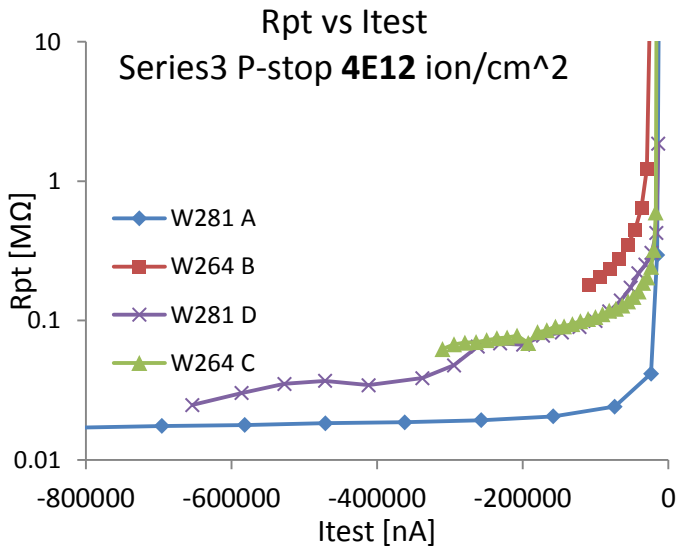
Calculated Rpt's as a function of Itest for the same structure, BZ4C, and different bias voltages are the same contrary to Rpt's evaluated for different PT structures but for the same bias voltage which show different dependences. Structure BZ4A is very effective at high current.

Punch Through Protection Structures - Rpt

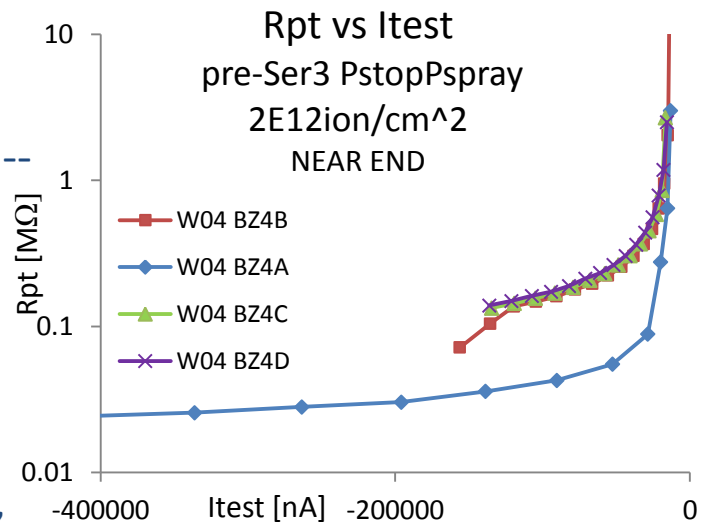
Non-irradiated





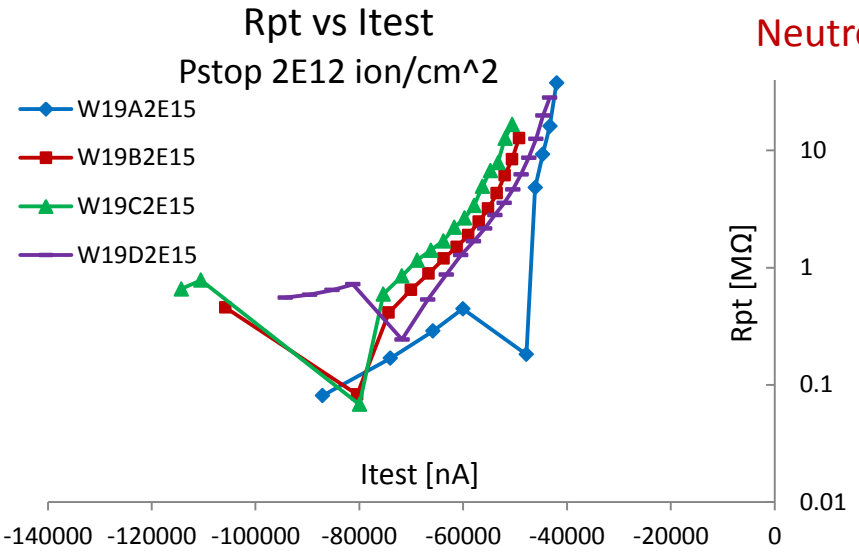


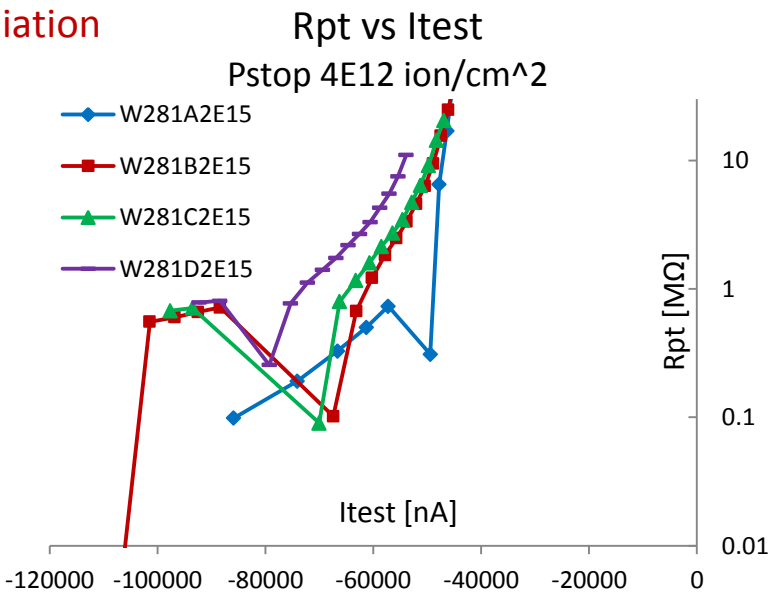
Structure BZ4A seems to be the most effective short at low currents : -8µA, --18µA and -26µA for all P-stop ion concentrations: 2E12, 4E12 and 1E13 ion/cm^2 , respectively.

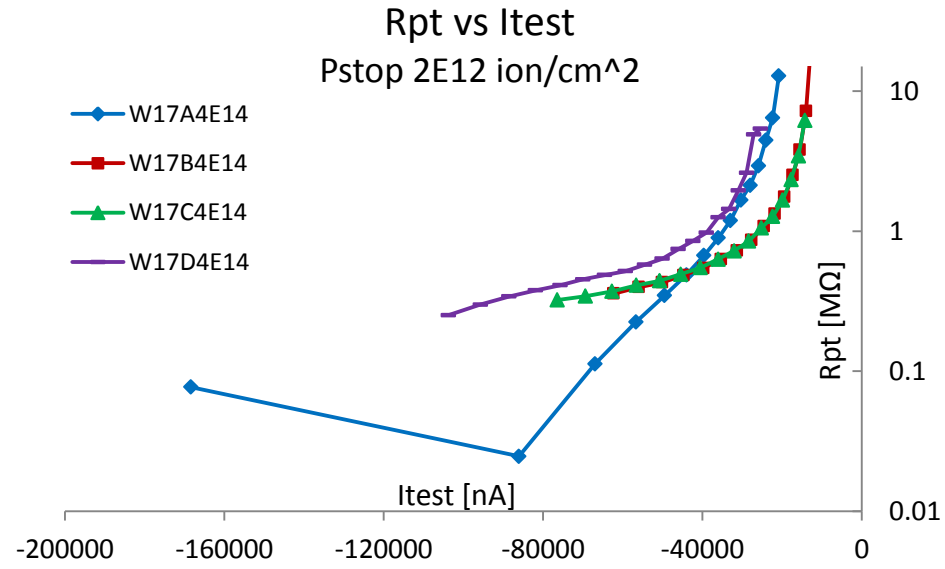


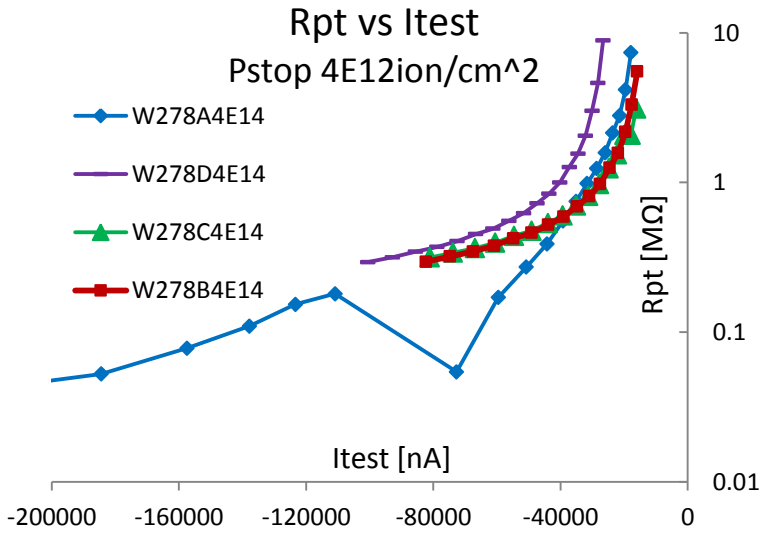
Punch Through Protection Structures - Rpt

Neutron irradiation

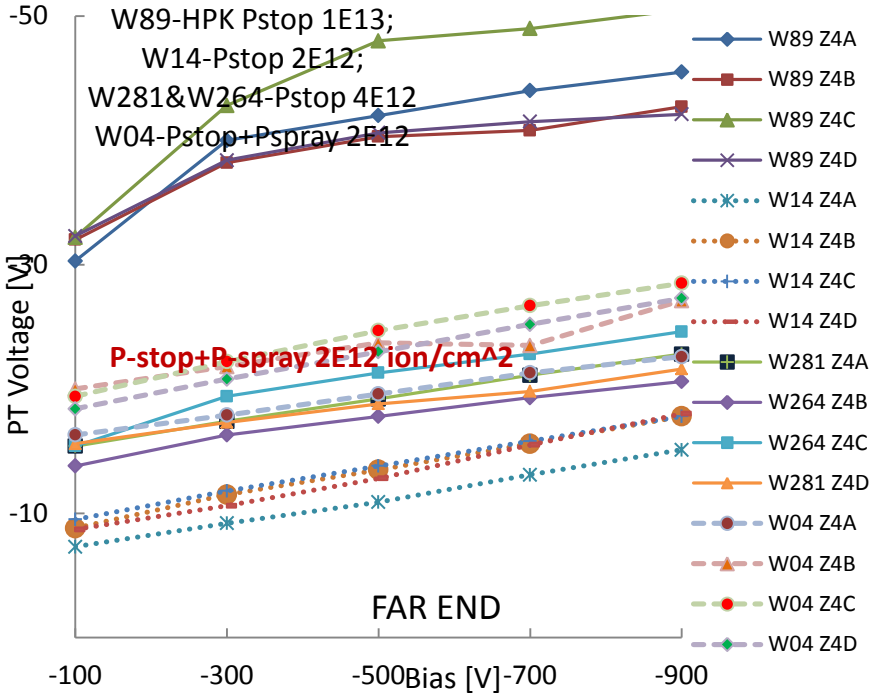


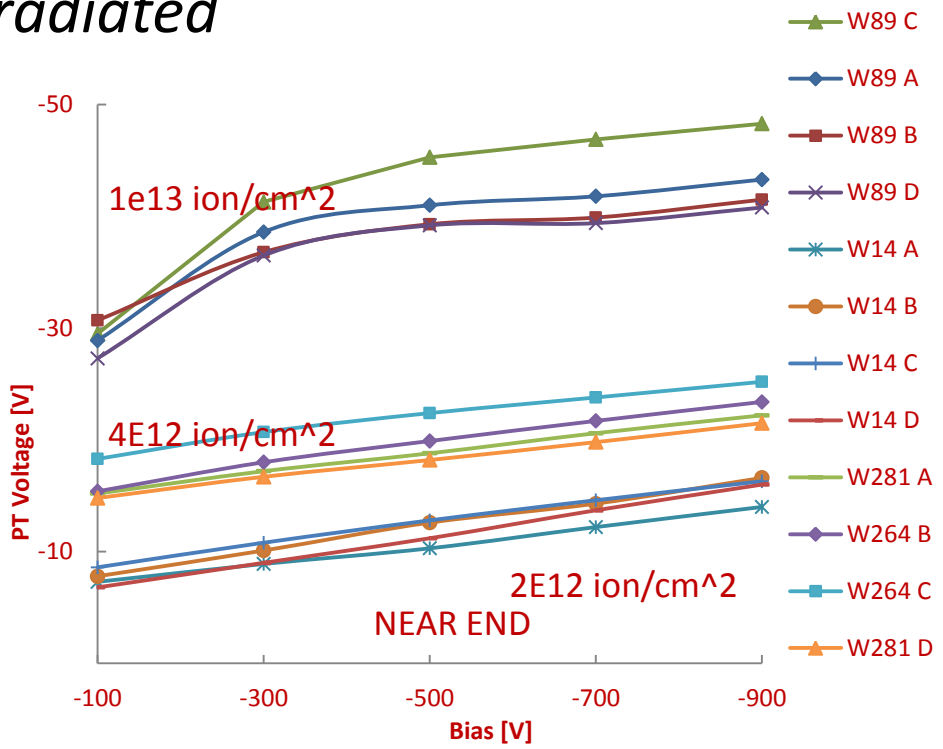






Punch Through Voltage non-irradiated





-Punch through voltage dominantly depends on P-stop ion concentration for all punch through structures.

-PT voltage for P-stop+P-spray isolation is considerable higher than for P-stop isolation at same p-dose 2E12 ion/cm^2

-Differences among PT voltages for each structure BZ4A-D are small for all concentrations, several volts only

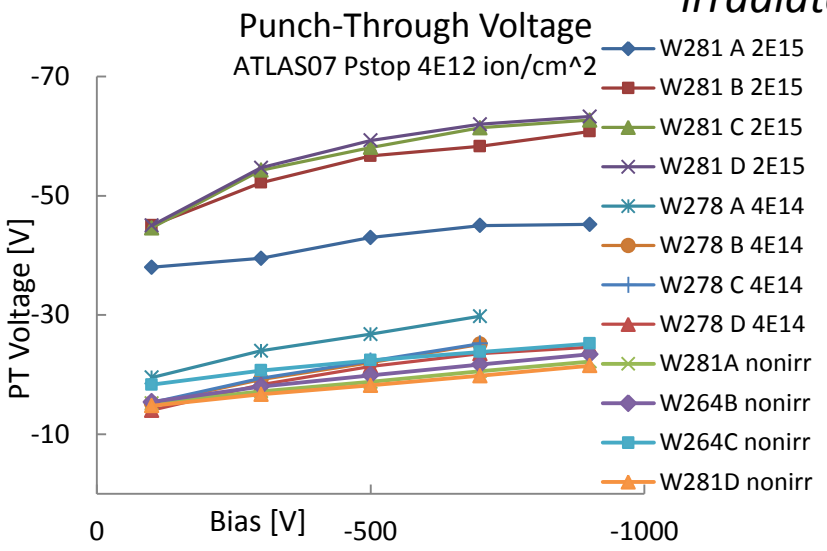
-PT voltage increases with applied bias, for concentration 1E13 ion/cm^2 is observed nearly saturation for Vb>500V.

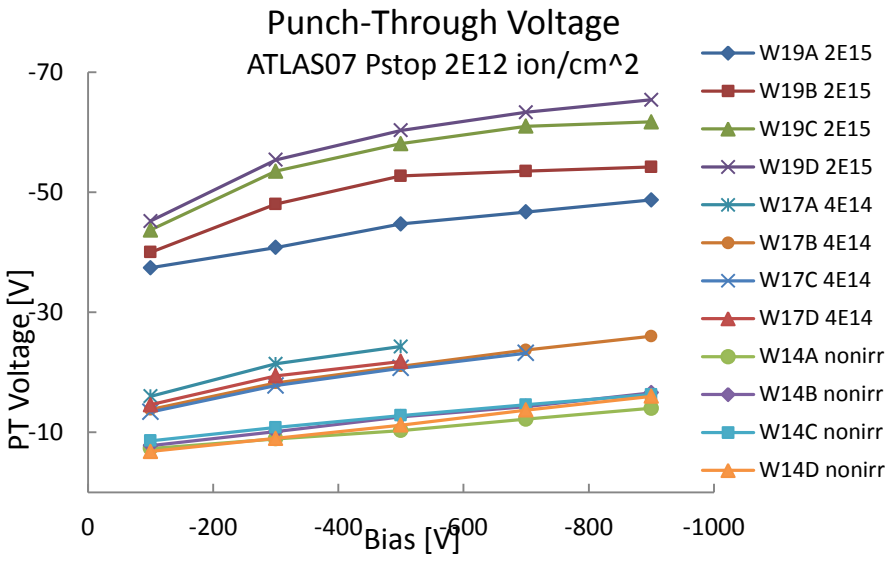
-PT voltages are smaller than 50V, i.e. they are significantly below the hold-off voltages of the coupling capacitor which are typically tested to 100V.

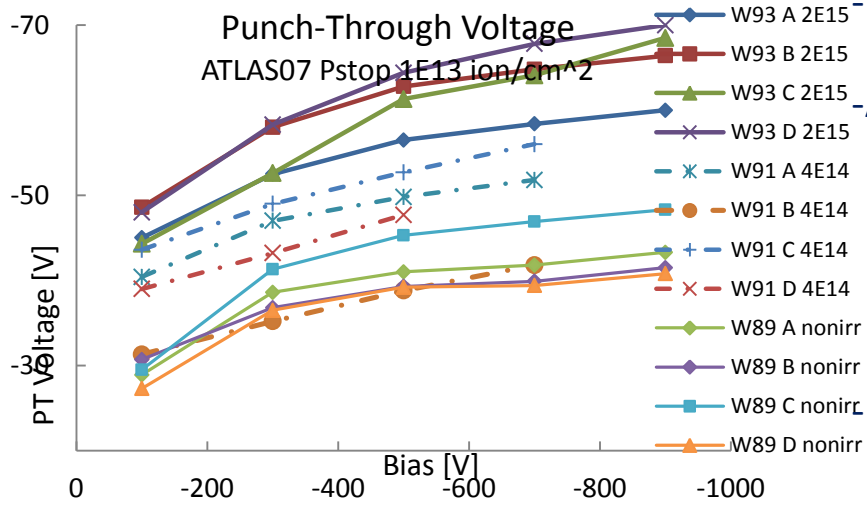
There is practically no difference (1-2 V only) of PT voltages measured on FAR END and NEAR END.

Punch Through Voltage

irradiated





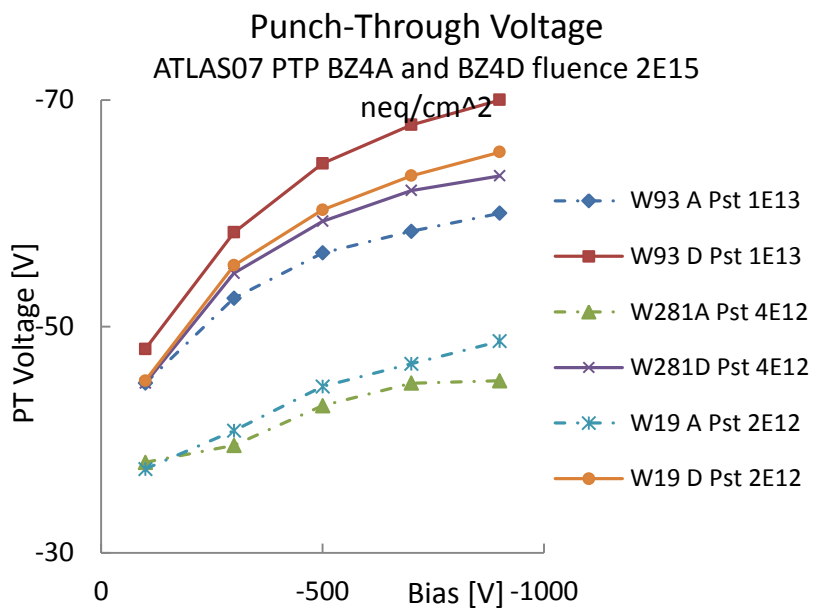


-At fluency about 4E14 neq/cm^2 and lower, an efficiency of special structures diminishes

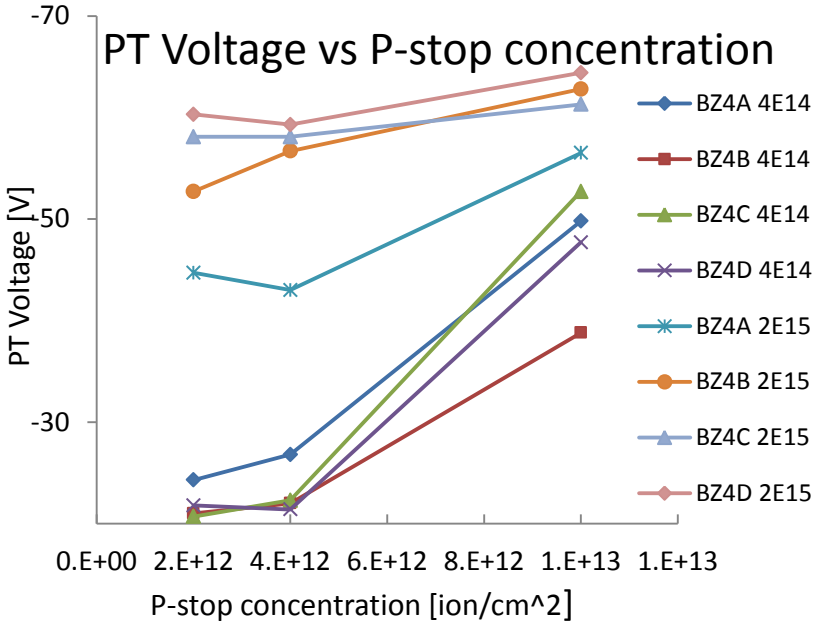
-PT voltage increases with fluency and ion concentration

-At high fluency 2E15 neq/cm^2 and all tested ion concentrations the superiority belongs to the structure BZ4A with suppressed PTV with respect to structures BZ4B and BZ4C. BZ4D without any special structure reaches highest PT voltages.

-PT voltages for P-stop ion concentration 1E13 ion/cm^2 exceeds safety level of 50V even for BZ4A and fluency 4E14 neq/cm^2 and therefore concentration 1E13 ion/cm^2 is not suited to the protection against beam splashes



A comparison of PT voltages measured on special structure BZ4A with “no structure” BZ4D for various ion concentration at fluency 2E15 neq/cm^2.



PT voltage dependence on the P-stop ion concentration has shown a small difference between 2E12 and 4E12 ion/cm^2 and also for some structures (A and D) the PTV has minimum at 4E12ion/cm^2.

Since one can expect for higher p-stop dose the higher inter-strip resistance, the 4E12 ion concentration is preferable. (Rint will be measured soon).

Summary

Non-irradiated sensors ATLAS07 with p-stop isolation and with different ion concentrations were successfully operating up to 1000V, no onset of micro-discharges was observed.
On other side, irradiated sensors to fluency 4E14 neq/cm^2 behave differently and an onset of breakdowns is observed above already Vbias ~800V. For higher fluency, 2E15 neq/cm^2, no micro-discharges were found.

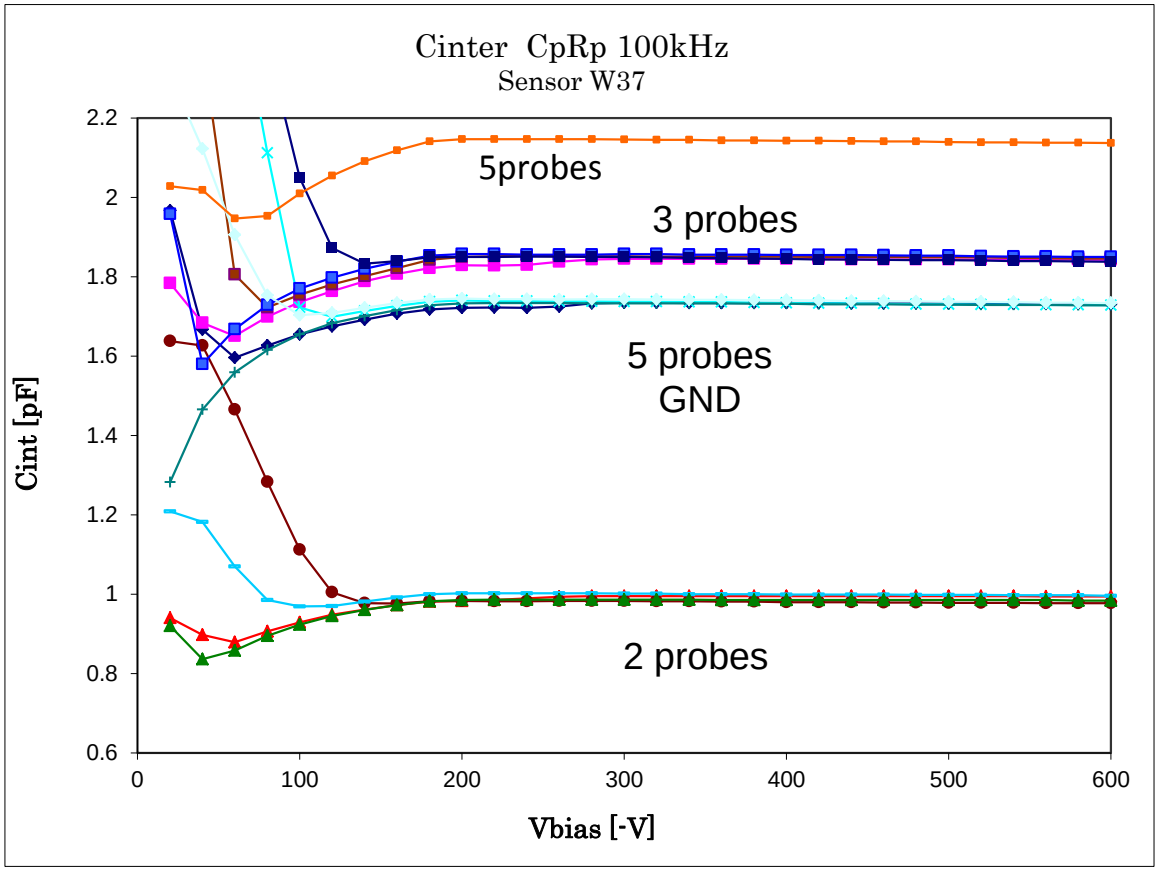
Punch through voltage dominantly depends on the P-stop ion concentration for all punch through structures, irradiated and non-irradiated samples and **PTV increases with fluency, p-dose and applied bias.**

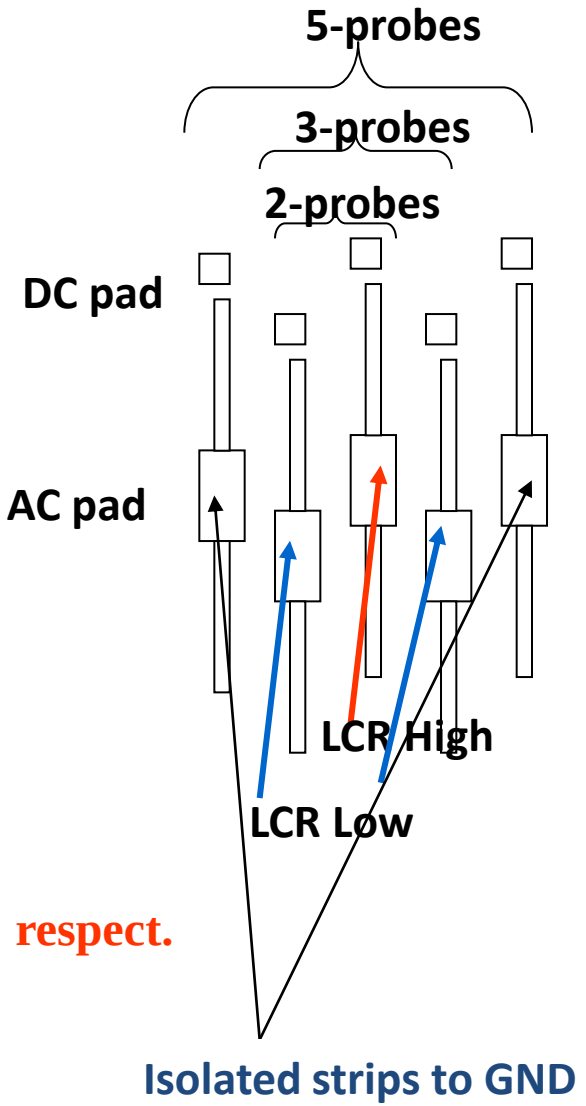
PT voltages for P-stop ion concentration 1E13 ion/cm^2 exceeds safety level of 50V even for BZ4A and fluency 4E14 neq/cm^2 and therefore **concentration 1E13 ion/cm^2 is not suited** to the protection against beam splashes

At high fluency 2E15 neq/cm^2 and all tested ion concentrations **the superiority belongs to the structure BZ4A with suppressed PTV** with respect to structures BZ4B and BZ4C. The BZ4D without any special structure reaches highest PT voltages.

Protection structure BZ4A made with P-stop concentration of 4E12ion/cm^2 ensures that PTV will be smaller than 50V, (i.e. significantly below the hold-off voltage of the coupling capacitor -typically ~100V), for fluency up to 2E15neq/cm^2.

Interstrip Capacitance - Method of measurement





Cint(5-pr)/Cint(3-pr)=0.939 and 0.913 for 100kHz and 1MHz, respect.
Cint(2-pr)/Cint(5-pr)=0.57

J.Bohm, M.Mikestikova et.al, NIM A636 (2011)S104-S110

Interstrip Capacitance

non-irradiated

Interstrip capacitance in this table was evaluated for Vbias=Vfd+10V

Wafer	W14	W264	W78	W89	W04
Series	Pre-Ser3	Series3	Series2 STD	Series2 HPK	Pstop Pspray
Ion/cm^2	2E12	4E12	1E13	1E13	2E12
Vfd [V]	-183	-292	-186	-252	-186
Cint BZ4A pF	0.69	0.66	0.68	0.69	0.71
Cint BZ4B pF	0.68	0.67	0.68	0.68	0.71
Cint BZ4C pF	0.68	0.67	0.68	0.68	0.71
Cint BZ4D pF	0.71	0.66	0.68	0.69	0.70

The inter-strip capacitance, Cint, is constant for bias voltages higher than respective full depletion voltages and Cint does not depend in this region on an ion concentration and the punch through protection structures within ±20fF.

Possible time dependence of Cint and an influence of relative humidity is in progress.