Punch through protection and p-stop ion concentration in HPK strip mini-sensors

Jan Bohm, Institute of Physics ASCR, Prague

Peter Kodys, Pavel Novotny, 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

Survey

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.
This report is a compilation of measured characteristics before irradiation. The second part of this study, i.e. after irradiation, will be available soon.

-Description of the sample of miniature sensors

-Bulk characteristics, IV and CV measurement

-Punch Through Protection and PT voltages

-Interstrip capacitance

-Interstrip resistance

-Thermal dependence of poly-silicon bias resistors of non-irradiated and of irradiated sensors up to 4E14neq/cm^2.

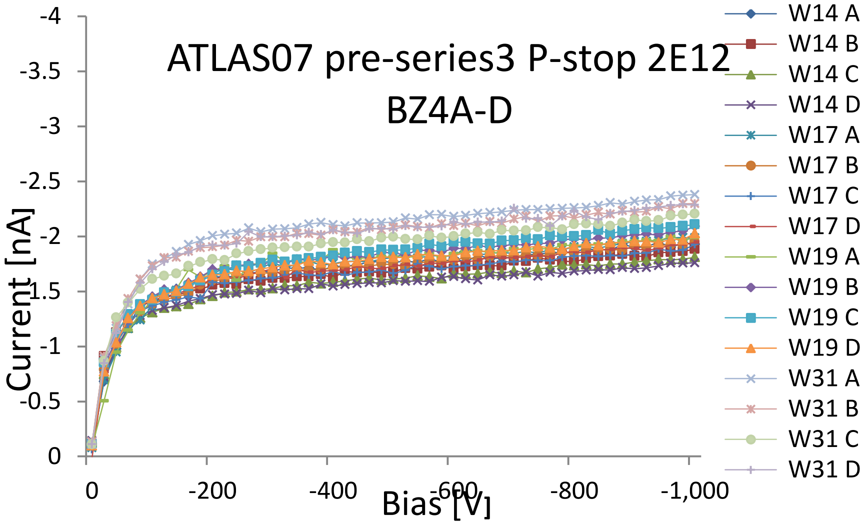
Sample of miniature sensors

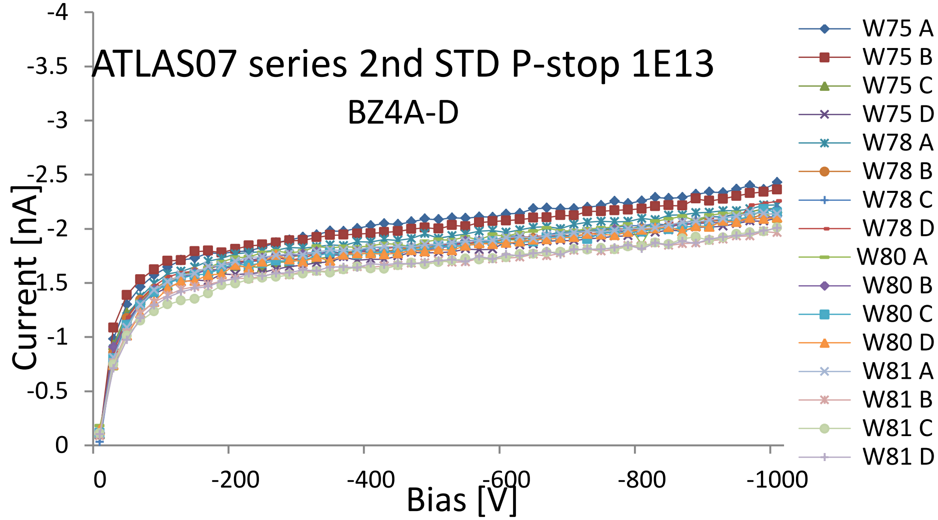
	ATLAS07-pre-series-3rd								ATLAS07-series2								total
	Pspray(2E12)+Pstop(2E12)				Pstop(2E12)				Pstop(1E13) STD				Pstop(1E13) HPK_ex				
	W4	W5	W6	W10	W14	W17	W19	W31	W75	W78	W80	W81	W89	W91	W93	W97	
BZ4A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	16
BZ4B	O	–	O	O	O	O	O	O	O	O	O	O	O	O	O	O	15
BZ4C	O	O	O	O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

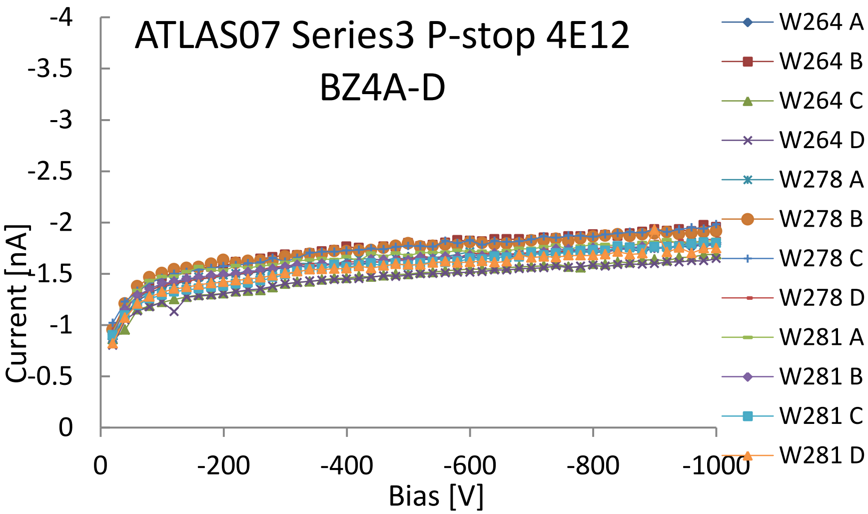
From Hamburg we received next 12 sensors BZ4A-D of Series 3 (wafers 264,278 and 281) with P-stop ion concentration **4E12 ion/cm^2**. **Many thanks to colleagues from DESY**.

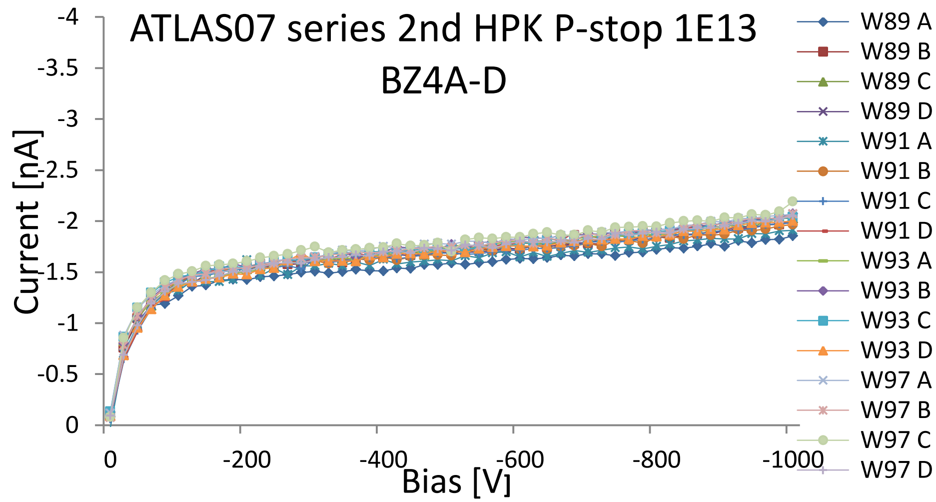
The micro-strip silicon **miniature sensors of 1cmx1cm** (strip length 0.8cm) are ATLAS07 Series fabricated by Hamamatsu Photonics (HPK) using 6” (150 mm) process technology . The baseline is ***p-type*** float zone silicon with crystal orientation <100> and having **thickness of 320 µ**. Sensors are 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)**

IV characteristics



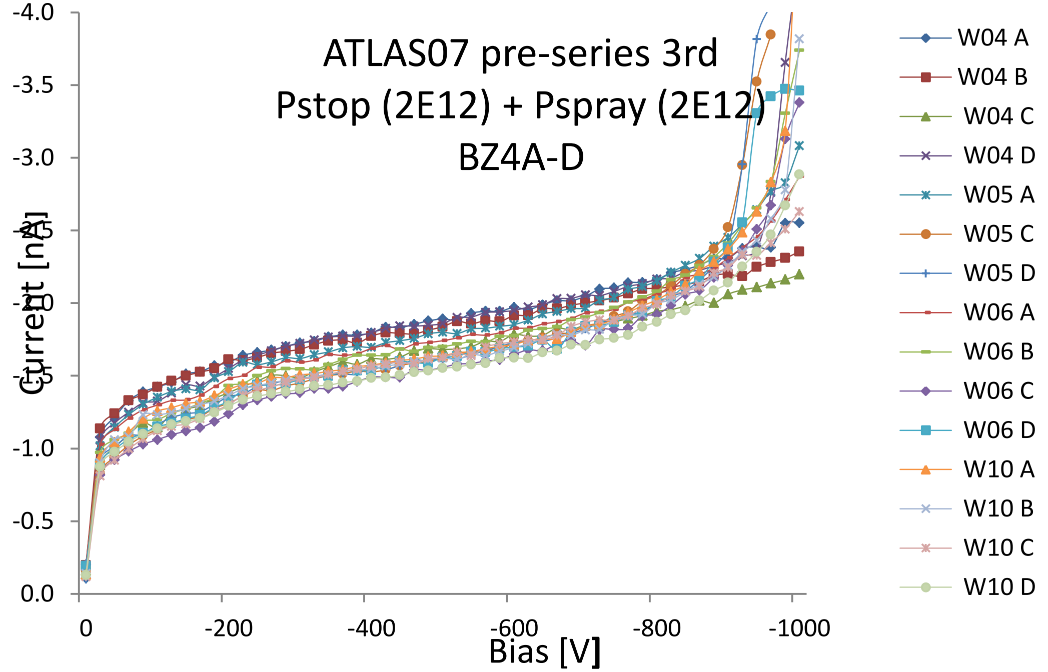






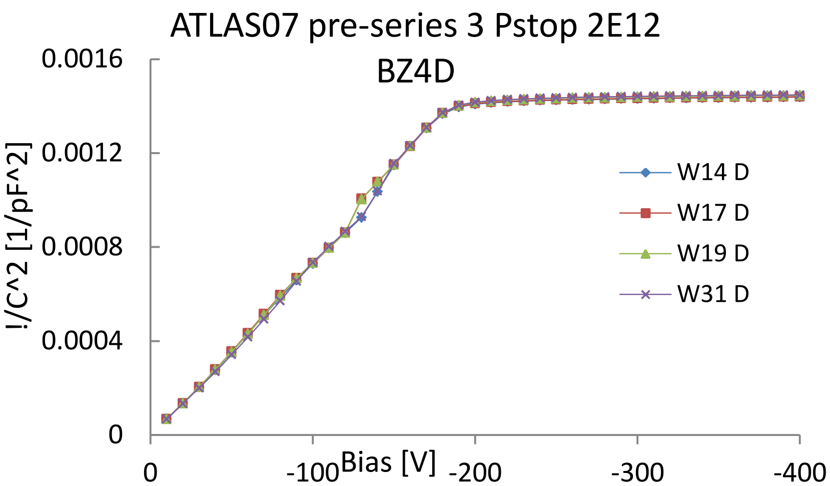
Measured sensors were placed on the table without vacuum chuck jig to avoid possible strong stresses which could cause breakdowns.

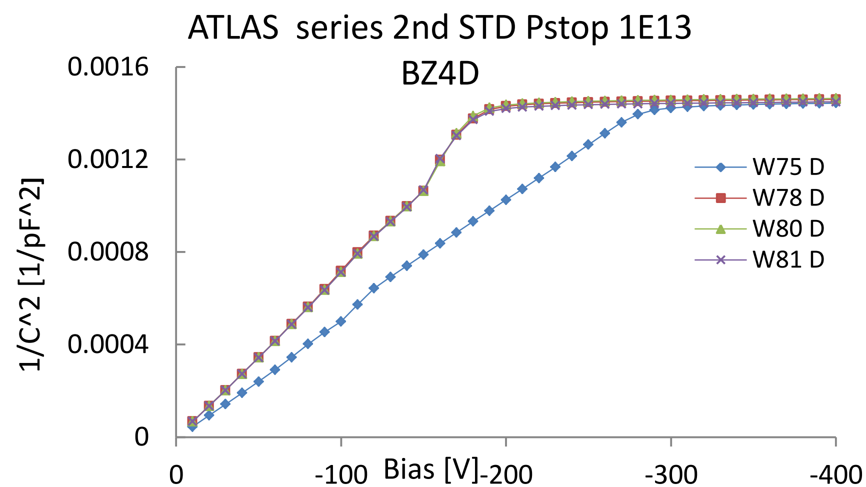
IV characteristics

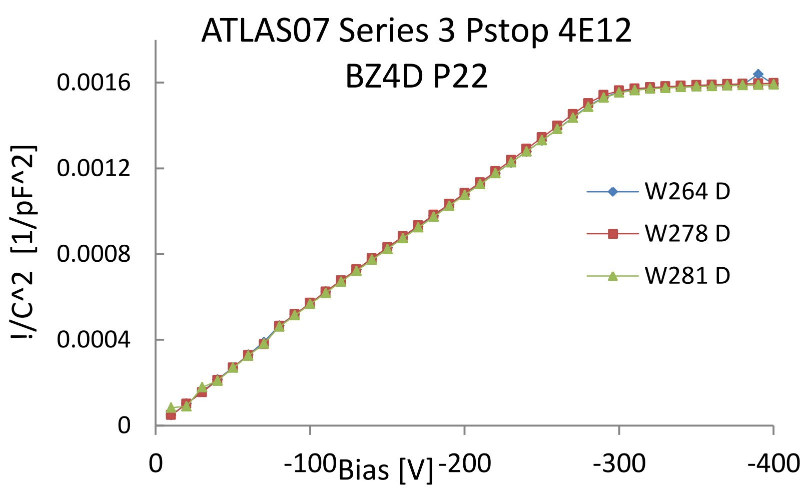


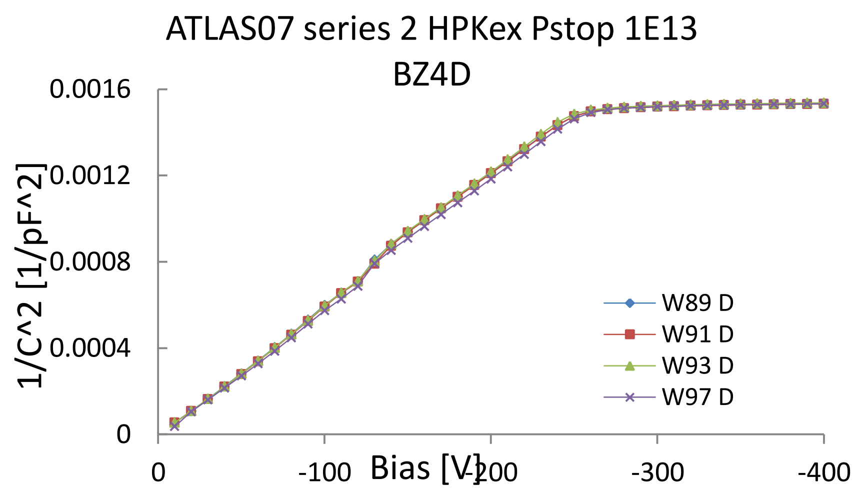
All sensors with p-stop isolation and with different ion concentrations were successfully operating up to 1000V, no onset of micro-discharges was observed.
On other side, sensors with P-stop + P-spray isolation behaves differently and an onset of breakdowns are above already Vbias=900V.

CV Characteristics





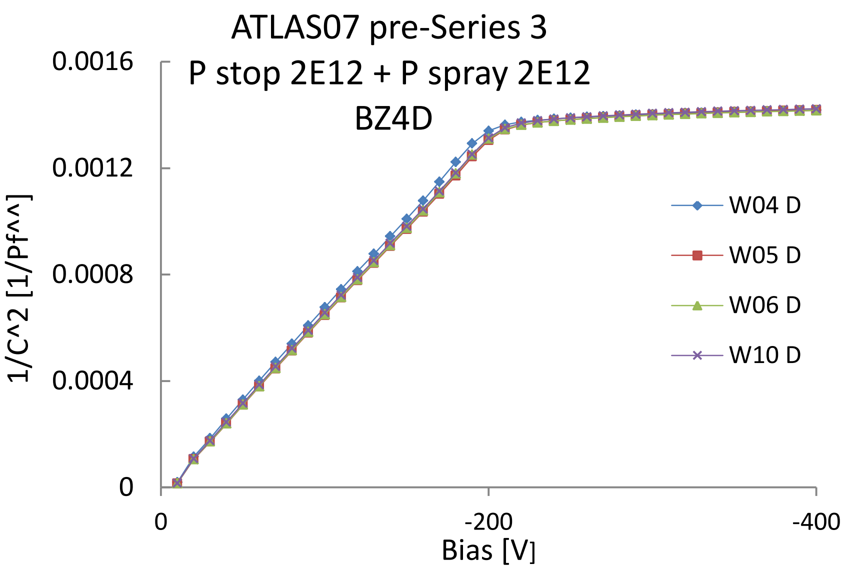


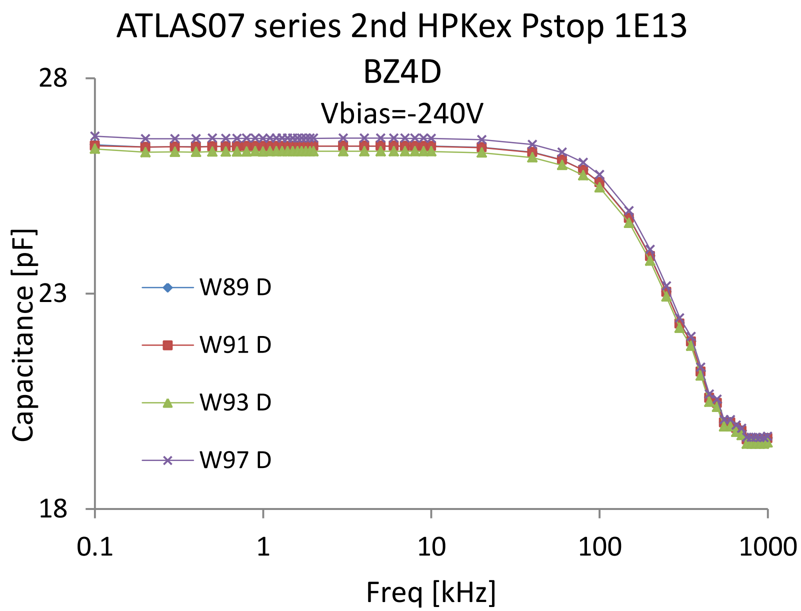


Bulk capacitance has been measured on sensors BZ4D at each wafers.

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

CV Characteristics



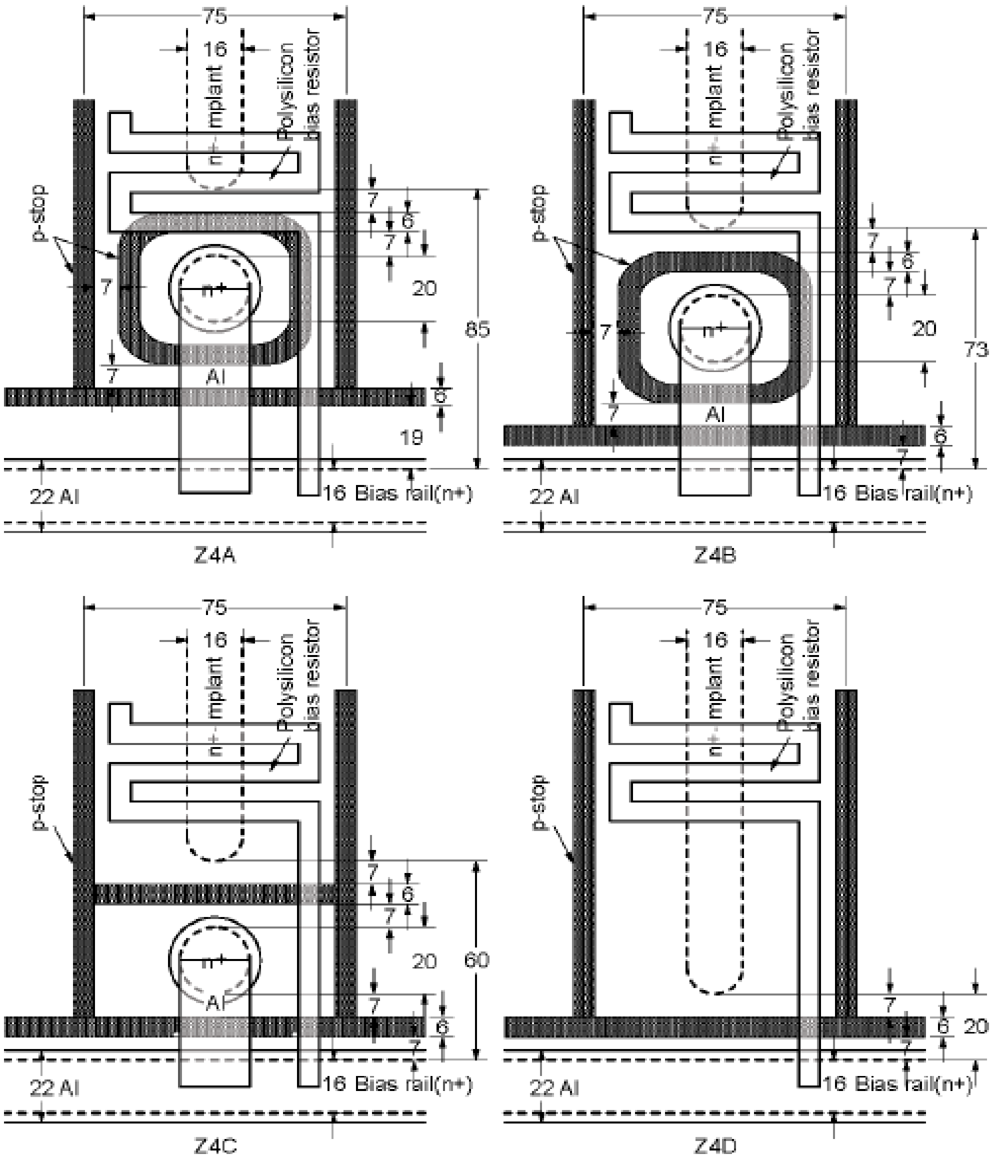


Bulk capacitance does not depend on testing frequency in range of 200Hz up to 20kHz

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

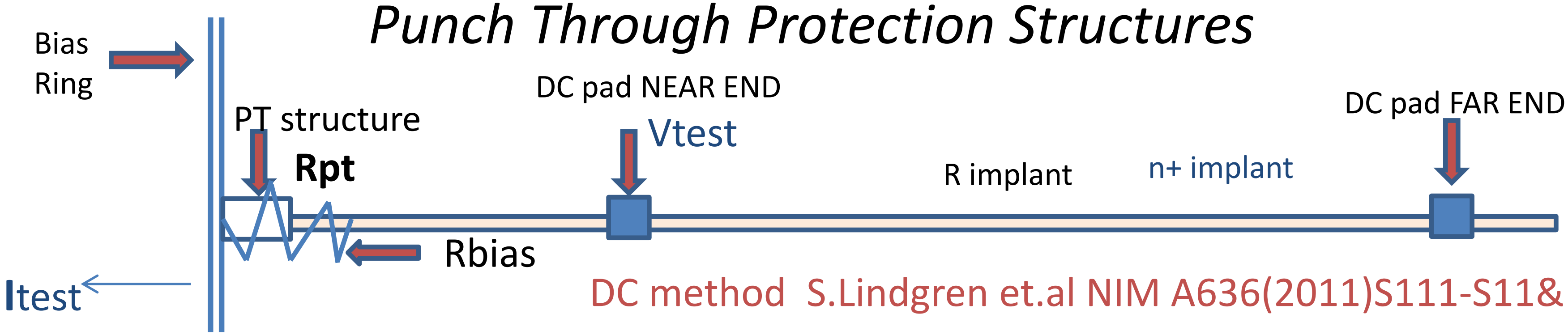
*) Sensors BZ4A-D from wafer W75 of Series 2 STD have higher full depletion voltage, Vfd=286V

Punch Through Protection Structures



A protection of AC coupling capacitors against the beam splashes should ensure special structures, Z4A,B,C and D 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 sensor Z4D without any other structure.

Punch Through Protection Structures

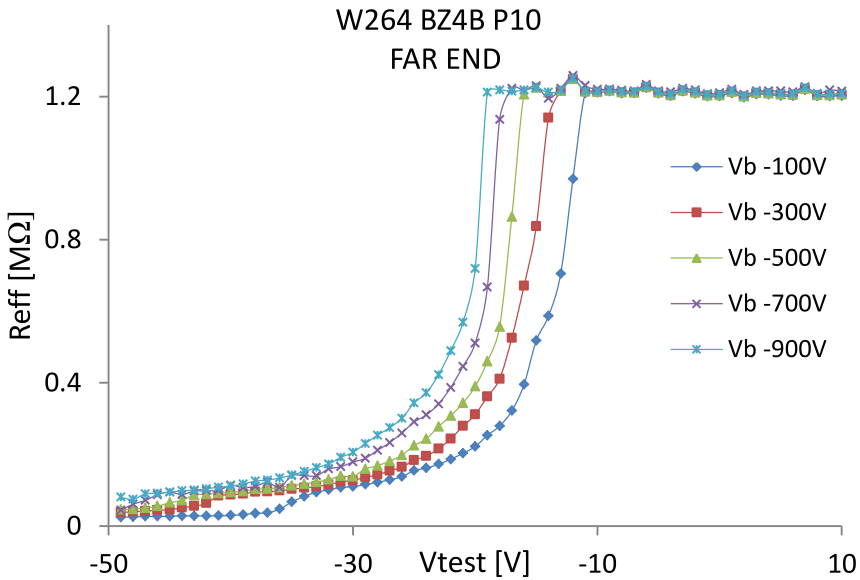


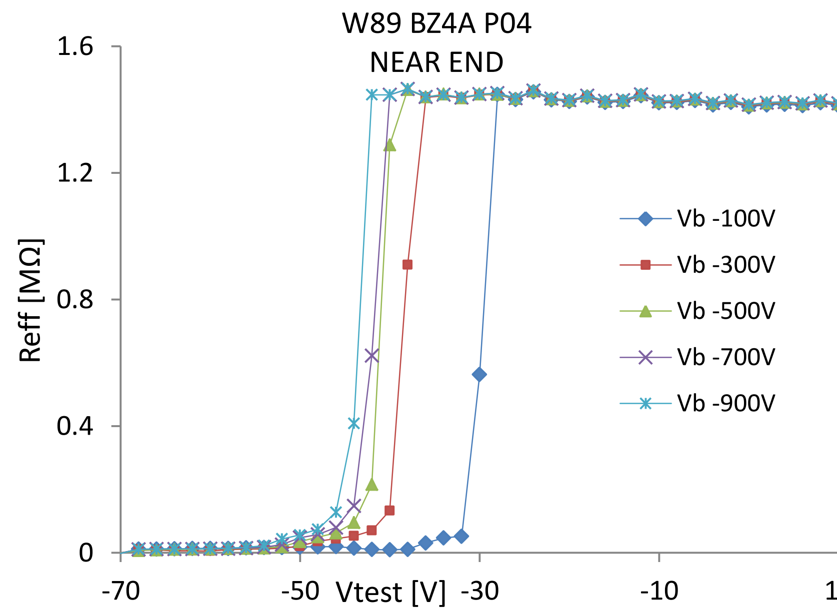
DC method S.Lindgren et.al NIM A636(2011)S111-S11&

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.**

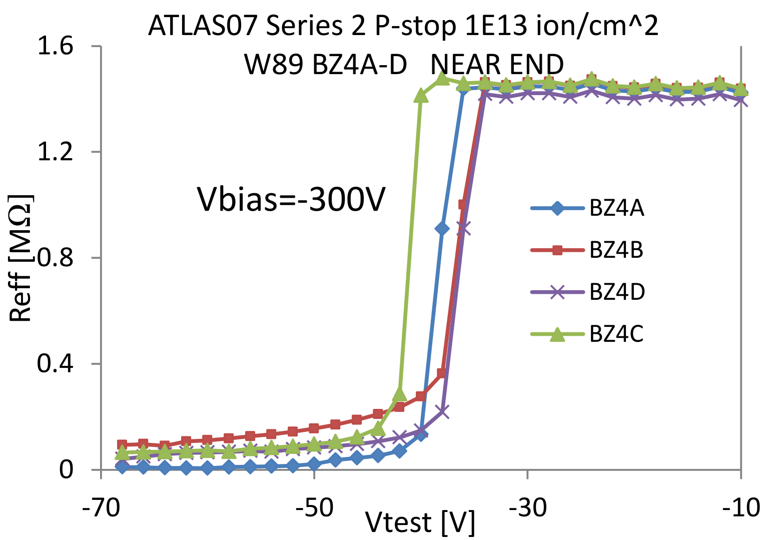
Punch-Through Voltage is the Test Voltage for **Rbias=Rpt**, i.e. for **Reff=Rbias/2.**

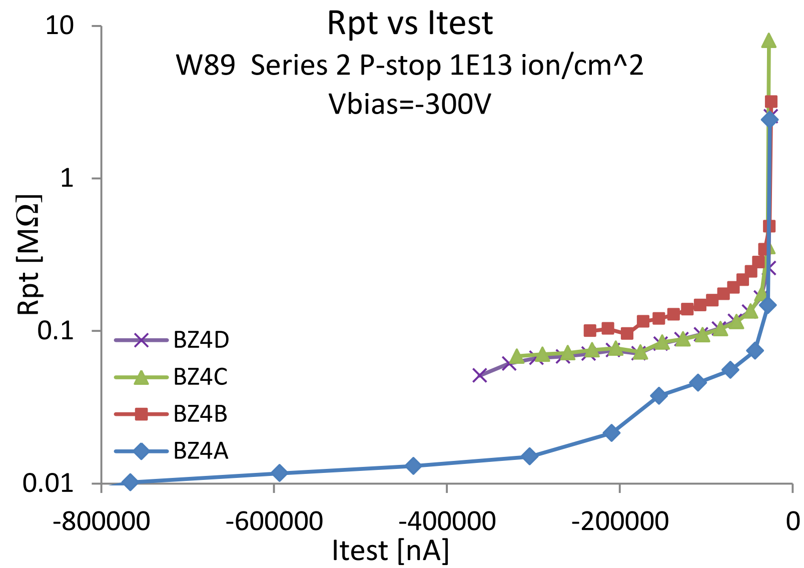
PT voltage is evaluated at bias voltages 100, 300, 500, 700 and 900V for PT structures Z4A-D

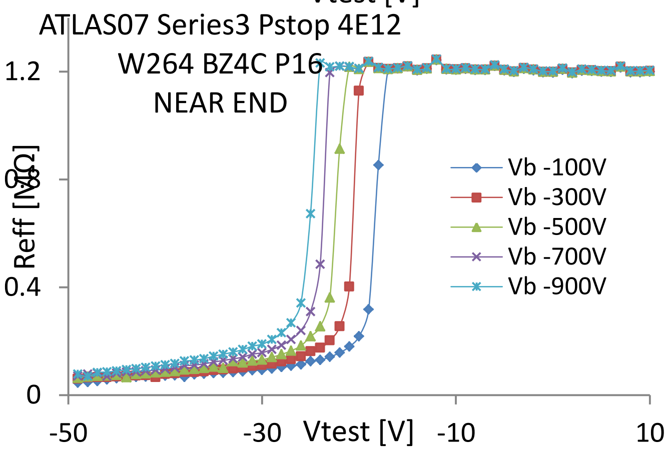


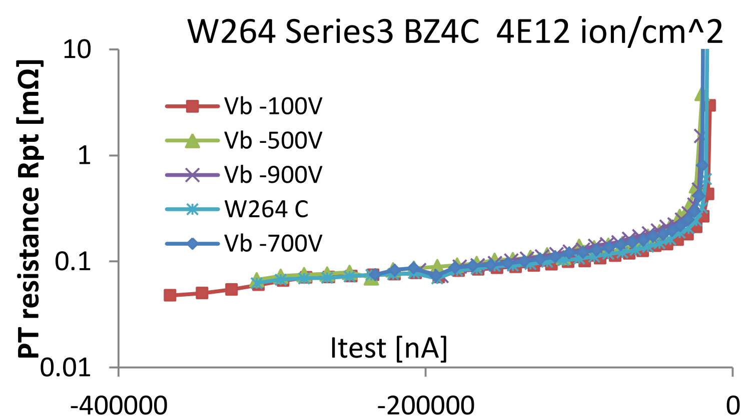


Punch Through Protection Structures - Rpt



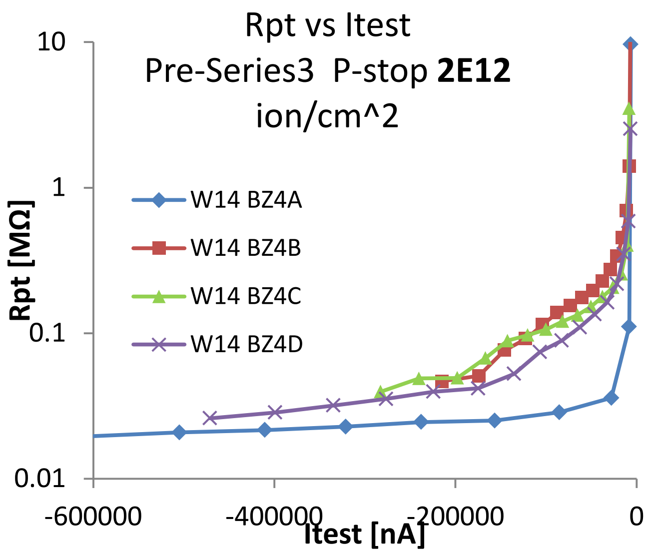


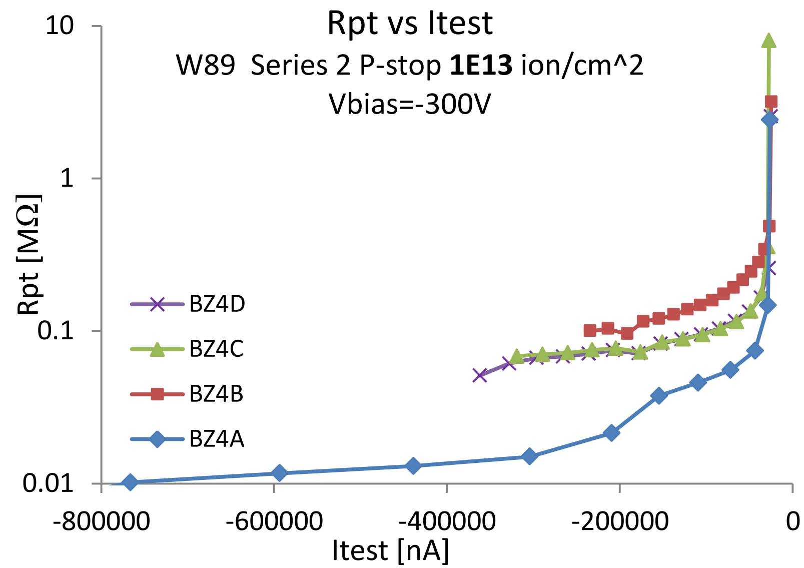


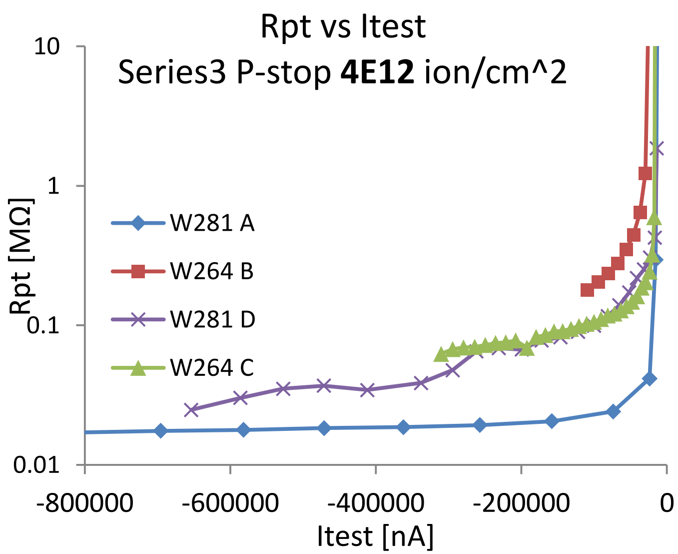


Calculated Rpt‘s as a function of Itest for the same structure, BZ4C, and different bias voltages are the same contrary to Rpt’s evaluated for different PT structures but the same bias voltage which show different dependences. Structure BZ4A is very effective at high current.

Punch Through Protection Structures - Rpt

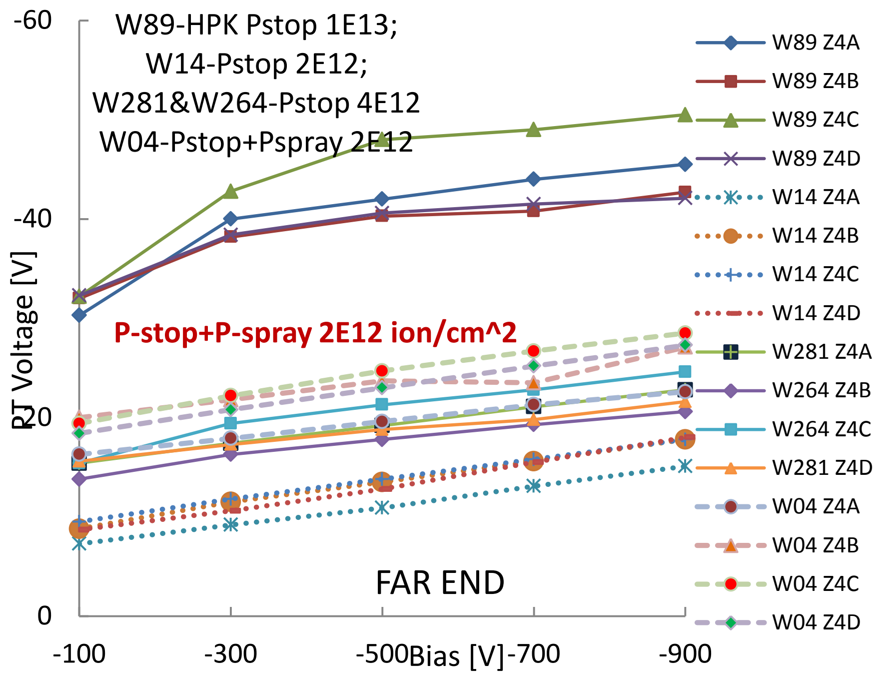


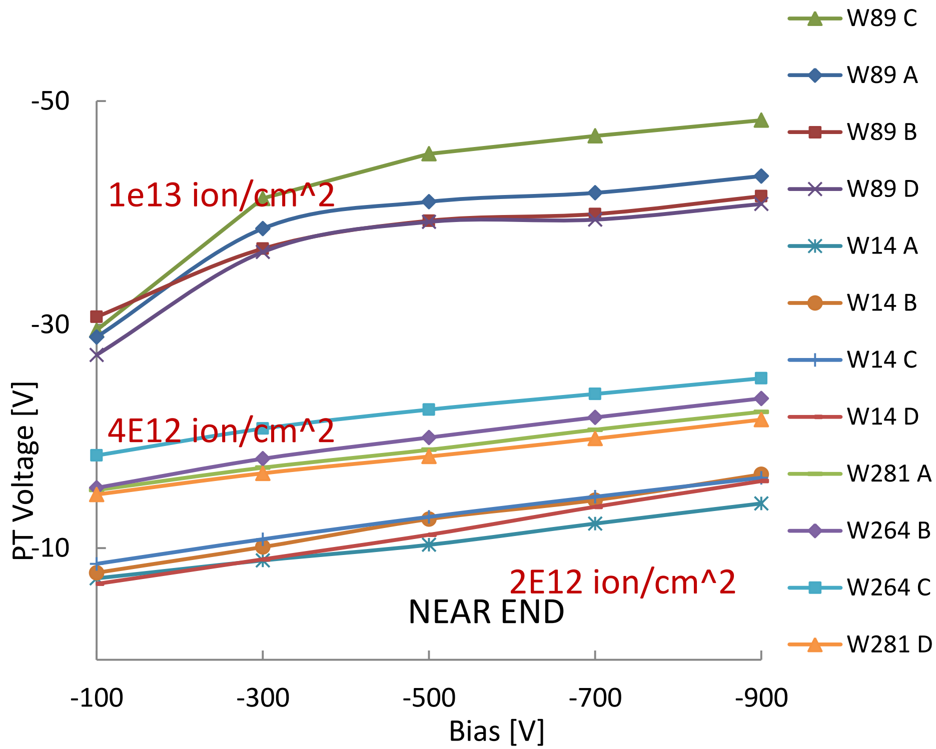




Structure BZ4A it seems to be the most effective short at low currents : -7µA, -18µA and -26µA for P-stop ion concentration 2E12, 4E12 and 1E13 ion/cm^2 , respectively.

Punch Through Voltage





-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

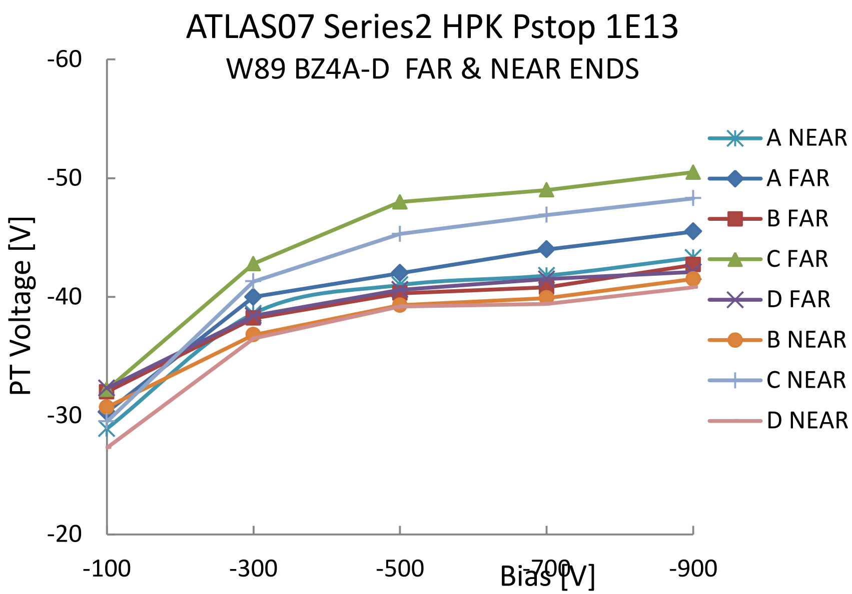
-Differences among PT voltages for each structure BZ4A-D are small for all concentrations, several volts only

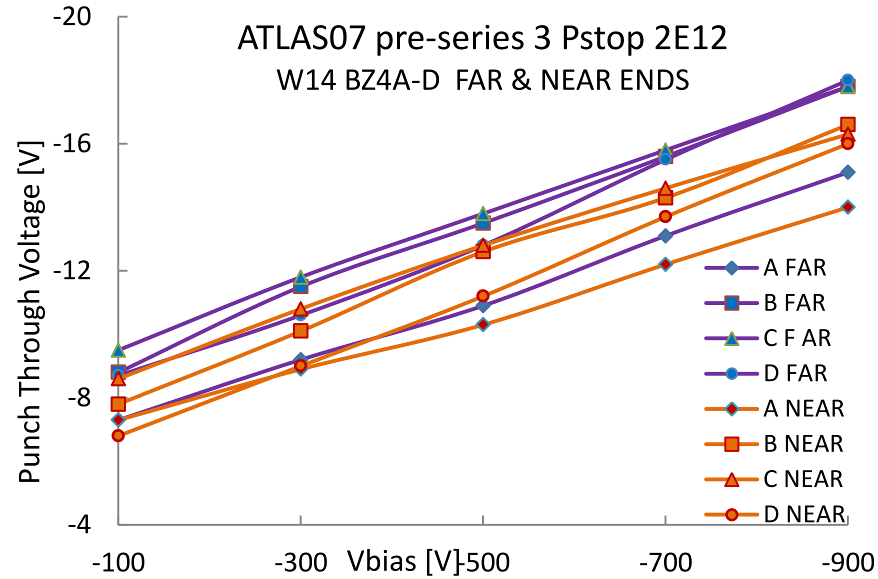
-PT voltage increases with applied bias, for concentration 1E13 ion/cm^2 is observed nearly saturation for Vb>500V.

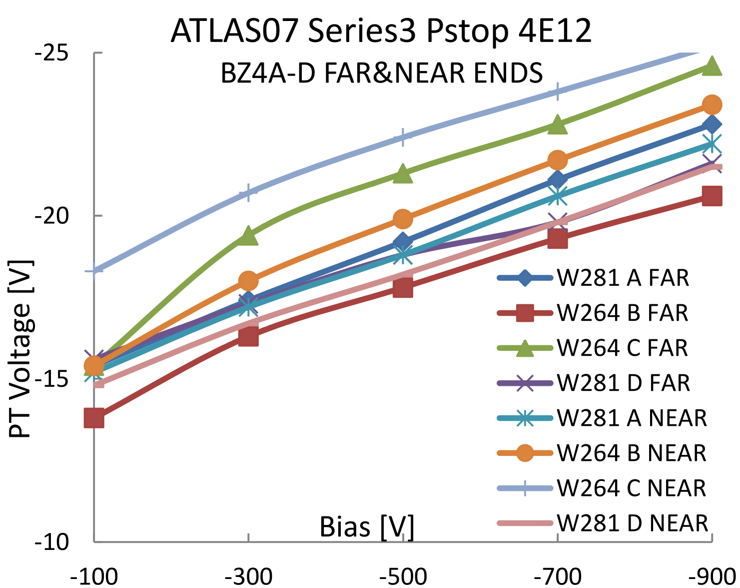
-PT voltages are smaller than 50V, i.e. they are significantly below the hold-off voltage of the coupling capacitor which are typically tested to 100V.

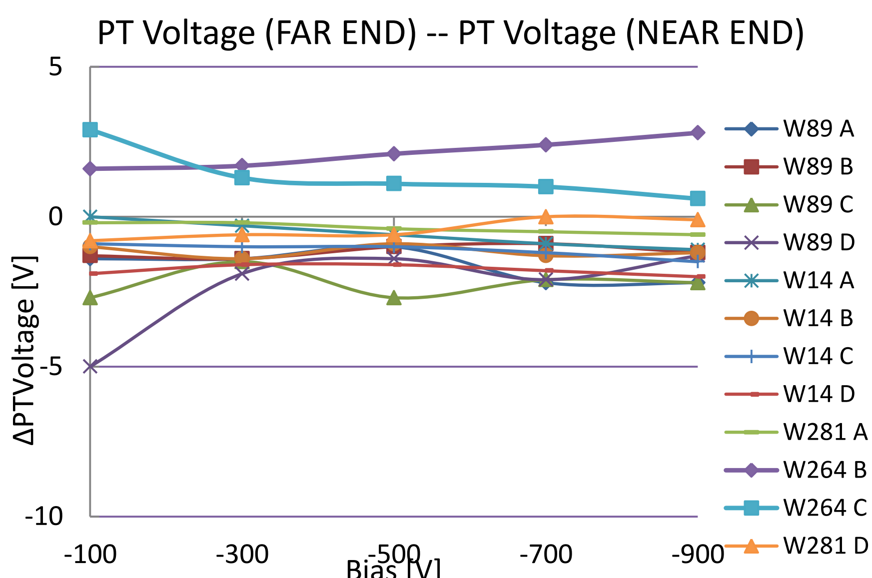
Punch through protection structures will be tested soon by laser technique.

Punch Through Protection Structures

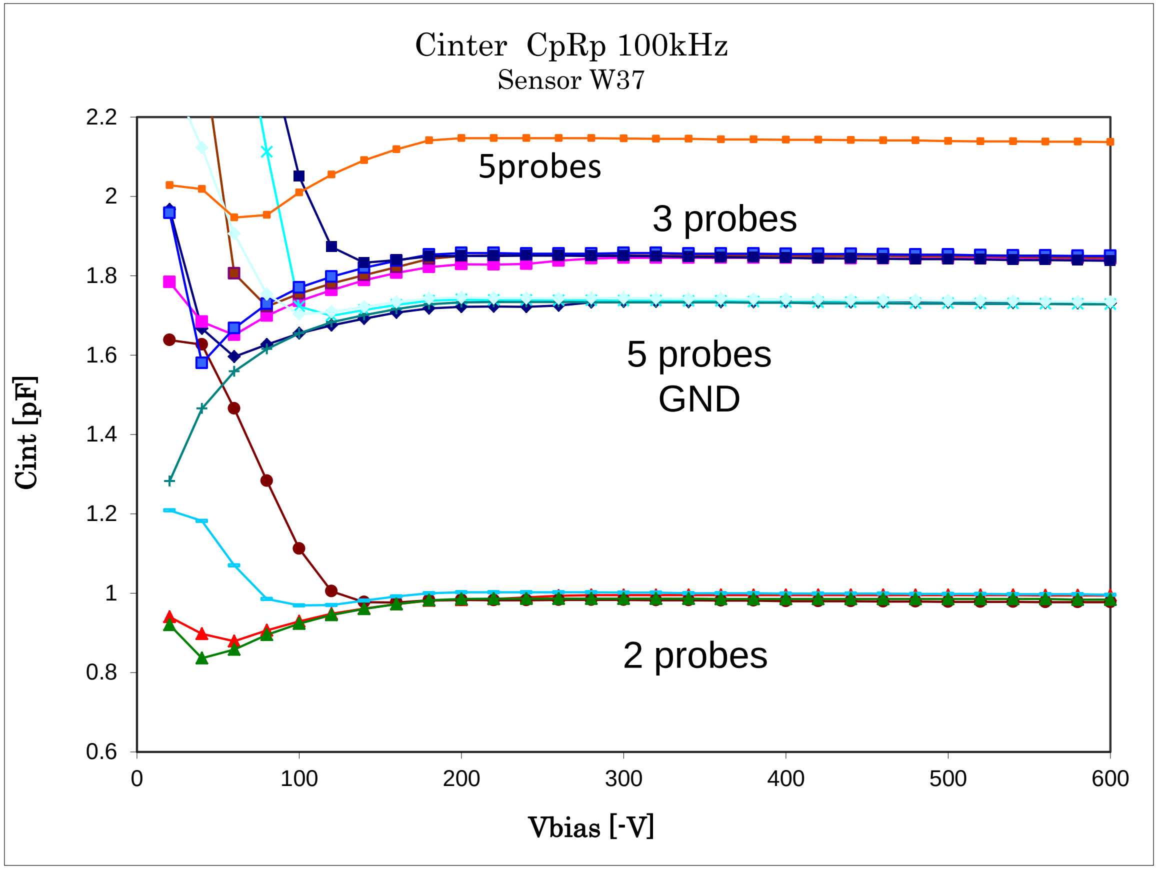


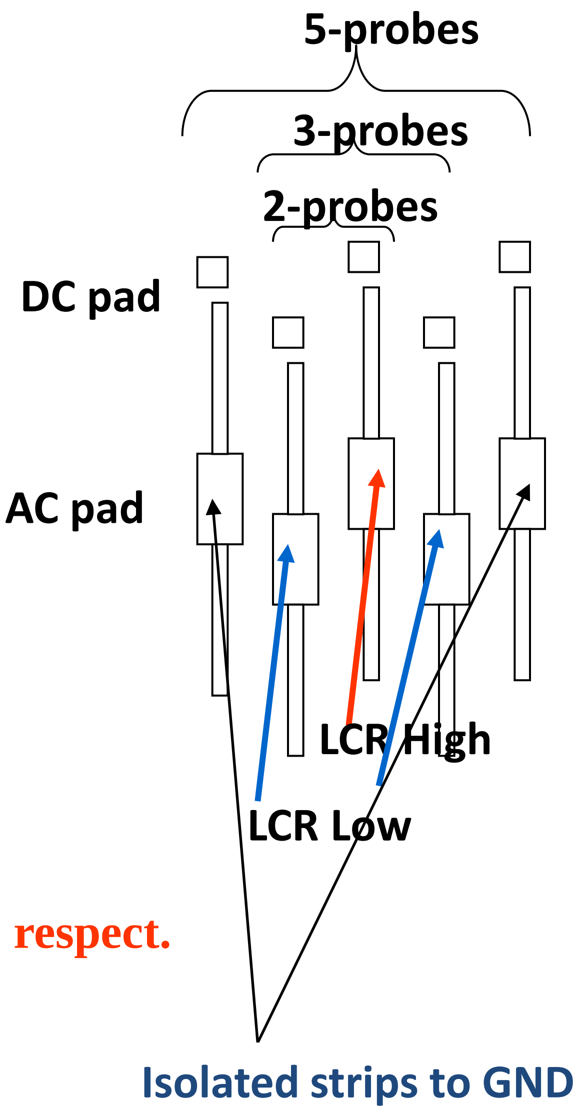






Interstrip Capacitance - Method of measurement

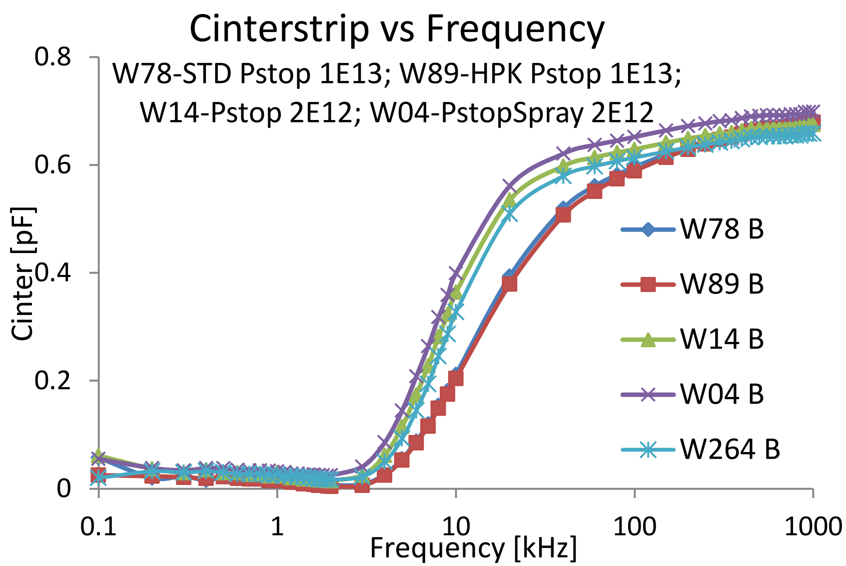


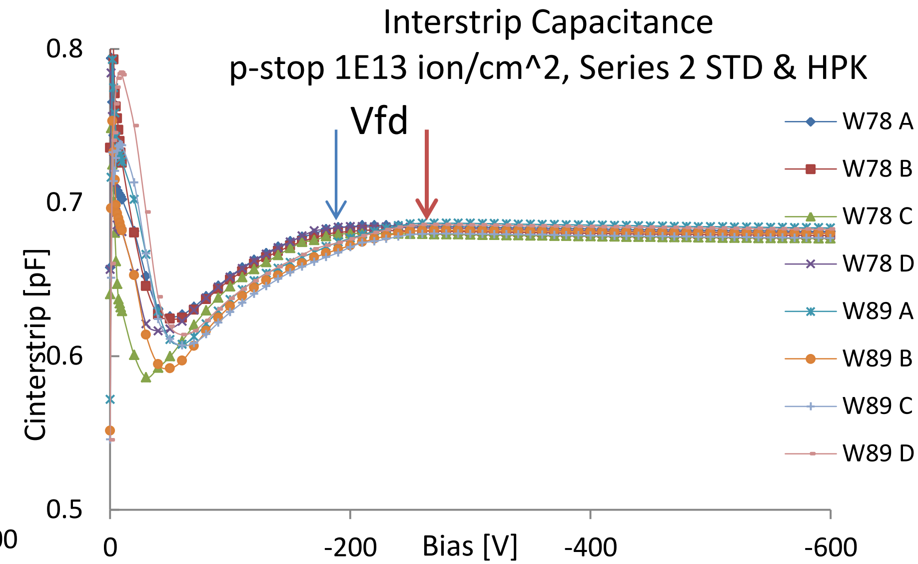


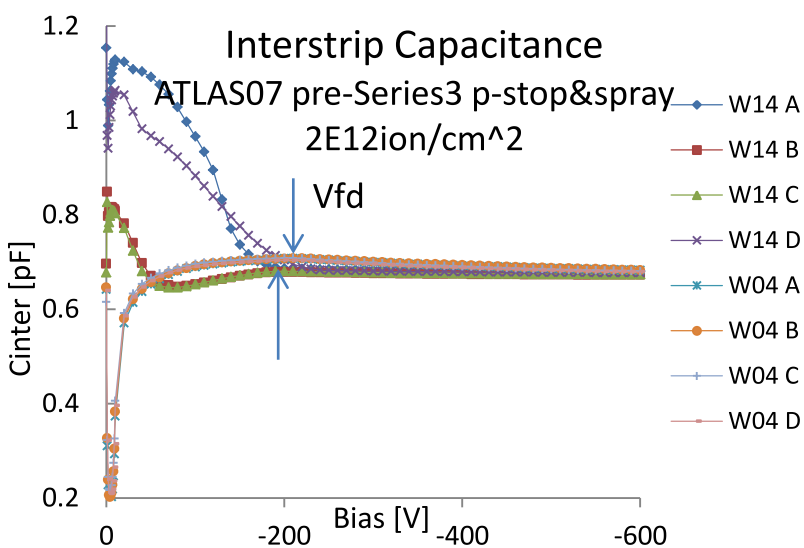
Cint(5-pr)/Cint(3-pr)=0.939 and 0.913 for 100kHz and 1MHz, respect.
Cint(2-pr)/Cint(5-pr)=0.57

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

Interstrip Capacitance





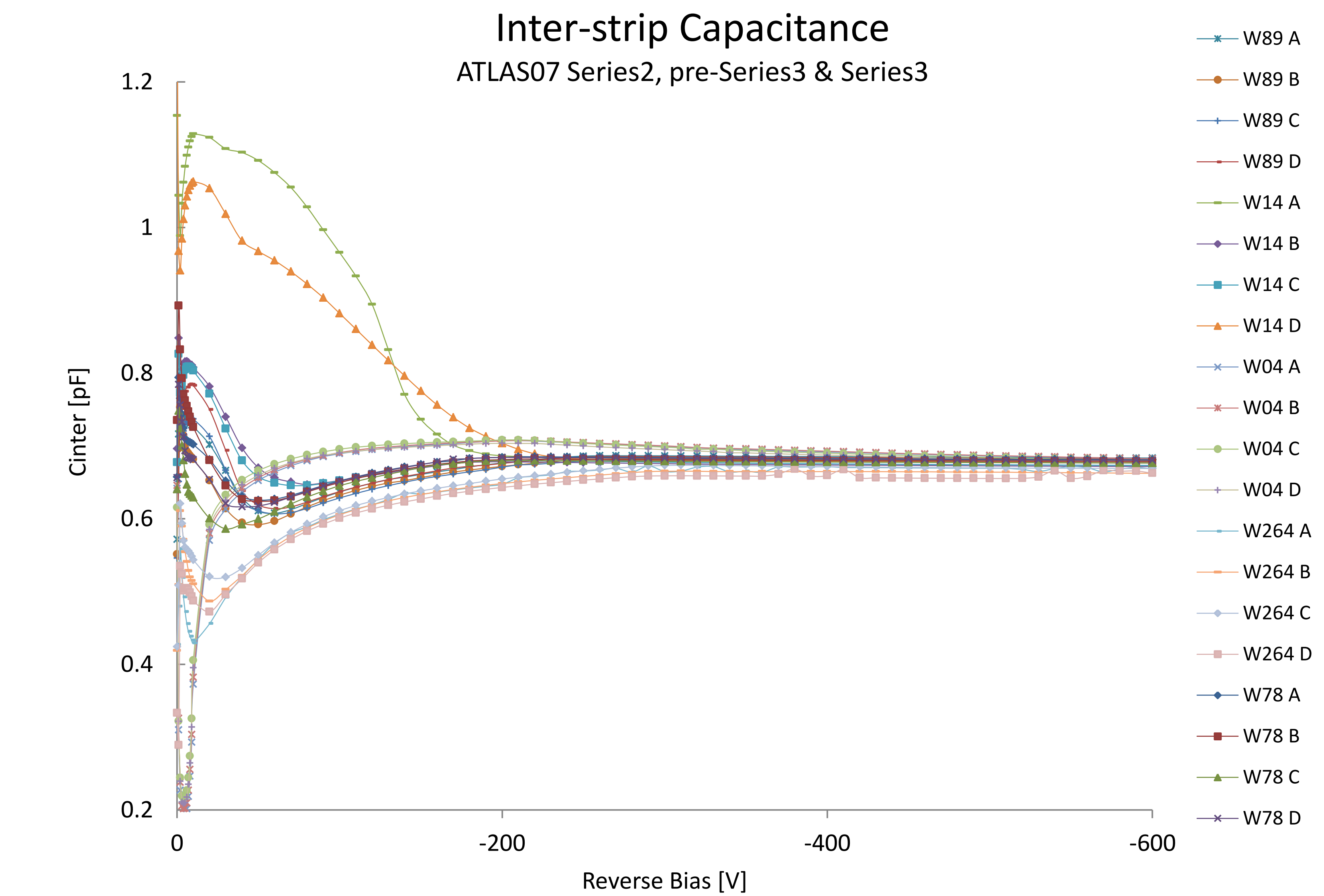


Interstrip capacitance is measured by 3 probes.

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 .

There is narrow deep minimum of Cint at Vbias =-4V for P-stop+P-spray isolation.


Inter-strip Capacitance
ATLAS07 Series2, pre-Series3 & Series3
Cinter [pF]
1.2
1
0.8
0.6
0.4
0.2
0
-200
-400
-600
Reverse Bias [V]
W89 A
W89 B
W89 C
W89 D
W14 A
W14 B
W14 C
W14 D
W04 A
W04 B
W04 C
W04 D
W264 A
W264 B
W264 C
W264 D
W78 A
W78 B
W78 C
W78 D

Interstrip Capacitance

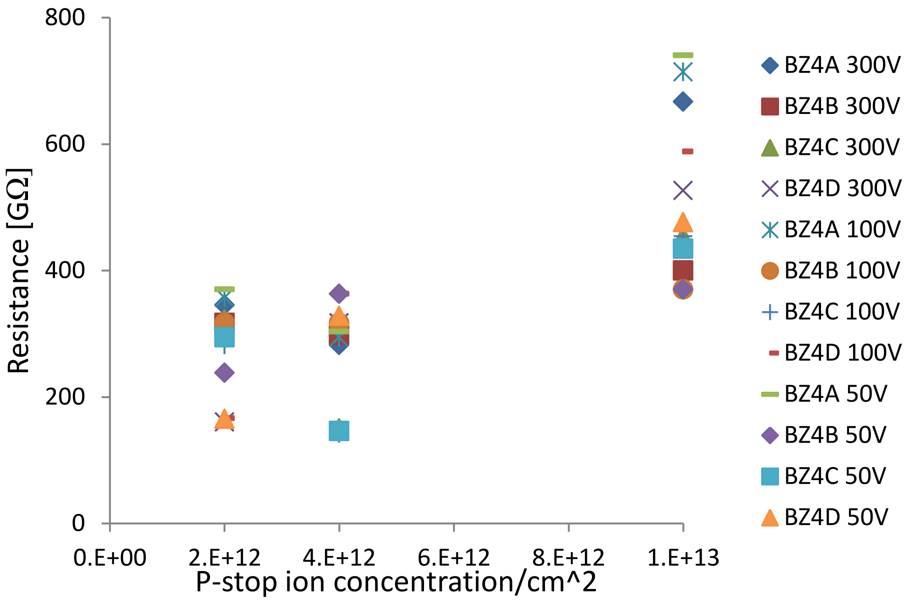
Interstrip capacitance in this table was evaluated for Vbias=Vfd+10V

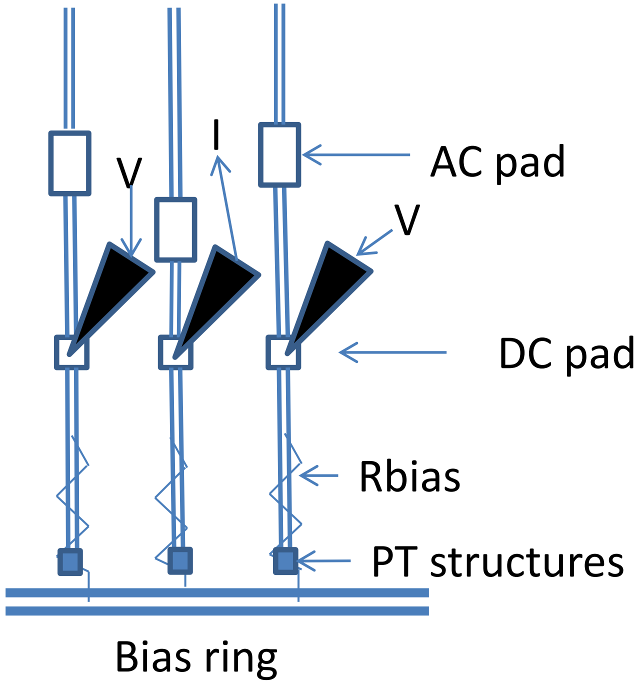
Wafer	W14	W264	W78	W89	W04
Series	Pre-Ser3	Series3	Series2 STD	Series2 HPK	Pstop Pspray
Ion/cm^2	2E12	4E12	1E13	1E13	2E12
Vfd [V]	-183	-292	-186	-252	-186
Cint BZ4A pF	0.69	0.66	0.68	0.69	0.71
Cint BZ4B pF	0.68	0.67	0.68	0.68	0.71
Cint BZ4C pF	0.68	0.67	0.68	0.68	0.71
Cint BZ4D pF	0.71	0.66	0.68	0.69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

Interstrip Resistance

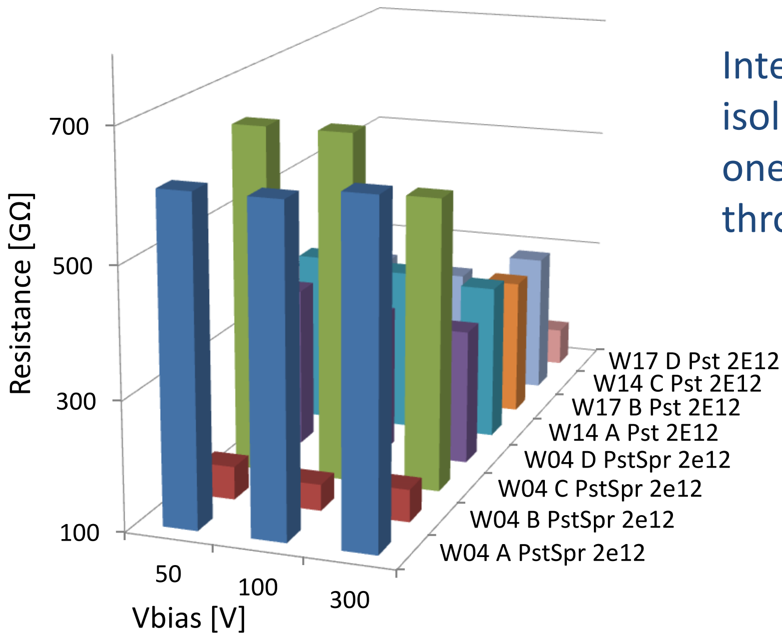




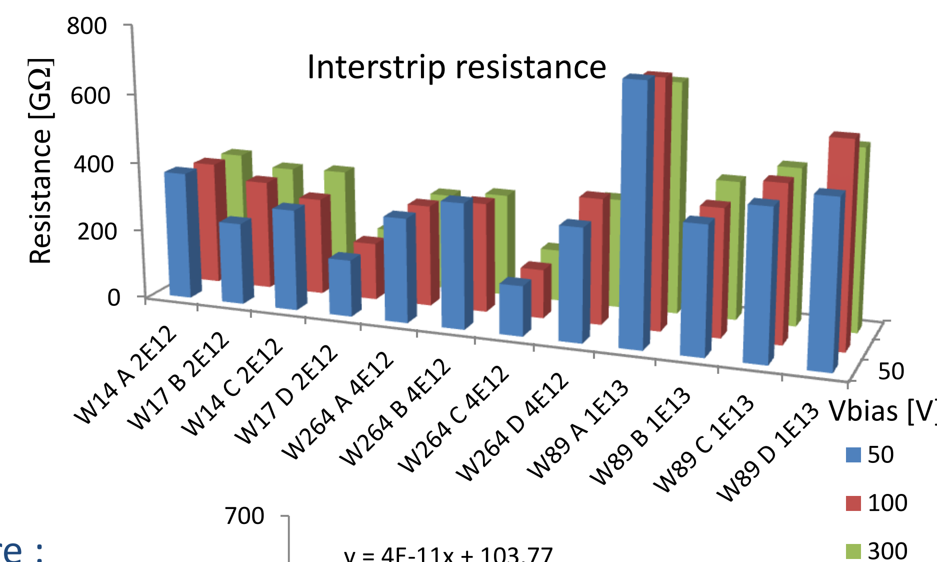
Rint = 2*dV/dI measured at Vbias=-50V, -100V and -300V

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

Interstrip Resistance

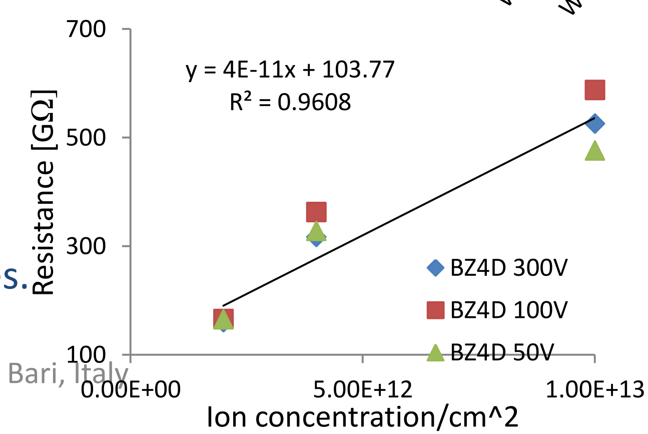


Interstrip resistance for case of P-stop + P-spray isolation is about two times higher than one for P-stop isolation for all punch through structures with exception of BZ4B.

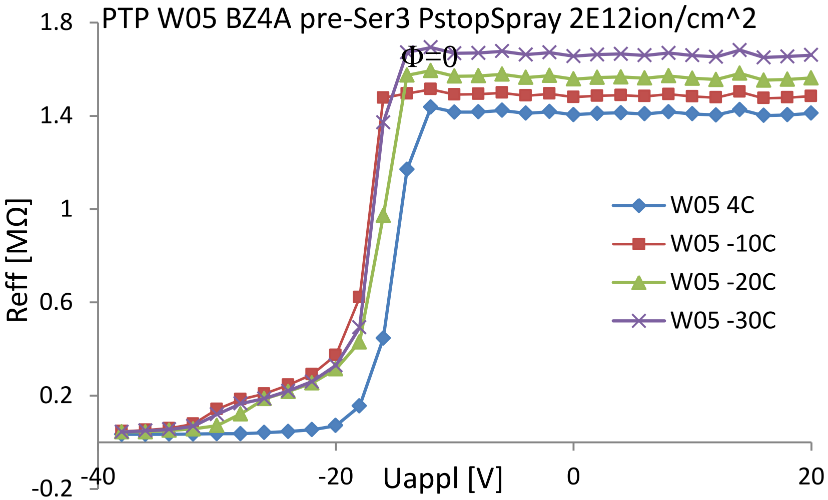


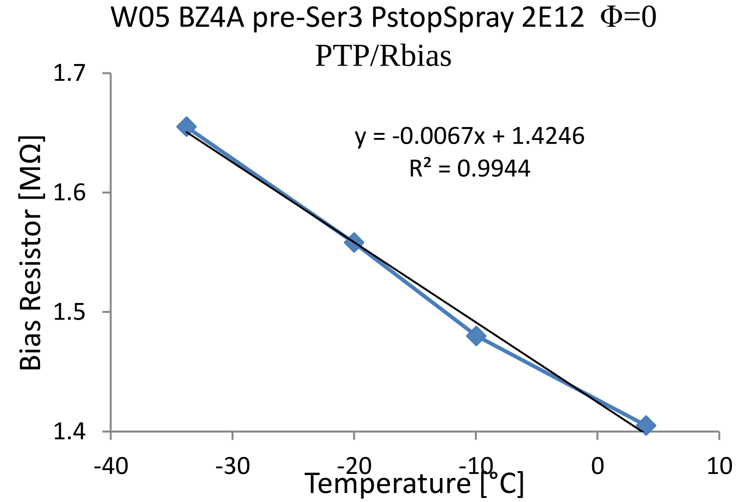
The interstrip resistance dependence on ion concentration can be estimated for Z4D structure : Rint=4E-11xIons/cm^2+103.8GΩ

Presumably not only ion concentration is responsible for Rint value but also fabrication processes in various series.

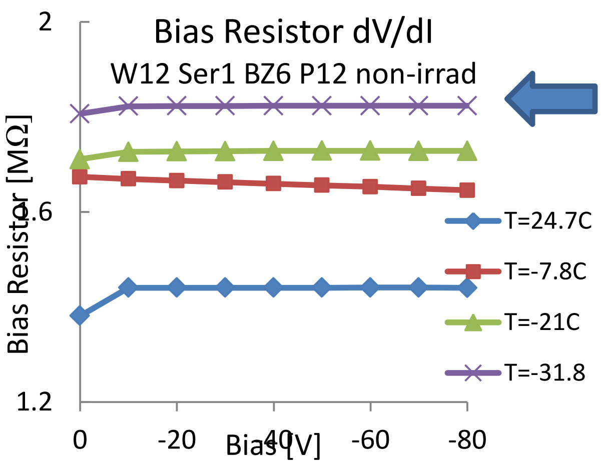


Thermal Dependence of Polysilicon Bias Resistor

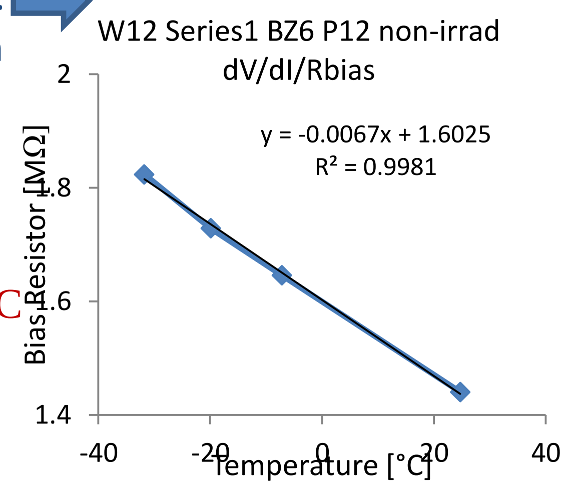




PT voltage is slightly higher for low temperature (-30C) than for room temperature (24C).
The difference is explained by lower bias resistance for room temperature than for -30C.

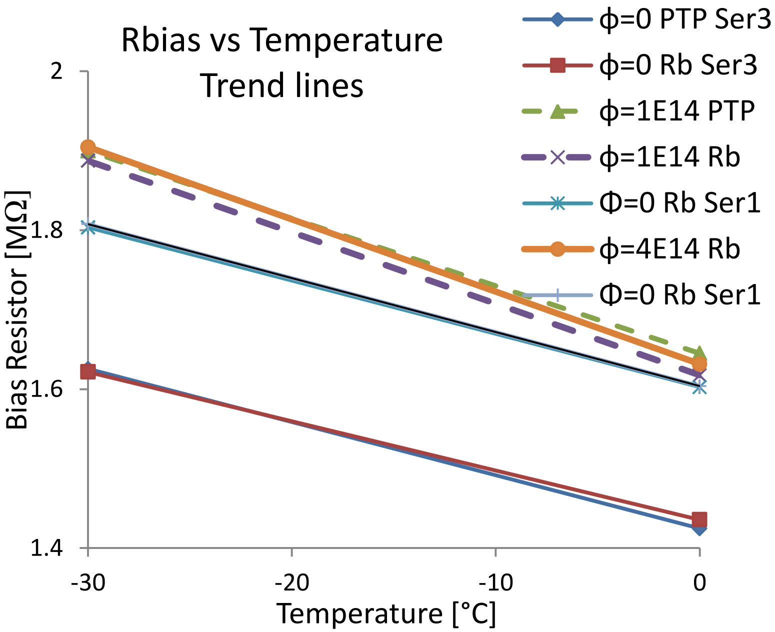


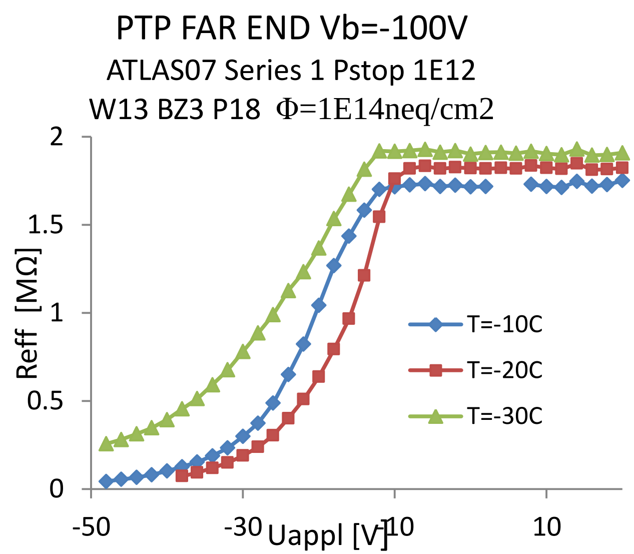
Points in the figure are taken at -80V.
Temperature was measured at each bias voltage.

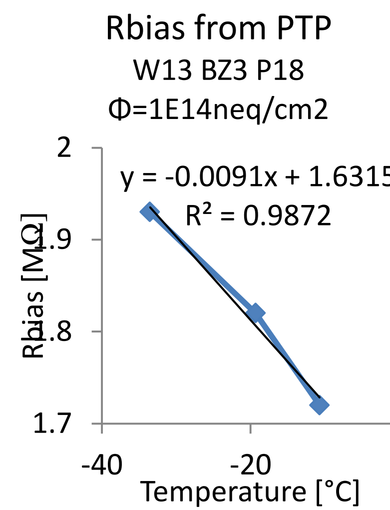


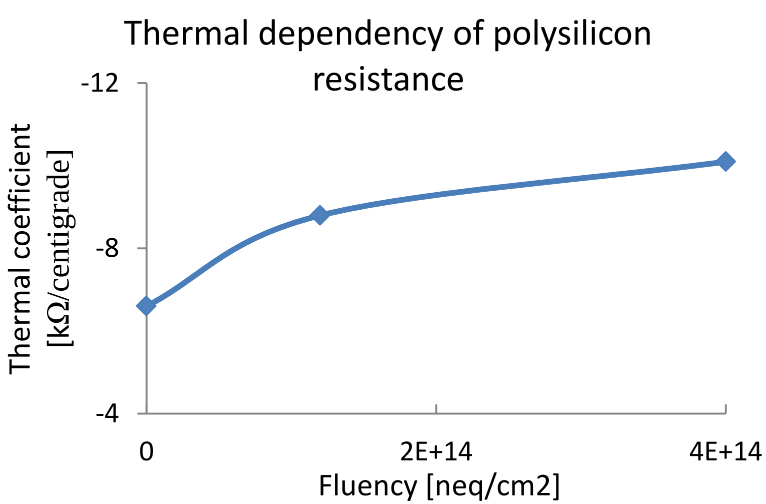
Both methods used for the evaluation of Rbias dependence on temperature gave the same slope of -0.0067 MΩ/1°C

Thermal Dependence of Poly silicon Bias Resistor









An evidence that the thermal coefficient of poly-silicon bias resistor increases with fluency?

The respective temperature coefficients are -6.7kΩ/1°C for non-irradiated sensors and -10.1kΩ/1°C for fluency 4e14neq/cm^2

Summary

All 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, sensors with P-stop + P-spray isolation behave differently and an onset of breakdowns are above already Vbias=900V.

Full depletion voltages of tested sensors are in the range of 180V-290V

Punch through voltage dominantly depends on the P-stop ion concentration for all punch through structures. PT voltage for P-stop+P-spray isolation is considerable higher than one for P-stop isolation at same p-dose 2E12 ion/cm^2. PT voltage increases with applied bias.
PT voltages are smaller than 50V, i.e. they are significantly below the hold-off voltage of the coupling capacitor which are typically tested to 100V.
Study of Rpt dependence on the test current shows that the most effective short, i.e. protection against beam splashes , ensures the structure BZ4A for all tested P-stop ion concentrations.
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.

Interstrip resistance increases with P-stop ion concentration from 4E12 up to 1E13ion/cm^2

The polysilicon bias resistance depends on temperature. The respective temperature coefficients are -6.7kΩ/1°C for non-irradiated sensors and -10.1kΩ/1°C for fluency 4e14neq/cm^2 .