Surface Damages in P-Bulk Silicon Microstrip Sensors

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On behalf of ATLAS R&D group: "Development of non-inverting silicon strip detectors for the ATLAS ID upgrade"

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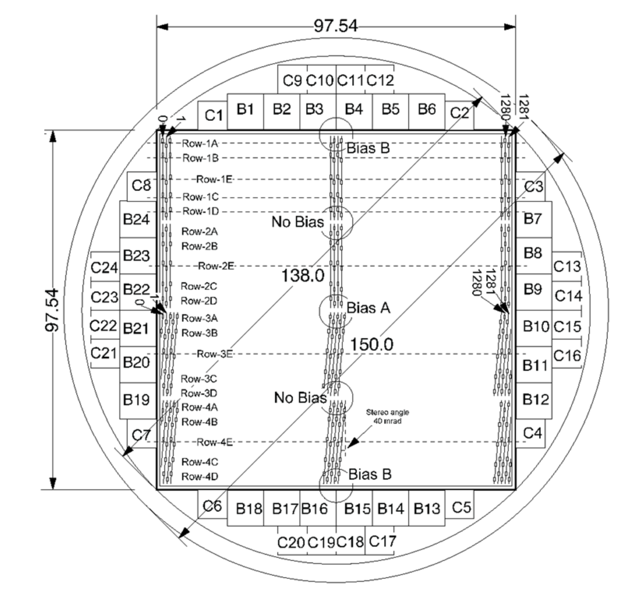
INTRODUCTION

Silicon microstrip detectors at the super LHC are required to remain operational up to a fluence of 1×10^{15} n_{eq}/cm^2. The lifetime of the present LHC ATLAS silicon detector is determined by impurity increase by radiation which raises the full depletion voltage above the system rating. We are investigating n^+-on-p microstrip sensors, p-bulk and n-readout. Since the radiation induced impurity is of p type, the junction stays at the strip side in n^+-on-p sensors, which allows us to operate the sensors under partial depletion when required. The strip isolation is crucial in p-bulk sensor design since the positive charges inherently trapped in the SiO_2 layer accumulate mobile electrons at the interface which degrade the individual strip readout.

Test sensors are fabricated by Hamamatsu Photonics, where various isolation structures are implemented using p-stop and p-spray technologies. We evaluated the radiation hardness of the sensors through irradiation with 70 MeV protons up to the fluence of 1.3×10^{15} n_{eq}/cm^2 and with ^{60}Co γs at a rate foreseen at the super LHC. The strip isolation, onset of micro-discharges, and punch through characteristics, are characterized in detail.

ATLAS07 SENSOR DESIGN

ATLAS07 sensors were fabricated by Hamamatsu Photonics. The wafer is 15 cm diameter made in FZ and <100> crystal orientation.



24 test sensors of 1×1 cm^2 are placed in an ATLAS07 wafer (Fig.1), where six different p-stop structures Z1-Z6 are designed (Fig. 2). Some wafers were p-sprayed, providing p-spray only (Z1) and with p-stop in addition (Z2-Z6).

doping density in B/cm^2	
P-stop (P2, P4, …):	$(2, 4, 10, 20)\times10^{12}$
P-spray (r1, r2, r4):	$(1, 2, 4)\times10^{12}$
stop+spray (P2r2,..):	$(2+2, 8+2, 8+4)\times10^{12}$

Fig.1: ATLAS07 wafer layout. B1-B24 are test sensors.

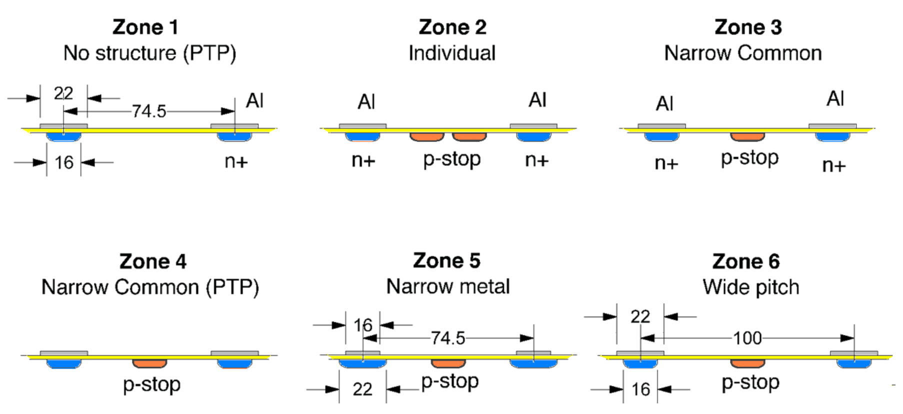


Fig.2: Z1-Z6 zone structures (dimension in μm). Some wafers have additional p-spray.

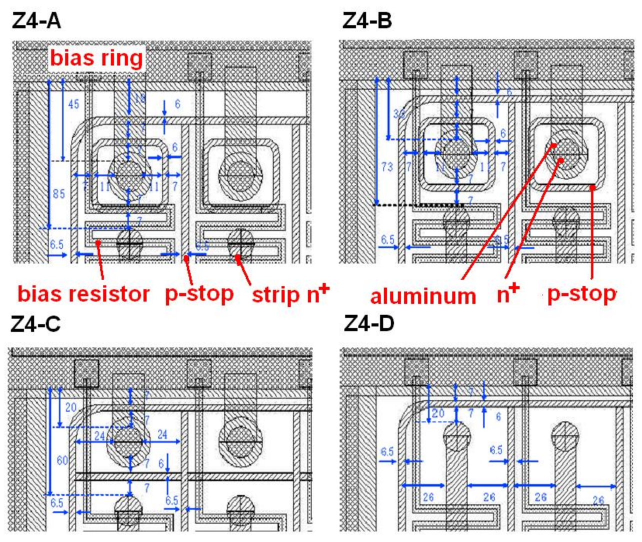


Fig.3: PT structures implemented in Z4.

PUNCH THROUGH PROTECTION

In case of beam splash creating many charges in short time, the voltage across SiO_2 insulator may exceed its rating(~100V for HPK). Z4s are implemented with punch through structures (PT), having shorter distances to the bias-ring (Fig.3) to route the emerging current.

pre-irradiation

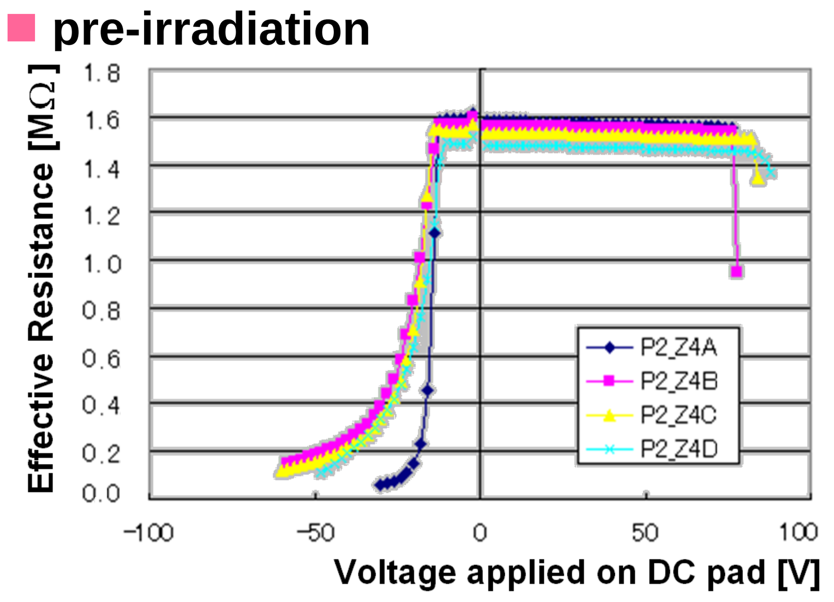


Fig.9: PT characteristics of P2 samples. Negative voltages are relevant to beam splash.

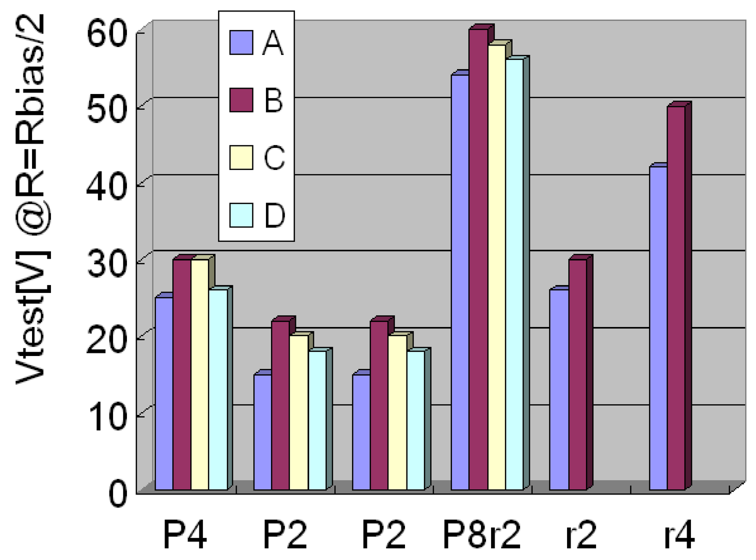
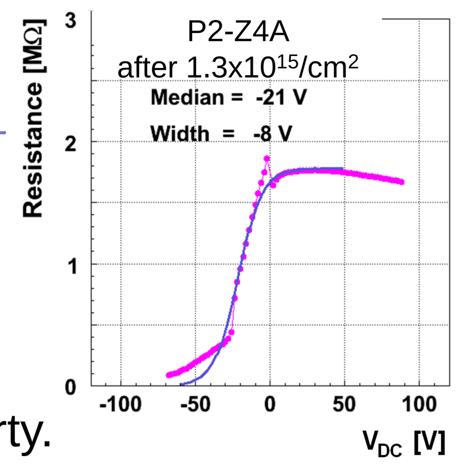
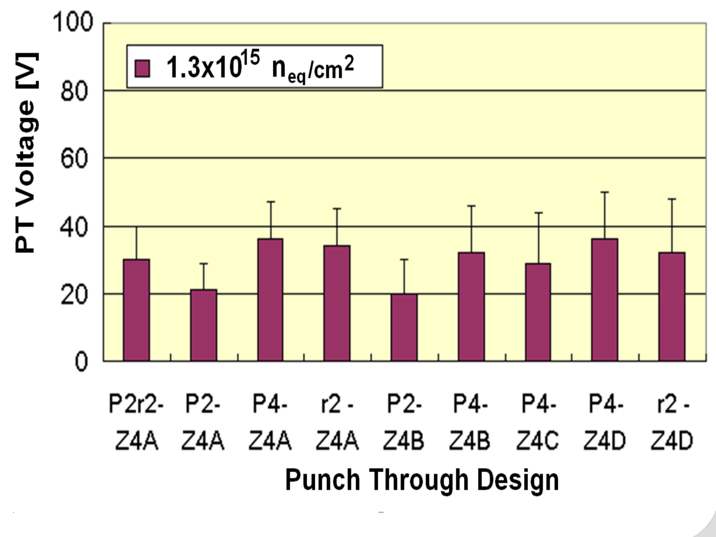


Fig.10: Summary of PT voltages. Difference among A-D structures is moderate than the isolation structures.

post-irradiation

Fig.11 (left): PT behavior after irradiation.
Fig.12 (right): Median PT voltages and widths (as error bars).





Small degradation is found, showing acceptable PT property.
(Post-irrad P8r2 should come shortly)

STRIP ISOLATION

The strip isolation is evaluated from the current with 5 V applied across neighboring DC pads while changing the detector bias (Fig. 5). The resistance should account two bias resistors in serial if the strip isolation is established.

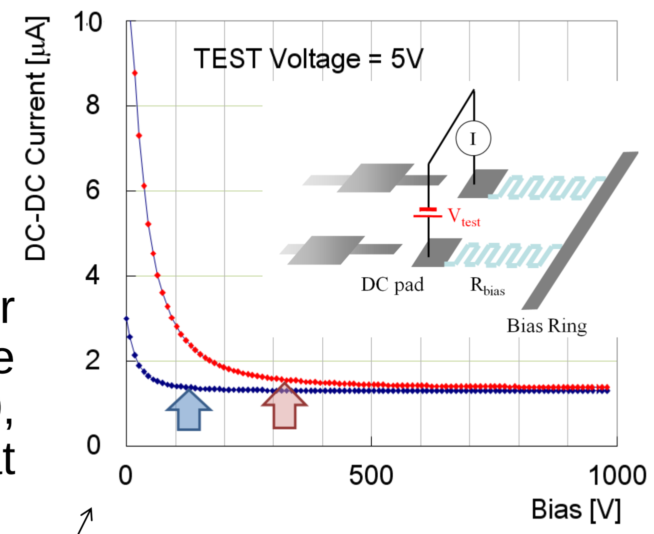
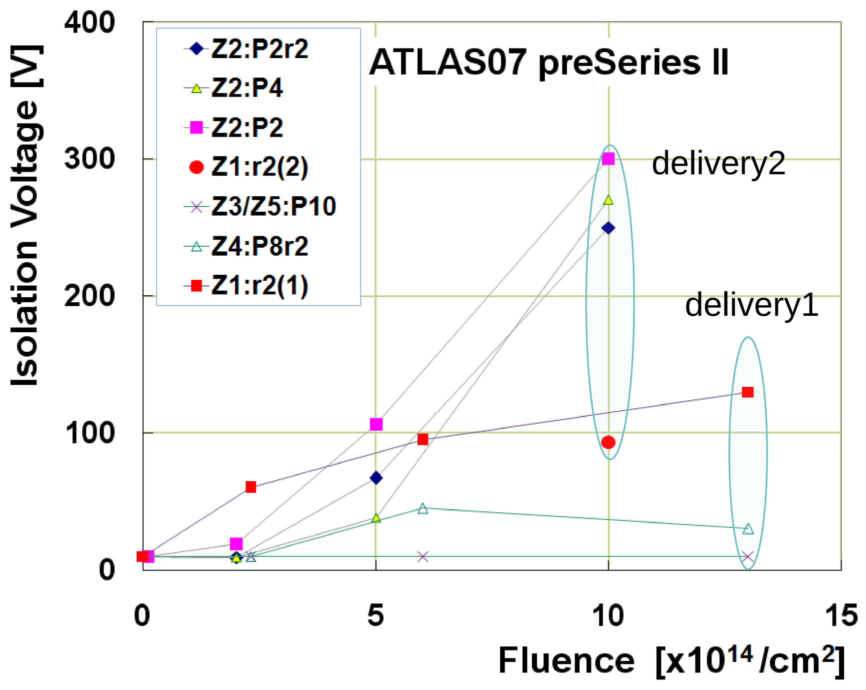


Fig. 5: Strip isolation is defined by the bias voltage where the induced current decreases and agrees to the asymptotic value within 10%.



The strip isolation for samples with dense p-stop doping (P10, P8r2) is achieved at a few 10 V. Others are degraded, reaching ~300V at 10^{15} /cm^2 except for p-spray only sample with ~100V (Fig. 6).

Fig. 6: Isolation voltages evaluated after post-irradiation annealing (80min @60^{o}C)is made. The data are from two deliveries.

In-situ strip isolation is evaluated during ^{60}Co irradiation at the rate expected at the super LHC. The resistance curves of P4 samples are saturated at 300 V bias in a few hrs at 0.1 kGy, and stayed similar for 4 days we tested (Fig. 7).

The isolation voltages are plotted for various samples including from ATLAS06 in Fig. 8 for two dose rates. Some samples, mostly P10, show slower transition, but all seem to saturate at the bias during irradiation.

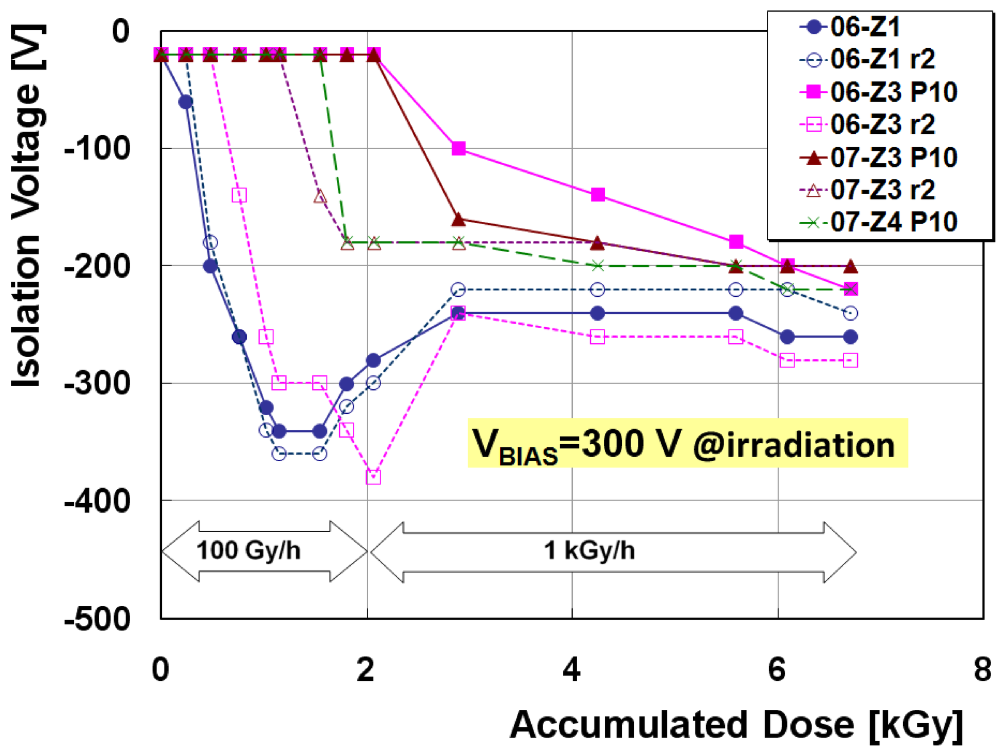


Fig. 8: Isolation voltages measured while ^{60}Co was in place. ATLAS06 samples (same wafers) are also included. The dose rate changed from 0.1 to 1 kGy/h. The bias during irradiation was 300 V.

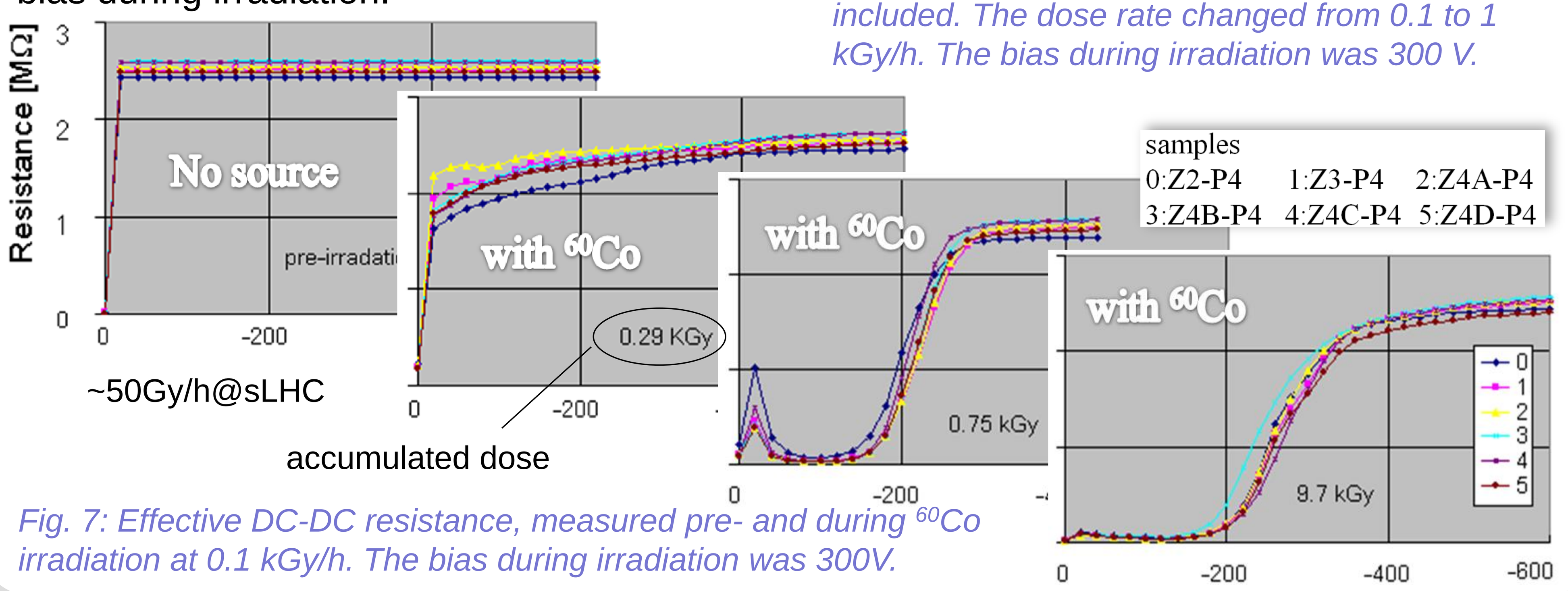


Fig. 7: Effective DC-DC resistance, measured pre- and during ^{60}Co irradiation at 0.1 kGy/h. The bias during irradiation was 300V.

LEAKAGE CURRENT

Micro-discharge (MD) is caused by surface effects, which should be affected by irradiation.

The MD onset voltage was traced while ^{60}Co source was in place (Fig. 13). The onset voltage, initially700V , decreased down to 280 V in 125 Gy and then start to rise.

Similar measurements were made in proton irradiation up to 10^{14} /cm^2 (Fig. 14). Among the tested 8 samples, all except two showed initial drops below 5×10^{11} /cm^2 .

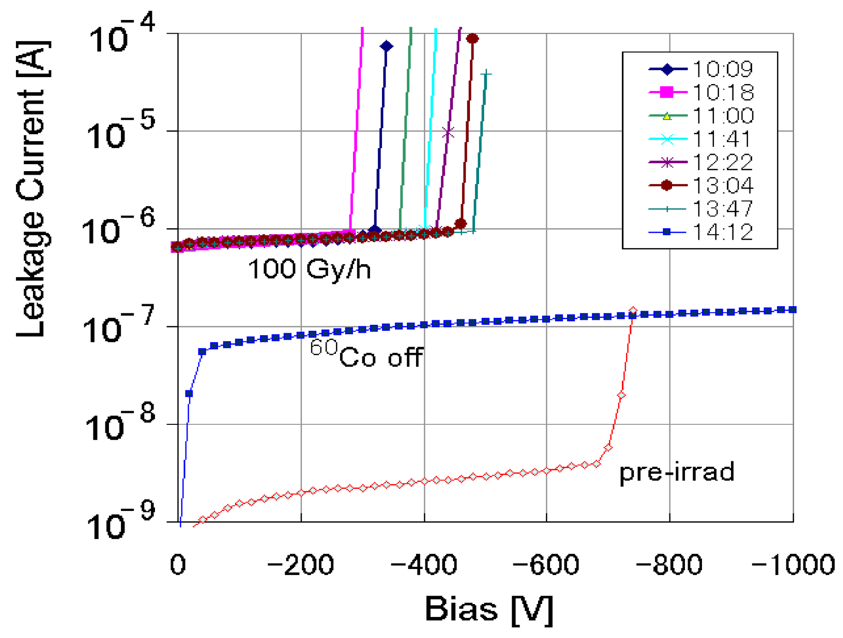


Fig.13: I-V history of a sample (Z3-r4) measured during ^{60}Co irradiation at 100 Gy/h, and pre- and post-irradiation. The sample has received 110 Gy before this series of measurement.

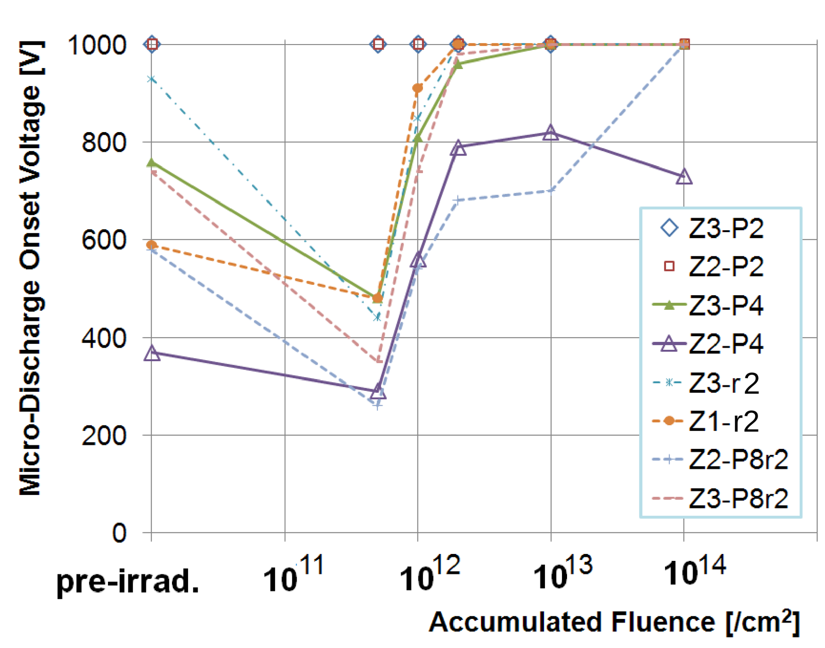


Fig.14: Micro-discharge onset voltages with accumulated fluence. I-V measurements were made right after the proton irradiation was intermitted.

SUMMARY

P-bulk and n-readout microstrip sensors are being designed for the super LHC. The surface properties of ATLAS07 sensors can be summarized as;

- Strip isolation after annealing is dependent on isolation doping. Samples with lightly doped p-stop and p-spray require 300 V bias after 1×10^{15} /cm^2. The in-situ isolation voltage reaches the bias set during irradiation within a few kGy and stays stable. Isolation measurement with readout amplifier connected is planned.
- Punch through protection structure is implemented successfully in ATLAS07.
- Micro-discharge onset voltage is found to decrease initially at very low fluence (~0.1 kGy or 10^{11} p/cm^2), then increases.