

# Development of Radiation Hard N-on-P Silicon Microstrip Sensors for Super LHC

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## INTRODUCTION

Radiation hardness of the present ATLAS silicon microstrip sensors needs to be 10-fold increased to be operational in environment at the super LHC, exceeding  $10^{15}$  1-MeV  $n_{eq}/cm^2$ . The n-on-p, n readout strips fabricated on p bulk, is one of the promising scheme, since the p-n junction stays at the strip side even with such intense radiation. This allows the detector to be operated under partial depletion if the full bias is not applicable to the full depletion voltage increased due to radiation damage. Sample n-on-p sensors are fabricated at Hamamatsu Photonics using commercially available 4" and 6" FZ and MCZ wafers. To suppress creation of the inversion layer under the oxide layer, which may degrade the strip isolation, we have evaluated various isolation structures, including p-stop, p-spray and field plate, with different p-stop concentrations. We irradiated  $1 \times 1$  cm<sup>2</sup> sample sensors with 70-MeV protons, and evaluated the leakage current, strip isolation, full depletion voltage, and charge collection as a function of the fluence ranging from  $10^{14}$  to  $5 \times 10^{15}$  1-MeV  $n_{eq}/cm^2$ .

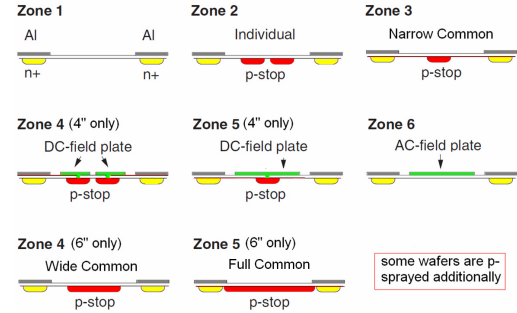
## SENSOR SAMPLES

Wafer growth, MCZ (magnetic Czochralski) or FZ (float zone); crystal orientation; and resistivity( $k\Omega cm$ ). FZ<sub>2</sub> in 6" process contains fewer defects.

HPK	MCZ	FZ	
4"	<100> 0.8	<111> 6	
HPK	MCZ	FZ	FZp
6"	<100> 2	<100> 5	<100> 5

Ion densities ( $/cm^2$ ) for P-stop and P-spray. P-spray only samples are available in Z1/Z6. Values are indicative only.

	P-stop HI	P-stop LO/Mid	P-stop (P-spray)
HPK 4"	$2 \times 10^{13}$	$5 \times 10^{12}$	$2 \times 10^{12}$ ( $2 \times 10^{12}$ )
HPK 6"	$2 \times 10^{13}$	$1 \times 10^{13}$	$8 \times 10^{12}$ ( $2 \times 10^{12}$ )

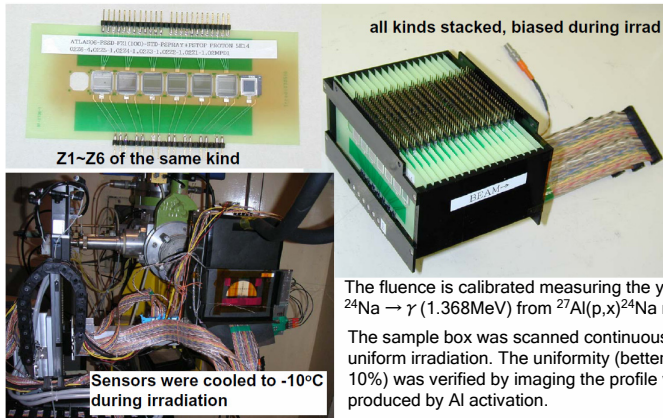


Six strip isolation structures (Zone 1-6) implemented on the same wafer. Some wafers are with additional p-spray. DC-field plates studied in 4" are replaced with wider and full common p-stop in 6".

Implants: 16  $\mu m$  wide at 80  $\mu m$  pitch  
 Bias resistors: 1.5 M $\Omega$  poly-Si  
 Aluminum: 22  $\mu m$  wide, AC-coupled  
 Dimensions: 10x10x0.3mm (strip length ~8 mm)

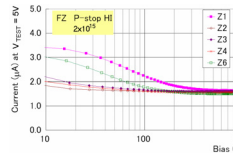
## PROTON IRRADIATION

Samples were irradiated uniformly with 70 MeV protons at CYRIC (Tohoku U), all 4" samples in November 2006, and 6" samples in May and August 2007. The samples were glued to PCB boards and wire-bonded for contacts necessary for the performance characterization.



The fluence is calibrated measuring the yield of  $^{24}Na \rightarrow \gamma$  (1.368MeV) from  $^{27}Al(p,x)^{24}Na$  reaction. The sample box was scanned continuously for uniform irradiation. The uniformity (better than 10%) was verified by imaging the profile with  $\gamma$ 's produced by Al activation.

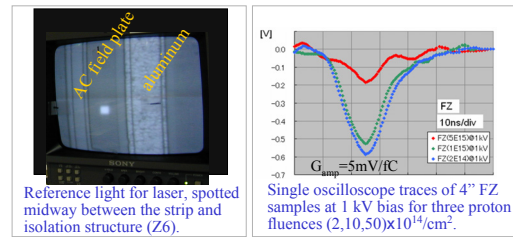
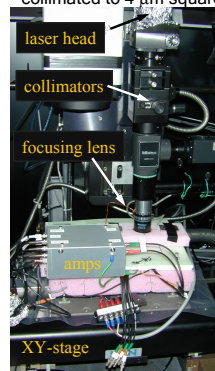
## PERFORMANCE CHARACTERIZATION



The **strip isolation** is evaluated from the current when 5V is applied across the two DC pads at neighbor, which reaches 1.5 $\mu A$ , defined by two bias resistors in series, when the isolation is achieved.

Current across DC pads for 5V test voltage, as a function of bias. Data are for 6" FZ with high P-stop concentration, irradiated to  $2 \times 10^{15}/cm^2$ , for Z1-Z6 (no Z5 for breakdown).

The **charge collection curve** (CCC) was measured at 25V step injecting 1064nm pulse laser collimated to 4  $\mu m$  square. The signals from the two strips nearby the laser were amplified with fast amplifiers (20ns peaking time) and recorded with an oscilloscope.

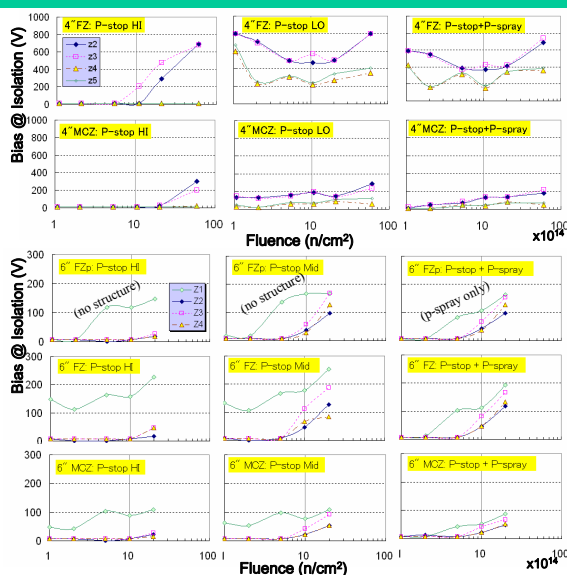


Reference light for laser, spotted midway between the strip and isolation structure (Z6). Single oscilloscope traces of 4" FZ samples at 1 kV bias for three proton fluences ( $2, 10, 50 \times 10^{14}/cm^2$ ).

Charge collection measurement system. The sample PCB board is placed together with a reference sample in an aluminum box (covered in foam). The box is cooled to -10°C and cooled N<sub>2</sub> gas flushes the irradiated sample to prevent thermal runaway. Signals are fed to fast amplifiers.

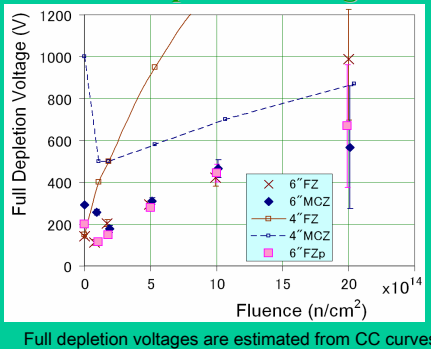
## RESULTS

### - Strip Isolation -



Bias voltage where the strip isolation is achieved.  
 Note: 4" data for bias resistors.  
 Note: 6" Z6 data for breakdown below ~500V.  
 Z5s, not shown, are isolated at 150V<sub>app</sub> of smaller than 50V.

### - Full Depletion Voltage -



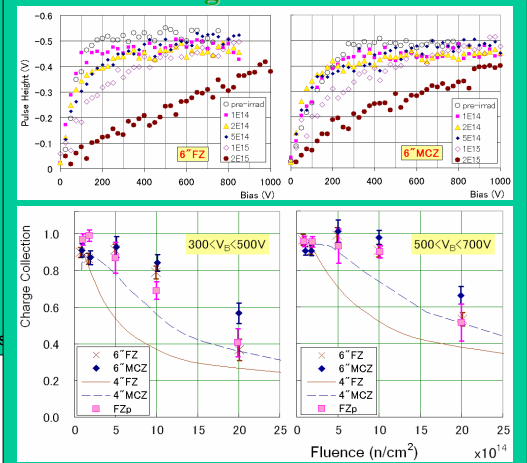
Full depletion voltages are estimated from CC curves

## SUMMARY

Radiation hardness of n<sup>+</sup>-on-p microstrip sensors is evaluated by irradiating protons up to  $5 \times 10^{15}/cm^2$ .

- ✓ **Isolation:** Crystal orientation <100> is substantially better than <111>. At  $2 \times 10^{15}/cm^2$ , FZ<100>, slightly worse than MCZ<100>, is isolated at biases less than 50V (150V) for high (middle) P-stop concentration, or 150V with p-spray.
- ✓ **Full depletion voltage:** 6" samples, FZ, FZp and MCZ, show similar fluence dependence. The full depletion voltage reaches 500V@ $1 \times 10^{15}/cm^2$ . 4" FZ evolution is significantly faster than the others.
- ✓ **Charge collection:** Approximately 50% of charge is collectable after  $2 \times 10^{15}/cm^2$  at 500V bias.

### - Charge Collection -



**Acknowledgment:** We acknowledge the team of CYRIC for performing excellent proton irradiation.