Irradiation Study of ATLAS ITk Strip Sensors, ATLAS18, with 80MeV Protons

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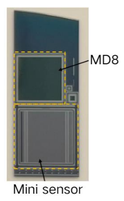
Abstract

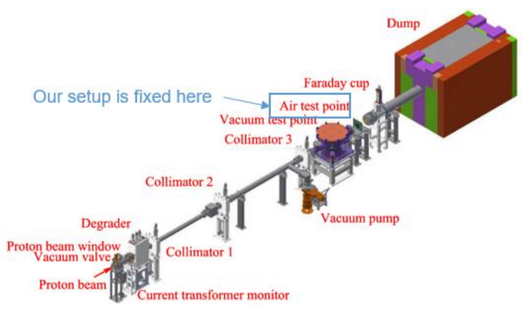
- The ATLAS experiment is planning a complete replacement of its inner detector(ID) with a new all-silicon inner tracker(ITk) for the HL-LHC
- To enhance the Quality Assurance (QA) program for confirming the key properties of the sensors, the strip sensor community is considering to include China Spallation Neutron Source (CSNS) as a proton irradiation site and Institute of High Energy Physics (IHEP) as a QA test site
- A total of 18 ATLAS ITk strip sensors for the irradiation study were irradiated with protons at CSNS, and measured at IHEP, including IV (leakage current-voltage), CV (capacitance-voltage) and CCE (charge collection efficiency) measurements
- The upgraded irradiation setup at CSNS and measurement setup at IHEP are shown in this work
- Irradiated samples were exchanged between IHEP, Ljubljana and Birmingham to cross-check CCE measurements

ATLAS ITk Strip Sensors

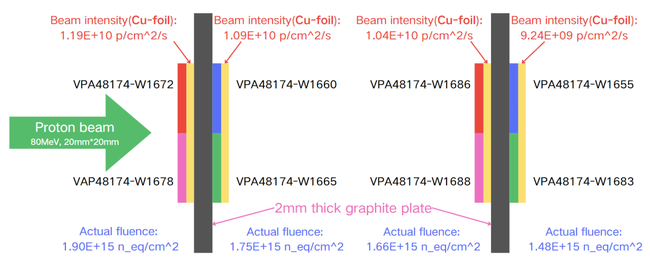
- QA test piece: a mini sensor (for CCE measurements) and an MD8 (for IV, CV measurements) [1]
- Mini sensor: $10 \times 10\ \mathrm{mm}^2$ miniature sensor, which contains 104 strips of 8 mm length, each biased through a 1.5 MΩ polysilicon resistor [2]
- MD8: monitor diode with size of $8 \times 8\ \mathrm{mm}^2$



Irradiation setup

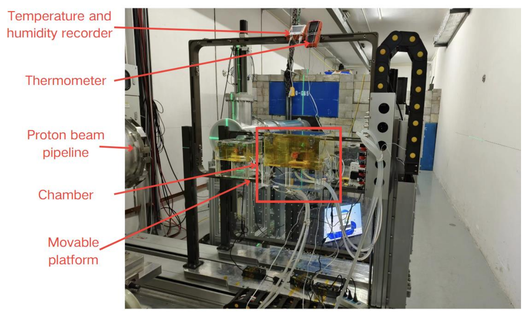


The main composition of Associated Proton Experiment Platform (APEP) [3]



Samples and Cu-foils in the direction of the proton beam, with beam intensityand actual fluence

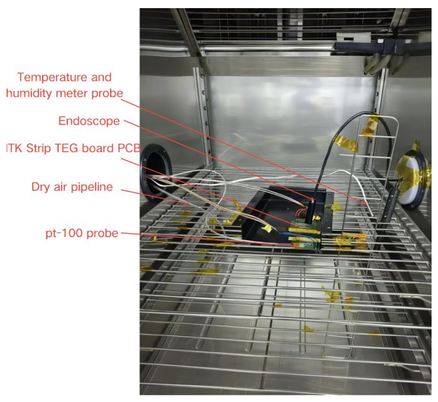
- Beam parameters: 80 MeV proton, beam size $20 \times 20\ \mathrm{mm}^2$, (after collimation), $1.06 \times 10^{10}\ \mathrm{protons/cm^2/s}$
- Beam spot uniformity: >90%
- Temperature: -20℃ (Peltier + water cooling),
- Humidity: <10%RH (Dry air)
- Irradiation fluence: using foil activation technique



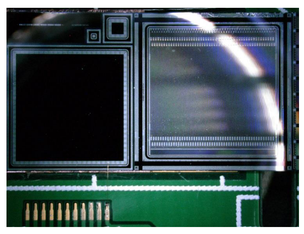
Irradiation setup at APEP of CSNS [4]

IV, CV measurement setup

IV, CV measurement setup in the cleanroom



Interior of the chamber

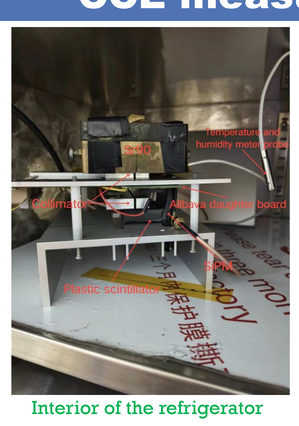


The MD8 was mounted on the PCB for IV and CV measurements

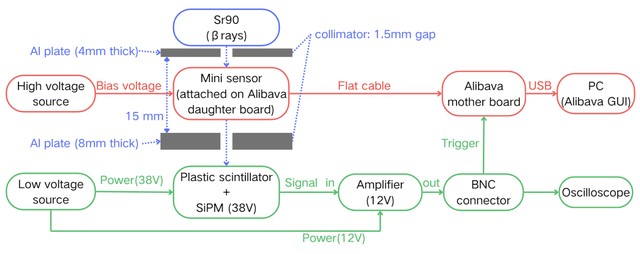
- Temperature: 20℃(unirradiated), -20℃(irradiated), controlled by the chamber
- Dry air flowed into the chamber to reduce humidity: <10%RH

CCE measurement setup

CCE measurement setup



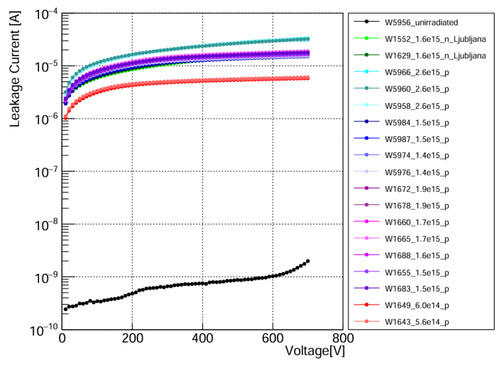
Interior of the refrigerator



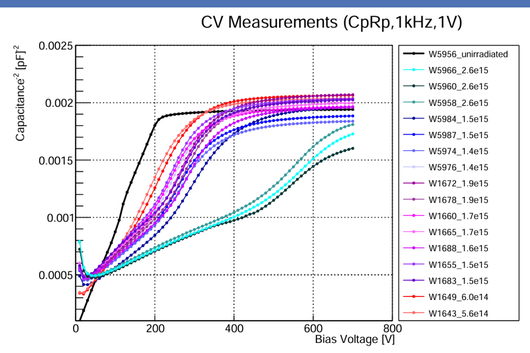
CE measurement connection

- Temperature: -20℃ (unirradiated & irradiated), controlled by the refrigerator
- Dry air flowed into the refrigerator to reduce humidity: <10%RH
- CCE measurement: It's a similar setup scheme as at other QA sites [5]. A β-ray penetrating mini sensor was detected by scintillator, and output charge was measured by the Alibava system. Collected charge is defined as the Most Probable Value of Landau function obtained from the fit of Landau convoluted with Gaussian to distribution of measured cluster charges.

IV, CV measurement results



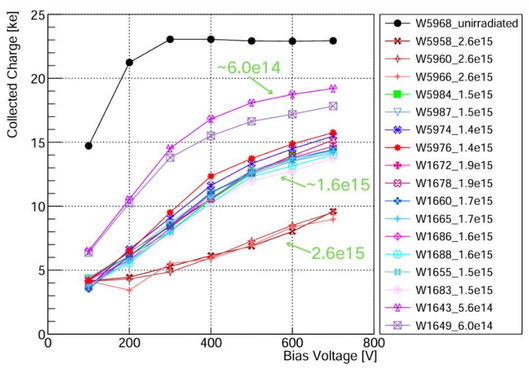
IV measurement results (annealed: 60℃, 80min)
W1552,W1629 shipped from Ljubljana were measured at IHEP.
Legend: SampleID_ActualFluence_IrradiationType



CV measurement results (annealed: 60℃, 80min)
All the samples were irradiated with protons at CSNS and measured at IHEP.
Legend: SampleID_ActualFluence

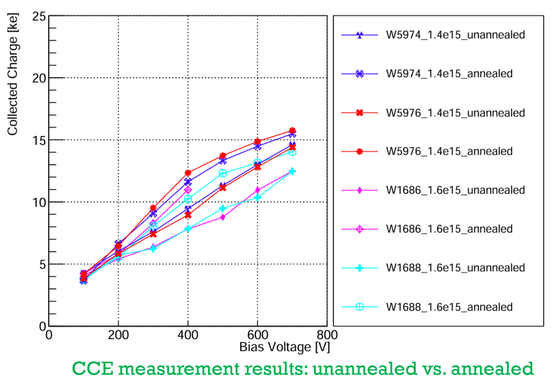
- All the samples meet the QA requirements [6]
  - Leakage current @500V: $< 0.1\mu\mathrm{A/cm}^2$ for unirradiated MD8, $< 20\mu\mathrm{A/cm}^2$ for $5.1 \times 10^{14}\ \mathrm{n_{eq}/cm^2}$, $< 0.1\mathrm{mA/cm}^2$ for $1.6 \times 10^{15}\ \mathrm{n_{eq}/cm^2}$
  - Full depletion voltage: <350V for unirradiated MD8
- For IV and CV, samples irradiated with the similar fluence have the similar behavior
- The higher the fluence, the larger the leakage current (damage constant: $\alpha = (3.65 \pm 0.32) \times 10^{-17}\mathrm{A/cm}$, after fit)

CCE measurement results

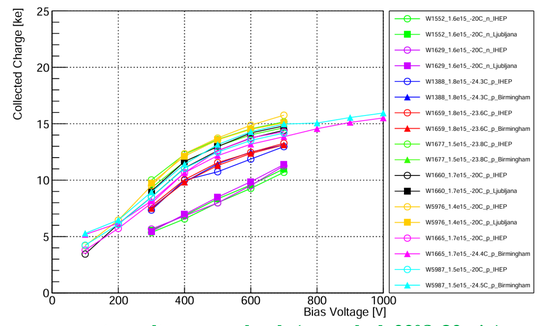


CCE measurement results (annealed: 60℃, 80min).
Irradiated with protons at CSNS and measured at IHEP

- The collected charges of all the samples are more than 6350e-@500V(meeting the QA requirement [6]), except W1686(only up to 400V)
- The annealed samples have better charge collection capability than the unannealed samples as expected
- CCE results measured at IHEP showed good consistency with results from Ljubljana and Birmingham(difference: <10%)



CCE measurement results: unannealed vs. annealed



CCE measurement results: cross-check (annealed: 60℃, 80min)
Legend:
SampleID_ActualFluence_Meas.Temp._IrradiationType_Meas.Site

Conclusion

- 18 samples have been irradiated with proton at CSNS and measured at IHEP, including IV, CV, and CCE measurements
- Irradiated samples were exchanged between IHEP, Ljubljana, and Birmingham to cross-check CCE measurements, and the results measured at IHEP showed good consistency with results from Ljubljana and Birmingham
- The irradiation and measurement setups are available for production testing

Reference

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