Quality Assurance methodology for the ATLAS ITk Strip Sensor Production

M. Ullán[a], P. Allport[b], K. Dette[c], V. Fadeyev[d], J. Fernández-Tejero[a], C. Fleta[a], L. Gonella[b], I. Kopsalis[b], R. S. Orr[c], Y. Unno[e]

[a] Centro Nacional de Microelectrónica (IMB-CNM, CSIC), Barcelona, Spain
[b] School of Physics and Astronomy, University of Birmingham, United Kingdom
[c] Department of Physics, University of Toronto, Toronto, Ontario M5S1A7, Canada
[d] Santa Cruz Institute for Particle Physics (SCIPP), University of California, Santa Cruz, USA
[e] IPNS, KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

ABSTRACT

The production of the strip sensors for the ATLAS Inner Tracker (ITk) will start in 2020. Nearly 22000 large area sensors will be produced over a period of roughly 4 years. A Quality Assurance (QA) strategy has been prepared to be carried out during the whole production period. Once the process has been characterized as providing the required pre-irradiation specifications and the proper radiation hardness, the onus is on the manufacturer to rigidly stick to that qualified process. Still, sample testing with specific device-element structures and irradiation of devices should be implemented by the ITk collaboration.
The main devices that will be used by the collaboration for QA purposes are miniature strip sensors (1x1 cm^2), monitor diodes (8x8 mm^2), and the ATLAS test chip. The ATLAS test chip contains several test structures to monitor specific technological and device-element parameters, such as conductive layers sheet resistance, critical parameters of the device oxides such as capacitance, thickness, breakdown voltage, flat-band voltage, etc; Si/SiO2 interfaces charges, and strip and inter-strip electrical characteristics.

QUALITY ASSURANCE

ISO 9000:2015: Quality Assurance: part of quality management focused on **providing confidence** that quality requirements **will be fulfilled**

- Focusses on preserving and improving the manufacturing process so that the quality of the resulting products is assured
- Involves monitoring of the process:
  - ✓ Manufacturing process control
  - ✓ Statistical monitoring of process fluctuations (UCL, LCL)
- Requires understanding of process parameters and relationship with device characteristics
  - ✓ understanding of device failure mechanisms
- Could involve destructive tests
  - ✓ Including radiation tests

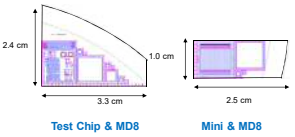
INTRODUCTION

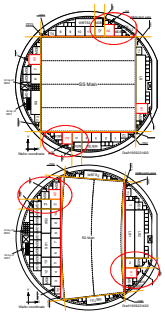
QUALITY ASSURANCE vs. QUALITY CONTROL

QA	QC
• QA aims to **prevent defects** on the process used to make the product	• QC aims to **identify defects** in the finished products
• Its goal is to **assure that the fault does not happen**	• Its goal is identifying and **discarding faulty products**
• It is a **proactive** process	• Is a **reactive** process
• It is **focus on the process**	• It is **focus on the product**
• Test can be made on **other structures**	• Tests are made **on the final products**

IMPLEMENTATION

- 2 QA pieces designed to be diced:
  - Piece 2: Mini sensor & diode (MD8)
  - Piece 1: Test Chip & diode (MD8)
- 4 such pieces (2+2) diced from 2 wafers of every batch in production





ITk STRIP SENSORS QA

Principles:

- For Mini sensor, focus on CCE (@1.6x10^{15} n$_{eq}$/cm^2)
- For Test Chip focus on pre-irrad and TID (@66 Mrad[Si])
- For MD8 focus on pre-irrad (V$_{FD}$) and 5x10^{14} n$_{eq}$/cm^2
- Sampling is split between odd and even batches
- All batches: 1 TestChip and one MD8 tested pre-irrad
- For every batch one Mini is irradiated with protons or neutrons to target fluence and one Test Chip is irradiated to target TID
- Additionally, some pieces irradiated with protons @CYRIC every 6 months (1.6x10^{15} n$_{eq}$/cm^2, 126 Mrads[Si])

IRRADIATION PLAN

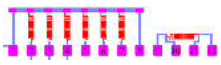
Mini & MD8	#pieces irradiated	Batches odd	Batches even	#per batch	#per shipment	#per month
Not-irrad						
p (CYRIC)	*12 pieces/irrad*	*1/6*	*1/6*	1/6	1	2
p (Bham)	6 pieces/irrad		1	0.5	3	6
n (Ljubl)	6 pieces/irrad	1		0.5	3	6
n (Ljubl) 5e14	6 pieces/irrad	1		0.5	3	6
γ (Prague)	0			0	0	0
TOTAL		2 1/6	1 1/6	1 2/3	10	20

Test chip & MD8	#pieces irradiated	Batches odd	Batches even	#per batch	#per shipment	#per month
Not-irrad		*1*	*1*	*1*	*6*	*12*
p (CYRIC)	*12 pieces/irrad*	*1/6*	*1/6*	1/6	1	2
p (Bham) 5e14	6 pieces/irrad	1		0.5	3	6
n (Ljubl)	6 pieces/irrad		1	0.5	3	6
γ (Prague)	18 pieces/irrad		1	0.5	3	6
TOTAL		2 1/6	3 1/6	2 2/3	16	32

TEST STRUCTURES

Resistors:

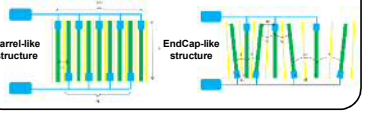
- Bias resistors
  - R$_{bias}$



- Cross-Bridge Resistors (CBR)
  - Measurement of Metal and n-implant sheet resistance
  - Measurement of actual line width (metal over/under-etch and implant lateral difusión)

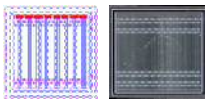
Strip sensor custom structures:

- Inter-digitated structures
  - R$_{int}$, C$_{int}$
  - Interdigitated structure with a total length and pitch identical to the corresponding Main sensor (2 strip rows)
  - The layout of this structure is adapted to each sensor type
  - One SS-like structure always included for reference



Mini sensors:

- 1x1 cm^2 strip sensor identical to Barrel-type MAIN sensors
  - IV, CCE

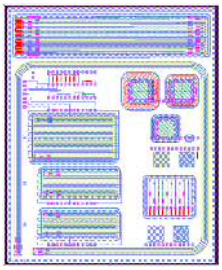


'Category A':

- Will always be tested.
- Results will be used for the batch acceptance decision

'Category B':

- *Structures for detailed studies*
- *Not always tested during production*
- *Acceptance criteria not specified*

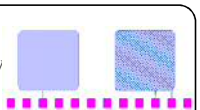


Diodes:

- *Gated diodes*
  - *Square 2x2 mm^2 diodes with a polysilicon gate*
  - *Surface generation current.*
  - *Characterization of the Si-SiO$_2$ interface quality and radiation damage*
- *Standard monitor diodes*
  - *2x2 and 1x1 mm^2*

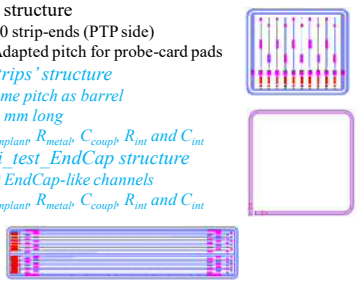
Capacitors:

- Coupling capacitor
  - C$_{coupl}$ & check up to 100 V
  - Comparable to strips area
- Field-oxide capacitor
  - Field oxide thickness, Flat-band voltage → Oxide charge
- *Coupling capacitor for breakdown voltage test*
  - *V$_{BD}$ > 100 V*
- *Field-oxide capacitor with p-stop implant*
  - *Oxide properties over the p-stop*



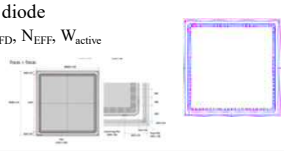
Strip & inter-strip parameter structures:

- PTP structure
  - 10 strip-ends (PTP side)
  - Adapted pitch for probe-card pads
- *'5-strips' structure*
  - *Same pitch as barrel*
  - *34 mm long*
  - *R$_{implant}$, R$_{metal}$, C$_{coupl}$, R$_{int}$ and C$_{int}$*
- *Mini_test_EndCap structure*
  - *10 EndCap-like channels*
  - *R$_{implant}$, R$_{metal}$, C$_{coupl}$, R$_{int}$ and C$_{int}$*



Monitor Diode (MD8):

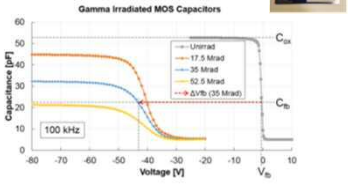
- 8x8 mm^2 diode
  - I$_{LEAK}$, V$_{FD}$, N$_{EFF}$, W$_{active}$



MEASUREMENTS

Test chip measurements

- Automatic probe table for unirradiated chips
- After irradiation, test chip wire-bonded to custom-made test board
- Example test: field-oxide capacitor

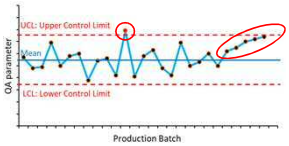


Mini sensor measurements

- Wire-bonding of irradiated mini to ALiBaVA System set-up and measuring the **response to a ^{90}Sr β-source**
- CCE(V) plots show how the peak value of the Landau evolves with voltage for different doses

Batch acceptance

- Key parameters control charts
- Monitoring through ITk Database



CONCLUSION

A full Quality Assurance (QA) plan is presented for the ATLAS ITk strip sensors. Differently from the Quality Control acceptance tests, the QA is carried out on test devices that will not be used in the final experiment. Commonly used test structures like mini-sensors and monitor diodes will be tested for standard post-irradiation IV, CV, and CCE measurements. Additionally, a newly developed test chip has been designed for the continuous test of the key technological and device parameters during production. A sampling strategy has been planned in order to optimize the available resources while being able to have a proper quality assurance monitoring.

This work is supported and financed in part by the Spanish Ministry of Economy and Competitiveness through the Particle Physics National Program, ref. FPA2015-65652-C4-4-R (MINECO/FEDER, UE), and co-financed with FEDER funds, by the Natural Sciences and Engineering Research Council of Canada (NSERC), grant SAPP-J-2018-00, and by the USA Department of Energy, Grant DE-SC0010107.

12th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, Hiroshima, Japan, 14-18 December 2019