Overview of Silicon Pixel Sensor Development for the ATLAS Insertable-B-Layer (IBL)

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For the ATLAS/IBL Collaboration

IEEE Nuclear Science Symposium (NSS)
22-30 October 2011, Valencia, Spain

Insertable B-Layer (IBL)

- New (4th) pixel layer mounted directly on beam-pipe
 - radius=33mm, $|\eta| < 2.5$, 0.2m^2
 - requires new (smaller) beam-pipe
- Reasons for IBL:
 - Back-up existing B-Layer (hard failures)
 - Improve physics performance
(Based on smaller radius and low mass)

Stringent requirements on sensor and front-end electronics

- Need of larger and faster font-end chip
- Better radiation hardness that current detector

Insertable B-Layer (IBL)

Layout:

- 14 Staves, each with 32 front-end chips
- No overlap on Z due to space restriction
- Operate at -15 C, CO₂ cooling, Ti pipe

Front-end/Sensor Design:

- NIEL dose = $5 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$ (w/ safety factor)
- Ionizing dose $\geq 250 \text{ Mrad}$
- Small dead area (slim/active edge)
- Max sensor power $< 200 \text{ mW/cm}^2$
- Max bias voltage: 1000V

Sensor Technology:

- Planar n-on-n and 3D double sided being considered
- 75% Planar and 25% 3D sensor layout:

Sensor facing beam

IBL: Font End Chip: FE-I4 ("A")

- Biggest chip in HEP to date
- Higher active fraction (x6)
(than ATLAS predecessor)
- Local memory cells (bus activity only on readout) → Lower power
- Higher data rate
- More radiation hard (130nm technology)

FE-I4

Pixel array	80x336
Chip size (mm ²)	20.2x19.0
Active fraction (%)	89
Analog/Digital current (uA/pix)	10/10
Analog/Digital voltage (V)	1.5/1.2
LVDS output (Mb/s)	160
Pixel size (um ²)	50x250

Planar Pixel Sensors

- Proven technology current ATLAS detector: n-on-n pixels (DOFZ silicon)
- Bias grid to evaluate sensor quality before bump-bonding
- Thinner substrate (200um, was 250um)
- Slim edge design (~200um, was 1mm)
 - Guard rings on p-side shifted beneath outer pixels (longer outer pixels to keep tile length design)
 - Distorts electric field on the sensor edge, but charge collection after irradiation dominated by region directly beneath implant

Vendor:
CiS-Germany

Two FE-I4 chip IBL planar sensor tile

~200um inactive edge 500um long pixel 250um

3D Pixel Sensors

- Pixel implants penetrate into the substrate: depletion region grows parallel to wafer surface
- Double sided process, p-bulk 230um thick, (FZ high resistivity wafers)
- Two vendors producing IBL 3D sensors with same specifications:
CNM (Spain) and FBK (Italy)

CNM 3D IBL sensors:

- 210um columns
- 3D Guard ring + fences (200um)
- Evaluate sensor quality on GR

Probe pad for quality assurance

3D Guard ring

p+ implant (fences)

3D Pixel Sensors

FBK 3D IBL sensors:

- Pass-through columns
- 200um inactive edge fences
- Evaluate sensor quality with temporary metal on each column

IBL Sensor Selection

Planar and 3D sensors have to meet wafer quality (bow, thickness tolerance, etc) and electrical specifications (leakage current, V_{break})

CNM: leakage current along the GR region

Device Performance

- Devices had been irradiated to IBL fluencies (5E15 neq/cm²)
- Irradiated and non-irradiated devices characterized before test-beams

Low threshold operation possible for irradiated devices

Irradiation of IBL Devices

- Several planar and 3D IBL devices irradiated to IBL fluencies ($5 \times 10^{15} \text{ neq/cm}^2$):
 - Proton irradiation at KIT (beam energy 23 MeV)
 - ✓ Estimated TID dose $\sim 750 \text{ Mrad}$ (IBL requirement: 250 Mrad)
 - Neutron irradiation at Ljubljana
 - Devices annealed: 120min at 60C for test-beam

Test-beams

- Test beam measurements critical to study performance of IBL devices:
 - ✓ Efficiency and position resolution
- Several test-beam periods carried out (DESY, CERN), and different devices tested:
 - ✧ Planar: 3 p-irr, 2 n-irr
 - ✧ 3D CNM: 2 p-irr, 2 n-irr
 - ✧ 3D FBK: 2 p-irr

ATLAS IBL testbeam September 2011, batch 4

drawing by Igor&Konstantin

September test-beam at CERN North area (H6), with the EUDET telescope September 2011

- ✓ Planar reference
- ✓ CNM p-irradiated
- ✓ Planar p-irradiated
- ✓ FBK p-irradiated

Test-beam Results

- Only part of the FE-I4 device covered by telescope planes
- Low threshold operation ($1500e^-$)
- Noisy, dead pixels masked out
- Efficiency determined from extrapolated track on devices

Efficiency = 97.5%

Planar

n-irr

$4E15 \text{ neq/cm}^2$

Test-beam Results

Pixel efficiency map:
fold efficiency
to $1 (\pm 0.5)$ pixel

CNM81 n-irr ($5E15 neq/cm^2$)

FBK13 un-irr

Effect of pass-through vs
partial readout columns
can be seen

CNM34 p-irr ($5E15 neq/cm^2$)

23-cluSize2-resY

Position resolution estimated from residual
distribution in two cluster hits:
9.5 μm (including $\sim 4 \mu m$ from telescope)

Summary

- ATLAS plans to insert a 4th layer (IBL) in 2013/14
- Planar and 3D pixel technologies being evaluated for IBL
 - 75% planar + 25% 3D layout being investigated
- Planar and 3D devices within the IBL requirements have been produced
 - Both technologies well developed
 - Inactive edges of $\sim 200 \text{ um}$
 - High efficiency ($>97\%$) after irradiation ($5E15 \text{ n}_{eq}/\text{cm}^2$) has been achieved
- Final planar and 3D sensor productions underway