**ATLAS Pixel IBL modules construction experience and developments for future upgrade**

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**PIXEL DETECTOR AND INSERTABLE B-LAYER (IBL) OVERVIEW**

During the LHC long shutdown in 2013 and 2014, the services of the detector have been renovated and a fourth layer of pixels, called Insertable B-Layer (IBL), has been placed around a new smaller radius beam-pipe. It will mitigate some loss of efficiency of the previous innermost layer when increasing the peak luminosity. Bringing the radiation hardness requirements stricter with respect to the present Pixel Detector, IBL represents a step in technology both for sensors and readout electronics.

- Large Hadron Collider Run 2 Upgrades
  - Energy upgrade: > 8 TeV → 14 TeV
  - Luminosity up to 2-3 x 10^34 cm^-2 s^-1

**ATLAS Pixel Upgrade essential for recovery**

- FE-I3 inefficiency in B-layer will reach 3% to 10%
- Limitation in Bandwidth
  - 3P: Preserving Data Taking Performance (b-tagging, tracking and PV)

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**SILICON RADIATION TECHNOLOGIES IN IBL**

**PLANAR FEATURES**
- n-in-n technology
- Lower thickness than pixel 250 μm → 200 μm
- Depletion voltage: 50 V

**ATLAS PIXEL SENSOR DESIGN**
- 16 guard rings covering a width of about 600 μm and the 500 μm safety margin are adding up to an overall inactive edge of 1100 μm between the edge pixels and the cutting edge.

**IBL DESIGN**
- The number of guard rings is decreased to 13 and the safety margin is reduced to ~ 90 μm.
- The edge pixels are extended to 500 μm length so that one half of them is placed opposite the guard rings.

**3D FEATURES**
- Double-side Double Type Columns (DDTC) process
- 250 μm thickness
- Depletion voltage: 15 V
- Guard ring fences: 200 μm thick inactive area
- CNM: No Full 3D columns (210 μm)
- FBK: Full 3D columns (230 μm)

**PLANAR SENSORS**
- FBK - The column electrodes traverse the full bulk thickness, requiring p-spray isolation on both sides.
- The bias- and read-out electrodes are left unfilled after doping. At the sensor edge are guard fence posts, these are rows of ohmic contacts that present the depletion region from reaching the dicing region.

**CNM - Columns do not traverse the substrate but stop at a short distance from the surface of the opposite side, furthermore the isolation implantation between the n-columns at the surface are made with the implantation of p-stops on the front size.**

The planar guard ring design in CNM sensors is made using the combination of a n+ 3D guard ring that is grounded, and fences that are at the bias voltage from the ohmic side.

**NEW FRONT-END (FE-I4) -**
- Produced by IBM 130 nm technology to cope higher radiation levels (750 Mrad) and larger occupancies
- 70 Million transistors
- 89% active area

**MODULE QA PRODUCTION FLOW**
- 150 μm thinning of FE-I4 with glass handling wafer

**MODULE QA**
- Bump bonding of sensor and FE(s)
- Electrode QA, TC and functionality test with 200 Am

**IBL MODULE QA**
- Preliminary electrical test after assembly - check if wire-bonds properly done.
- Electrical test at ambient temperature, in which is checked the proper basic functioning of the module (e.g. IV Curves, bump connectivity). Also done the Timing at working point of the Threshold and 90% @ 20 μA.
- Module is thermal cycling (-40, +40°C for 2-3 days) and retested at ambient temperature.
- Complete calibration of the module.
- A functionality test with 200 Am is done
- All tests are executed at ~30 °C.

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**CONCLUSION**

IBL modules production had good yield 75% for planar and 62% for 3D modules) and the insertion of the IBL has been crucial to maintain excellent performance of the ATLAS vertex detector and compensate possible inefficiencies of the old three layer Pixel Detector.