Diamond Pixel Sensors with ATLAS frontend electronics

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Outline

- Motivation
- Atlas Frontend Chip and modules
- Diamond single chip assemblies
- Full scale diamond module
Material Properties:
• Radiation hardness
• Low dielectric constant → low capacitance
• Low leakage current → low readout noise
• Fast signal collection time
• Room temperature operation → no cooling
ATLAS Detector

- One out of four large LHC experiments
- Typical onion layout:
  - Myon spectrometer
  - Calorimeters
  - Central tracking device with three sub detectors
Global support is a flat panel structure
- Made from carbon composite material
- Total weight is 4.4kg
- 80 Mio. readout channels
- \( \sim 1.8 \text{ m}^2 \)
Frontend Chip

Frontend-I3:
• Production chip for the Atlas Pixeldetector
• 0.25µm IBM
• Pixelsize 50x400µm
• 2880 pixels (18x160)
• radhard @100Mrad
• Wide range of tuning possibilities
• Designed for silicon sensors (capacity, mean charge)
Pixel cell of FE-I2

Bump connection to sensor

Differential discriminator

Second differential amplification stage

Internal pulse generator to inject charges

7 bit individual threshold tuning
FE-I ATLAS Analog Performance

- Very linear discharge $\Rightarrow$ good ToT
- Poor man's analog R/O
- Different injected charges

Threshold
Readout

4 simultaneous tasks are running permanently:

• A time stamp (8bit Gray Code) is distributed to all pixels
• When a pixel is hit, the time of rising and trailing edges are stored in the pixel
• The hit is flagged to the periphery with a fast asynchronous scan
• Time information and pixel number are written into a buffer pool (common to a column pair)
• The hit in the pixel is cleared
• If a trigger arrives, the time of the hit (leading edge data) is compared to the time for hits associated to this trigger. Valid hits are flagged, older hits are deleted.
• The trigger is queued in a FIFO
• All valid hits of a trigger are sent out serially. All triggers in the FIFO are processed.
FE-I ATLAS Performance

Threshold tuneable
down to 1500e
Irradiated Modules after 100 Mrad

Before irradiation:

- \( \langle \text{ENC} \rangle = 152 \text{e} \)
- \( \sigma_{\text{thr}} = 40 \text{e} \)

After 100 Mrad:

- ATLAS lab measurements:
  - \( \langle \text{ENC} \rangle = 182 \text{e} \)
  - \( \sigma_{\text{thr}} = 127 \text{e} \)

- 20 yrs LHC

NoRDHia workshop@GSI

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Hybrid pixel detector

- All Diamond sensors provided by RD42
- Pb/Sn bumping done by Fraunhofer IZM Berlin
- Bumpsize 20µm
  Spacing 50µm
Diamond Bumping

- Challenge: Bumping process is designed for wafer scale IC, not for single die/module
- The diamond has to be glued into a support substrate wafer for underbump metallization (UBM)
- Bump is on FE-Chip side
UnderBump Metallisation

- Deposition of plating base
- Application of photo resist
- Galvanic metallization
UnderBump Metallisation

- Removal of photo resist and plating base (if plating base removed only partial shorts between pixels, this has happened)

- Cut out of diamond
- Flip Chip bump bonding
Diamond Singlechip Assemblies

Active area 7.6x8mm²
Diamonds at Bonn

- 2001: UTS5, poor bumping quality, only a corner of good bumps, radsoft FE-C
- 2002: CD91, better bumping, but sensor worked less well than UTS5, radsoft
- 2003: CD109, glue remnants on chip
- 2003: CD114, shorts between pixels due to plating base not etched away
- 7/2004: CD114 expected

Testbeam HitMap Data
Diamond singlechip UTS5 (2001)

Source Test

Map of hits from TOT meas. chip 0

Americium241 source (~4600e)
Diamond singlechip CD109

Cadmium109 source (~1500e)
Diamond singlechip UTS5
Diamond Measurements

Threshold distribution

- Constant: 243.1
- Mean: 1543
- Sigma: 96.1

Threshold
~1500e

Dispersion
~100e

Noise distribution

- Constant: 166.3
- Mean: 131.6
- Sigma: 11.48

Noise
~130e

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Atlas Pixel Modul

- Sensor ~6x2cm²
- 46000 pixels
- 16 Atlas FE-I3 chips
Full Diamond Pixel Module

• Practice piece in processing at Fraunhofer IZM
• Full Atlas type Module planned to be ready late summer this year
Summary

- Have first assemblies with ATLAS Frontend Chip
- Atlas FE-I3 suitable also for diamond sensors
- Full scale Diamond module in preparation
Testbeam Results

Residual distribution in both pixel dimensions

M. Keil
Pb/Sn Bump

- wettable metallization (ep-Cu)
- plating base (Cu)
- adhesion layer & diffusion barrier (Ti:W)
- passivation (SiO2, Si3N4, SiON)
- VO-pad (Al)
- chip (Si)

Pb40Sn60
Pb95Sn5
Testbeam Results

Collected charge during testbeam with fitted landau distribution.

Correlation between hits of diamond detector and beamtelescope

M. Keil
Testbeam Results

Charge collection distance

M. Keil, in agreement with simulations T. Lari

Collection distance 228±4μm @20°