Active Edge and 3D Sensors

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International Symposium on Detector Development
SLAC, April 5, 2006
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Project Members

- **Molecular Biology Consortium** - C. Kenney, E. Westbrook, A. Thompson, E. Perozziello
- **Brunel University** - J. Hasi, A. Kok, C. da Via, S. Watts
- **University of Hawaii** - S. Parker
- **Lawrence Berkeley Laboratory** - D. Gnani, E. Mandelli, G. Meddeler
- **CERN – M. Deile, G. Anelli**
- **European Synchrotron Research Facility** - J. Morse
Standard Planar

• Sawed Edge
• Edge is Undefined
• Many Dangling Bonds
• Effective Short Between Surfaces
Active Edge Concept

Wrap Top Field Oxide Around Side

- Induced Electron Sheet
- Float-zone N-type Silicon
- P$^+$
- Thermal Oxide
- N+ Electrode
Active Edge Concept

Wrap Bottom Implant Around Side

N⁺ Diffusion

Float-zone N-type Silicon

P⁺

Thermal Oxide

Induced Electron Sheet

N⁺ Electrode
Fabrication

- Use Support Wafer
- No Sawing
- Plasma Dice Instead
- Dope and Grow Field Oxide on Edges
- Otherwise same as Standard Planar
ALS X-ray microbeam signal on the 1\textsuperscript{ST} and 2\textsuperscript{ND} channels of a Active Edge planar detector

- Current Integration Mode
- 16 Strips
- 150 mm Pitch
- 100 mm thick

MEASURED DEAD EDGE < 5 µm
O Volts Bias

- Diffusion Paths 100 mm long
- Still 80% of Signal at Edge
- Low Trapping Probability
- Long Life times in Bulk
Wire Bonds

- Sensitive up to Edge
- Even With No Implant!
Benefits for Crystallography

Direct absorption in silicon:
Single X-photon sensitivity
(Pseudo) counting detector: dynamic range??
active edges => large area can be covered with small sensors (yield!)
and with near zero insensitive border areas
Quasi-continuous readout with no deadtime (continuous spindle rotation?)
Single pixel spatial response (~100µm typical ‘pixel’ size)
System Geometry

All X Rays are within 3 Degrees of Normal to the Sensors
ASIC Design

1. 64 x 64 pixels, each 150 µm x 150 µm.
2. Readout pixels are only 144 µm x 150 µm, keeping the readout chip fully under the sensor.
3. Each pixel has an integrating amplifier.
4. 2 rows are read out together, using 128 lines.
5. Integration resumes after 1 µs.
6. Pulse heights are digitized in a Wilkinson ADC.
7. Readout moves to next two rows after an additional µs.
8. Data is output to the computer from alternate buffers. The full sensor is readout every 64 µs.
9. Charge-shared signals can be recombined in the computer.
10. Small replaceable units for efficiency
PXTAL ASIC

- 8 by 64 Pixel Array, plus Full-Size 9th Test Column
- 128 ADCs
PXTAL Bumps

- Indium Bumps Deposited at Stanford
- Indium to Indium
- 4 μm Bump Height
- Flip-chip Bonding Done at Stanford
Photon Counting

- Simultaneous Fit to All 8 Peaks
- Fit to Poisson Distribution Envelope
Active-Edge Beam Stops

- All 6 Surfaces are Sensitive
- Square 220 µm Sides
- 3 – 10 mm Long
- Small Shadow
- Linear

Signal (a.u.)

Vertical Slit Separation (microns)

2000 4000 6000 8000 10000 12000 14000

0 20 40 60 80 100
TOTEM

- LHC Experiment
- Roman Pots – 220 m from CMS
- Close to Beam
- Active Edge is Critical for Physics

- Supplying Half of Sensors
- 10 cm² Sensors
- 120 Sensors
TOTEM SENSOR BEHAVIOR

- NICE IV CURVE
- NO EXCESS EDGE CURRENT
- NORMAL LANDAU
3D with Active Edges

- No Guard Rings
- No Dead Area at Edges
- Allows Seamless Tiling
- Edge is an Electrode
- Efficient Wafer Use

- 200 $\mu$m pitch
- 16 Strips
- 180 $\mu$m thick
3D silicon detectors were proposed in 1995 by S. Parker, and active edges in 1997 by C. Kenney.

Combine traditional VLSI processing and MEMS (Micro Electro Mechanical Systems) technology.

Electrodes are processed inside the detector bulk instead of being implanted on the Wafer’s surface.

The edge is an electrode! Dead volume at the Edge < 2 microns! Essential for
- Large area coverage
- Forward physics

1. NIMA 395 (1997) 328
7. NIMA 509 (2003)86-91
no low-side tail, so very few, if any, events with partial charge collection efficiency
3D Active Edge Scan

4 N⁺ Electrodes

30 Volts

4 P⁺ Electrodes

microns

Edge
Sensitive to Within 2 μm of Edge!

Based on Full-Width at Half Maximum
Drawn Strip Pitch = 200 μm
Measured InterStrip Pitch = 199 +/- 2 μm

Measured Edge Strip Width = 200 +/- 2 μm
X5 test beam at CERN

- 3D
- Active Edge
- 180 µm Thick
- 16 Strips
- 100 GeV Muons
- 5 µm Telescope
Some results from the CERN X5 beam test (100 GeV muons)

Measured hit position in 3D sensor plane #3 vs. predicted position from beam telescope.

Fitted 3D sensor width = 3,203 ±4µm. Drawn width = 3,195 µm. Sensor efficiency = 98%. System efficiency less due to DAQ, triggering electronics.
3Dc Radiation hardness tests

Volume = 1.2 x 1.33 x 0.23 mm³
Inter-electrode spacing = 71 µm
n-electrode readout
n-type before irradiation

- 50 µm pitch pixels
- Different fluences
  Highest beyond 10^{16} p/cm²

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<tr>
<th>Name</th>
<th>Fluence n_{1MeV}/cm^2</th>
<th>Fluence p/cm^2</th>
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<tr>
<td>7F</td>
<td>3.74e15</td>
<td>6.0e15</td>
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<td>7A</td>
<td>5.98e15</td>
<td>9.6e15</td>
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<tr>
<td>7D</td>
<td>8.60e15</td>
<td>1.4e16</td>
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Graph 1:
- 3Dc PRELIMINARY
- 1060 laser beam
  Spot size = 500 µm diameter,
  1000 averages, T = -10°C,
  Ampli-gain=1000

Graph 2:
- 3Dc PRELIMINARY
- 3D silicon C. DaVia et al. March 06
- 1.8x10^{16} p/cm²
  10 years
  SLHC at
  10^{24} cm²s⁻¹
  At r=4cm
3D TIMING

- 0.25 micron amplifier and
- Response of sensor same as pulser

- 0.13 micron amplifier and
  100 micron “diameter” hexagon/strip

FWHM = 2.5 ns

0.13 µm Amplifier

Min rise time RT = 3.5 ns

0.25 µm Amplifier
FP420 – Forward Physics at 420 meters

- DIFFRACTIVE PHYSICS
- GOOD MASS RECONSTRUCTION
- AUGMENT CMS & ATLAS
- UP/DOWNSTREAM of ATLAS & CMS
- INSTALLED IN ROMAN POTS

Albert De Roeck
Mike Albrow

PHYSICS:
E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al.
V. Petrov et al…
• ACTIVE EDGES for PHYSICS ACCEPTANCE
• 3D for RADIATION DAMAGE
• PIXELS for MOMENTA RECONSTRUCTION
• PIXELS for OCCUPANCY
• 200 $\mu$m THICK
• 50 $\mu$m by 400 $\mu$m PIXELS
• ROTATE SENSORS for X & Y
• OFFSET PLANES $\sigma < 10 \, \mu$m

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<thead>
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<th></th>
<th>2E</th>
<th>3E</th>
<th>4E</th>
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<tr>
<td>Electrode Area (%)</td>
<td>4</td>
<td>6</td>
<td>8</td>
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<tr>
<td>Depletion Distance (microns)</td>
<td>100</td>
<td>70</td>
<td>50</td>
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Cell Design

- Single Sensor Yield > 50 %
- Breakdown Independent of Electrode Spacing
- Active Edges Robust against Breakdown
ATLAS UPGRADE

- ATLAS ASIC for FP420
- SENSORS FULLY COMPATIBLE with ATLAS ELECTRONICS
- 3D IS RAD HARD ENOUGH for B-LAYER
- BUMP 3D SENSORS and ATLAS ASICs
- CERN BEAM TEST in FALL 2006
Tiling the Plane
PXTAL Movie

- 12 keV Photons
- Detector Stage Scanned