Bump Bonding for Pixel Detectors

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Outline

- Introduction
- Applications in High Energy Physics
- Applications to X-ray Imaging
- Common Requirements
- Specific Requirements
- Accessible Companies and Technologies
- Comparison of Technologies
- Remaining Challenges for LHC
- Beyond LHC
Hybrid Pixel Detector

- sensor chip (e.g. silicon)
- high resistivity n-type silicon
- p-type silicon layer
- aluminium layer
- electronics chip
- single pixel read-out cell
- flip chip bonding with solder bumps

Workshop on Bonding and Die Attach Technologies
M.Campbell
11-12 June 2003
Because of charge sharing threshold normally set around 1/3rd Landau peak

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Signal, Threshold, Noise
CERN Experiment WA97 (1995)

5 x 5 cm² area
7 detector planes
Pixel dimensions 75 x 500 µm²
Trigger precision 1 µsec
1 kHz trigger rate

NB. Dead area ~3% in total over 7 x 5 x 5 cm²
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Alice pixel detector

- 2 barrel layers
- $p^+$ on n detectors
- pixel dimensions 50 $\mu$m x 425 $\mu$m
- chip contains 256 x 32 pixels
- 1 x 5 chips/module
- ~ 240 modules
- ~ 2 million channels in total

see talk of Petra Riedler
Atlas pixel detector

- 3 barrel layers and 3 disk layers
- \( n^+ \) on \( n \) detectors with \( p \) spray isolation
- pixel dimensions 50 \( \mu \text{m} \) x 400 \( \mu \text{m} \)
- chip contains 160 x 18 pixels
- 2 x 8 chips/module
- \( \sim \) 1 500 modules
- \( \sim \) 100 million channels in total
BTeV pixel detector

- 31 station 10 cm x 10 cm
- n+ on n detectors with p-stop or p-spray
- pixel dimensions 50 $\mu$m x 400 $\mu$m
- chip contains 128 x 22 pixels (tentative)
- 1 x (4 to 8) chips/module
- ~ 30 million channels in total
CMS pixel detector

- 3 barrel layers and 2 disk layers
- \( n^+ \) on \( n \) detectors with dual concentric broken p-stop rings
- pixel dimensions 150 \( \mu m \) x 150 \( \mu m \)
- chip contains 52 x 53 pixels
- 2 x 8 chips/module
- ~ 752 modules
- ~ 33 million channels in total in barrel

see talks of Alan Honma and Christian Brönnimann
LHCb RICH readout

- Chip/detector assembly inside Hybrid Photon Detector (under vacuum)
- Single photo-electron detection required (5000 e-)
- p^+ on n detectors
- Pixel dimensions 500 \(\mu\)m x 500 \(\mu\)m
- Chip contains 32 x 32 super-pixels (each super pixel contains 8 sub pixels)
- ~ 1000 tubes needed
- ~ 1 million channels in total

See talk by Thierry Gys

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Synchrotron Applications

- **PILATUS (SLS)**
  - 44 x 78 pixels, 217µm pitch
  - 2 x 8 chip ladders
  - see talk by Christian Brönniman

- **ALADIN (RAL)**
  - 64 x 64 pixels, 150µm pitch
  - 1 x 7 chip ladders

- **XPAD (Marseilles)**
  - 24 x 25 pixels, 330µm pitch
  - 2 x 5 chip ladders
Medical Imaging Applications

- **Integrating systems**
  - Nova R&D Mary chip
    - 192 x 384 pixels, 50\(\mu\)m pitch
  - AJAT DIC100
    - Xx x yy pixels, 100\(\mu\)m pitch

- **Photon counting systems**
  - MPEC2.3 (Bonn) 32 x 32 pixels, 200\(\mu\)m pitch
  - Medipix2 256 x 256 pixels, 55\(\mu\)m pitch
Common Requirements

- Pitch ~ 50\(\mu\)m
- Chips > 1 cm\(^2\)
- 1 000 – 100 000 bumps/chip
- Large area coverage -> multi-chip ladders (5-16 chips per ladder)
- Dead area between ladders should be limited
- Deep sub-micron CMOS (8” wafers)
Application Specific Requirements

- **HEP**
  - Low mass assembly
  - Thin Si detectors and (post bumping thinned CMOS)
  - Pitch limited by material budget – going < 50μm
  - Makes no sense in present systems

- **For Photo Multiplier Tube Encapsulation**
  - Vacuum compatible technology
  - High temperature cycling

- **X-ray imaging**
  - High $\rho$ (exotic!) material
<table>
<thead>
<tr>
<th>Company</th>
<th>Technology</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS</td>
<td>In (cold)</td>
<td>Atlas/Alice</td>
</tr>
<tr>
<td>IZM</td>
<td>SnPb (eutectic)</td>
<td>Altas</td>
</tr>
<tr>
<td>MCNC</td>
<td>SbPb (eutectic)</td>
<td>BTeV</td>
</tr>
<tr>
<td>PSI</td>
<td>In (reflow)</td>
<td>CMS</td>
</tr>
<tr>
<td>VTT</td>
<td>SnPb (eutectic)</td>
<td>Alice/NA60</td>
</tr>
<tr>
<td></td>
<td>SnPb (high Pb)</td>
<td>LHCb RICH</td>
</tr>
</tbody>
</table>

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## Comparison of Used Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pull Strength (g/bump)</th>
<th>Max Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In (cold)</td>
<td>0.1</td>
<td>100</td>
</tr>
<tr>
<td>In (reflow)</td>
<td>0.2-0.3</td>
<td>250</td>
</tr>
<tr>
<td>SnPb (eutectic)</td>
<td>1</td>
<td>230</td>
</tr>
<tr>
<td>SnPb (reflow)</td>
<td>??</td>
<td>380</td>
</tr>
</tbody>
</table>
Typical defect and causes

- Missing corners – poor co-planarity during alignment / reflow
- Low pull strength – poor UBM adhesion / poor wetting (in reflow processes)
- Local shorts between pixels – too much compression / movement during reflow
- High detector leakage currents – incomplete field layer etching / poor dicing
Remaining challenges for the LHC

- Selection and burn-in of KGD
- Total quantities (~ 40 000 installed placements needed!)
- QA during production and feedback to suppliers
- Lifetime testing of bumps
- Handling of large numbers of extremely thin and (sometimes) fragile components
- Rework
A controversial question:

Will bump bonding problems sign the death warrant for hybrid pixel detectors in HEP?

Depends on how we do for LHC….

Cost

Ultimately, hybrid pixels provide unbeaten pattern recognition.
Beyond LHC1

- Solutions for single chip tiling
- Thinner assemblies
- Inter-layer interconnect
- True vertex finding…

- X-ray imaging community may become a large user too (depends on developments..)