Modulbauentwicklung für das Phase-II Upgrade des äußeren CMS-Spurdetektors
Module Prototyping for the Phase-II Upgrade of the CMS Outer Tracker

DPG Würzburg – 19.03.18  T 41.8
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The Phase-II Upgrade of the CMS Outer Tracker

- New silicon tracker of the CMS-Experiment for HL-LHC by 2026
  - Increased granularity
  - Radiation tolerant to up to $10^{15}$ $n_{eq}/cm^2$
  - Reduced material budget
  - Sensors operated at $-20^\circ C$
- Outer tracker will consist of ~13000 double-sided modules
  - 2S: strip/strip sensor
  - PS: pixel/strip sensor
- Contribution to Level 1 Trigger by $p_T$-module concept
**p_T-Module Concept**

- Bending of tracks identified on double-sided sensor module by a coincidence logic
- High-\(p_T\) particle information contributes to Level 1 trigger
- Cut on \(p_T\) keeps trigger rates under control
  
  → **Alignment of superimposed strips in 2S Modules needs to be \(\Theta < 400 \text{ \mu rad}\) to ensure functionality of coincidence logic**
  (offsets can be corrected by software)

**High-\(p_T\): pass**

**Low-\(p_T\): fail**

- Top Sensor
- Bottom Sensor

- Sensor strips
- 10 cm
- Tilt 40 \(\mu\)m
2S Module for the CMS Outer Tracker

**Service Hybrid**
- Powering
- Data transmission

**2 Front-end Flex Hybrids**
- 8 CMS Binary Chips each
- 1 Concentrator Chip each
  - Connected to both sensors

**Spacer**
- Carbon fiber reinforced aluminum
- Mechanical fixation

**2 Silicon Strip Sensors**
- 2 x 1016 strips (5 cm) each
- Bottom to top strip alignment of <400 µrad
Assembly and test procedure of 2S Modules

1. Glue polyimide HV isolation and attach HV tails on sensor backside

- Dicing precision (metrology)

2. Glue sensors on bridge

- Optical inspection
- Sensor I(V)

3. Glue readout and service hybrids on bare module

- Module metrology
- Sensor I(V)

4. Place 4000 wire-bonds

- Module test

5. Encapsulate wire-bonds

- Module test

Optical inspection

Sensor I(V)

Module metrology

Sensor I(V)

Dicing precision (metrology)

HV/LV test

Module test

For module test station, see Roland Koppenhöfer, T25.1
Backplane polyimide isolation and HV tails

- Thin gluing layer for good cooling contact
- Apply thin glue line with 0.06 ml/mm on sensor backplane with a volumetric dispenser on gantry
- Place polyimide strips with precision jigs and attach HV tails
Bare module gluing

- Glue applied on polyimide with a stamp
- Sensors and bridges are precisely placed on top of each other in a jig
- Alignment pins allow high gluing precision
  → High sensor dicing precision necessary for good top strip to bottom strip alignment
Bare module metrology – concept

- Two-step measurement to measure bottom strip to top strip alignment
  - Sensor dicing angle
    - Optical, pattern recognition
    - Before assembly
  - Edge alignment
    - Laser measurement along edge
    - After assembly

5MP Microscope

Bare module

Sensor Bridge

Reflection

1. Dicing precision

2. Edge alignment

Vacuum jig

Laser

Strip to strip alignment

933.1 µm  933.5 µm

Sensor edge

Distance measurement

Aluminum mask
Metrology measurements

- Bottom sensor dicing angle: 
  \(-9 \pm 11 \, \mu\text{rad}\)

- Top sensor dicing angle: 
  \(-15 \pm 11 \, \mu\text{rad}\)

- Edge alignment: 
  \(23 \pm 35 \, \mu\text{rad}\)

- Top strip to bottom strip alignment: 
  \(-1 \pm 57 \, \mu\text{rad}\)

\textbf{Specs:} < 400 \, \mu\text{rad}
Hybrid gluing

- Hybrids aligned to sensors on jig
- Apply 1.5 mg of glue with dispensing gantry on each joint
Wire-bonding

- Wire-bond jig locks module into position during bonding
- ~4000 wire-bonds per module
- Preliminary studies for bond parameters:
  - No lift-offs
  - ~10g pull force

- Each readout channel successfully wire-bonded

Bottom row
Length: 3.4 mm
Height: 500 µm

Top row
Length: 4.2 mm
Height: 600 µm
Sr90 source measurement

Entries

Strip

Top sensor
Bottom sensor
To come: Wire-bond encapsulation

- Protect bonds with silicone elastomer
  - Mechanical damage: touching
  - Chemical damage: (electrochemical) corrosion
  - Keep bond feet from lifting from the bond pad
- Earlier: Tested on dummy material
  - Application techniques
  - Irradiation studies
- Next: Further studies on dummy modules planned
Summary, Outlook

- $p_T$-Modules are a key element of the CMS Outer Tracker Upgrade
- The modules detect high-$p_T$ particles with a coincidence logic connected to two precisely aligned silicon sensors
- During production various assembly and test stations are used
  - Precision jigs
  - Dispensing gantry
  - Metrology station
  - ...

- We built our first functional 2S module within specification
  - Bottom to top strip alignment: $-1 \pm 57$ µrad
  - HV stable up to 1000 V
  - $I(V)$ characteristics not impaired during assembly