

Pixel detectors hybridization with Anisotropic Conductive Films

CLIC vertex detector

and different prototypes





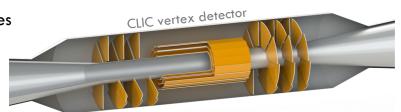
mvicente@cern.ch - 28/08/19

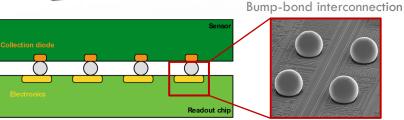
Vertex detector with high demands for the pixel detector modules

- Extremely low mass, 0.2 % X₀ per detection layer
- □ Single hit resolution of ~3 μm

Under study for the future CLIC vertex pixel detector

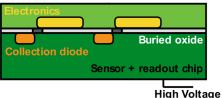
- Hybrid detector (sensor and read-out as individual devices)
 - Pixel size of 25 μm x25 μm
 - Read-out ASIC and sensor thickness of 50 µm (each)
 - Challenging and expensive solder bump-bonds is a drawback





Alternatives to bump-bonding (check Silicon Vertex & Tracking Detectors, Simon Spannagel – 15.03.10)

SOI monolithic detector



HR CMOS MAPS

Shielded electronics Collection diode High resistivity substrate

Sensor + readout chip

High Voltage

HV CMOS MAPS



High Voltage

Collection diode

Electronics

Glue

Electronics

Read-out chip

HV CMOS CCPD hybrid

High Voltage

Hybridization with ACF

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but what is ACF?

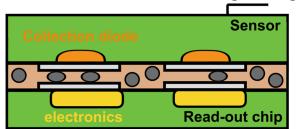
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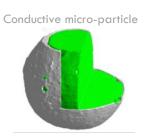
- Anisotropic Conductive Film (ACF)
 - Adhesive film filled with conductive micro-particles
 - Anisotropic as the electrical connection is done only in the (vertical) direction, from the sensor pads towards the RO ASIC pads
 - Statistically, a few conductive balls get stuck under the pads and crushed during bonding, establishing electrical contact

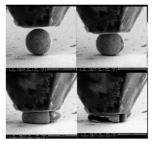
Challenges

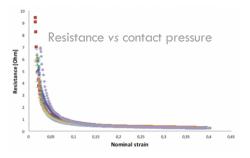
- Need to ensure the presence of at least 1-2 balls under each pad
- □ Force, temperature and time for the bonding process need to be optimized to ensure good contacts
- The viscosity of each material need to be optimized for limiting the mobility of particles while promoting the film flow











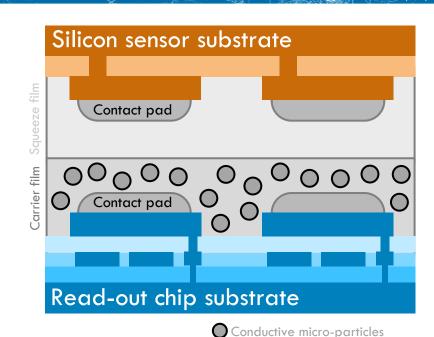
ACF characteristics

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and bonding process

- Device preparation
 - **ENIG** Electroless nickel immersion gold
 - Mask-less process to grow contact pads
 - No Under-Bump Metallization needed
- Anisotropic Conductive Film
 - Two layers film. Total thickness ~ 18 μm
 - Particle diameter ~ 3 μm
 - Curing starts at ~ 100 ℃
 - Recommended bonding temperature = 150-180°C
 - ACF-63: Ni/polymer Film with high density of particles
 - ACF-64: Au/Ni/polymer Film with lower particle density
- Bonding
 - Pre-bonding: 10 kg at 80°C during 10 seconds (1 kg for test-structure)
 - Bonding: 100 kg w/80°C (during "flow_time" seconds) and 150°C (for 18 seconds) (8 kg and 15 s for the test-structure)



ACF characteristics

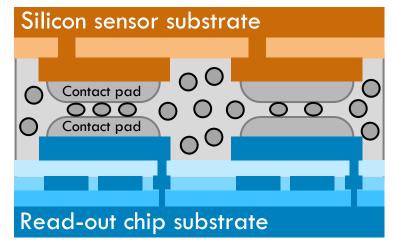
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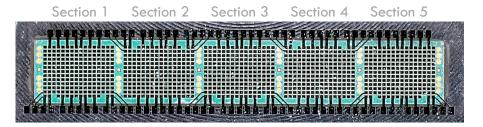
Conductive micro-particles

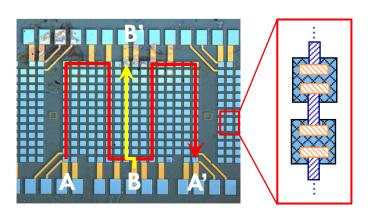
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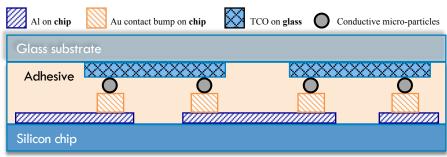
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w/ Conpart test-structure

- Test structure (1.5 x 10 mm²) designed with a matrix of pads
 - Complete matrix measurement (from A to A') or 12 individual matrix segments measurement (such as from B to B')
- 5 different sections to evaluate different contact bump sizes
 - Section 1: 15 μm x 60 μm = 900 μm² (lower resistance expected)
 - Section 2: 12 μ m x 50 μ m = **600** μ m²
 - Section 3: 10 μ m x 40 μ m = **400** μ m²
 - Section 4: 10 μ m x 35 μ m = **350** μ m²
 - Section 5: 10 μ m x 30 μ m = **300** μ m²







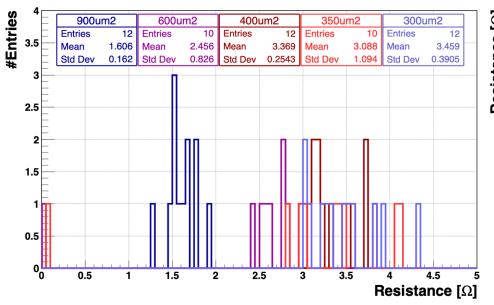
ACF bonding trials

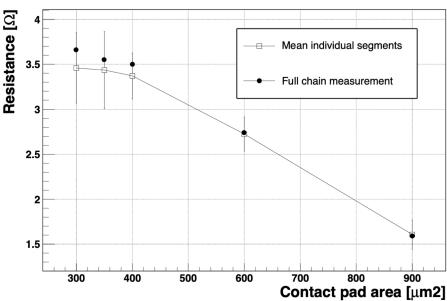






- □ Electrical **resistance** measurement: 1st test-structure, assembled with **ACF 63**
 - Resistance scales with the bump size, as larger bumps will capture more conductive micro-particles, lowering the electrical resistance
 - The full matrix resistance measurement varies slightly from the mean resistance of the individual segments





ACF bonding trials

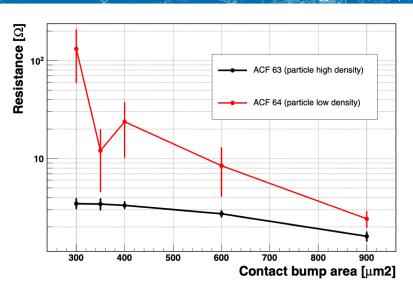


w/ Conpart test-structure - ACF 63 vs 64



8

- 2nd test-structure measured, assembled with **ACF 64**
 - With lower particle density, it will have a lower probability to capture conductive micro-particles
- The measurement of the full matrix failed for all sections, with exception to 350 µm² showing 51.5 Ohm
- Many segments measurement has shown open contact (OC)
 or very right resistance (> 10 kOhm) HR
 - □ 300 µm2: 1 OC, 4 HR □ 350 µm2: 4 OC
 - 400 µm2: 3 OC, 1 HR 600 µm2: 4 OC
 - 900 µm2: 2 OC



- Results shows that ACF bonding is feasible and resulting bonding resistance is within bonding specifications for a bump-bonded hybrid pixel detector (≥ 100 Ohm)
 - Timepix/Timepix3 has a contact area of $\sim 400 \ \mu m^2$
 - The contact area of CLICpix2 chip is $\sim 200 \ \mu m^2$

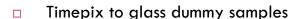
ACF bonding trials

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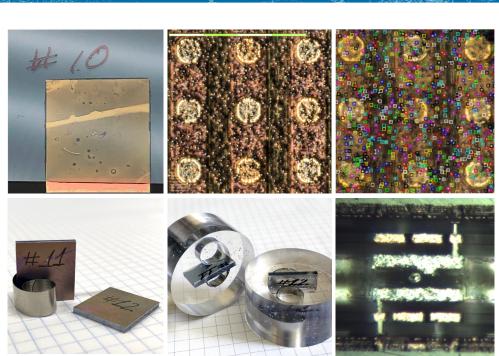
and detector samples produced

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- \square S9: Timepix2 + ACF-63 + flow time = 500s
- \square S10: Timepix + ACF-63 + flow time = 100s
- \square S13: Timepix* + ACF-63 + flow time = 50s
- \square S14: Timepix* + ACF-63 + flow time = 500s
- \square S15: Timepix* + ACF-64 + flow time = 500s
- \square S16: Timepix + ACF-64 + flow time = 500s
 - *ENIG pitch = $110 \mu m$
- ☐ Timepix to Timepix samples (without ENIG)
 - S11: Timepix-Timepix, ACF-63, T_{flow} = 100s
 - S12: Timepix-Timepix, ACF-64, T_{flow} = 100s

Timepix area ~ 15 x 15 mm²



Glass samples visual inspection

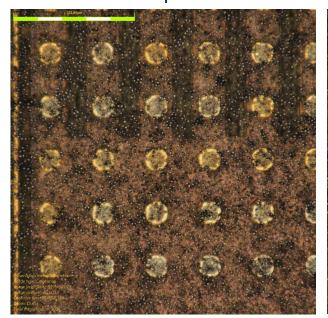


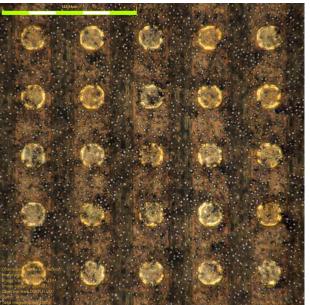


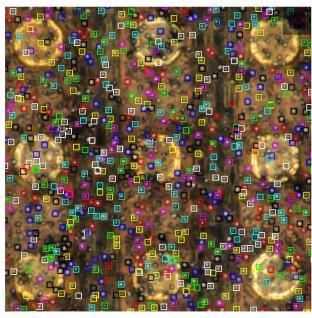
Sample 10 – ACF 63 – Flow for 100s

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Initial visual inspection shows about ~ 10 particles per pixel pad







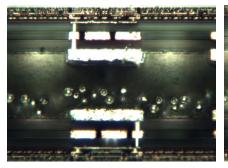
Cross-section measurement

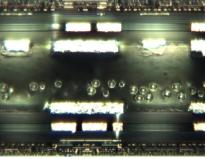


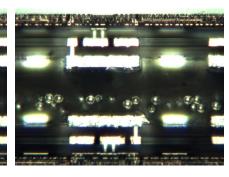


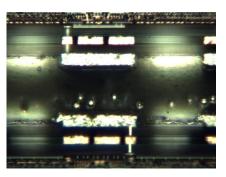


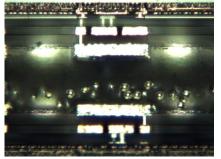
- **S11**, high density film
- Good capture rate per pad
- Pictures shows no particle being crushed
 - As expected without ENIG contact bumps/pads
- □ Pixel pad gap ~ **18 µm**
 - Good agreement with film thickness
 - Squeeze film not completely squeezed out
 - Thinner film needed for next assemblies;













Glass samples visual inspection

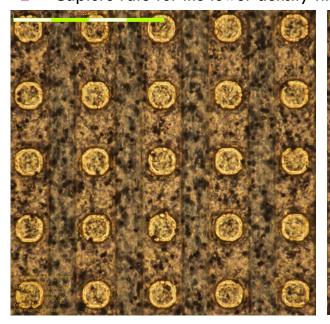


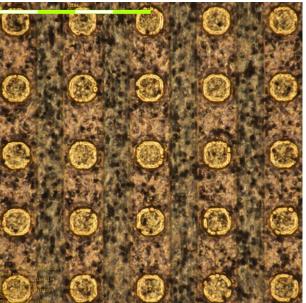


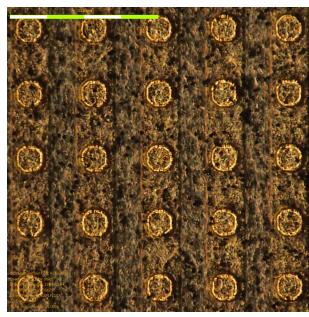
Sample 16 – ACF 64 – Flow for 500s

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Capture rate for the lower density film is about 1-3 particles







Cross-section measurements

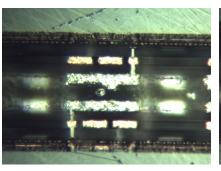




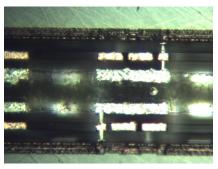
Timepix-to-Timepix - Sample #12 - ACF 64

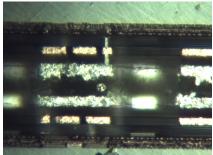


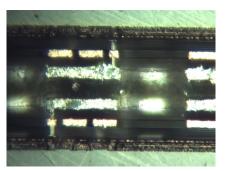
- \$12, low density film
- Low particle capture rate
 - Confirming surface pictures
- No crushed particles
 - As expected without the ENIG contact pads
- Smaller pixel gap \sim **6 \mum**
 - ACF 64 film is less viscous with respect to ACF 63

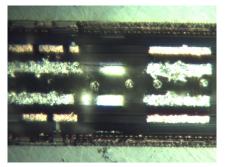












Conclusions

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and future steps

- The CLIC vertex detector has high demanding requirements
 - Currently, standard hybrid detector fabrication processes does not provide satisfactory fabrication yields
 - Bump-bonding additional fabrication process steps increases the detector production cost and complexity
- Detector hybridization with ACF combines the easier assembly process from CCPDs (possible with in-house flip-chip), with the DC coupling to planar silicon sensors as current bump-bonded hybrid pixel detectors
- Electrical resistance measurement on dedicated test-structures has shown that the ACF DC coupling is achieved between different devices
 - Resulting resistance of **2-4 Ohm** (with the high density **ACF 63**) is bellow the expected resistance used in the read-out chip design
 - As expected, ACF 64 results in higher electrical resistance due to the lower quantity of conductive particles available
 - Nevertheless, resistance keeps good < 100 Ohm
- Future assembly tests will follow using the Timepix3 chip with a standard planar silicon sensor, processed with the ENIG contact pads
 - ENIG deposition in read-out ASIC and sensor wafers is on-going