



Update on ACF interconnect studies for novel pixel detector hybridization

CLICdp Collaboration meeting 01/10/2020

Mateus Vicente (EP-DT-TP)

Work context

and talk outline

Vertex detector with high demands for the pixel detector modules

- **CLICpix2** hybrid pixel detector
 - Pixel pitch of 25 μm x25 μm
 - Challenging and expensive solder bump bonding is a drawback
 - See talk by Morag Williams

CLICdp investigated alternative technologies to standard bump bonding

 Check: <u>Pixel detector hybridisation alternatives to bump-bonding</u> and <u>Anisotropic Conductive Film (ACF) developments</u>

Talk outline

- Bonding with Anisotropic Conductive Films
- First test-beam results with an ACF bonded Timepix3 assembly
 - + cross-section measurements
- First in-house under bump metallization trials at CERN





CLICpix2 + planar Si sensor 128 x 128 pixels 25 µm pixel pitch 3.2 x 3.2 mm²

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Timepix3 + planar Si sensor 256 x 256 pixels 55 µm pixel pitch 14 x 14 mm²



ACF – Anisotropic Conductive Film µ-particle bonding

- Multiple 3 µm polymer spheres plated with Ni-Au embedded in an adhesive film
 - µ-particles gets **captured** between the UBM in the sensor and ROC during thermocompression
 - Permanent attachment and an anisotropic electrical connection only in the direction of the compression
- **Conpart (AIDAinnova & EP-R&D** partner): Specialized in providing and characterizing the µ-particles









Bonded Timepix3/sensor pixels

ACF particle deformation

van der Pauw measurement

ROC pixel matrix w/ ACF

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Polymer

core

HirAuconing

conpart

Timepix3 ACF hybrid

First assembly tests – Test-beam at DESY

- □ The ACF sample was tested at DESY during one night with 5.4 GeV electrons
 - Recorded tracks coverage limited by telescope acceptance (Mimosa26 smaller than Timepix3)
 - Lack of hits around the center of the pixel matrix still to be understood
 - Recorded efficiency shows 390 pixels with 100% efficiency Analysis still on-going
 - Signal from surrounding pixels most likely coming from cross-talk
 - Cluster size map shows tracks going through unconnected pixels generating larger clusters w.r.t. pixels with 100% efficiency



Timepix3 ACF hybrid

First assembly tests – Cross-section measurements



- After test-beam data acquisition, the sample was prepared for cross-section measurements
 - Assembly was removed from PCB
 - In order to locate the cross-section area within the chip (within mm precision (~20 pixels)), the efficiency map was inverted horizontally, printed with a 1:1 scale, and glued to the backside of the Timepix3
 - Assembly was embedded on a transparent resin



Timepix3 ACF hybrid

First assembly tests – Cross-section measurements



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- Cross-section around the first columns shows a few pixels with ACF particles slightly crushed
 - Higher bonding force/pressure would be desirable
- Cross-section around the last columns shows a gap between the pixels about 2 µm larger
 - ROC/sensor parallelism < 200 µrad
 - Electrical connection is only achieved when two particles are crushed together between UBM pads







ACFs available



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Random distribution of ACF particles in the film makes the capture rate vary significantly

Current film from vendor "D"

Min. connection area $[\mu m^2]$	1,000 or 1,400	
Film thickness [µm]	18	
Particle diameter [μmΦ]	3	
Particle density [pcs./mm ²]	35.000 (estimated)	
Particles configuration	Spread over filled layer	
Bonding Temperature [°C]	150 to 180	
Bonding Time [sec]	5	
Bonding Pressure [MPa]	30 to 80	



*Top

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*Particle configuration

Started contact with new suppliers of 2D particle-aligned ACF Possible new film from vendor "H"

Min. connection area [µm ²]	500 or 400	
Film thickness [µm]	16	
Particle diameter [μmΦ]	3.5	
Particle density [pcs./mm ²]	23.000	
Particles configuration*	Aligned on layer surface	
Bonding Temperature [°C]	130 to 170	
Bonding Time [sec]	5	
Bonding Pressure [MPa]	40 to 90	



*Particle configuration

Opportunity to have a 3D particle aligned ACF also from vendor "D" under investigation





*100 MPa \sim 1000 kgf/cm² 256x256 * 320 $\mu m^2 \sim$ 0.20 cm² (Timepix3) 128x128 * 200 $\mu m^2 \sim$ 0.03 cm² (CLICpix2)

UBM for ACF bonding

the EN(EP)IG plating process

EN(EP)IG - Electroless Nickel (Electroless Palladium) Immersion Gold

- Wet chemical deposition of Ni (Pd) Au for the under bump metallization
 - Self-patterning on exposed metal contacts under openings in the passivation layer
 - Maskless process → lower cost
 - Industrial/commercial used process requires full wafer processing
 - Tests of in-house single-chip plating process started at CERN with CLICpix2 chip and sensor



Sensor pixel matrix with ENEPIG



Cross-section of ENEPIG pad



CLICpix2 pixels on a bare chip



ENIG pad





CLICpix2 pixels on a plated chip

UBM for ACF CLICpix2 bonding

the EN(EP)IG plating process at CERN

With the help of CERN EP-DT-EF (Engineering Facilities) – Thank you Rui and Ercan!

- Initial tests with 4 bad quality sensors and 2 CLICpix2 chips, within 4 different platting trials
 - Simple chip holder with Kapton tape
 - All plating process is done manually and time controlled
 - **3** main baths: Zn for Al surface activation; Ni for the UBM pad bulk; Au for Ni oxidization protection
 - Baths are kept on a controlled temperature and are chemically controlled on a daily basis



Chips on sample holder

ENIG plating line and Ercan

Zn activation bath

Ni plating bath

Au plating bath

UBM for ACF CLICpix2 bonding

the EN(EP)IG plating process at CERN



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- **D** First test with strong initial cleaning using a brush and phosphorus based solution
 - double zincation process and 20 minutes on the Ni bath, + 10 min Au plating
 - sensor plating delaminated with an adhesive tape puling test, most likely due to aggressive steps before the Ni bath, poor quality of sensor metal layer, and thin/negligible passivation layer (500-700 nm thermal oxide)
- Second sensor plating test with softer surface cleaning
 - + single Zn bath and 15 minutes Ni bath, + 10 min Au plating
 - → Successful tape test without any delamination, but overgrown UBM pad shorts all pixels together



Bare CLICpix2 sensor pixel matrix



First CLICpix2 sensor ENIG plating



Second sensor ENIG plating trial

UBM for ACF CLICpix2 bonding the EN(EP)IG plating process at CERN

The bad sensor plating results are due to the lack of a thick passivation protection on top of of the metal layer

- Ni is growing unconstrained through the remaining passivation layer and shorts the pixel at their bottom part
- For the 3rd and 4th trial we included the CLICpix2 chip, knowing it has a better passivation
- Process finally used

- 20 s brush cleaning on P based solution
- 10 s Zn activation
- 7 and 3 min Ni plating
- 10 min Au plating
 - Intermediate cleaning steps with cold and demineralized water
- Successful CLICpix2 plating and no short for the sensor chip with 3 min Ni plating (only on the pixel matrix)





UBM for ACF CLICpix2 bonding the EN(EP)IG plating process at CERN



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Conclusions

- Hybridization with anisotropic conductive films
 - Micro-bumps embedded in an adhesive film
 - Particles trapped between the sensor and ROC creates an electrical contact only in the direction of the compression
 - In-house UBM and flip-chip process
 - Maskless ENIG deposition started using the CLICpix2 chip
 - Deposition characterization measurements to follow soon, together with first CLICpix2/sensor ACF assemblies
- First tests were done with the Timepix3 chip
 - □ First assembly for proof-of-concept with motivating results
 - Uniformity of ACF connection to be further investigated/optimized
 - Higher bonding force/pressure can be achieved (up to 400 kg)
 - 100 kg might be already sufficient for the smaller CLICpix2 chip (\sim 5% of area \rightarrow 20x higher pressure)
 - Flip-chip planarity calibration
 - Possible to achieve planarity of 10s of µrads (100s of nm gap increase over 10s of mm)
 - Planarity check of UBM pads to follow with interferometry measurements
 - Cross-talk still needs to be understood

ACF bonding characterization Conpart test-structure W/

- Test structure with 5 matrices of pads with different sizes
 - Resistance scales with the **pad size** and film **particle count**
 - Acceptable resistance in hybrid pixel detectors is $\lesssim 100 \Omega$
 - Timepix3 pixel contact pad is ~320 µm²; CLICpix2 is ~200 µm²





Test-structure pad with ACF particles captured





In-house Flip-chip at Geneva University ACCµRA[™]100 device bonder





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- Semi-automatic flip-chip bonder, co-financed by CERN
 - Substrates up to 100 mm x 100 mm and chips up to 22 mm
 - Chip-to-chip or chip-to-wafer bonding

- Alignment stage resolutions: 0.015 μm in XY; 1 μrad in θ
 - Post-bonding accuracy 0.5-1 μm achieved and planarity < 100's μrad</p>
- Heating up to 400 °C and force applied by bonding arm up to 100 kg
- Dispenser system allows for automated dispense of glue
 - Additional options for + thermosonic bonding + reflow + UV curing...





Hybridization with ACF

flip-chip process

- Film thickness $\sim 18 \ \mu m$, curing starts at $\sim 100 \ C$
- Film is perforated for better film transfer to the ASIC
- Pre-bonding (film transfer): 100 kg at 80 °C (10 seconds)
- Bonding: 100 kg and 80 °C for 500s, and final curing at 150 °C for 18s



TPX3 to TPX3 bonding stage with ACF in between

TPX3 on bonding head and ACF on chuck

ACF transfer to ASIC

Flip-chip at Geneva University







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Flip-chip calibration

- ToT \sim Capacitance \sim distance between pixel pads
 - Gradient seen in some CCPD samples
 - Bad parallelism between HV-CMOS sensor and read-out ASIC









Achievable flip-chip planarity



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-	COLORED IN HERITECTION COLORED	24.40 mm	
	Peri	phery	
COLORAD DE COLORAD DE COLORADO	Analog matrix 2	Analog matrix 1	CONTRACTOR OF TAXABLE
CMOS	Sub-matrix 1 Extra DPTUB + high gain	Sub-matrix 1 Extra DPTUB + ELT	NMOS
monolithic r	Sub-matrix 2 No DPTUB + high gain	Sub-matrix 2 No DPTUB + ELT	monolithic r
natrix	Sub-matrix 3 No DPTUB + Iow gain	Sub-matrix 3 No DPTUB + Linear transistor	natrix







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Figure 7. Left: deposition of epoxy on the H35DEMO matrix by the automatic glue time-pressure dispenser of the Acc μ ra 100. Middle: glue (partially) deposited on double pixel column. Right: 100 μ mthin H35DEMO-FE-I4 assembly on PCB.

Figure 8. Thickness of the glue layer along the chip edge at two locations along the chip at 2 cm distance showing good parallelism, less than 100 nm difference measured with an optical microscope, from left to right.

Figure 9. Combined ToT map from analog matrix 1 (left) and 2 (right). The lower threshold on the second analog matrix is due to the higher FE-I4 threshold (3000 e), comparing with the 2000 ethreshold for the first analog matrix, during data acquisition.

Non-destructive test trials

500 nm nano-tomography





Non-destructive test trials

nano-laminography

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