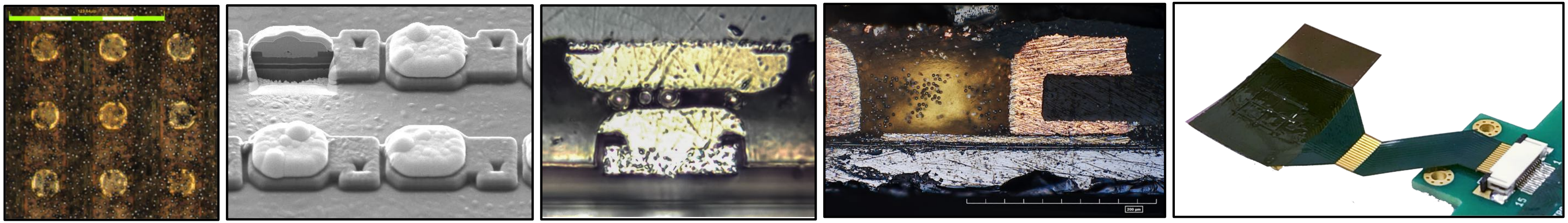
EP-DT
Detector Technologies

EP R&D

*updated on Feb 23rd

Pixel detector hybridization and integration with Anisotropic Conductive Films



16th "Trento" Workshop
17/02/2021

Jerome Alozy[1], Mathieu Benoit[2], Michael Campbell[1], Florian Dachs[1], Dominik Dannheim[1], Didier Ferrere[3], Helge Kristiansen[4], Magnus Mager[1], Petra Riedler[1], Molly Strimbeck[4], Mateus Vicente[1]

1: CERN 2: BNL 3: UNIGE 4: Conpart

ACF hybridization and integration

Outline

Work performed within the **CERN EP R&D** program, supported by the **ATLAS, ALICE, CLICdp,** and **Medipix3** collaborations

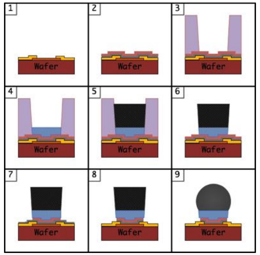
- Pixel detector **hybridization**
- Introduction to **Anisotropic Conductive Films (ACF)**
- **In-house** ACF hybridization process development
- Module **integration** with ACF

Hybrid pixel detectors

Bump-bonding interconnection

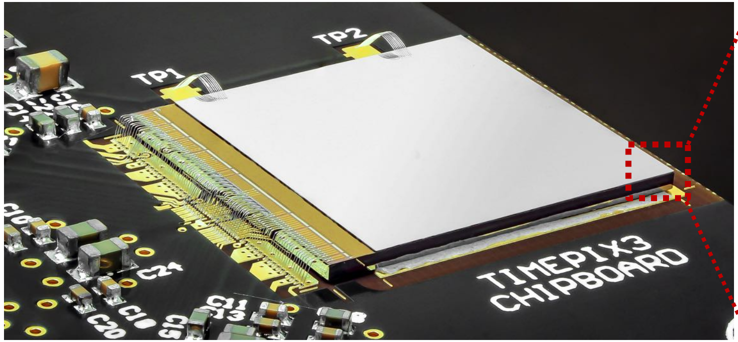
- Hybrid design allows to optimize sensor and read-out chip (ROC) independently
  - **Interconnection** technology must keep up with **pixel miniaturization**
- Standard interconnection technology ➔ **Bump-bonding**
  - Photolithographic process; requires **full wafers** for UBM and bumps deposition
  - Complex and **expensive** → Can add up to half of the module production cost
    - **Not well suited** for an **R&D** phase and **multi-project wafer** productions

Bump deposition process

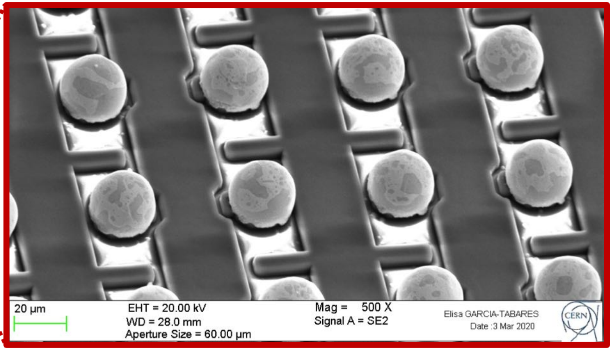


1) cleaning of wafers
2) field metal deposition
3) thick photoresist lithography
4) electroplating of UBM
5) electroplating of solder
6) stripping of photoresist
7) wet etching of seed layer
8) wet etching of adhesion layer
9) solder reflow

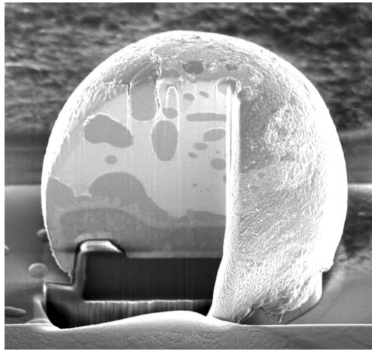
Timepix3 ROC bump-bonded to a 50 µm active edge silicon sensor



Solder bumps on the Timepix3 pixel matrix



Bump cross-section

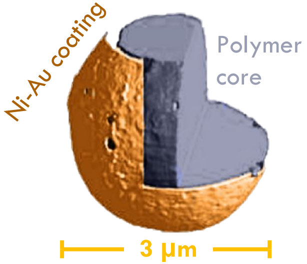


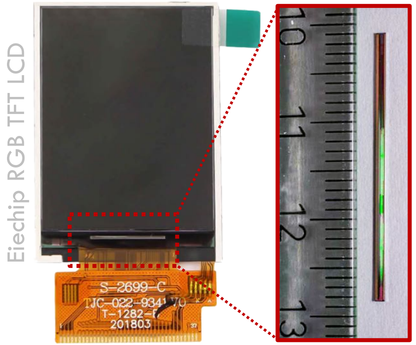
ACF – Anisotropic Conductive Films

Use in industry

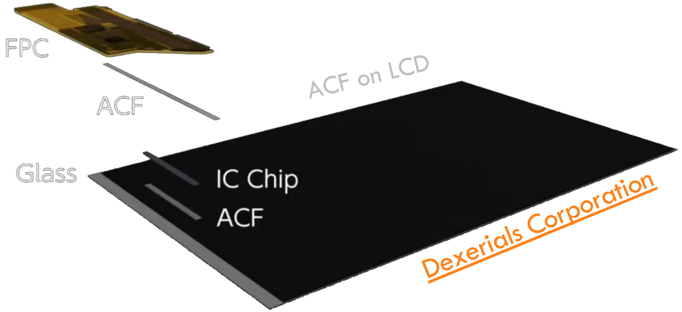
ACF is the **dominating interconnect** technology for **displays** (LCD and OLED), camera modules and RFID chips

- Multiple **3 µm polymer** spheres **plated** with **conductive coating** embedded in an **adhesive film**
  - Conductive µ-particles gets **captured** between the contact pads of the devices during thermocompression
    - **Permanent mechanical attachment** and **anisotropic electrical connection** in the direction of the compression
- Slim display driver ICs: 25-30 mm in length, ~1mm width, with contact pads of **~600 µm²**
  - ~1000s contact pad with pitch of **25 µm,** arranged in a single row
    - Pixel detector **challenges: ~100.000s pads** with fine pitch in **2D → Smaller contact pads** (~300 µm²)



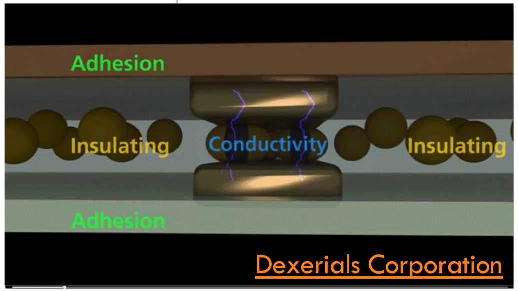

Eiechip RGB TFT LCD

Display IC chip



Dexerials Corporation

ACF on contact pads



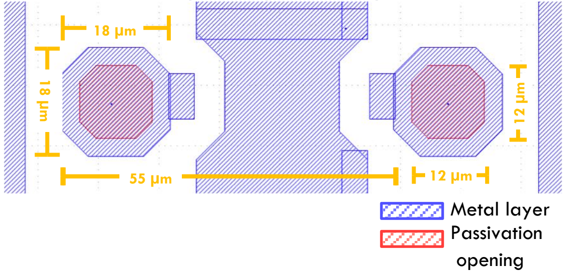
Dexerials Corporation

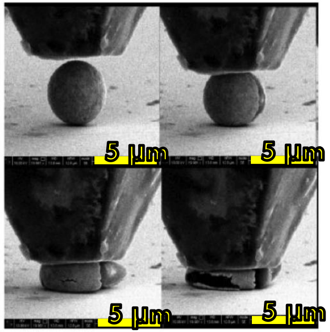
ACF – Anisotropic Conductive Films

µ-particle bonding hybridization

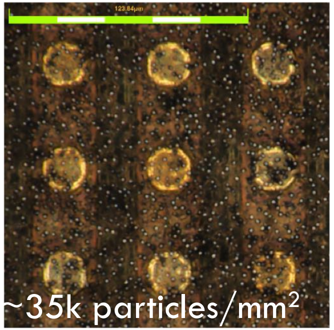
- **Timepix3 (+ planar Si sensor)**
  - **Widely** used read-out ASIC (HEP, medicine, space, education…) – Medipix collaboration
  - 14 x 14 mm^2; 256 x 256 pixels; **55 µm** pixel pitch; **18 µm** wide pixel pads
- **ACF hybridization**
  - Replace single solder bump with multiple µm conductive particles
  - Hybridization **minimum pitch reduced** with ACF particle diameter
  - **In-house UBM** post-processing and **flip-chip** bonding

Timepix3 top metal layer

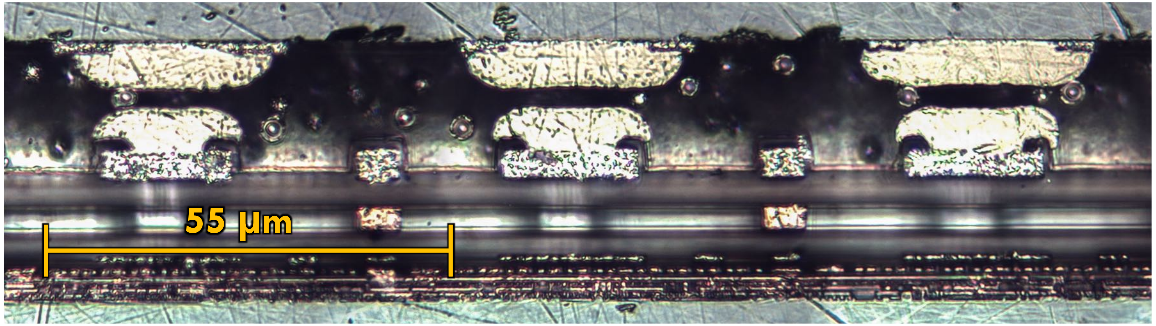




ACF particle deformation



Timepix3 pixel matrix w/ ACF



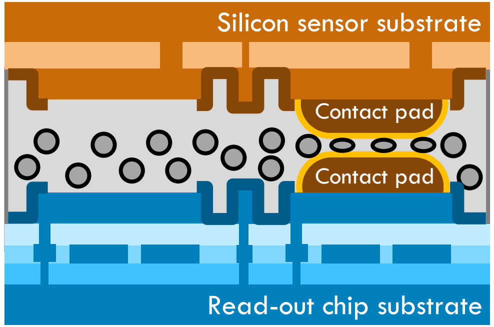
Timepix3 (bottom) coupled to a silicon sensor (top) via ACF

UBM for ACF

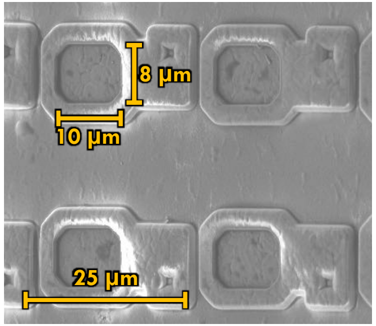
ENIG – Electroless Nickel Immersion Gold

- **UBM** needed to **pinch** the ACF particles (between the device's pads) and establish the electrical contact
- ENIG is a **wet chemical** deposition of **Ni** and **Au** (without external electrical current)
  - Self-patterning on exposed metal contacts under **passivation layer openings**
    - **Maskless process ➔ lower cost**
- Qualified an industrial ENIPIG process for **full wafers** (Timepix3 and sensor)
  - **In-house** ENIG UBM plating on CLICpix2 (**single devices**) as first small-pixel plating test

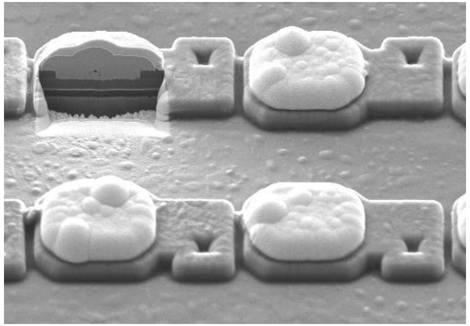
Plated *VS* Unplated pixels



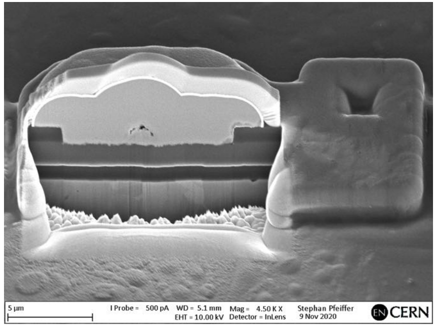
Bare CLICpix2 pixel matrix



CLICpix2 pixels after ENIG



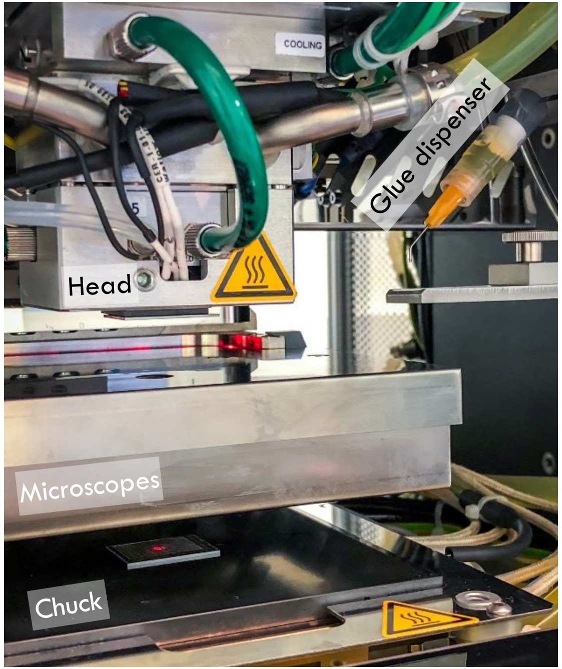
CLICpix2 pixel ENIG cross-section

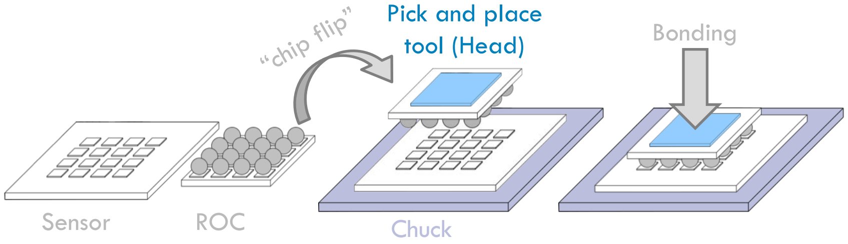


In-house Flip-chip

ACCµRA™ 100 device bonder

- **Semi-automatic flip-chip** bonder at **Geneva University**
  - Substrates up to **100 mm x 100 mm** and chips up to **22 mm x 22 mm**
    - Chip-to-chip, chip-to-wafer or chip-to-circuit bonding
  - Alignment stage resolutions: **0.015 µm** in **XY; 1 µrad** in **θ**
    - Post-bonding accuracy **0.5-1 µm** achieved and planarity **< 10's µrad**
  - Heating up to **400 ℃** 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…

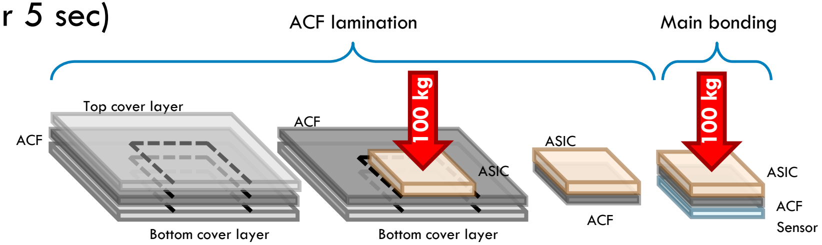




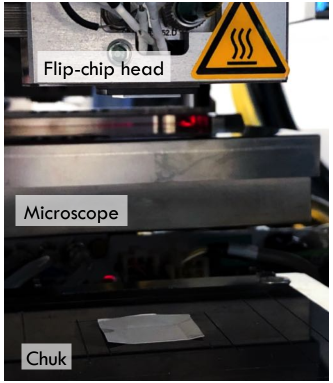
ACF bonding

characteristics and process

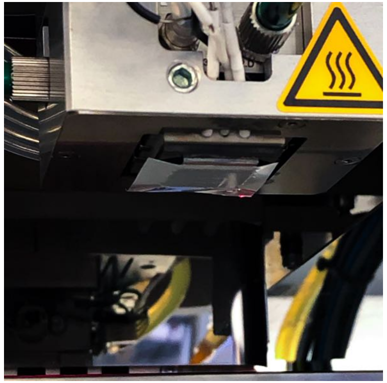
- ACF lamination process: 50~80 ℃ (<10 kgf/cm^2, for1~2 sec)
- Main bonding pressure: 306~815 kgf/cm^2 (150~180 ℃ for 5 sec)
  - **Timepix3:** 256x256 * 320 $\mu m^2 \approx 0.20$ cm^2 → **61~163 kgf**
  - **CLICpix2:** 128x128 * 200 $\mu m^2 \approx 0.03$ cm^2 → **9~24 kgf**



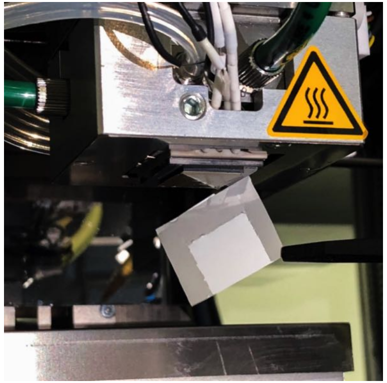
TPX3 on bonding head and ACF on chuck



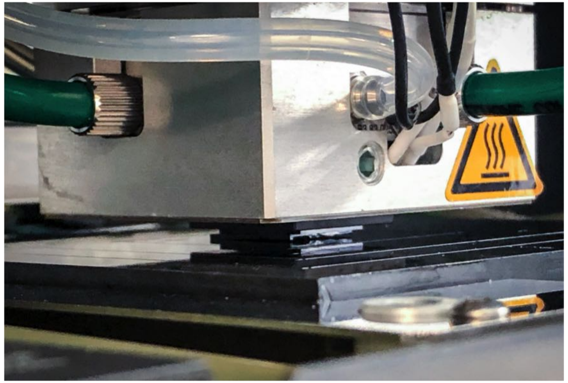
ACF lamination to ASIC



Removal of ACF protective cover film



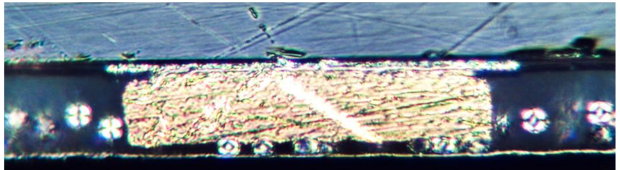
TPX3 to sensor bonding stage with ACF in between



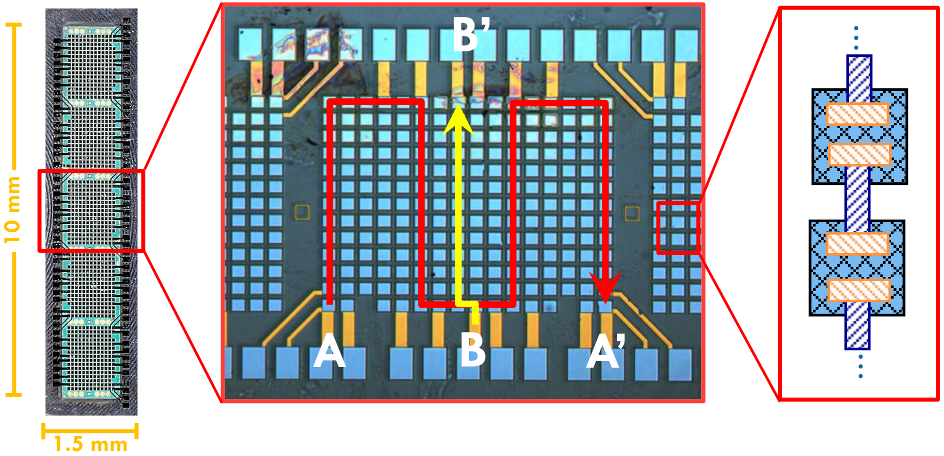
ACF bonding

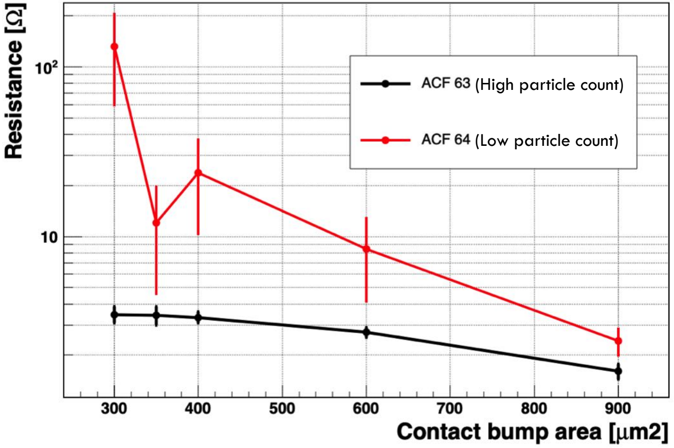
resistance measurement with test-structure

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



Test-structure pad with ACF particles captured





Timepix3 ACF hybrid

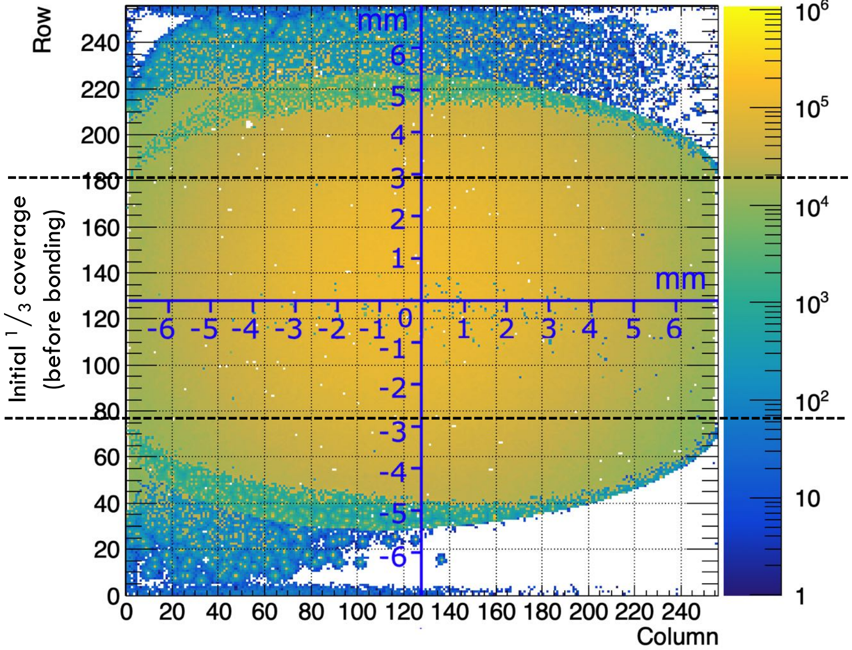
pixel connectivity test with a Sr^{90} source

- ☐ Good bonding results with pixel matrix partial coverage

Timepix3 ~50% laminated with ACF

To be wire-bonded and tested on Feb 26th

Hit-map from 600 s long Sr^{90} illumination (~30% ACF coverage)



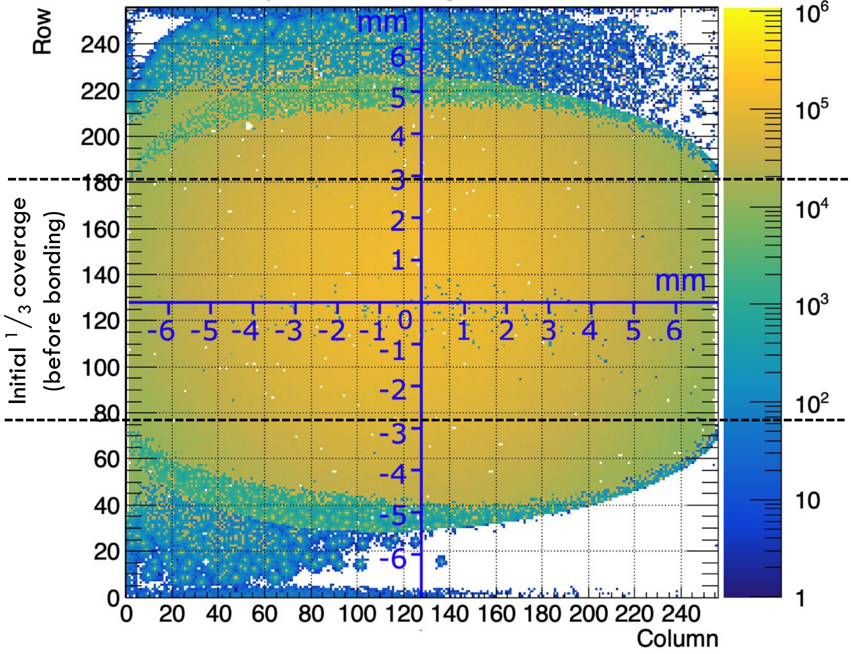
Timepix3 ACF hybrid

pixel connectivity test with a Sr^{90} source

- Good bonding results with pixel matrix partial coverage
    - Compression/spreading of the ACF (during bonding) helps to achieve connectivity in regions outside ACF lamination
        - Tuning of ACF lamination and bonding parameters on-going
- Initial ACF thickness (18 µm) must be compressed to ~2 µm
    - MPa bonding pressure required is bordering the bonding force achievable with the current flip-chip machine
        - Low connectivity yield (so far) when trying to bond the full 256 x 256 pixel matrix
        - Bonding force/temperature/time and surface topology must be carefully evaluated

➔ **Proof-of-principle achieved.** Further process optimization required for achieving good yield over the full surface

Hit-map from 600 s long Sr90 illumination

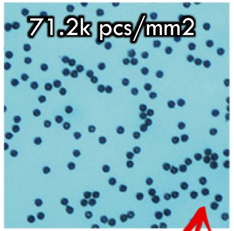


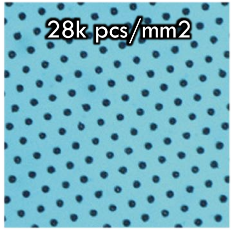
ACF hybridization

Future steps

- Ongoing **process optimization** for Timepix3 ACF assemblies
  - Different pixel matrix coverages and tuned flip-chip parameters
- Assemblies of **CLICpix2 + planar Si sensor**
  - 128 x 128 pixels, **25 µm pixel pitch, 3.2 x 3.2 mm^2**
    - The smaller area increases the effective bonding pressure (keeping the same bonding force)
      - Mechanical sample show full compression of the ACF
- Tests with new **particle aligned** ACF

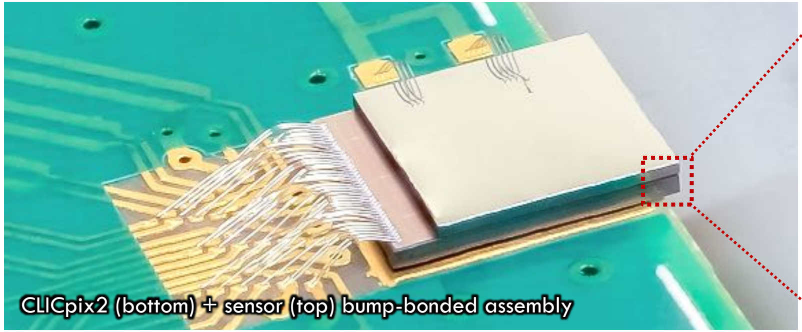
Currently available ACF
Minimum bonding area: 1000 µm^2

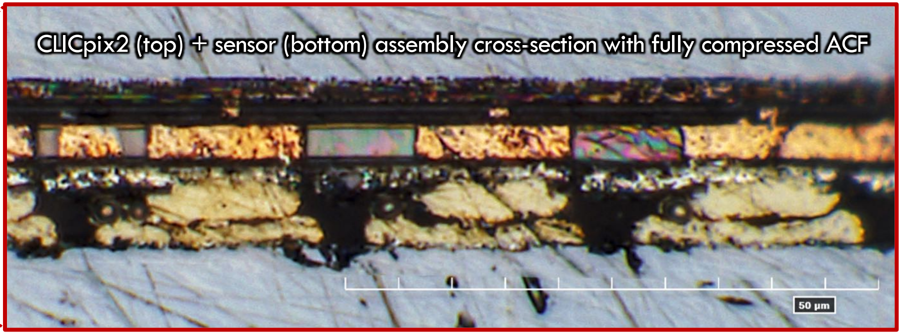




Particle aligned ACF
Minimum bonding area: 300-400 µm^2

3 µm conductive particles!





Module integration with ACF

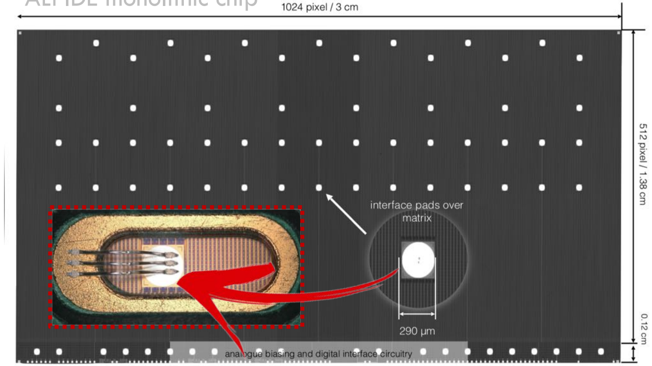
ALPIDE ACF tests

- ACF for thin monolithic detectors electro-mechanical bonding to chip-carrier flex Kaptons
  - ACF allows the interconnection of the chip with the outside world

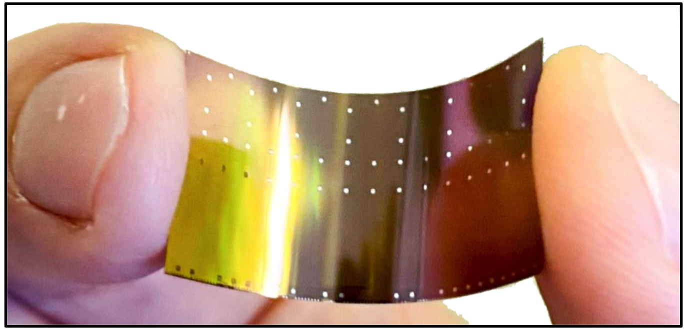
    + a lightweight (few µm thick = flexible) mechanical fixation to its carrier board/flex
- **ALPIDE** as a test vehicle for bent modules
  - Profit from setup developed for testing curved wire-bonded ALPIDEs

Towards: Development of ultra-thin and large flexible modules

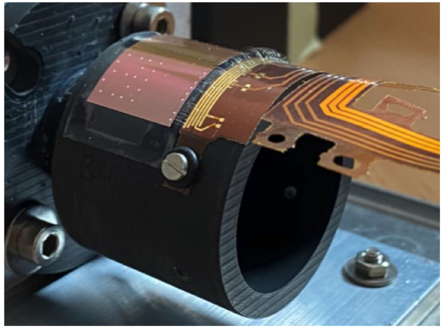
ALPIDE monolithic chip



Bent 50 µm thick ALPIDE chip



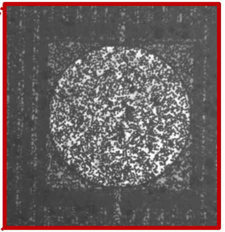
Bent ALPIDE wire-bonded to flex



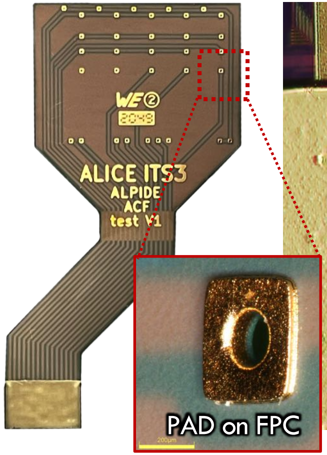
ALPIDE ACF bonding tests

ALPIDE flex, ENIG and bonding

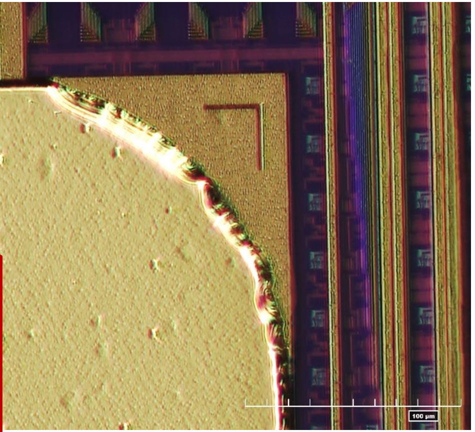
- Produced new flex printed circuit (FPC), with a ZIF socket, for the ACF bonding trials
  - Currently limited in size due to bonding head dimensions of 22 mm x 22 mm
- In-house ENIG plating on the ALPIDE chip for higher bonding pads
- Lower force (**20 kgf**) and reduced bonding time required (low interconnect density)


ACF particles over ALPIDE pad

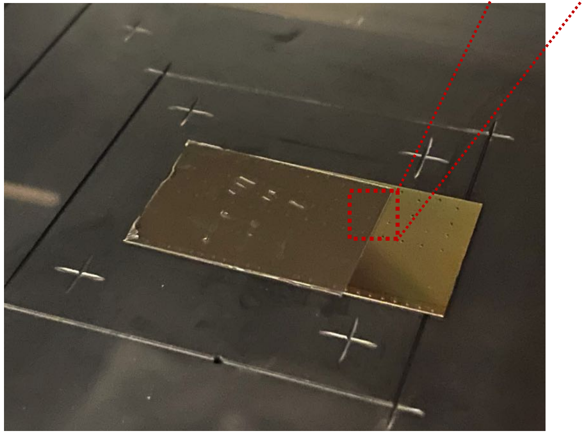
ALPIDE flex V1



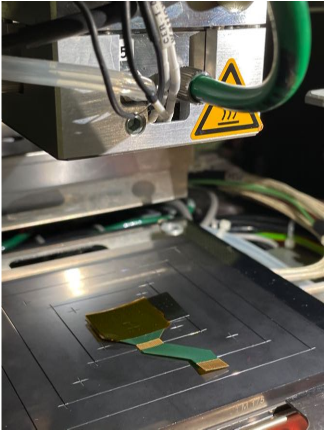
ENIG grown on ALPIDE interface pad



ALPIDE with ACF (partially) laminated



ALPIDE/flex after bonding



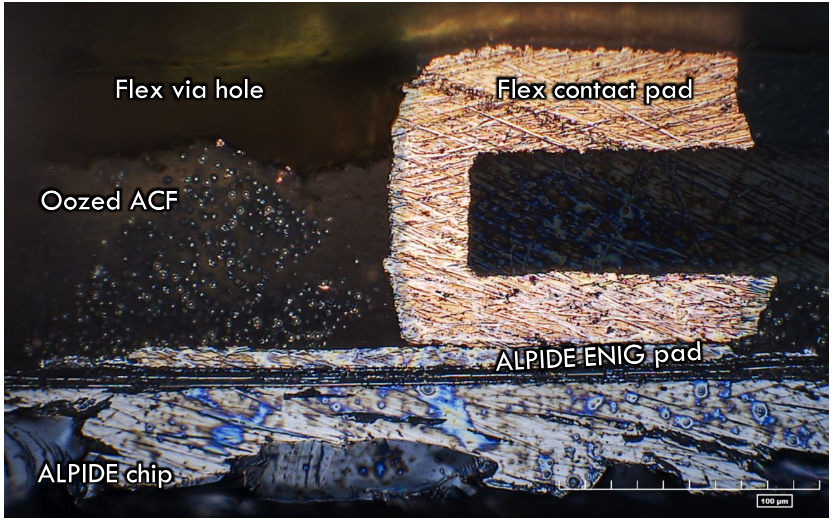
ALPIDE ACF bonding tests

Mechanical cross-section

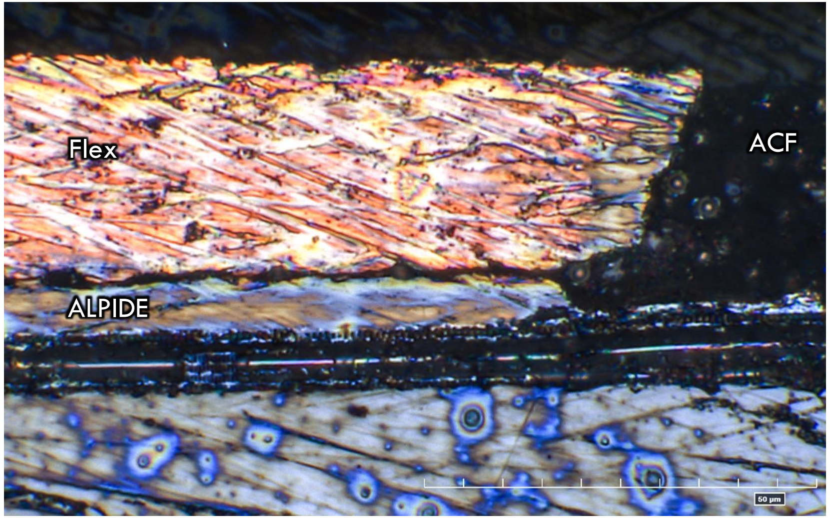
- First mechanical cross-section investigation
  - ALPIDE ENIG pad thickness of about **10 µm**
  - Good ACF compression achieved
    - ACF compressed in ~1µm gap between the pads, oozing (“squeezing out”) to the volume between the pads

*pads are misaligned in order to maximize the pad overlap area (as the FPC via hole and the ALPIDE pad have similar size)

ALPIDE-FPC assembly cross-section



ALPIDE-FPC assembly cross-section ZOOM

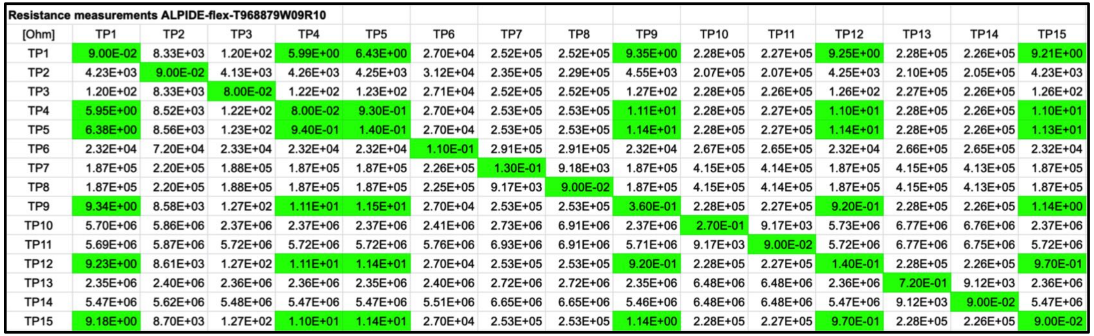


ALPIDE ACF bonding tests

Initial bonding verification

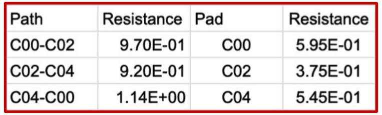
- Flex and breakout board with probing points for testing the connections
  - Verification of the bonding quality in-situ, right after flip-chip assembly
    - Faster tuning of the bonding parameters
      - Possible monitoring even during flip-chip bonding!

➔ Extracted contact resistances between **~0.4-0.6 Ω**

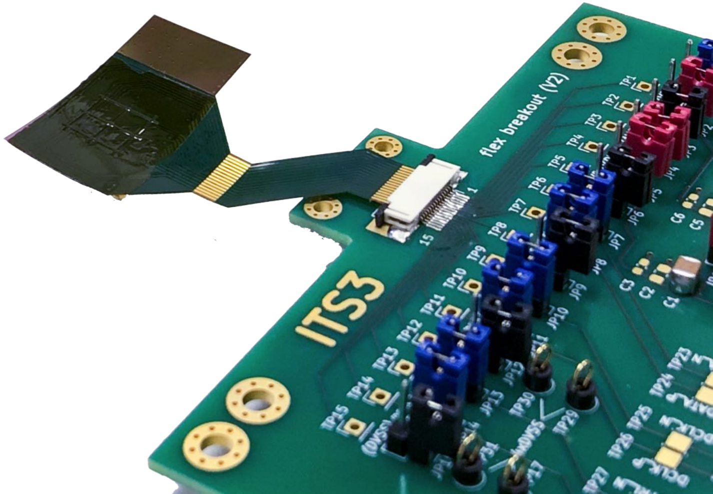


Resistance measurements ALPIDE-flex-T968879W09R10

[Ohm]	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12	TP13	TP14	TP15
TP1	9.00E-02	8.33E+03	1.20E+02	5.99E+00	6.43E+00	2.70E+04	2.52E+05	2.52E+05	9.35E+00	2.28E+05	2.27E+05	9.25E+00	2.28E+05	2.26E+05	9.21E+00
TP2	4.23E+03	9.00E-02	4.13E+03	4.26E+03	4.25E+03	3.12E+04	2.35E+05	2.29E+05	4.55E+03	2.07E+05	2.07E+05	4.25E+03	2.10E+05	2.05E+05	4.23E+03
TP3	1.20E+02	8.33E+03	8.00E-02	1.22E+02	1.23E+02	2.71E+04	2.52E+05	2.52E+05	1.27E+02	2.28E+05	2.26E+05	1.26E+02	2.27E+05	2.26E+05	1.26E+02
TP4	5.95E+00	8.52E+03	1.22E+02	8.00E-02	9.30E-01	2.70E+04	2.53E+05	2.53E+05	1.11E+01	2.28E+05	2.27E+05	1.10E+01	2.28E+05	2.26E+05	1.10E+01
TP5	6.38E+00	8.56E+03	1.23E+02	9.40E-01	1.40E-01	2.70E+04	2.53E+05	2.53E+05	1.14E+01	2.28E+05	2.27E+05	1.14E+01	2.28E+05	2.26E+05	1.13E+01
TP6	2.32E+04	7.20E+04	2.33E+04	2.32E+04	2.32E+04	1.10E-01	2.91E+05	2.91E+05	2.32E+04	2.67E+05	2.65E+05	2.32E+04	2.66E+05	2.65E+05	2.32E+04
TP7	1.87E+05	2.20E+05	1.88E+05	1.87E+05	1.87E+05	2.26E+05	1.30E-01	9.18E+03	1.87E+05	4.15E+05	4.14E+05	1.87E+05	4.15E+05	4.13E+05	1.87E+05
TP8	1.87E+05	2.20E+05	1.88E+05	1.87E+05	1.87E+05	2.25E+05	9.17E+03	9.00E-02	1.87E+05	4.15E+05	4.14E+05	1.87E+05	4.15E+05	4.13E+05	1.87E+05
TP9	9.34E+00	8.58E+03	1.27E+02	1.11E+01	1.15E+01	2.70E+04	2.53E+05	2.53E+05	3.60E-01	2.28E+05	2.27E+05	9.20E-01	2.28E+05	2.26E+05	1.14E+00
TP10	5.70E+06	5.86E+06	2.37E+06	2.37E+06	2.37E+06	2.41E+06	2.73E+06	6.91E+06	2.37E+06	2.70E-01	9.17E+03	5.73E+06	6.77E+06	6.76E+06	2.37E+06
TP11	5.69E+06	5.87E+06	5.72E+06	5.72E+06	5.72E+06	5.76E+06	6.93E+06	6.91E+06	5.71E+06	9.17E+03	9.00E-02	5.72E+06	6.77E+06	6.75E+06	5.72E+06
TP12	9.23E+00	8.61E+03	1.27E+02	1.11E+01	1.14E+01	2.70E+04	2.53E+05	2.53E+05	9.20E-01	2.28E+05	2.27E+05	1.40E-01	2.28E+05	2.26E+05	9.70E-01
TP13	2.35E+06	2.40E+06	2.36E+06	2.36E+06	2.35E+06	2.40E+06	2.72E+06	2.72E+06	2.35E+06	6.48E+06	6.48E+06	2.36E+06	7.20E-01	9.12E+03	2.36E+06
TP14	5.47E+06	5.62E+06	5.48E+06	5.47E+06	5.47E+06	5.51E+06	6.65E+06	6.65E+06	5.46E+06	6.48E+06	6.48E+06	5.47E+06	9.12E+03	9.00E-02	5.47E+06
TP15	9.18E+00	8.70E+03	1.27E+02	1.10E+01	1.14E+01	2.70E+04	2.53E+05	2.53E+05	1.14E+00	2.28E+05	2.27E+05	9.70E-01	2.28E+05	2.26E+05	9.00E-02



Path	Resistance	Pad	Resistance
C00-C02	9.70E-01	C00	5.95E-01
C02-C04	9.20E-01	C02	3.75E-01
C04-C00	1.14E+00	C04	5.45E-01



ALPIDE ACF bonding tests

Sr^{90} illumination test and next steps

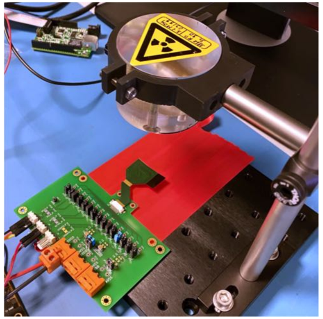
- Read-out works and shows good results ➔ Good communication/interconnection between ROC and Flex
  - 4 samples produced so far, all of them working as expected

Next steps:

- Next iteration with optimized FPC

  Towards: Tiling of 4-side buttable modules with minimum dead-area
- Assembly flexibility and connection evolution to be tested

ALPIDE-FPC and a Sr^{90} source



ALPIDE hit-map with FPC shadow (1000s 1M events)

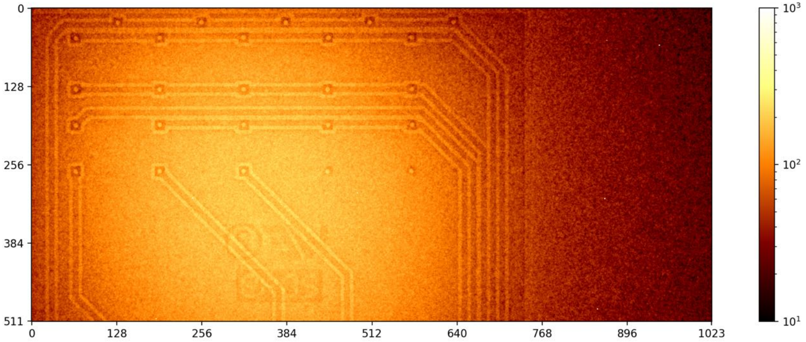
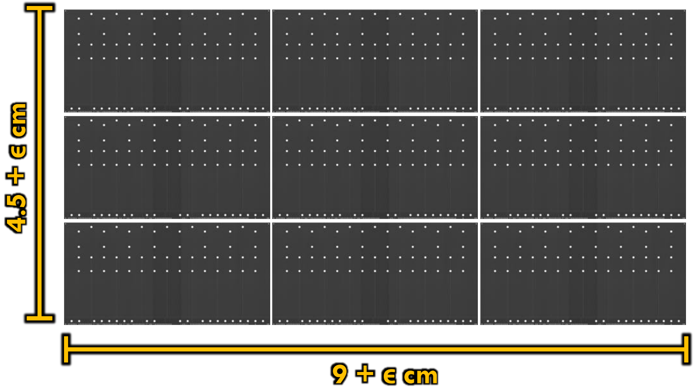


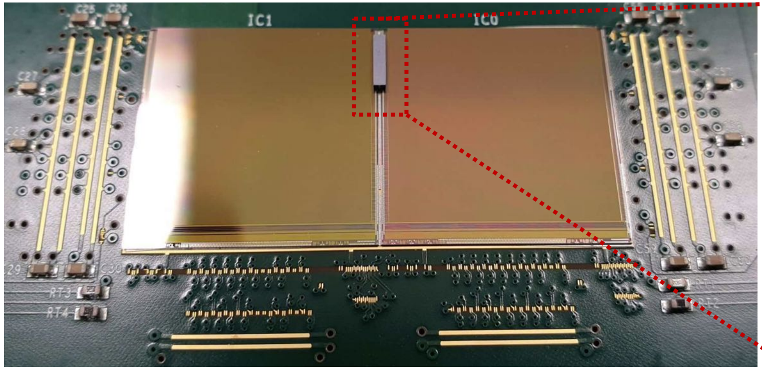
Illustration of 3x3 ALPIDE 4-side buttable module



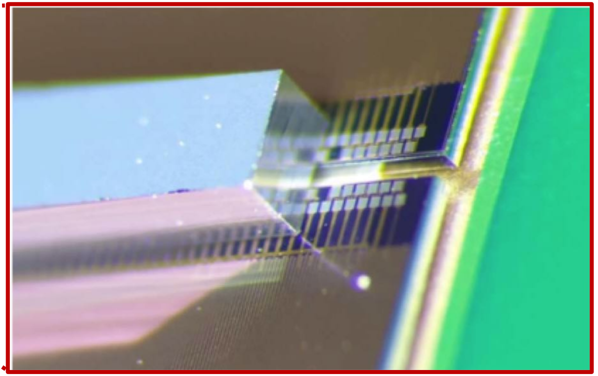
ACF for MALTA (planning)

- The **MALTA** chip was designed with large area pixel modules in view. See Petra’s talk
  - Chip-to-chip asynchronous transmission of power and data via CMOS IO pads
    - Via Al wedge wire-bonding **Or** Via a **Si-bridge** chip
      - Si-bridge allows a smaller gap (between the chips) w.r.t. wedge wire-bonding → Module with **smaller dead-area**
  - Successful tests with bump-bonding of Si-bridges have been made (cf. Petra’s slides)
    - Existing plated chips can be alternatively connected with ACF → MALTA **ENIG plating** and **bonding preparations** on-going

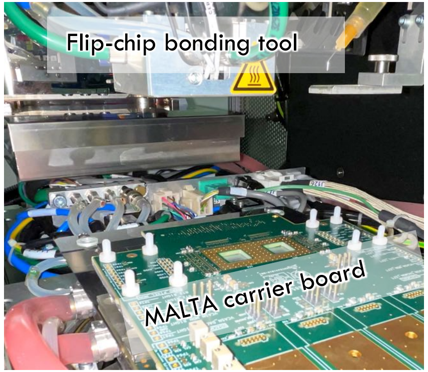
MALTA double module with Si interposer chip



Interposer Si chip between two MALTAs



Double-MALTA PCB in the flip-chip machine



Conclusions and outlook

Motivating first hybridization and interconnection results

- **In-house UBM** plating and **flip-chip** assembly
- (Partially) Successful **Timepix3 ACF hybridization**
  - Work-in-progress for 100% matrix coverage and connectivity yield

Towards: Fine pitch hybridization (25 μm pitch)

  - Mechanical sample on CLICpix2 device shows expected bonding gap

- First successful **ALPIDE-flex integration** with **ACF**
  - Assembly flexibility and connection reliability to be tested

Towards: Larger 3x3 flexible module assembly w/ new flex design

- Planning on-going for MALTA module integration