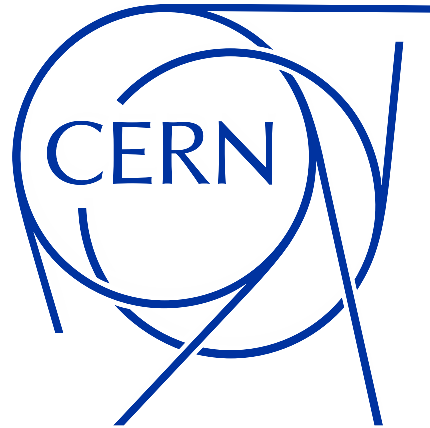


UNIVERSITÉ
DE GENÈVE

Pixel detector hybridization and integration with anisotropic conductive adhesives

Alexander Volker[1], Janis Viktor Schmidt[1], Dominik Dannheim[1], Peter Svihra[1], Mateus Vicente Barreto Pinto[2], Rui de Oliveira[1], Justus Braach[1], Matteo Centis Vignali[4], Giovanni Calderini[5], Marie Ruat[3], Xiao Yang[1], Débora Magalhaes[3]

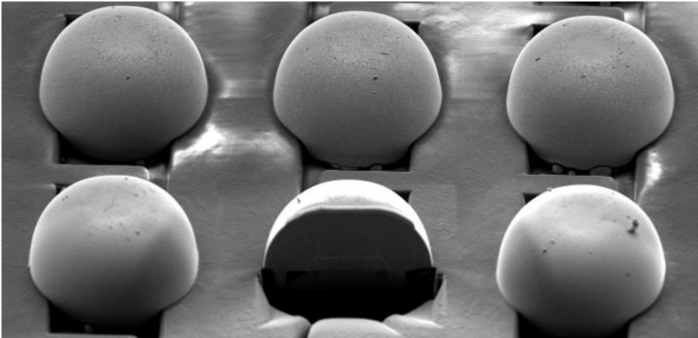
29.09.2023

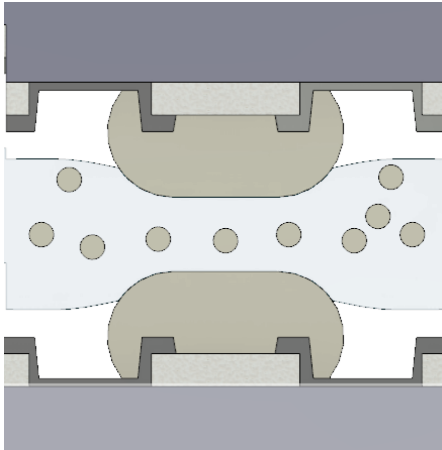
(1) CERN (2) UniGe (3) ESRF (4) FBK (5) LPNHE

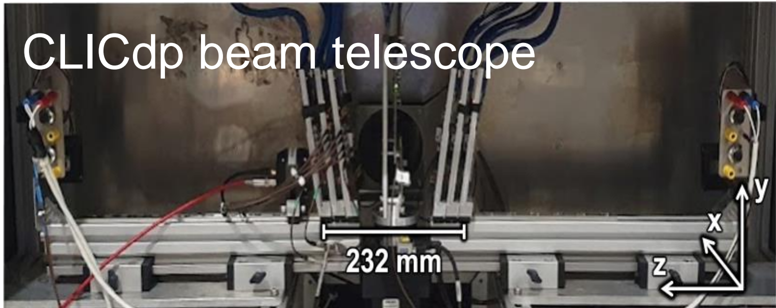
Introduction

- **Hybridisation and module interconnect are needed for a wide range of devices**
- **Development of interconnect technologies**
  - Fast turnaround
  - Cost effective
  - In-house
  - Single die processing
  - Maskless
- **Activities are performed within the EP R&D programme (WP1.3) and AIDAinnova (WP6)**

Process Overview

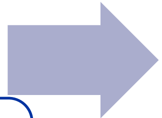






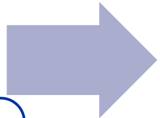
Surface treatment

- Nickel growth
- Pad topology



ACA

- Lamination
- Flip-chip bonding

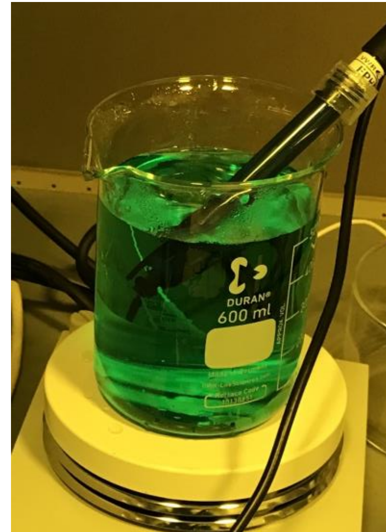


Testing

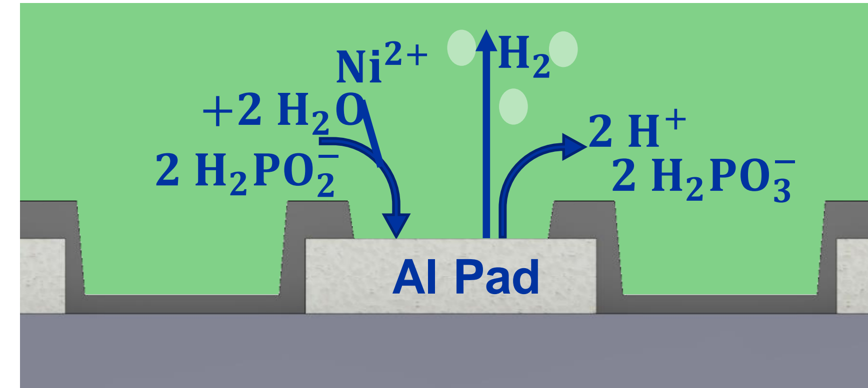
- Cross-section
- Source and Test-beam measurement

Electroless Nickel Immersion Gold (ENIG)

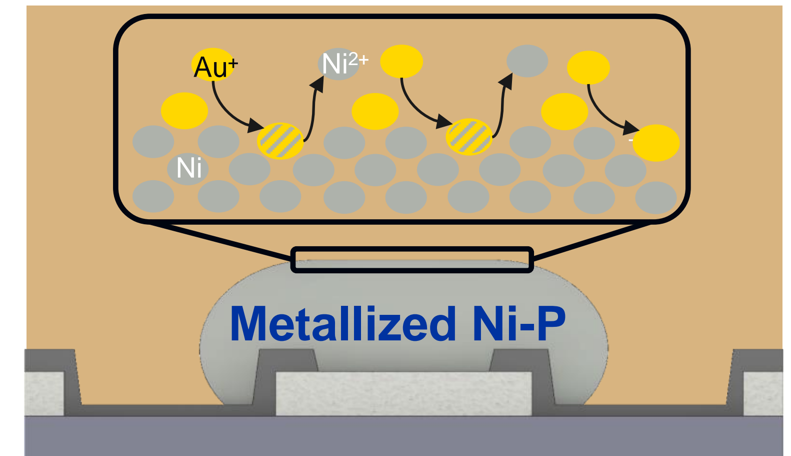
- **Electroless Nickel (Ni-P):**
  - Commonly used **UBM (Under Bump Metallurgy)** process (small plating heights)
  - Processing step to create pad topologies for further bonding
  - Self-catalytic reaction
    - Typically used on Copper and **Aluminum**
    - Creates mushroom like topologies
    - Plating height dependent of processing time
- **Immersion Gold:**
  - Ni-atoms at the surface are replaced with Au-atoms
  - <=100nm thickness
  - Corrosion protection



Small scale Electroless Nickel bath on a hot plate. In house R&D at the Micro Pattern Technology labs at CERN



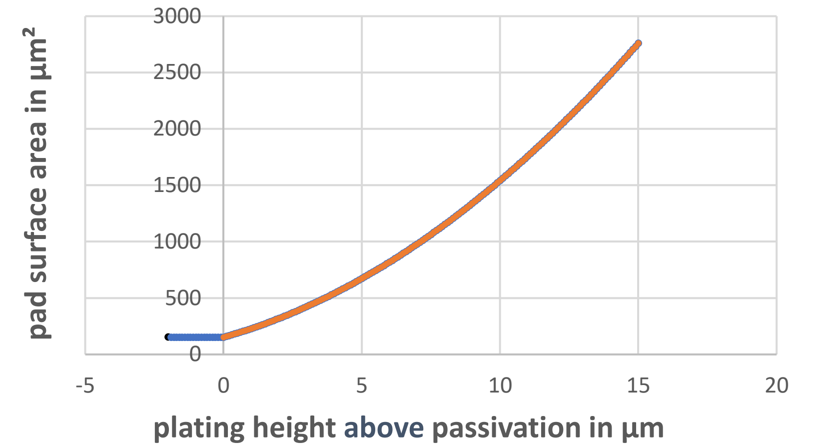
Chemical processes of Electroless Nickel plating



Chemical processes of Immersion Gold plating on previously metallized Ni-P

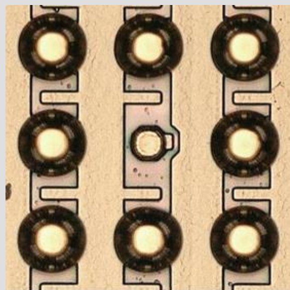
ENIG Development

- **Main focus is creating a stable and reliable process for plating adjusted for the specific device**
  - Better temperature control
  - Controlled stirring (factoring in process changes)
  - Optimized sample holder
  - Stabilisier concentration adjustment
  - Clean room enviroment
  - Plating test devices



Device	Pad size Al top layer	Pixel pitch	ENIG height
Timepix3	12-14 µm	55 µm	6-12 µm
SPHIRD	15 µm	50 µm	7-9 µm
MALTA	88 µm	120 µm	3-10µm
ALTIROC2	92 µm	1300 µm	5-15 µm

Plating challenges (example Timepix3 ASIC):


Skipped pad

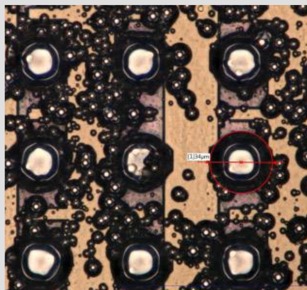
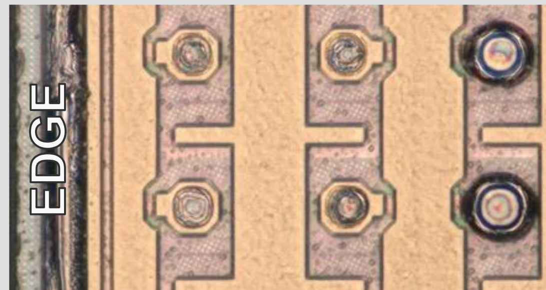
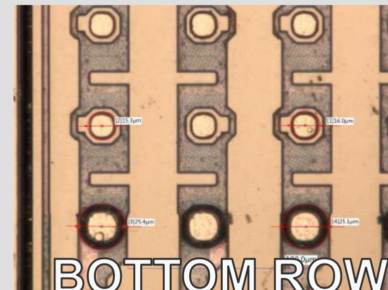


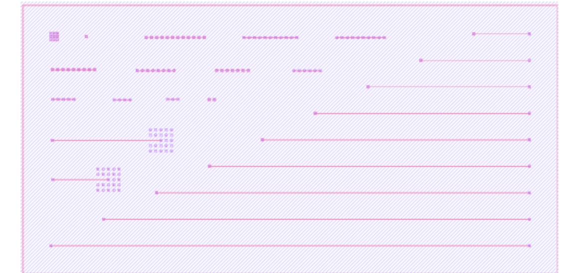
Plate out / overplating



Missing/less plating near edge of chip

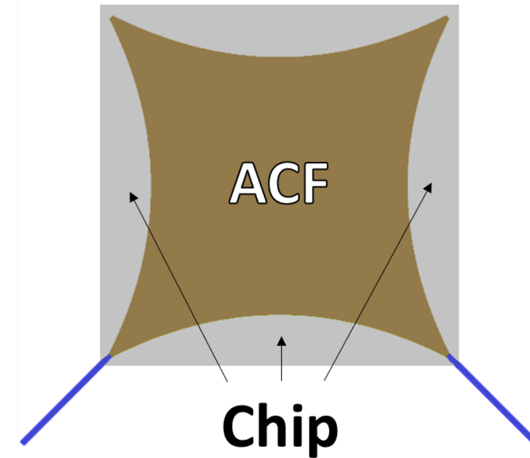


Shorted pads with different plating growth

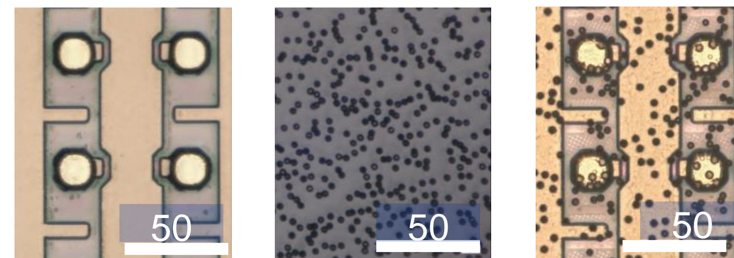

Test device for plating on layouts with different pad connections

Anisotropic Conductive Adhesives (ACA)

- **Anisotropic conductive film (ACF):**
  - Conductive particles embedded in epoxy film
  - Comercially available (used in display interconnection)
  - Typically cures at temperatures >100°C
  - Can be shape optimized (lowering adhesive quantity)
- **Anisotropic conductive paste (ACP):**
  - Conductive particles embedded in Araldite 2011
  - Mixed in-house
  - Particles supplied by Conpart AS
- **Application specific choice for adhesive and particles**
  - Radiation hardness
  - Chip layout (pixel pad size and pitch)



ACF shape optimization for large area small pitch devices to reduce adhesive quantity



(left) Pixel pads of a Timepix3 ASIC (middle) ACF with particles visible (right) ACF laminated on the Timepix ASIC

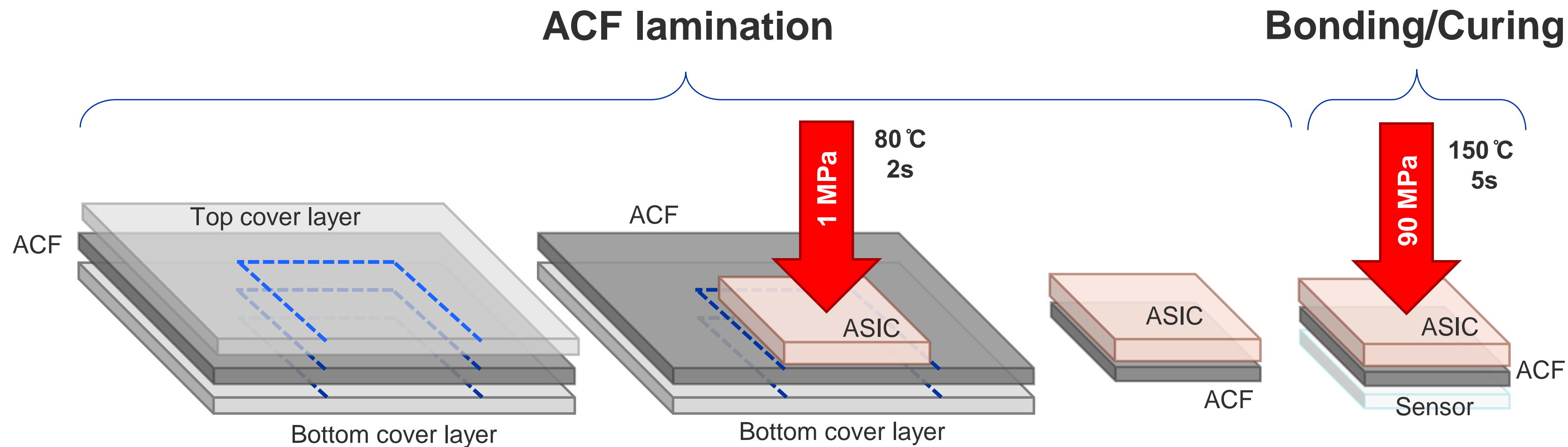
Table of ACF available in our lab:

ACF	1	2	3	4	5
Part. diameter [µm]	3	3	3.5	10	3.2
Thickness [µm]	18	14	16	50	18
Particle density [pcs/mm²]	71k	60k	23k	-	28k
Pressure [MPa]	30-80	50-90	40-90	30-50	40-80
Aligned	no	no	same depth	no	grid
Sheet or reel	sheet	reel	sheet	reel	reel

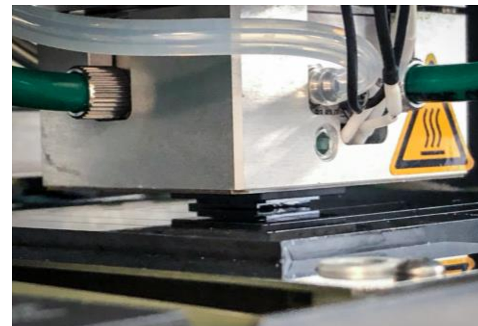
Table of conductive particles available:

Conductive particles (ACP)	1	2	3	4	5
Part. diameter [µm]	4	5	10	20	30
Conductive material (coating)	Ag	Au	Ag	Ag	Ag

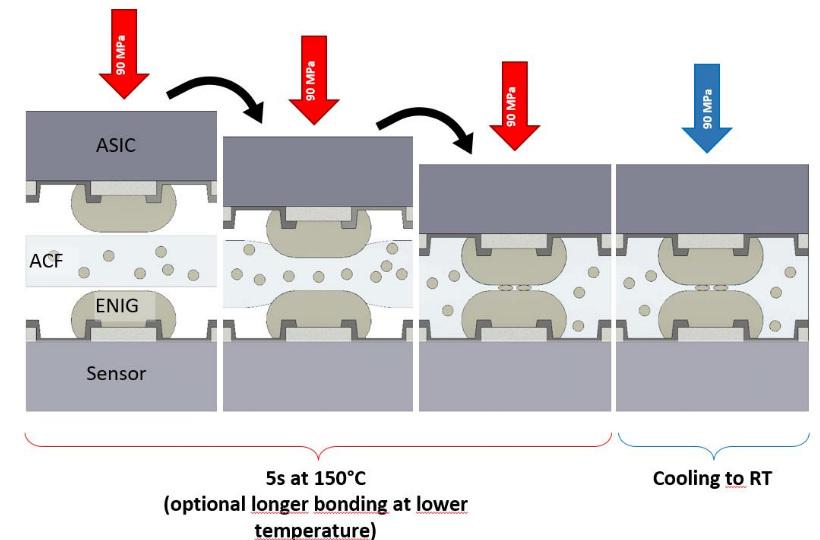
Flip-chip Bonding



- **Quantity of adhesive important**
- **Bonding pressure**
  - Depends on pad/bump area
  - Fine pitch bonding uses higher bonding force for same chip size
  - Large chips with small pitch need forces exeeding 100kgf (maxium of our flip-chip bonder)



SET ACCμRA100 flip-chip bonder with integrated dispensing system



Test devices

For general interconnection tests we use daisy chain devices in different layouts

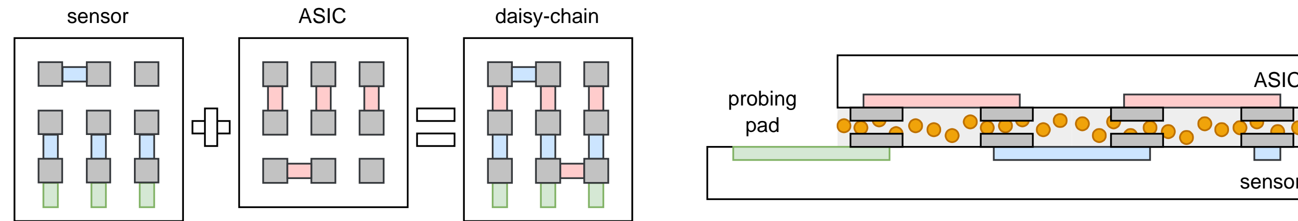
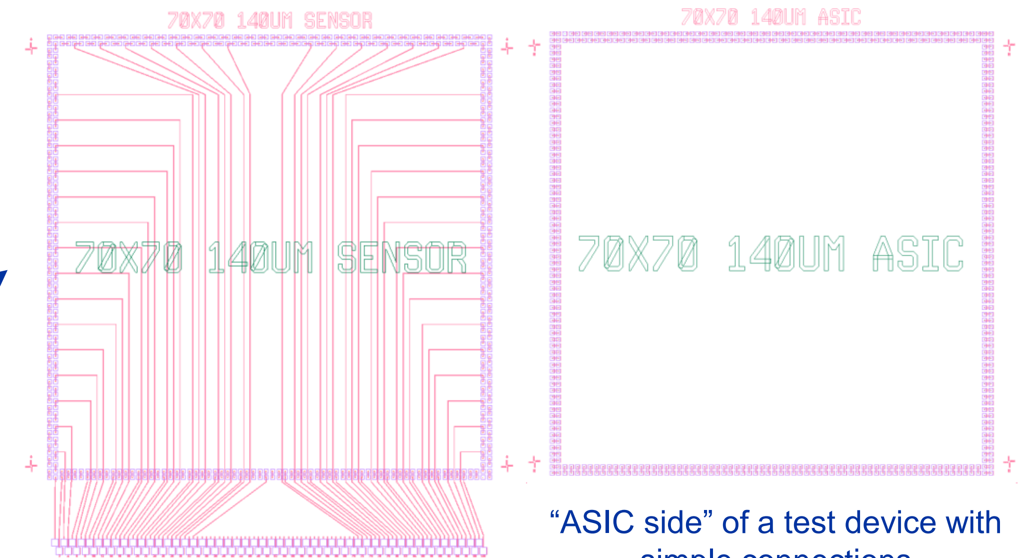


Table of all test devices designed and produced at **FBK**:

	pitch	size in mm	connections	per wafer	type	diceable
160x160 20um	20 um	3.2 x 3.2	25600	36	grid	no
CLICpix2	25 um	3.2 x 3.2	16384	34	grid	no
400x400 25um	25 um	20 x 20	640000	5	grid	yes
Timepix3	55 um	14 x 14	65536	4	grid	no
Timepix3 islands	55 um	14 x 14	65536	4	grid	no
RD53	50 um	20 x 20	160000	4	grid	no
RD53 islands	50 um	20 x 20	160000	2	grid	no
70x70 140um	140 um	20 x 20	2112	3	peripheral	yes
10x10 1000um	1000 um	20 x 20	400	3	grid	yes
3x3 4500um	4500 um	20 x 20	36	1	grid	yes



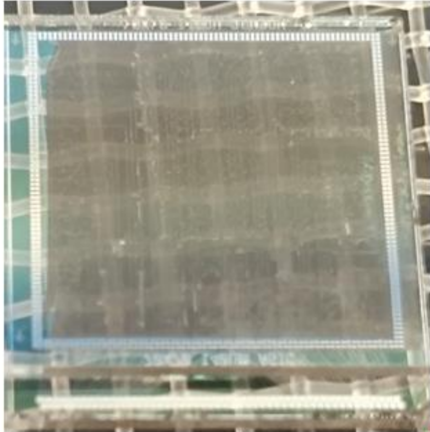
"Sensor side" of a test device with test pads at the bottom

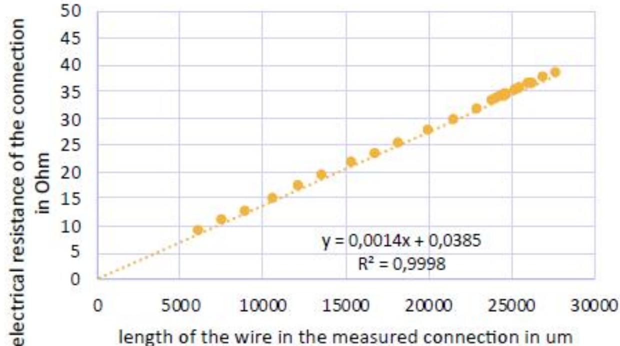
"ASIC side" of a test device with simple connections

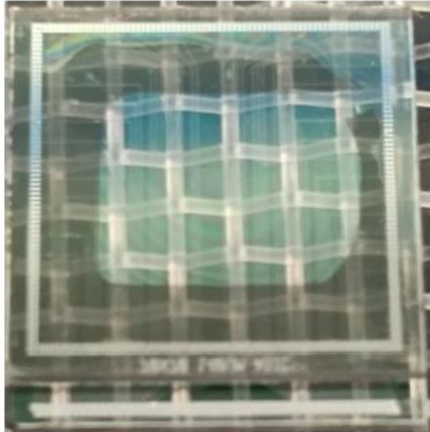
Results from test devices (preliminary)

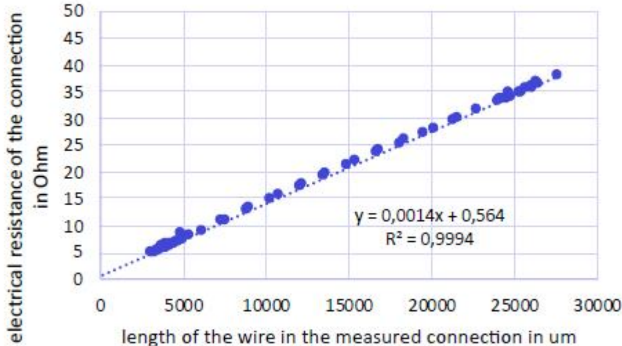
Unlaminated pads or broken lines are <u>not</u> shown in the plot

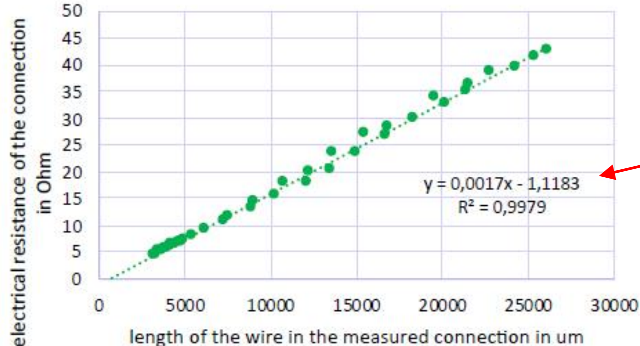
We get sucessfull connections for all pads where the epoxy has spread to









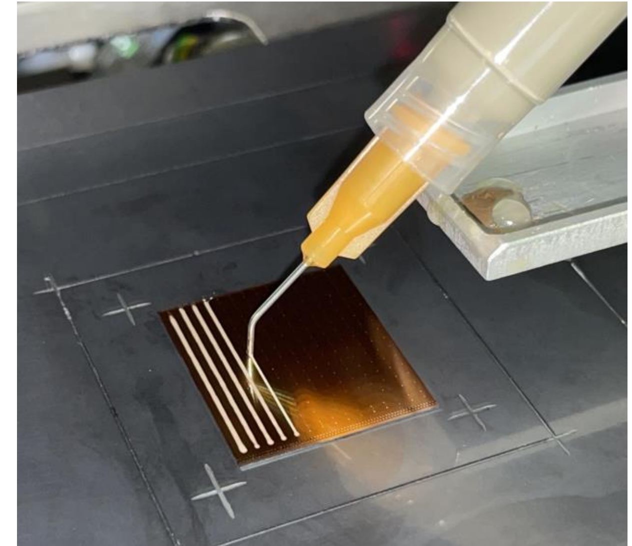


Negative value not physical

ALTIROC2 LGAD assembly

- **15 by 15 pixels with 1300 µm pitch**
- **ACP bonded with 10 µm diameter particles**
- **Plating height of 12 µm (only ASIC side)**
- **First results show four pixels not connected out of 225 (98%+ connection yield)**
- **Further tests ongoing**

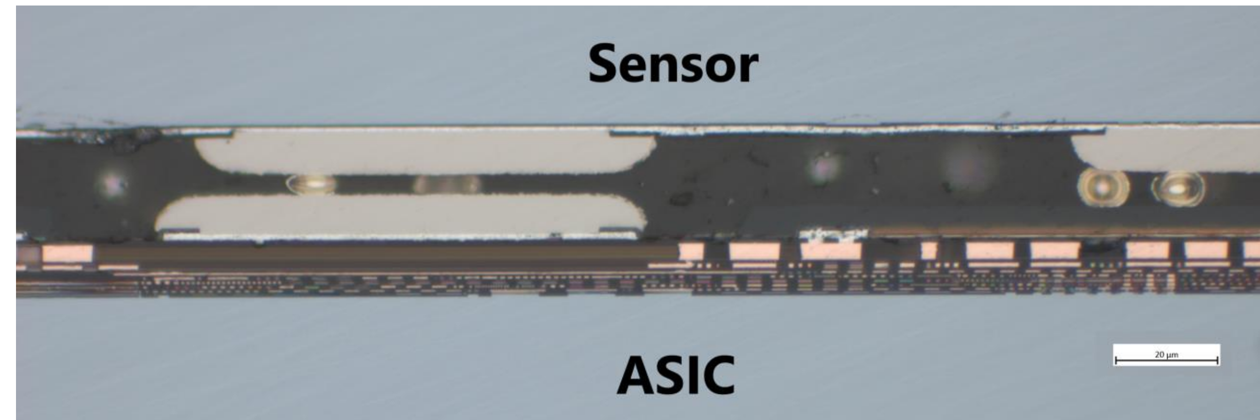
Also see talk by Xiao Yang on ATLAS LGAD (Wed)



Dispensing lines of ACP on the ALTIROC2 ASIC for bonding with LGAD sensor

Replacement of bump bonding possible

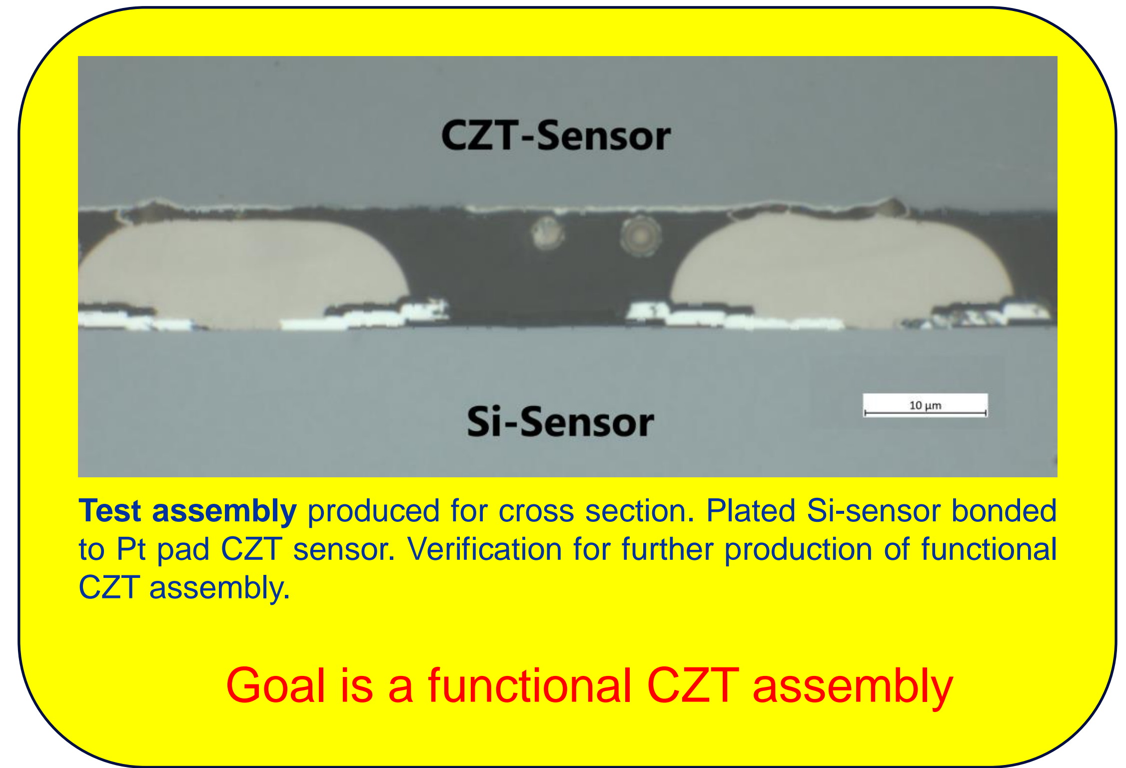
- ACA is expected to result in higher mechanical stability compared to low-density bump bonds
- Further test with larger particles and possibly higher ENIG plating



Cross section of an ALTIROC2 ASIC and LGAD sensor assembly for visual verification of electrical connection. Particles used are 10 µm in diameter.

SPHIRD

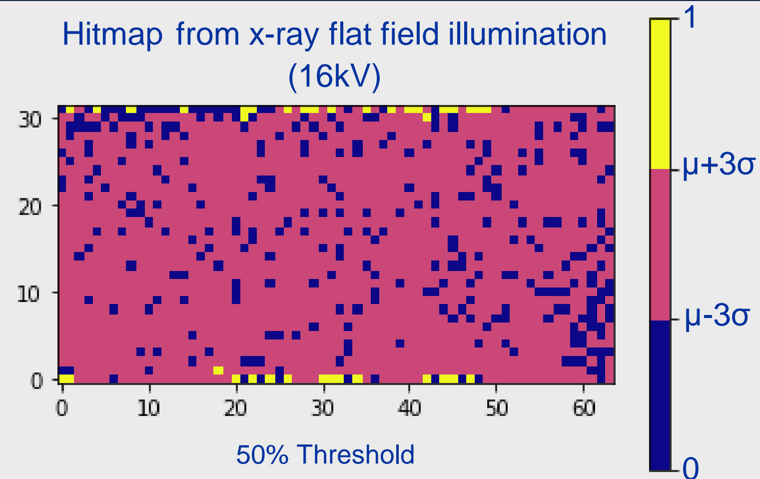
- X-ray detector developed at ESRF
- 32 by 16 pixels with 50 µm pitch
- ACF bonded assembly
- Lab and test-beam measurements show 80-85% of pixels with normal response, 20% with very weak or no connection
- CZT and CdTe sensor bonding currently in preperation



Test assembly produced for cross section. Plated Si-sensor bonded to Pt pad CZT sensor. Verification for further production of functional CZT assembly.

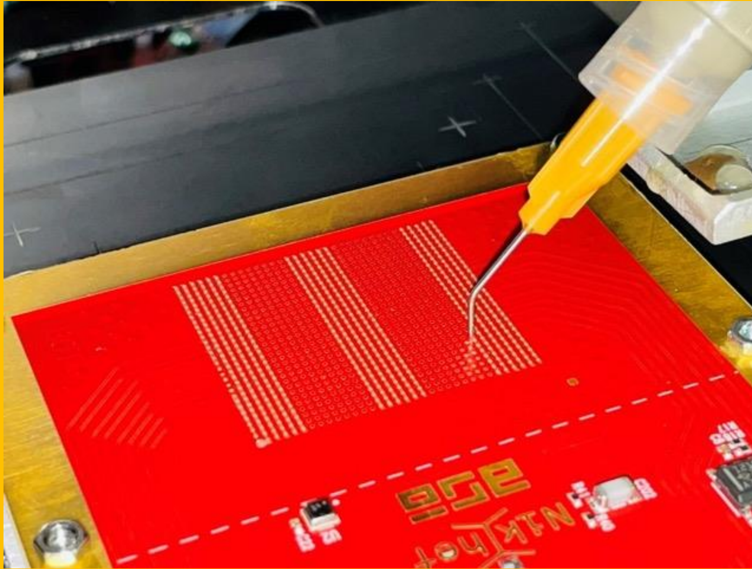
Goal is a functional CZT assembly

83.45% of the pixels behave in a gaussian way. This is the expected response.
Of the non gaussian pixels there are two groups. One group with no response of about 10% and a second group which shows a very weak response.

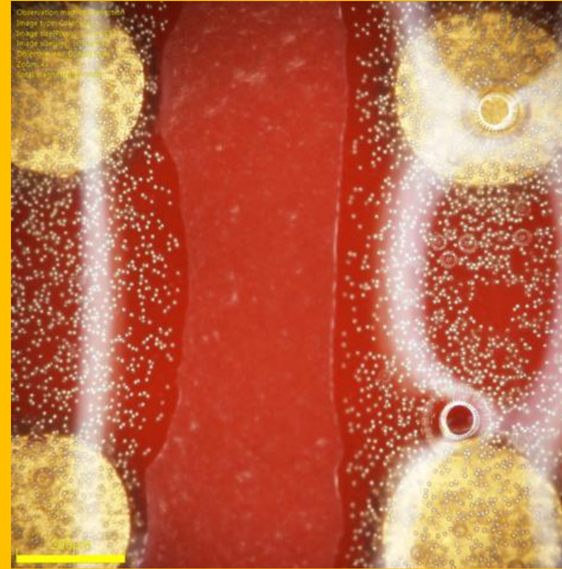


FIRST functional Si-assembly results

Timepix4 TSV module integration



Dispensing of the ACP on the connection pads of the PCB



Close up of the pads covered by the ACP with particles visible

Bonded module connected for electrical testing

- ACP with 5 Vol% of 10 µm diameter conductive particles bonded under 100 kgf
- Integration of Timepix4 TSV module (28.22 mm x 24.7 mm) with 540 connection pads (300 µm diameter and 900 µm pitch) successful!
- Electrical tests show behaviour identical to wire bonded module

Conclusion/Outlook

- **Assemblies/Modules for different projects sucessfully produced**
  - ALTIROC/LGAD
  - SPHIRD Si
  - Timepix4TSV integration
  - Timepix3/Silicon sensor and Malta module integration (not shown today)
- **Further optimization on the developed processes**
  - ENIG challenges
  - Larger conductive particles
  - ACF shape
- **Further testing of produced assemblies**
- **Work on more challenging assemblies like Timepix3 (large area and small pitch)**
- **Studies into thermal and mechanical stability**

Thank You

Timepix3 assembly

- 256 by 256 pixels with 55 µm pitch
- Testbeam and source measurments done
- Possibly adhesive quantity still to high
- Weak coupling in inefficient region
- Further optimization in plating height and ACF shape needed

Threshold increase by about 6000e-