Update on plating and in-house hybridisation activities

AIDAinnova WP6

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

- Ahmet LALE
- I joined CERN and Dominik DANNHEIM's team on January 8th, 2024 (as a fellow).
- Previously, I was a Project Manager at SAFRAN Sensing Technologies in Yverdon, Switzerland, focusing on the development of inertial MEMS (gyroscopes, accelerometers).
- Thesis in the field of nanowire-based microsensors for healthcare applications, at LAAS-CNRS, in Toulouse, France.

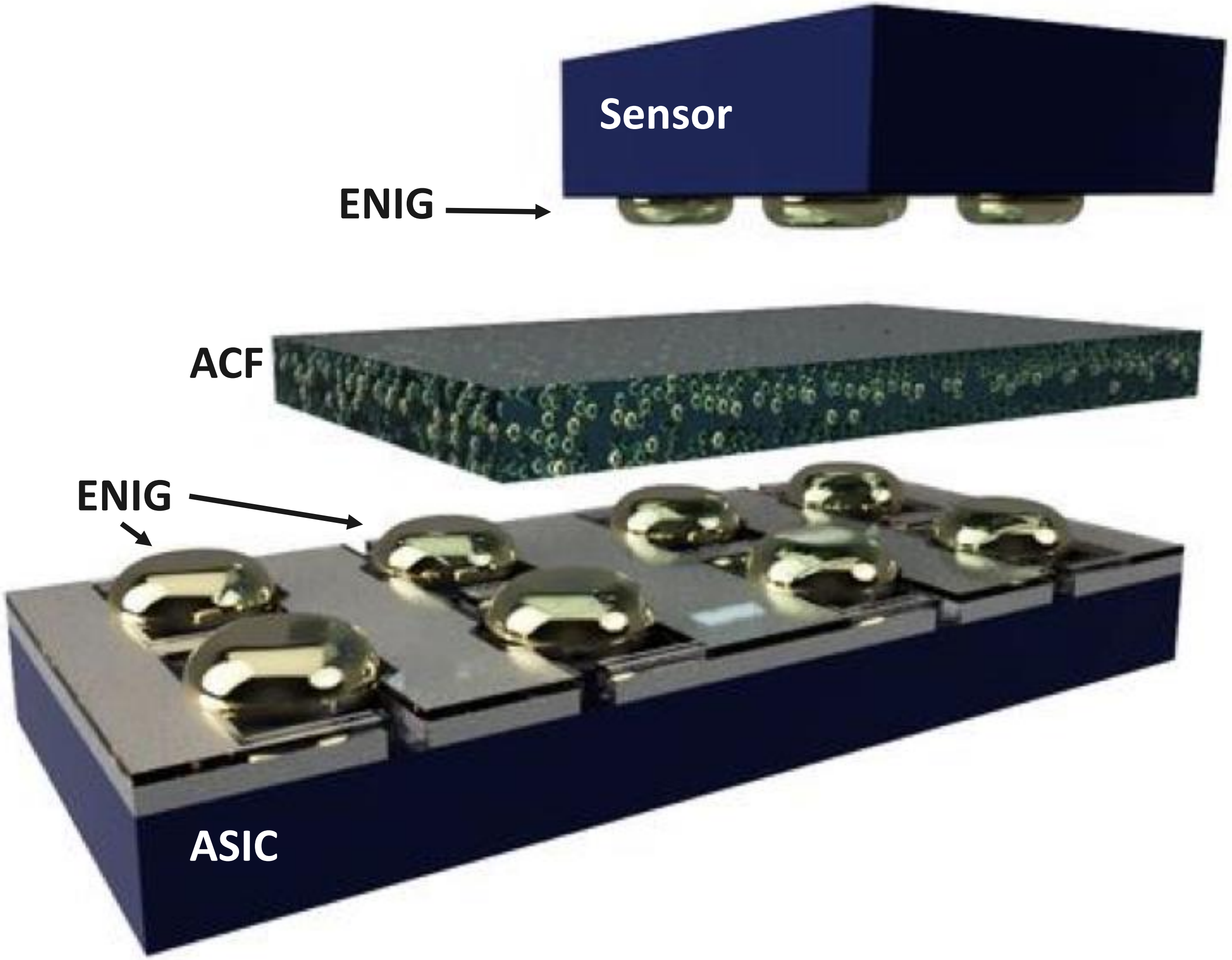
Summary

- Setup improvements for ENIG plating
- Results regarding the ENIG plating and areas for ENIG improvements
- Issues of Timepix3 assemblies
- Timepix4 assemblies with copper pillars and NCA (None Conductive Adhesive)

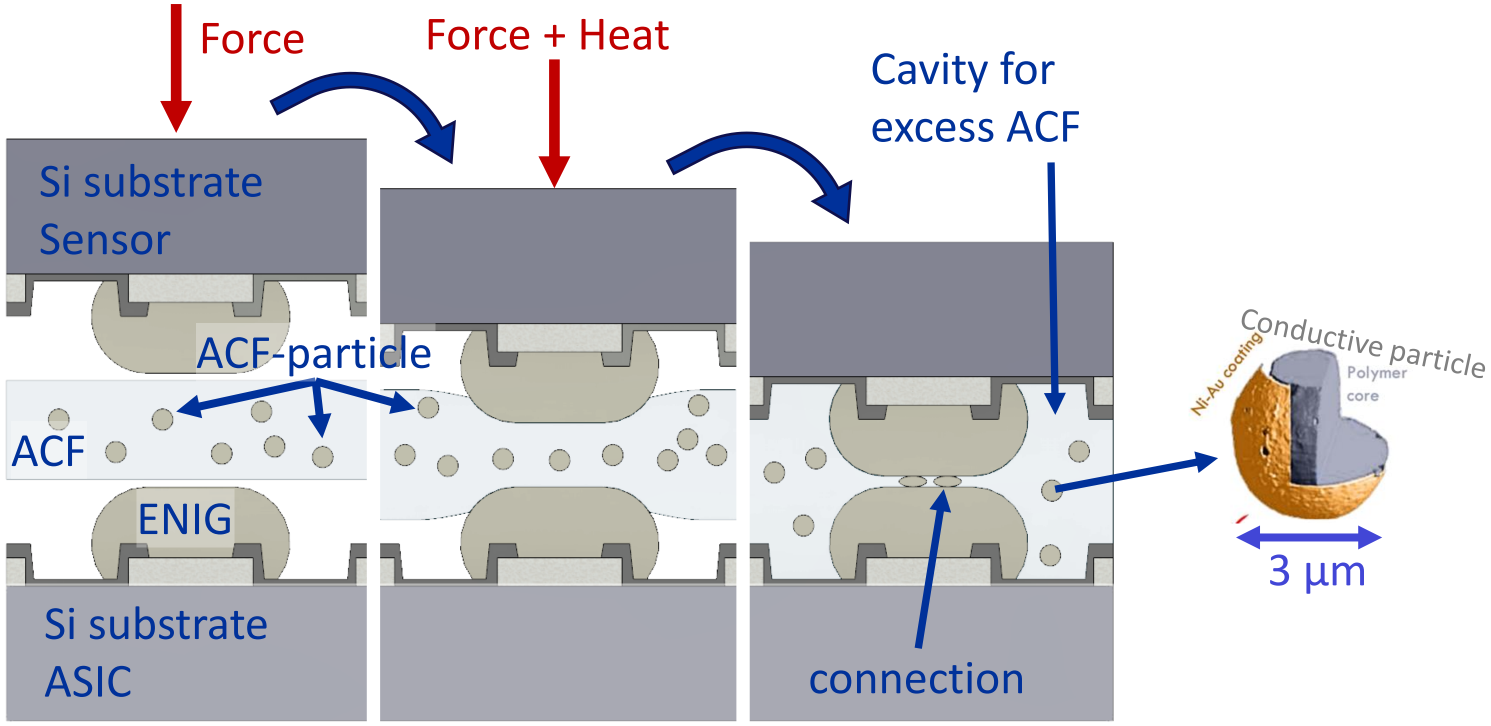
Hybridisation with Flip-chip and ACA

- Two main steps for hybridization with ACA (Anisotropic Conductive Adhesive):
  - Creation of bumps on the pads of Sensor and ASIC
  - Flip-chip assembly with an anisotropic conductive layer between the chips

  - **ACF: A**nisotropic **C**onductive **F**ilm
  - **ACP: A**nisotropic **C**onductive **P**aste

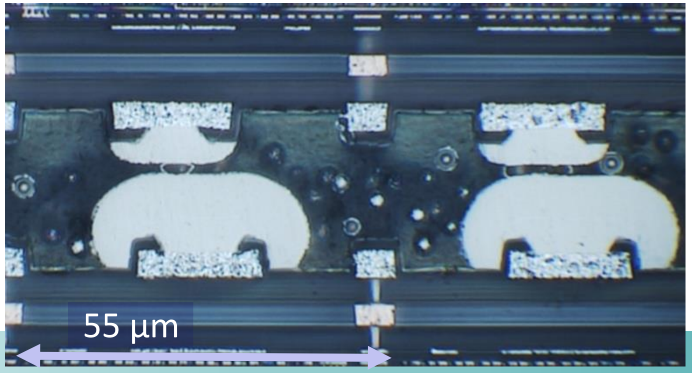


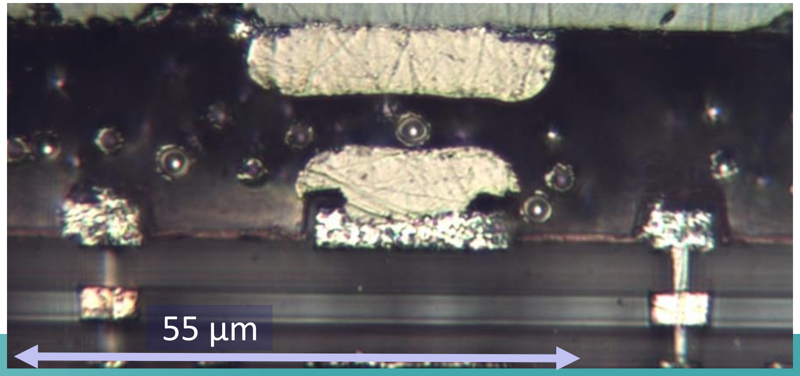
Hybridisation with Flip-chip and ACA



Key points for hybridisation with ACA:

- High uniformity and reproducibility of ENIG bumps
- Avoid overplating (plating on areas that should not be plated)
- Planarity of the assembly during flipchip
- Enough cavity volume for excess ACF/ACP

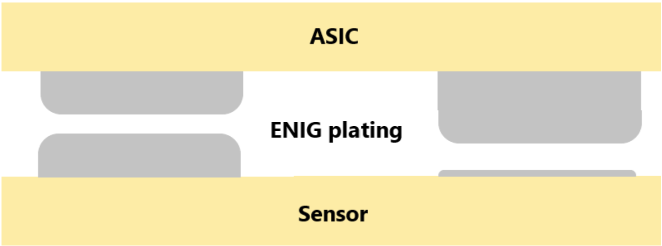




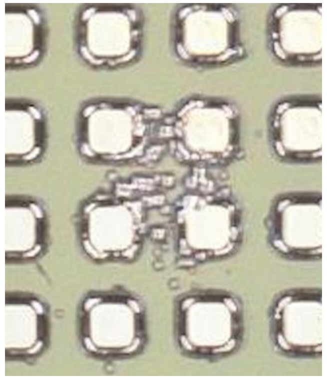
What needed improvement:

- Uniformity of nickel bump height across the chips
- Improve nickel deposition on chip edges
- Reduce/eliminate overplating phenomenon (plating on areas that should not be plated)
- Enhance deposition reproducibility from one chip to another
- ENIG on smaller pads with a lower pitch (higher connection density, Timepix3, CLICpix2…)

Illustration of non uniform plating



Example of overplating

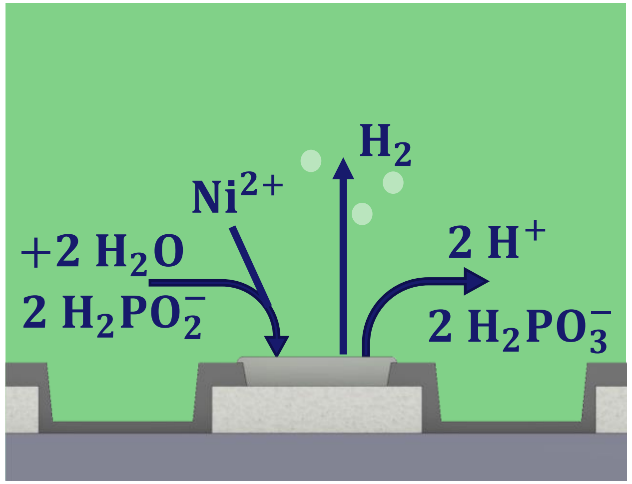


Electroless Nickel Immersion Gold (ENIG)

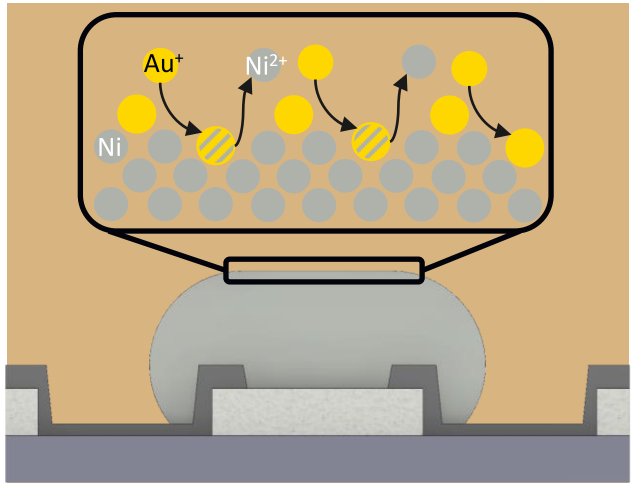
- Electroless Nickel
  - Self-catalytic reaction on pad surface
  - Performed on aluminium (activated surface) or on previous nickel deposits in a nickel bath
- Immersion Gold
  - Corrosion protection, very thin layer (< 1 µm)

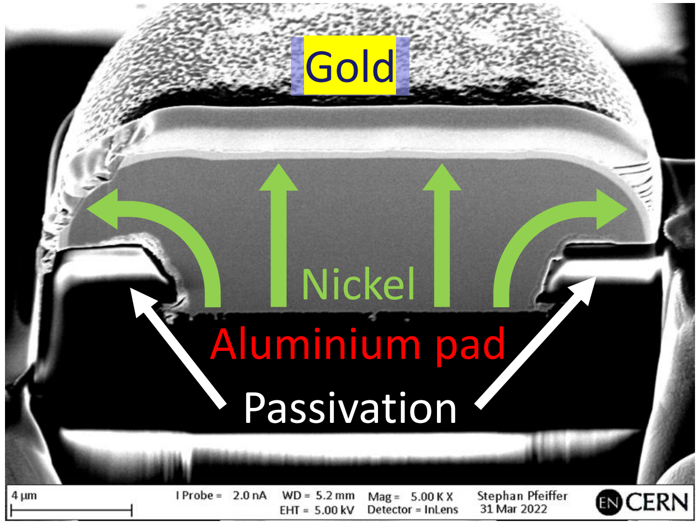
- Ongoing optimisation of the process in EP-DT Micro-Pattern Technologies lab
  - Cleaning, oxide removal, nickel bath stability,…
  - Optimisation performed for different pad topologies

Electroless Nickel



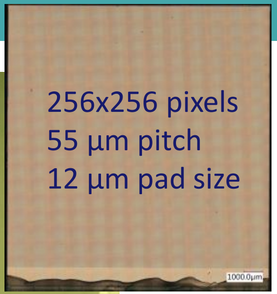
Immersion Gold

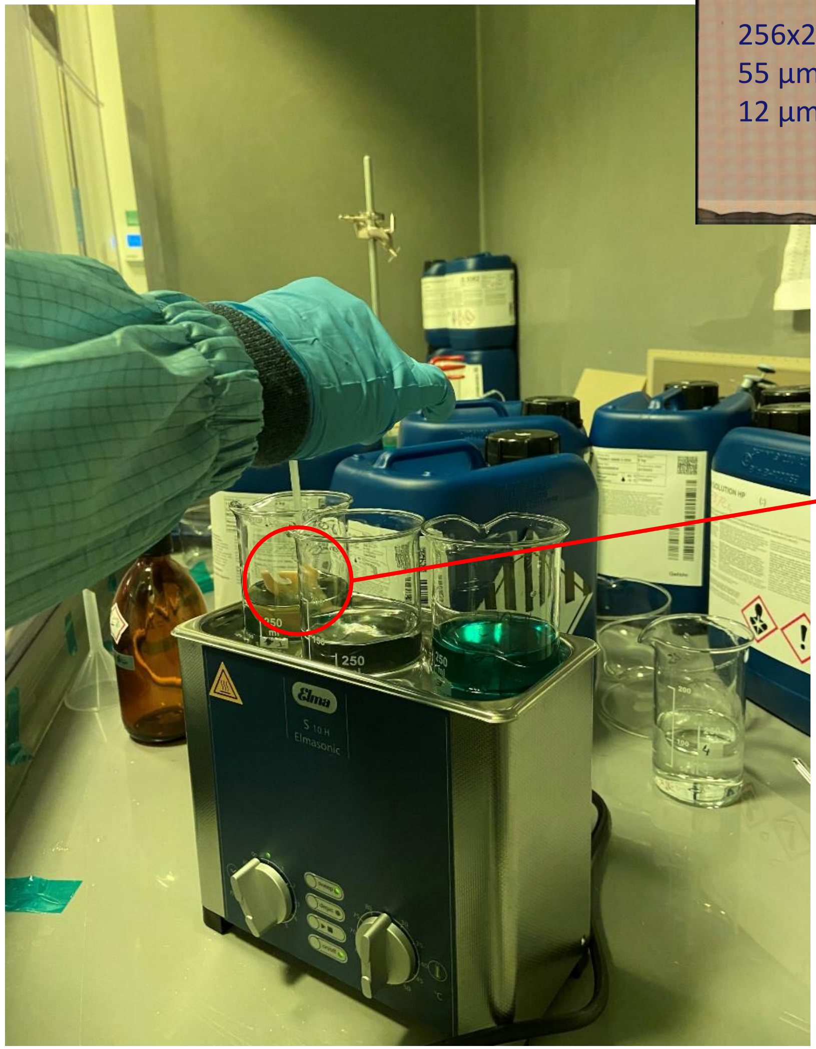




PRE-TREATMENT SETUP

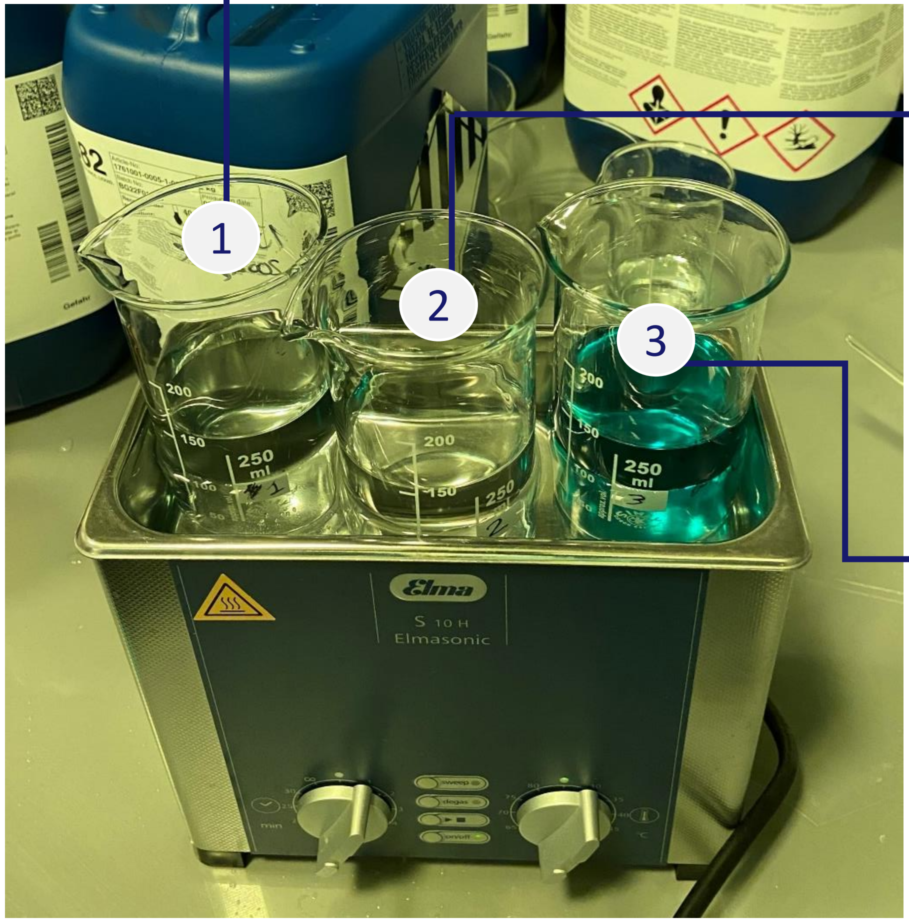
- Pre-treatment baths of ENIG process to perform better under agitated conditions
- An ultrasonic bath sonicator was included in the process setup to ensure the above
- Previous setup was static, sample was placed horizontally
- Current setup was dynamic, sample was placed vertically using a plastic hook with movements in a to-and-fro motion





Timepix3 sample on hook

PRE-TREATMENT SETUP



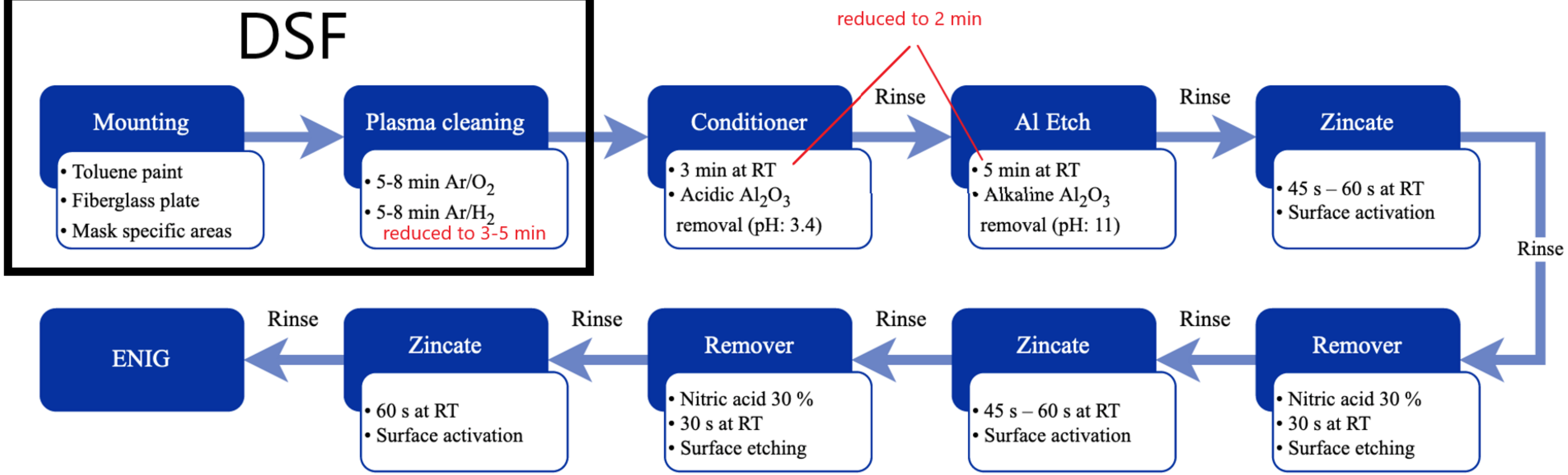
Xenolyte Conditioner ACA2

Xenolyte Al Etch MA

Xenolyte Zincate CFA

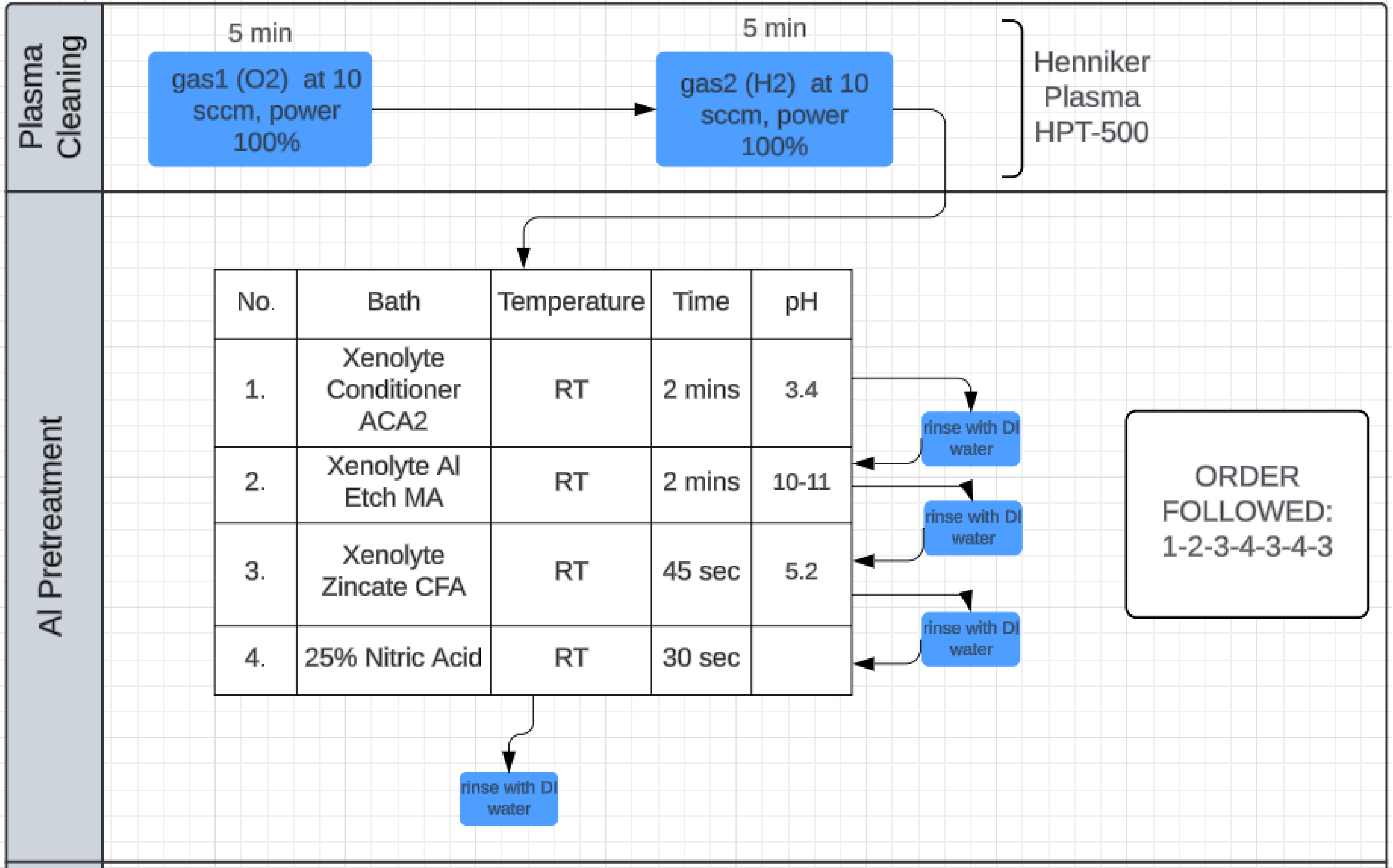
25% Nitric Acid

Procedure



DSF
Mounting
• Toluene paint
• Fiberglass plate
• Mask specific areas
Plasma cleaning
• 5-8 min Ar/O_2
• 5-8 min Ar/H_2
reduced to 3-5 min
Conditioner
• 3 min at RT
• Acidic Al_2O_3 removal (pH: 3.4)
reduced to 2 min
Rinse
Al Etch
• 5 min at RT
• Alkaline Al_2O_3 removal (pH: 11)
Rinse
Zincate
• 45 s – 60 s at RT
• Surface activation
Rinse
Remover
• Nitric acid 30 %
• 30 s at RT
• Surface etching
Rinse
Zincate
• 45 s – 60 s at RT
• Surface activation
Rinse
Remover
• Nitric acid 30 %
• 30 s at RT
• Surface etching
Rinse
Zincate
• 60 s at RT
• Surface activation
Rinse
ENIG

PROCESS FLOW OF PRE-TREATMENT

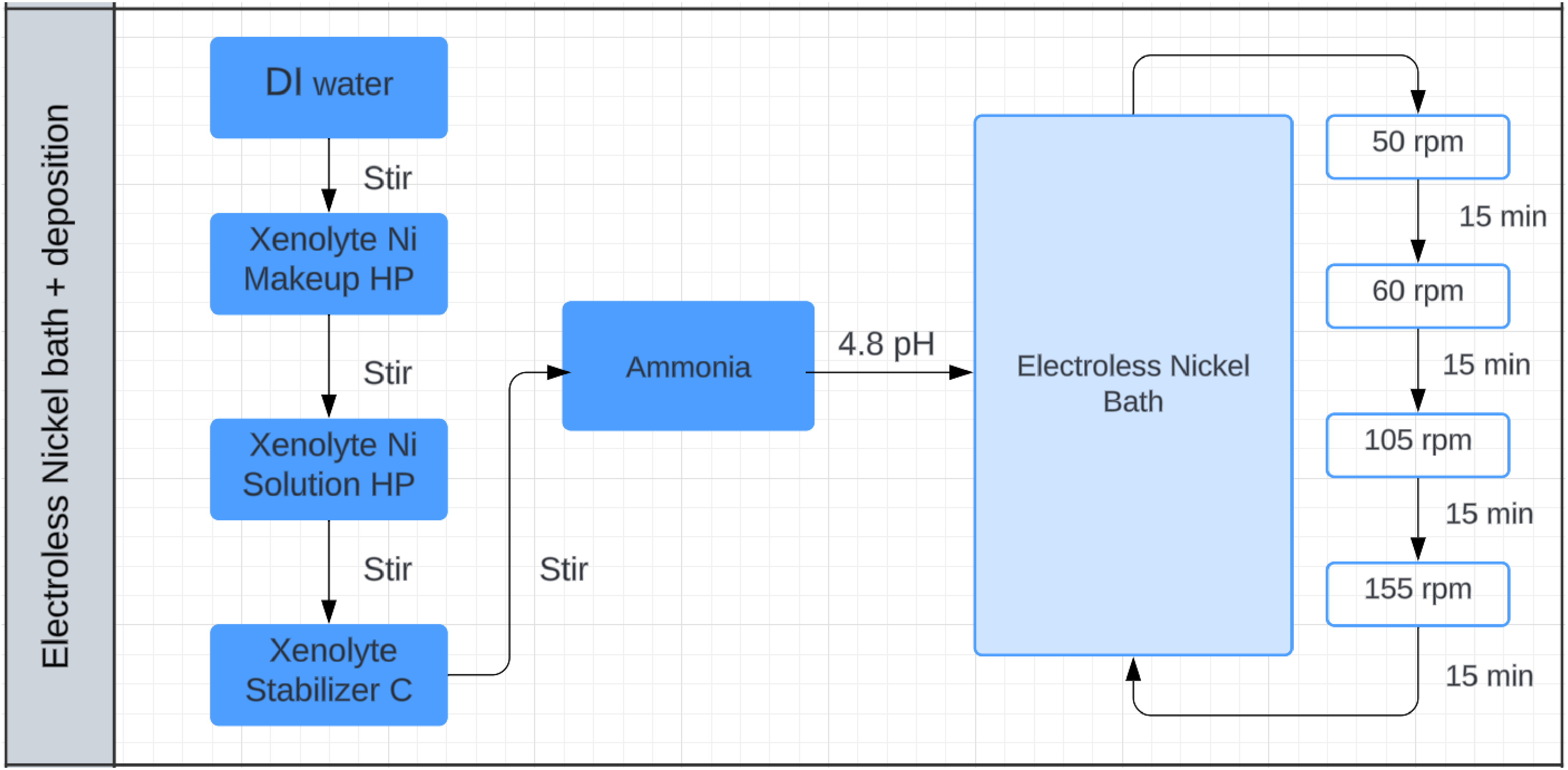


No.	Bath	Temperature	Time	pH
1.	Xenolyte Conditioner ACA2	RT	2 mins	3.4
2.	Xenolyte Al Etch MA	RT	2 mins	10-11
3.	Xenolyte Zincate CFA	RT	45 sec	5.2
4.	25% Nitric Acid	RT	30 sec	

NICKEL DEPOSITION SETUP

- The chemicals used were from provider ATOTECH and added in a specific ratio
- The rotation using the magnetic spinner was done first at 50 rpm, 60 rpm, 105 rpm and finally 155 rpm (in 15 minute intervals)
- The deposition was done for one hour with slight manual agitation
- The pH was maintained with Ammonia

PROCESS FLOW OF NICKEL DEPOSITION



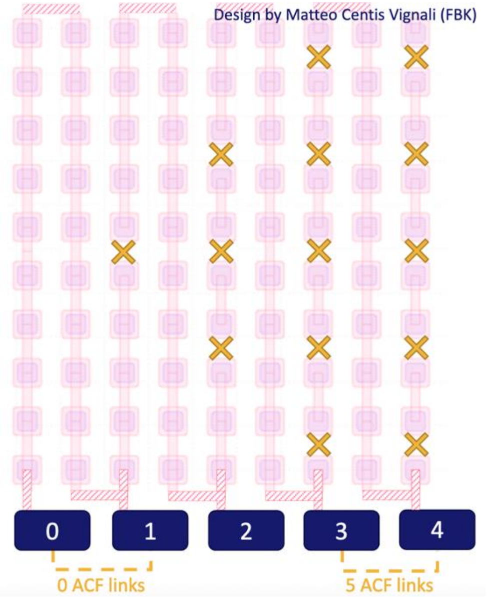
Next steps and implementations:

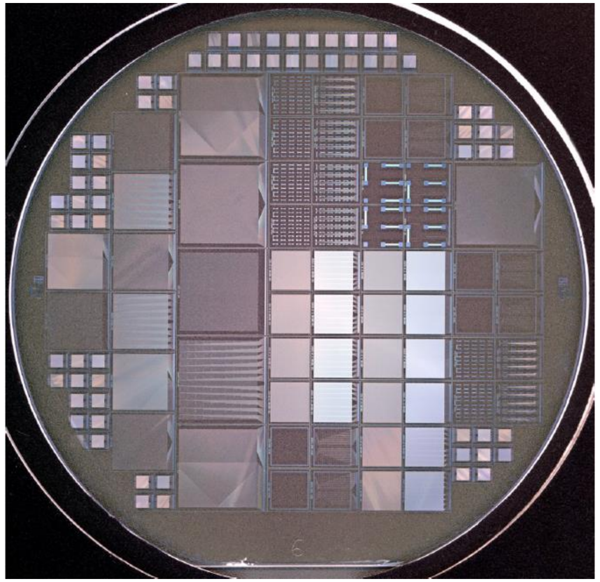
- Add a shaking table to integrate more agitation
- Use small back-and-forth movements during deposition instead of using only rotational movements (for even plating on edges)
- Test different time durations for the plating
- Continue to use the ultrasonic bath/sonicator for pre-treatment
- Observe how the changes between clockwise and anti-clockwise rotations influence the plating

Results regarding the ENIG plating

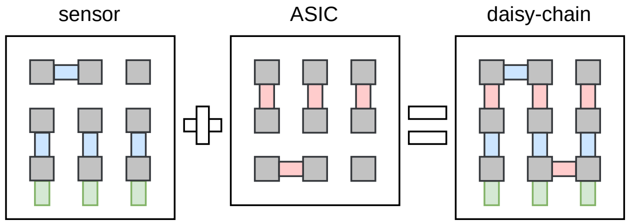
Daisy-chain devices
Production

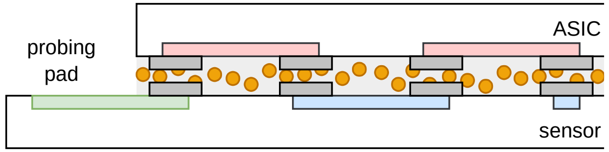
- Daisy-chain 6” quartz wafer with 625 µm thickness
  Designed and produced at FBK
- Study of ACF interconnection properties
  - Low-pitch and large-pitch reliability
  - Resistance measurements
  - Mechanical analysis





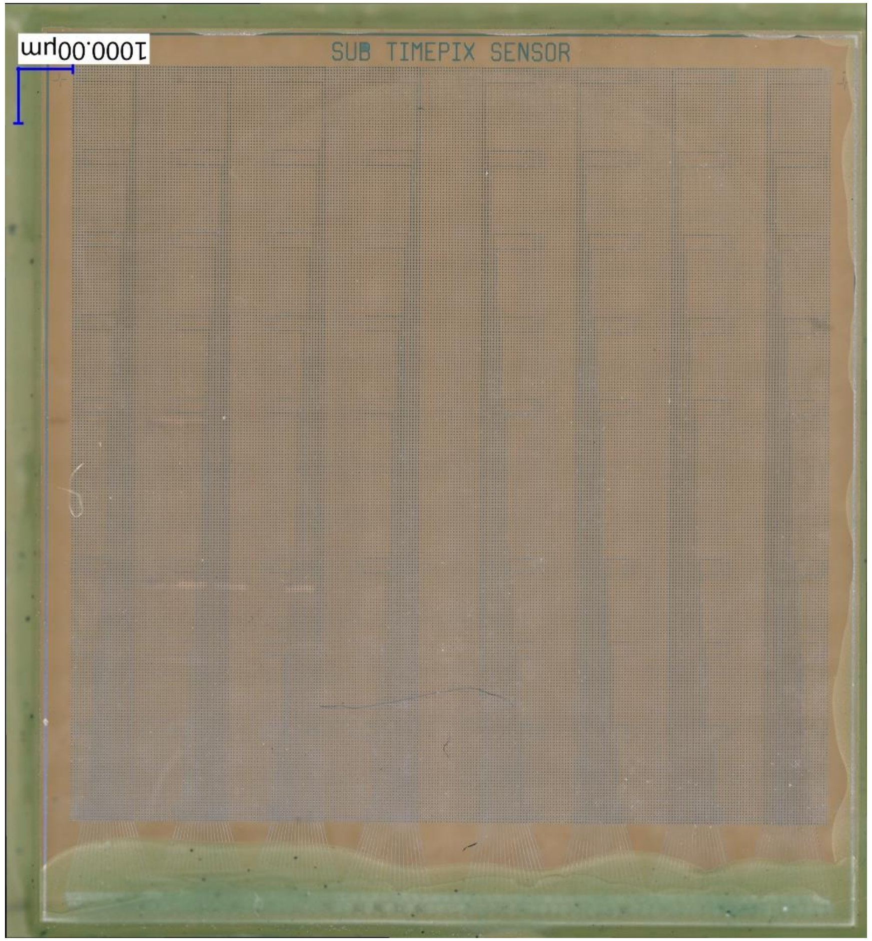
	pitch	size in mm	connections	per wafer	type	diceable
160x160 20um	20 um	3.2 x 3.2	25600	36	grid	no
CLICpix2	25 um	3.2 x 3.2	16384	34	grid	no
400x400 25um	25 um	20 x 20	640000	5	grid	yes
Timepix3	55 um	14 x 14	65536	4	grid	no
Timepix3 islands	55 um	14 x 14	65536	4	grid	no
RD53	50 um	20 x 20	160000	4	grid	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



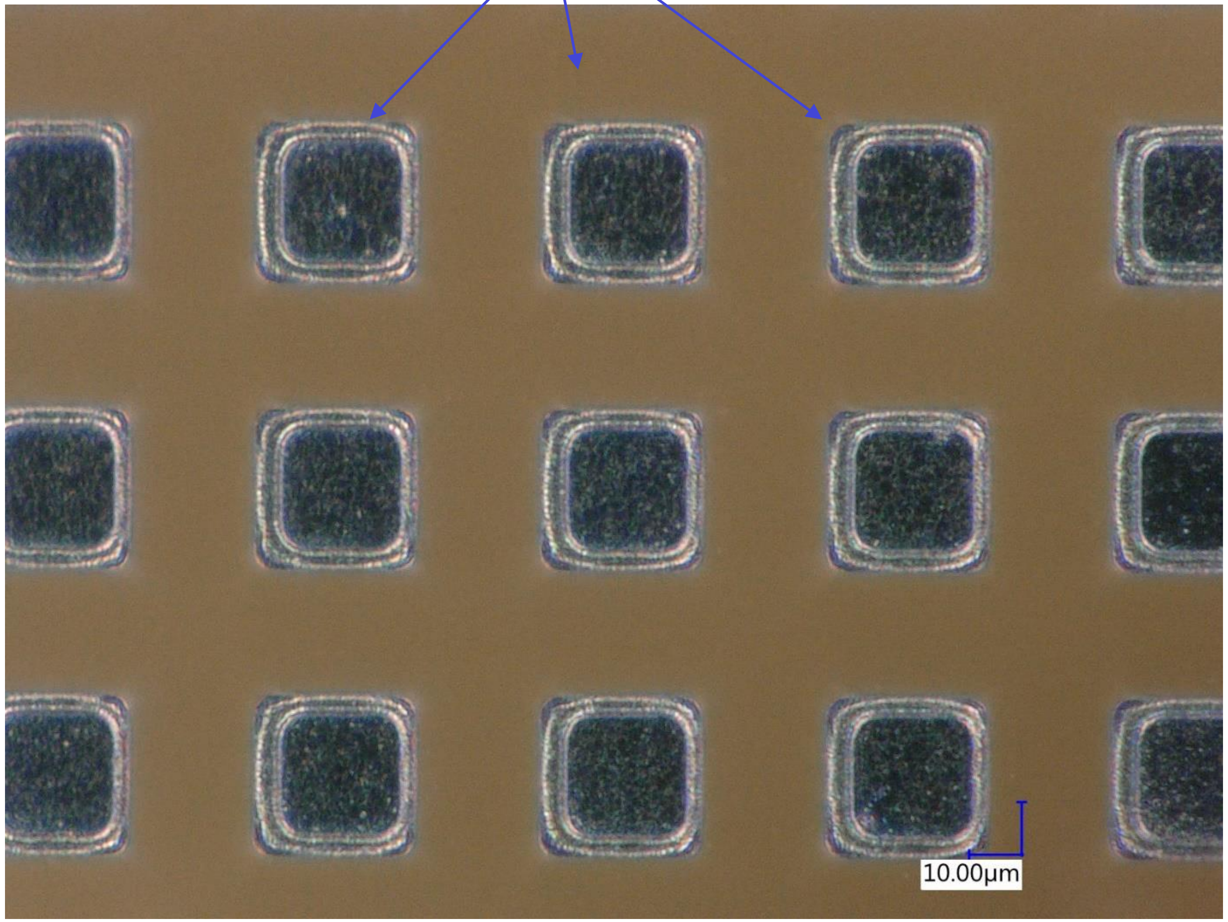


ENIG plating

Timepix3 daisychain, 55µm pitch, 22µm pads, 14x14mm chip

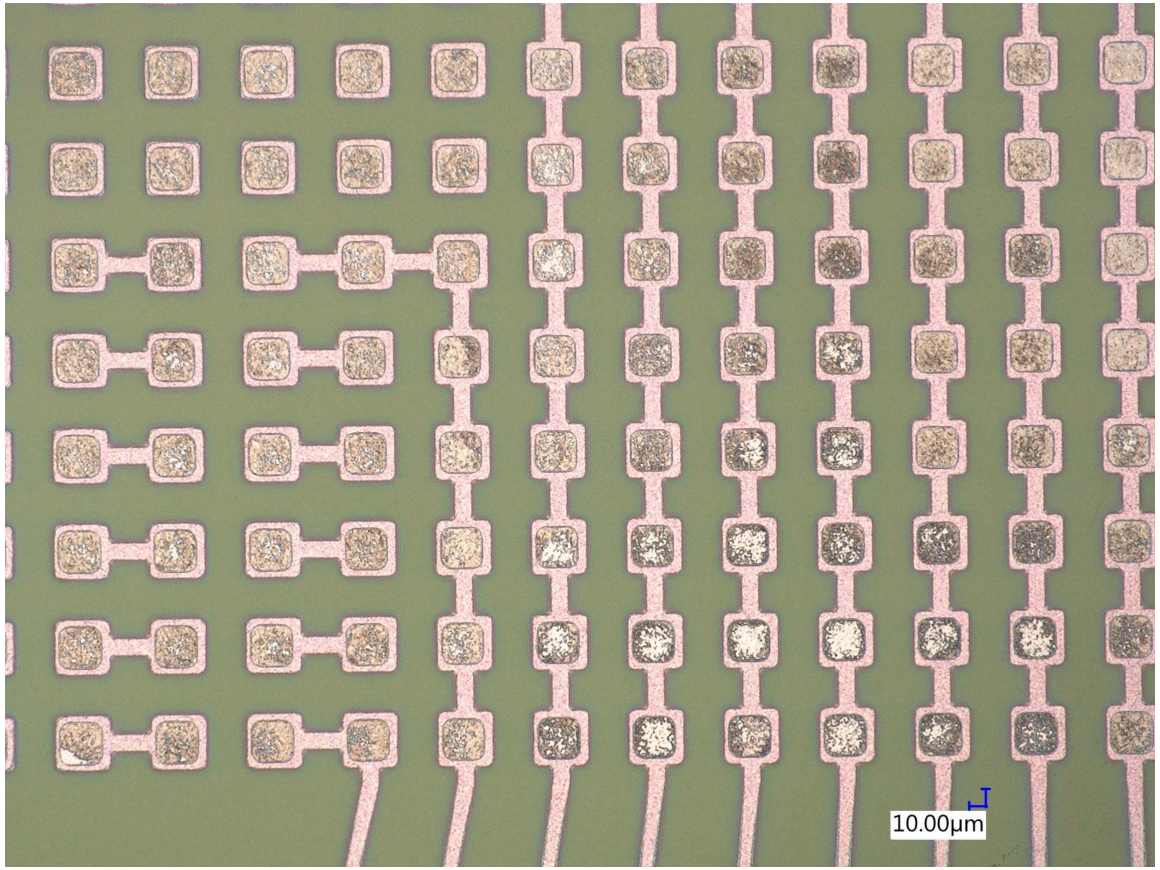


Zinc plating (before Nickel Plating)
Aluminium Pads (ring illumination)

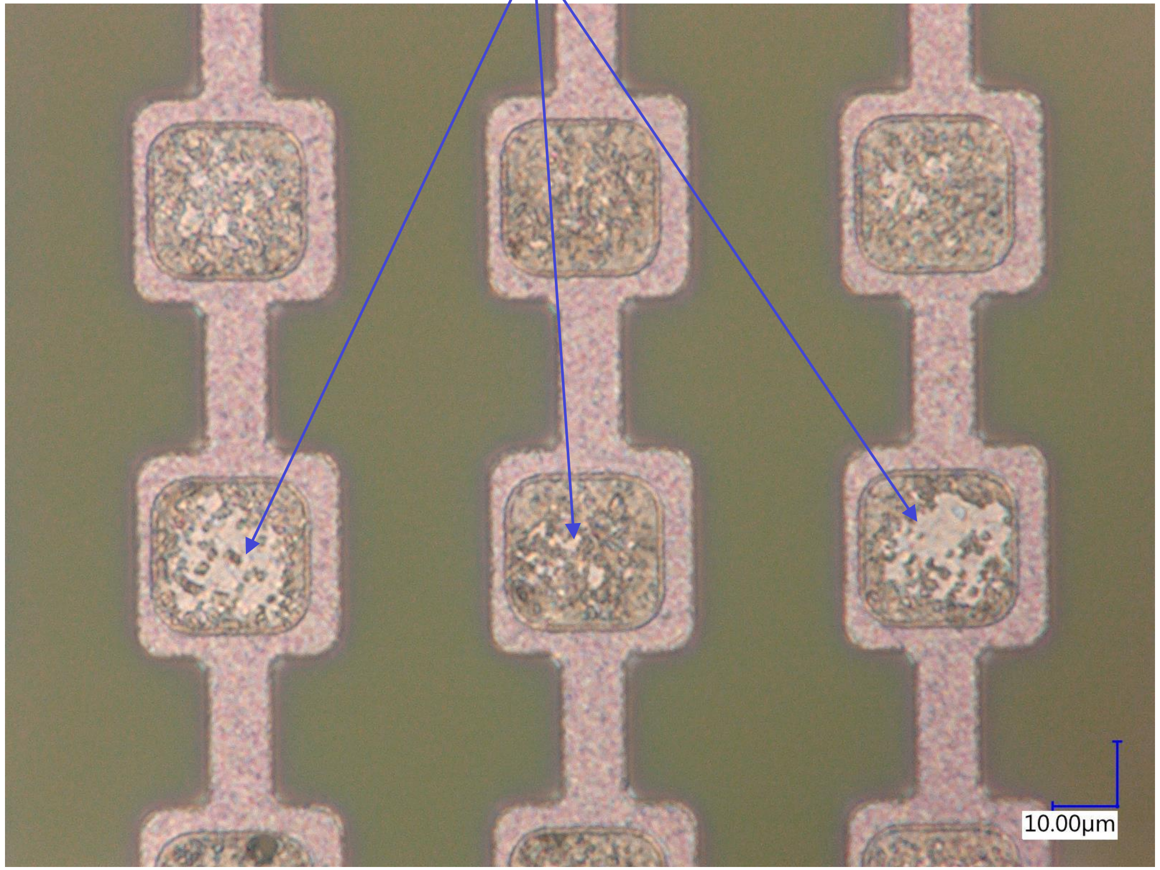


ENIG plating

- After Plasma, surface treatment, zinc deposition.
- Before nickel plating



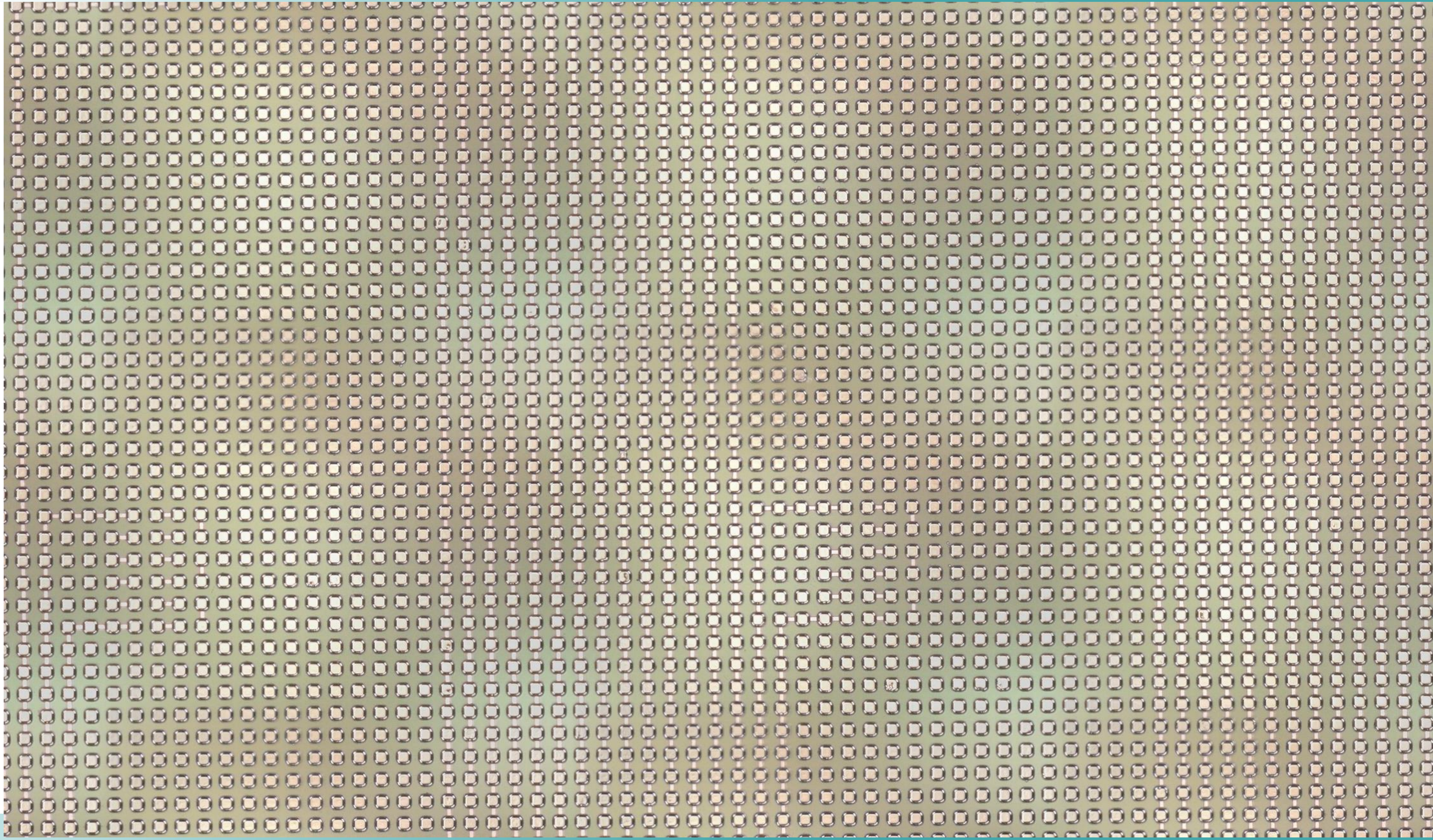
Islands of zinc on aluminium ?



ENIG plating

After nickel deposition:

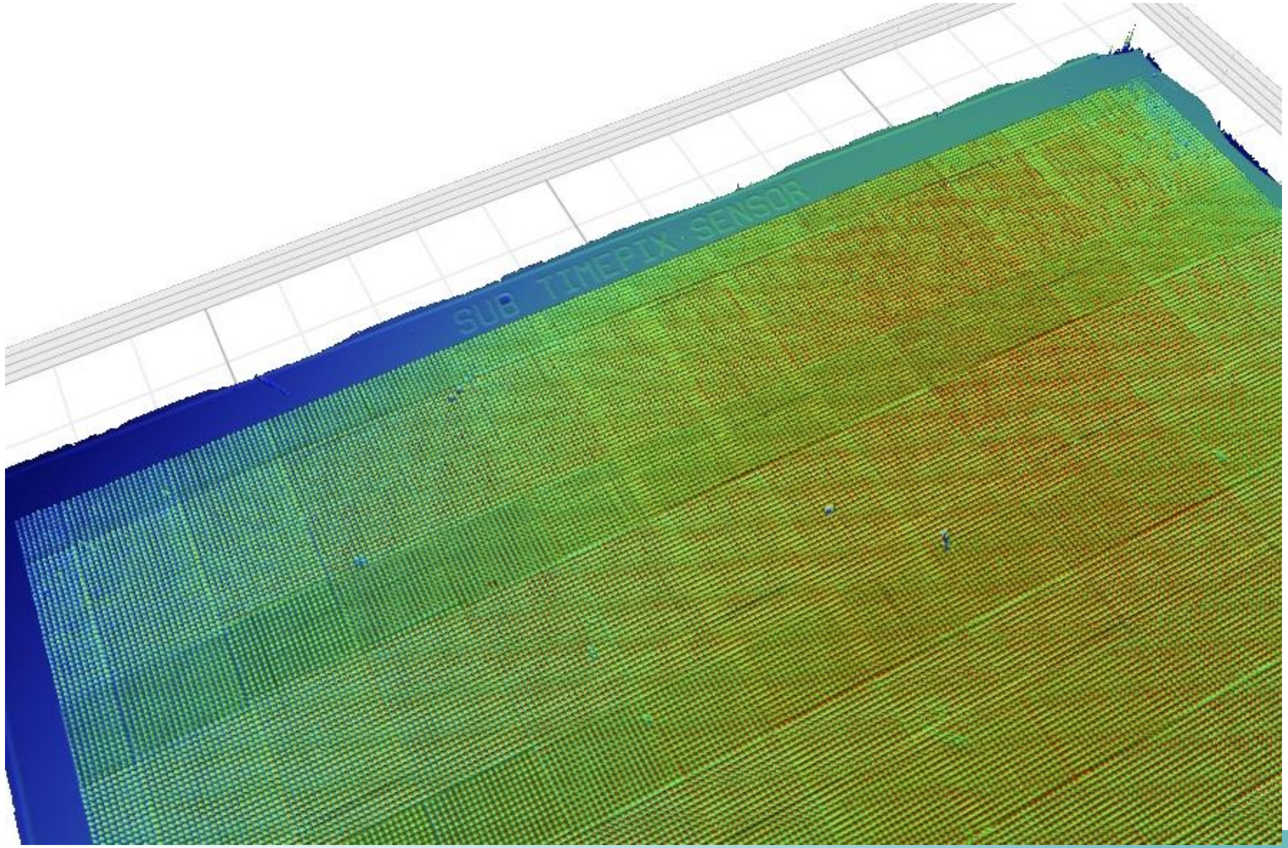
- Good ENIG results on 22µm pads and 55µm pitch

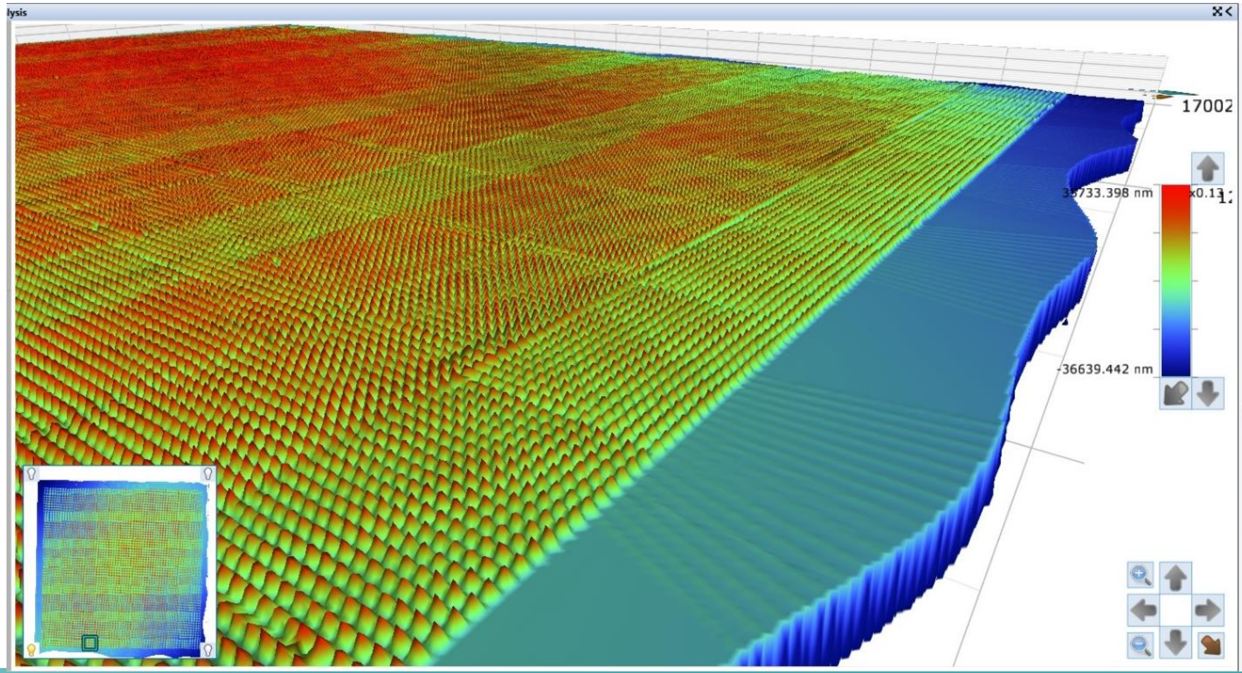


ENIG plating

- New equipment available at Campus Biotech for characterizing all nickel bumps on a chip, allows for quick identification of problematic areas, if any.
- High bump height 10.5µm
- Good ENIG homogeneity with a variation of only 0.5µm (except for the first 2 rows on each edge).
- Very few defects, approximately 98% of 65 536 pads are compliant.

Bruker Contour optical profilometer (at Campus Biotech)

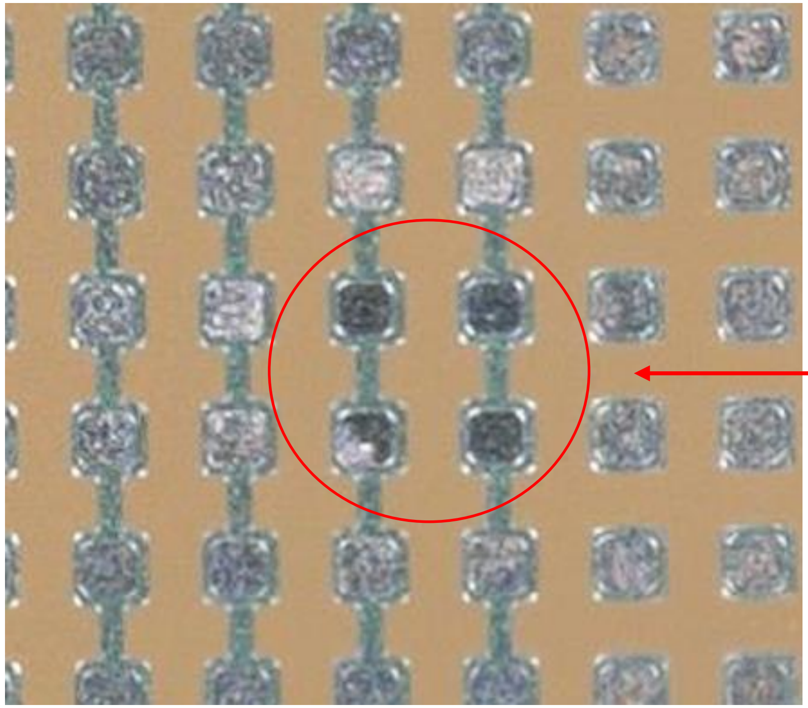




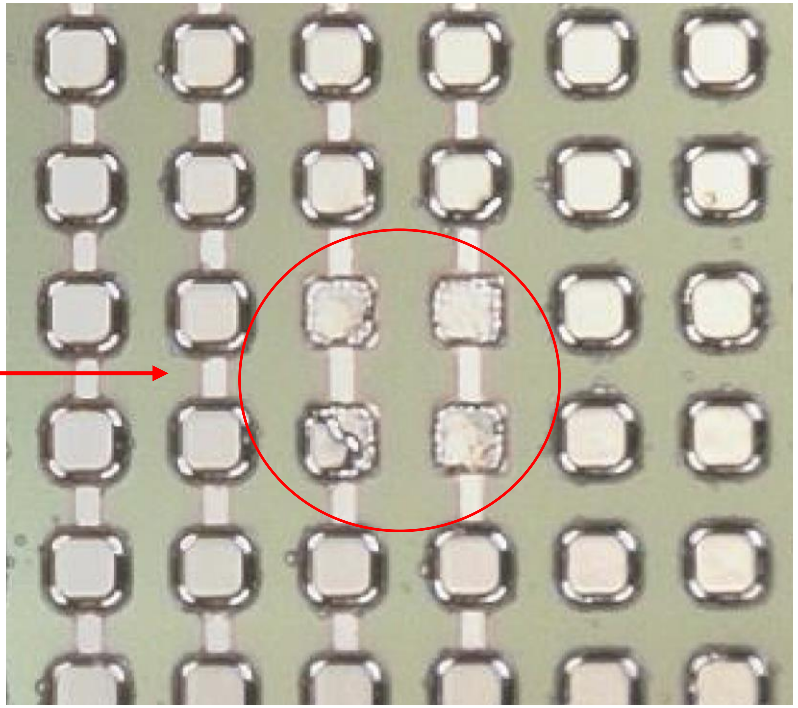
Areas for ENIG improvements

ENIG plating

Before nickel plating, (After zinc plating)



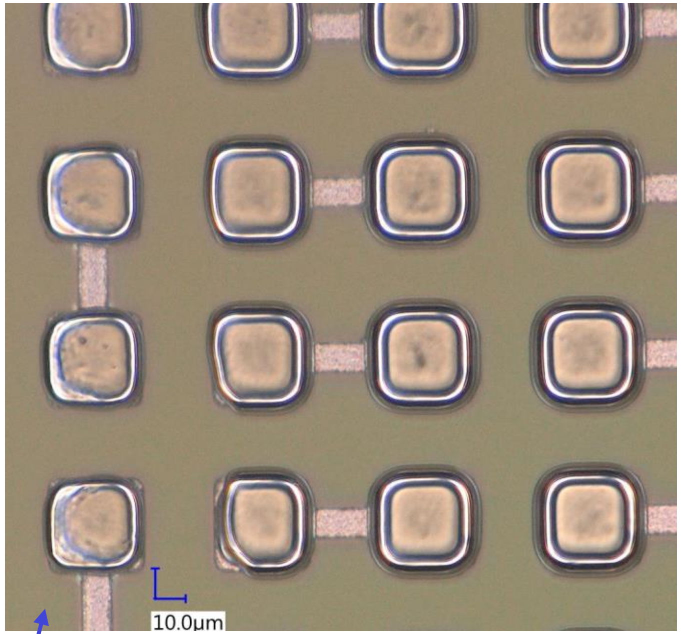
After nickel plating



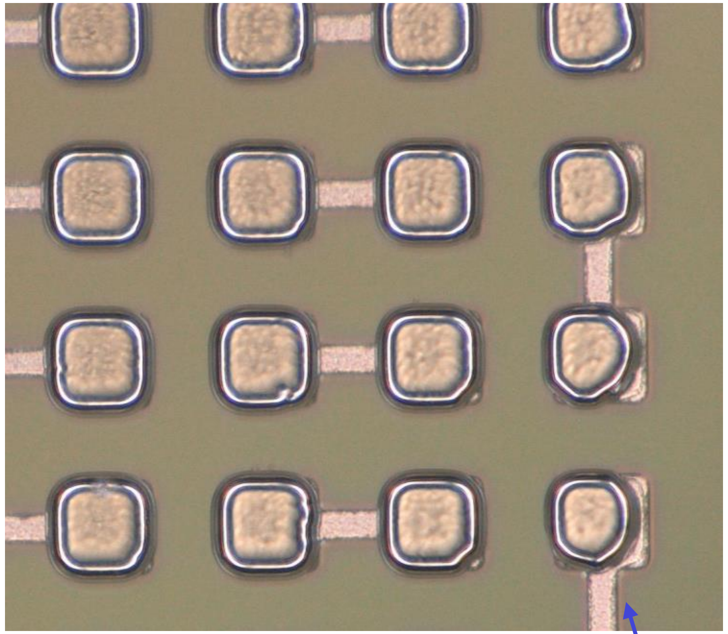
We have decided to study the zinc deposition first because a lot of issues with ENIG seem to be caused by a problem at the zinc plating step (or before). Was not studied before.

Plating issues at the edge of chips

Bottom left of Timepix3 daisychain chip



Bottom right of Timepix3 daisychain chip



Direction of stirring half of nickel deposition time

Direction of stirring half of nickel deposition time

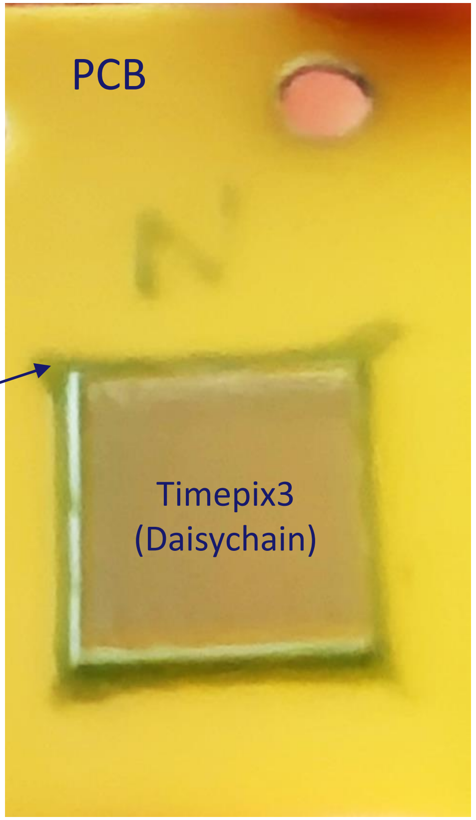
First pixel column

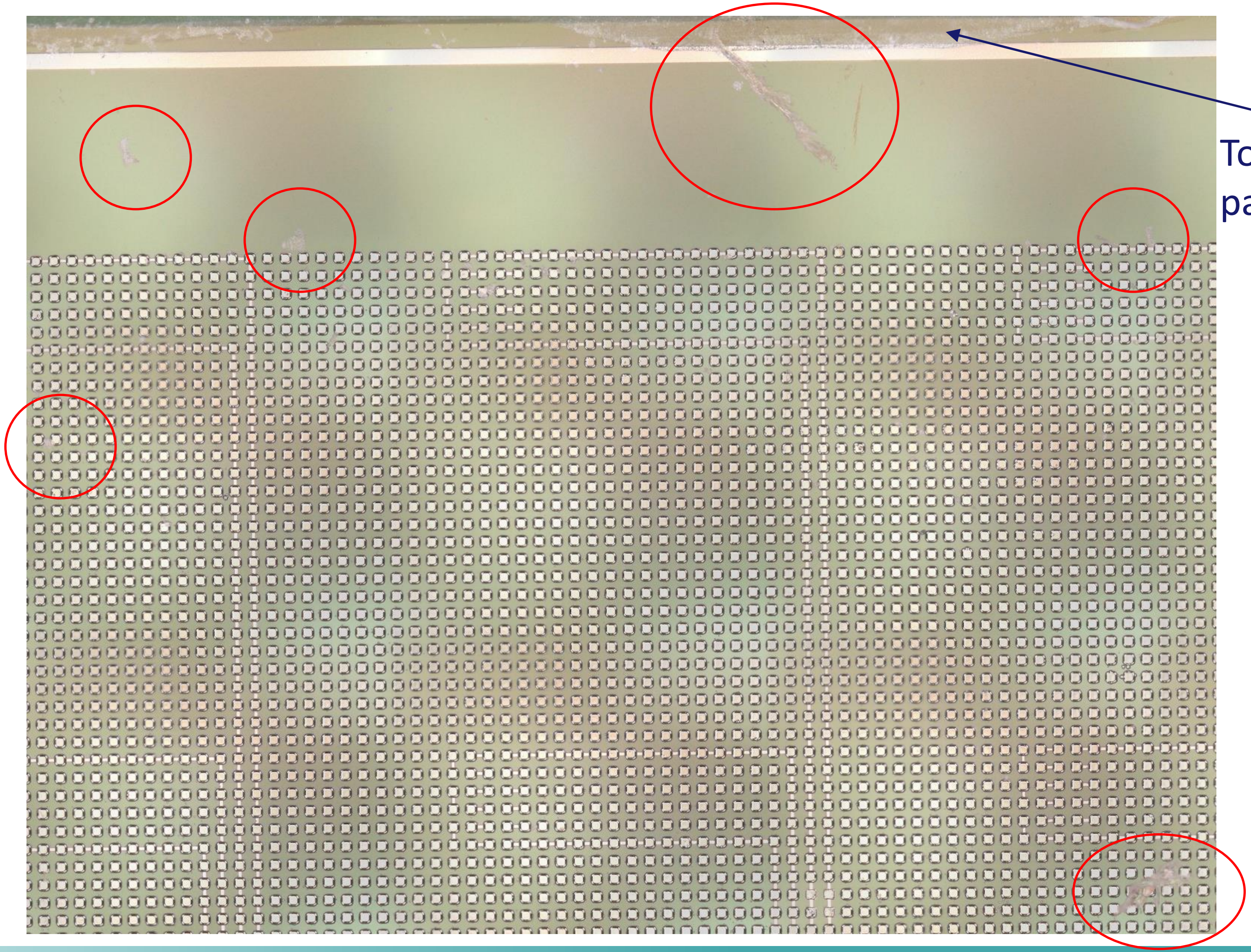
Last pixel column

We have to work on the stirring during nickel deposition

Particule deposition from the toluene paint used to protect the back side

Toluene Paint





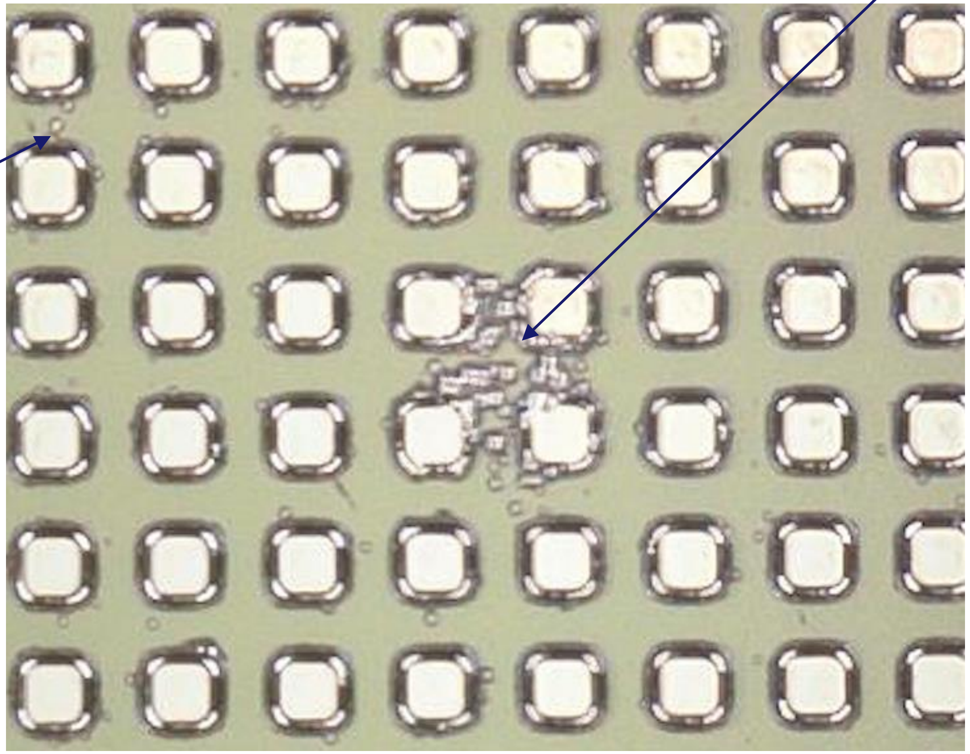
Toluene paint

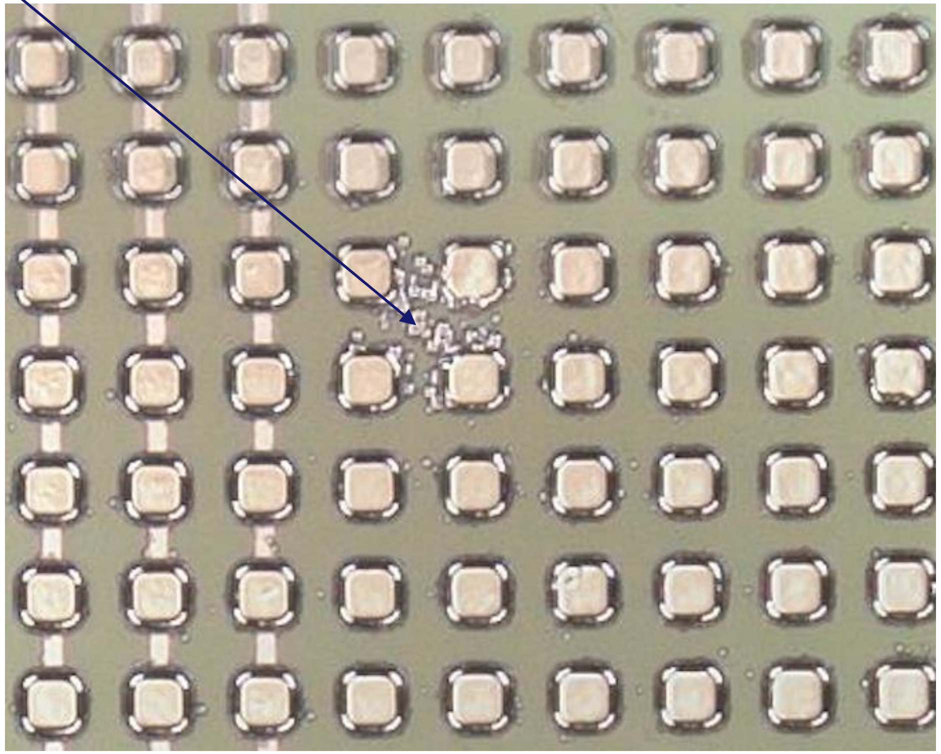
ENIG plating

Few clusters of overplating (6 identified, 24 pads out of 65 536)

Small nickel balls on the surface, 5% of the surface is affected.

(not problematic because they are too small to create short circuits)





Conclusion regarding plating:

- Good results achieved with ENIG on Timepix3 with 22µm pads and 55µm pitch.
  - Thanks to setup optimisations (of course needs to be confirmed on more samples)

- Identified several areas for improvement to achieve even better results.
  - Improvement of the zinc plating step
  - Improvement of the stirring during nickel deposition
  - Particules deposition from the toluene paint

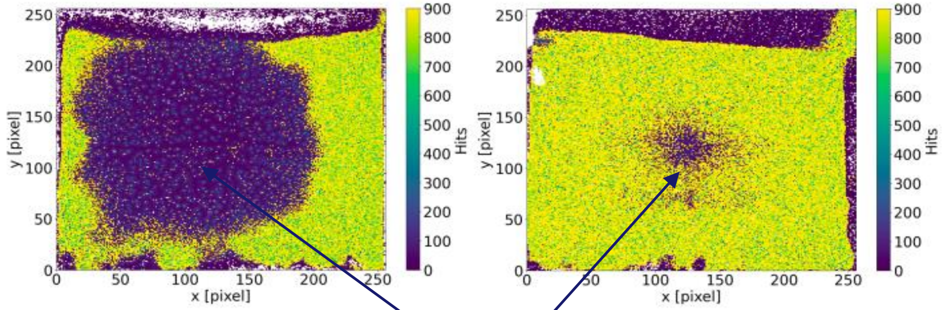
- Next trials will be conducted on chips with 20µm pads and 25µm pitch (from daisy chain wafers).

Issues of Timepix3 assemblies

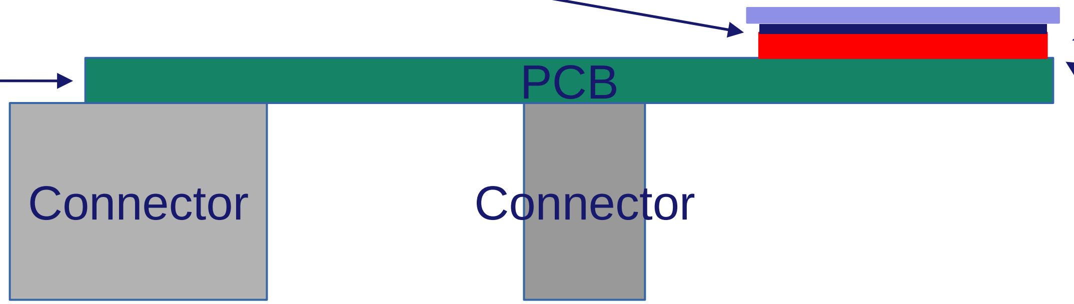
Issues of Timepix3 assemblies

- Issue: The pixels in the center of the sensor are not functioning

Timepix3 Hitmaps (Sr90 exposure)



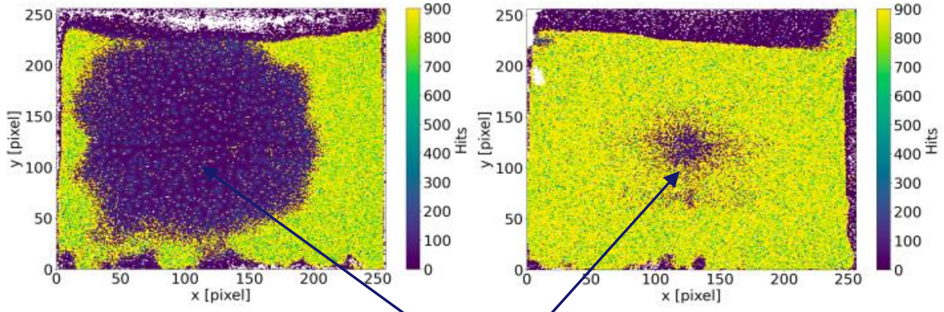
Non-functional pixel.



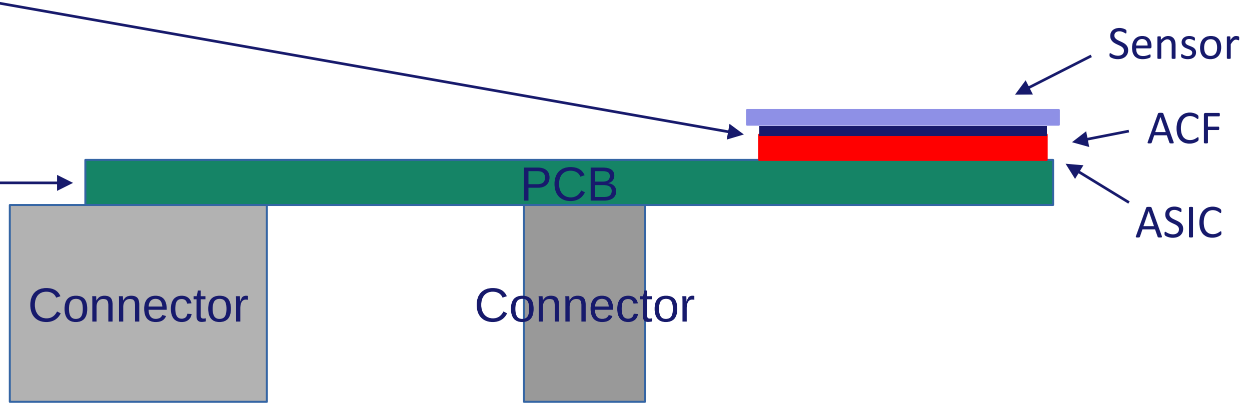
Issues of Timepix3 assemblies

- Hypothesis: The sensor is curved after assembly, increasing the distance between the chips in the center and preventing contact.

Timepix3 Hitmaps (Sr90 exposure)



Non-functional pixel.



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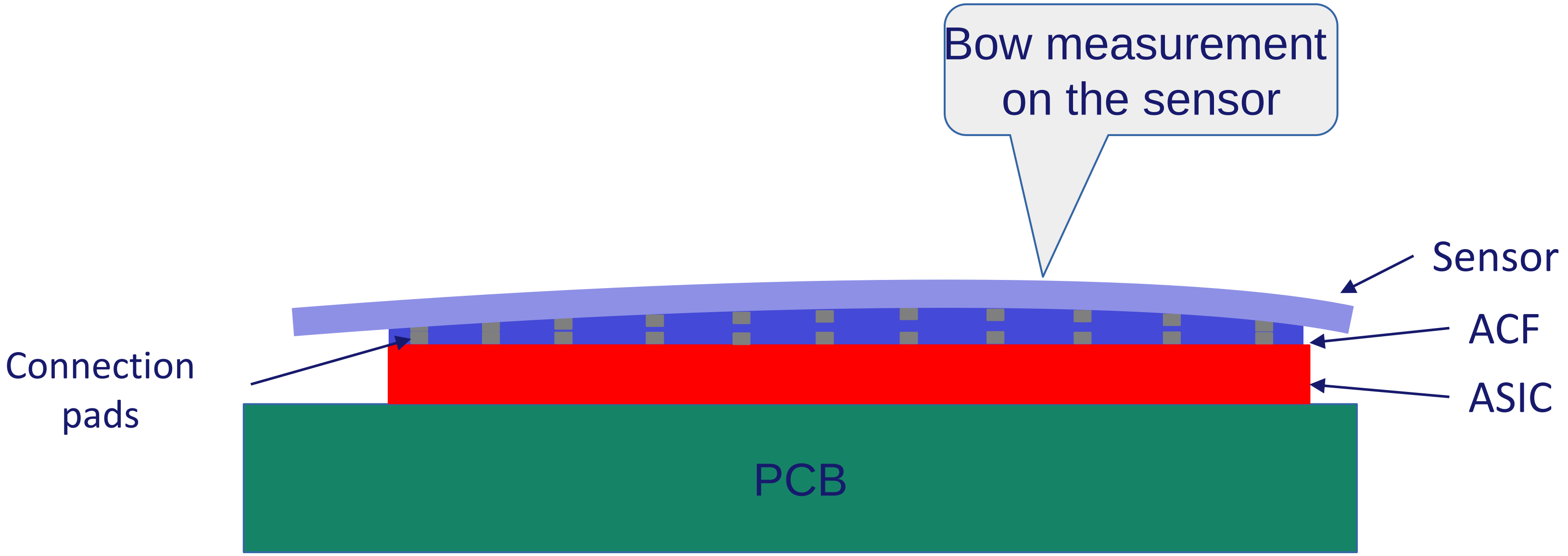
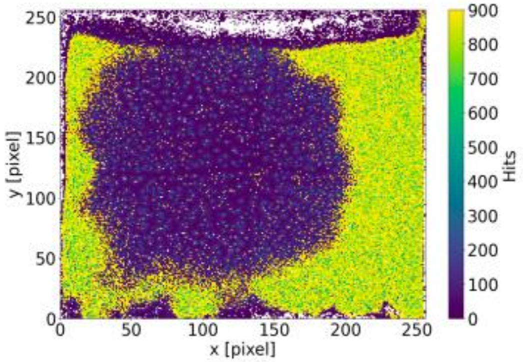
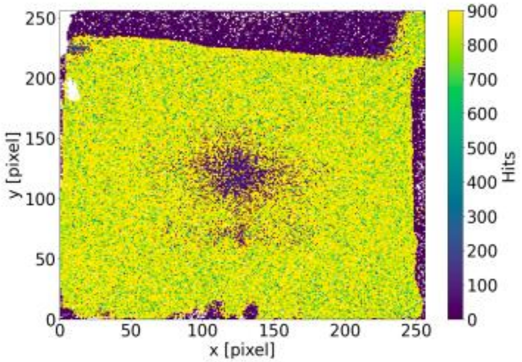
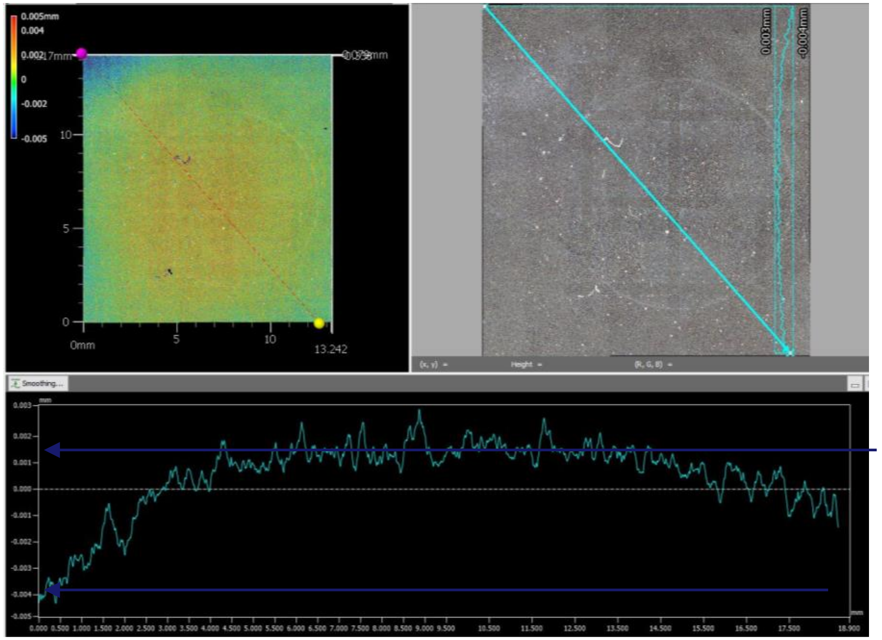


Keyence VR 3200 (Thin film lab, CERN)

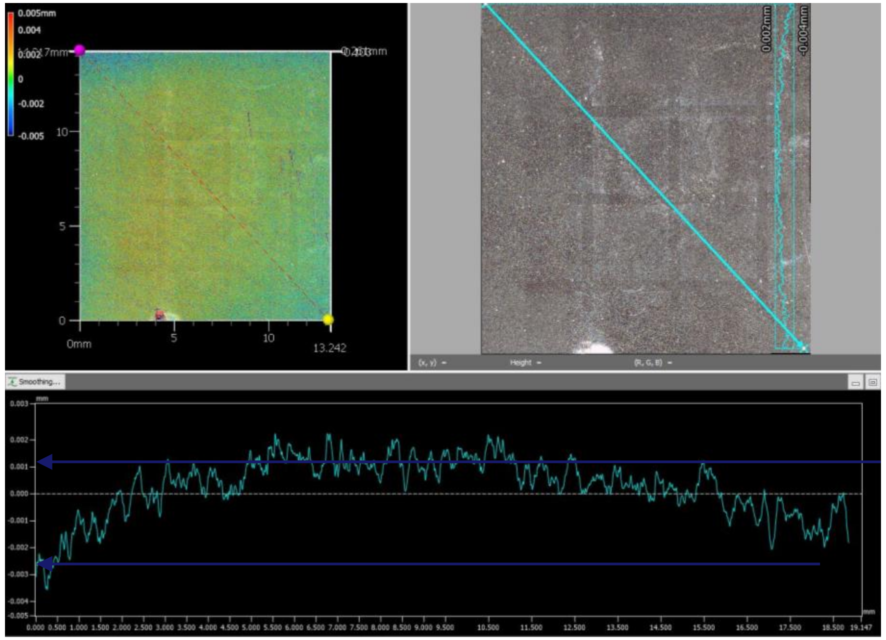






5.5µm

3.8µm



*(The bow is not related to a curvature of the PCB)

Conclusion:

- Connection issues at the center of the assemblies appear to be indeed related to a curvature problem, which increases the distance between chips at the center and leads to poor connections

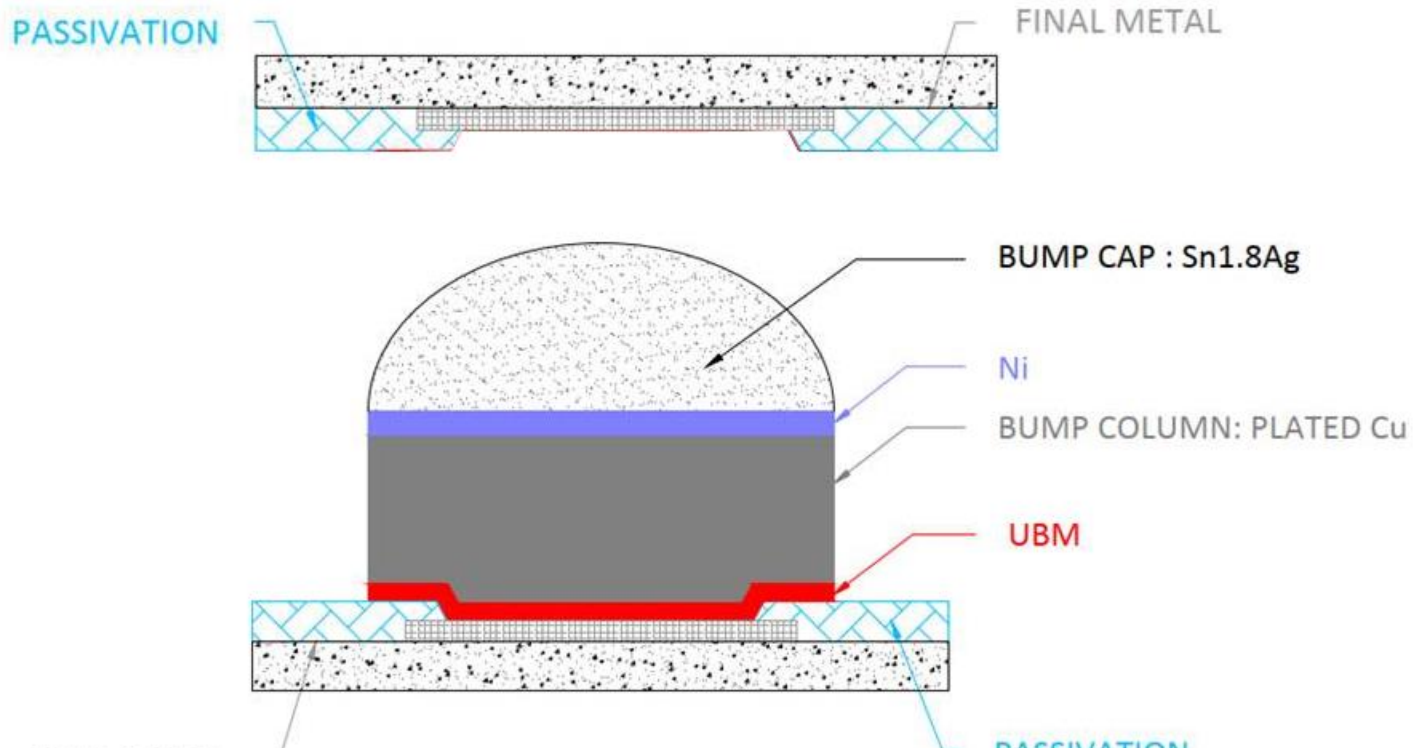
Next steps :

- Disassembly of the chips from the PCB
- X-ray observations to inspect the connections between the sensor and the ASIC.
- Cutting of the sensor and polishing to observe the cross-section and the connections.

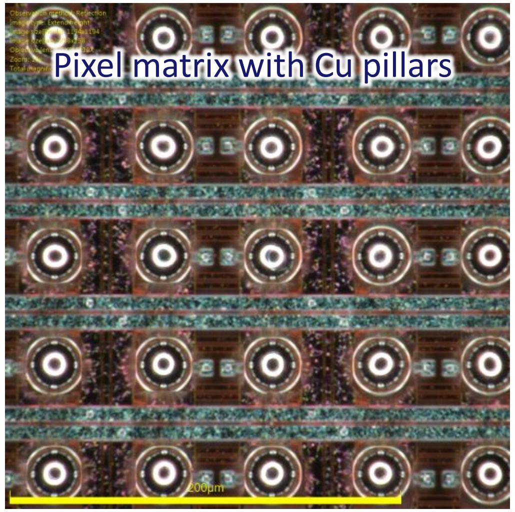
Timepix4 assemblies with copper pillars and NCA (None Conductive Adhesive)

Timepix4 assemblies with copper pillars and NCA

Bonding two Timepix4, one with Cu pillars and the other without.

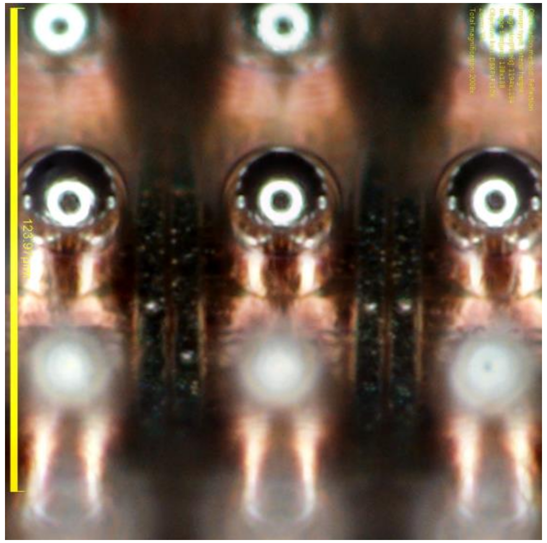


A single pixel



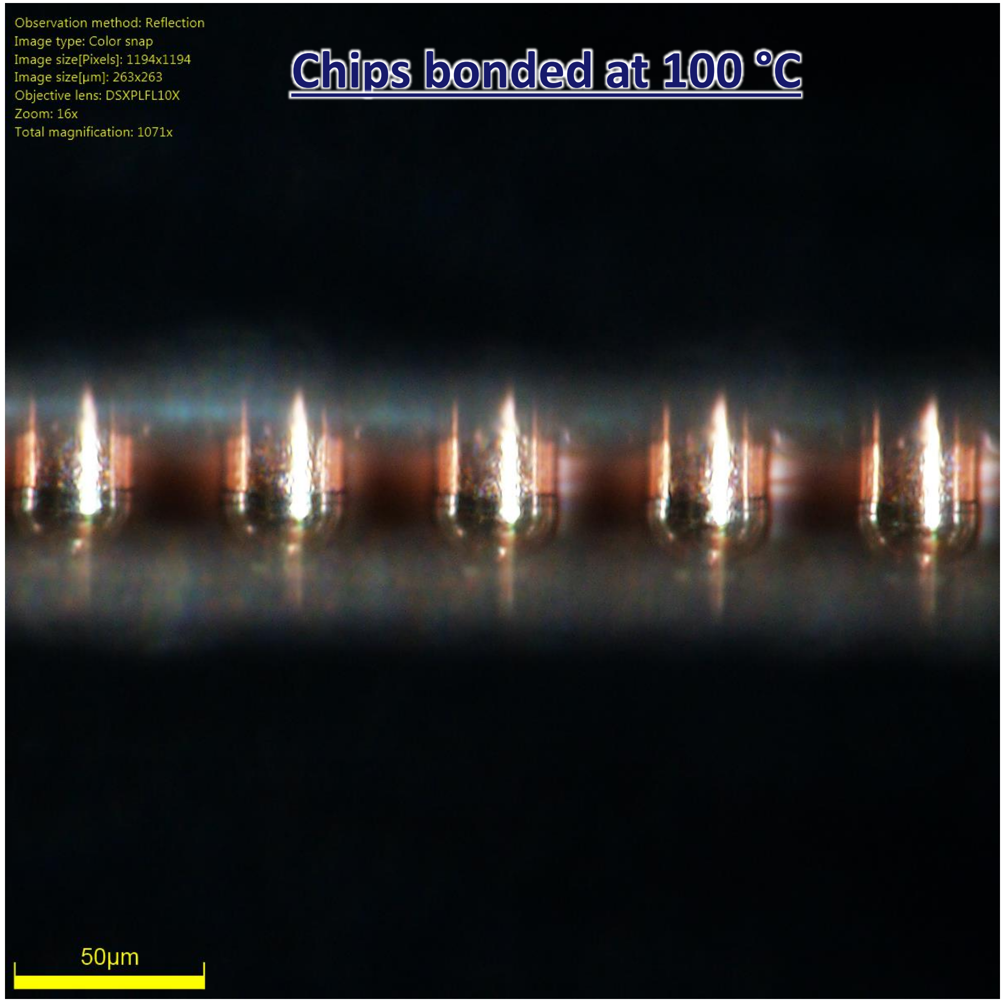
Copper pillars (with Sn1.8Ag caps)

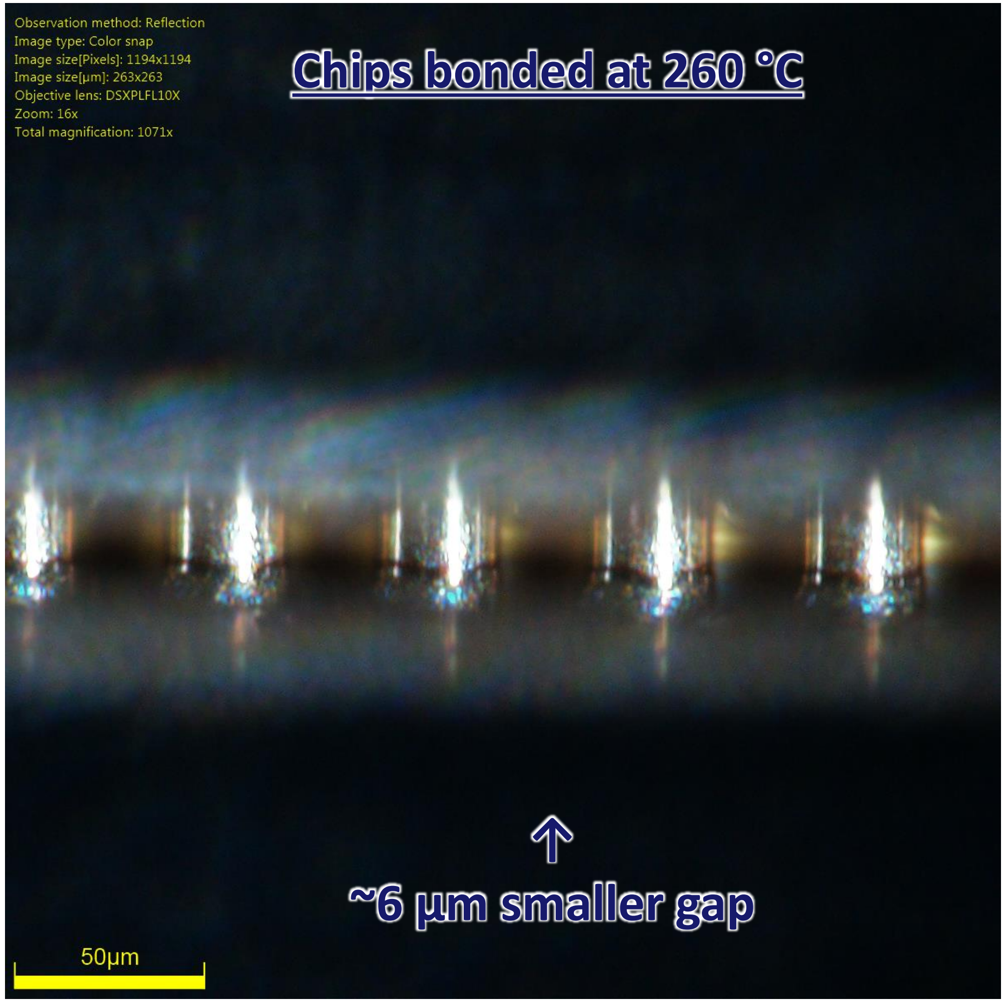
Pixel matrix with Cu pillars (tilted)



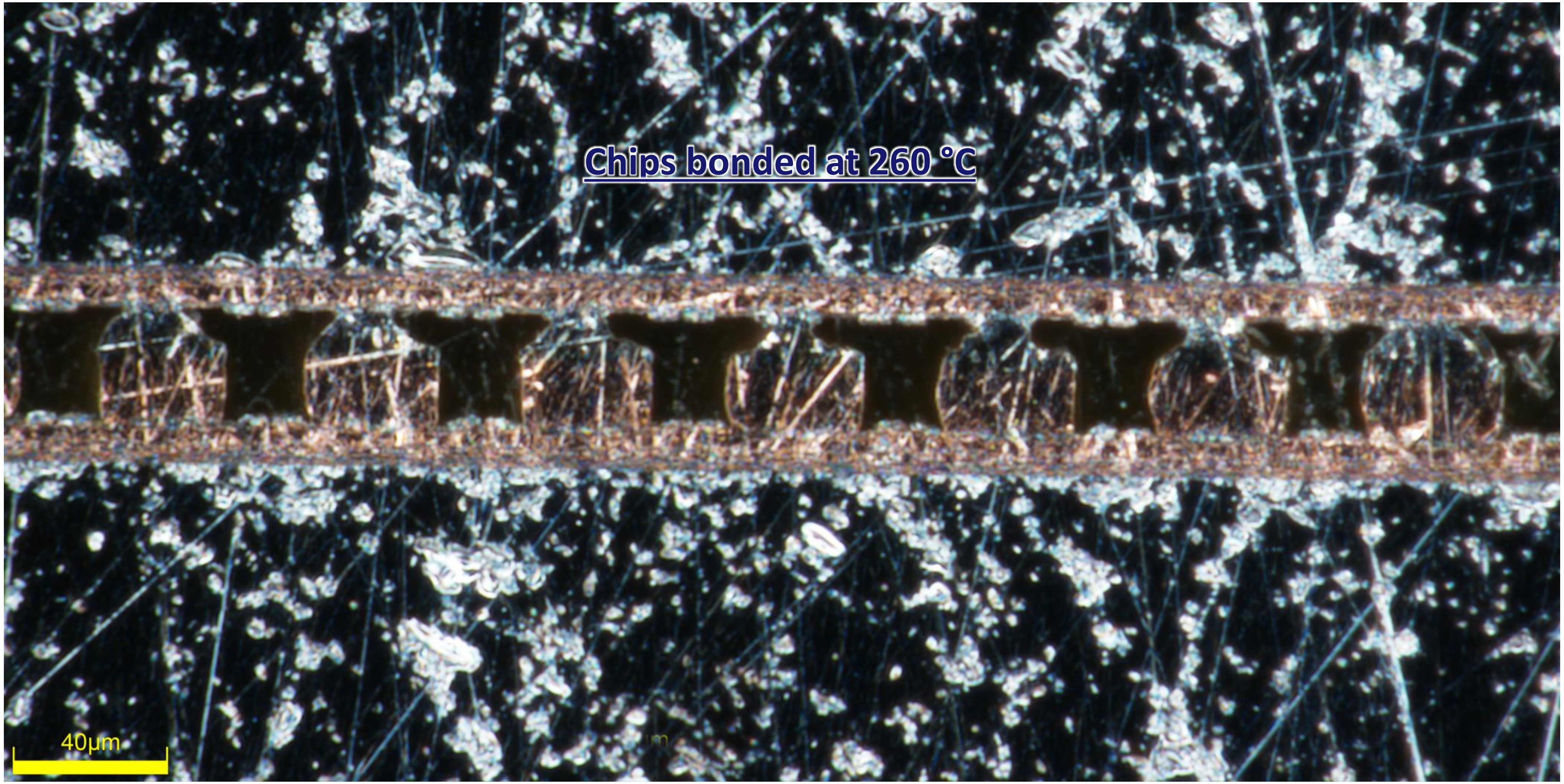
Timepix4 assemblies with copper pillars and NCA

Edge view of bonded chips (no cross-section)



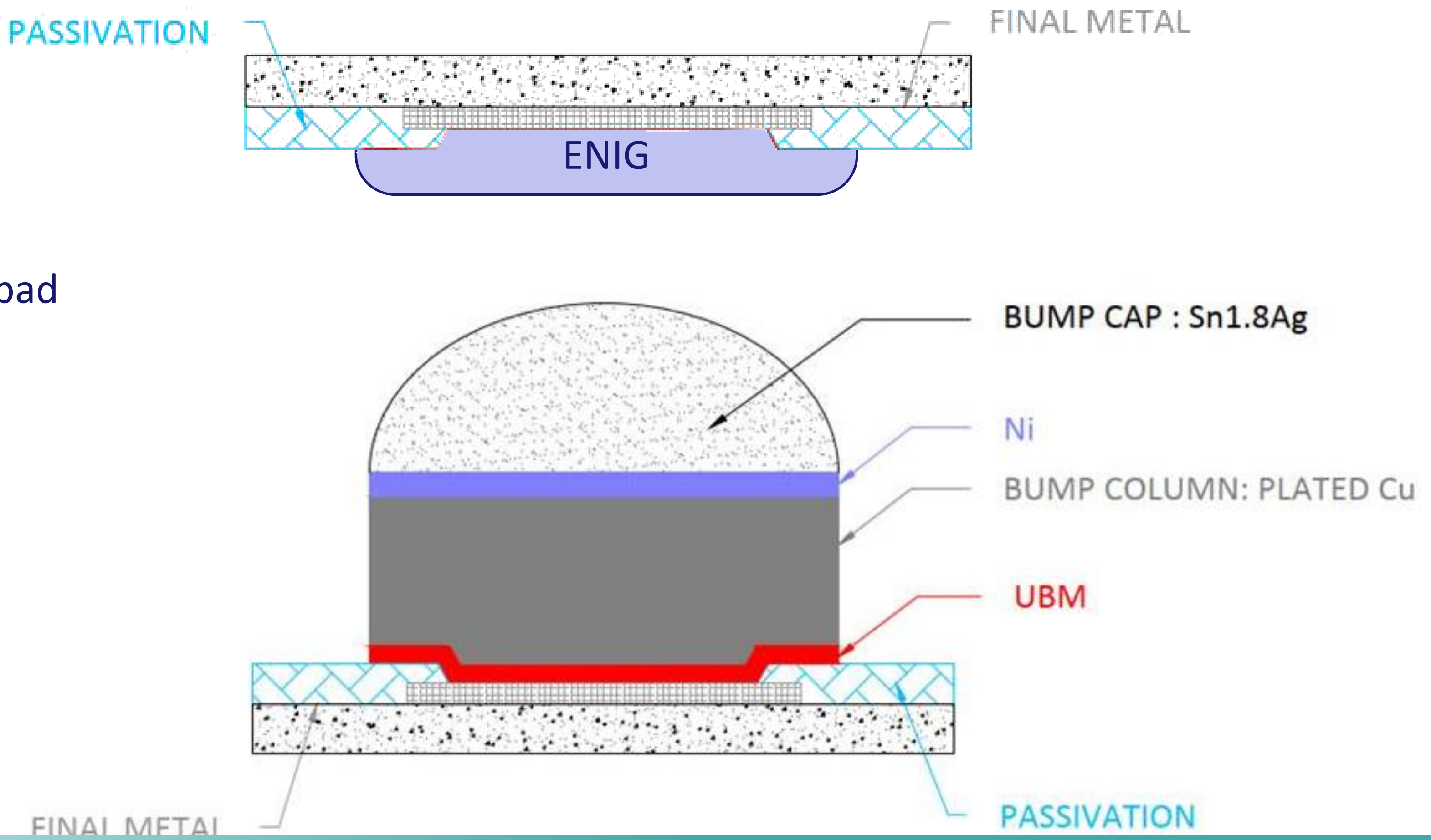


Timepix4 assemblies with copper pillars and NCA



Next step:

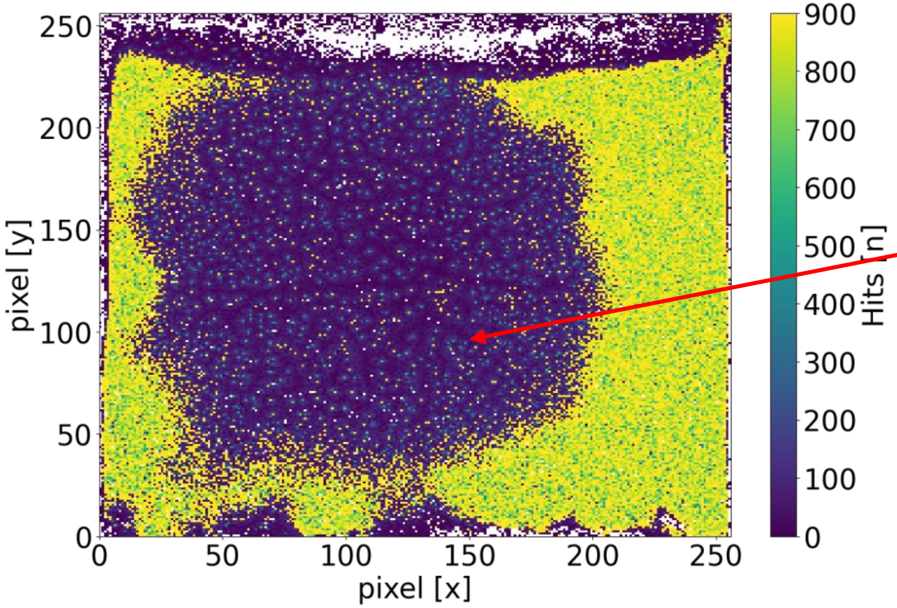
- ENIG plating for Cu pillar counterpart pad



Thank you for your attention

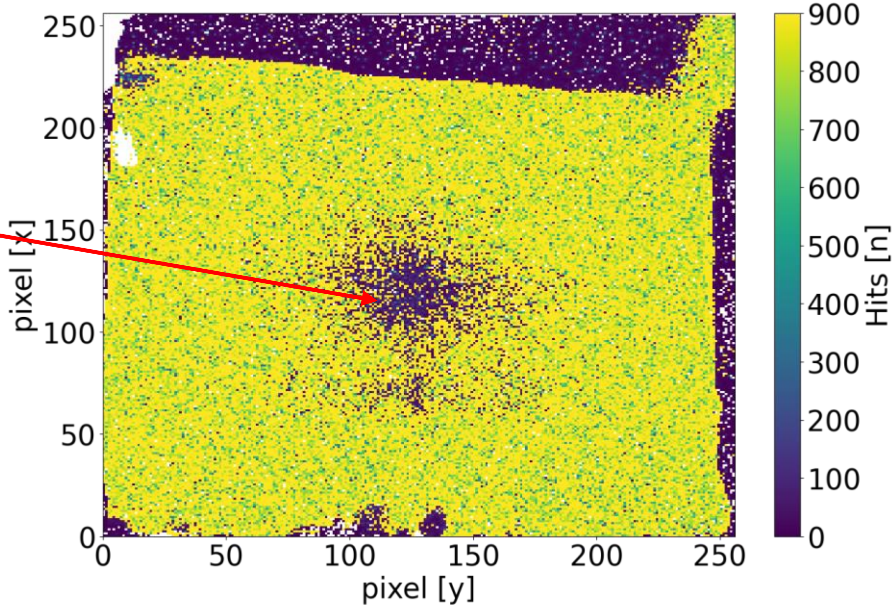
- Evaluation of Timepix3 assemblies using Sr90 exposure

W43_L9: 100% coverage of 18 μm ACF1



Non-functional pixels

W43_L8: 90% coverage of 14 μm ACF2



	Part. diameter [μm]	Thickness [μm]	Part. density [pcs/mm^2]	Bonding pressure [Mpa]	Sheet/reel
ACF 1	3	18	71k	30-80	sheet
ACF 2	3	14	60k	50-90	reel

Thermal cycling study

Alexander Volker

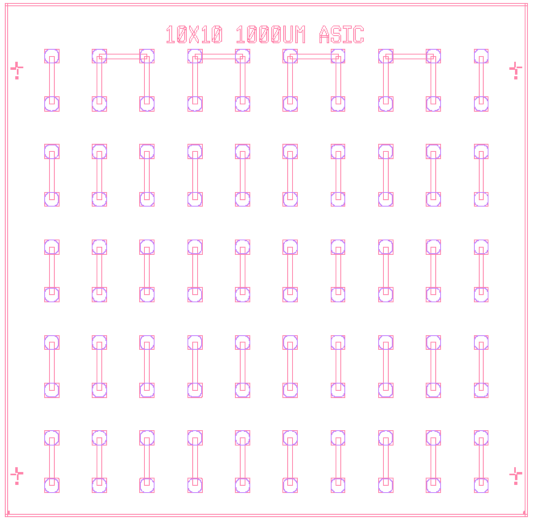
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

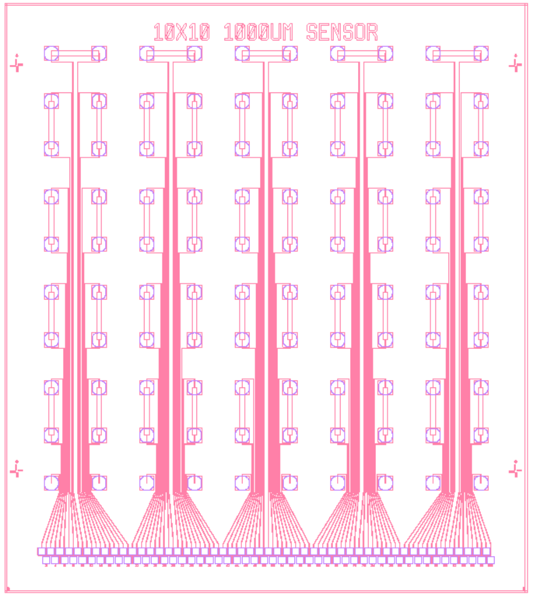
Chain device study

- **Thermal cycling:**
  - Two variations with one more aggresive as well as one uncycled reference sample.
  - Lower temperature range -40°C to -60°C
  - Upper temperature range 80°C to 120°C

Easier cycle1 (-40°C to 80°C) Harsher cycle2 (-60°C to 120°C)

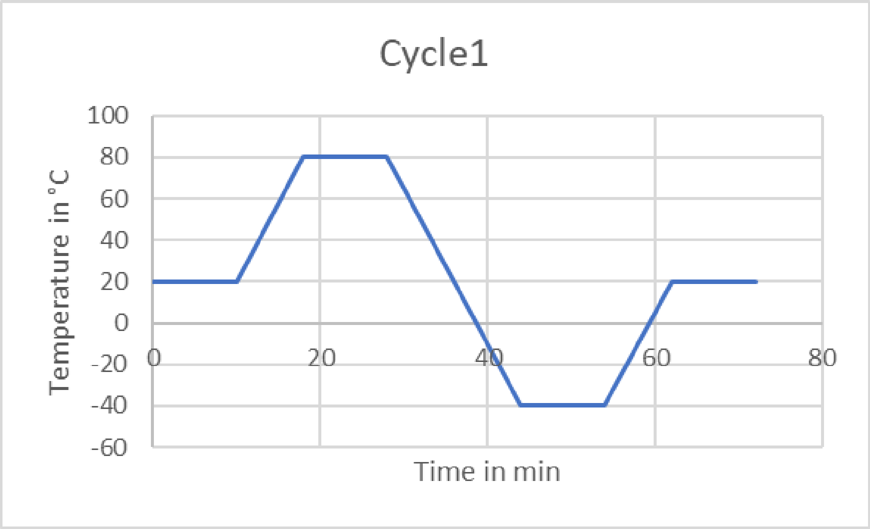
Daisy-chain device
10x10 pixels
1000 µm pitch
~150 µm pad radius





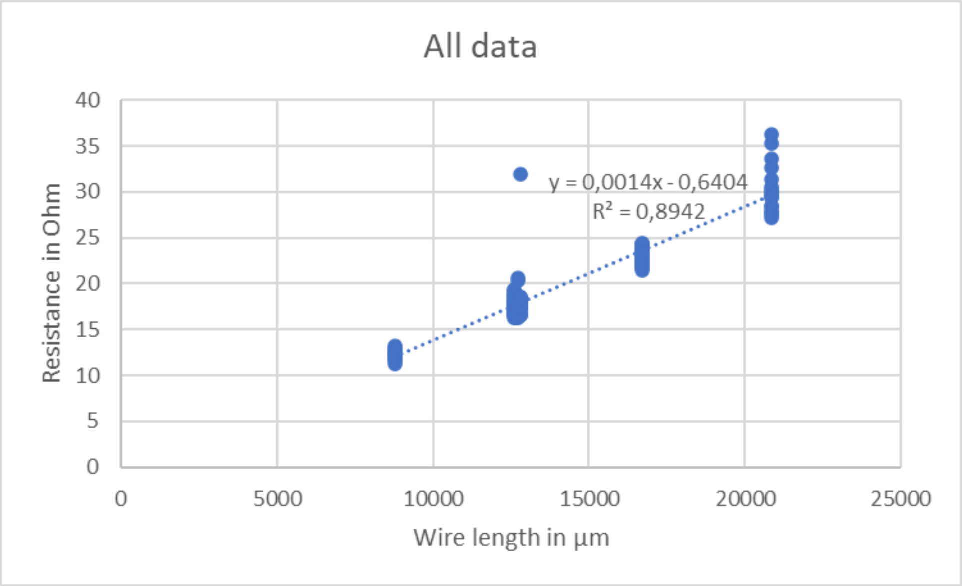
Thermal cycling curves

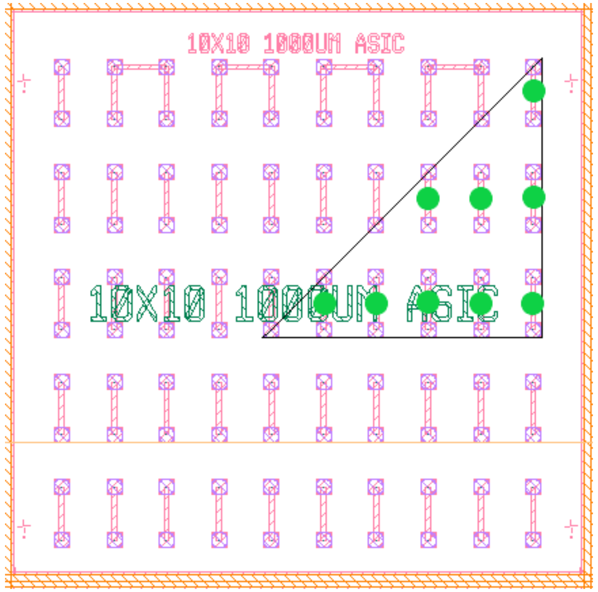
- 20 cycles each
- Holding time of 10 min at each plateau
- Temperature ramping speed of 7.5 °C/min



Resistivity measurements

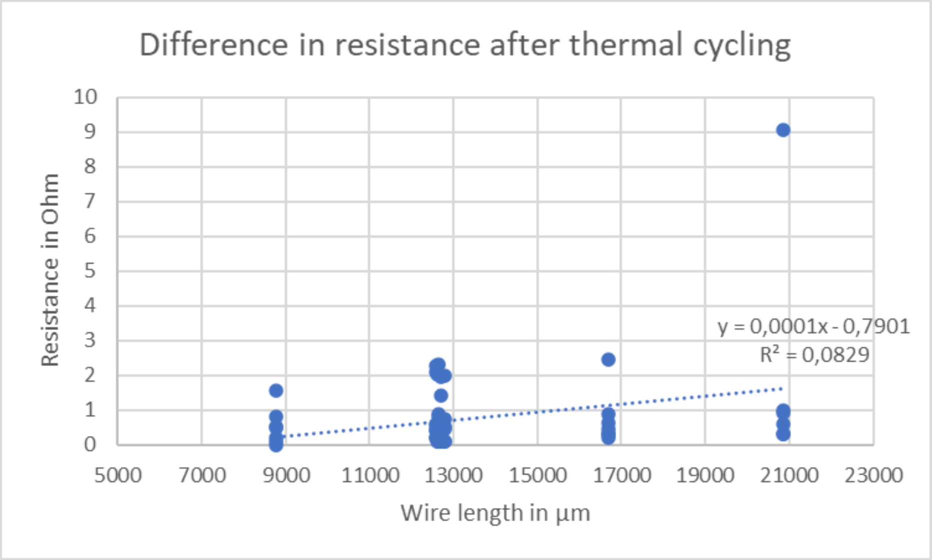
- 9 connections tested per device (before and after cycling)
- 100 µA testing current 4 wire probe measurment
- Corner connection most unstable





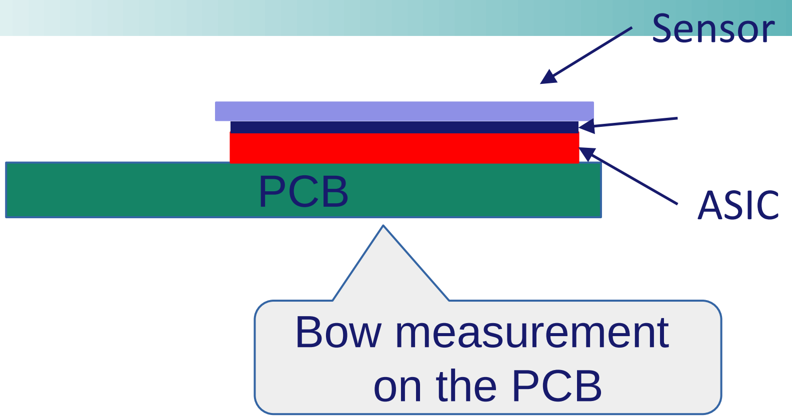
Resistivity measurements

- 5 connections no longer connected after cycling
  - 2 in Cycle1
  - 3 in Cycle2
  - Outliers failed after thermal cycling
- Cycle1 increased resistance by 0,3 Ohm on average and 0,2 Ohm median
- Cycle2 increased resistance by 1,21 Ohm on average and 0,68 Ohm median
- Batch1 (plating on both sides) showed less of a resistance increase than Batch2 (plating on one side)



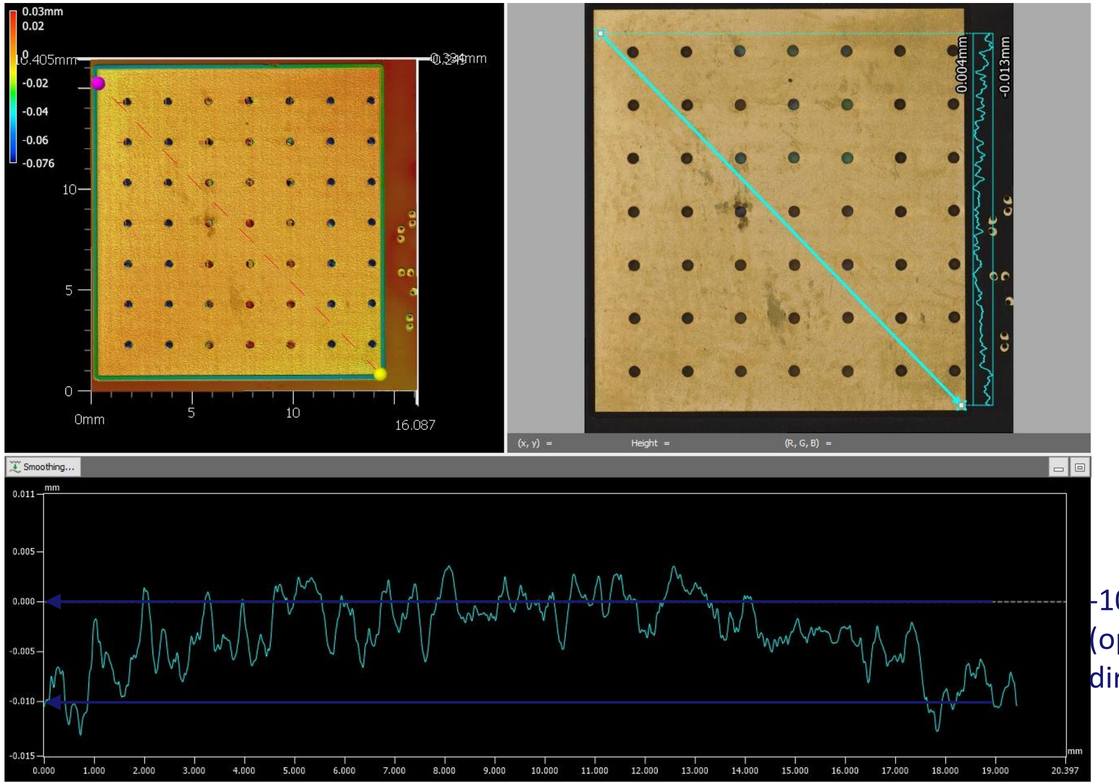
Backup

Timepix3 bow measurements



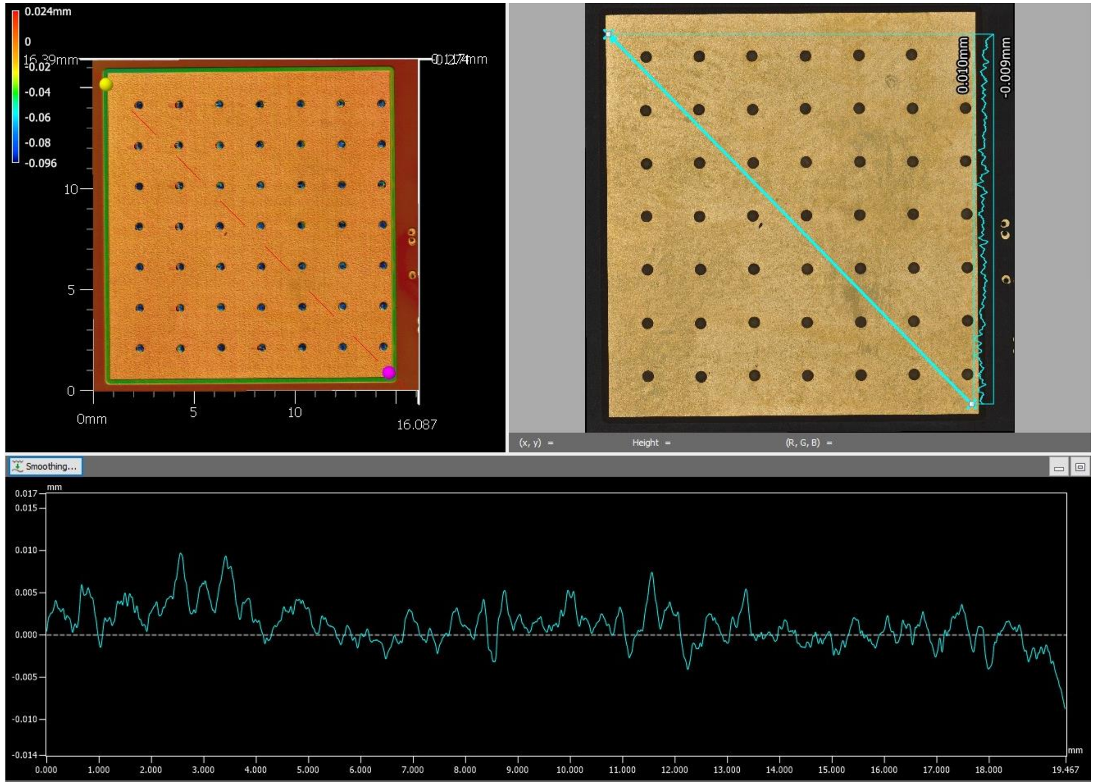
BOW Measurements on the back side of the PCB, beneath the chip

Conclusion : The bow of the chips is not caused by the PCB



-10µm (opposite direction)

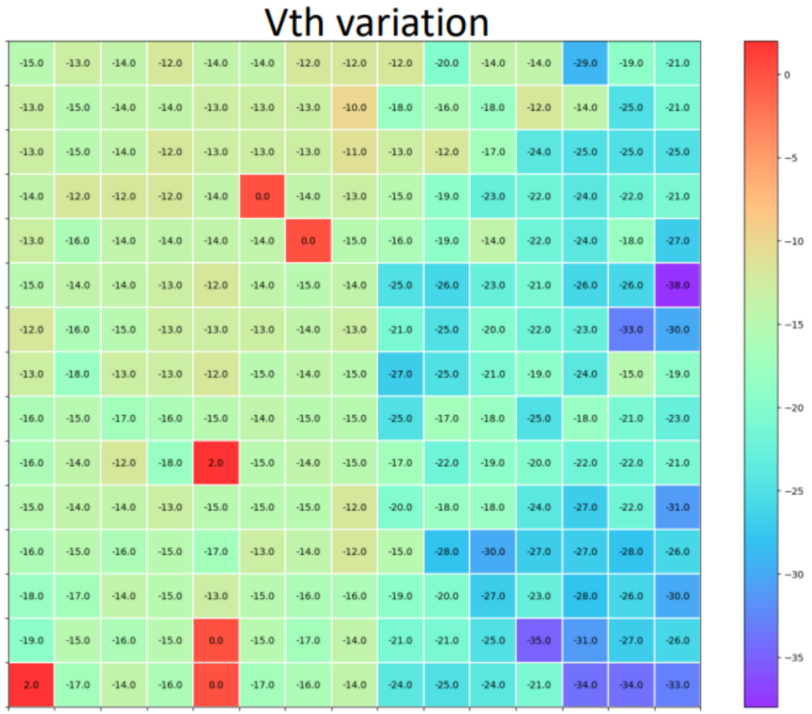
0µm

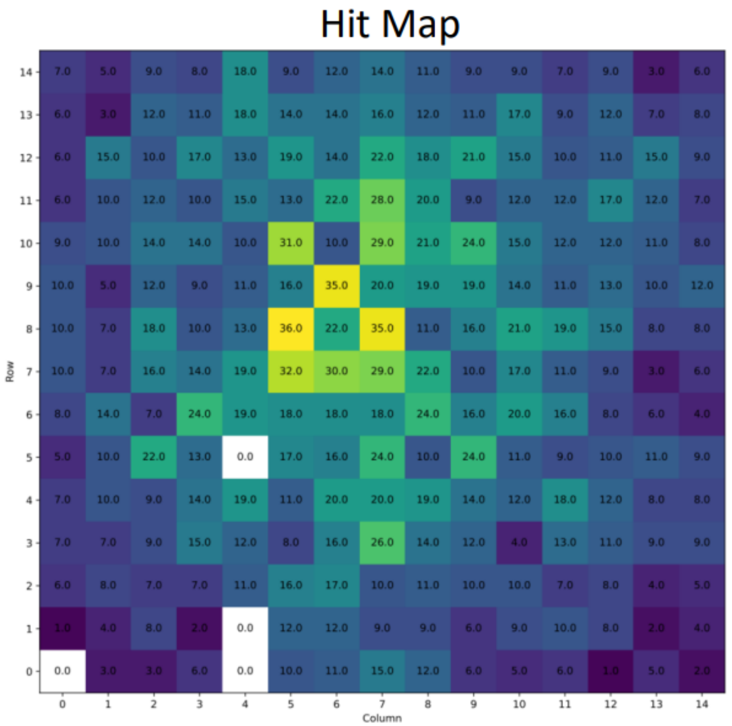


ALTIROC2 LGAD assembly testing

by Aonan Wang (USTC)

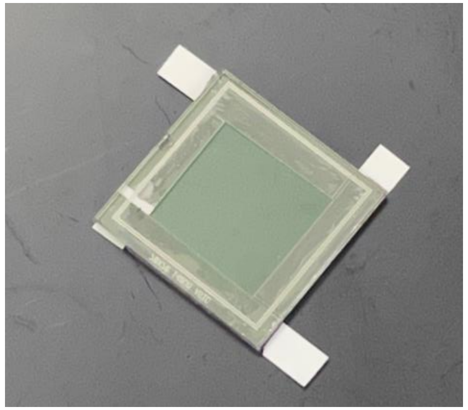
- Bonding with ACP: 10 µm particles (glue deposited in rows)
- Preliminary results show only few pixels not connected
- Source tests to verify all pixel response performed (6→4 unconnected pixels)



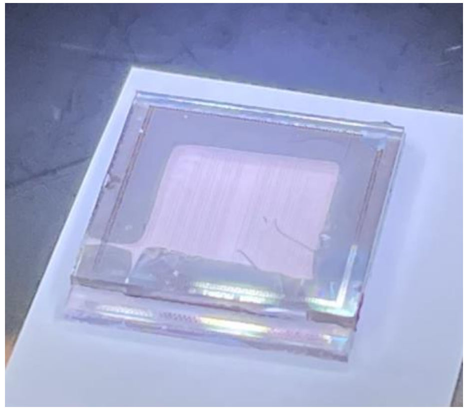


FBK daisy-chain devices Testing

lamination



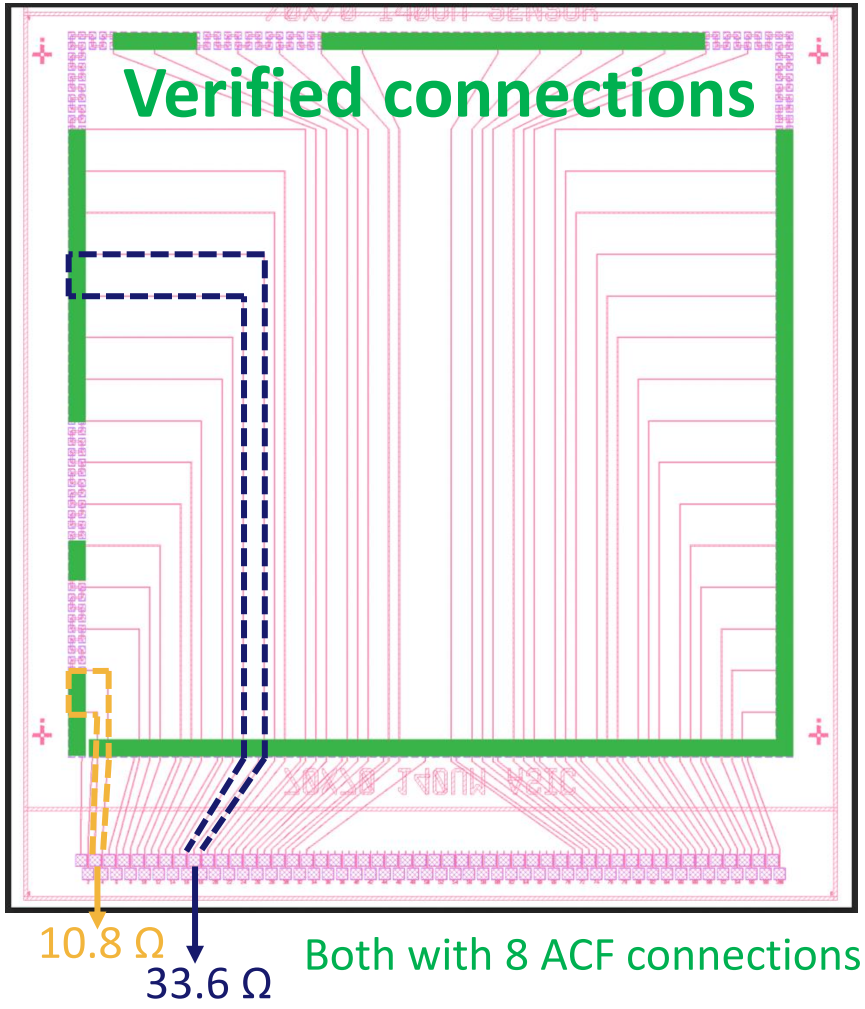
bonded



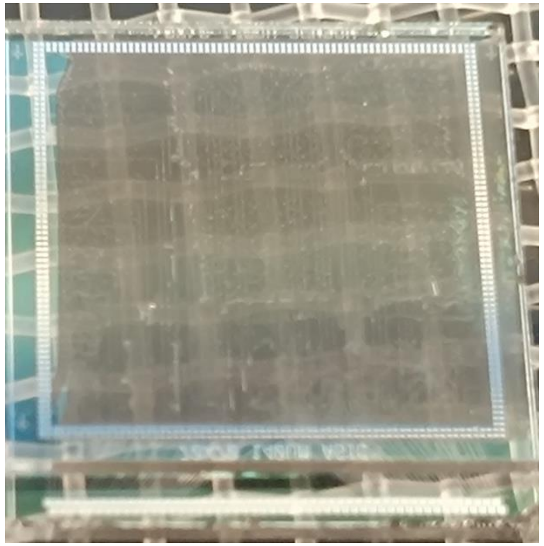
	Part. diameter [µm]	Thickness [µm]	Part. density [pcs/mm²]	Bonding pressure [Mpa]	Sheet/reel
ACF 1	3	18	71k	30-80	sheet
ACF 2	3	14	60k	50-90	reel

- Bonding peripheral-type device
  - Used sheet and 2 mm ACF film (18 µm / 14 µm thickness)
  - pad area 7744 μm^2
- Good connection yield
  - Missing connections due to ACF lamination / mechanical damage
  - <u>2-wire measurement of resistivity</u>, dominated by metal line length

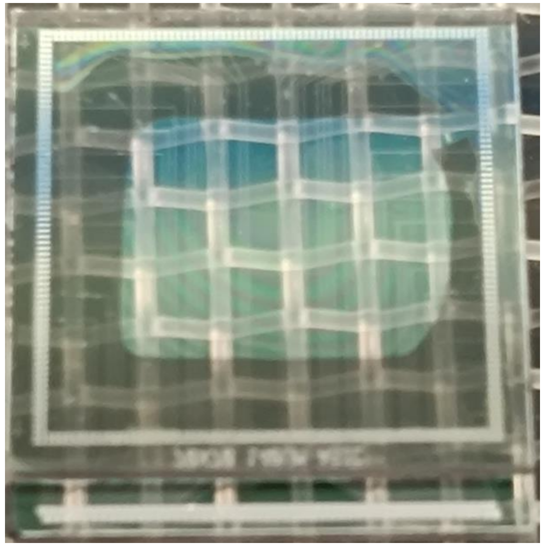
original design by Matteo Centis Vignali (FBK)



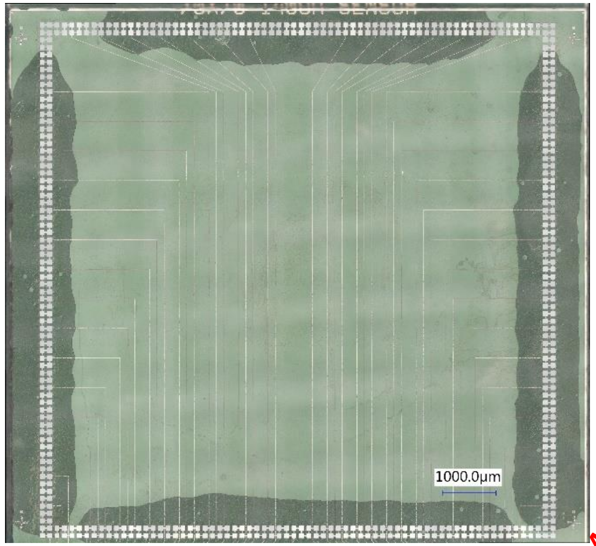
FBK daisy-chain devices Testing



3 µm particles

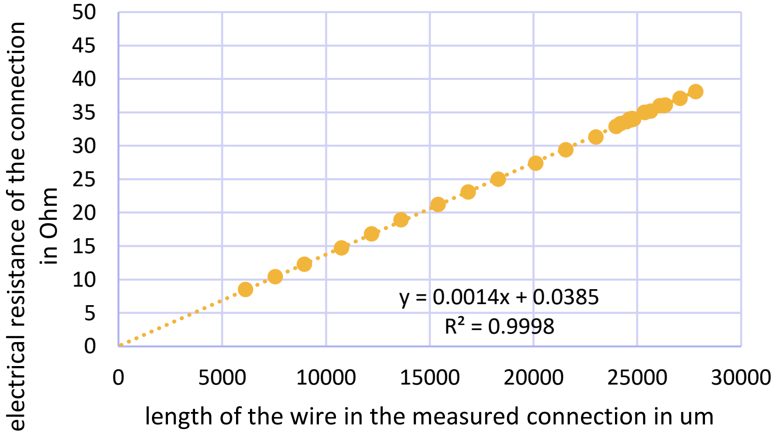


3 µm particles

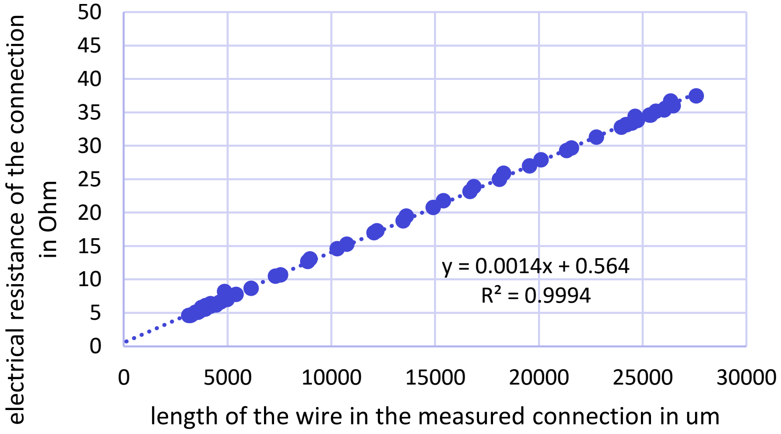


4 µm particles

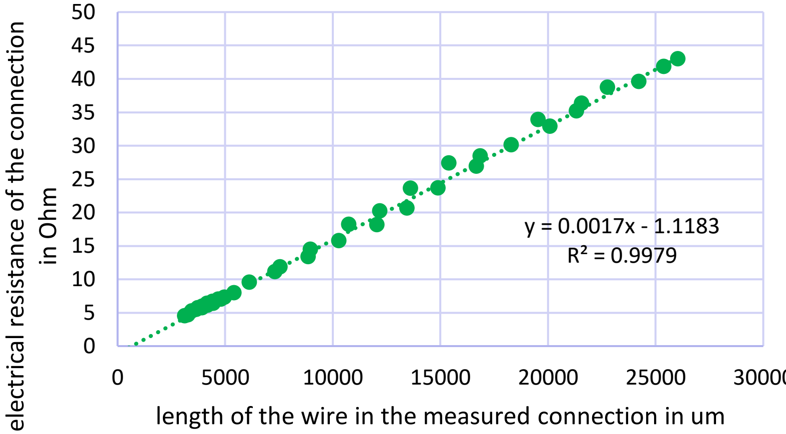
18 µm ACF – resistance measurement



14 µm ACF – resistance measurement

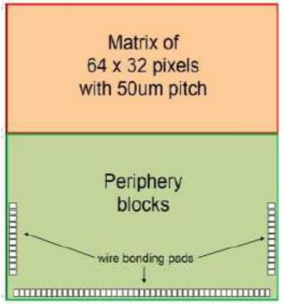


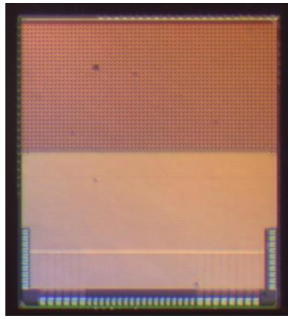
ACP – resistance measurement



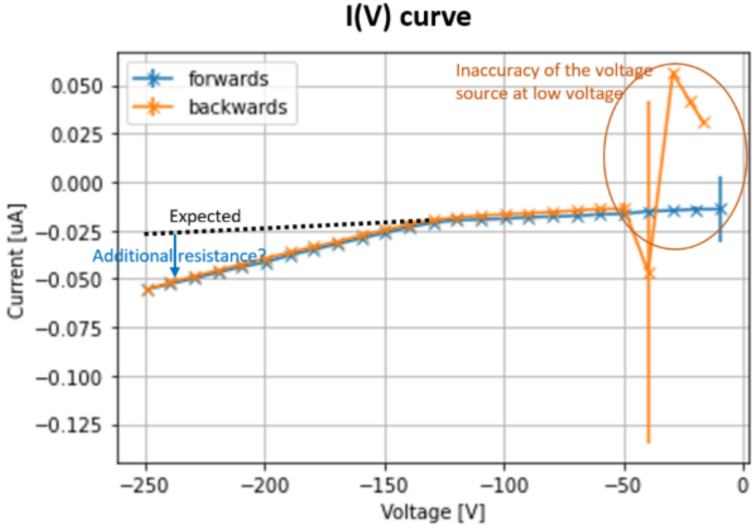
SPHIRD silicon assembly testing

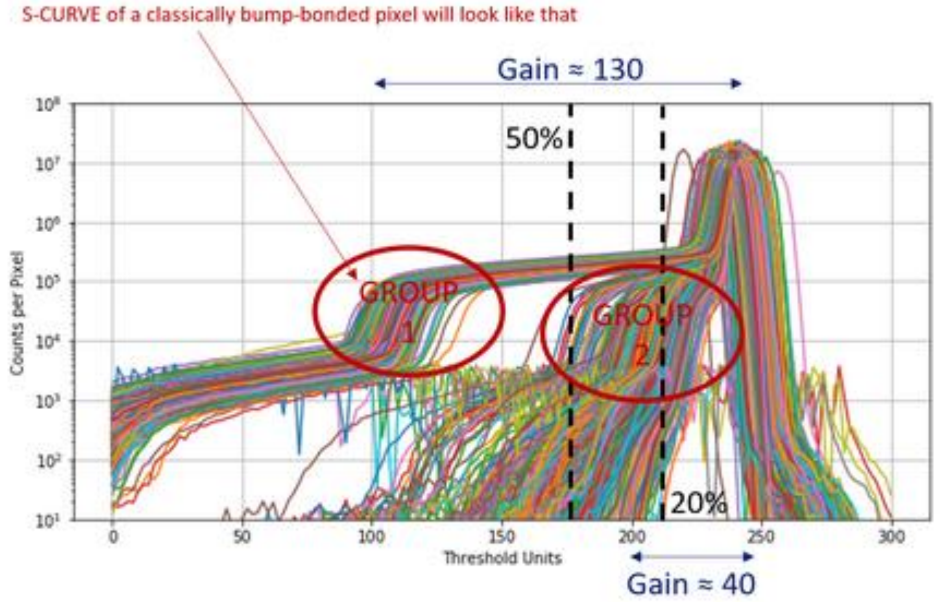
by Marie Ruat (ESRF)

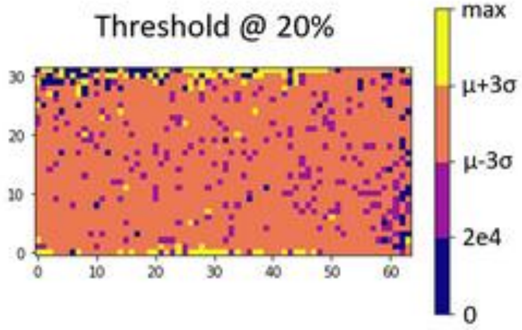


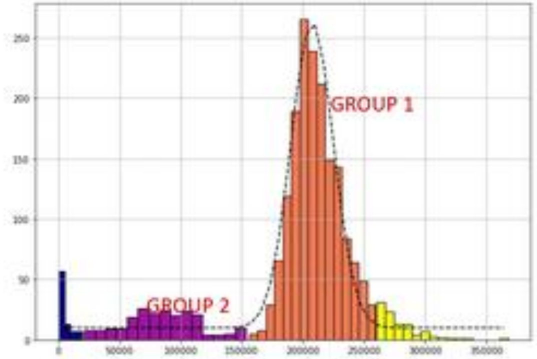


- Bonded with 5kgf 2mm ACF stripe (full coverage)
- Different IV behaviour than expected
- Number of pixels with different response to signal
  - “weakly coupled” pixels, probably capacitive coupling due to missing ACF particles



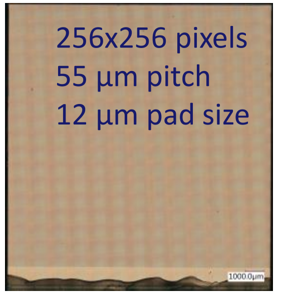






- Ongoing main goal bonding of CdTe or CZT sensors

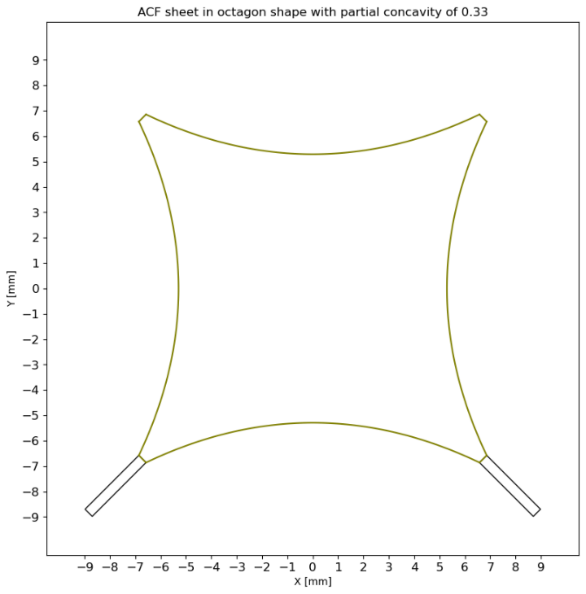
Timepix3 silicon assembly testing

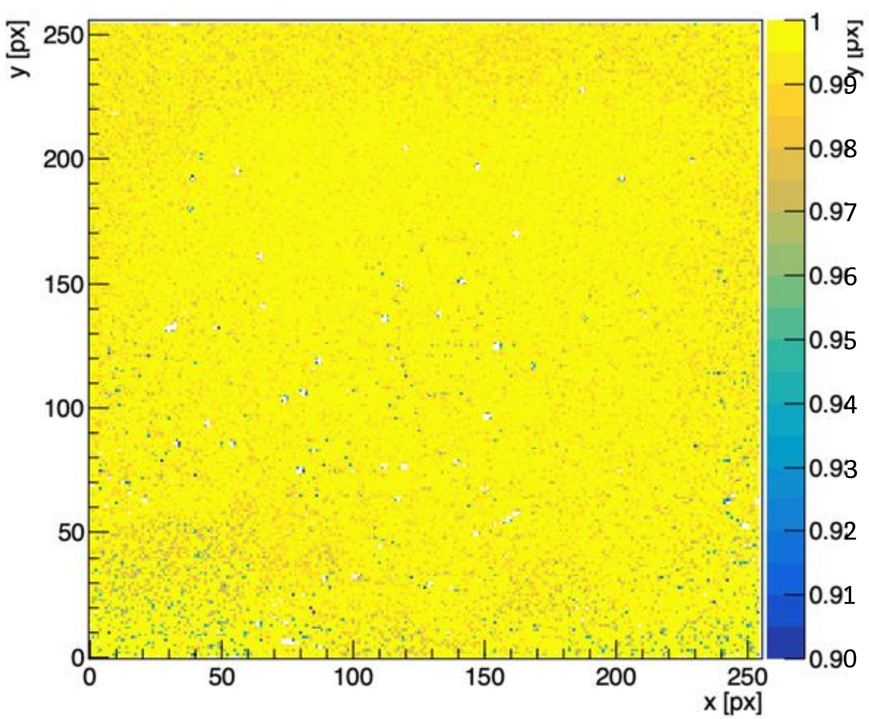


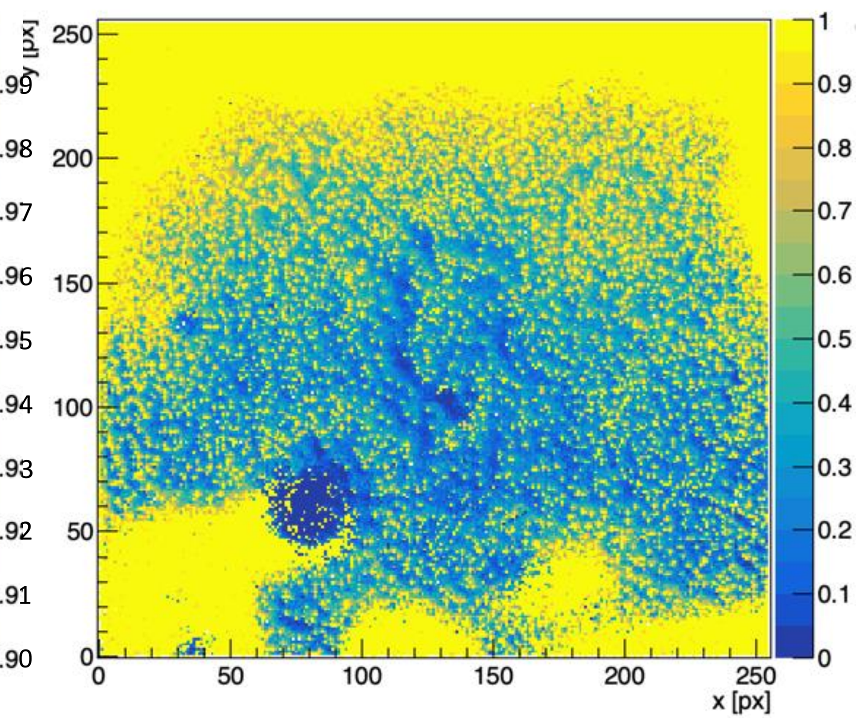
- 100% coverage using 18µm ACF, plating 7 µm
- Testbeam evaluation of in-pixel efficiency
  - With threshold change regions become inefficient (weak coupling)
- Reach higher plating

Threshold increase by about 6000e-
(signal from MIP should be still enough)

Plan to optimise ACF area

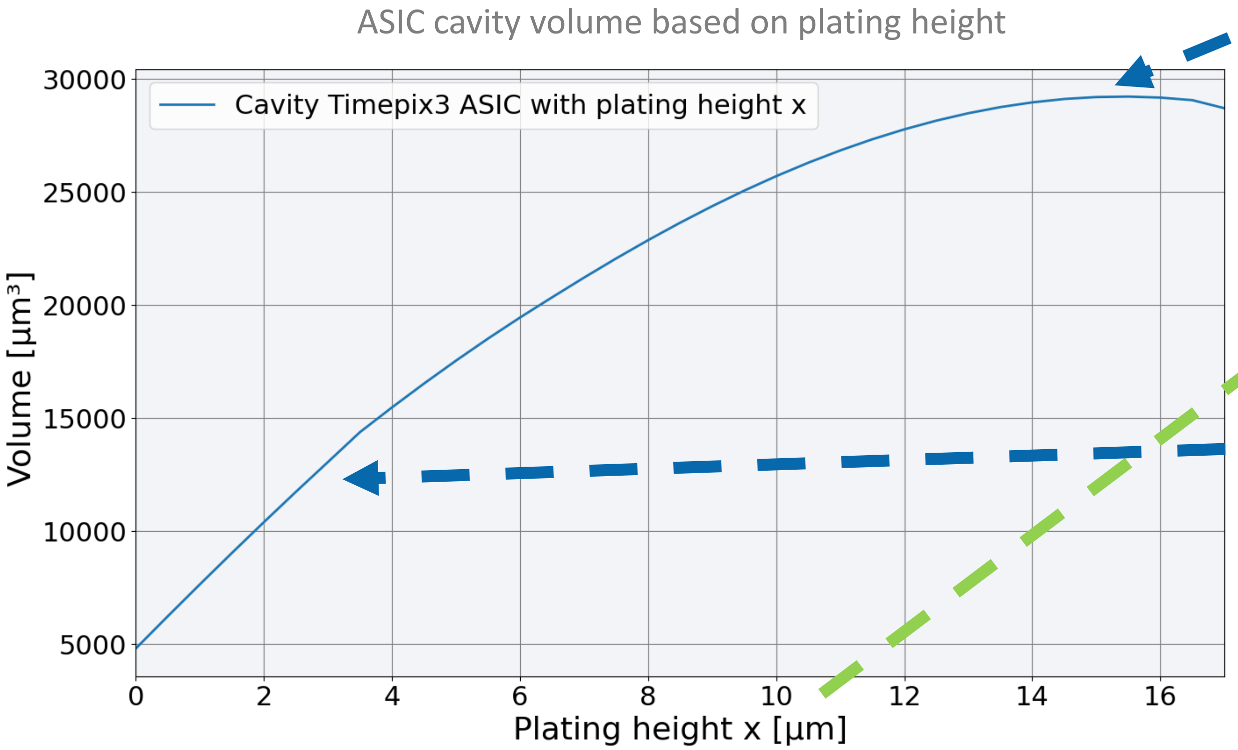


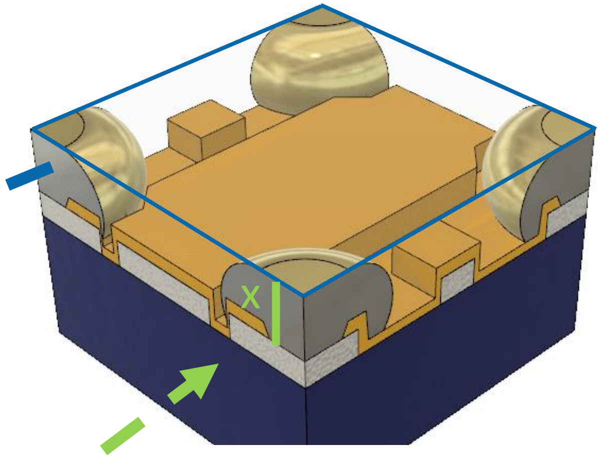


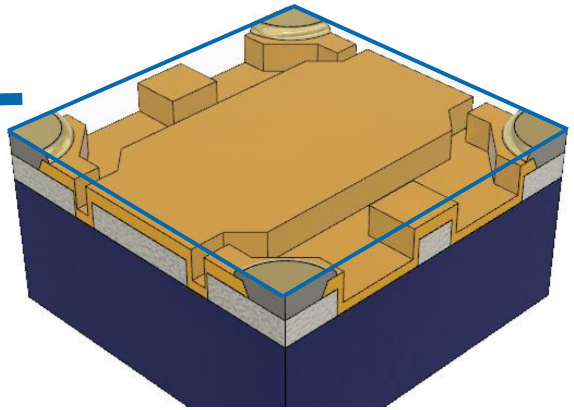


ENIG UBM plating need for increased height

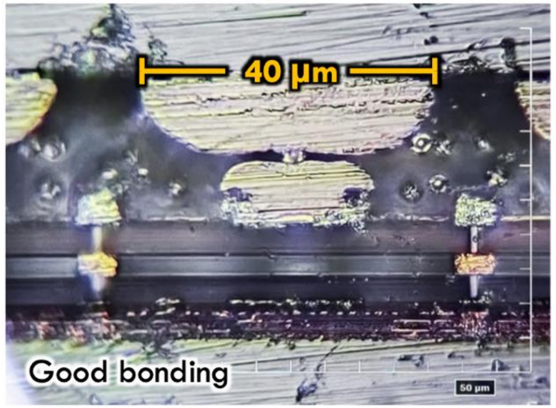
- Need for sufficiently large cavity volume between sensor and ASIC after bonding to fit excess adhesive
  - **Volume** directly related to plating height **x**
  - Developed approximate model for calculation



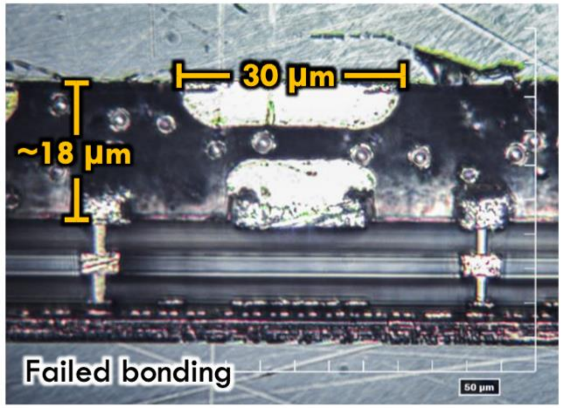




Timepix3 assembly w/ re-worked pad

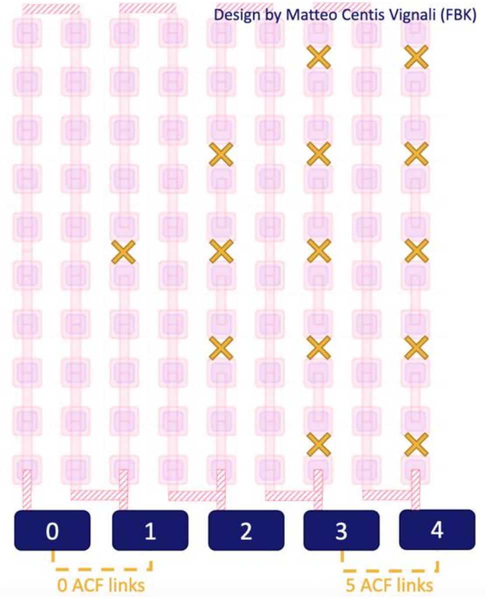


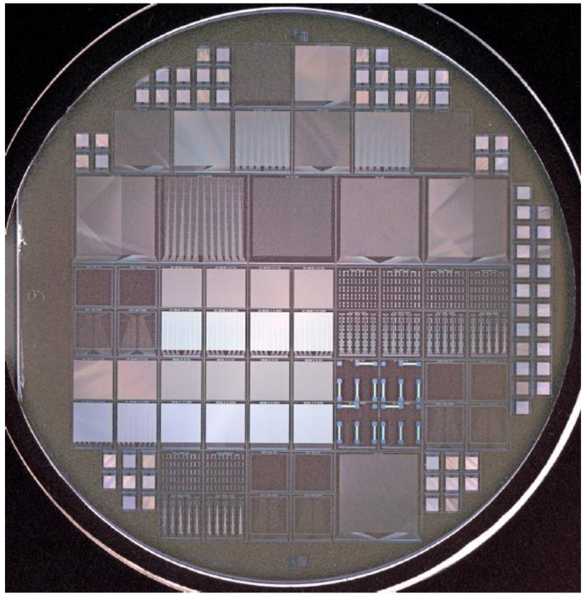
Timepix3 assembly w/ original ENEPIG



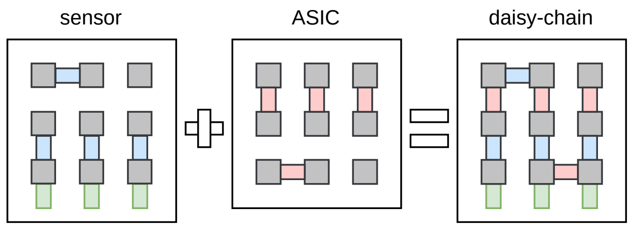
Daisy-chain devices Production

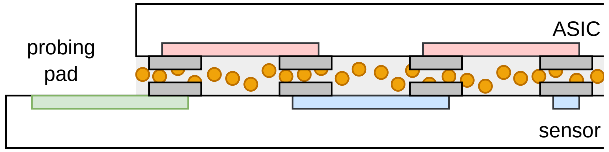
- Daisy-chain 6” quartz wafer with 625 µm thickness
  Designed and produced at FBK
- Study of ACF interconnection properties
  - Low-pitch and large-pitch reliability
  - Resistance measurements
  - Mechanical analysis
- Surface properties matched to ASICs
  - Al metal pads 2.5 µm thick
  - 950 nm thick passivation
- 4 out of 8 wafers at CERN (2 diced at FBK, 1 diced at CMi)





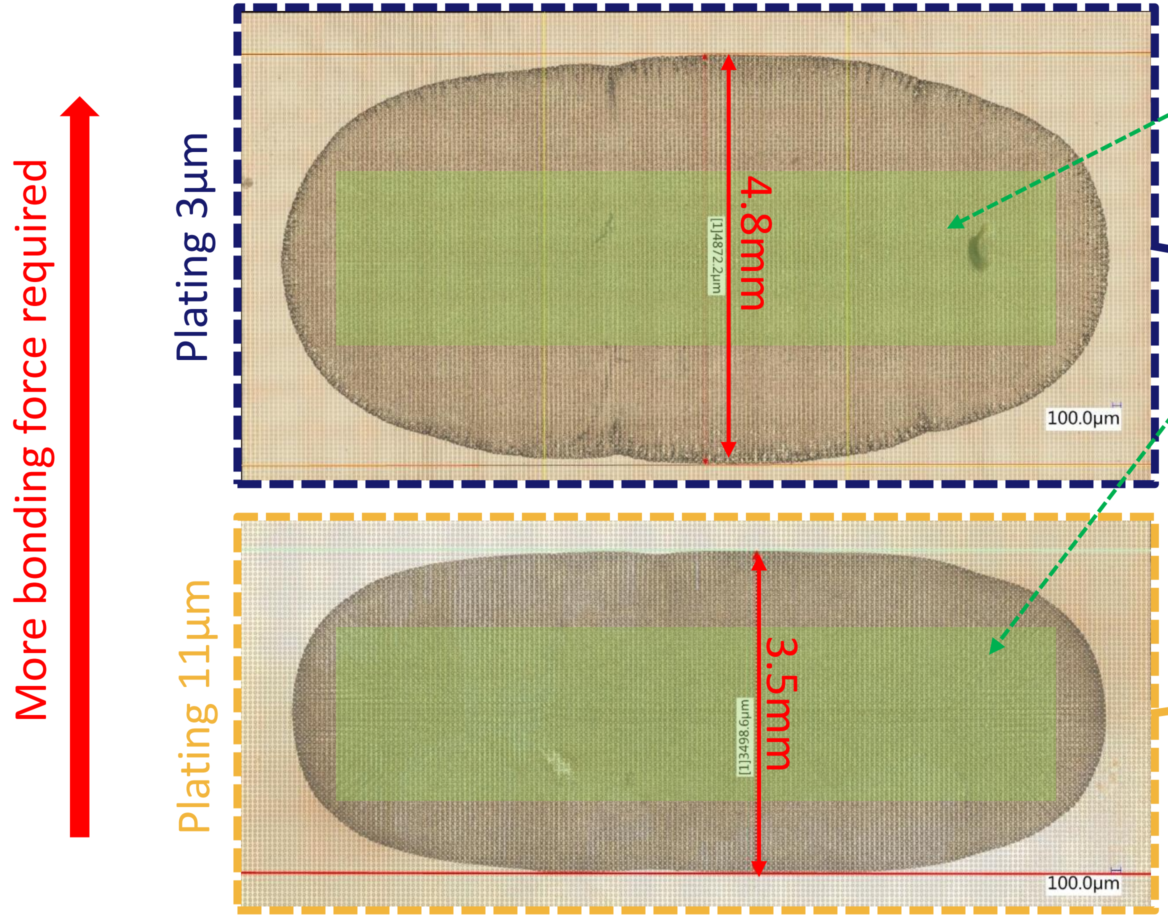
	pitch	size in mm	connections	per wafer	type	diceable
160x160 20um	20 um	3.2 x 3.2	25600	36	grid	no
CLICpix2	25 um	3.2 x 3.2	16384	34	grid	no
400x400 25um	25 um	20 x 20	640000	5	grid	yes
Timepix3	55 um	14 x 14	65536	4	grid	no
Timepix3 islands	55 um	14 x 14	65536	4	grid	no
RD53	50 um	20 x 20	160000	4	grid	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

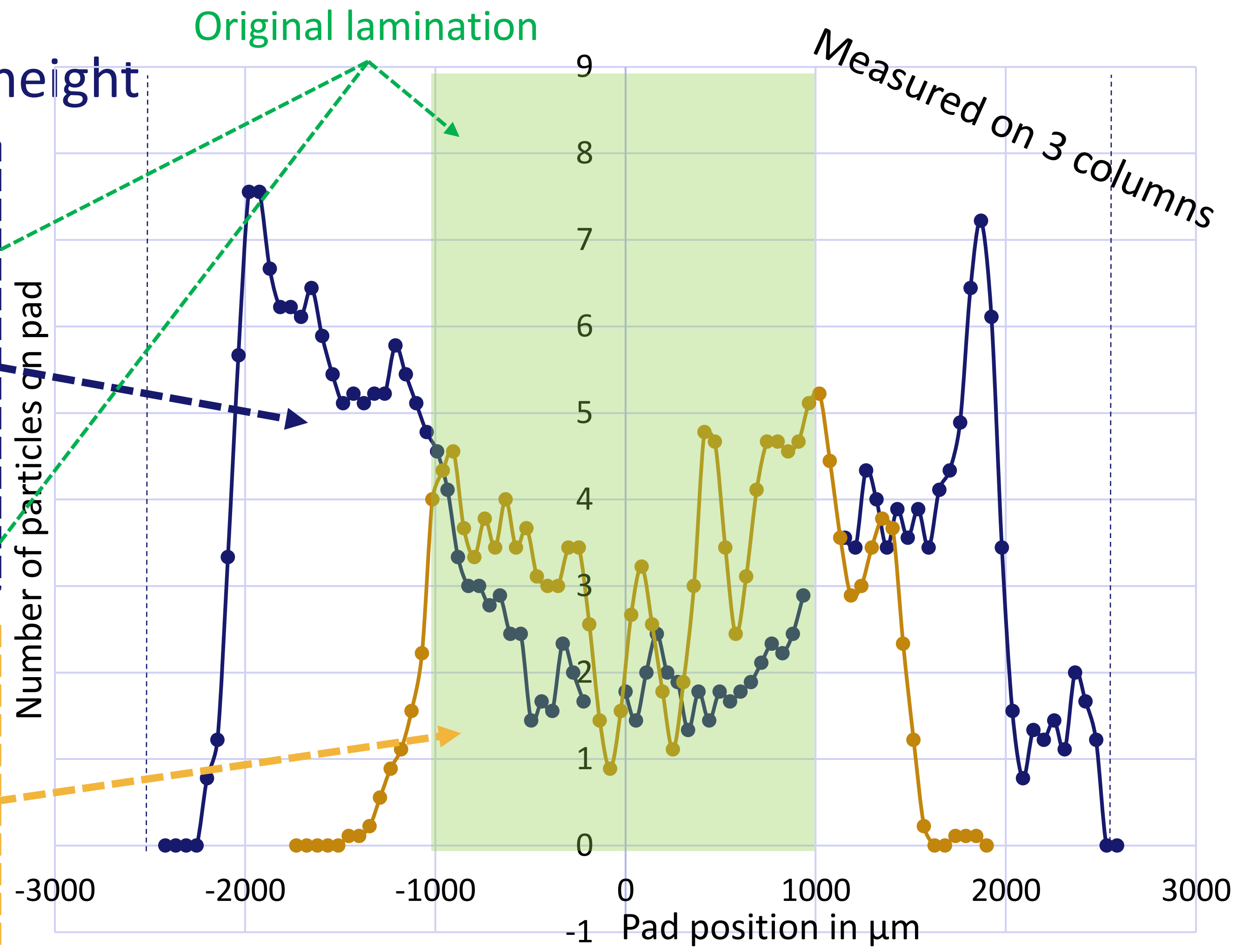




ACF plating height dependency Timepix3 on glass

- Different spread of ACF based on plating height



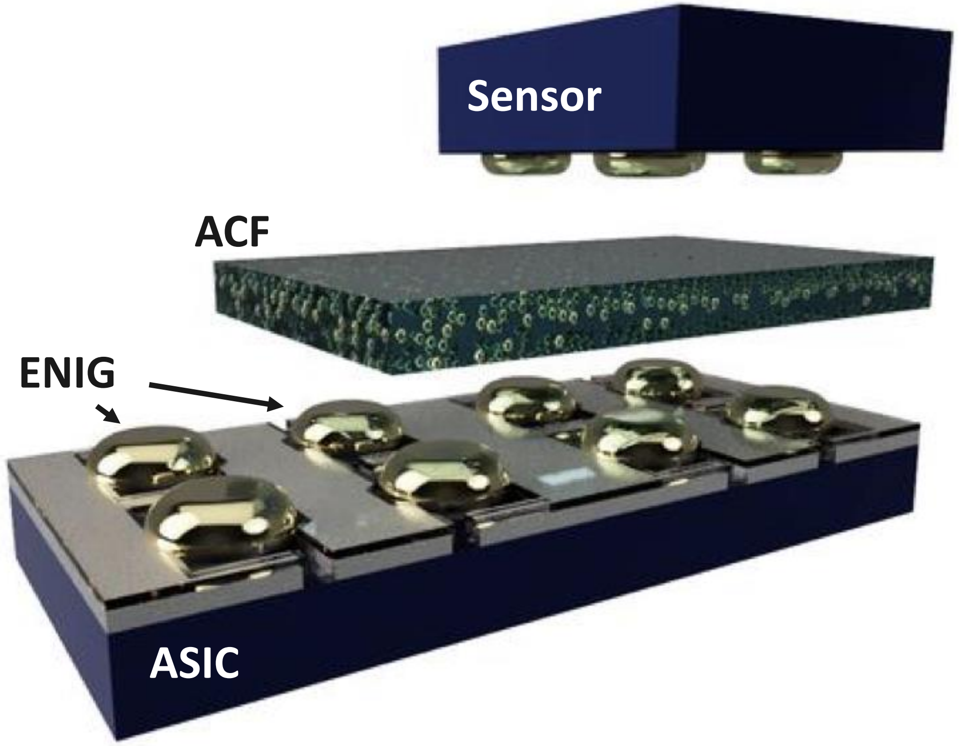


ACF BONDING

- Multiple ACFs available

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	Particles at same depth	no	surface grid
Sheet or reel	sheet	reel	sheet	reel	reel

Illustration of the layers for ACF bonding before bonding



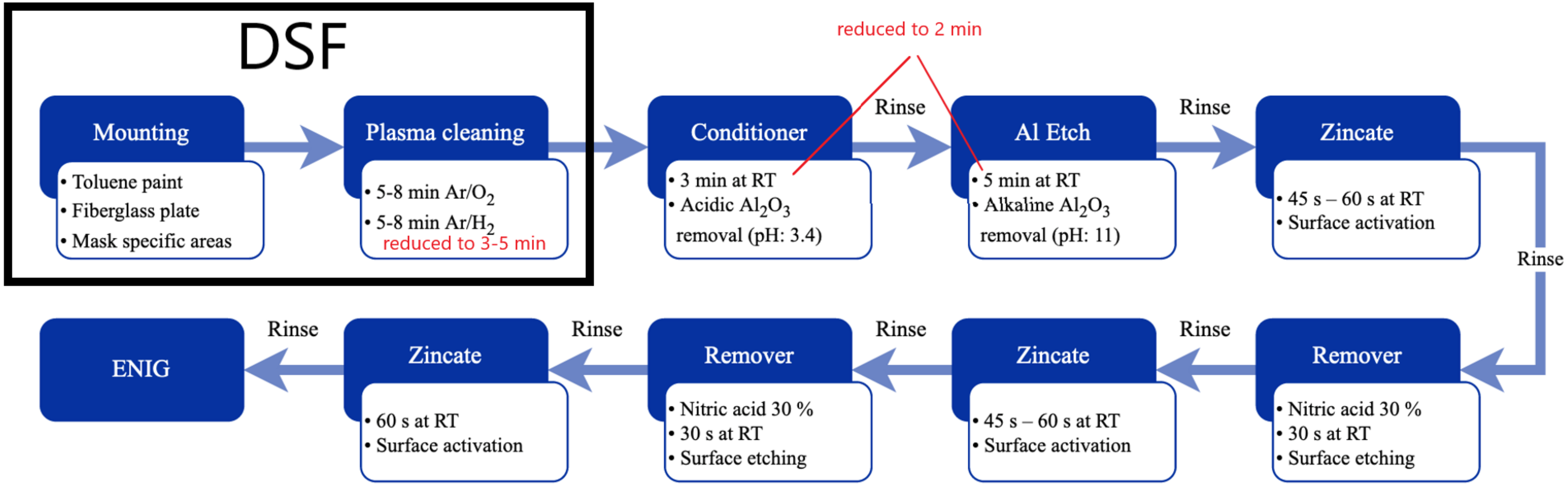
Preparation
- Electrical testing
- Visual inspection

ENIG (UBM)
- Nickel growth
- Pad topology

ACF bonding
- Lamination
- Flip-chip bonding

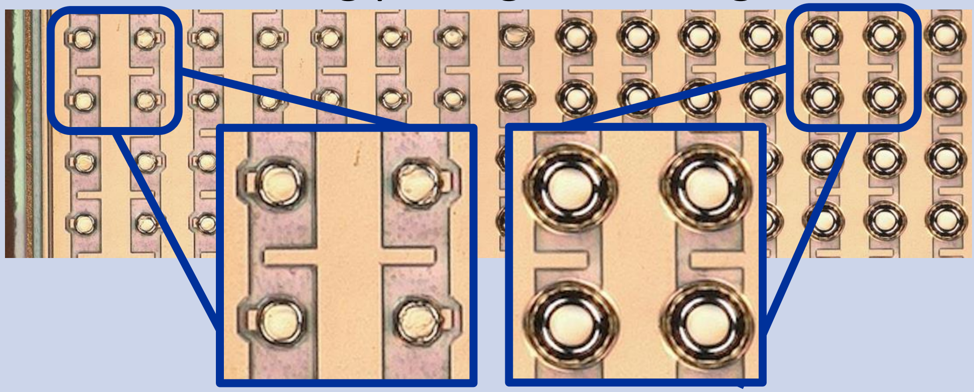
Testing
- Cross-section
- Source and Test-beam measurement

Procedure

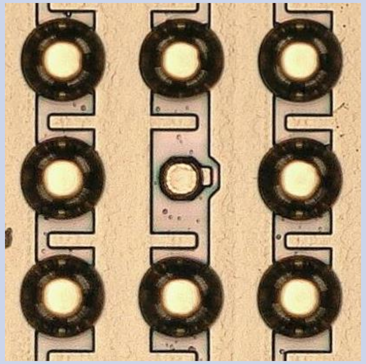

DSF
Mounting
• Toluene paint
• Fiberglass plate
• Mask specific areas
Plasma cleaning
• 5-8 min Ar/O2
• 5-8 min Ar/H2
reduced to 3-5 min
Conditioner
• 3 min at RT
• Acidic Al2O3 removal (pH: 3.4)
reduced to 2 min
Rinse
Al Etch
• 5 min at RT
• Alkaline Al2O3 removal (pH: 11)
Rinse
Zincate
• 45 s – 60 s at RT
• Surface activation
Rinse
Remover
• Nitric acid 30 %
• 30 s at RT
• Surface etching
Rinse
Zincate
• 45 s – 60 s at RT
• Surface activation
Rinse
Remover
• Nitric acid 30 %
• 30 s at RT
• Surface etching
Rinse
Zincate
• 60 s at RT
• Surface activation
Rinse
ENIG

Uniformity

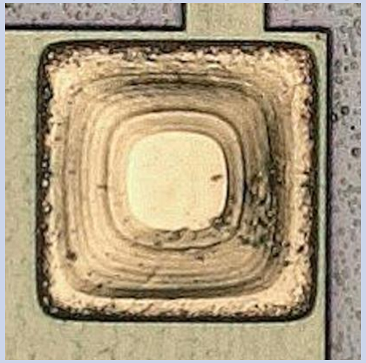
Missing plating at the edge



Skipp plating

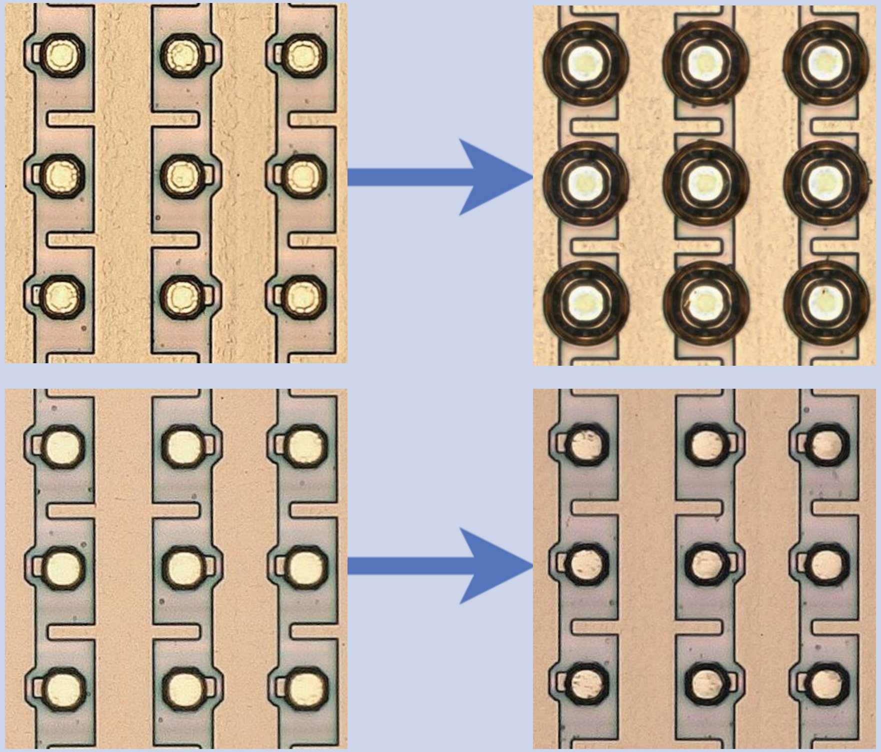


Step plating



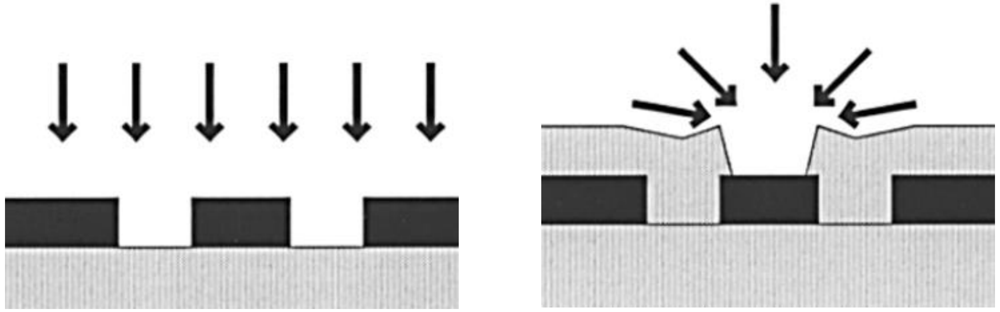
Reproducibility

- Different results with same procedure

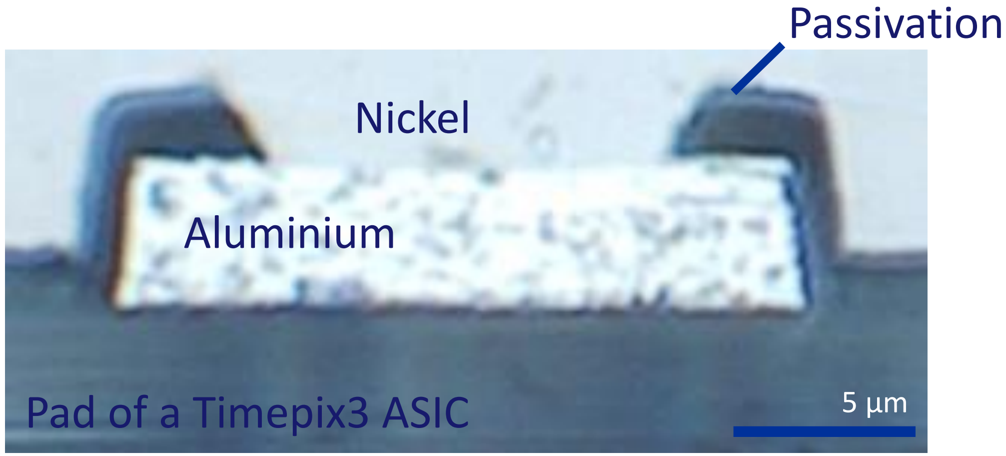


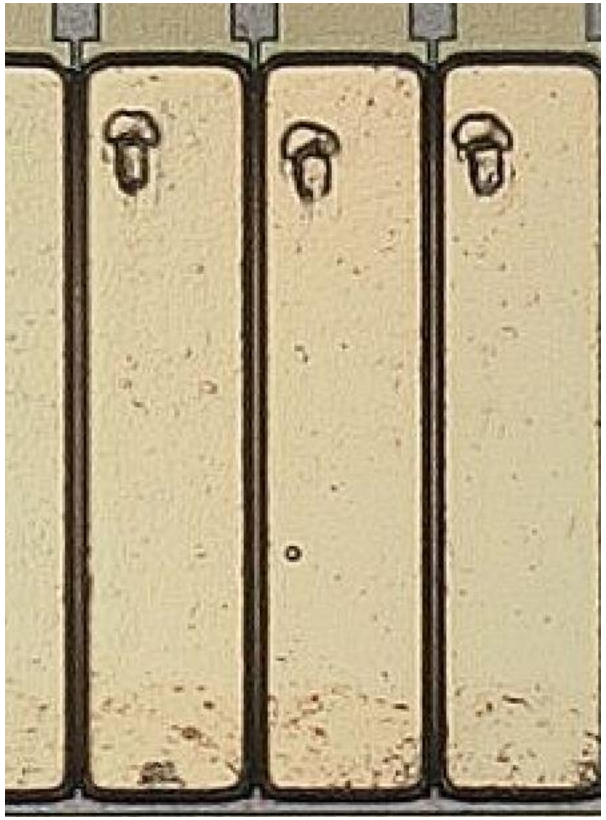
Possible causes

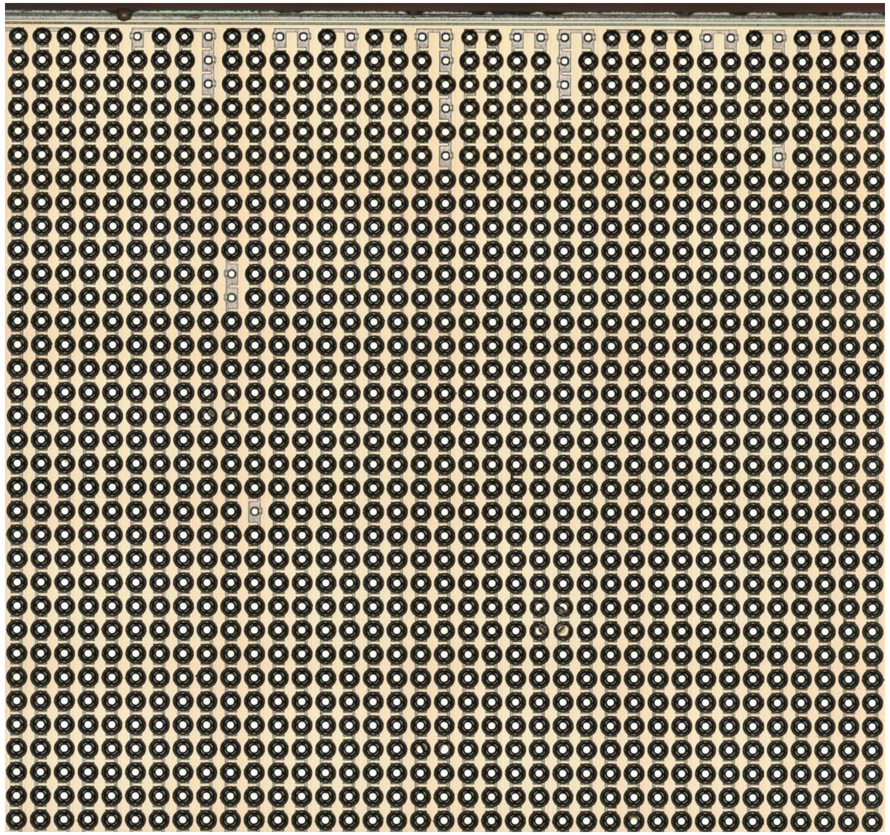
- Insufficient pre-treatment
  - Oxide layer
- ENIG bath optimised for PCBs
  - Surfaces several 100 µm
- Different diffusion to small pads
  - Sensitive to impurities in Ni-bath
  - Metal ion and bath-additives can act as catalyst poison
- Topology can case wetting issues
  - Surface tension of bath can prevent H_2 of escaping
  - No wetting on pad bottom

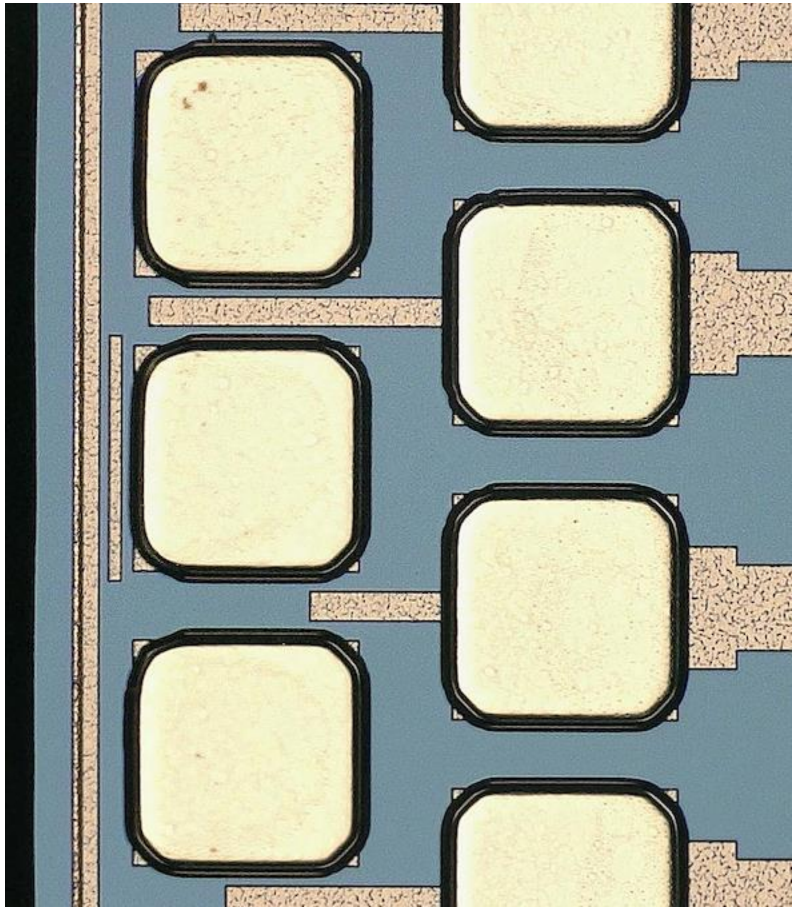


S. Zhang et al 1999 J. Electrochem. Soc.146 2870

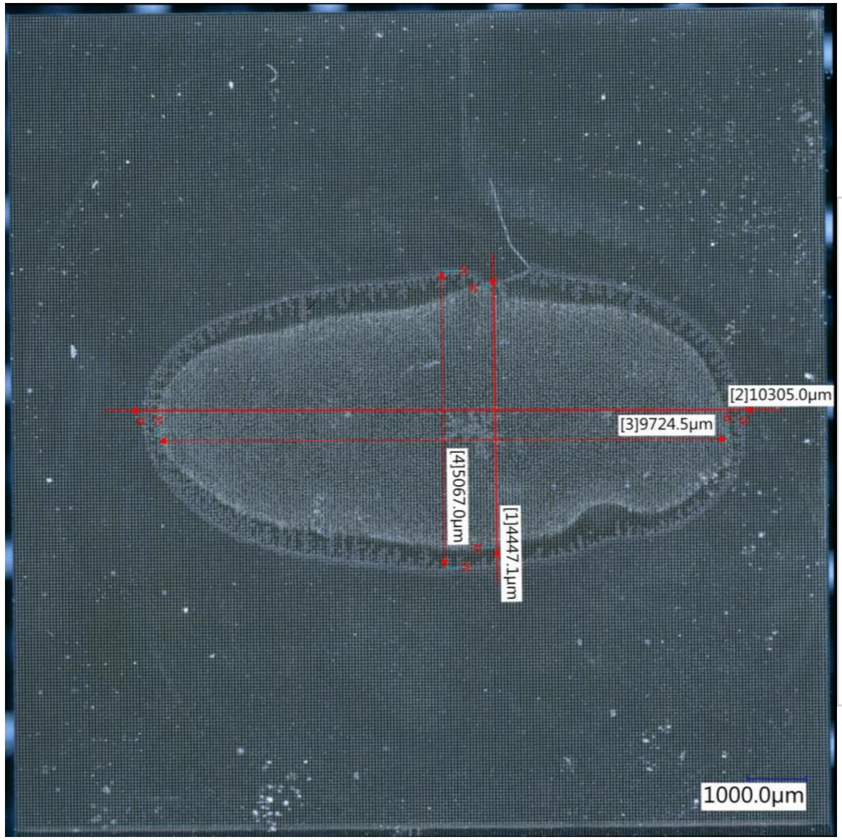



Bonding pads Timepix3


Timepix3


MALTA pads

ACP bonding spread



Measurements of spread for the 3 µm sample. There are different ranges for epoxy spread and particle spread.

- Similar to ACF spread
  - Particle density saturates