Update
Hybridisation and Integration with Conductive Adhesive Bonding

AIDAinnova WP6

24-27 April 2023

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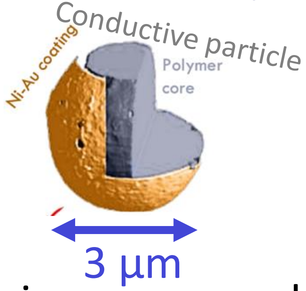
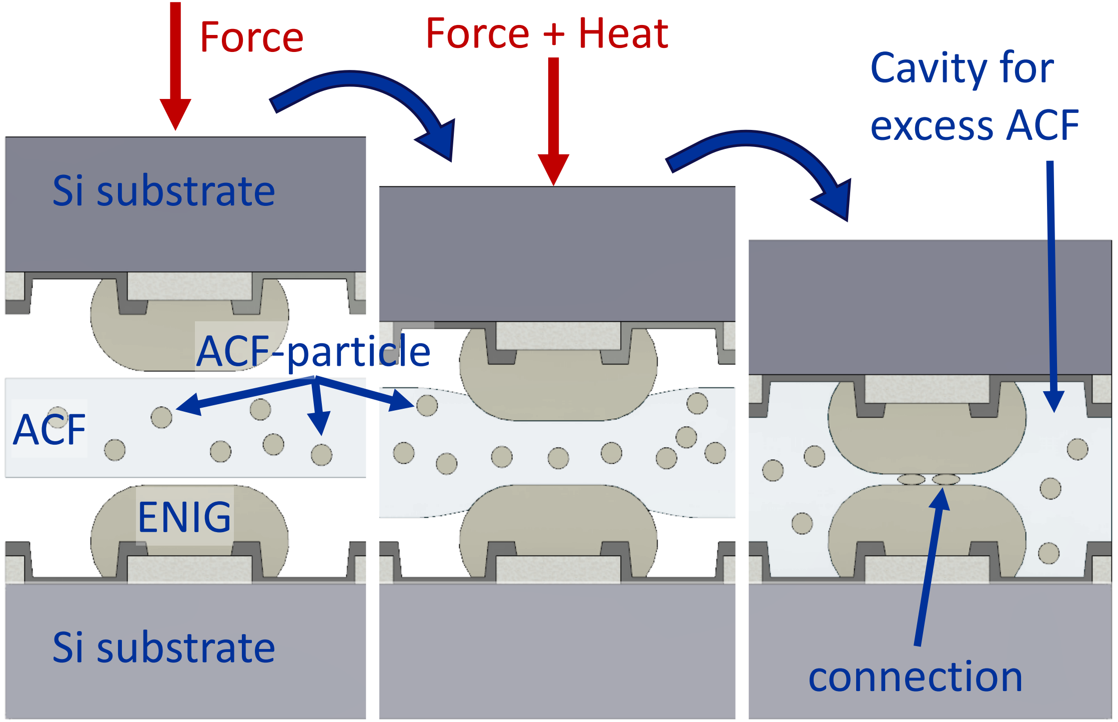
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101004761.

Introduction

- **A**nisotropic **C**onductive **F**ilm/**P**aste (or **N**on-conductive) – **ACF/ACP** or **NCF/NCP**
  - Widely used for display production as strips
    → Transfer to small pitch area application
- Thermo-compression bonding process
  - Anisotropic / Vertical electrical connection via compressed conductive particles or direct contact of metal pads
  - Permanent mechanical bonding
- Specific topology
  → ENIG as Under Bump Metallisation (UBM)





Preparation
- Electrical testing
- Visual inspection

→

ENIG (UBM)
- Nickel growth
- Pad topology

→

ACF bonding
- Lamination
- Flip-chip bonding

→

Testing
- Cross-section
- Electrical, source and Test-beam measurement

AIDA innova

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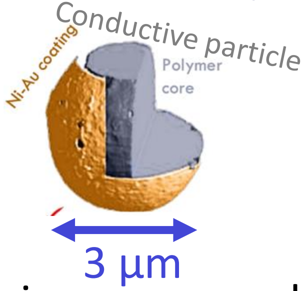

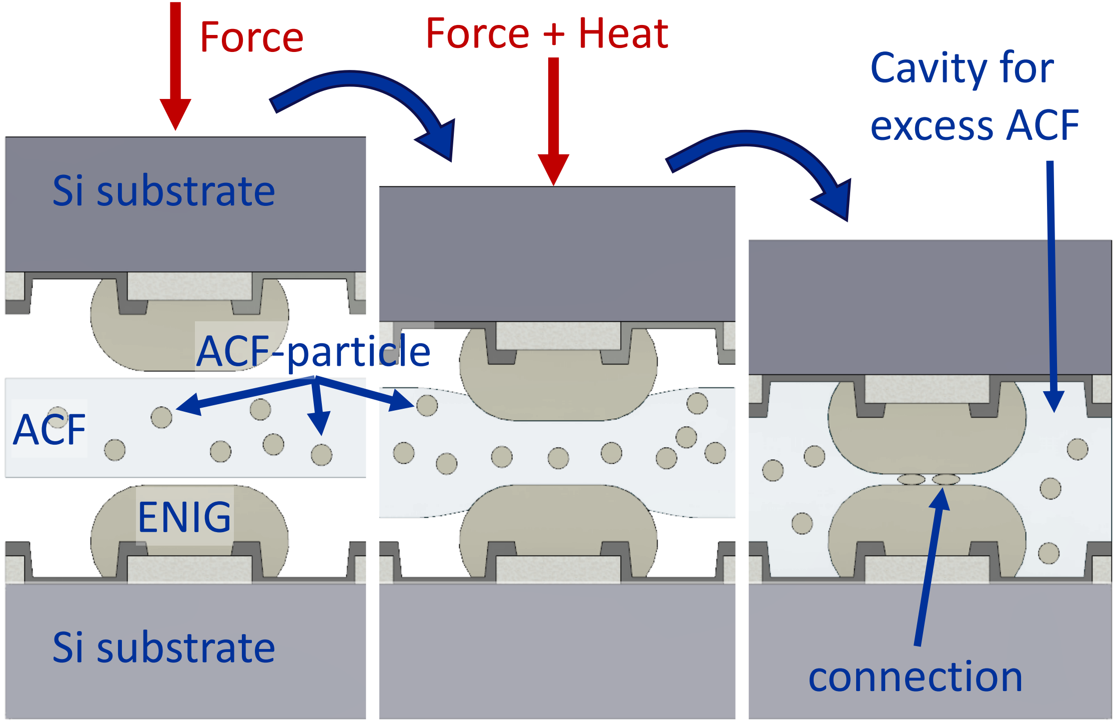

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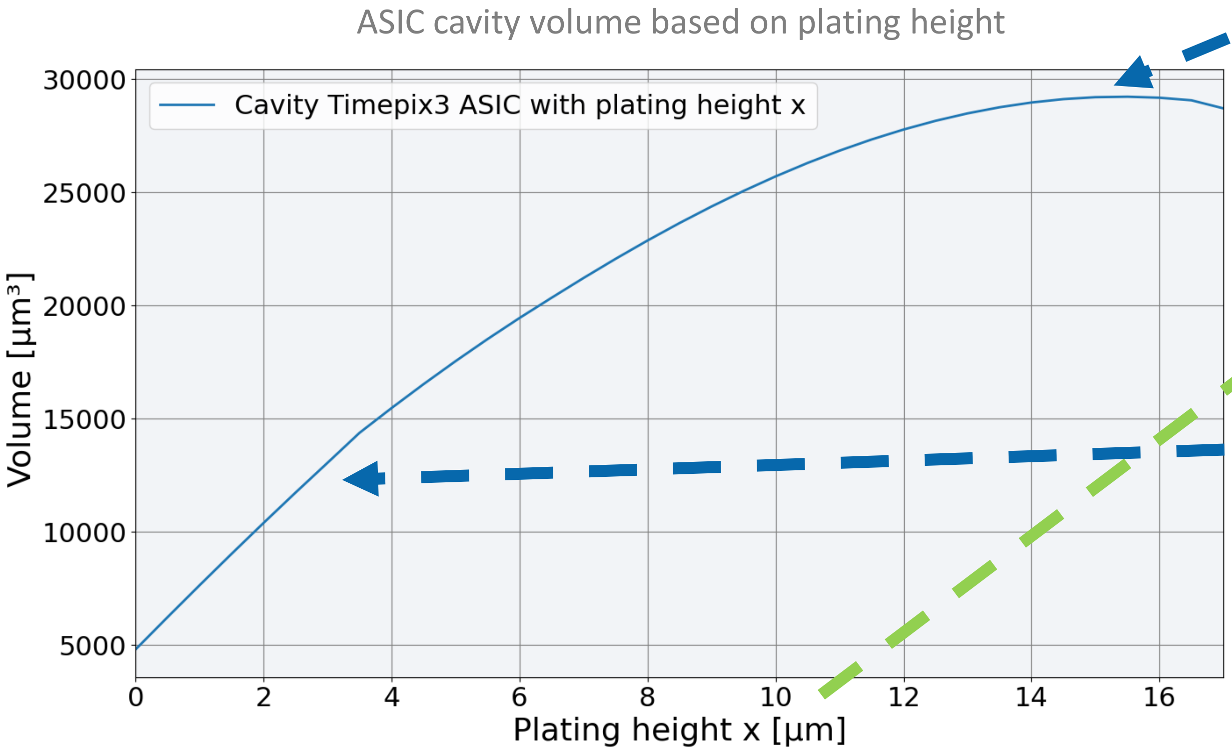
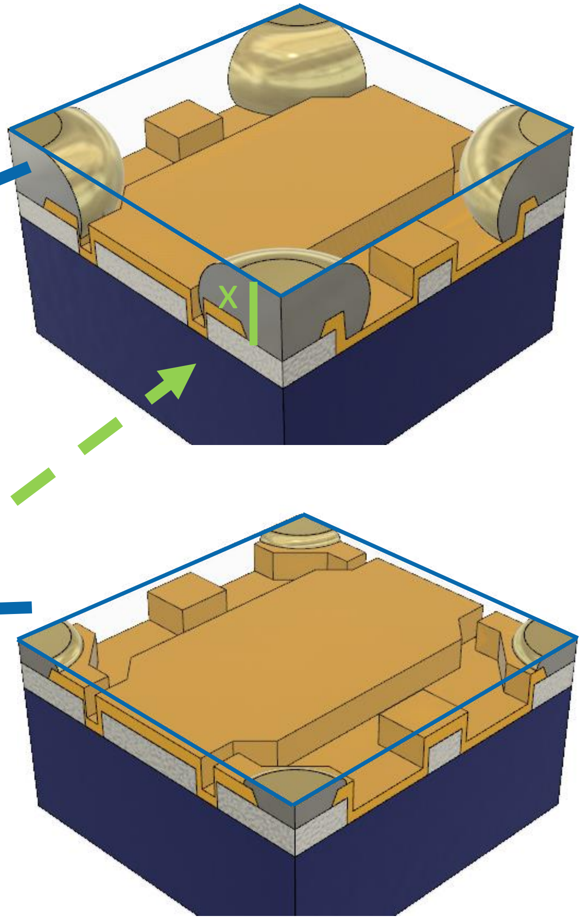
ENIG UBM plating
need for increased height

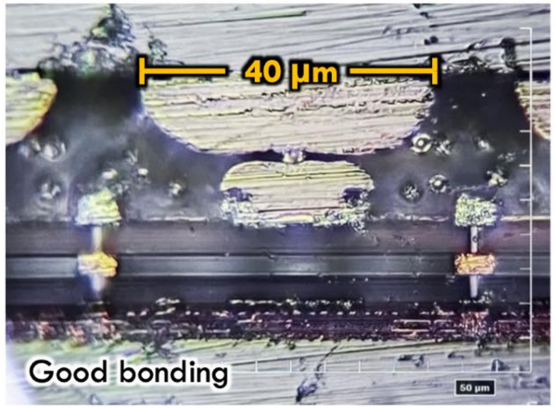
- Need for sufficiently large cavity volume between sensor and ASIC after bonding to fit excess adhesive
  - **Volume** directly related to plating height **x**
  - Developed approximate model for calculation

ASIC cavity volume based on plating height

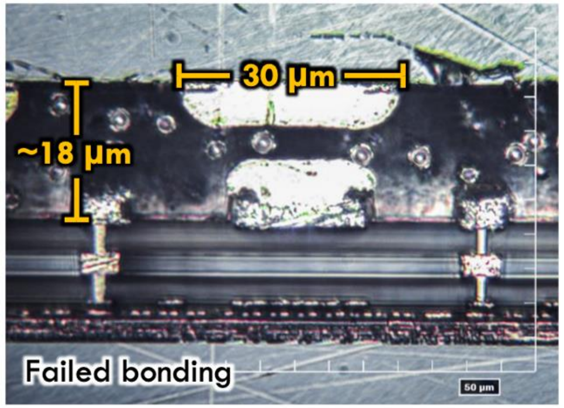




Timepix3 assembly w/ re-worked pad



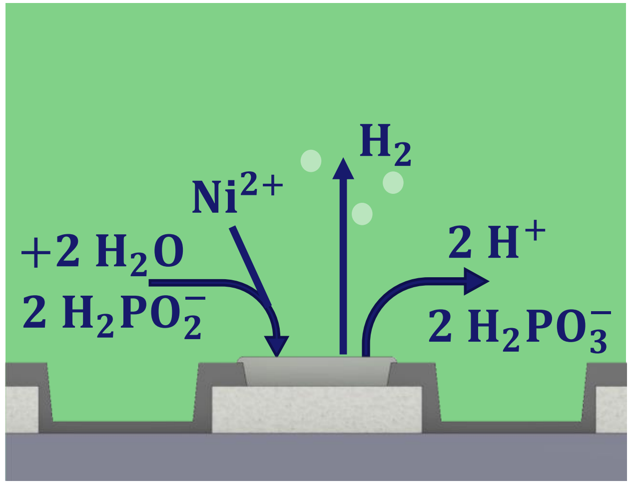
Timepix3 assembly w/ original ENEPIG



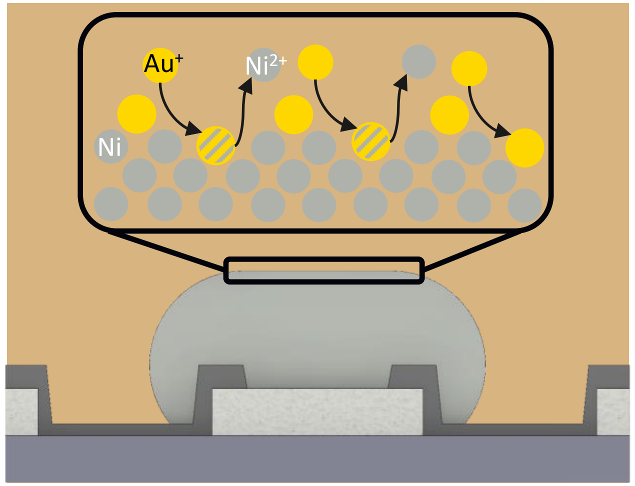
ENIG UBM plating need for increased height

- 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)

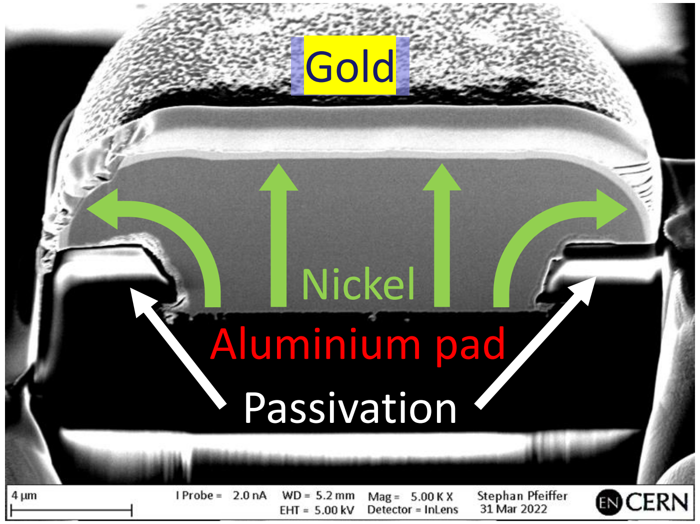
Electroless Nickel



Immersion Gold



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



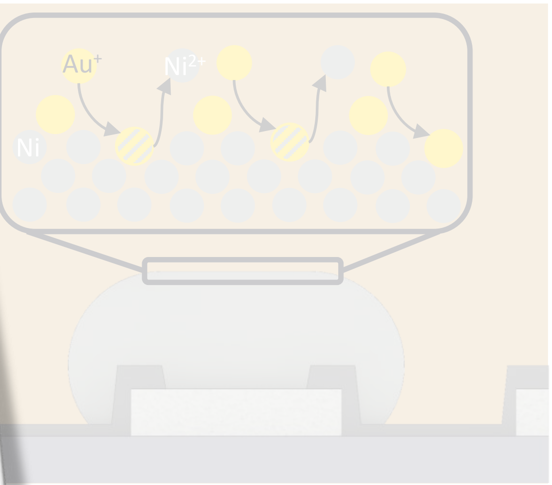
ENIG UBM plating
need for increased height

- Electroless Nickel
  - Self-catalytic
  - Perf
    or o
- Immer
  - Corro
- Ongoing
  EP-DT M
  - Cleani
    stabilit
  - Optimis
    topolog

Consistently achieving uniform plating!

32x64 pixels
50 µm pitch
Collaboration with ESRF

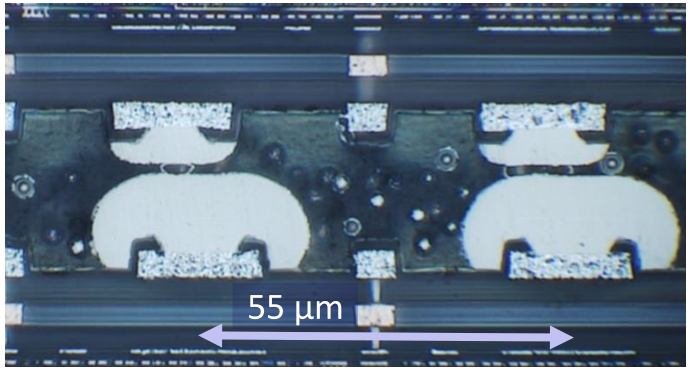
Immersion Gold



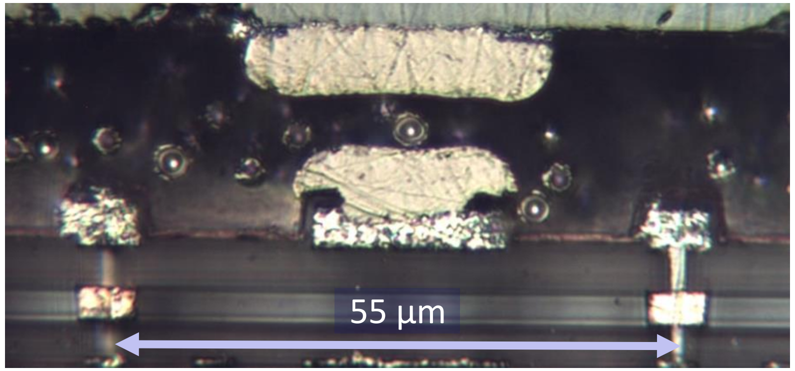
TESTING

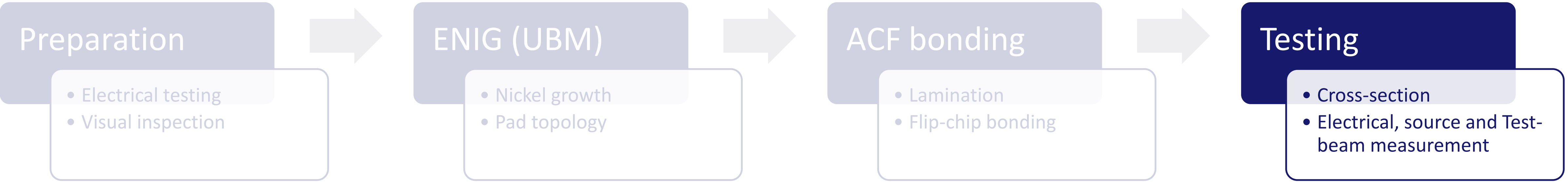
- Cross-section
  - Pad distance
  - Alignment
- Lab measurements
- Test-beam measurements

Cross-section Timepix3-Timepix3 ACF dummy sample



Cross-section Timepix3 ASCI-sensor ACF sample





Preparation
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ENIG (UBM)
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ACF bonding
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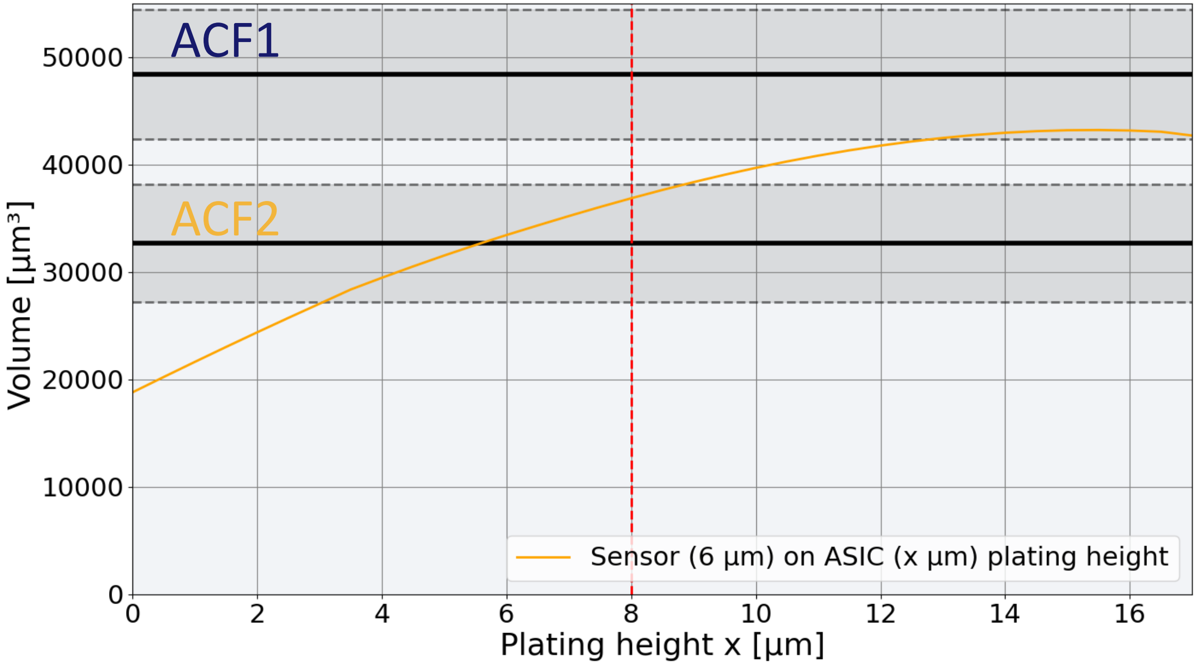
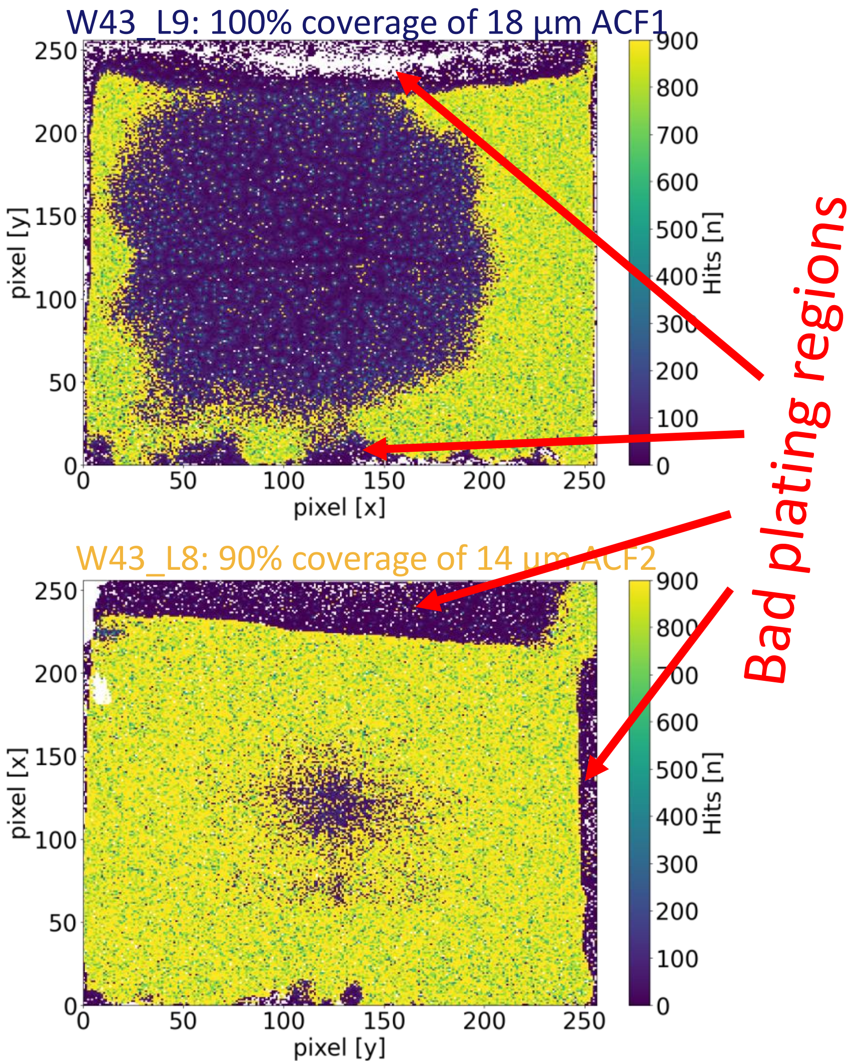
Testing
- Cross-section
- Electrical, source and Test-beam measurement

Bonding evaluation
SR90

- Evaluation of plating height and different ACF materials using Sr90 exposure of electrical assemblies

	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



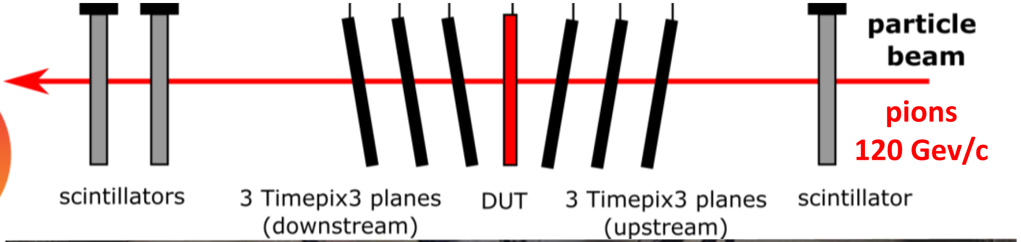


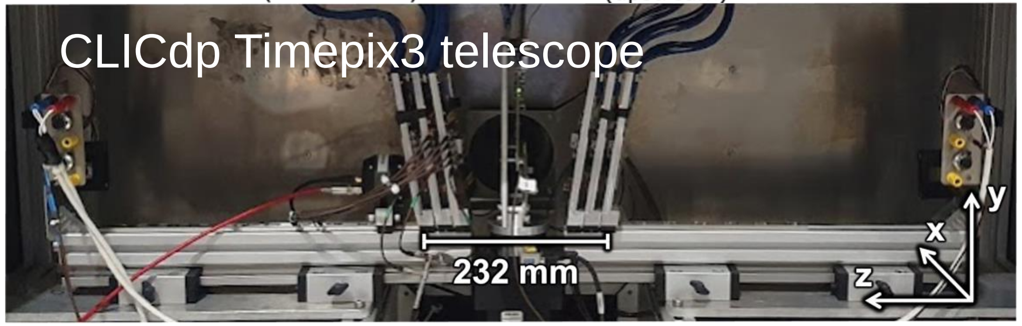
W43_L9: 100% coverage of 18 µm ACF1

W43_L8: 90% coverage of 14 µm ACF2

Bad plating regions

Bonding evaluation beam test

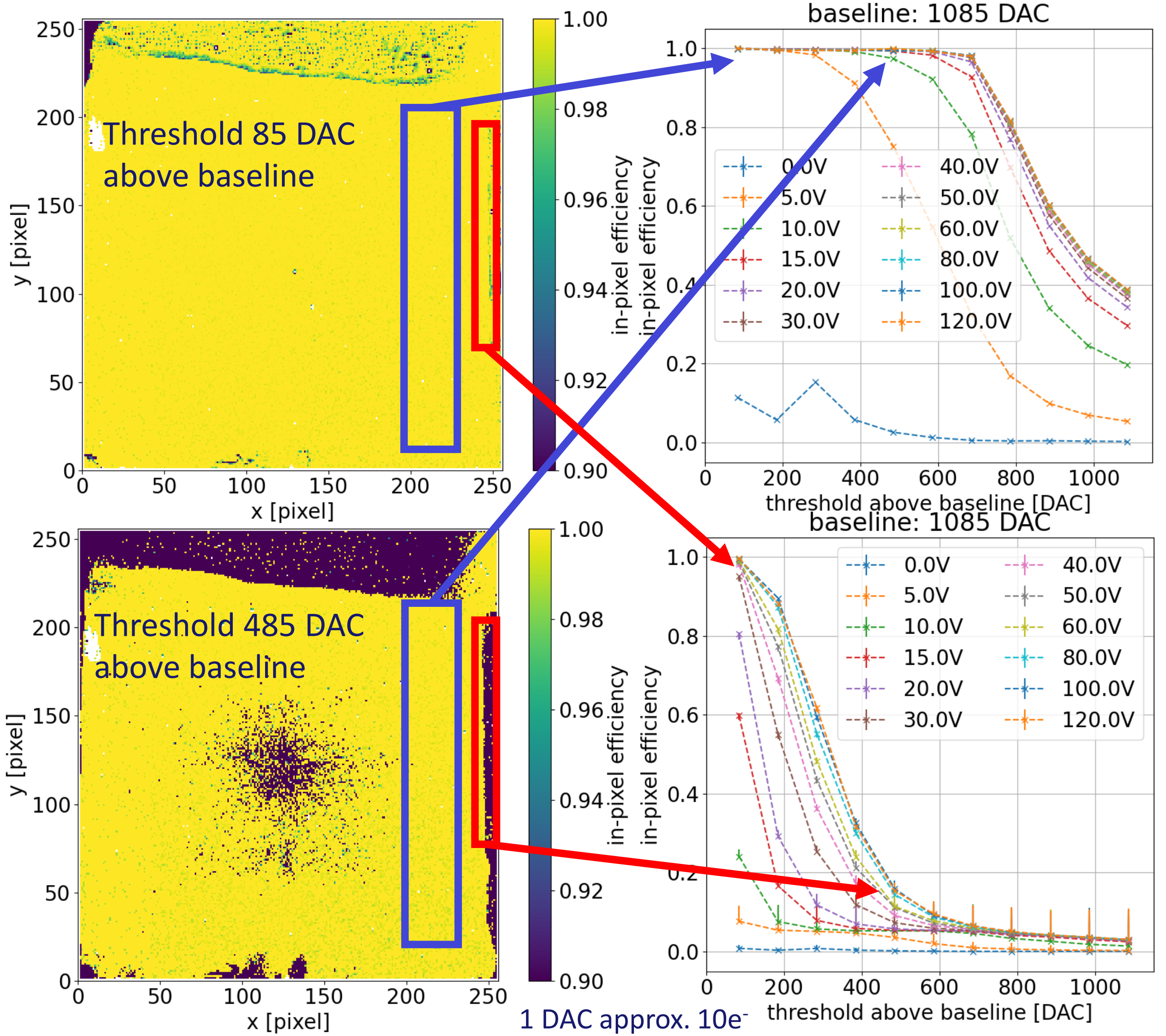




- High in-pixel efficiency at low thresholds
  - 99.96% in the “good” area
  - 99.05% in the area with low plating
- Different behaviour for higher thresholds
  - Stable in the ”good” area
  - Fast drop in the area with low plating

➢Weak coupling in some areas

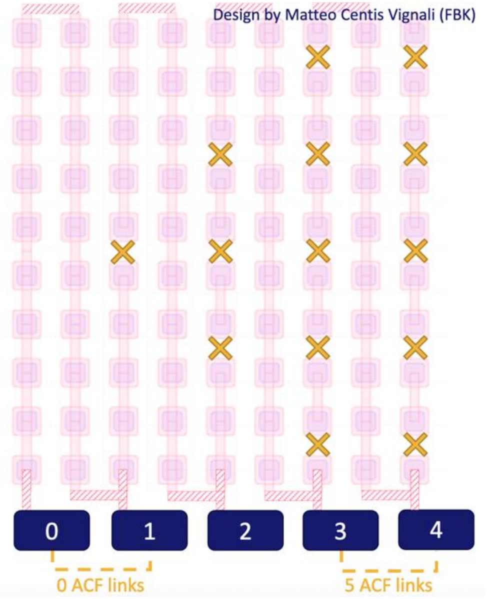
W43_L8 with 14 µm ACF2

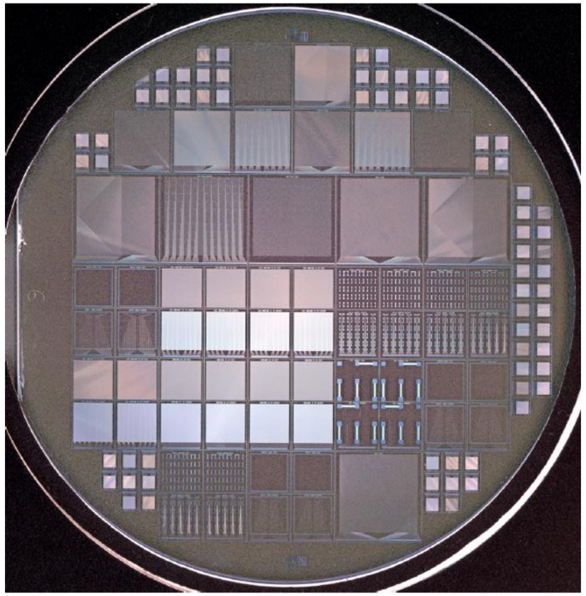


1 DAC approx. 10e$^-$

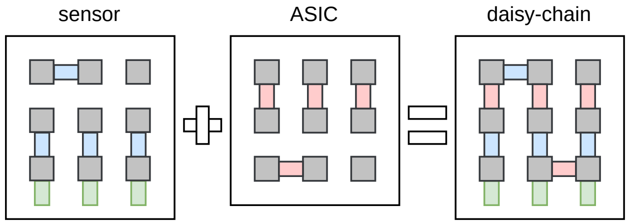
Daisy-chain devices
Production

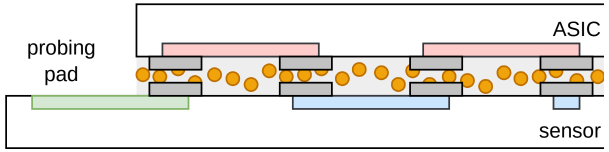
- Daisy-chain 6” quartz wafer with 625 µm thickness
  Designed and produced at FBK
- Study of ACF interconnection properties
  - Low-pitch and large-pitch reliability
  - Resistance measurements
  - Mechanical analysis
- Surface properties matched to ASICs
  - Al metal pads 2.5 µm thick
  - 950 nm thick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


Design by Matteo Centis Vignali (FBK)



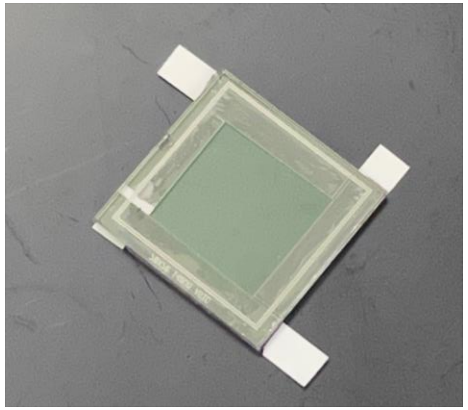
	pitch	size in mm	connections	per wafer	type	diceable
160x160 20um	20 um	3.2 x 3.2	25600	36	grid	no
CLICpix2	25 um	3.2 x 3.2	16384	34	grid	no
400x400 25um	25 um	20 x 20	640000	5	grid	yes
Timepix3	55 um	14 x 14	65536	4	grid	no
Timepix3 islands	55 um	14 x 14	65536	4	grid	no
RD53	50 um	20 x 20	160000	4	grid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



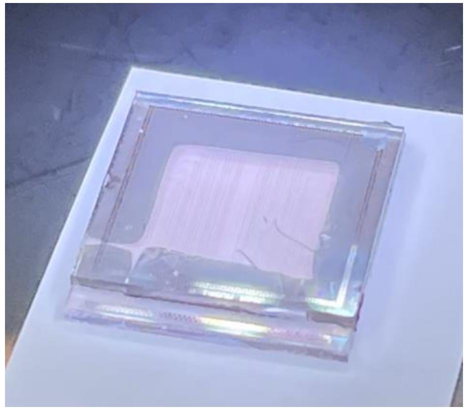


Daisy-chain devices
Testing

lamination



bonded



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ACF 1	3	18	71k	30-80	sheet
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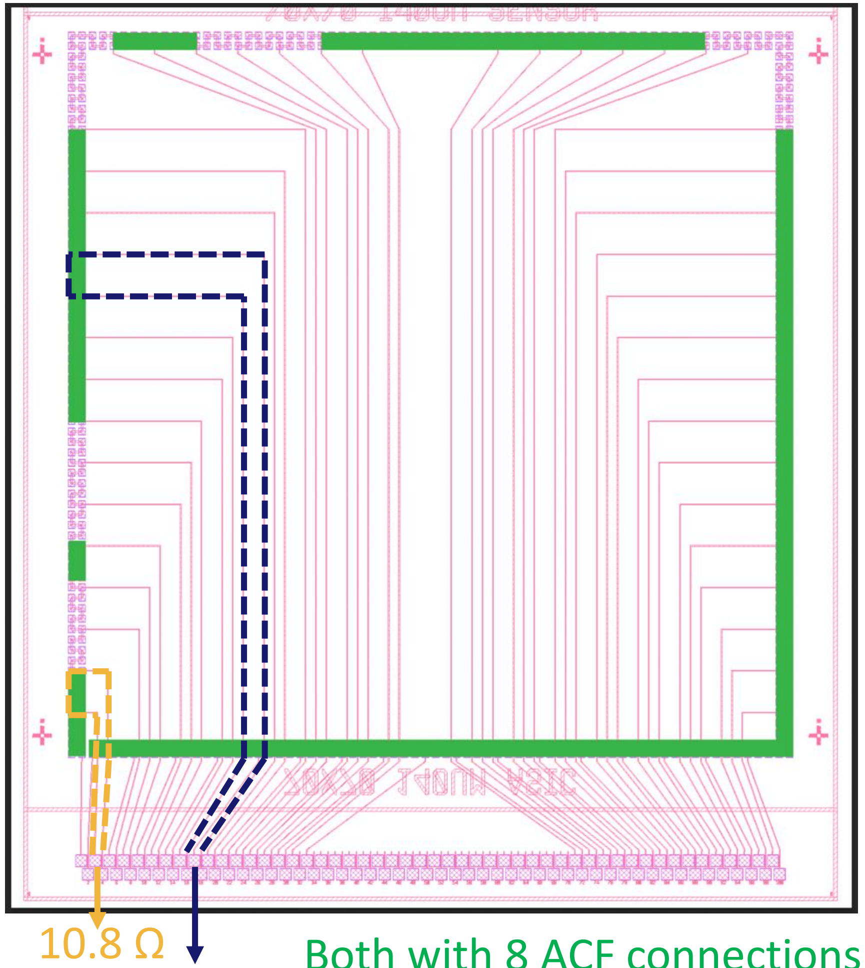
- Bonding peripheral-type device
  - Used sheet and 2 mm ACF film (18 µm / 14 µm thickness)
  - pad area 7744 µm^2
- Good connection yield
  - Missing connections due to ACF lamination / mechanical damage
  - <u>2-wire measurement of resistivity</u>, dominated by metal line length

Verified connections

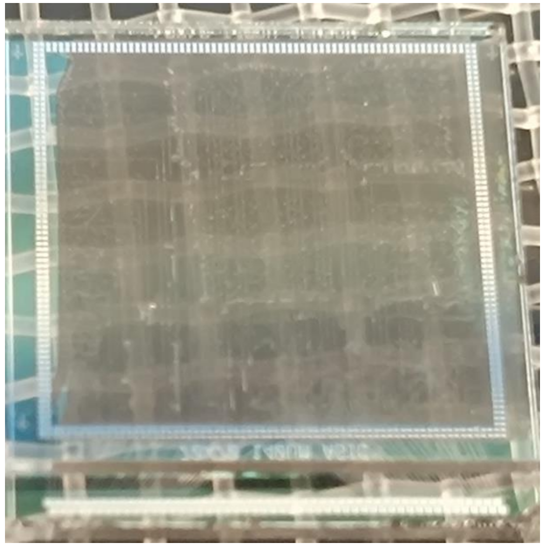


10.8 Ω

33.6 Ω

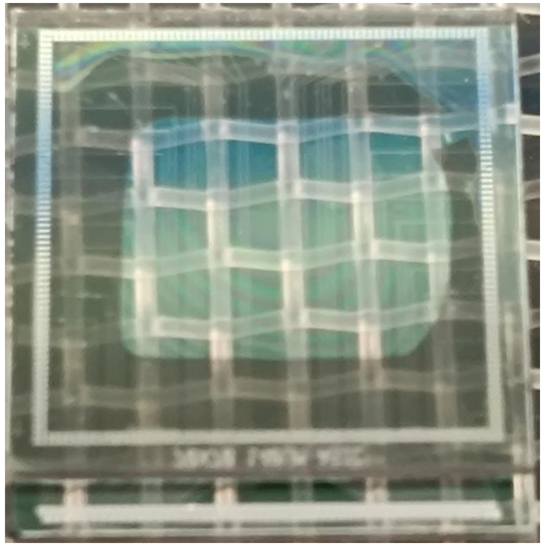
Both with 8 ACF connections

Daisy-chain devices Testing



18 µm ACF thickness (sheet)

- Missing lamination on the left side (no connecion)

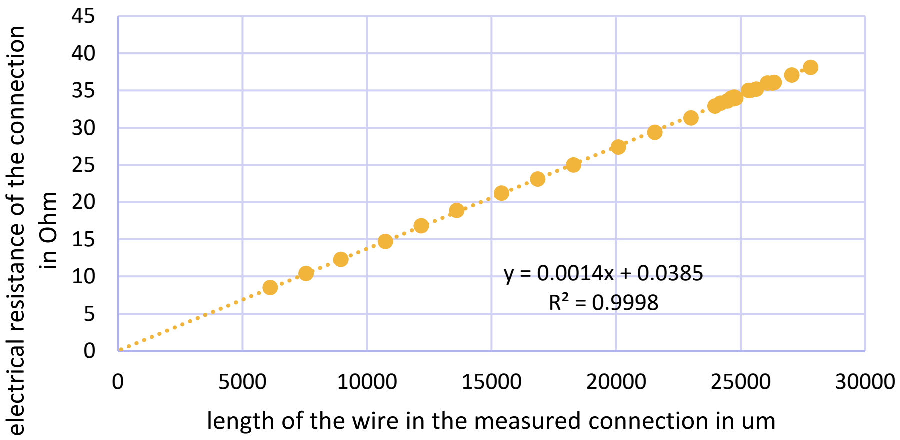


14 µm ACF thickness (4 stripes)

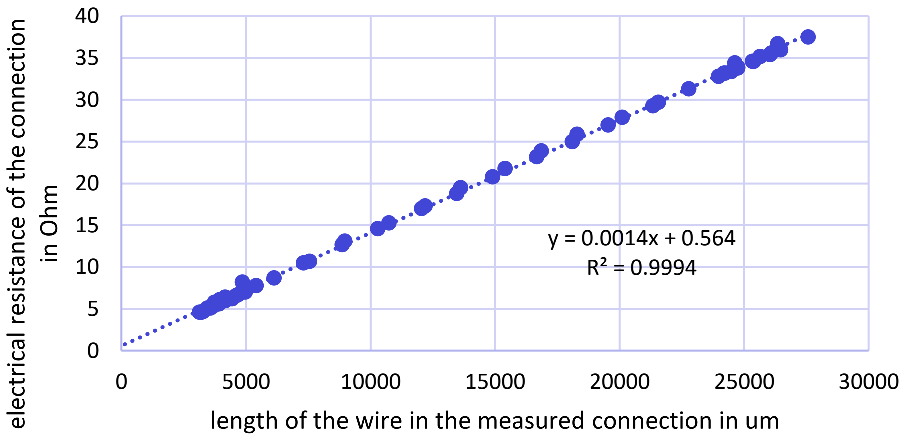
- Missing lamination in the top right corner (no connection and 2 high values near the area)

Daisy-chain devices Testing

18 µm ACF – resistance measurement



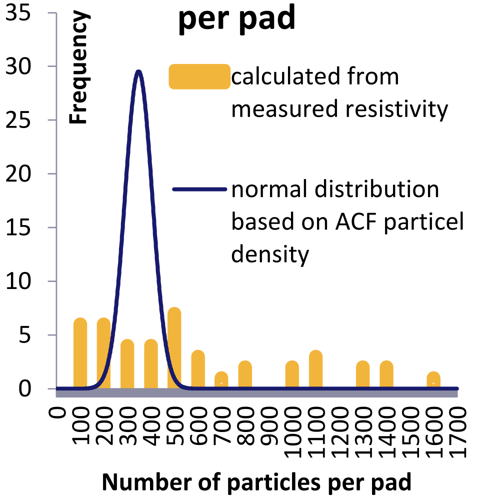
14 µm ACF – resistance measurement



- **Linear offset (0.564 ± 0.075) Ω from 14 µm ACF**
- On average 8.7 connections in single chain
  => (0.065 ± 0.009) Ω per connection
- (60000 ± 10000) part. per mm^2
  => (464 ± 77) part. per connection
- **Single particle resistance R = (30.2 ± 6.5) Ω**

Identical calculation for 18 µm ACF

18 µm ACF - particles per pad



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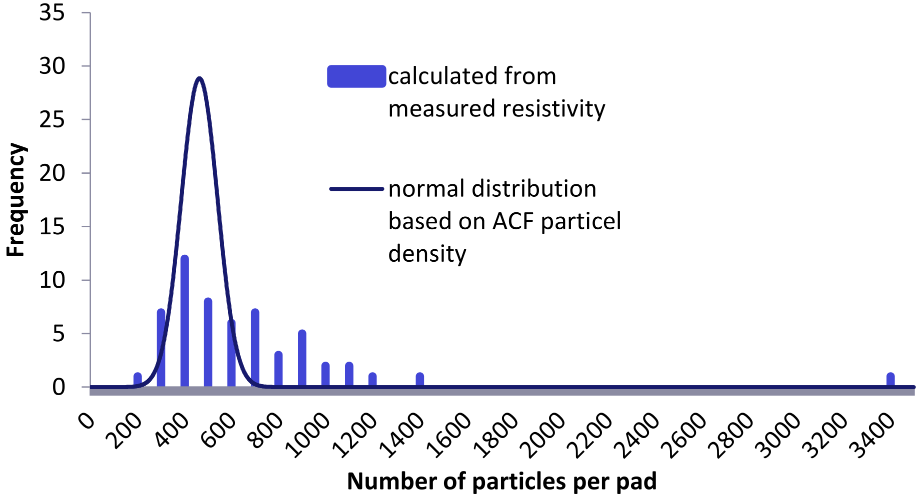
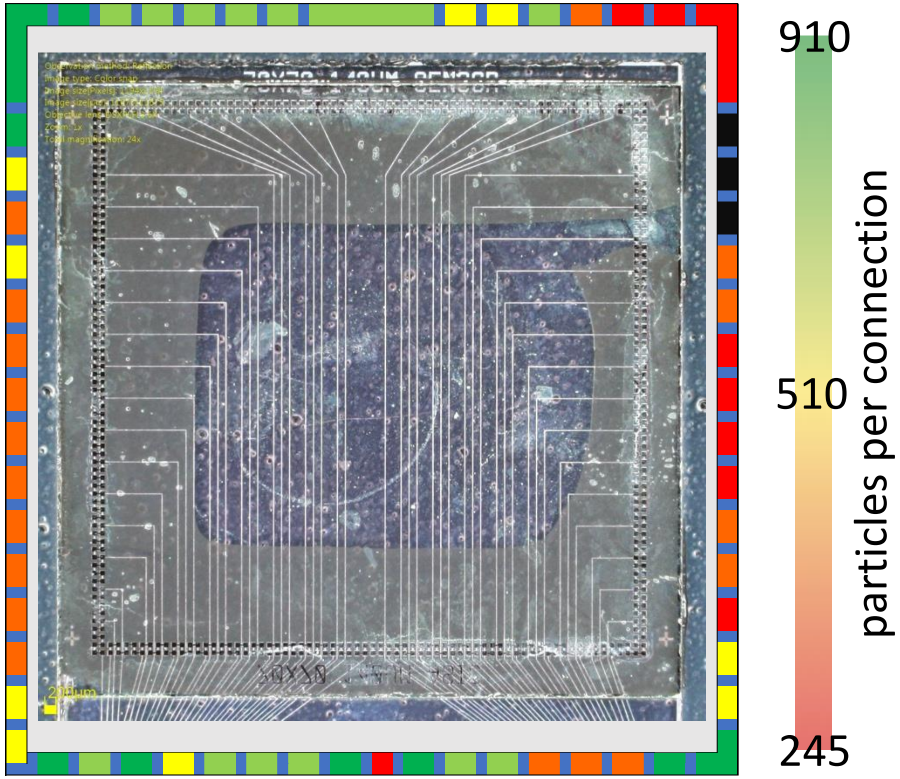


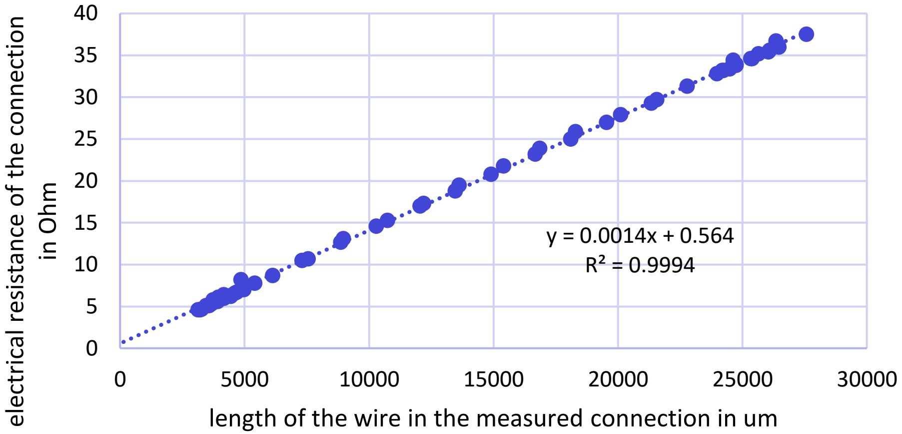
- **Based on calculated single particle resistance, recalculated number of particles per single connection**
  -> circular definition, but ballpark good enough to observe difference across the assembly

Daisy-chain devices Testing

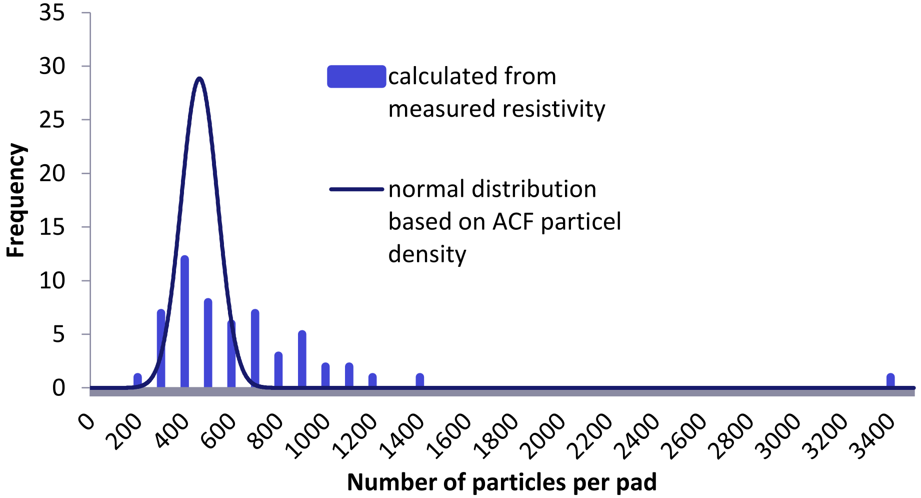
14 µm ACF assembly



14 µm ACF – resistance measurement



14 µm ACF - particles per pad



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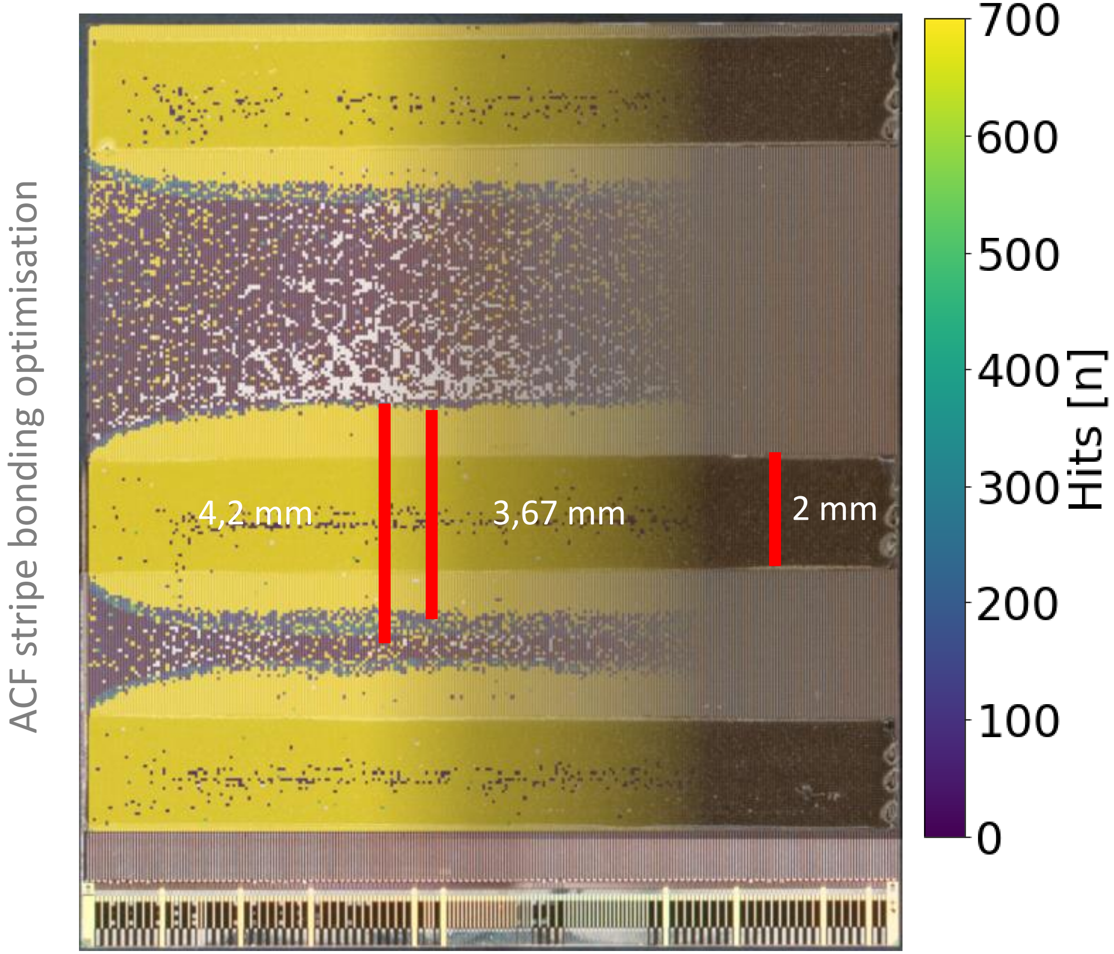
Flow of ACFs

- Better connection near the edge
- ACF and particles flow
- Connect area > covered area

- Applying ACF with gaps
  - Less adhesive volume
  - Lover cavity volume needed

→ Possible yield improvement through gaps in the ACF coverage



Conclusion and outlook

- Improving the ENIG plating
  - Already very good yield for larger pads (above 80 µm pad size)
  - Improvements of plating ongoing for smaller structures
    - Plating of 5 µm height uniform, higher still with unstable results
  - Starting plating trials for CLICpix2 assemblies (25 µm pitch, real and daisy-chains)

- Studies of mechanical and electrical performance using daisy-chains
  - Good resistivity results, need to investigate impact of temperature/humidity/radiation
- Further evaluation and improvement of bonding parameters
  e.g. Plating height, particle density, ACF thickness, ACF coverage

- Test-beam data analysis of bonded sample ongoing
  - Estimated high connection yield in plated areas

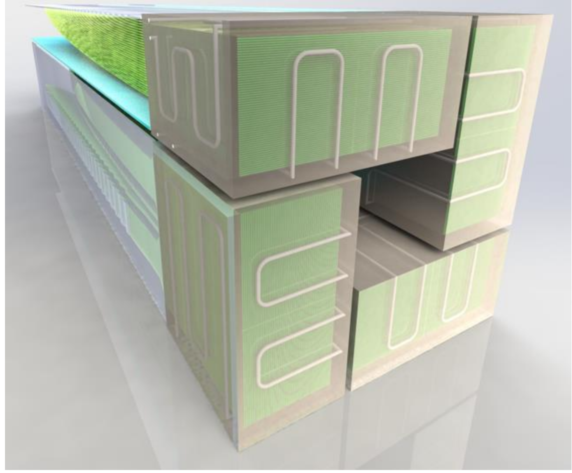
Backup

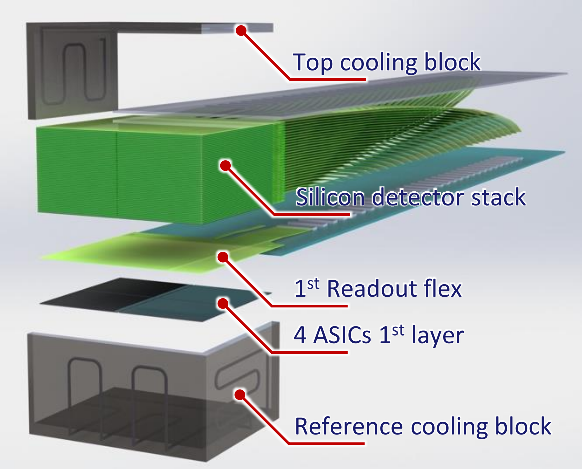
100µPET

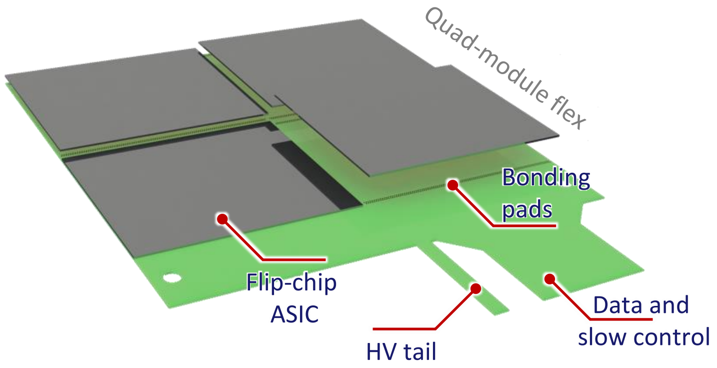
ULTRA-HIGH RESOLUTION MOLECULAR IMAGING

by Mateus Vicente

- SNSF Sinergia project with **University of Geneva** + **EPFL** + **University of Lucerne** and **HUG**
  - Deliverable: Small-animal PET scanner using monolithic silicon pixel detectors for molecular imaging with ultra-high resolution
    - https://doi.org/10.1016/j.nima.2022.167952 or latest slides from CERN EP R&D WP 1.3 meeting
    - SiGe BiCMOS MAPS: **2.2 x 3 cm²**; **100 µm** pixel pitch; **250 µm** thick active silicon sensor
      - Unprecedent scanner granularity and depth-of-interaction ⇒ **Volumetric Spatial resolution = 0.015mm³**
    - Module layers with **2x2 chips (~30 cm²)** and **4** detection **"towers",** each with **60** detection layers **= 960 chips!**
      - **With developments from this AIDAinnova WP, ASIC and scanner are designed for flip-chip bonding with conductive adhesives**





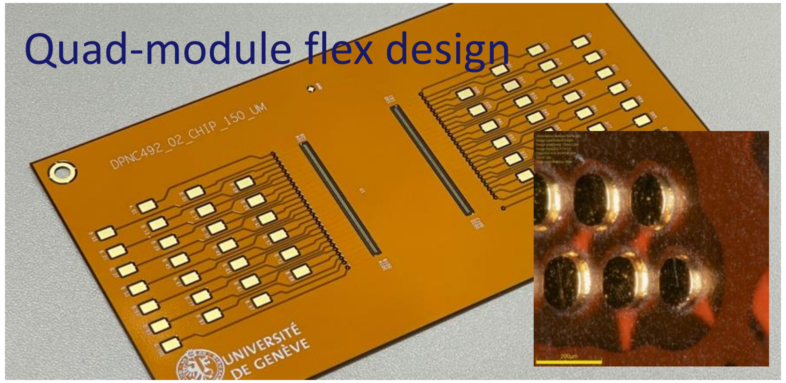


100µPET

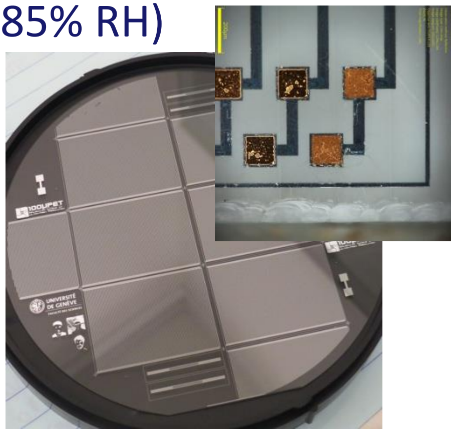
ULTRA-HIGH RESOLUTION MOLECULAR IMAGING

by Mateus Vicente

- Flip-chip bonding prototyped with single-chip flex and quartz pad-wafer
  - 4 layers flex (200µm thick) and test-chip, both with ENIG pads
- Bonding reliability depends on amount of adhesive
  - Epoxy’s cure shrinkage provides compressive force among bonding pads
  - **2.5 Ohms measured (2-wire) for ACP and NCP samples**
    - Including probing resistance, flex routing and 8 pairs of bonded pads
      - Small 0.1 Ohm drift within 3 weeks
- Next steps: Reliability tests (temp. cycles and 85°C/85% RH)


Quad-module flex design

+



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Electroless Nickel Immersion Gold

- Widly used in PCB metalisation
- Consists of two consecutive baths
- Nickel as bulk deposit & Immersion Gold for corrosion protection

Electroless Nickel

- Reaction on catalytic surface

$$2\,H_2PO_2^- + 2\,H_2O \rightarrow 2\,H_2PO_3^- + H_2 + 2\,H^+ + 2\,e^-$$
$$Ni^{2+} + 2e^- \rightarrow \mathbf{Ni}$$
$$H_2PO_2^- + 2\,H^+ + e^- \rightarrow \mathbf{P} + H_2O$$

- 8 – 10 % phosphorus content
- ≈ 5 µm/15 minutes

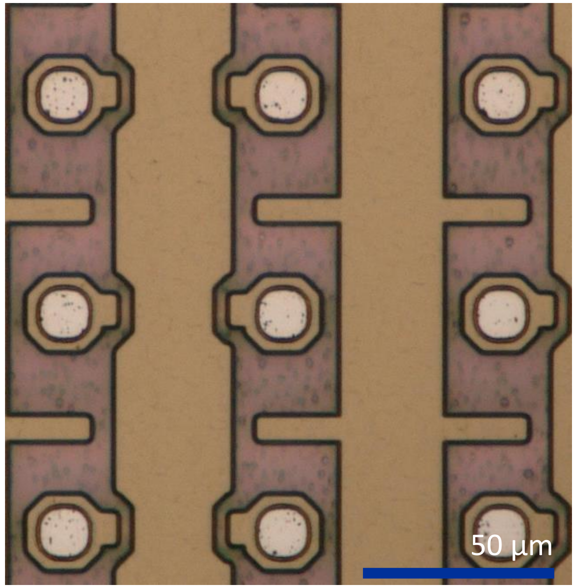
Immersion Gold

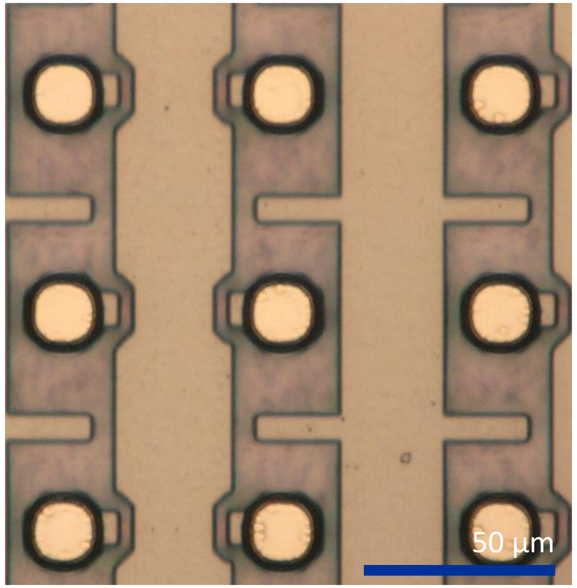
- Reaction with Ni on surface

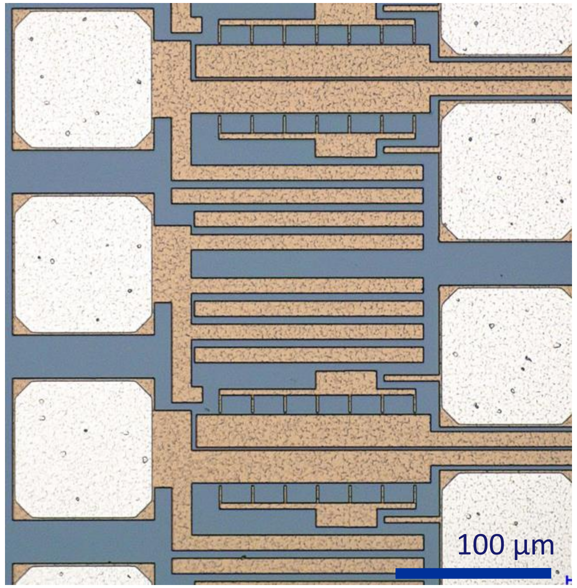
$$Ni \rightarrow 2e^- + Ni^{-2} \qquad E_{Ni^{2+}/Ni} = -0{,}275\ V$$
$$Au^+ + e^- \rightarrow Au \qquad E_{Au^+/Au} = 1{,}692\ V$$

- ≈ 0,8 µm/10 minutes
- Decreasing speed with increasing thickness

Samples for ENIG studies







Bare Timepix3 ASIC

- 55 µm pitch
- Pad diameter: 12 µm
- Pad material: Aluminium

Plated Timepix3 ASIC

- 55 µm pitch
- Pad diameter: 18 µm
- Pad material: Aluminium
- Previous wafer-level ENEPIG

MALTA

- bonding interface for IO pads
- Replacing wire-bonding
- Pad size: 88 µm x 88 µm
- Pad material: Aluminium

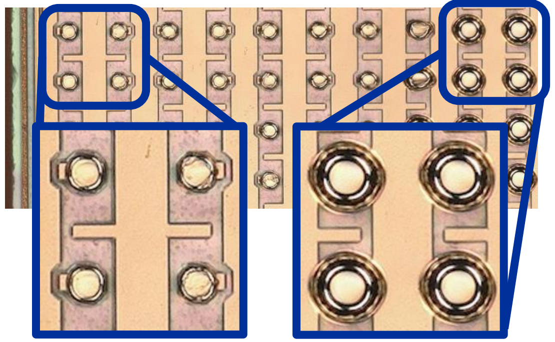
ENIG CHALLENGES

- Defective plating
  - Skip or step plating
  - Missing plating near edge

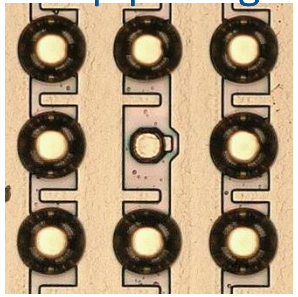
→Diffusion controlled catalyst poisoning

- Stabilizer and contamination
- Poison is adsorbed on surface
- Faster diffusion to small pads
- Diffusion layer is reduced by convection

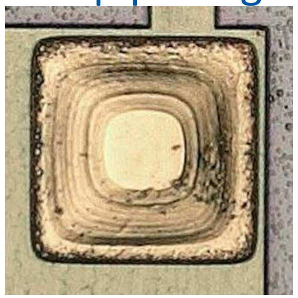
Missing plating at the edge

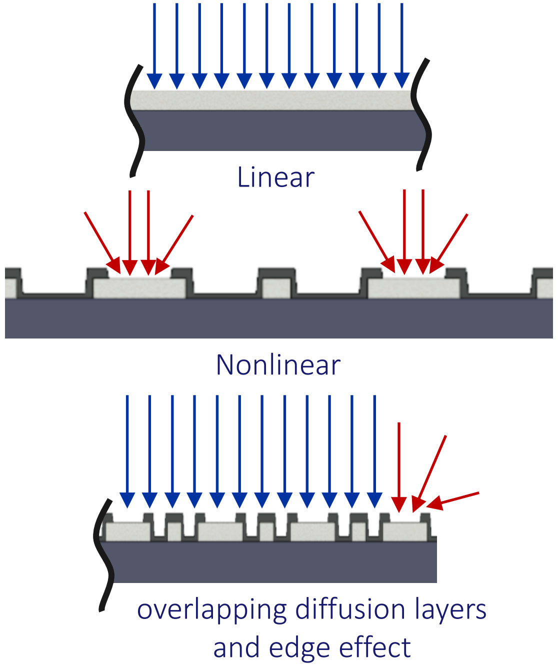


Skip plating

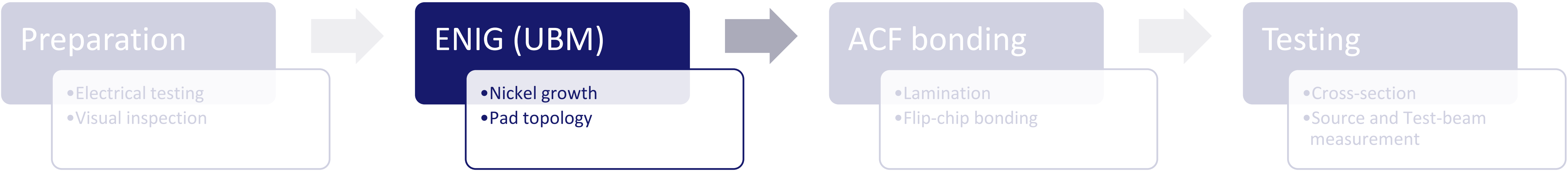


Step plating





S. Zhang *et al* 1999 *J. Electrochem. Soc.*



Preparation
- Electrical testing
- Visual inspection

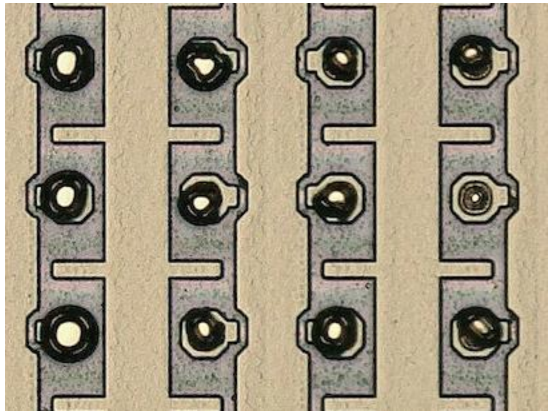
ENIG (UBM)
- Nickel growth
- Pad topology

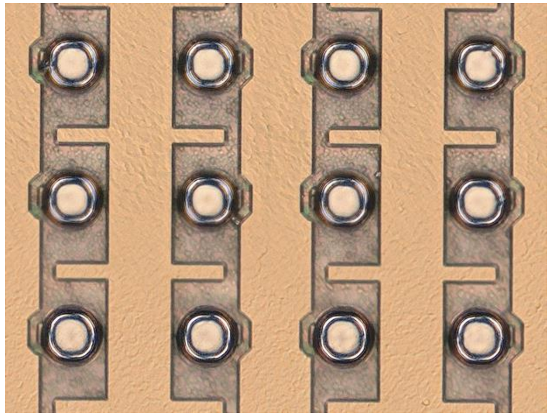
ACF bonding
- Lamination
- Flip-chip bonding

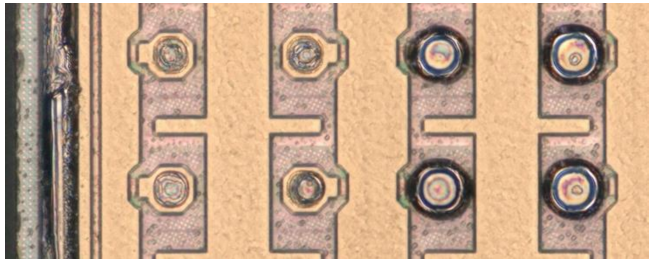
Testing
- Cross-section
- Source and Test-beam measurement

New chemicals and equipment for electroless nickel

- Chemicals for the semiconductor industry
  - Produced in clean-room
  - Separate Stabilizer
  - New activation chemicals
- Moved to a dedicated clean-room area
- Adjustment of parameters in progress
  - reducer, stabilizer concentration
  - Temperature and pH level
- Edge effect for single-dies challenging


Best result on blank Timepix3 ASICs with old chemicals


Best result on blank Timepix3 ASICs with new chemicals


Missing plating near the edge

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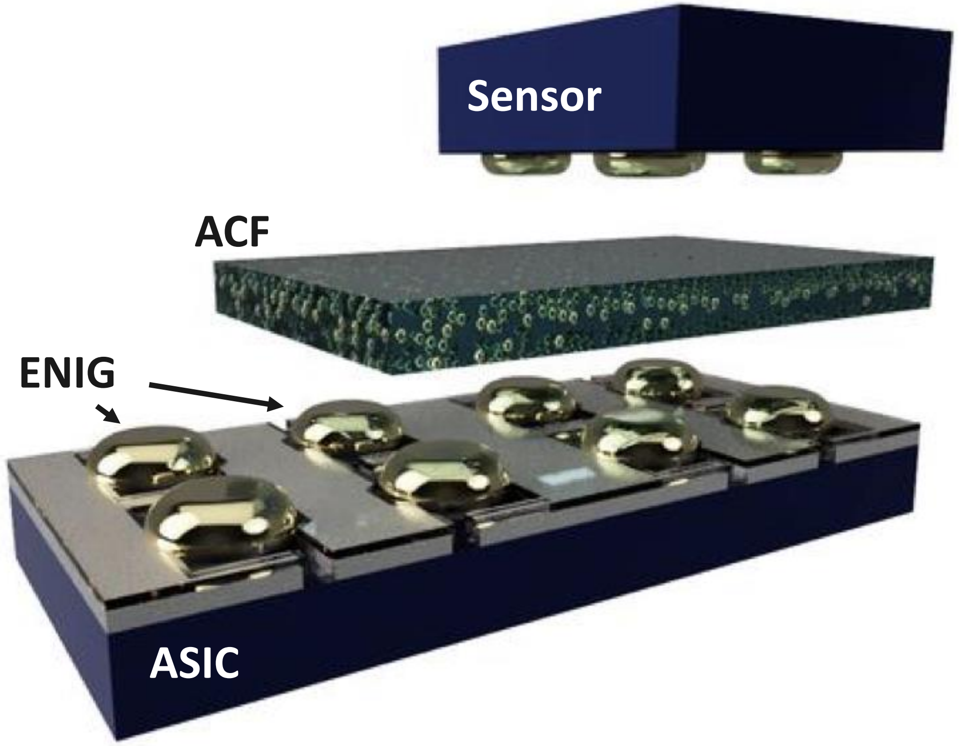
ACF BONDING

- 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/mm^2]	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



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Testing
- Cross-section
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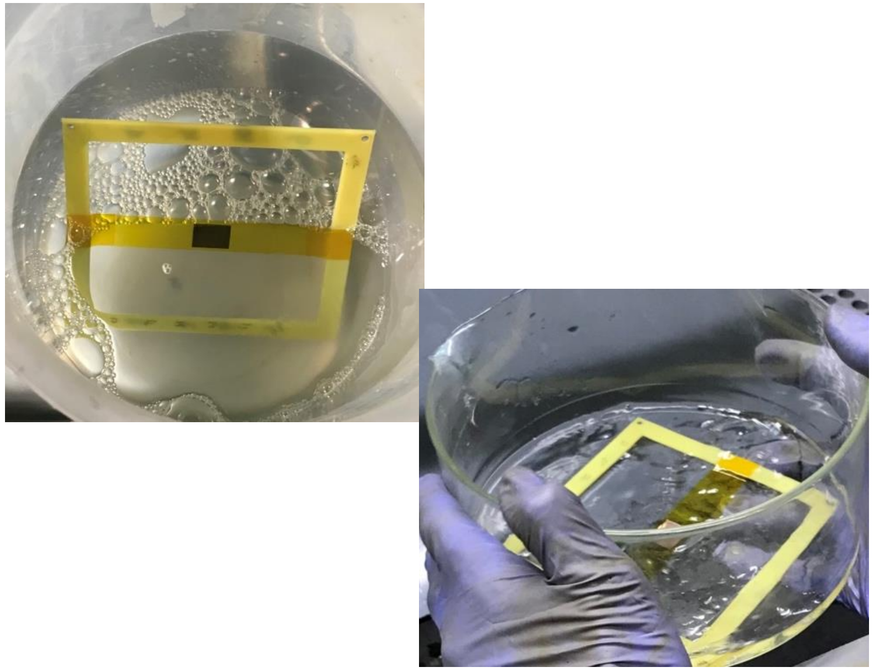
Procedure

- To remove contaminations like dust & grease

1. Alkaline detergent in ultrasonic bath
2. Acetone bath
3. Ethanol bath
4. Rinsing with DI-Water



Cleaning
- Chemical cleaning in ultrasonic baths

Paint deposition
- Toluene solvable
- Mask specific areas

Aluminum Pad

ENEPIG Pad

Removing Al_2O_3

Au removal Surface preparation

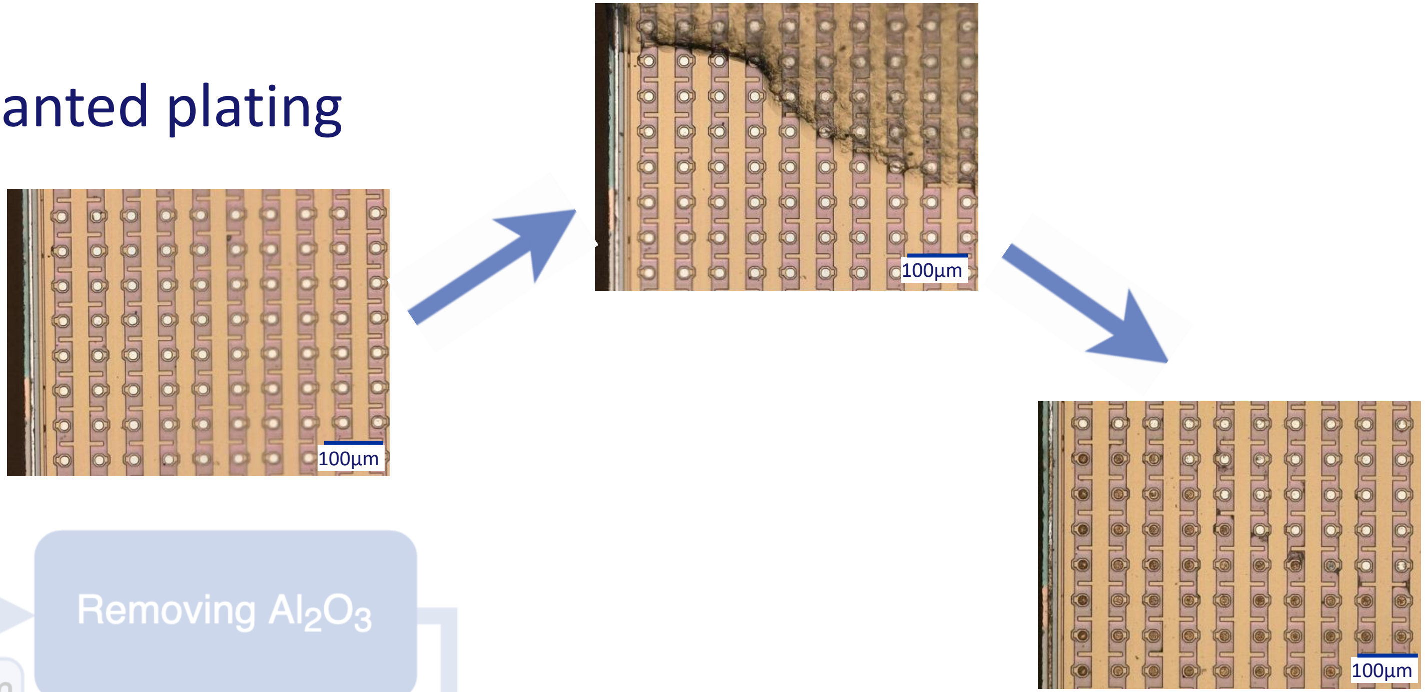
Nickel deposition
- Self catalytic
- 5 µm in 15 min

Immersion Gold
- Outer layer of Pad
- Passivation

Procedure

- Masking paint covers parts from unwanted plating

1. Applying paint
2. Drying
3. Rinsing with Ethanol
4. Rinsing with DI-Water



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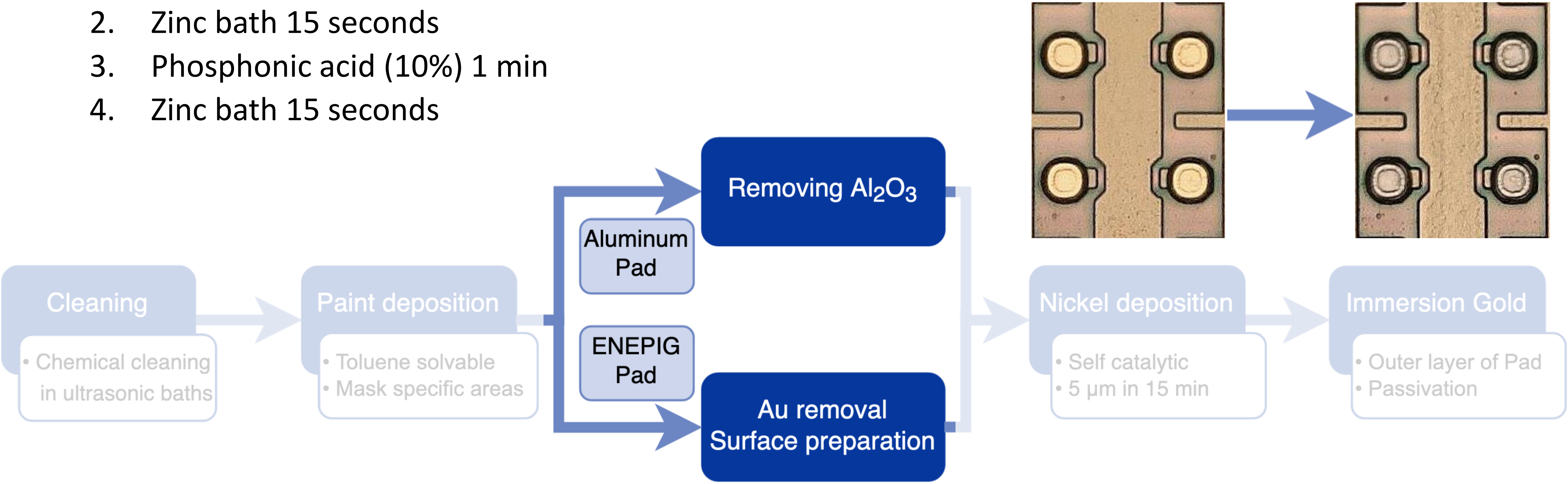
Procedure

Aluminium Pads

- Double zincation
  1. Phosphonic acid (10%) 2 min
  2. Zinc bath 15 seconds
  3. Phosphonic acid (10%) 1 min
  4. Zinc bath 15 seconds

Nickel-Palladium-Gold Pads

- Gold removal
  1. Cyanide bath 5 min



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Aluminum Pad → Removing Al_2O_3

ENEPIG Pad → Au removal Surface preparation

Nickel deposition
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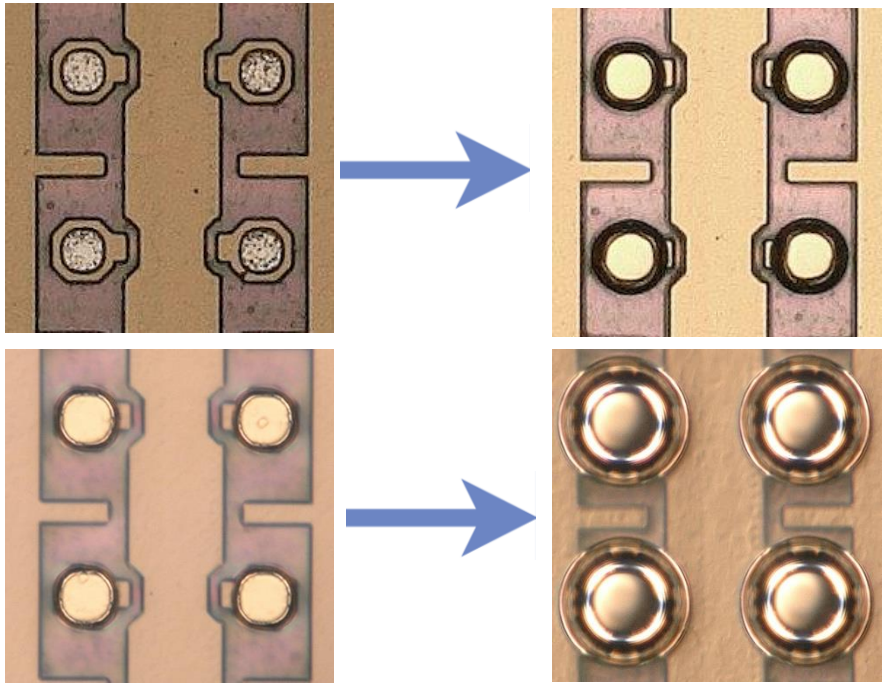
- 5 µm in 15 min

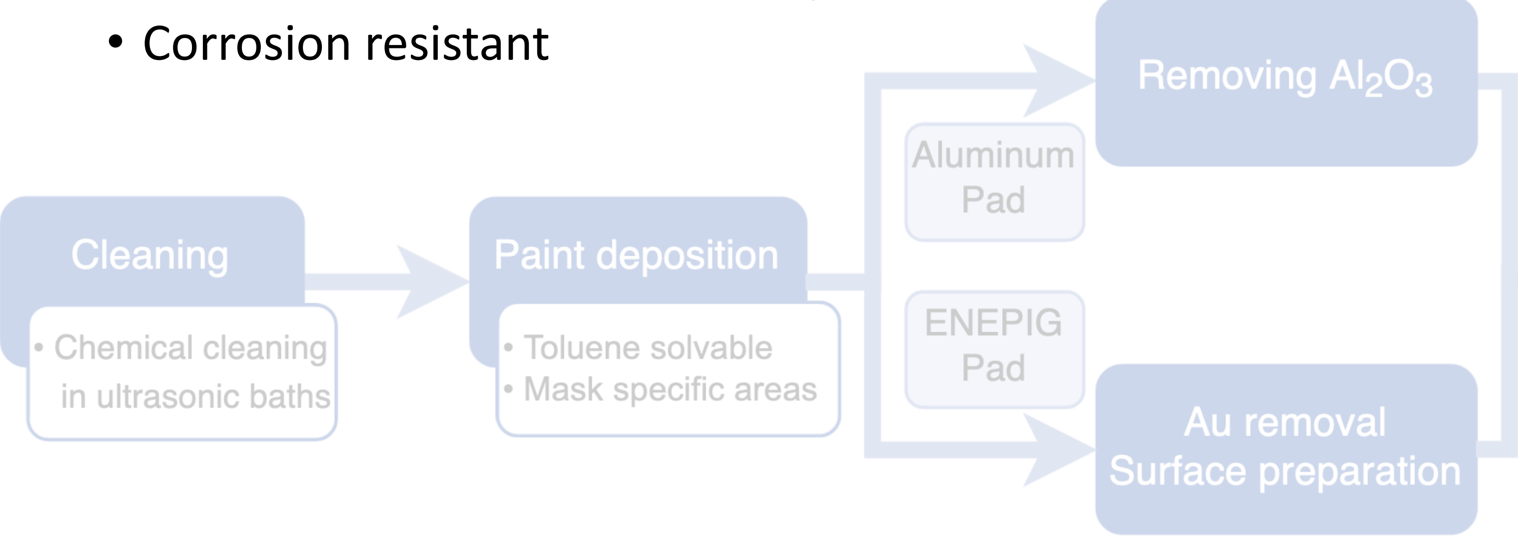
Immersion Gold
- Outer layer of Pad
- Passivation

Procedure

1. $2\,H_2PO_2^- + 2\,H_2O + Ni^{2+} \rightarrow 2\,H_2PO_3^- + H_2 + 2\,H^+ + 2\,Ni$
2. $2\,Au^+ + Ni \rightarrow 2\,Au + Ni^{2+}$

- Surface must act as a catalyst
- New created Ni-layer acts as catalyst
- Outer Ni atoms immersed by Au
  - Corrosion resistant





Cleaning
- Chemical cleaning in ultrasonic baths

Paint deposition
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Aluminum Pad → **Removing Al_2O_3**

ENEPIG Pad → **Au removal Surface preparation**

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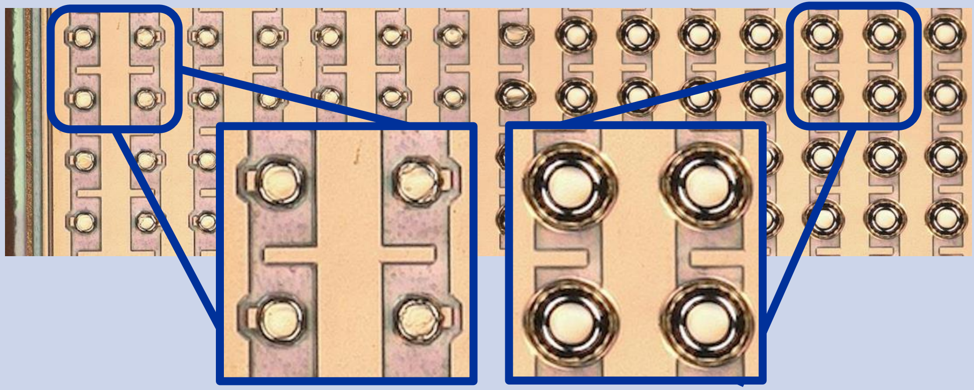
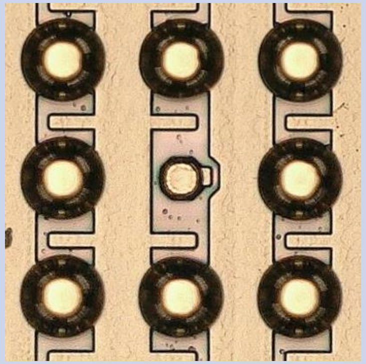
Main difficulties

Uniformity

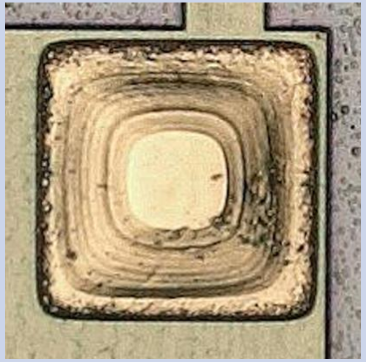
Missing plating at the edge



Skipp plating

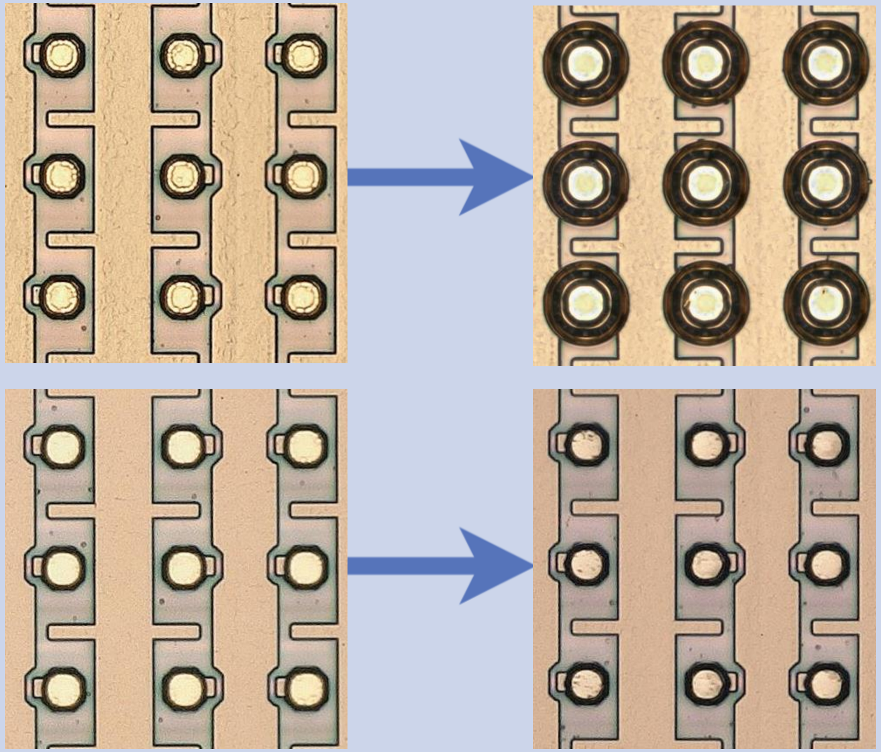


Step plating



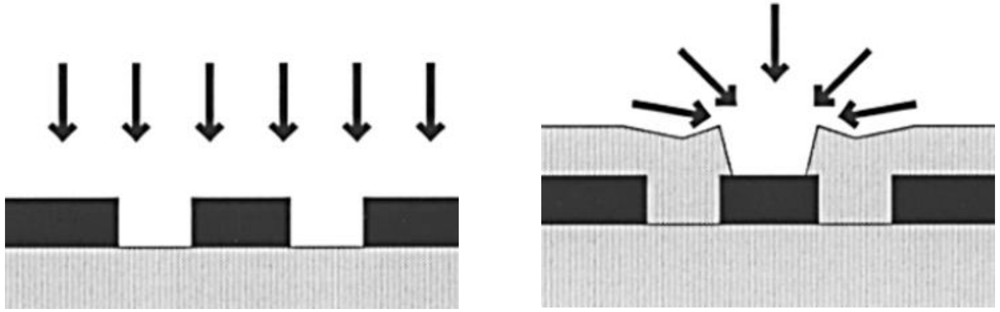
Reproducibility

- Different results with same procedure

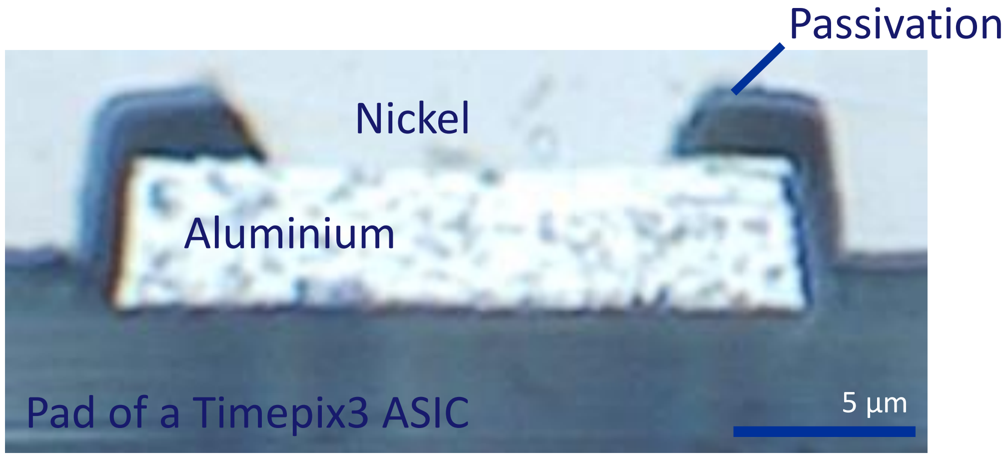


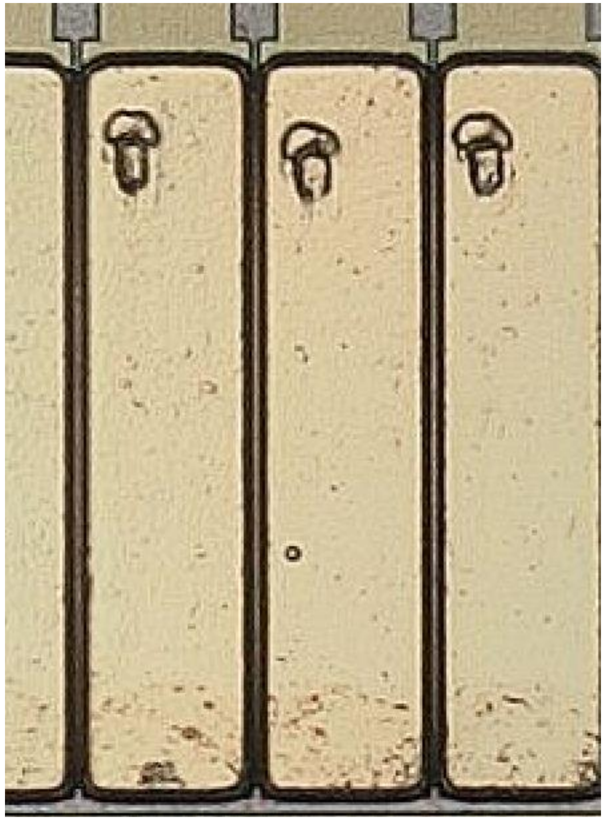
Possible causes

- 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

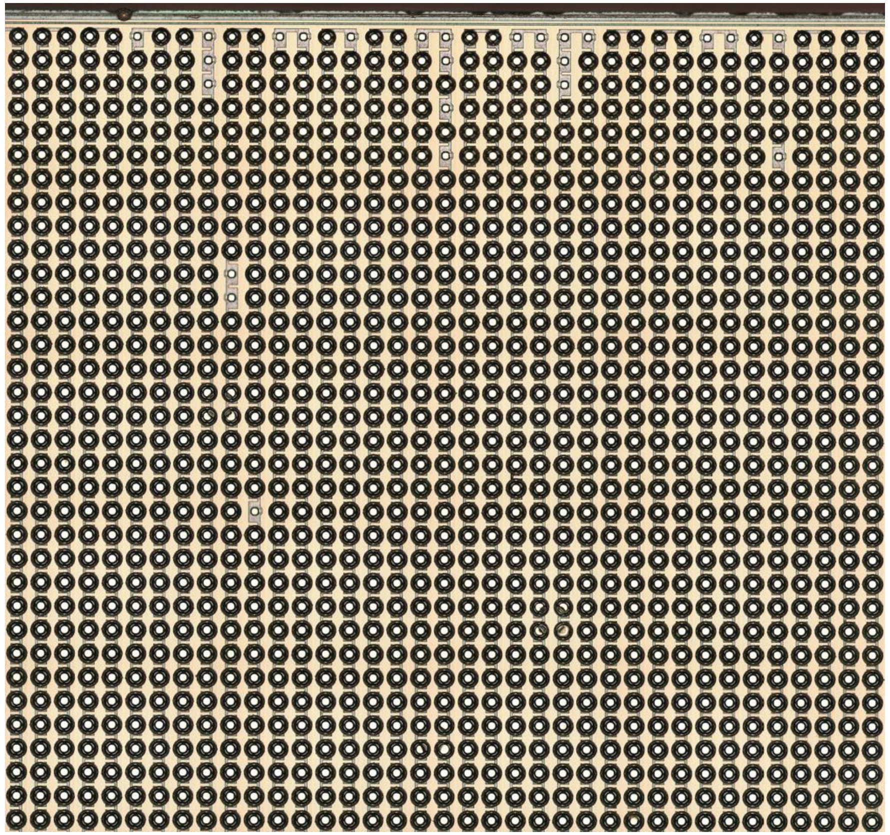


S. Zhang et al 1999 J. Electrochem. Soc.146 2870

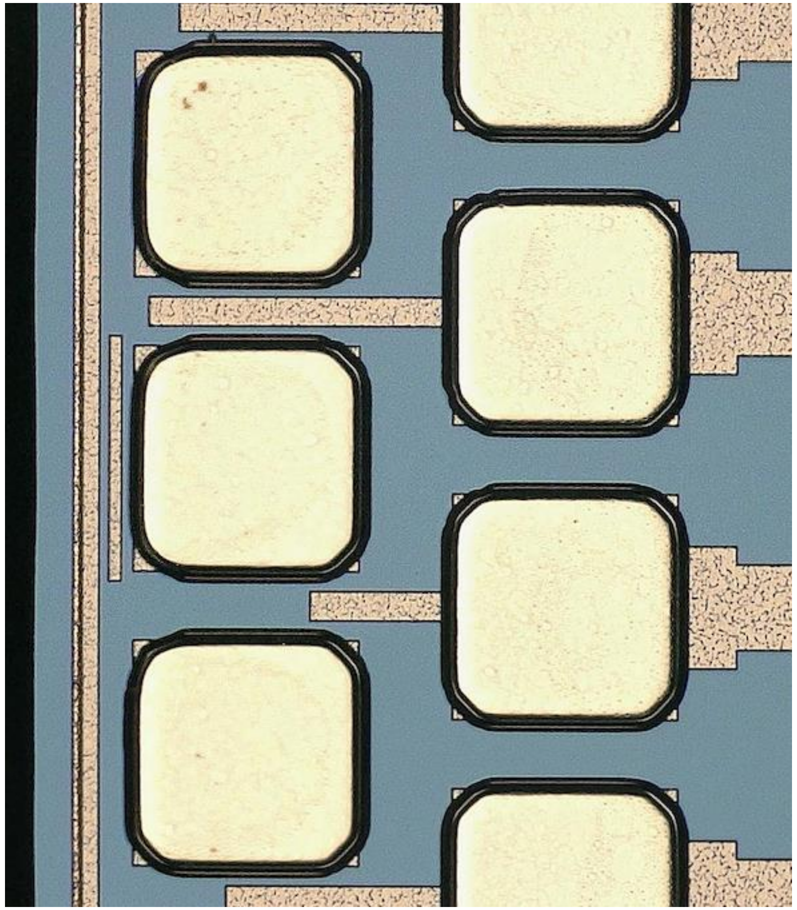




Bonding pads Timepix3

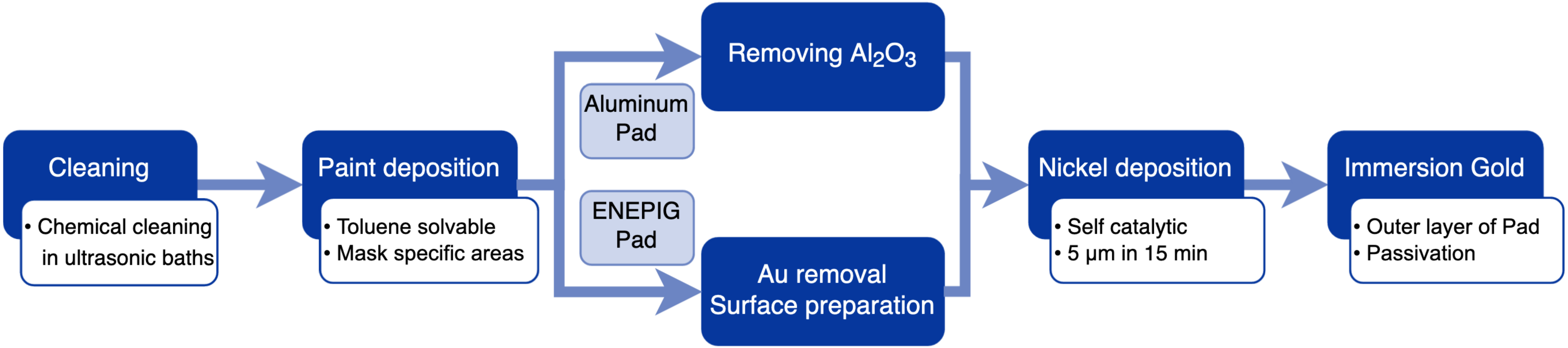


Timepix3



MALTA pads

Procedure



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ENEPIG Pad

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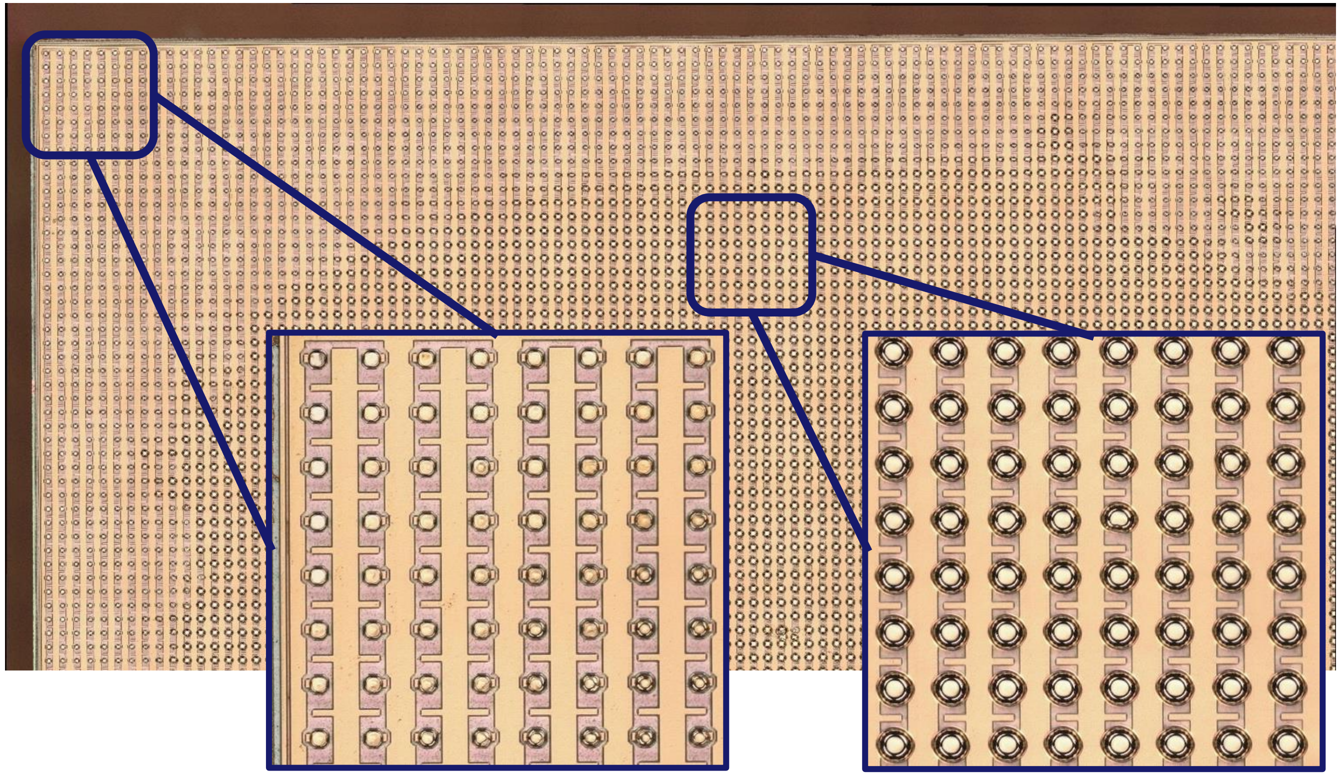
Immersion Gold
- Outer layer of Pad
- Passivation

UBM – in-house ENIG

Processing at Micro Pattern Technologies lab (CERN)

- The nickel deposition process is not yet fully optimized
  - Further investigation of nickel growth uniformity is needed
    - Possibly caused by insufficient sample wetting
  - Pads without previous UBM contain too much aluminium oxide, preventing nickel deposition
    - Mechanical polishing helped on larger pads



- Parts of cleaning steps seem to damage the protective paint
  - Liquids captured beneath cause deposition of nickel
  - Probably caused by acetone US bath