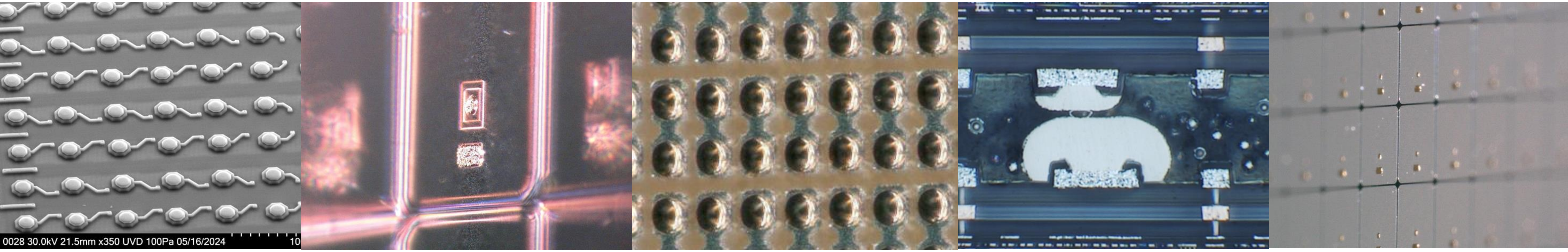
EP-DT
Detector Technologies

EP R&D

Pixel detector hybridization with ACA Anisotropic Conductive Adhesives



PIXEL 2024

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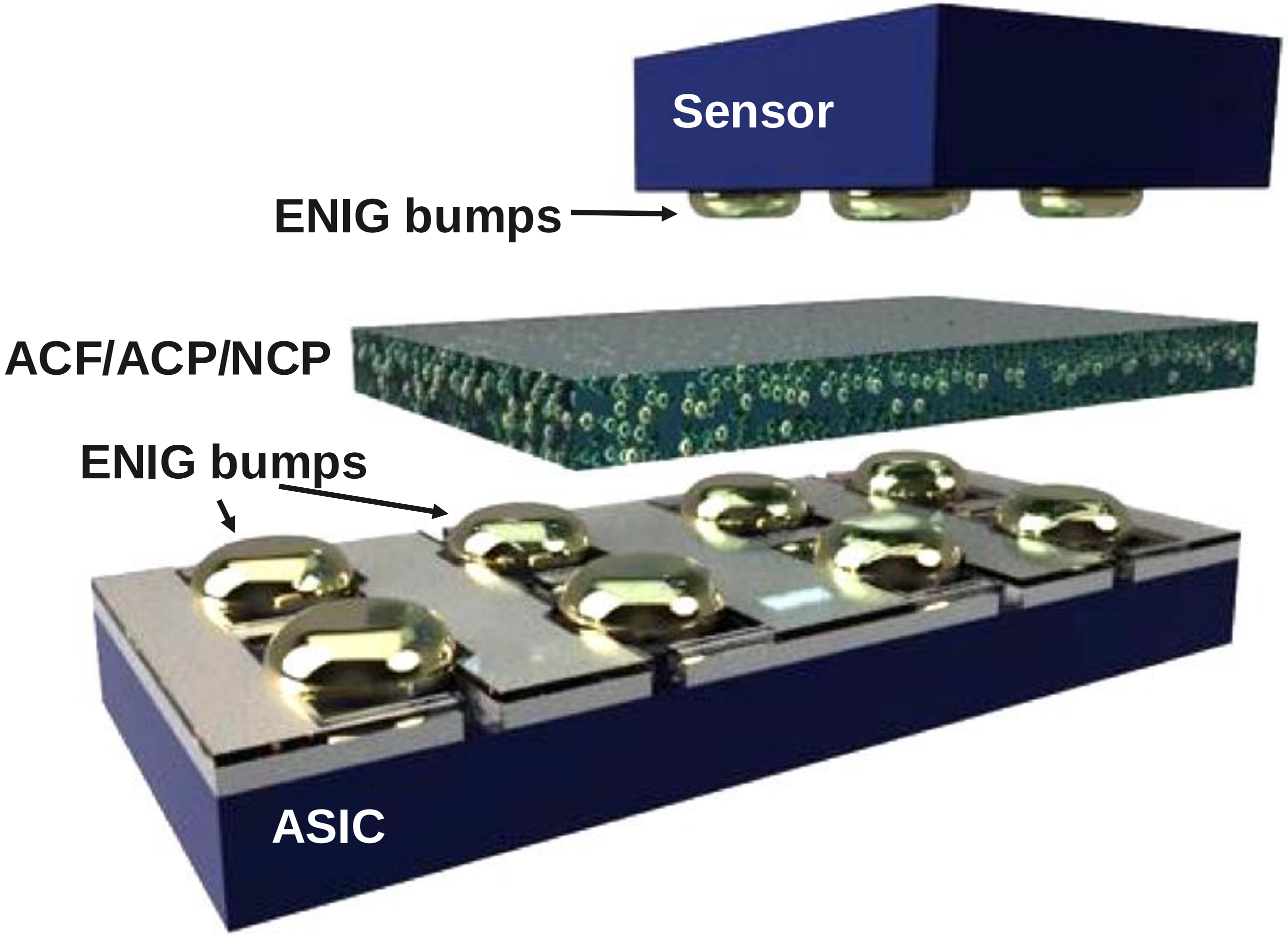
1: CERN 2: Hamburg University 3: LPNHE-Paris, Centre National de la Recherche Scientifique
4: Universite de Geneve 5: KIT - Karlsruhe Institute of Technology 6: FBK

Introduction

Development of an in-house module hybridization technique in two main steps:

1. Creation of bumps on the pads of Sensor and ASIC with ENIG plating
2. Flip-chip assembly with an anisotropic conductive layer or non-conductive layer between the chips



Advantages:

- Single die processing
- Adaptable to the application
- Low temperature process
- Maskless
- In-house (short turnaround time, quick adjustments)

- **ENIG: E**lectroless **N**ickel **I**mmersion **G**old
- **ACF: A**nisotropic **C**onductive **F**ilm
- **ACP: A**nisotropic **C**onductive **P**aste
- **NCP**: **N**on-**C**onductive **P**aste

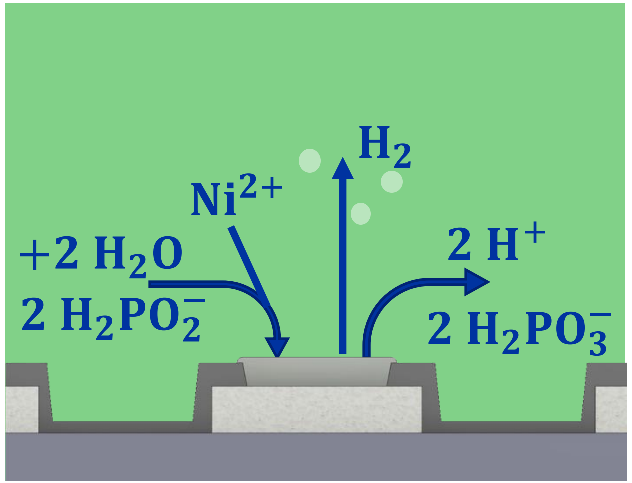
1) Creation of bumps on the pads of chips with ENIG plating

Introduction

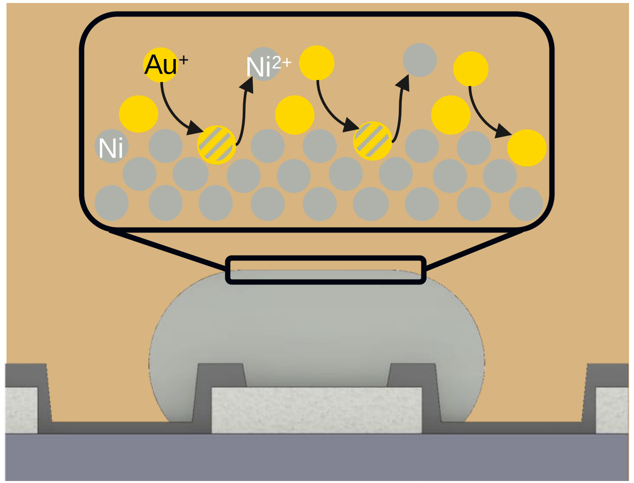
3 main steps for Electroless Nickel Immersion Gold (ENIG) plating:

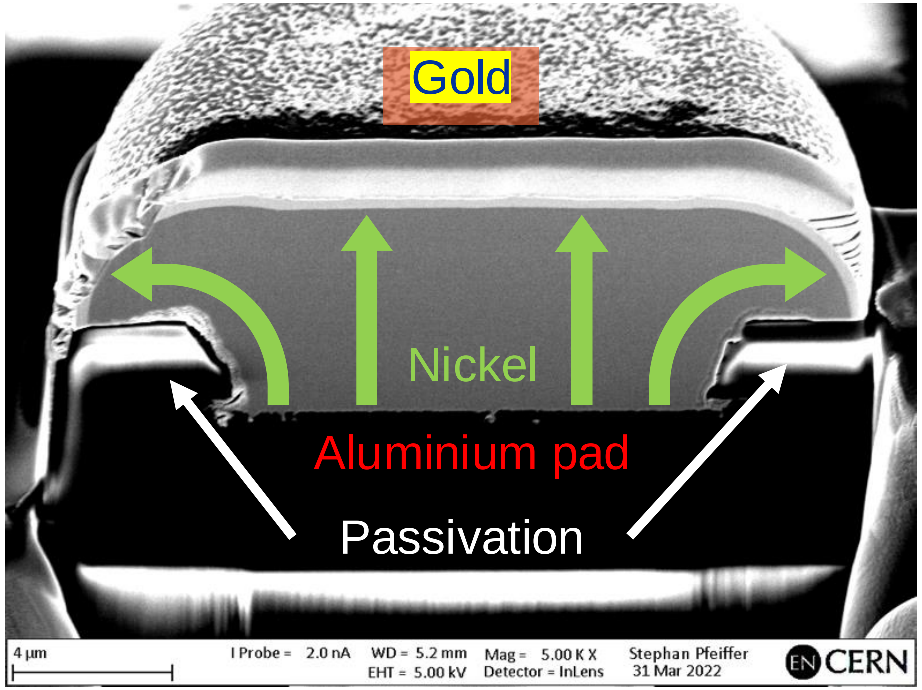
1. Pre-treatment and zincation of the aluminium pad
2. Electroless Nickel deposition (creation of the bump)
   - Self-catalytic reaction on pad surface, bump height controlled by immersion time
3. Immersion Gold
   - Corrosion protection, bondable surface, very thin layer (< 1 µm)

Electroless Nickel



Immersion Gold



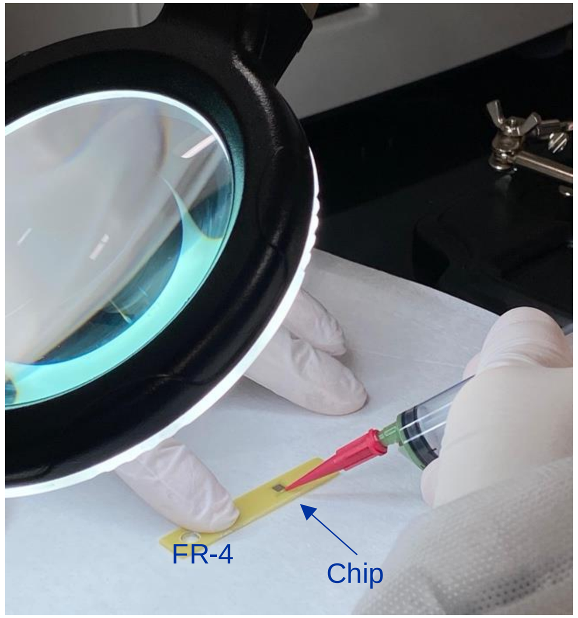


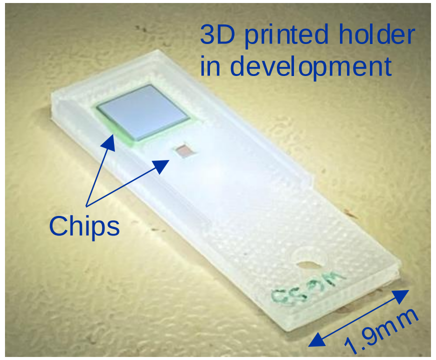
FIB cross-section of an ENIG bump on an aluminium pad

Sample preparation

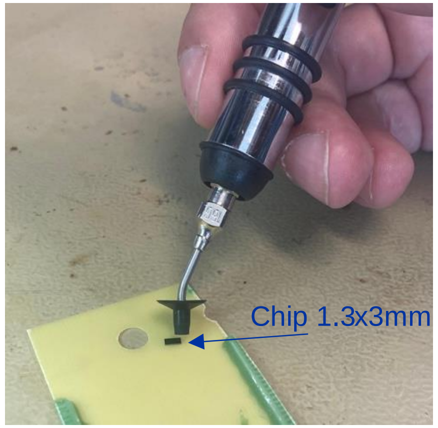
Samples preparation:

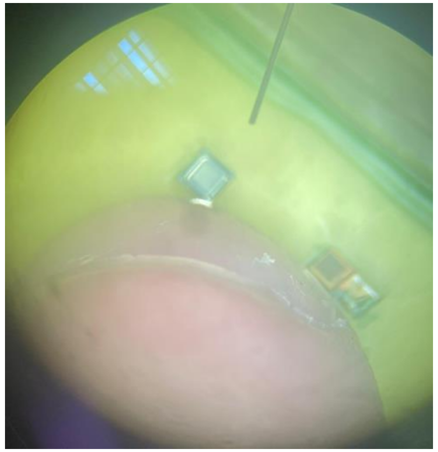
- Gluing the chip on holder
- Protection of bonding pads





Challenges for the preparation of small-sized chips (handling, gluing, protection of bonding pads)





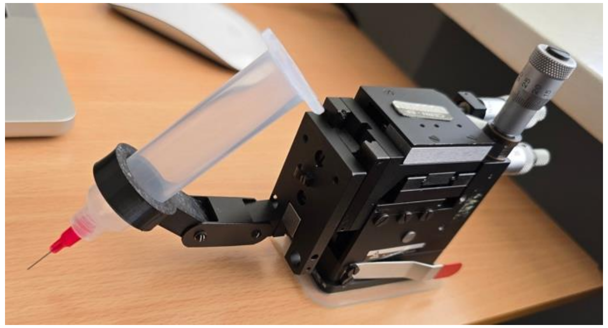
Development of a microdispenser


Probe station micromanipulator

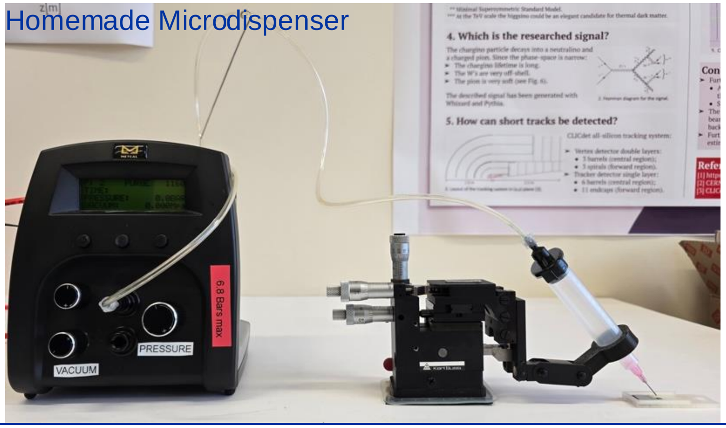
+

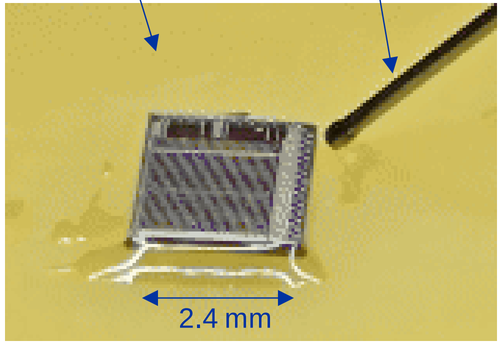
3D printed adaptor

=



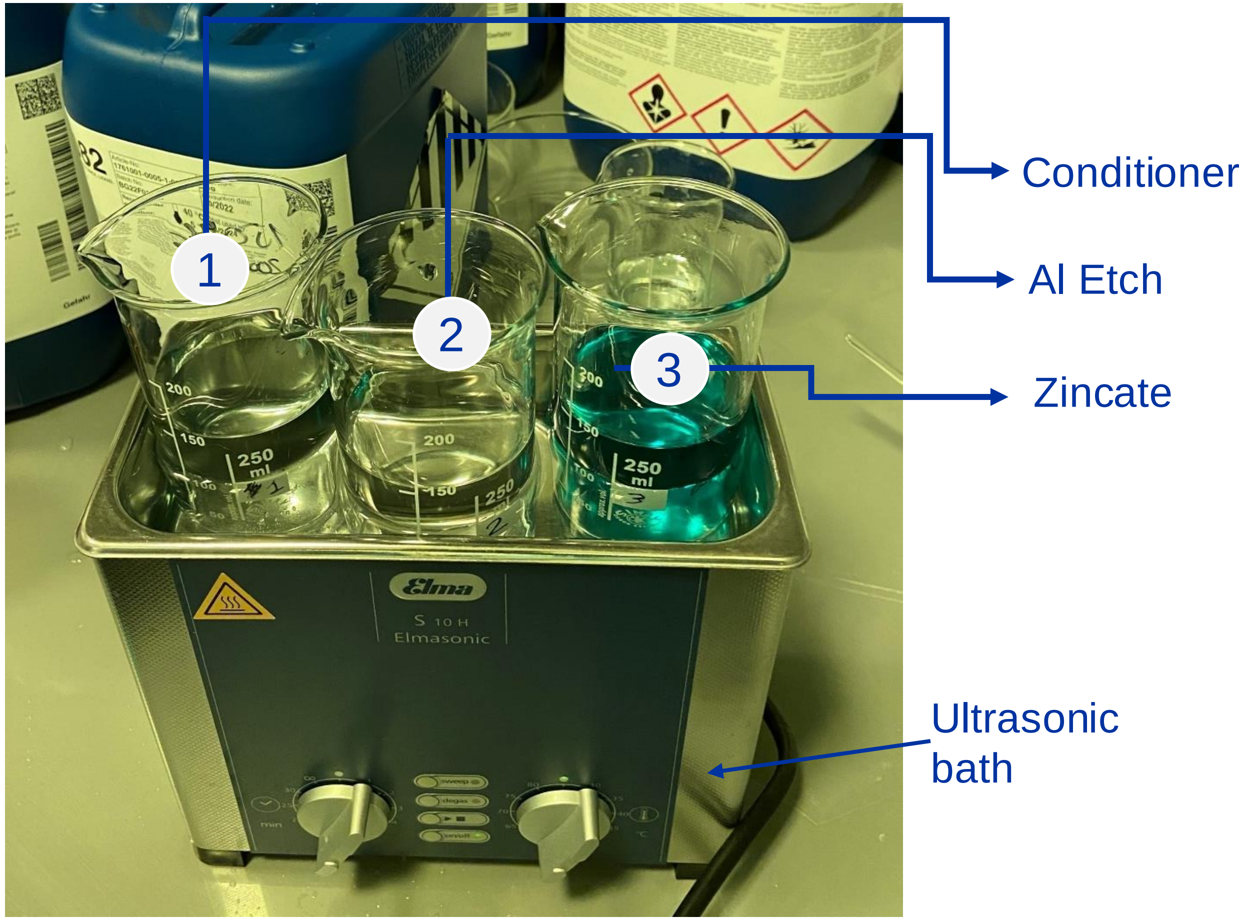
Homemade Microdispenser



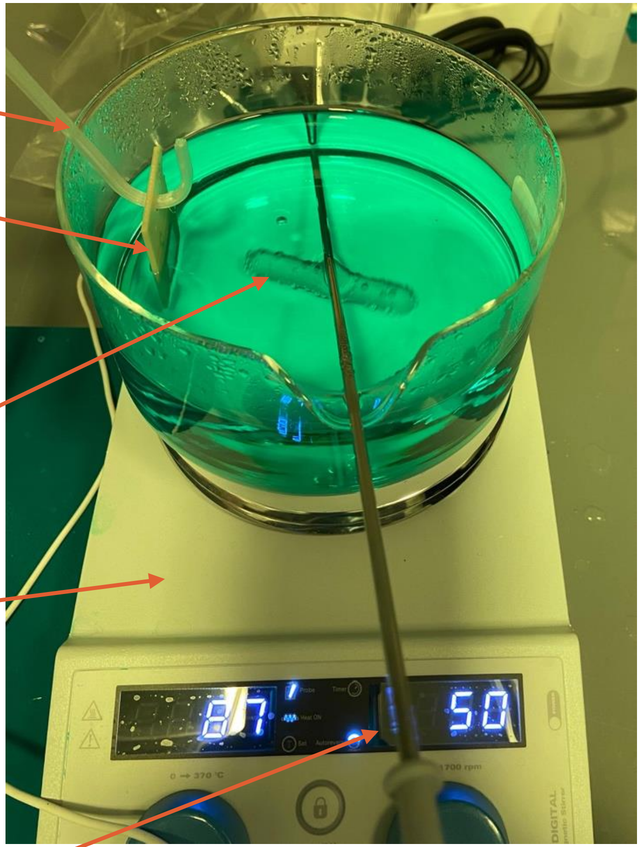


Pre-treatment setup

Pre-treatment: ultrasound + manual movements



Nickel Plating setup



Hook

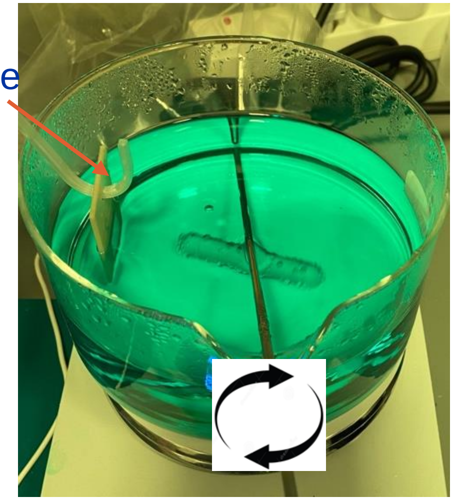
Sample

Stirring magnet

Hot plate

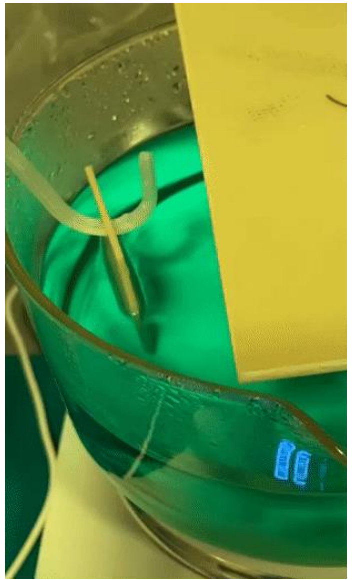
Temperature probe

Stirring optimisation



Sample

Swing movements



Bubbles removal from surface of chip

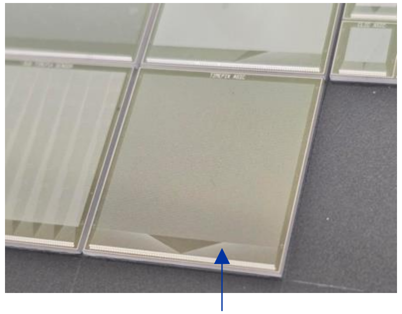
Frequent calibration

- pH metre
- Temperature probe
- Micropipette

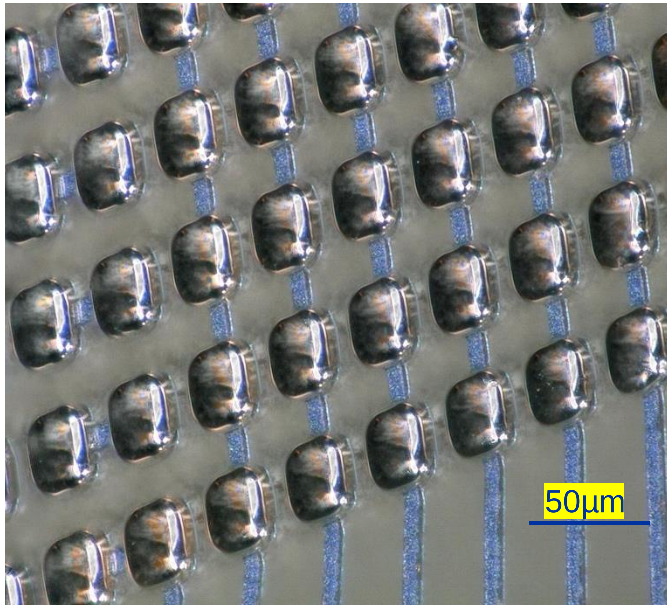
Avoiding cross-contaminations

ENIG plating results on test structures

Timepix3 type daisy-chain test structures, 22x22 µm pads and 55 µm pitch

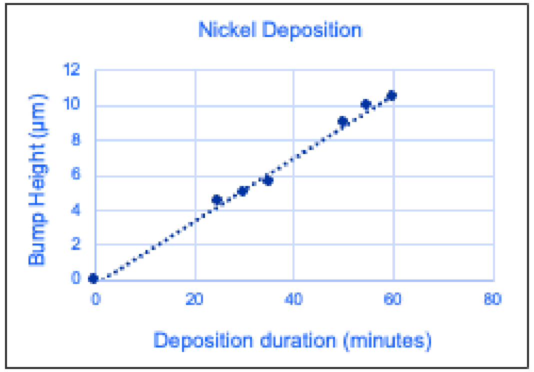


Timepix 3 type daisy-chain device test structure (14x14mm)



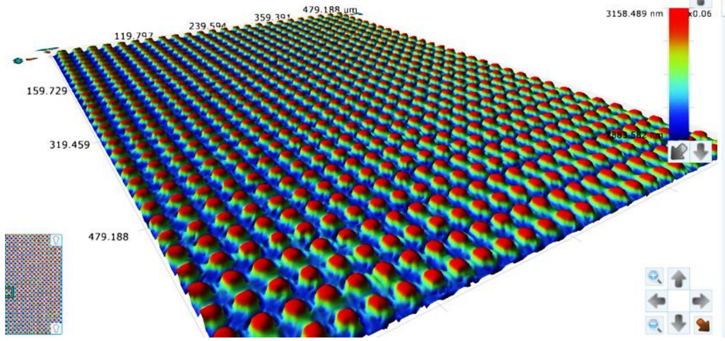
Excellent ENIG results:

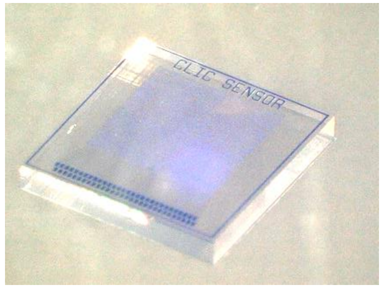
- Good bump homogeneity
- >99% of 65536 pads correctly plated
- Bumps height: 10 µm (± 0.5 µm) 55min deposition



Small pitch/small pads test structures, <u>20 µm pitch, 10x8 µm rectangular pad size</u> (High connection density)

Optical profilometry after ENIG plating





Small pitch/small pads test structures test structures (3.2x3.2mm)

Excellent ENIG results:

- Good bump homogeneity
- >99% of 16384 pads correctly plated
- Bumps height: 4.5 µm (± 0.2 µm) 25min deposition

ENIG plating results on functional chips

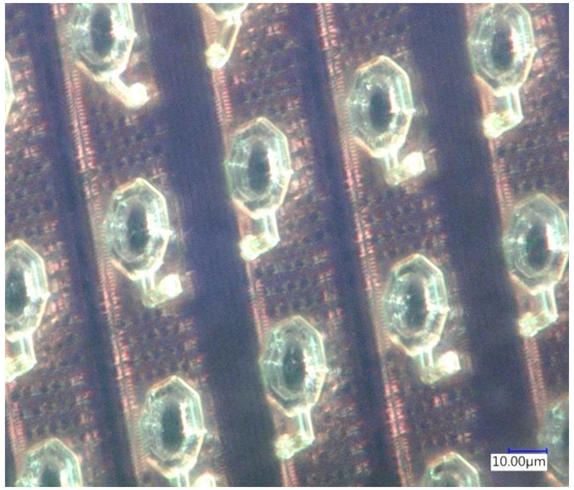
TimeSpot ASIC
Functional chip
55µm pitch, 19µm pads

Excellent ENIG results:

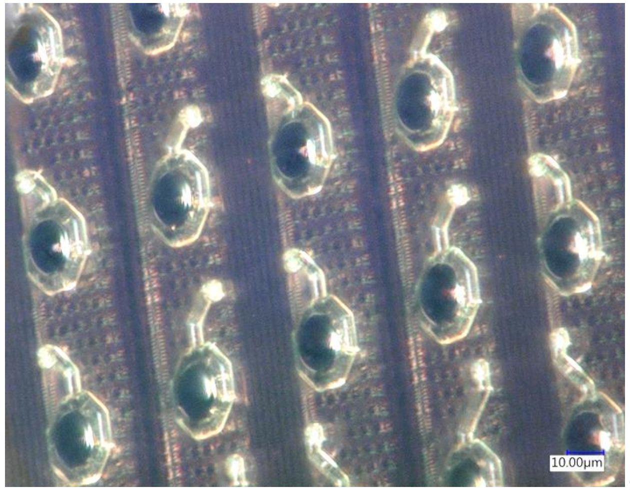
- 100% of pads correctly plated (1184 pads)
- Pads height: 10 µm (+/-0.5 µm) 1h deposition

Collaboration with INFN Cagliari (Angelo LOI, Adriano LAI)
https://web.infn.it/timespot/

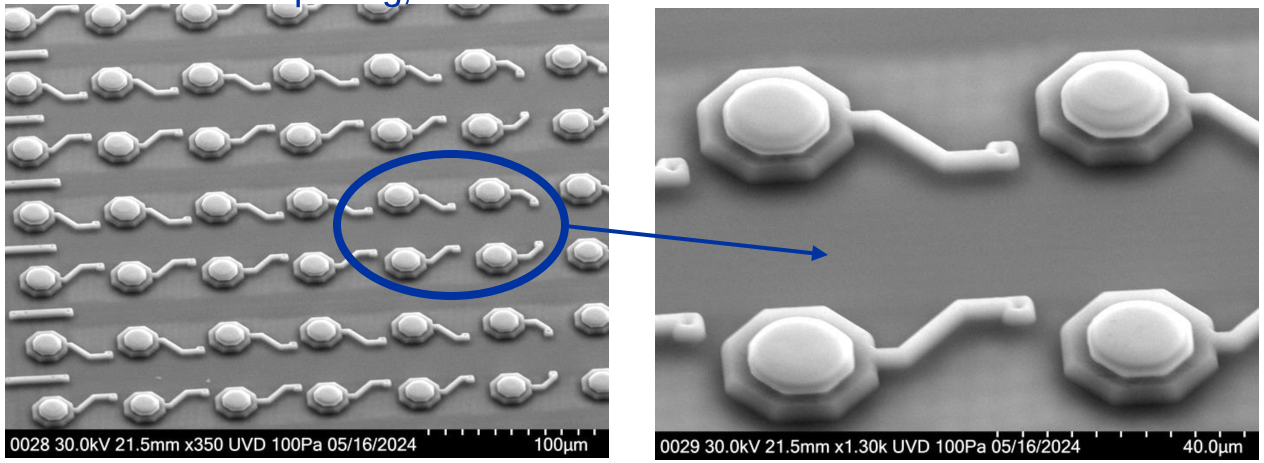
Before plating, optical microscope



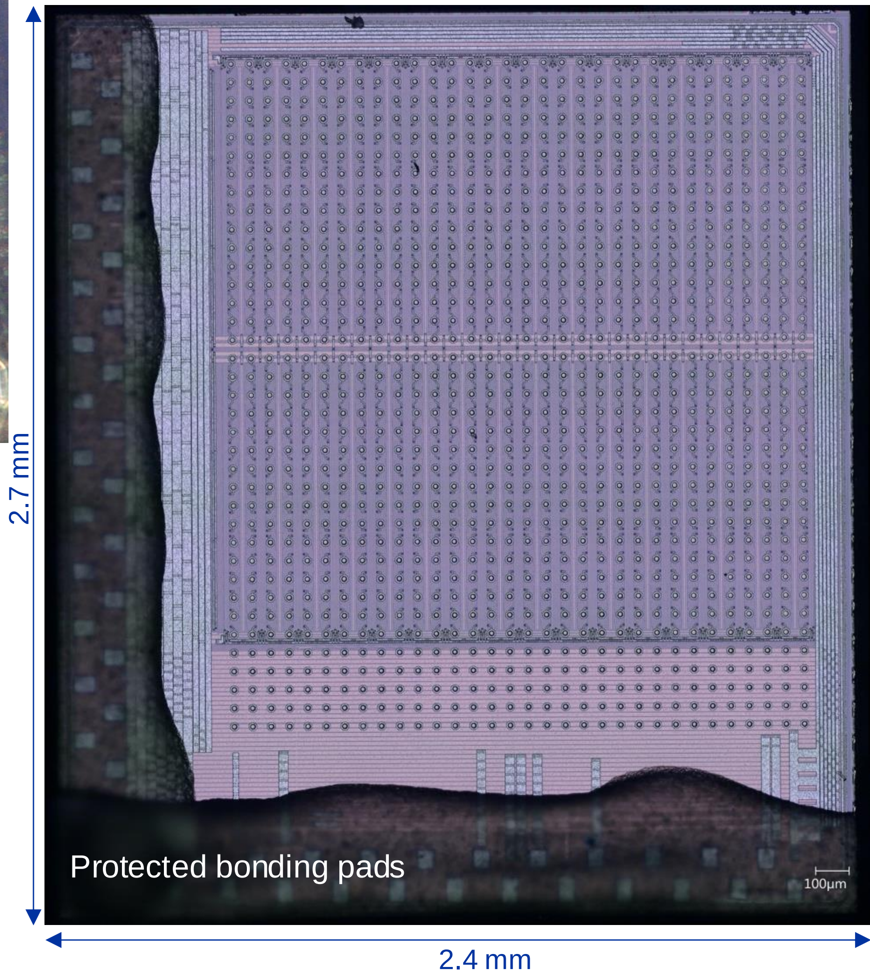
After 1h plating, optical microscope



After plating, SEM



TimeSpot ASIC



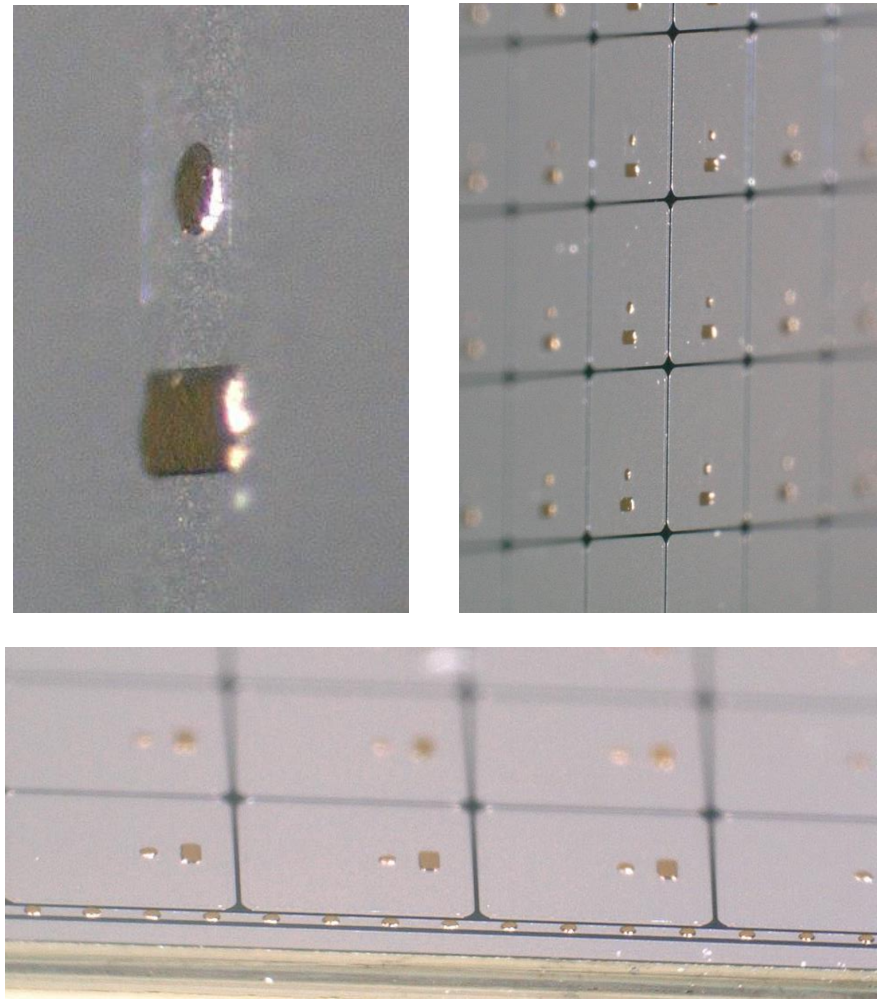
ENIG plating results on functional chips

ATLAS HGTD
LGAD sensors
Functional chips
1.3mm pitch, 90 µm diameter pads

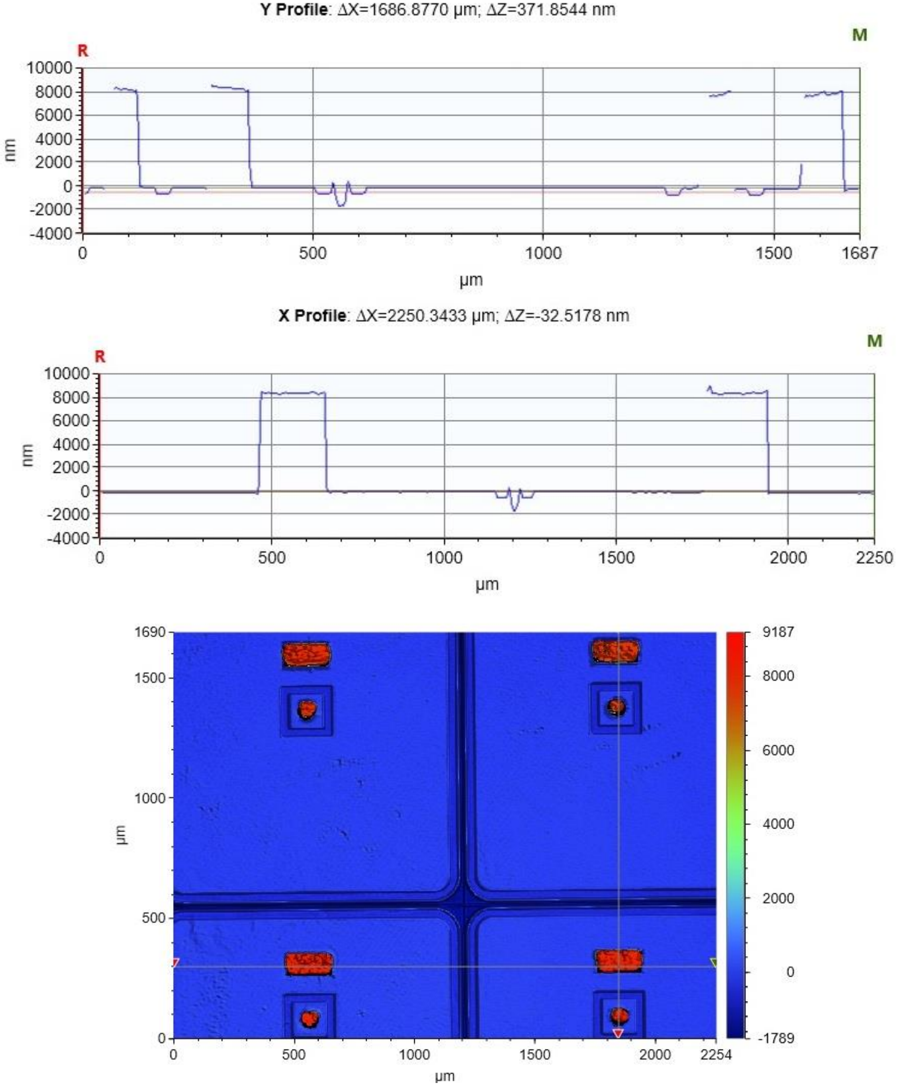
Good ENIG results:

- Homogeneity of bumps achieved with no overplating
- No skipped pads
- Bumps height: 8.5 µm (± 0.7 µm) (1h deposition)

Optical microscope, 62° tilt



Optical profilometry after ENIG plating



ENIG plating results on functional chips

KEK AC-LGAD
Sensors and ASICs

Functional chips
100 µm pitch, 40 µm diameter pads

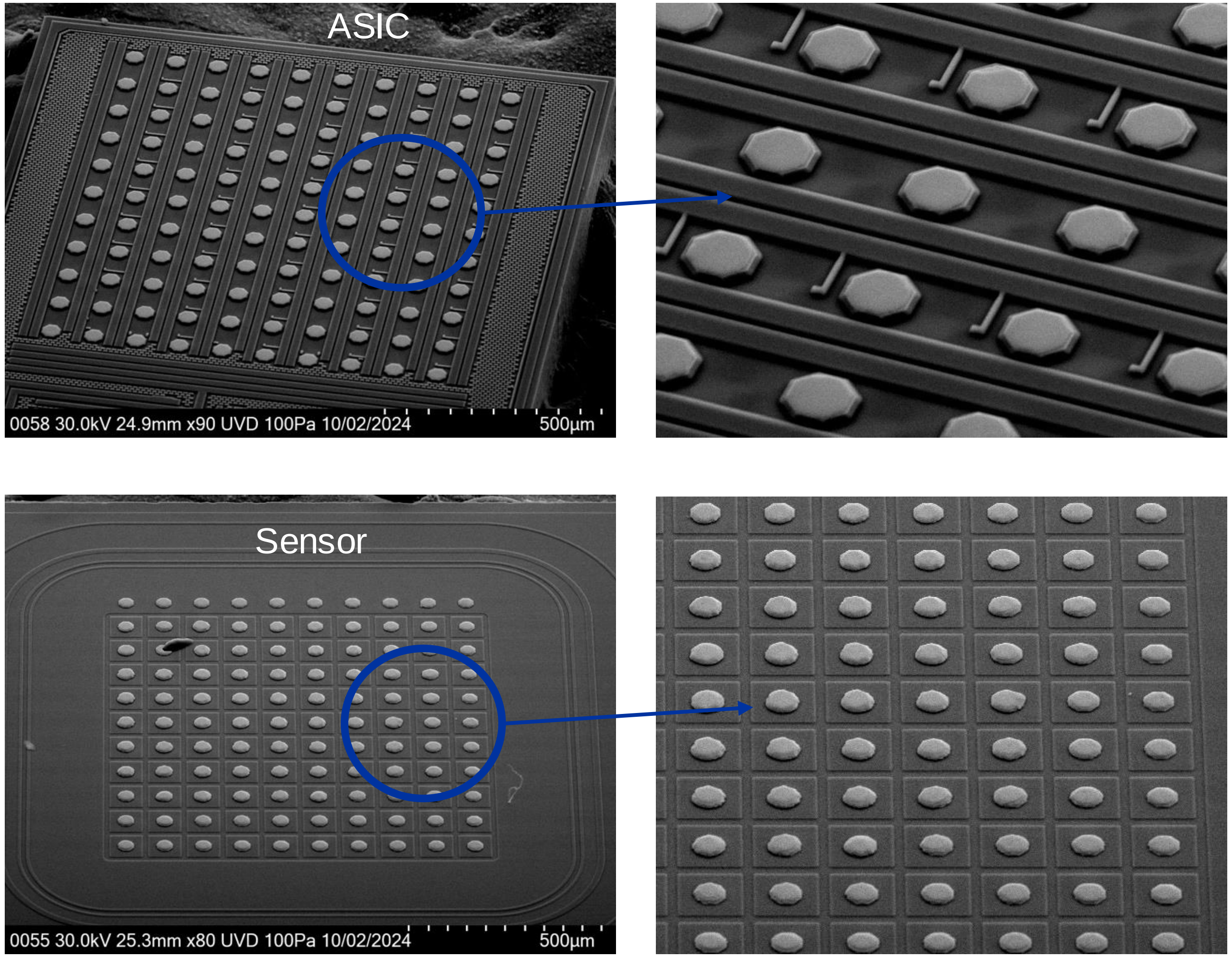
Good ENIG results:

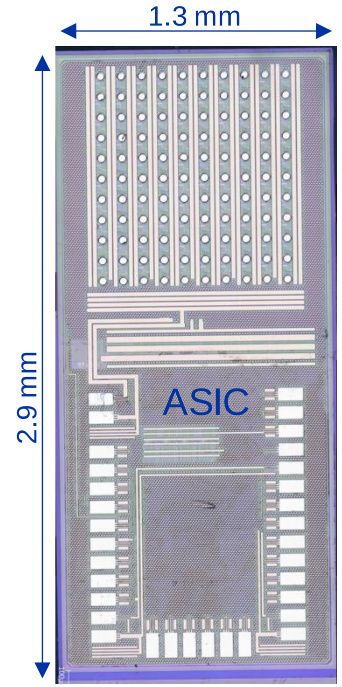
- Homogeneity of bumps achieved with no overplating
- No skipped pads
- Bumps height: 8.5 µm (± 0.6 µm)

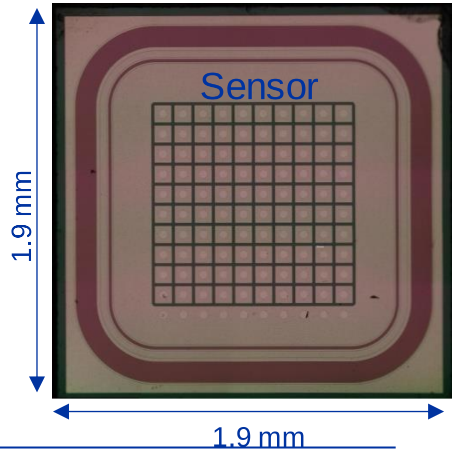
Collaboration with KEK (Koji NAKAMURA) and University of Geneva (Lorenzo PAOLOZZI)

Tomoka Imamura, Sayuka Kita, Koji Nakamura, and Kazuhiko Hara, “Development of HPK Capacitive Coupled LGAD (AC-LGAD) detectors”, PoS, vol. VERTEX2023, pp. 032, 2024

After plating, SEM







ENIG plating results on functional chips

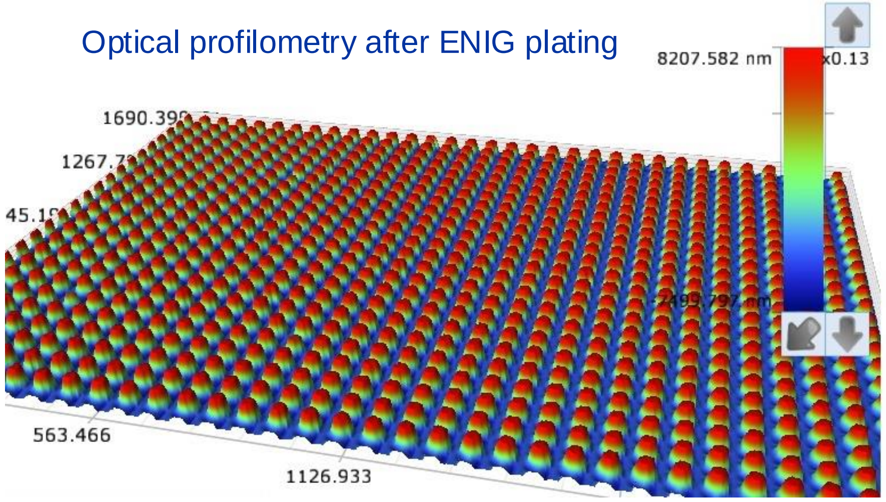
ColorPix2 Functional chips 70 µm pitch, 40 µm pads

Good ENIG results:

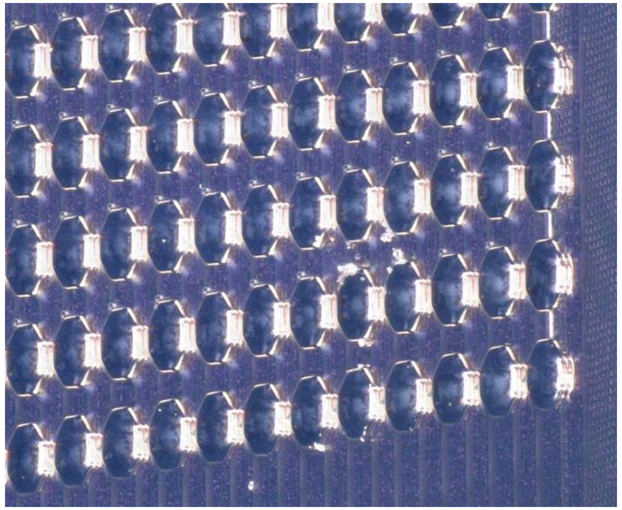
- Homogeneity of bumps achieved with no overplating
- No skipped pads
- Bumps height: 11 µm (± 0.5 µm) 1h deposition

“Color imaging of Xrays”, FNSPE CTU in Prague https://indico.cern.ch/event/829863/contributions/5053901/attachments/2567463/4426692/PIXEL2022_poster.pdf

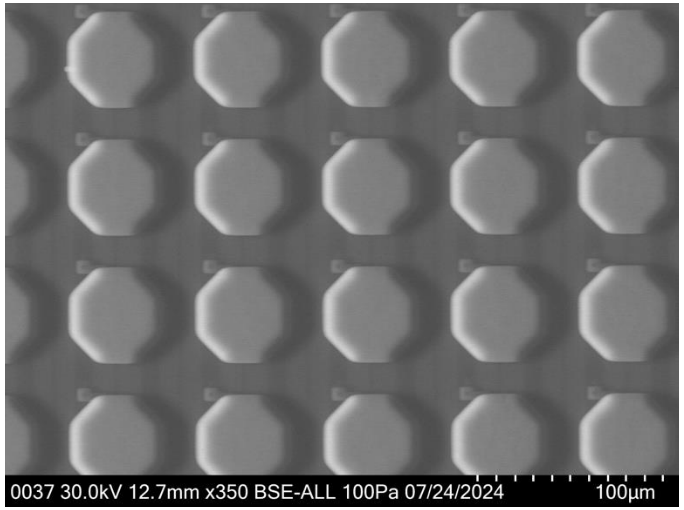
Optical profilometry after ENIG plating



Optical microscope, 61° tilt



After plating, SEM



Optical microscopy after ENIG plating

Conclusion for ENIG plating

Optimised ENIG plating:

- Reproducibility
- Almost no skipped pads
- No overplating
- Uniformity (even at the edge of the chips)

Tested on different configurations:

- High pad density (20 µm pitch) and small pads (10 µm)
- Low pad density (1.3 mm pitch) and large pads (90 µm)
- Successful plating of functional chips TimeSpot, ColorPix, KEK AC-LGAD ASICs and sensors, and LGAD sensors for ALTIROC3

	Pad size	Pitch	ENIG height	Chip size
"Timepix3" daisy-chain test structures	12-22 µm	55 µm	10 µm	14x14 mm
"Small pitch" daisy-chain test structures	10x8 µm^2 (rectangular)	20 µm	4.5 µm	3.2x3.2 mm
TimeSpot ASIC	19 µm	55 µm	10 µm	2.4x2.7 mm
ATLAS HGTD LGAD sensors	90 µm	1.3 mm	8.5 µm	20x22 mm
KEK AC-LGAD Sensor and ASIC	40 µm	100 µm	8.5 µm	ASIC 1.3x2.9 mm Sensor 1.9x1.9 mm
ColorPix2	40 µm	70 µm	11 µm	3x4.9 mm

2) Flip-chip assembly

Bonding with Anisotropic Conductive Adhesive (ACA)

Bonding done at Geneva University using semi-automatic flip-chip bonder

- Precise temperature, pressure and alignment control
- Heating up to 400℃ and force applied up to 100 kgf
- Available for bonding with **A**nisotropic **C**onductive and **N**on-conductive **F**ilm/**P**aste – **ACF/ACP** or **NCF/NCP**

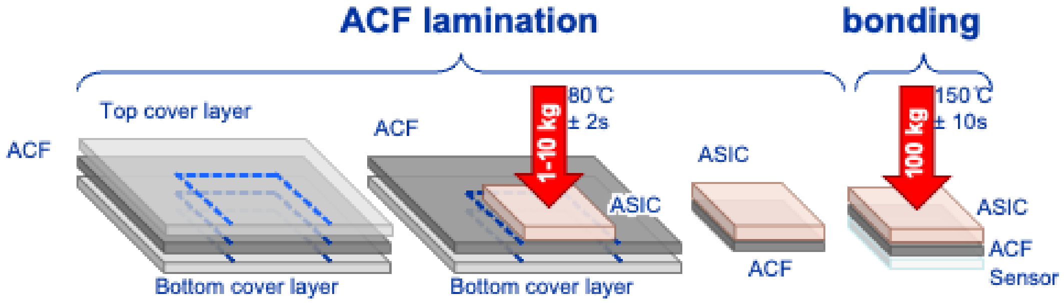
UNIVERSITÉ
DE GENÈVE
FACULTÈ DES SCIENCES

Collaboration with Mateus Vicente


Flip-chip bonder SET ACCµRA100

ACF bonding has two steps: lamination and bonding

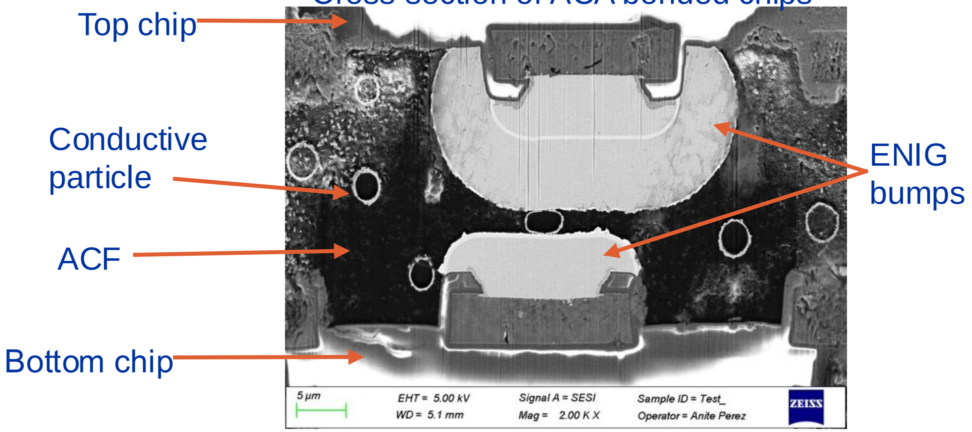
- ACF lamination at 80°C, ≈ 5 kg/cm2
- Bonding at 150°C, ≈ 50 kg/cm2



ACP bonding has three steps:

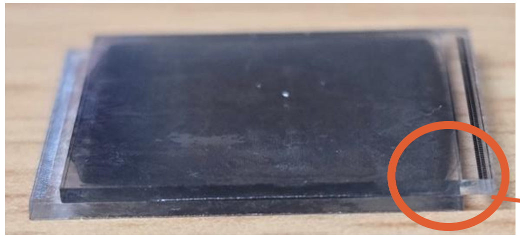
- Mixing the micro-particles with the liquid adhesive
- Dispensing the mix on the bottom chip
- Flip-chip bonding

Cross-section of ACA bonded chips

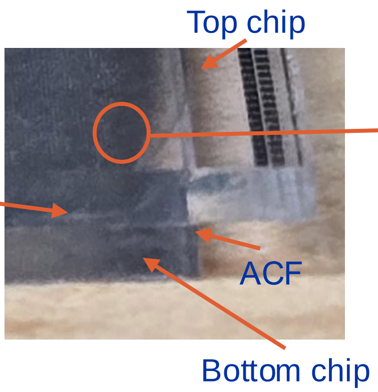


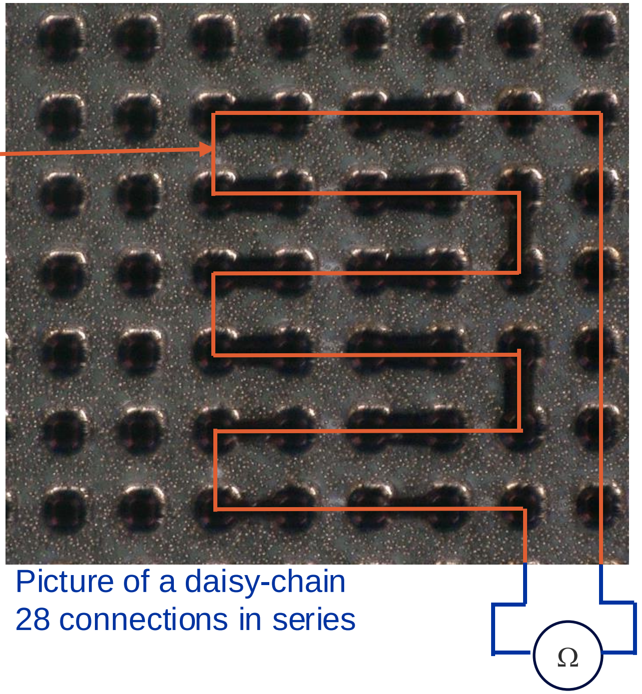
Characterisation of daisy-chain test structures

ACF bonding

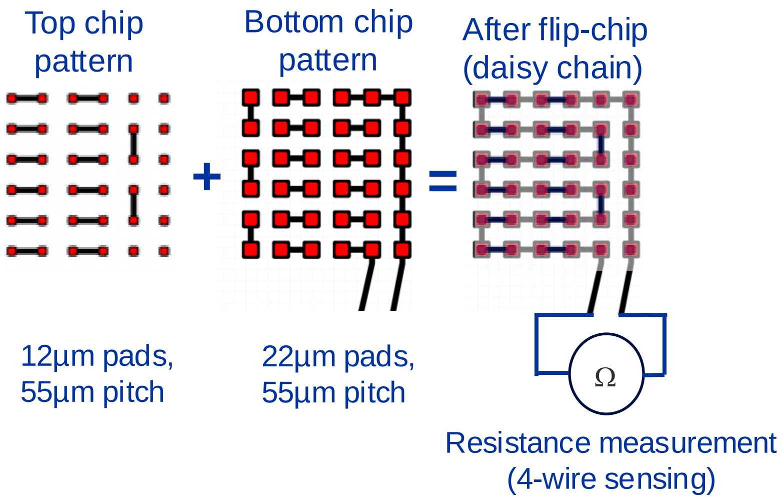


Timepix3 type daisy-chain test chips, flip-chip bonded with 18 µm ACF (3 µm particles)





Picture of a daisy-chain
28 connections in series



Top chip pattern

Bottom chip pattern

After flip-chip (daisy chain)

12µm pads,
55µm pitch

22µm pads,
55µm pitch

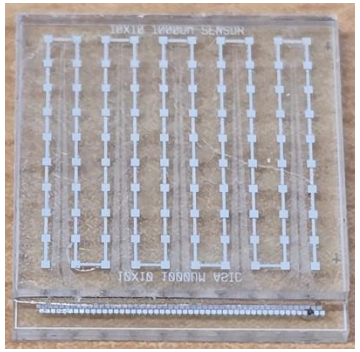
Resistance measurement
(4-wire sensing)

After flip-chip bonding
- ≈ 96 % of pads connected

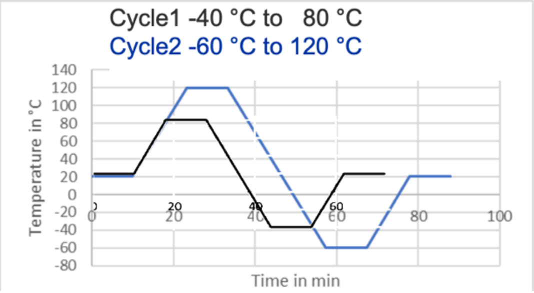
After thermal cycling (25 cycles from -55°C to 60°C, 10°C/min):
- ≈ 95 % of pads still connected

ACP bonding

Daisy-chain test chips with 10x10 connections, 300 µm pads, 1 mm pitch, flip-chip bonded with ACP (20 µm Ag particles)



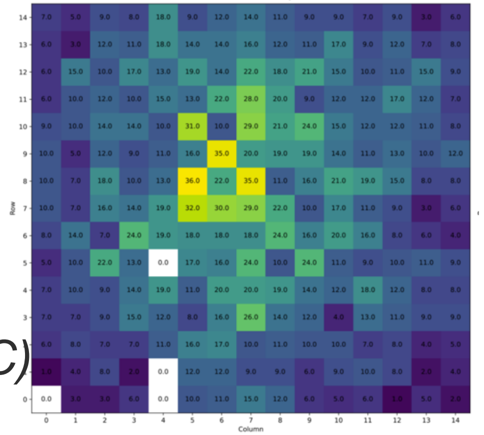
- 97.1 % of pads connected
- After thermal cycling (20 cycles from -40°C to 80°C): 94.5 % pads still connected
- After thermal cycling (20 cycles from -60°C to 120°C): 91.7 % pads still connected



Hybridisation and characterisation of functional chips

ALTIROC2/3

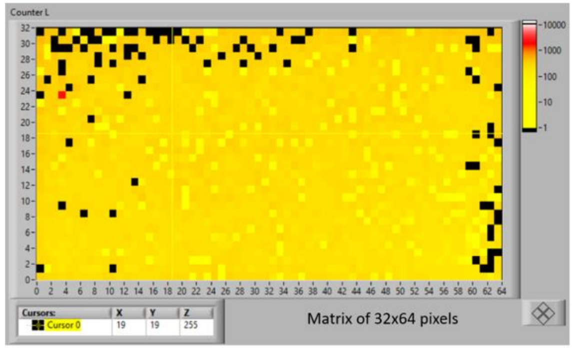
- 15x15 pixels, 1300 µm pitch
- <u>LGAD sensor</u>
    - ACP with 10 µm particles
    - 98.2% yield
    - *Tested by A. Wang (USTC)*



ALTIROC2 response

SPHIRD

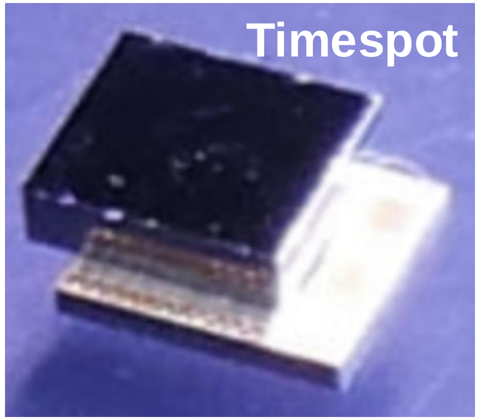
- 32x64 pixels, 50 µm pitch
- <u>Si planar sensor</u>
    - ACF 14 µm thick
    - 85% yield
      (+7% weak response)
    - *Tested by M. Ruat (ESRF)*



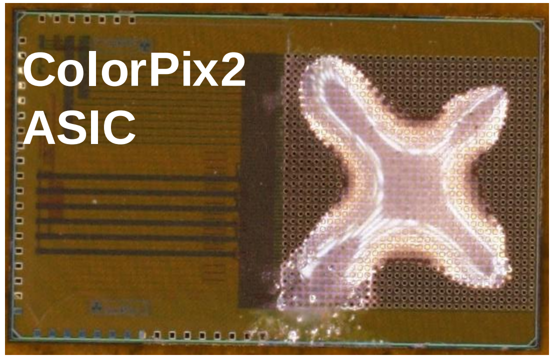
SPHIRD Si response

Timespot

- 32x32 pixels, 55 µm pitch
- <u>Si 3D trench sensor</u>
    - ACF 18 µm thick
    - 85% yield
    - *Provided by A. Loi (INFN)*



ColorPix2



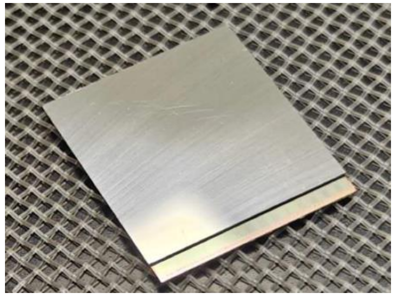
- 32x32 pixels, 70 µm pitch
- <u>CZT sensor 1.8 mm thick</u>
    - NCP
    - around 70% yield
    - *Tested by J. Jirsa (FNSPE CTU)*

Gold-stud hybridisation of ALTIROC3/A and LGAD sensors

- Using ALTIROC3/A ASICs and LGAD sensors from ATLAS High-Granularity Timing Detector (HGTD) to develop new in-house bonding process for sensor and ASIC qualification
- Single and stacked double gold studs used for the connections between the chips, epoxy underfill for bonding
- Used for radiation-hardness qualification of LGAD sensors
- Low temperature process (60°C) to avoid uncontrolled annealing

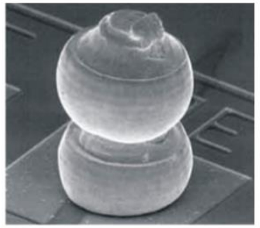
Process tested with un-irradiated and irradiated sensors, excellent interconnect yield achieved for both single and double gold studs. Impact of thermal cycling on interconnects to be studied.

ALTIROC/LGAD Hybrid



Gold stud

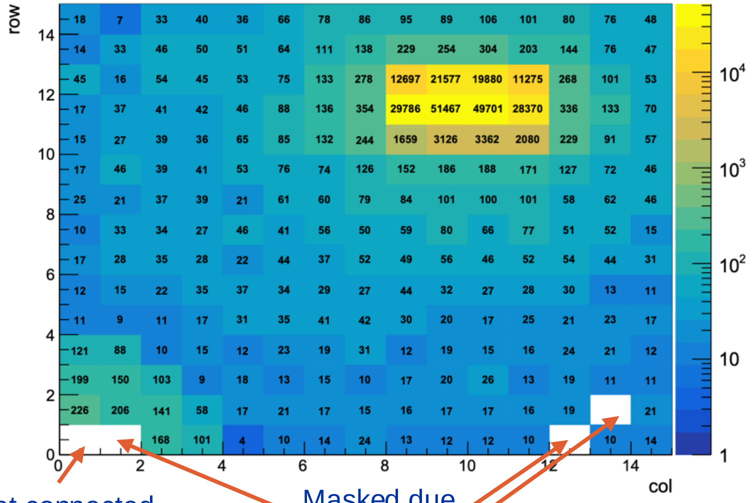
Stacked Gold studs



Pictures from Hybrid SA

Preferred this solution to increase the gap between ASIC and sensor from 20 µm to 35 µm and thereby decrease coupling between them

Test-beam occupancy map of ALTIROC with double gold studs + irradiated LGAD sensor



18	7	33	40	36	66	78	86	95	89	106	101	80	76	48
14	33	46	50	51	64	111	138	229	254	304	203	144	76	47
45	16	54	45	53	75	133	278	12697	21577	19880	11275	268	101	53
17	37	41	42	46	88	136	354	29786	51467	49701	28370	336	133	70
15	27	39	36	65	85	132	244	1659	3126	3362	2080	229	91	57
17	46	39	41	53	76	74	126	152	186	188	171	127	72	46
25	21	37	39	21	61	60	79	84	101	100	101	58	62	46
10	33	34	27	46	41	56	50	59	80	66	77	51	52	15
17	28	35	28	22	44	37	52	49	56	46	52	54	44	31
12	15	22	35	37	34	29	27	44	32	27	28	30	13	11
11	9	11	17	31	35	41	42	30	20	17	25	21	23	17
121	88	10	15	12	23	19	31	12	19	15	16	24	21	12
199	150	103	9	18	13	15	10	17	20	26	13	19	11	11
226	206	141	58	17	21	17	15	16	17	17	16	19		21
		168	101	4	10	14	24	13	12	12	10		10	14

Not connected
by design

Masked due
to high noise

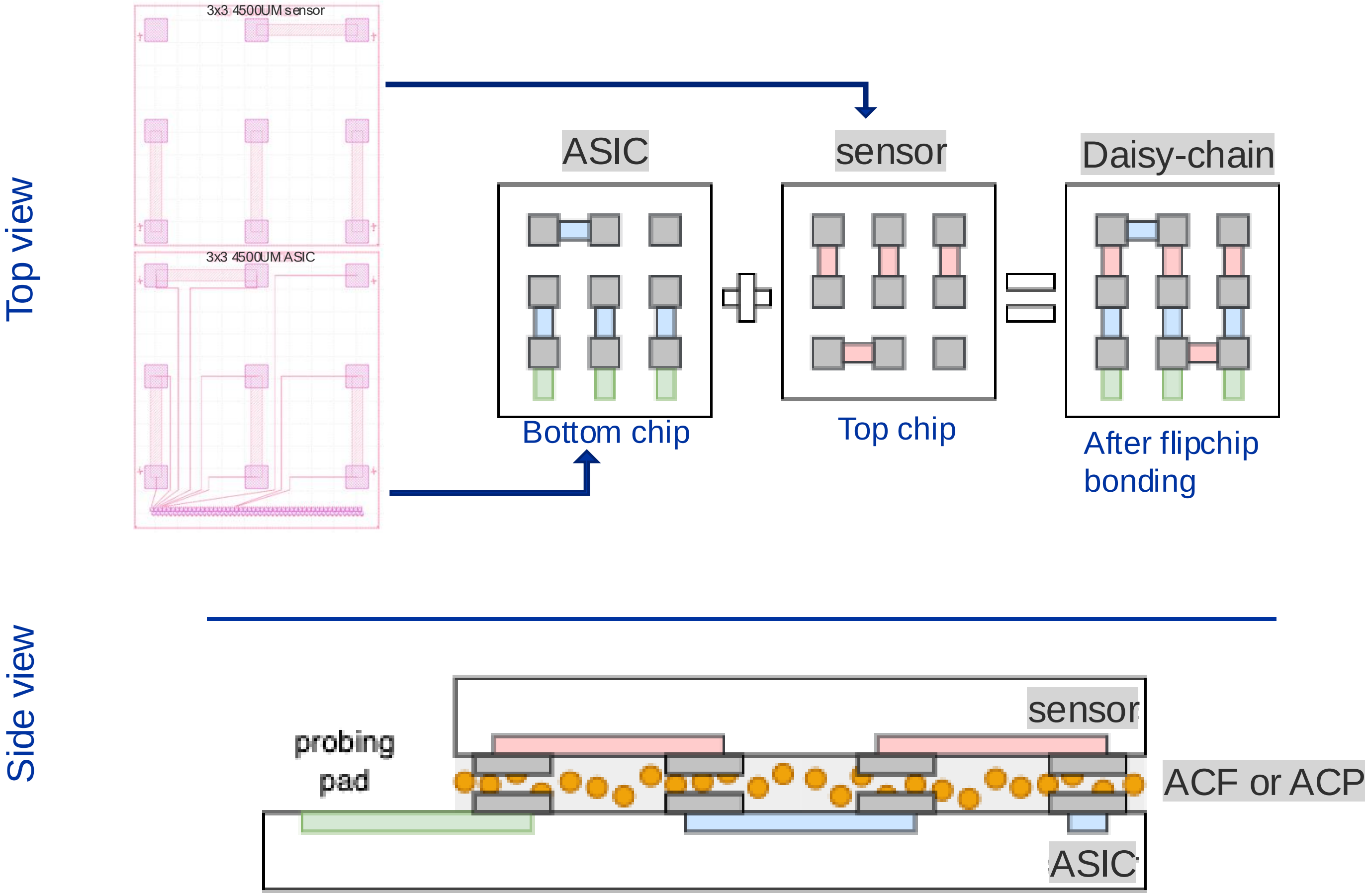
Confirmation of good inter-connection with occupancy map (≈ 100%)

Gold-stud hybridisation process suitable for large pitch (>100µm), large pads (>80µm) chips

Conclusion

- **Optimised ENIG plating tested on many different configurations**
  - Dummy test chips, functional chips, with different pad size, pitch, chip size…
- **Different approaches studied for hybridisation**
  - ACF, ACP, NCP, Gold Studs
- **Successful flipchip bonding of different chips with different sizes**
  - Optimisation of bonding parameters (pressure, time, temperature)
- **Reliability tests in climate chamber (ongoing)**
  - Good results for both the ACF and the ACP

Test dedicated daisy-chain chips on glass wafer



Daisy chain devices produced at FBK

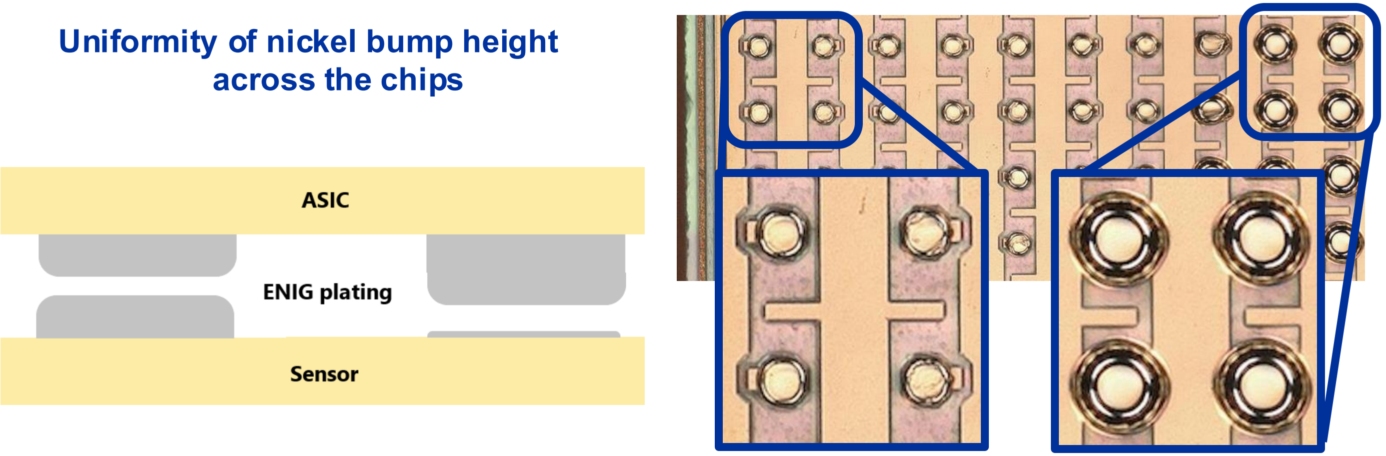
Designed to validate interconnect yield, electrical resistance, thermo-mechanical stress

- 6” glass wafers, 625 µm thick
- Varying Bonding area, pad size and pitch, matching different target applications

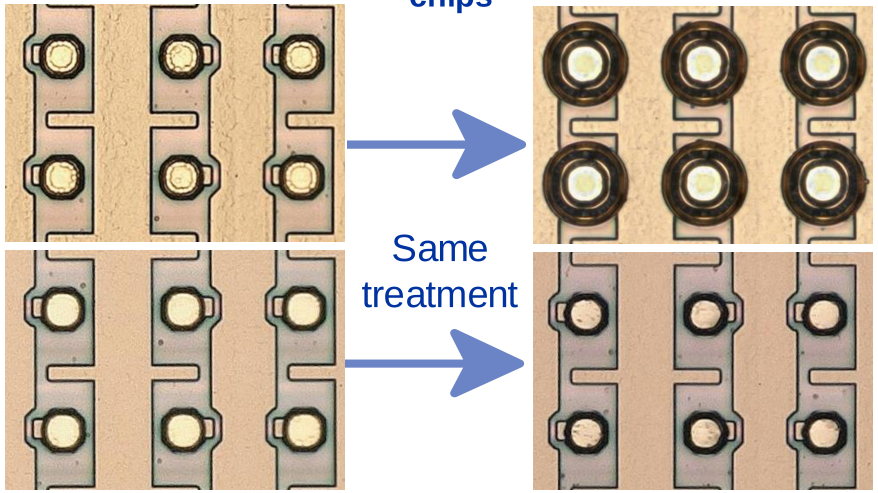
https://zenodo.org/records/7310324

Challenges of initial platings

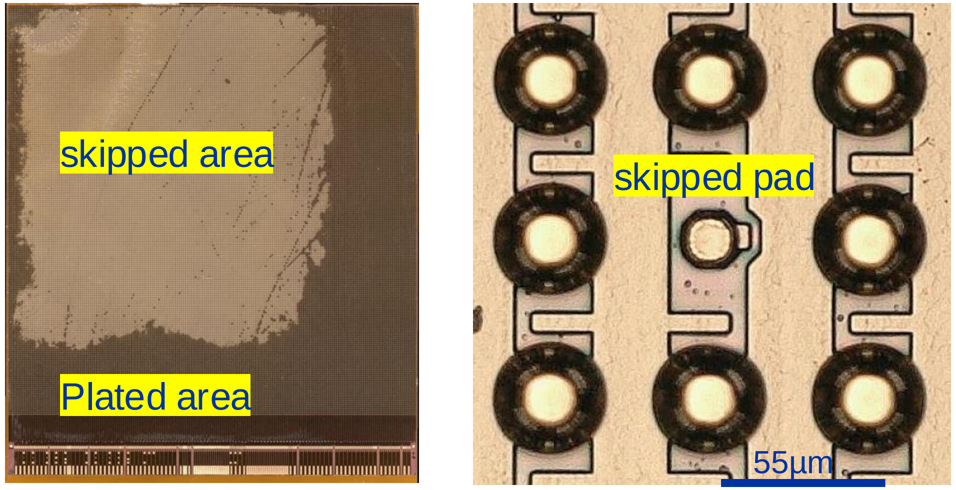
Uniformity of nickel bump height across the chips



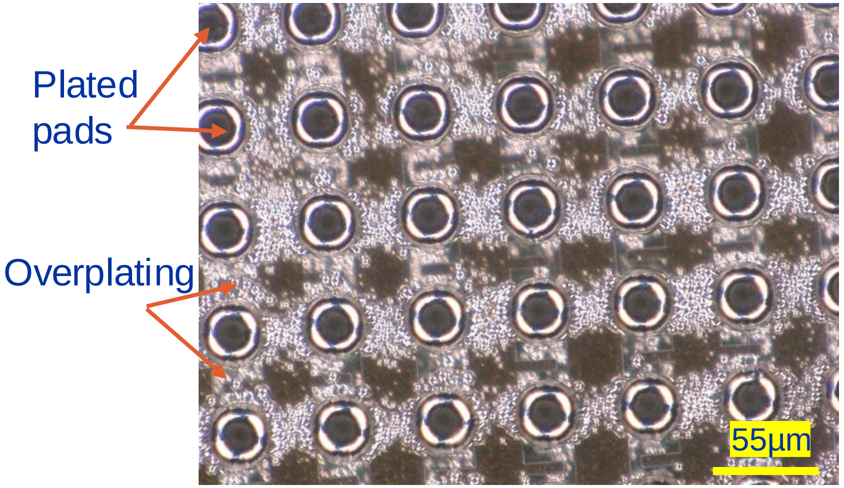
Deposition reproducibility on different chips



Non-plated or skipped pads/areas



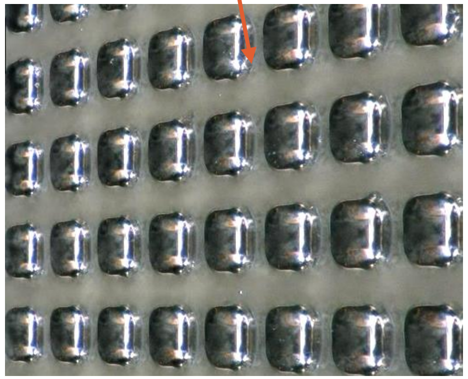
Overplating (plating on areas that should not be plated)



ENIG plating on high connection density chips (ex: CLICpix2, 12µm pads; 25µm pitch) !!

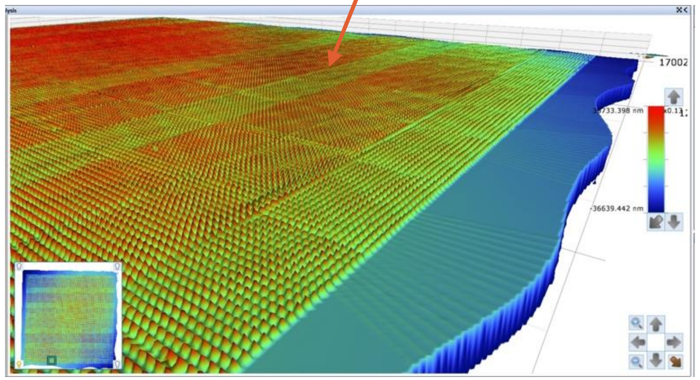
Characterisation of ENIG plating

Keyence optical microscope



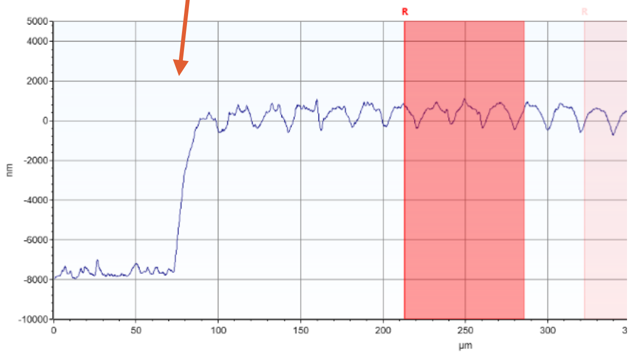
Optical profilometer

Bruker Contour



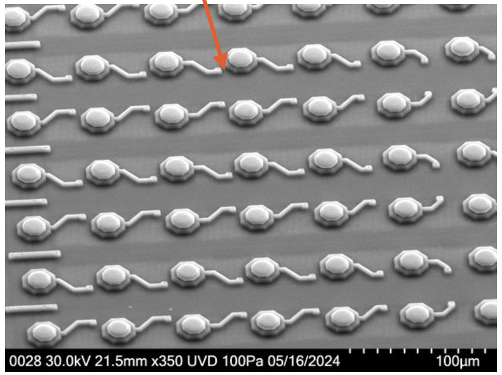
Mechanical profilometer

Bruker Dektat XT Stylus



SEM

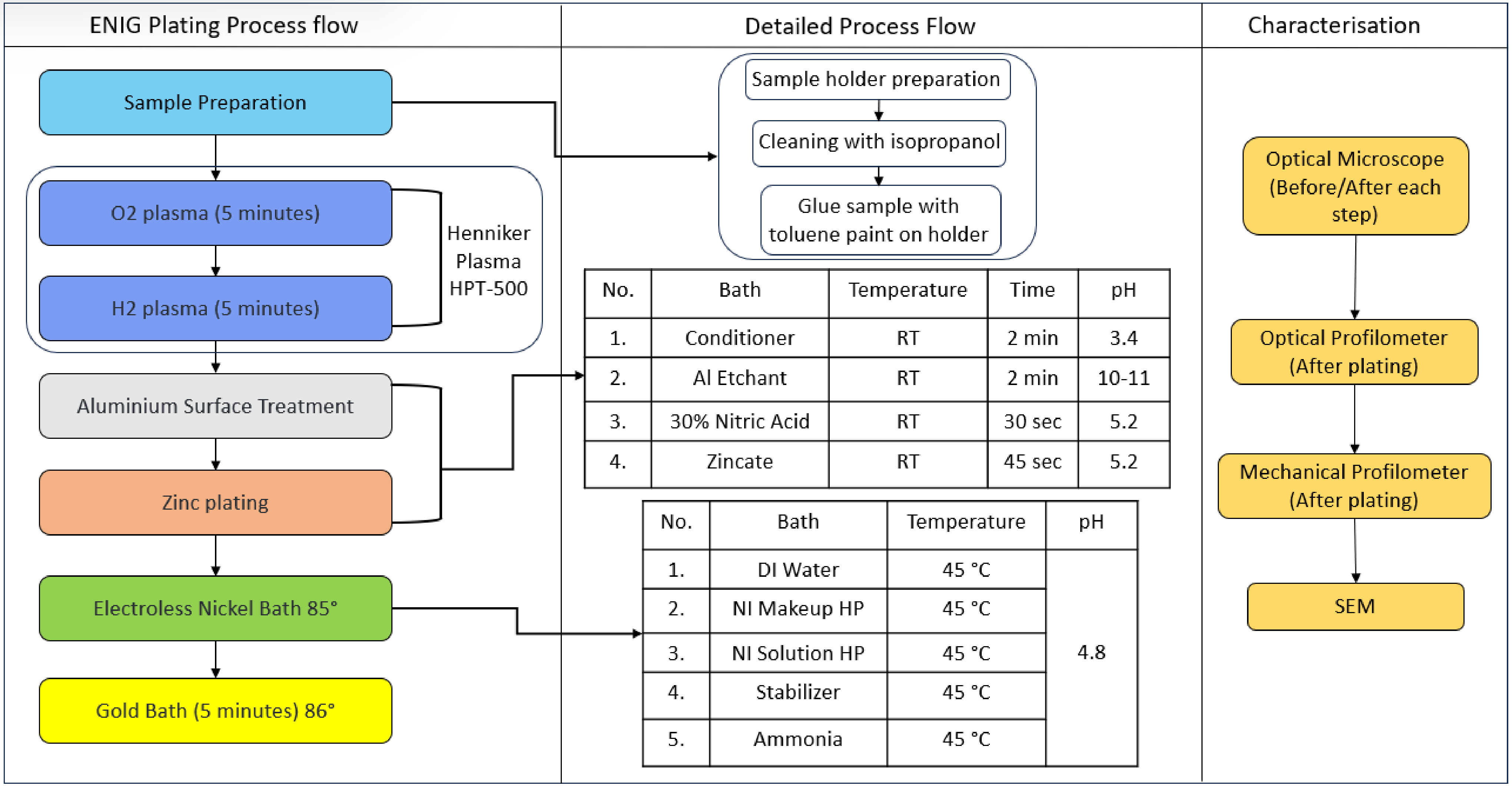
Hitachi SU5000



Process flow documentation

Systematic studies:

- Process flow
- Experimental design
- Quality control
- Detailed reports
- …



ENIG Plating Process flow

Sample Preparation

O2 plasma (5 minutes)

H2 plasma (5 minutes)

Henniker Plasma HPT-500

Aluminium Surface Treatment

Zinc plating

Electroless Nickel Bath 85°

Gold Bath (5 minutes) 86°

Detailed Process Flow

Sample holder preparation

Cleaning with isopropanol

Glue sample with toluene paint on holder

No.	Bath	Temperature	Time	pH
1.	Conditioner	RT	2 min	3.4
2.	Al Etchant	RT	2 min	10-11
3.	30% Nitric Acid	RT	30 sec	5.2
4.	Zincate	RT	45 sec	5.2

No.	Bath	Temperature	pH
1.	DI Water	45 °C	4.8
2.	NI Makeup HP	45 °C	
3.	NI Solution HP	45 °C	
4.	Stabilizer	45 °C	
5.	Ammonia	45 °C	

Characterisation

Optical Microscope (Before/After each step)

Optical Profilometer (After plating)

Mechanical Profilometer (After plating)

SEM