fTOF Sensor-ASIC Interconnection

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

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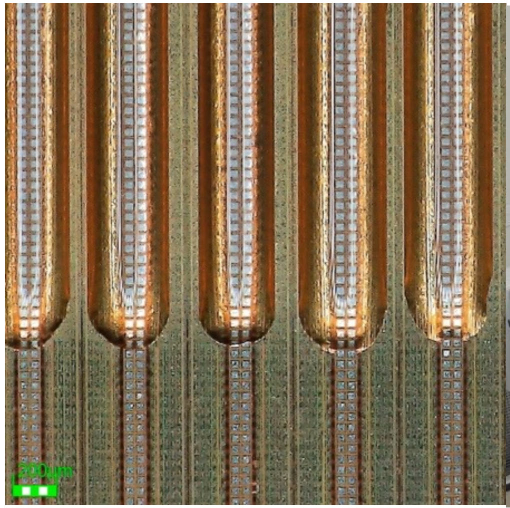
Outline

- ORNL relevant equipment
- ”Traditional” Bump-bonding baseline
  - Step of processing
  - Traditional vendors and opportunities
- Alternative low-cost bump bonding
  - Anisotropic Conductive Film/Adhesive
  - Z-bonding techniques
  - Copper Pillars
- QA/QC Considerations and next step

SET FC150 precision bonder

Brand new FC150 bonder currently in production, installation planned in September 24 in CNMS Class 100 clean room

- Up to 100mm substrate and chip handling
- +- 1μm post-bonding accuracy
- +- 1μRad parallelism with active levelling
- Pressure up to 200 kg
- Temperature up to 400C (~1C/s)
- Can be operated in fully automated mode
- Liquid dispenser integrated in the machine for glue, solder,AC underfill distribution

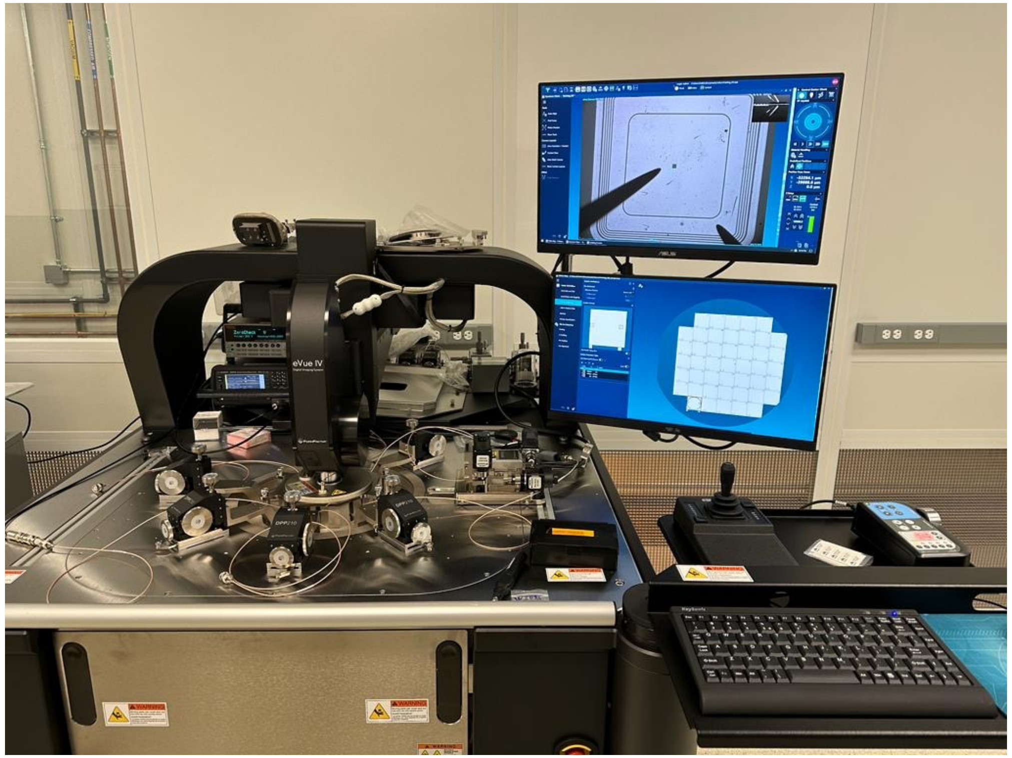


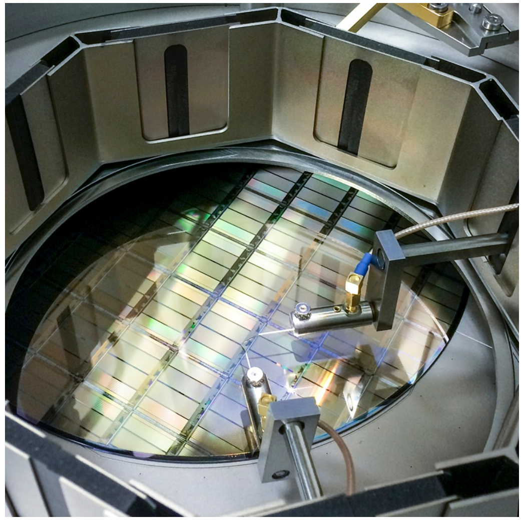

CNMS Class 1000 clean room

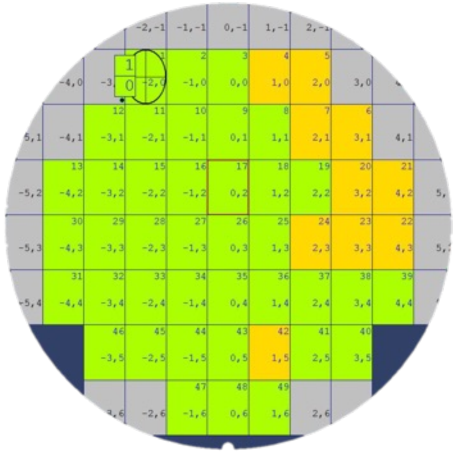
FormFactor CM300xi probe station

We purchased a **300 mm semi-automatic prober** that will be installed at ORNL:

- Accommodate 5-300mm sample size
- Light tight and airtight thermal chamber
  - **-60C to 125C testing range**
- Probes :
  - **8 x DC probe for parametric measurement**
  - **2 x RF probes**
  - **1 x XYZ robotic probe with optical probing**
  - **Probe card holder for open, closed top probe cards**
- 4 x Cameras :
  - Top view up to 1000x
  - Bottom-up view (probe alignment)
  - Side view (wafer surface alignment)
  - Auxiliary view (closed top probe card alignment)
- **Fully automated alignment of wafers and dices**
- **Fully programmable for unattended testing**

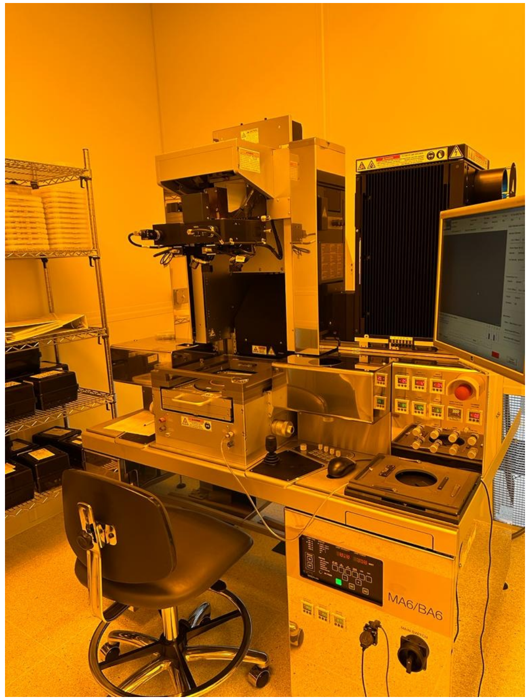


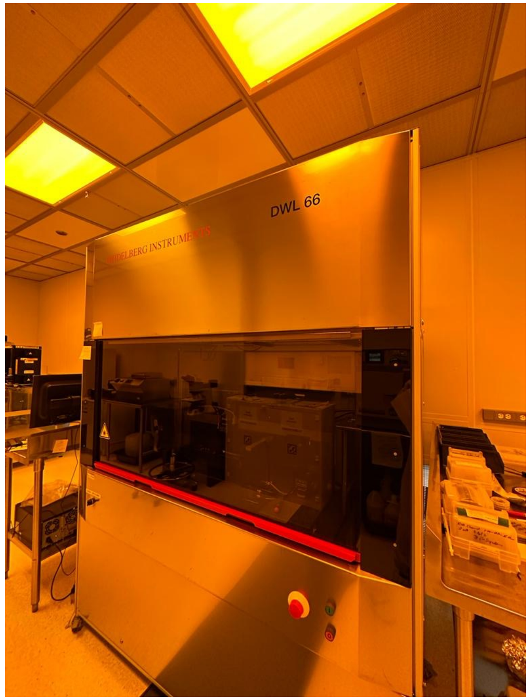




Same machine installed at University of Geneva, CERN building 14, FNAL

Equipment and facilities





Lithography and mask alignment

- Allow for development of metal traces, etch area on samples up to 4”

Sputtering, wet chemistry, etching

- Allows the metallization, etching and pattering of interconnect of our prototypes
- Ex: ENIG deposition on pads, etching of metals, Kapton and epoxy

ORNL Physics Division granted access to CNMS facilities

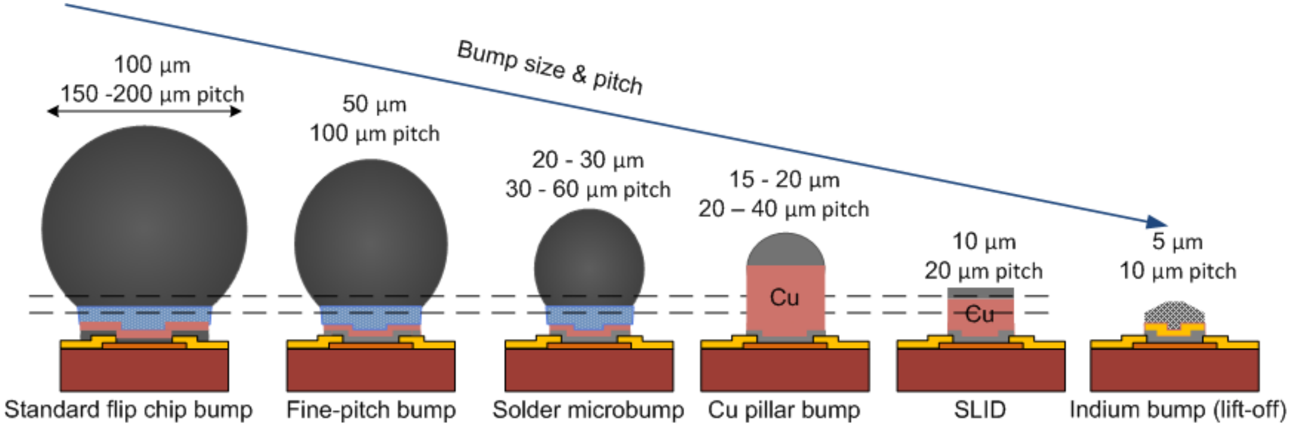
OAK RIDGE National Laboratory

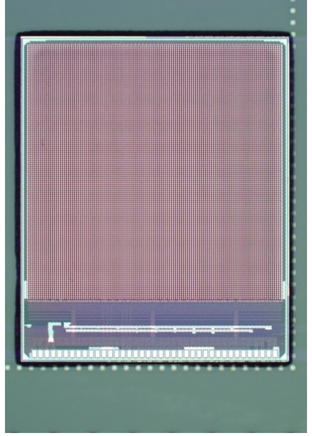
"Traditional" Bump-bonding baseline

Bump-Bonding

Bump-Bonding method for fine-pitch were developed and refined for LHC experiments (ATLAS,ALICE,CMS, Timepix/Medipix). Bumps are deposited with a lithographic process

- Self-Alignment
- Mechanical rigidity
- Good ohmic connection (<1 Ohm)
- Costly
- Finer pitch, finer solder deposition, more refined lithography
- Large channel count put constraint on the bonding process (N/bumps)





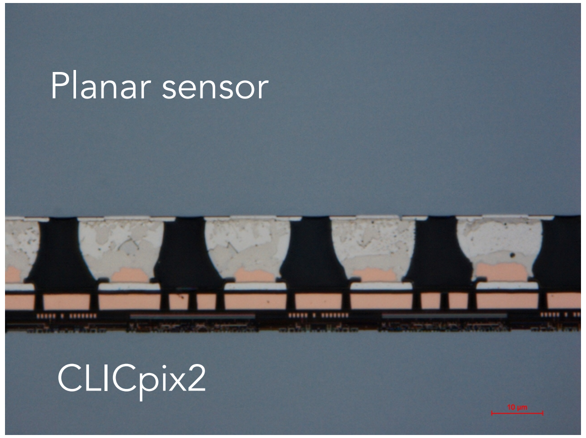
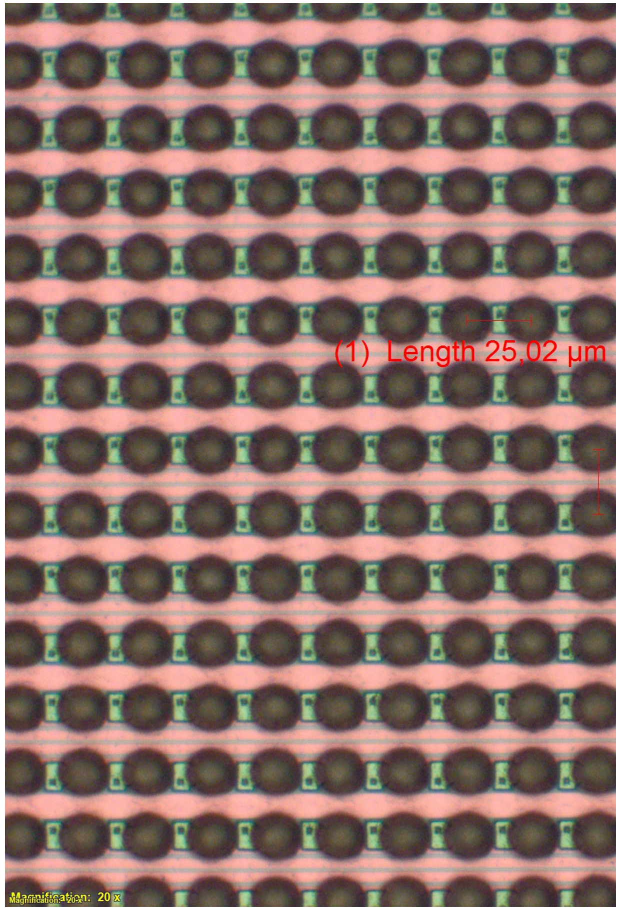
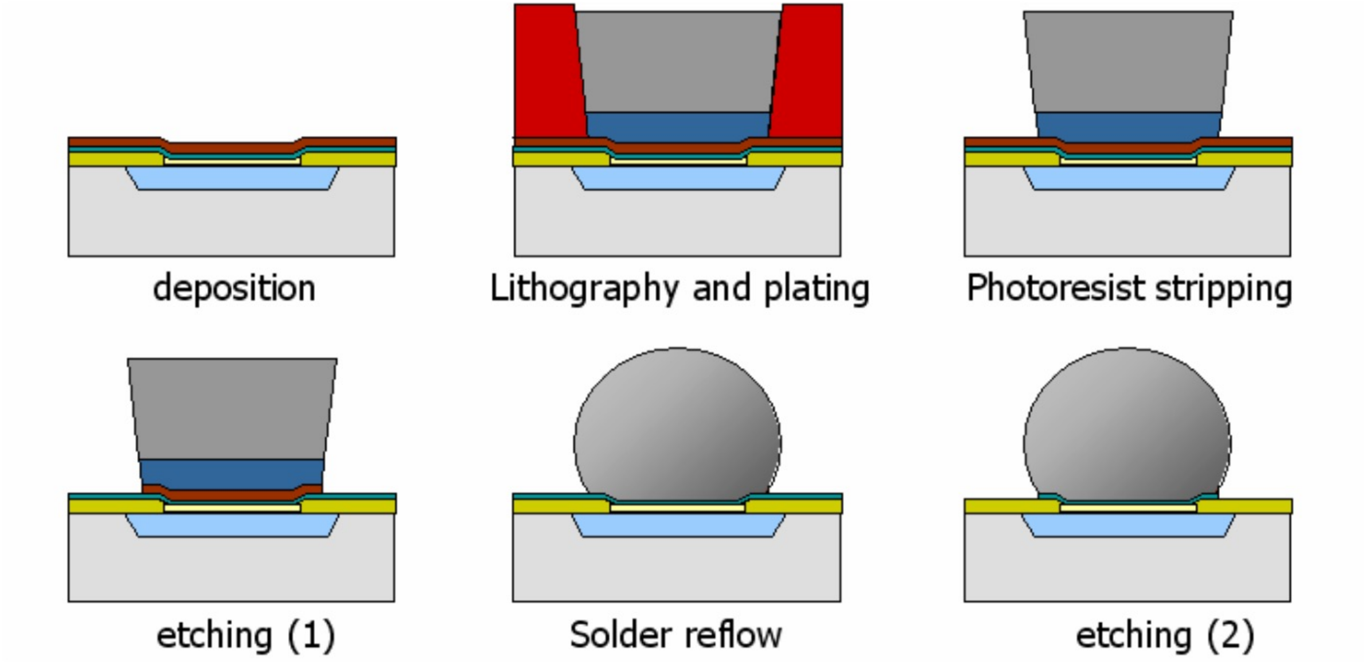


Image of a bumped CLICpix2 ASIC from IZM:



Bump-bonding processing



The outline of bump bond process steps. (1) deposition of field metal layers (2) Lithography and electroplating of Ni and solder layers (3) removal of the photoresist (4) etch removal of top field metal (5) reflow of solder bump (6) final etch of field metal

Traditional bump-bonding is accomplished by processing both the ASIC and sensor wafers with lithographic process to form the bumps and receiving UBM on the sensor side

- Sensors are usually 6" wafers
- Modern ASICs will be on 12" wafers
- Involve mixed-contractor processing
  - Sensor either receive UBM at sensor vendor or need to added by bump vendor
  - Bump vendor needs to be able to process 300mm wafers

Low-Cost interconnect technologies

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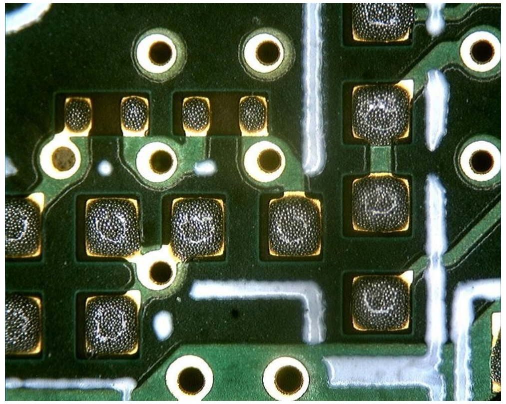
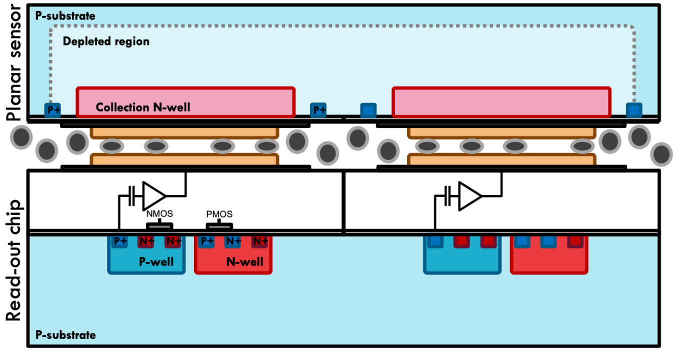
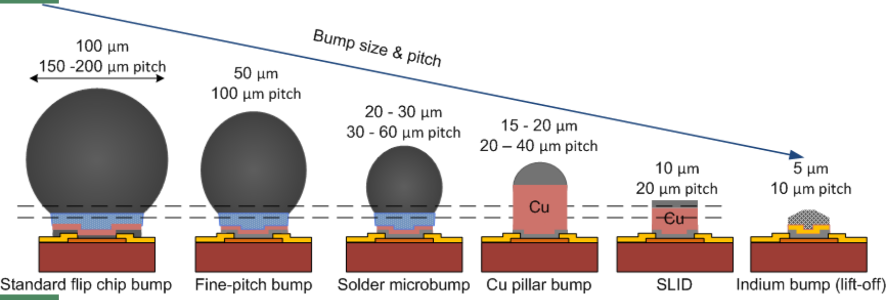
Low-cost bonding and assembly techniques

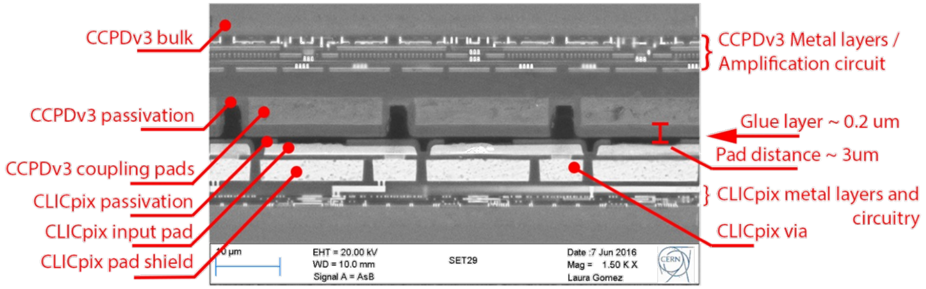
- Hybridization of Silicon sensors to its readout electronics represents **often more than 50% of the detector cost**
- In-foundry **3D Integration comes with a steep price ($200k/5mm²)**, but the interconnect density not always required. Many applications require less density and could be assembled via low-cost integration techniques. **There is a need for small to mid scale 3D integration capabilities as complementary to other efforts.**
- **Modern industry techniques for low-cost fine pitch bump bonding exist** but have yet to be adapted for HEP applications
  - LGAD based detectors with a few 100 µm pitch still using technique optimized for < 50 µm
  - Techniques for **fine pitch bonding at low cost exist in the industry**
    - **Anisotropic conductive adhesive, Ball Grid Array, 3D printing** used widely in Phone, TV industry with pads less than 250 µm²
    - These bonding methods **need to be adapted and qualified for HEP application** (radiation hardness, durability, signal integrity, sensor pre-processing etc.)
    - **Capacitive Coupling** has been demonstrated with Silicon detectors for HEP but never applied to AC-LGAD

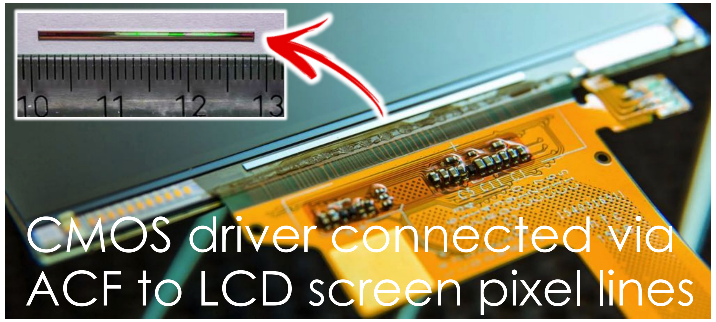


3D Printed solder on PCB (CC)

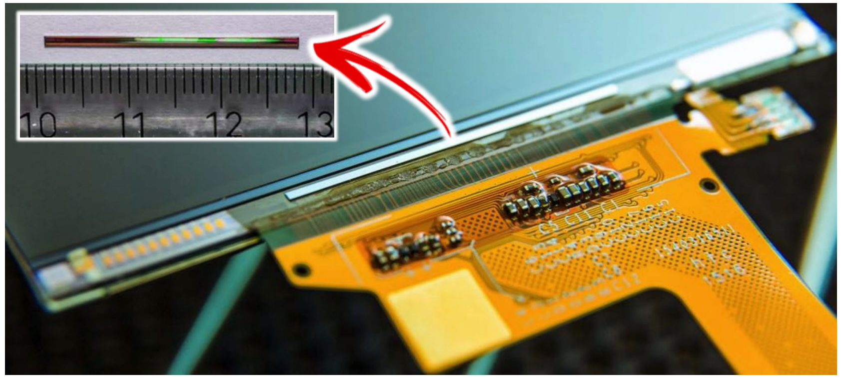








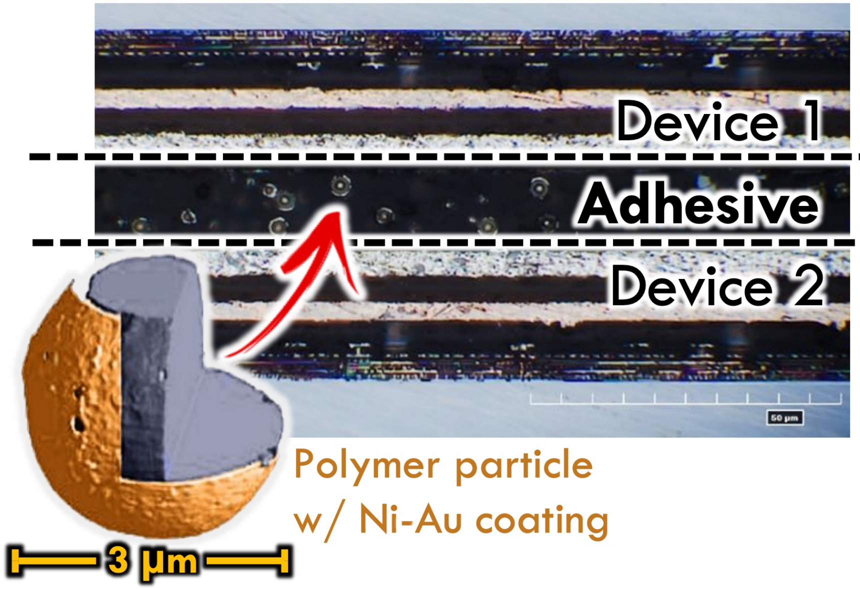
Anisotropic Conductive Films (ACF)



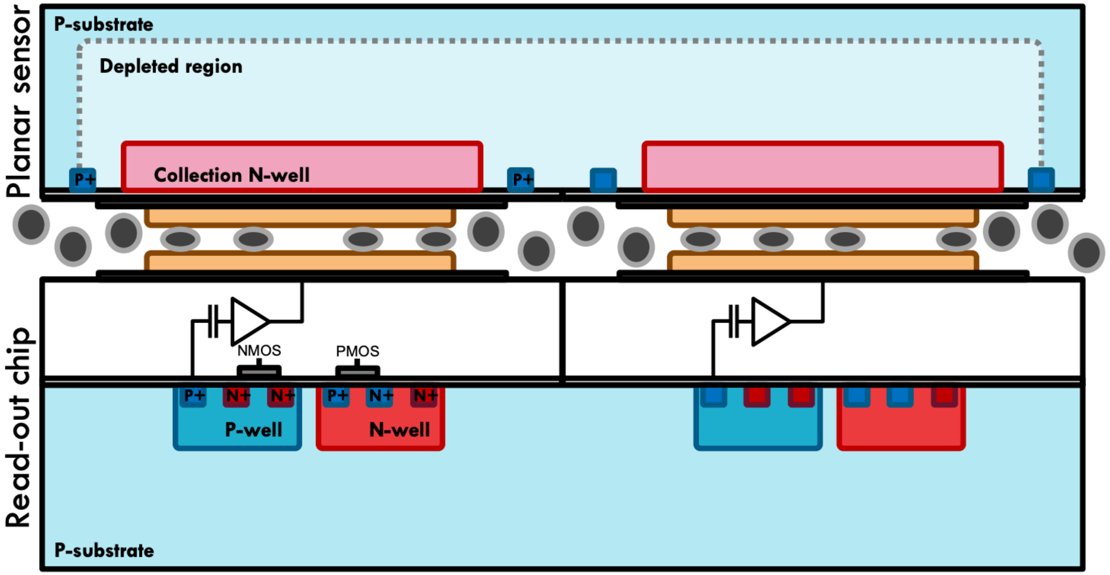
ACF is a technology developed for the LCD Display industry to connect drivers to each pixel row. Next step in the industry is µLED, which are driven individually and can measure as little as 15x15µm^2. Medipix and CLIC have been working with industry partners to adapt this process to pixel sensors

- Low cost, no lithography involved
- Wafer processing for pillar (ENIG) can be done in house with modest equipment

Bonding cross-section

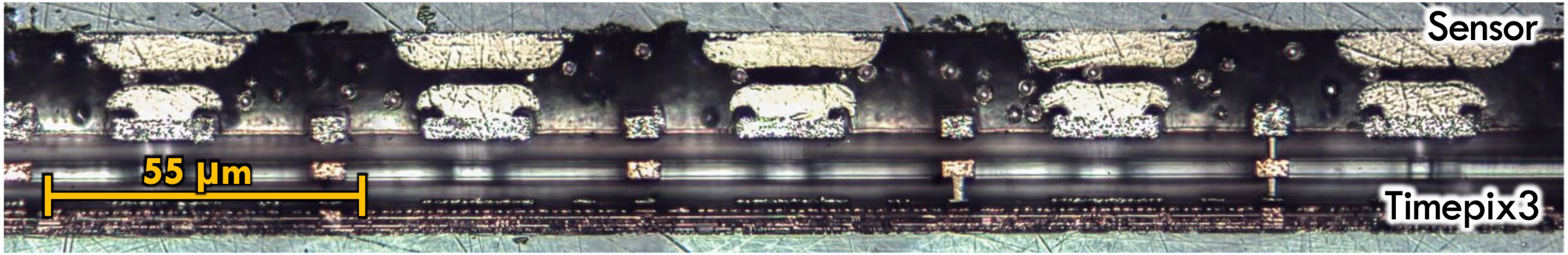


Polymer particle w/ Ni-Au coating

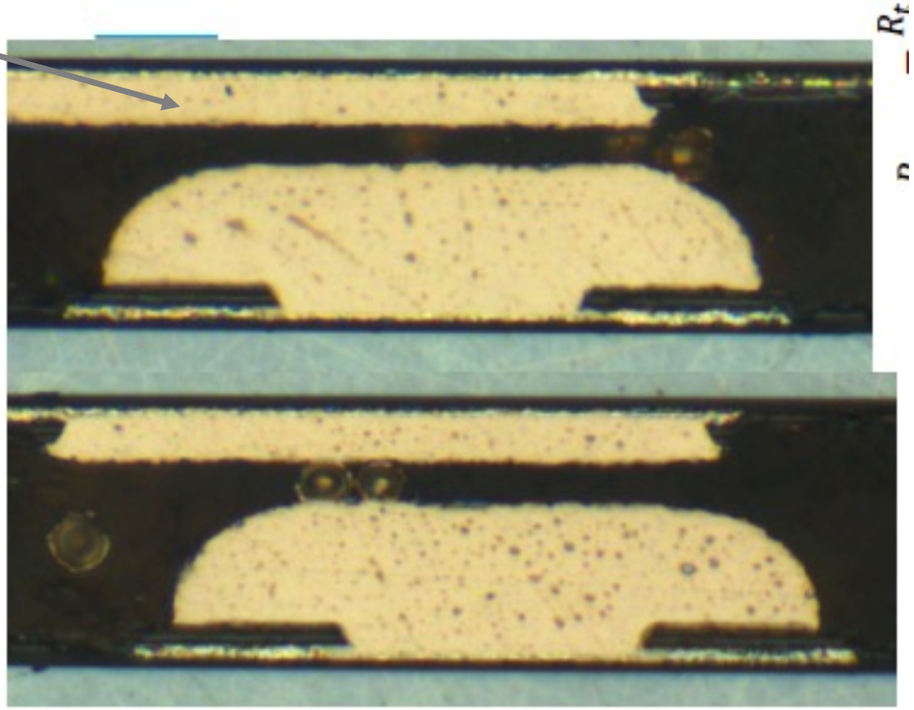


ACF results

Timepix3-ACF-sensor assembly cross-section



Pads can be planarized via Chemical-Mechanical polishing



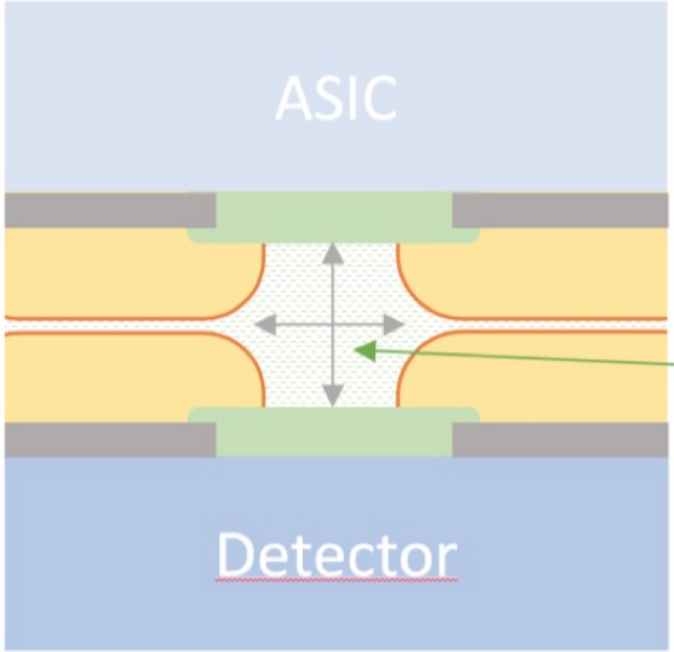


Figure 9: Bump height and available area for squeeze film flow

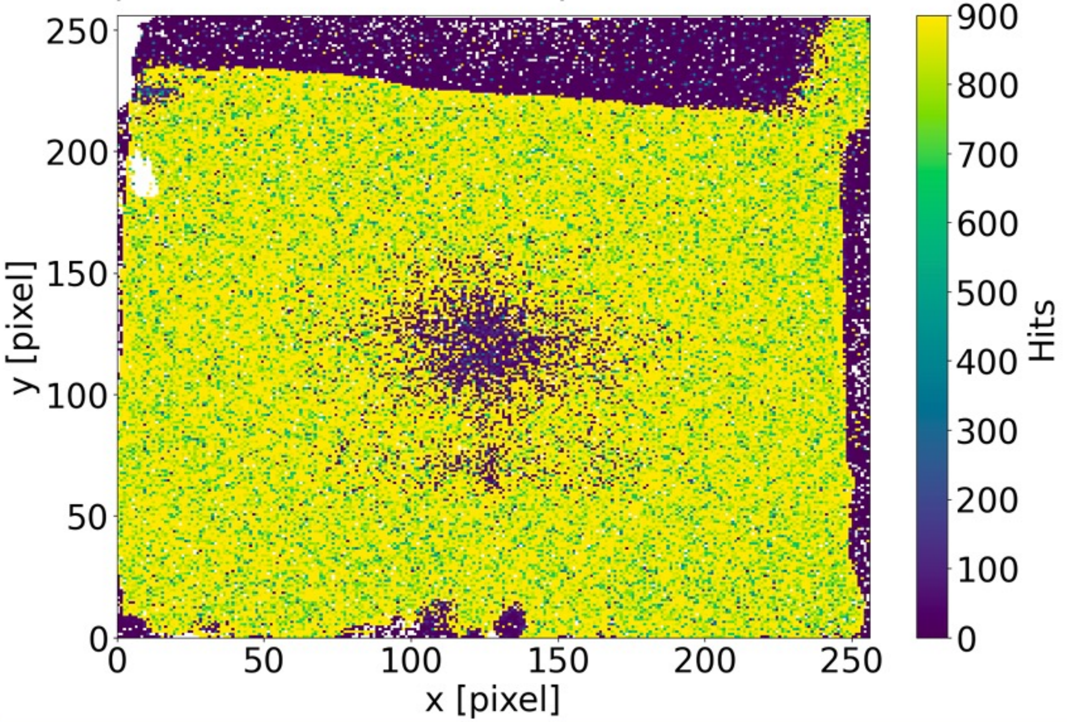
Area available for squeeze flow

Inter-pad adhesive provide mechanical stability

Preliminary results with Timepix3

Sample 2:
~90% coverage of 14 µm ACF

Hit-map from Sr^{90} illumination Timepix3



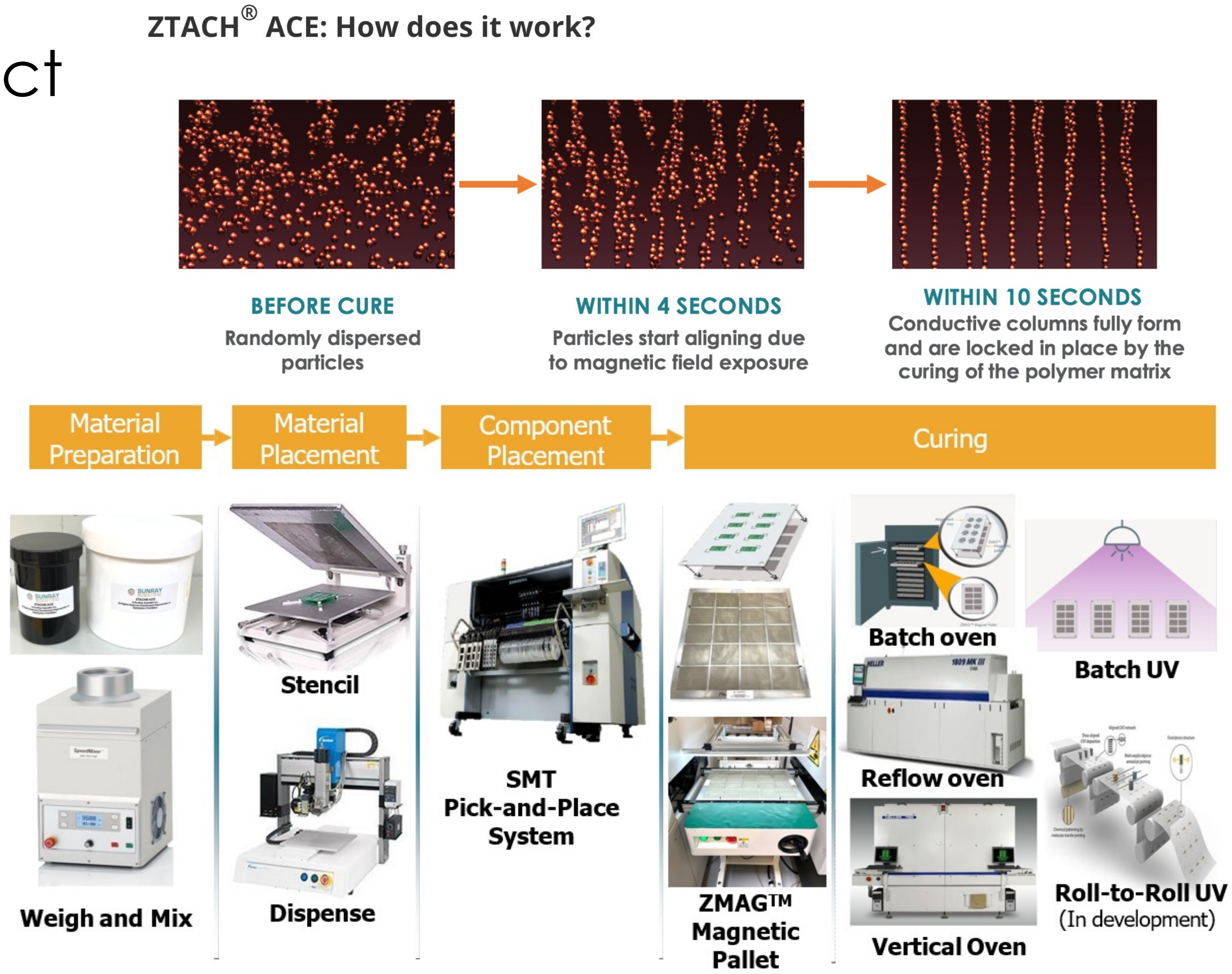
ACF coverage on Timepix3 ASIC

https://indico.cern.ch/event/1223972/contributions/5262059/attachments/2603036/4495146/202302_trento_ACA_Schmidt.pdf

Z-TACH interconnect

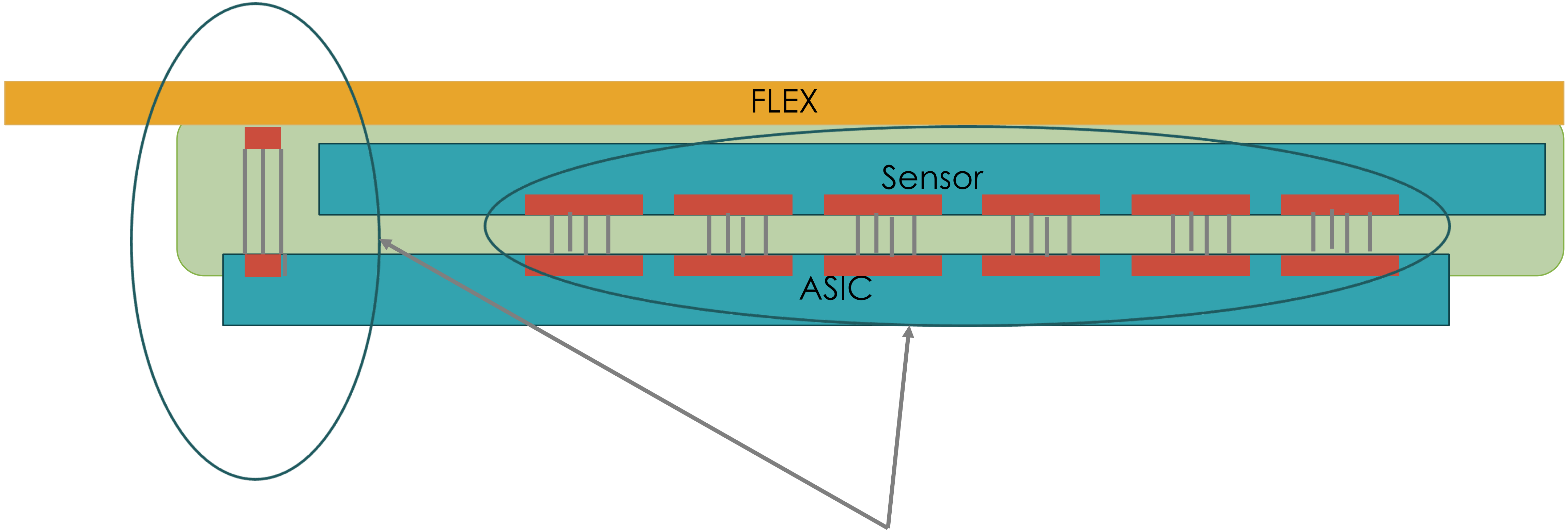
Z-bonding is a pressure-less bonding method for interconnection of pads using magnetic field to create aligned conduction channel between pads

- Works with ENIG deposition on pads
- Can handle multi-level bonding and complex pad geometries



Source : https://sunrayscientific.com/solutions/

Z-Bonding, multi-level capabilities

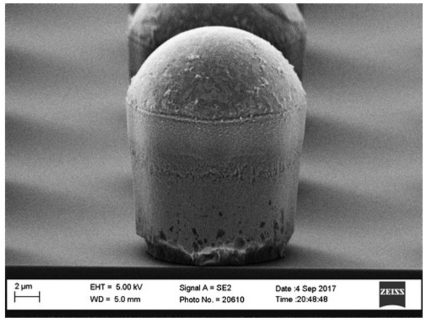


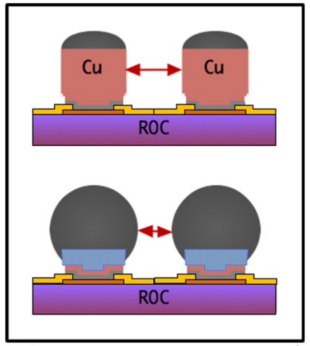
Interconnection between Flex, Sensor and ASIC are done in one pass, by dispensing the adhesive and placing various components. Conductive channels are formed in one go in the magnetic casettes .

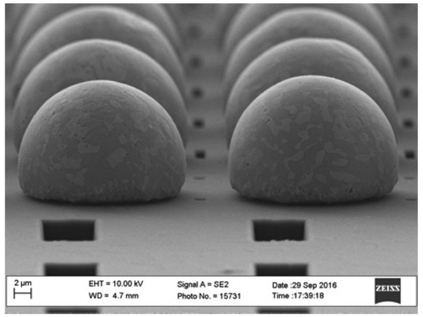
Low-cost bumping of 300mm, recent development with copper pillars

Cu pillar bump structures with solder (AgSn) cap have become mainstream

- Widely available in industry and lead-free
- Compliant with fine-pitch because of aspect ratio
- Less coupling between bumps due to aspect ratio
- Common and low cost (~300CHF/wafer) on 300mm
- Can be flip-chipped in-house to sensor with UBM

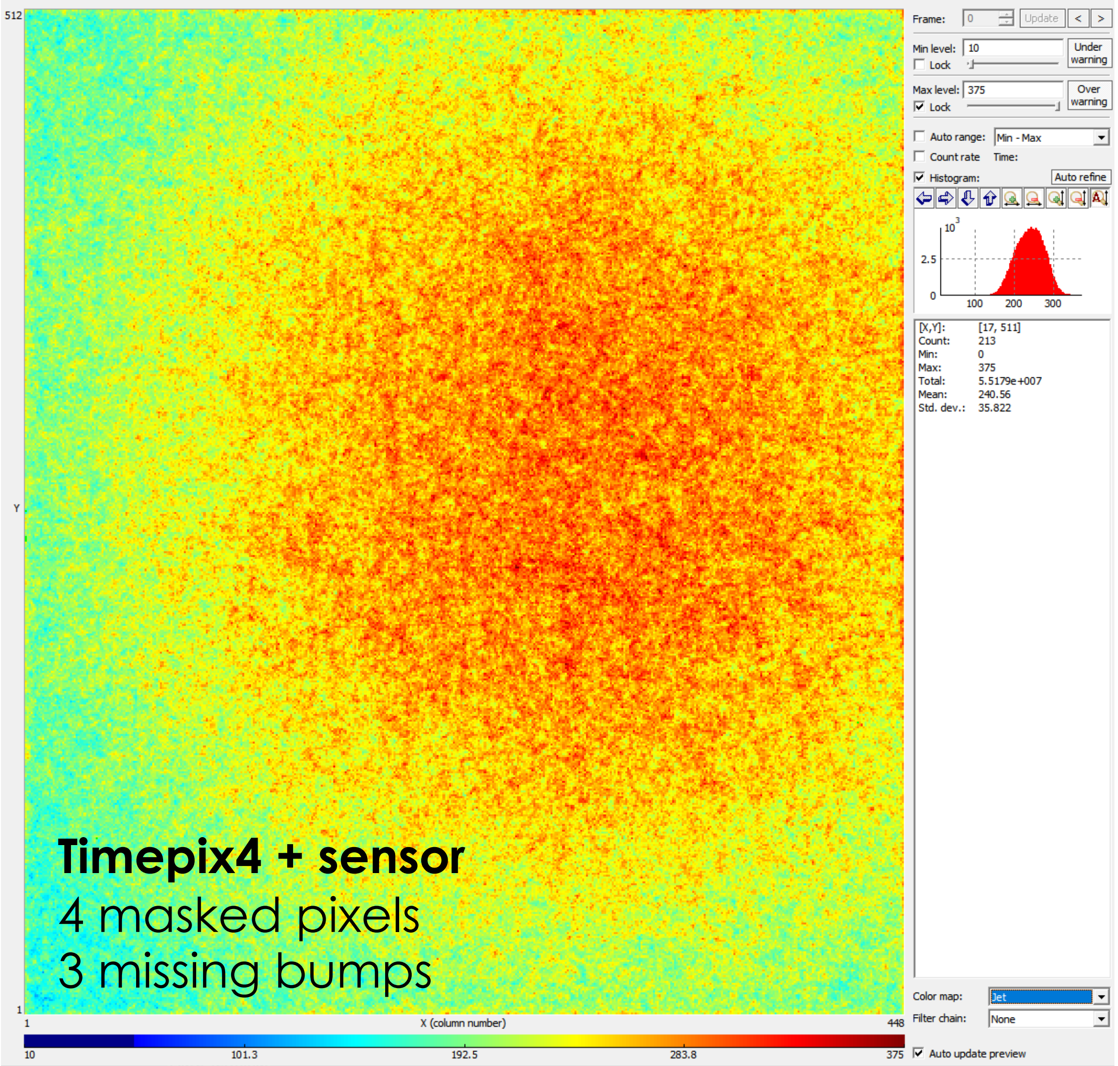






Cu pillars with solder cap @ 25 um pitch

Ni/SnPb solder bumps @ 25 um pitch



Credits to Advafab, Timepix4 Collaboration
https://indico.cern.ch/event/627245/contributions/2676713/attachments/1522282/2378712/S_Vahanen_Advacam_VERTEX_2017.pdf

QA/QC procedure for sensor and bump bonding testing

- The main deliverable for the sensor part of the scope is **known good assemblies** , tested to meet the market survey requirements at the vendors
- The testing done at assembly QA/QC sites covers the test not doable but the vendors
  - **Visual/X-Ray inspection** of the sensors after transport to the lab
  - **DC Characterization** of a **subset of assemblies** (~2.5% selected at random + marginal samples)
  - **Transient analysis** with Laser test setup to extract timing, CCE (1% selected at random + marginal samples)
  - Repeat test after **irradiation** to verify compliance with market survey parameters

Next steps : Preparing for bonding

- To exercise bonding with realistic dimension, we need access to Silicon/Test structure
  - Bumping on 300mm wafers require mechanical dummies of that dimension to exercise the process
  - Bonding of thin sensors using traditional/novel techniques need to be demonstrated
  - Thermal management, module assembly method require realistic dummies
- **The community need a concerted effort to procure large size electrical/mechanical dummies** for practicing bonding and module assembly
  - ORNL interested in producing Silicon samples in our clean room, looking into alternate sources

Next steps : Validating

- Mechanical/electrical prototypes need to be studied to ensure operation for the lifetime of the detector
  - Thermal cycling, thermal shock testing to avoid issue with CTE, bump-disconnection
  - Realistic operation with cooling to ensure sufficient Thermal Figure Of Merit (TFM) for our configuration
  - Exercise assembly procedure and ensure appropriate tooling is employed
  - Test reliability of all involved materials w.r.t. to radiation hardness
  - Identify possible issues with vibration, deformation , noise in realistic final assemblies

Thank you !