

3D & SYSTEMS SUMMIT

Improving Collective and Sequential Processes for Advanced Self-assembly D2W Hybrid Bonding

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Improving Collective and Sequential Processes for Advanced Self-assembly Die-to-Wafer Hybrid Bonding

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SYSTEMS
SUMMIT**

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DRESDEN, GERMANY

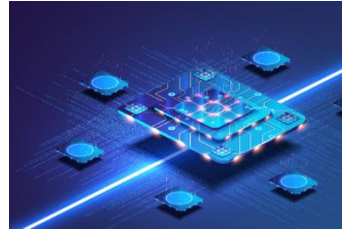


Heterogeneous 3D Integration

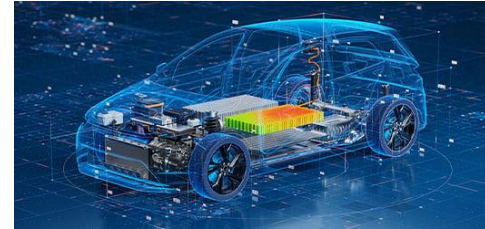
Application diversity & Technology Maturity



HPC



Photonics



Automotive



Space & Defense

Heterogeneous 3D Integration

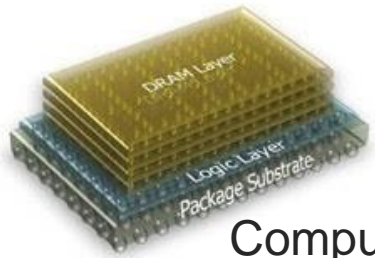
The right technology for the right function

Improved Energy efficiency

Reduced Cost

System Scale'up

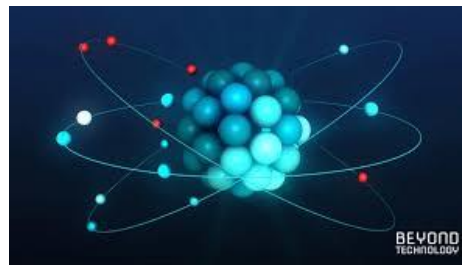
Plug & Play with chiplets



Compute & Memories



Power : Discrete & HPC PoL



Quantum



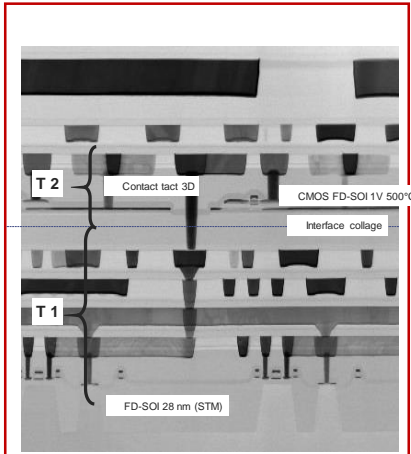
Sensor & Display



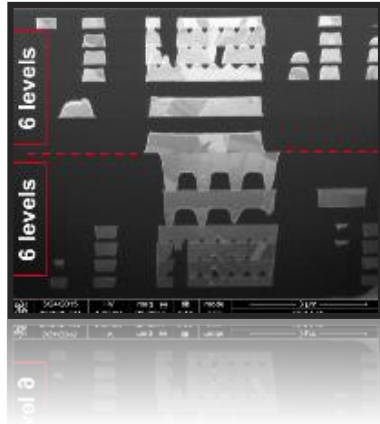
RF & RADAR

Heterogeneous Integration : Interconnect Landscape

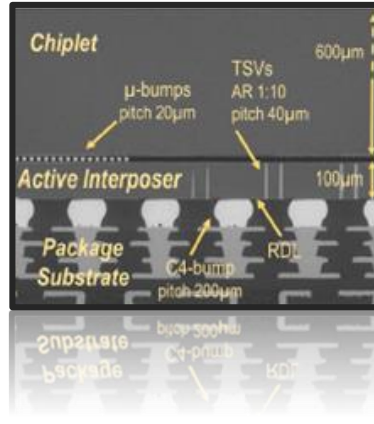
Continuous improvements, driven by pitch, PPAC+S performances, with material diversity, and Application & STCO requirements



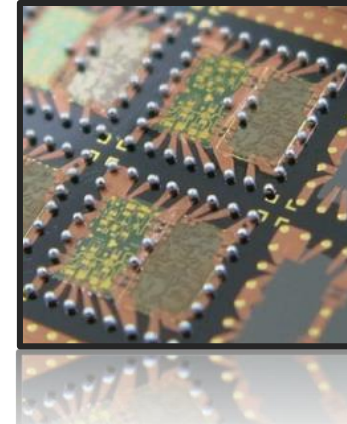
3D sequential
 Wafer-to-wafer
 3DVIA current demo:
 0,1 Φ & 0,2 μm pitch
 Scalable to
 0,03 Φ & 0,08 μm pitch



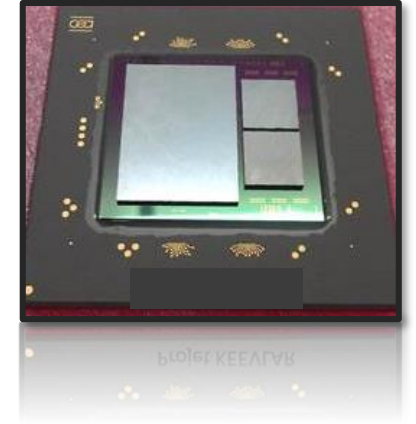
Direct hybrid bonding
 Wafer-to-wafer
 Min. pitch = 1 μm \rightarrow 200nm
 Die-to-wafer
 Min. pitch = 4 μm \rightarrow < 1 μm
 Self-assembly



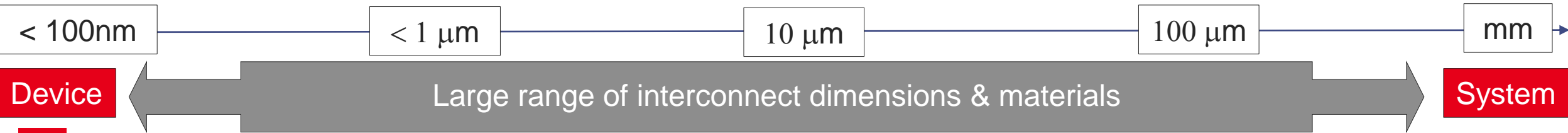
Active interposers
 Through-silicon-Vias
 TSV 0,3 to 80 μm Φ
 TSV middle & TSV last
 RDL 20 μm pitch
 Cu pillars 10 μm Φ



Fan-Out-Wafer-Level-Packaging (FOWLP)
 Heterogeneous
 System-in-Package
 Thermal extraction



Die-level packaging
 Harsh environments
 Power modules
 Cryo-packaging for quantum computing



Outline

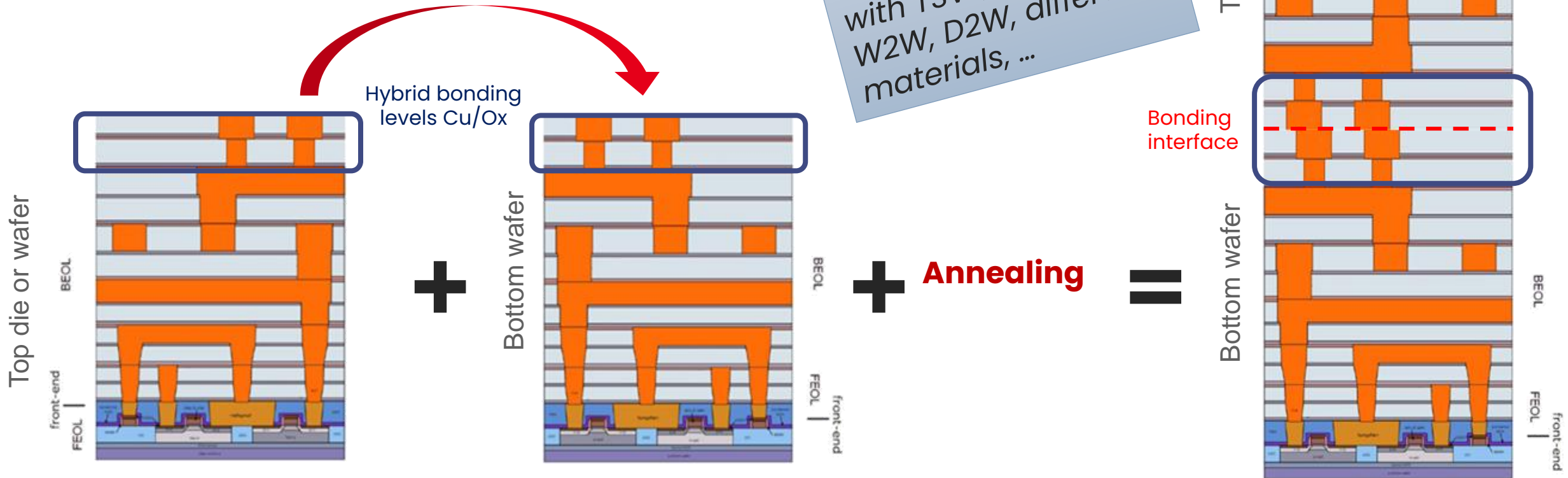
- Heterogeneous 3D Integration landscape
- Hybrid Bonding challenges
- Self-Assembly Concept & Results
- Self-Assembly Sequential & Collective Assembly flows
- Conclusions & Perspectives

Hybrid Bonding for 3D interconnections

Assemble 2 technologies through Cu/oxide interface

- No organics
- **Dense** interconnections: $10\mu\text{m} - 100\text{nm}$ pitch
- Better **thermo-mechanical** withstanding

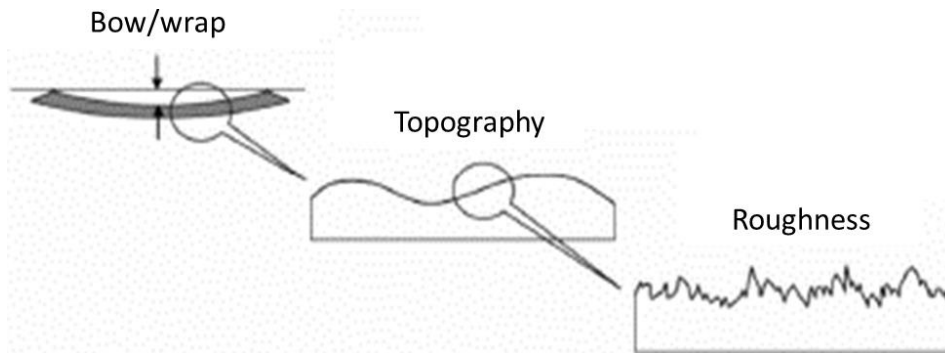
Can be combined:
with TSVs, F2F, F2B,
W2W, D2W, different
materials, ...



Extreme surface criteria for Hybrid Bonding

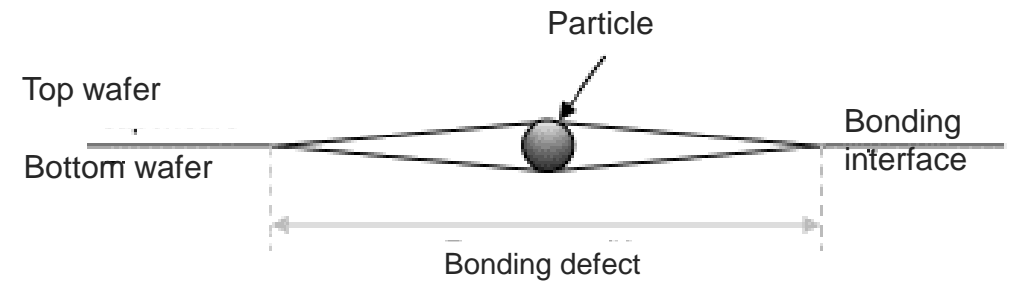
FLATNESS

At different scales



CLEANLINESS

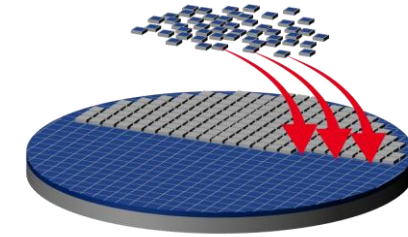
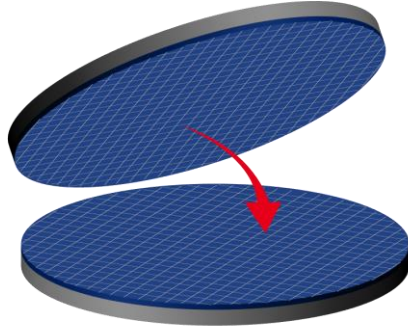
Organic & particle contamination



1 μm particle \rightarrow 5 mm bonding defect

Hybrid Bonding Assembly configurations

W2W vs. D2W



- High assembly throughput
- High alignment accuracy

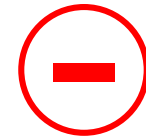


- Design limitation : same die size
- Yield limitation

**Mass production for imagers
Target of next gen Memories (HBM, ...)**



- Different die size
- Known Good Dies (KGD) for test & yield

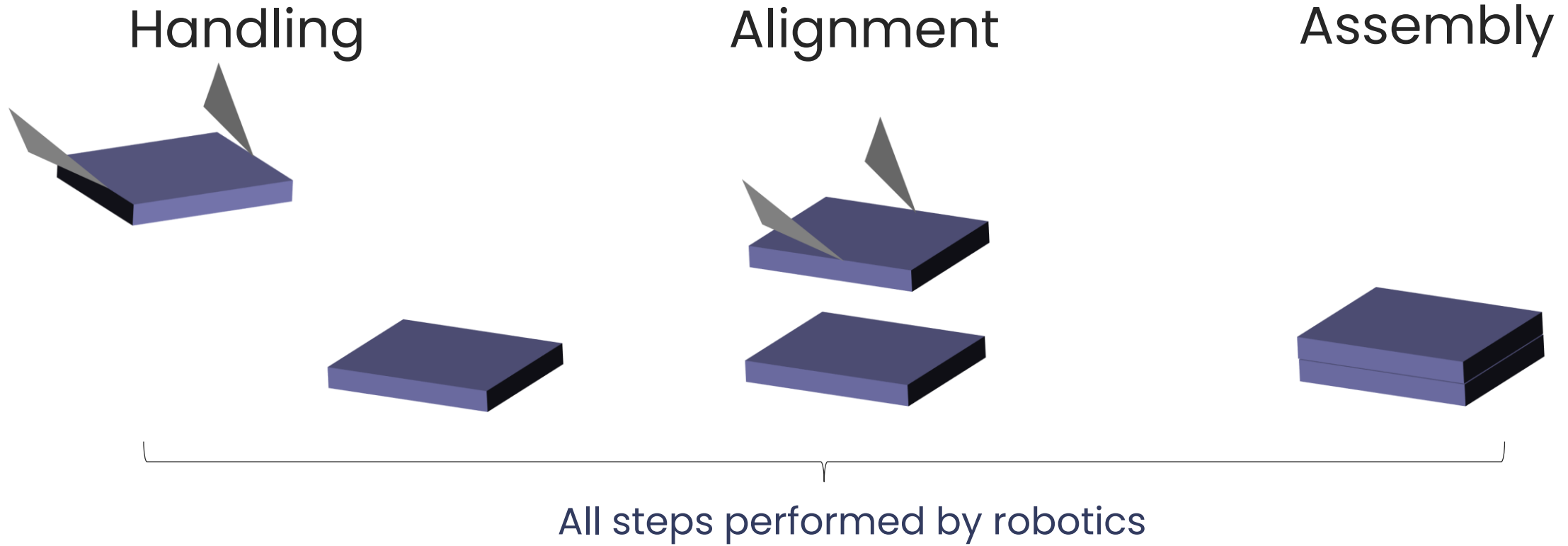


- Low assembly throughput
- Reduced alignment accuracy

**Mandatory for Chiplet & Heterogeneous
Integration for most applications !**

Breakthrough processes needed

Limitation of D2W Pick&Place

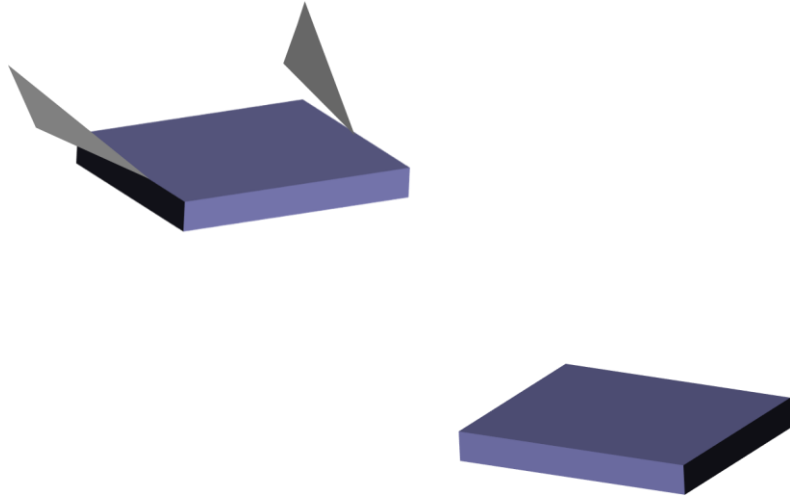


Accuracy ⇔ (low) throughput tradeoff

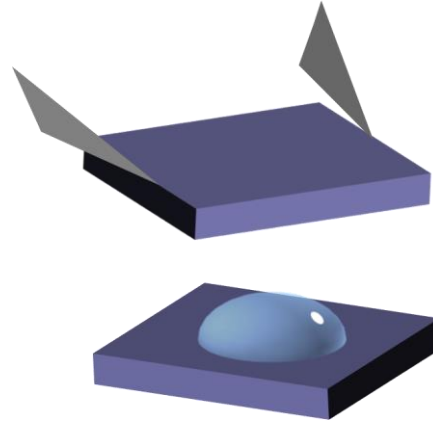
Self-Assembly for throughput increase



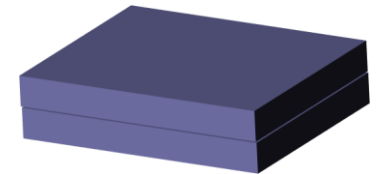
Handling



Alignment



Assembly



High speed robotics



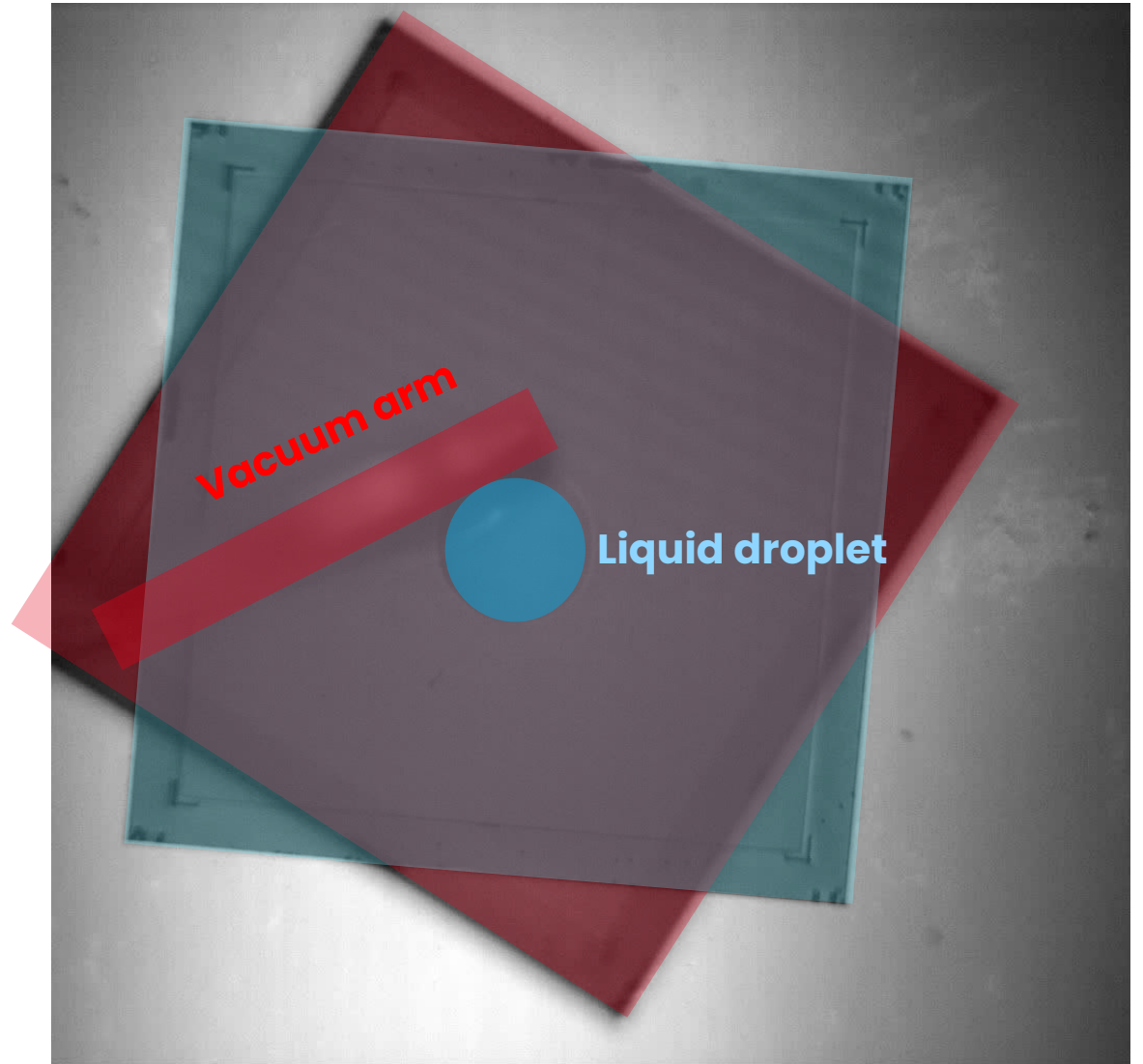
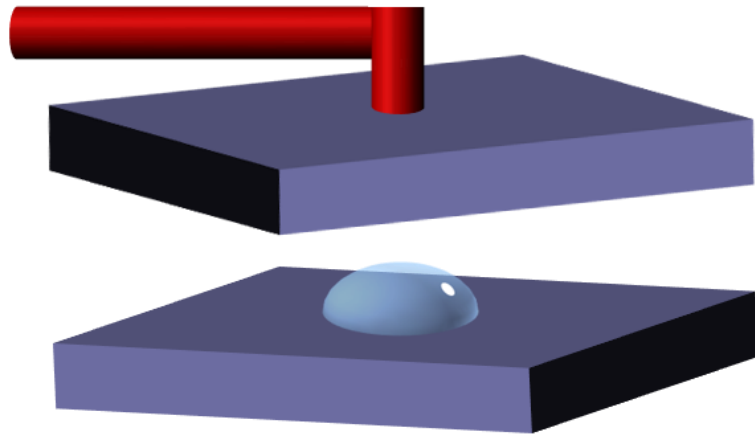
Physics

High throughput with $<1 \mu\text{m}$ alignment

Self-Assembly: a breakthrough process



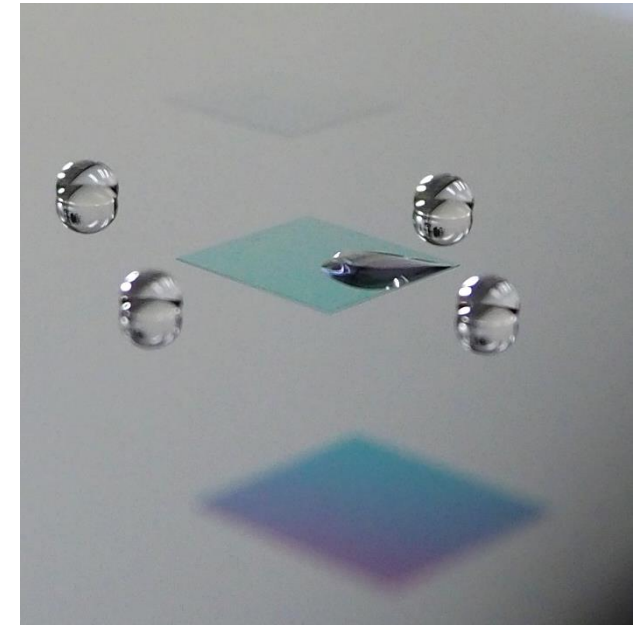
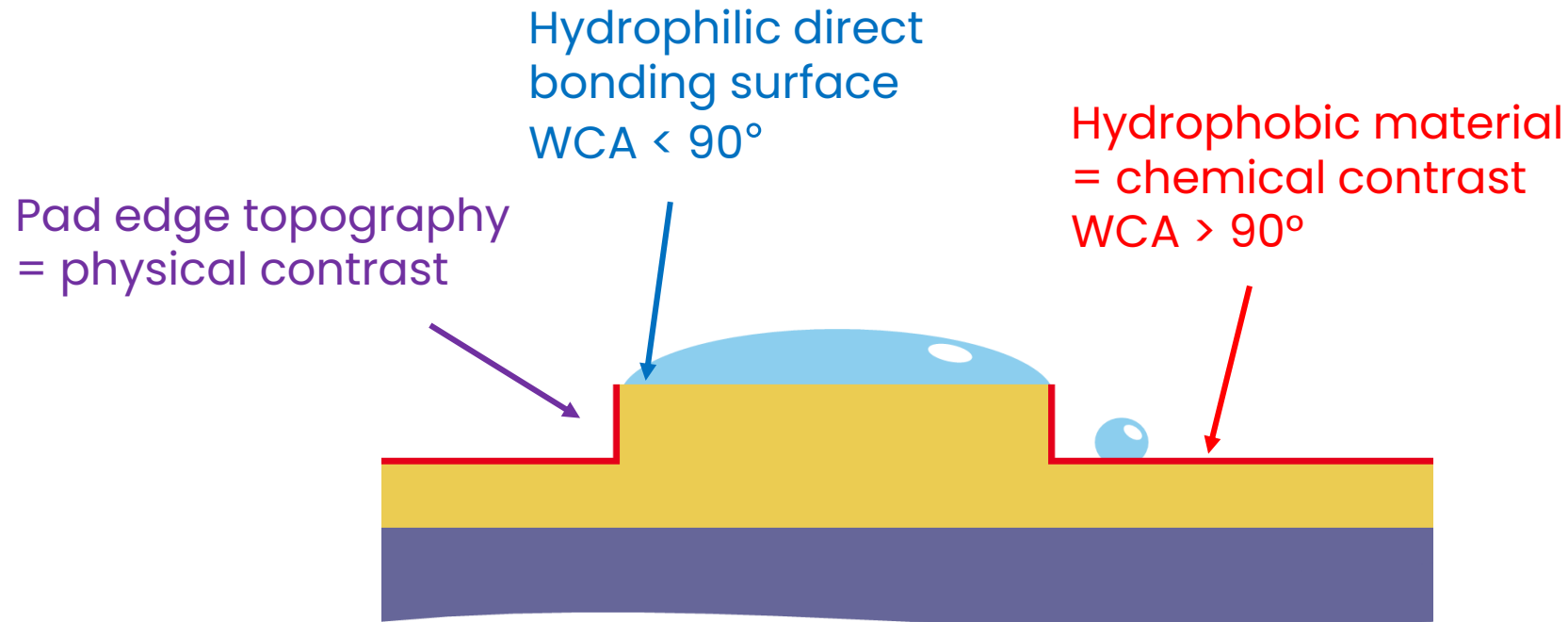
Self-alignment thanks to capillary forces



Self-Assembly prerequisite configuration

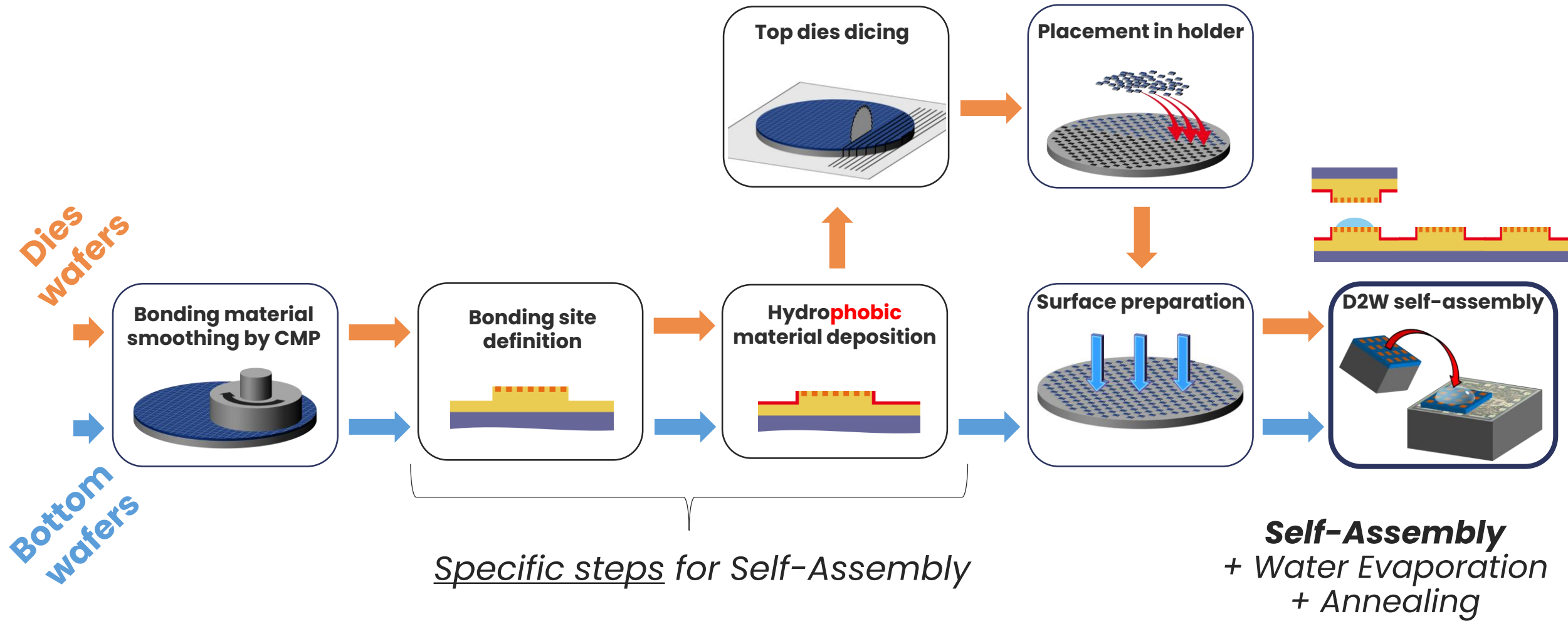


Water droplet must be well contained on the bonding surface



*WCA : Water Contact Angle

Self-Assembly process flow



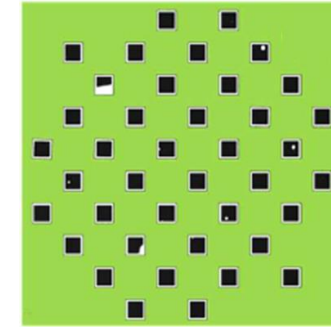
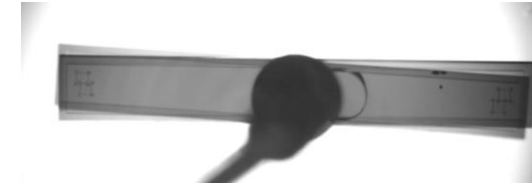
Self-Assembly successes

Oxide Bonding surfaces

✓ SA is compatible¹ with various die sizes and geometry
 $8 \times 8 \text{ mm}^2$, $2.7 \times 2.7 \text{ mm}^2$, $1.3 \times 11.8 \text{ mm}^2$, $2.2 \times 11.8 \text{ mm}^2$

✓ Bonding yield² (referring to defectless bonded dies after annealing)
 = **up to 96 - 100%**

✓ Alignment performance² = **80% < 200nm**



Hybrid Bonding surfaces

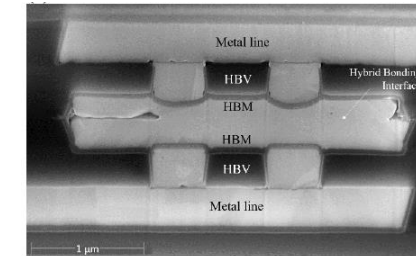
✓ Water droplet compatible with Cu²

✓ Electrical yield³ = **80% for DC 5000 links, 50% for DC 50000 links**

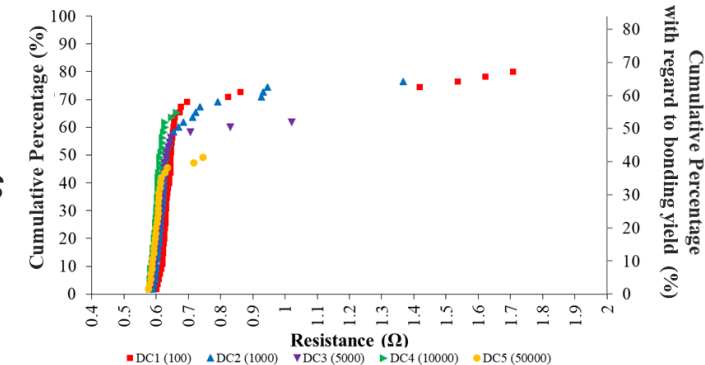
Similar to standard P&P Die-To-Wafer reference –

Need process improvement regarding bonding yield with hybrid surfaces

✓ Throughput / Speed : **To be evaluated**



HB cross section (L/S 3/6 μm)



¹ A. Bond et al., "Collective Die-to-Wafer Self-Assembly for High Alignment Accuracy and High Throughput 3D integration", in 2022 ECTC

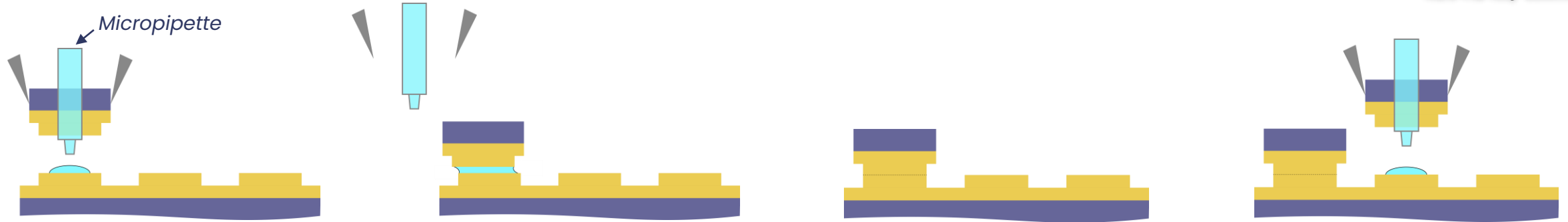
² E. Bourjot et al. "Integration And Process Challenges Of Self Assembly Applied To Die-To-Wafer Hybrid Bonding." in 2023 ECTC

³ A. Tholon et al., "Electrical performance of self-assembly applied to die-to-wafer hybrid bonding" in 2024 ESTC

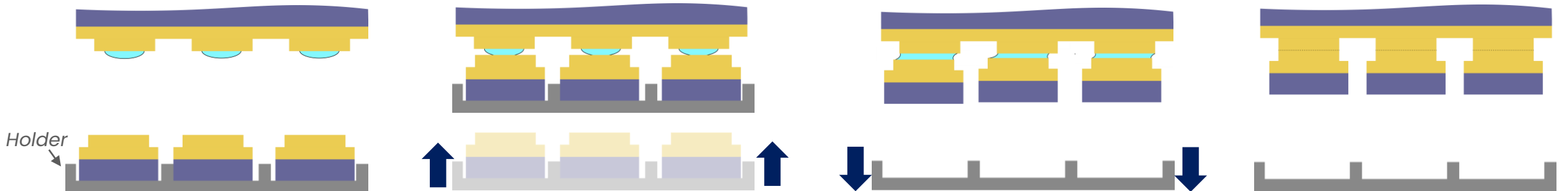
Sequential versus Collective Self-Assembly



Sequential assembly:

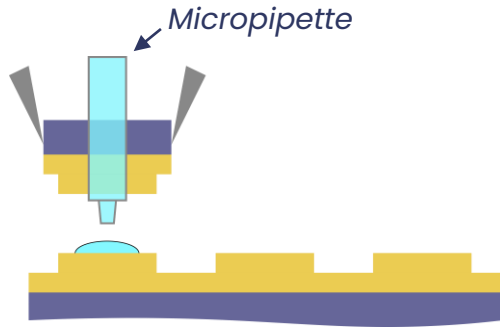


Collective assembly:

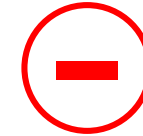


Sequential versus Collective Self-Assembly

Sequential assembly:



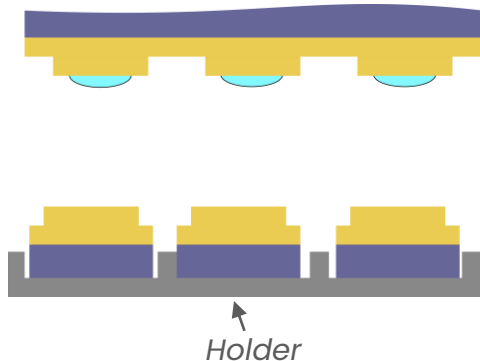
- Good control of water dispense
- High alignment performance
- Interdie <math>< 100 \mu\text{m}</math>



- Reduced assembly gain

Target x10 throughput vs DtW HB

Collective assembly:



- High assembly throughput

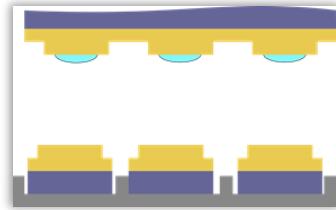
- Need water collective dispense
- Need dedicated holder
- Interdie limited by the holder

Target x100 throughput vs DtW HB

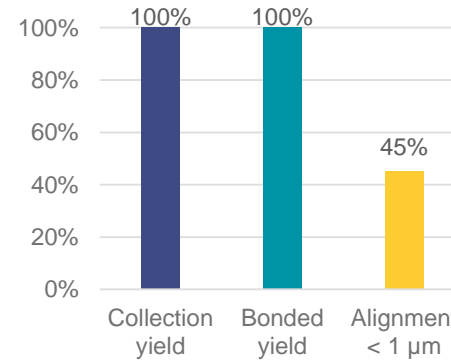
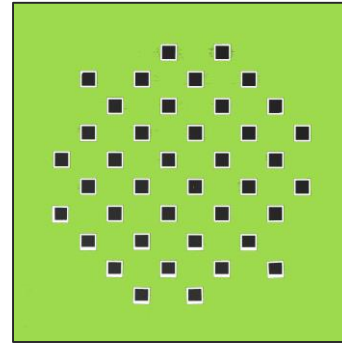
Collective Self-Assembly improvement



New EVG810 tool dedicated to collective self-assembly

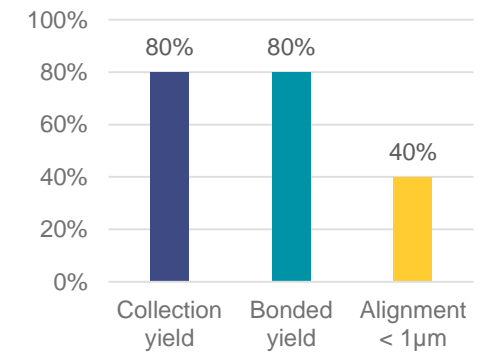
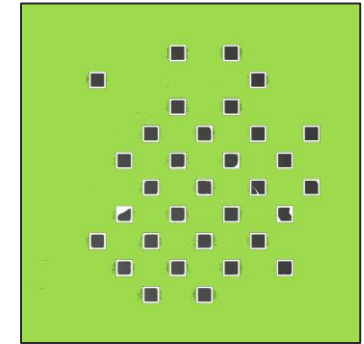


New type of holder



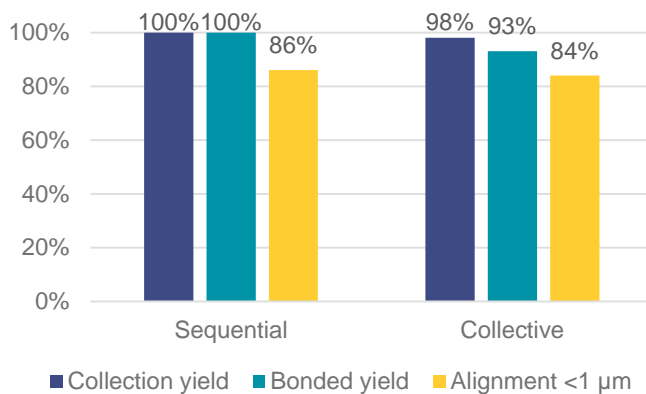
100% yield achieved
→ 250 μm interdie reachable

New water collective dispense



Under development with promising results*

Collective vs Sequential ?



Unpublished

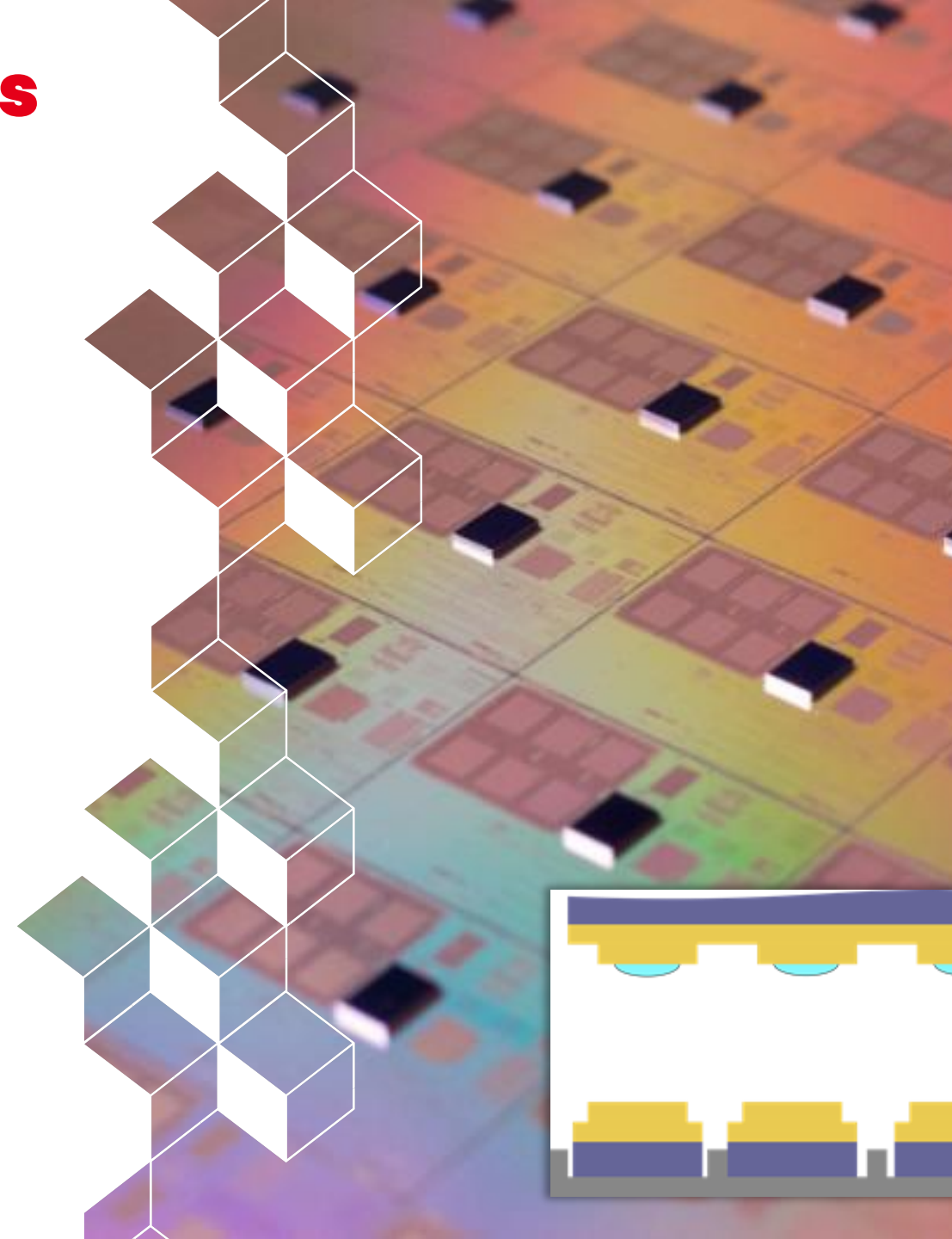
Conclusions and Perspectives

Self-Assembly Hybrid Bonding Die-to-Wafer process has been demonstrated:

- Bonding yield 100%
- Die Alignment < 200 nm
- Hybrid bonding compatible with water droplets
- Two flows available :
 - Sequential assembly with new SET tool
 - Collective assembly with new EVG tool

Perspectives:

- Process improvement of hybrid surfaces to improve bonding yield
- Process improvement of holder and collective water dispense to improve collective process



Acknowledgment

CEA Leti team:

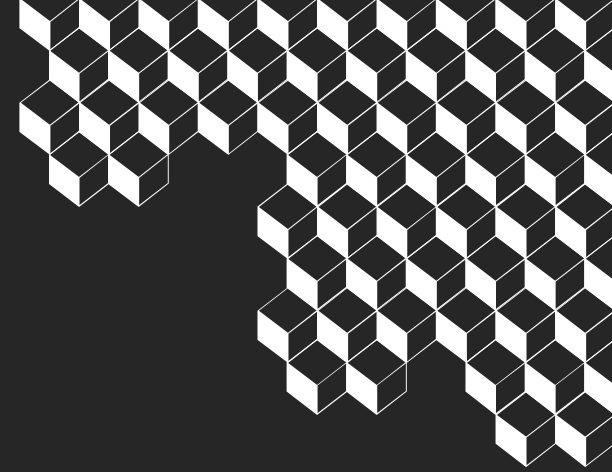
Adèle Thiolon, Pierre Montmeat, Thierry Enot, Mélanie Vacon, Lilian Masarotto, Frank Fournel

FAMES Pilot Line



Our partners:





**Thank you
Questions ?**

