JUNE 15

Confidential

Fraunhofer ENAS

SÜSS MicroTec

Metrology for Hybrid Bonding

Thomas Schmidt, Product Manager Bonder
Business Unit Advanced Backend Solutions

Agenda

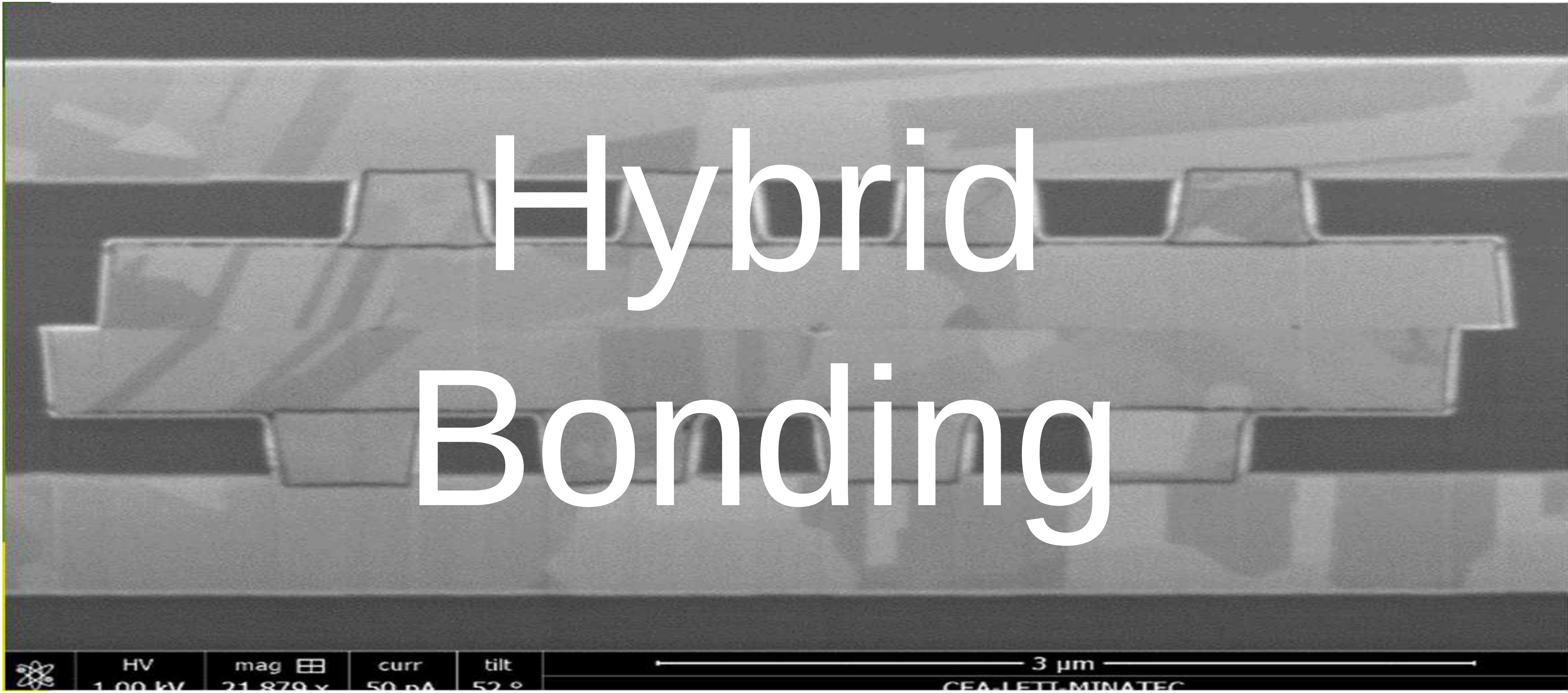
01 **Introduction to Hybrid Bonding (W2W/D2W)**

02 **Metrology requirements for Hybrid Bonding**

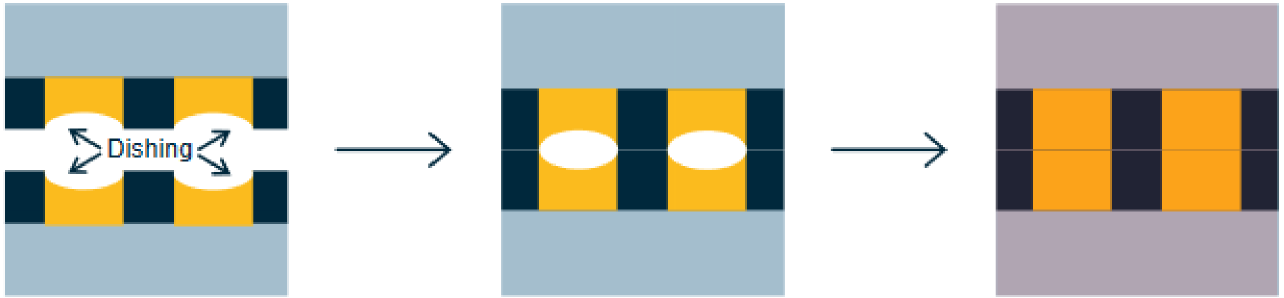
03 **SUSS MM200 integrated metrology station and metrology capability**

04 **The challenge with D2W bonding**

Hybrid Bonding



Hybrid Bonding – a combination of hydrophilic fusion bonding and Cu diffusion which requires front-end cleanliness levels

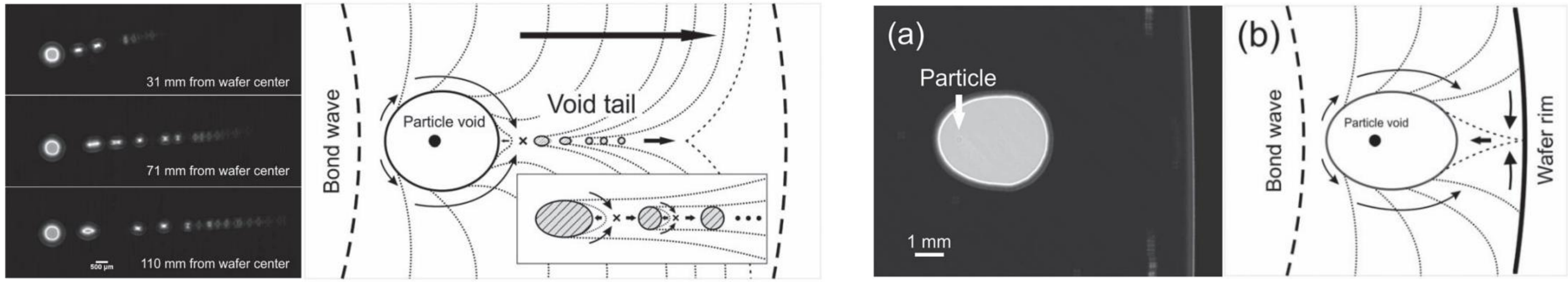


Surface preparation (cleaning and plasma activation) and D2W or W2W alignment

Fusion bonding of dielectric at room temperature

Annealing to form a strong covalent bond and metal inter-diffusion

■ Silicon ■ Dielectric ■ Cu



SiCN bond wave propagation from center to edge leaves large voids around particles as well as void tail from bond wave collisions: 25µm polymer particle leaves ~700µm void close to wafer center

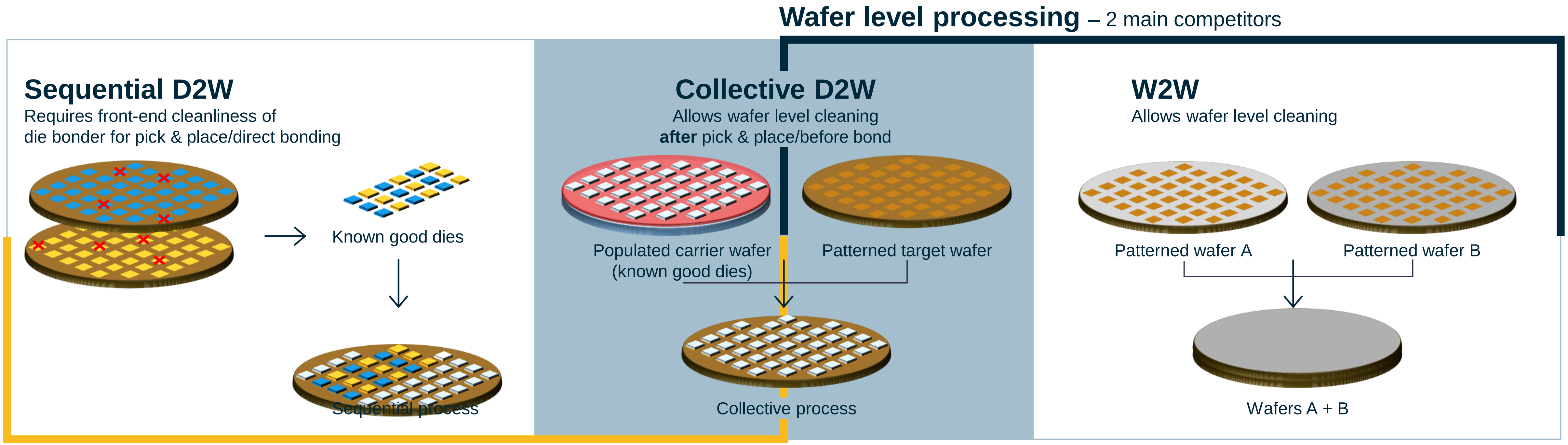
Source: imec (F. Nagano et al), Void Formation Mechanism Related to Particles During Wafer-to-Wafer Direct Bonding, ECS Journal of Solid State Science and Technology (2022)

Hybrid Bonding = mechanical contact (hydrophilic fusion bonding)
+ electrical Cu-Cu contact

Cu expansion of ~1 - 2nm during annealing ensures sufficient mechanical contact for metal diffusion to take place → electrical contact

Front-end cleanliness is essential in order to avoid particle induced voids which can be several mm in size, even for small particles

SUSS MicroTec's solutions for different hybrid bonding processing schemes



Wafer level processing – 2 main competitors

Sequential D2W

Requires front-end cleanliness of
die bonder for pick & place/direct bonding

Collective D2W

Allows wafer level cleaning
after pick & place/before bond

W2W

Allows wafer level cleaning

Single die processing – 2–3 main competitors in R&D phase

Pick & Place Bonding

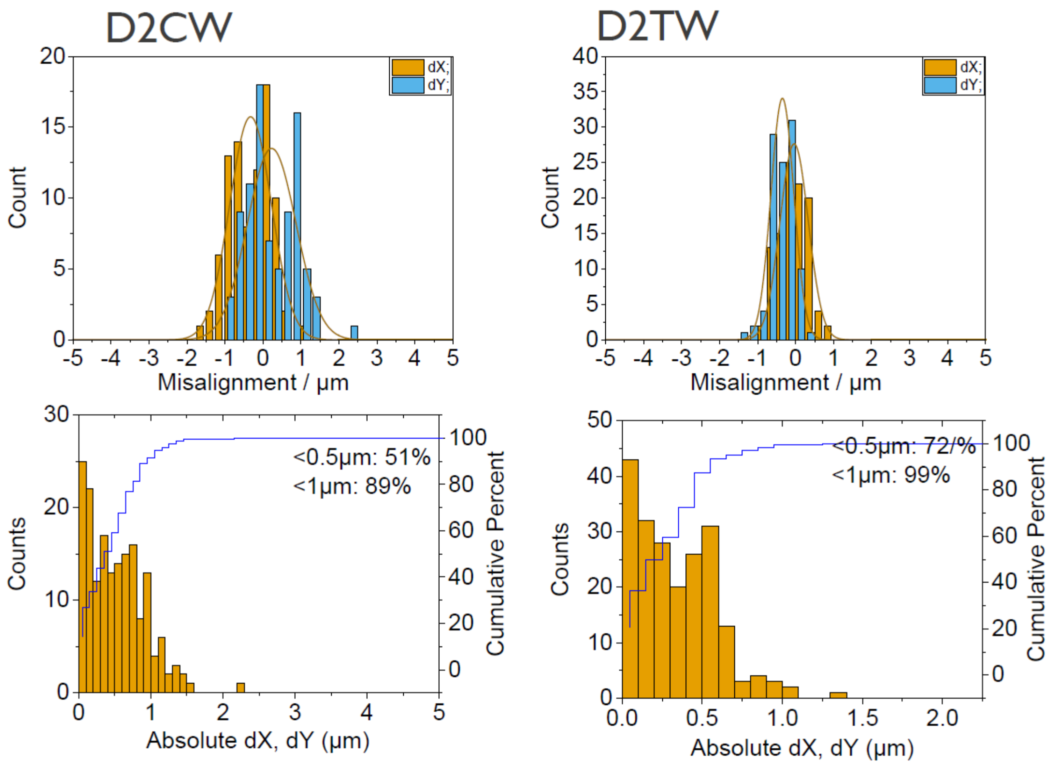
Surface Preparation

= Wet Clean & Plasma Activation

Surface Preparation & Bonding

All 3 processes avilable in **new** single platform: **XBC300 Gen2 D2W/W2W**

Collective D2W Hybrid Bonding allows for wafer level cleaning **& overlay optimization**

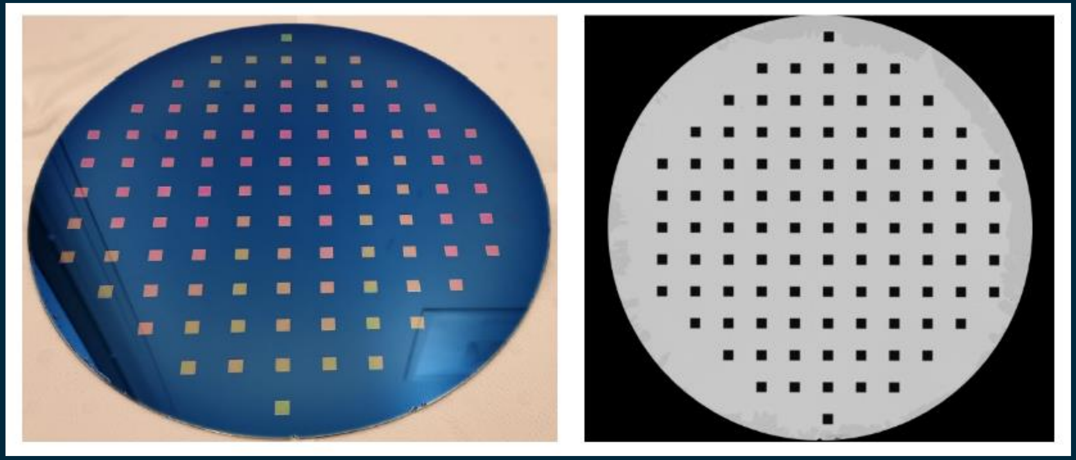


Alignment measurements after Die to Carrier Wafer (D2CW) transfer with imec's latest Flip Chip Bonder and Die to Target Wafer (D2TW) transfer with SUSS MicroTec's W2W bond aligner

Source: imec (partner technical week H2/2022, D110, K. Kennes), Impact of temporary substrates and adhesives on die-to-wafer overlay

Collective D2W Hybrid Bonding process flow enables wafer level cleaning after Die to Carrier Wafer (D2CW) transfer
→ ensures best possible cleanliness

Die to Target Wafer (D2TW) transfer shows **100% yield** after mechanical debonding of temporary carrier

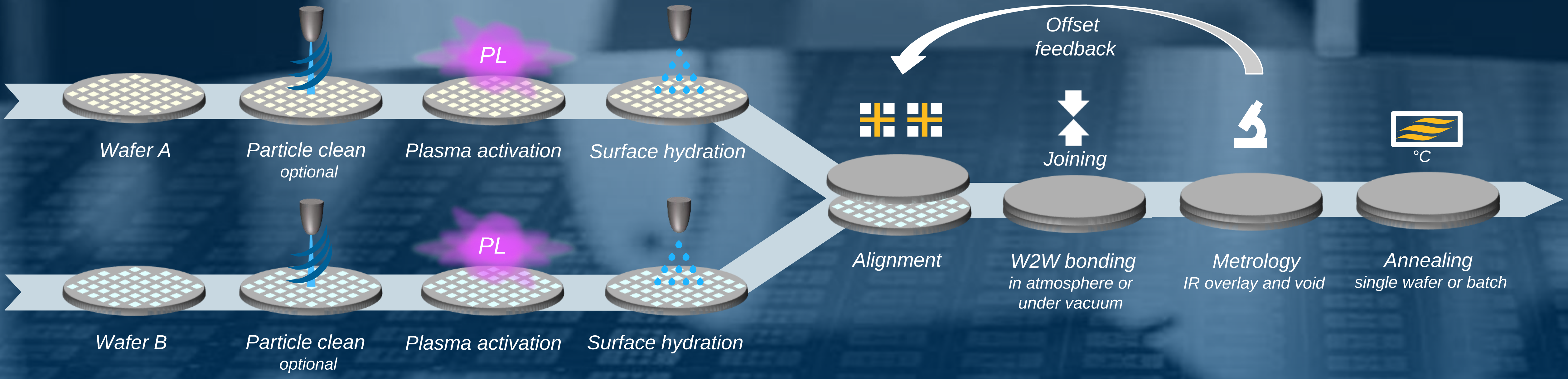


- Overlay errors after D2CW transfer with Flip Chip Bonder can partially be compensated by higher accuracy W2W bond aligner during collective D2TW transfer:

X / Y error **<1µm**: 89% after D2CW → **99%** after D2TW

X / Y error **<0.5µm**: 51% after D2CW → **72%** after D2TW

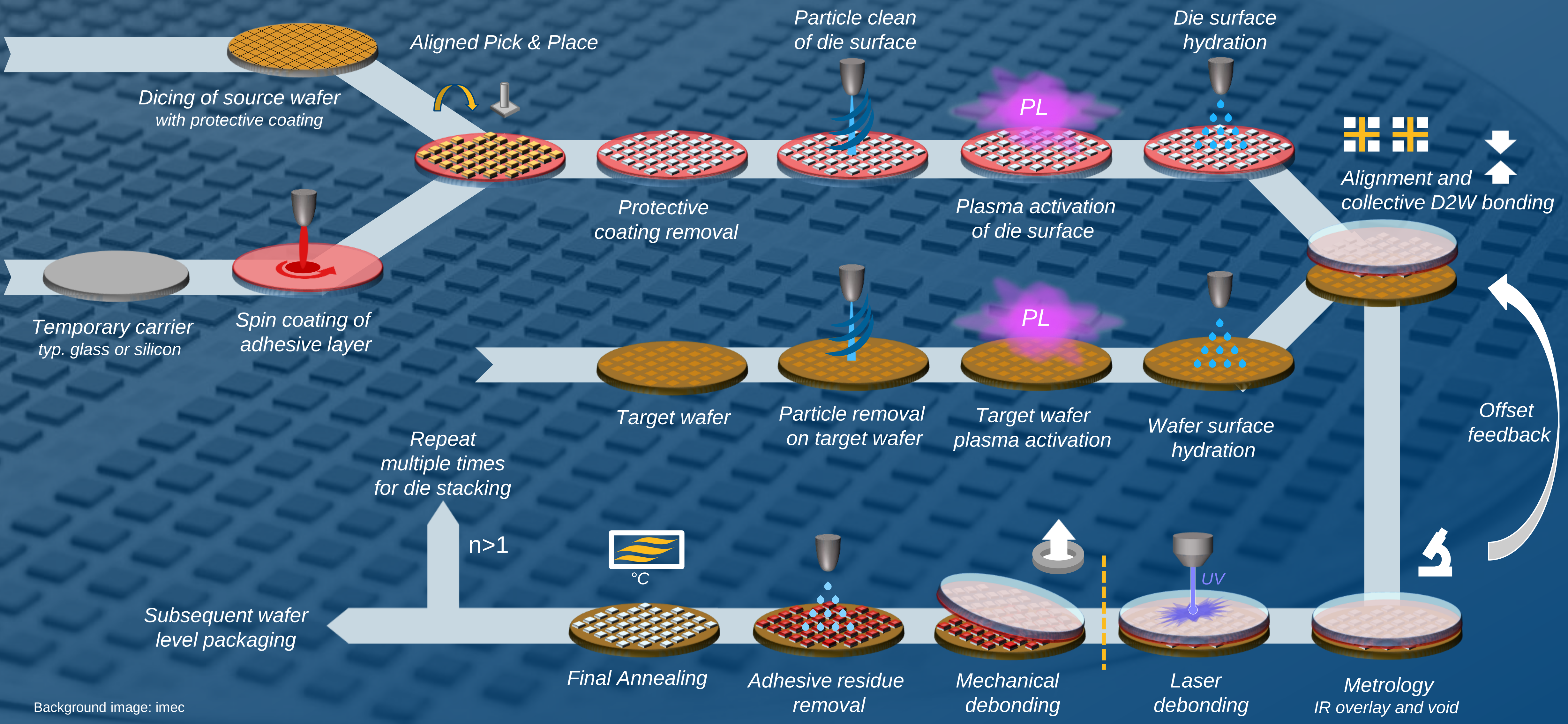
General process flow for W2W Hybrid Bonding



General metrology requirements:

Surface roughness	AFM
Copper pad topography	SPM or AFM
Cleanliness prior to bonding (particles)	optical inspection/DI scan
Voids after bonding	CSAM or transmissive IR imaging
Post-bond overlay	transmissive/reflective IR imaging
Bond strength	e.g. Maszara testing

General process flow for Collective D2W Hybrid Bonding



Dicing of source wafer
with protective coating

Temporary carrier
typ. glass or silicon

Spin coating of
adhesive layer

Aligned Pick & Place

Protective
coating removal

Particle clean
of die surface

Plasma activation
of die surface

Die surface
hydration

Target wafer

Particle removal
on target wafer

Target wafer
plasma activation

Wafer surface
hydration

Alignment and
collective D2W bonding

Offset
feedback

Metrology
IR overlay and void

Laser
debonding

Mechanical
debonding

Adhesive residue
removal

Final Annealing

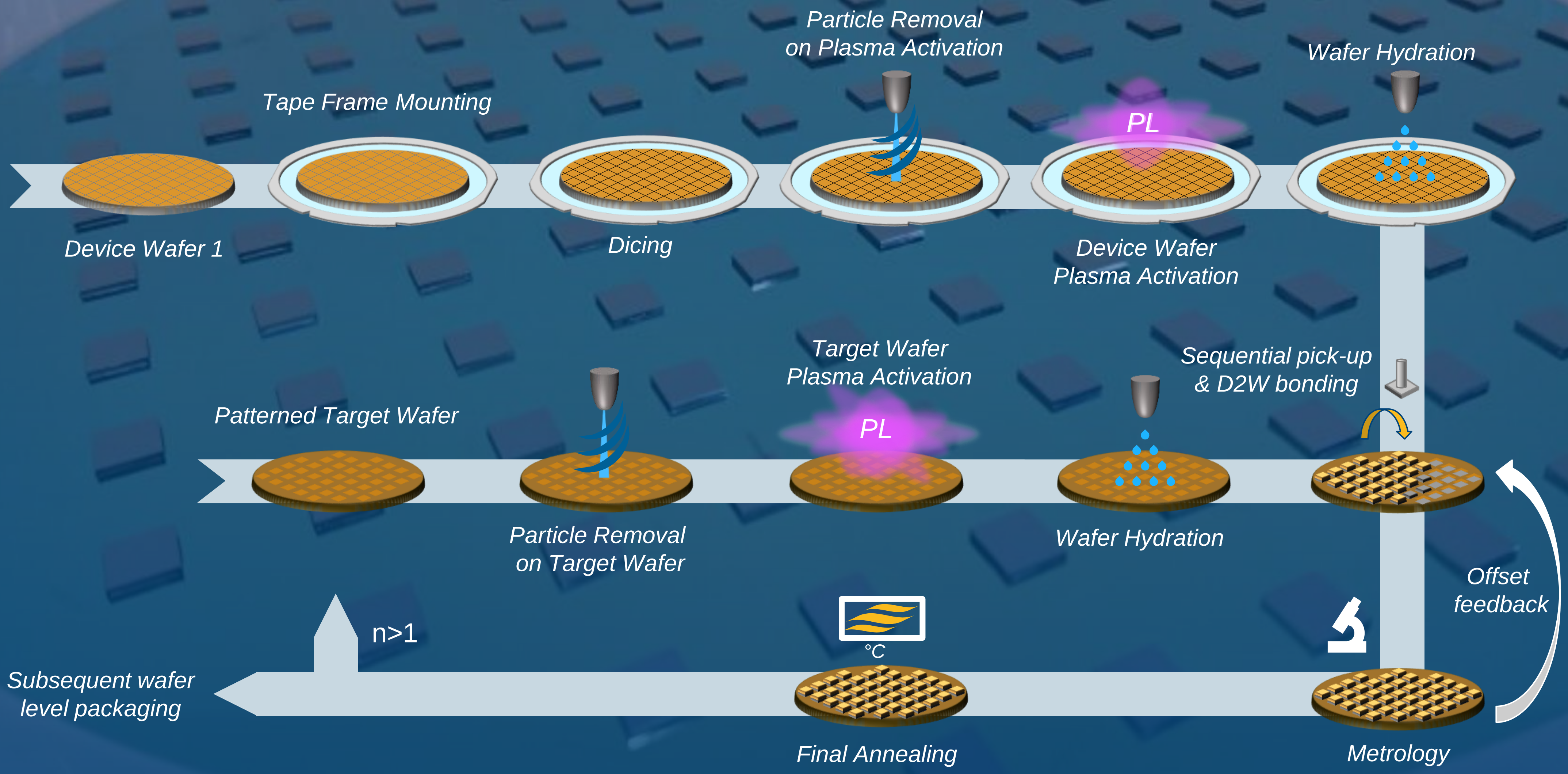
Repeat
multiple times
for die stacking

n>1

Subsequent wafer
level packaging

Background image: imec

General process flow for Sequential D2W Hybrid Bonding

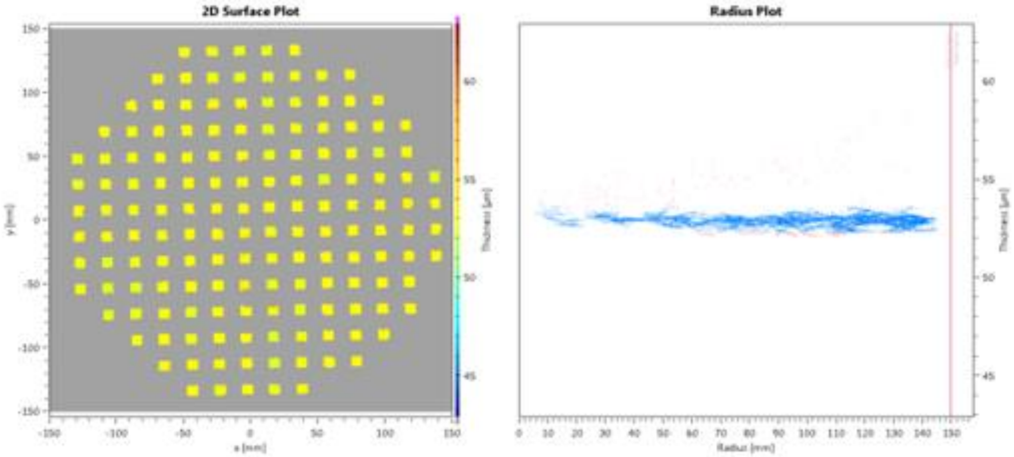


Sequential and collective D2W

General metrology requirements:

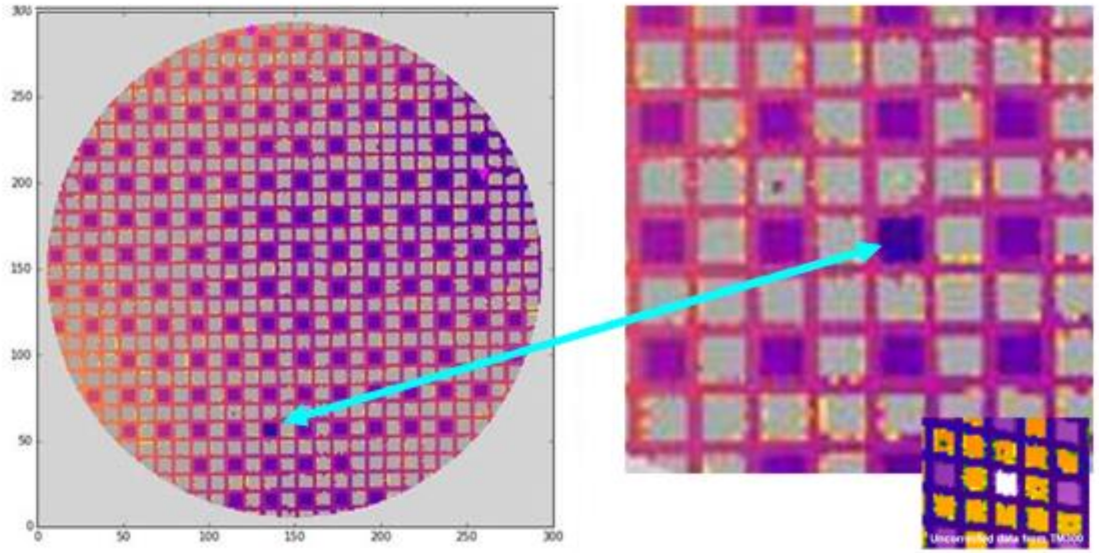
Surface roughness	AFM
Copper pad topography	SPM or AFM
Cleanliness prior to bonding (particles)	optical inspection/DI scan
Chipped edges after dicing	optical inspection/DI scan
Voids after bonding	CSAM or transmissive IR imaging
Post-bond overlay	transmissive/reflective IR imaging with 3D focus capability (multiple die layers)
TTV	optical measurement (interferometric)
Thin film measurement	optical measurement (interferometric)
Co-planarity measurement	optical inspection (chromatic confocal)
Bond strength	e.g. shear testing?

Metrology capability @ SUSS MicroTec

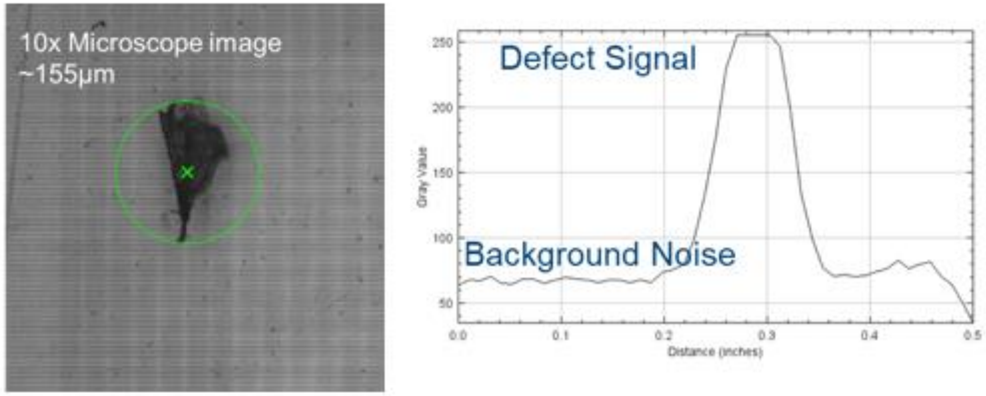


Wafer ID / Lot ID : -
Lot ID : -
Wafer Size : 300.00 mm
Refractive Index : 3.70
Resolution : 1.00 mm
Edge Exclusion : 0.00 mm
Mean Thickness : 52.92 µm
Min. Thickness : 39.93 µm
Max. Thickness : 64.69 µm
TTV (100%) : 24.76 µm
TTV (95%) : 1.29 µm
Quality Threshold : 30.00

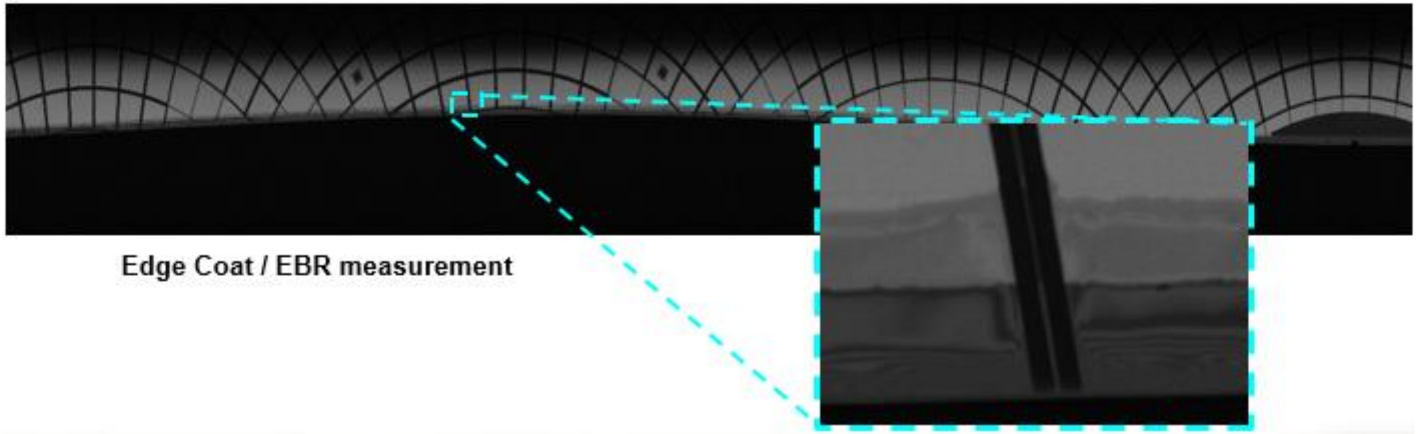
Thin-film measurement of adhesive layer underneath dies for collective D2W



Co-planarity measurement of populated wafer (collective D2W) also showing missing die locatiopns and chip double placement



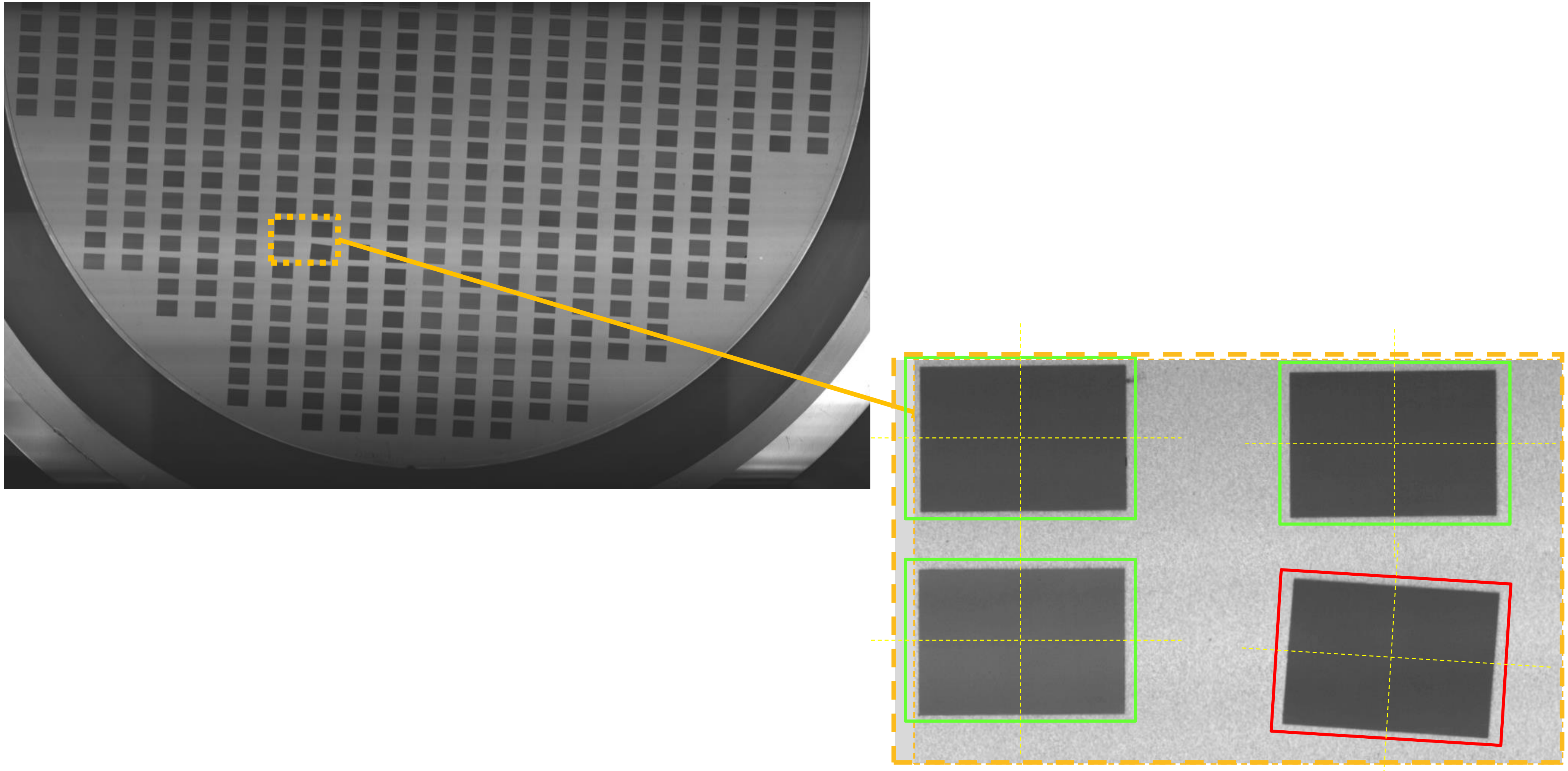
Defect Inspection on patterned 300mm wafer



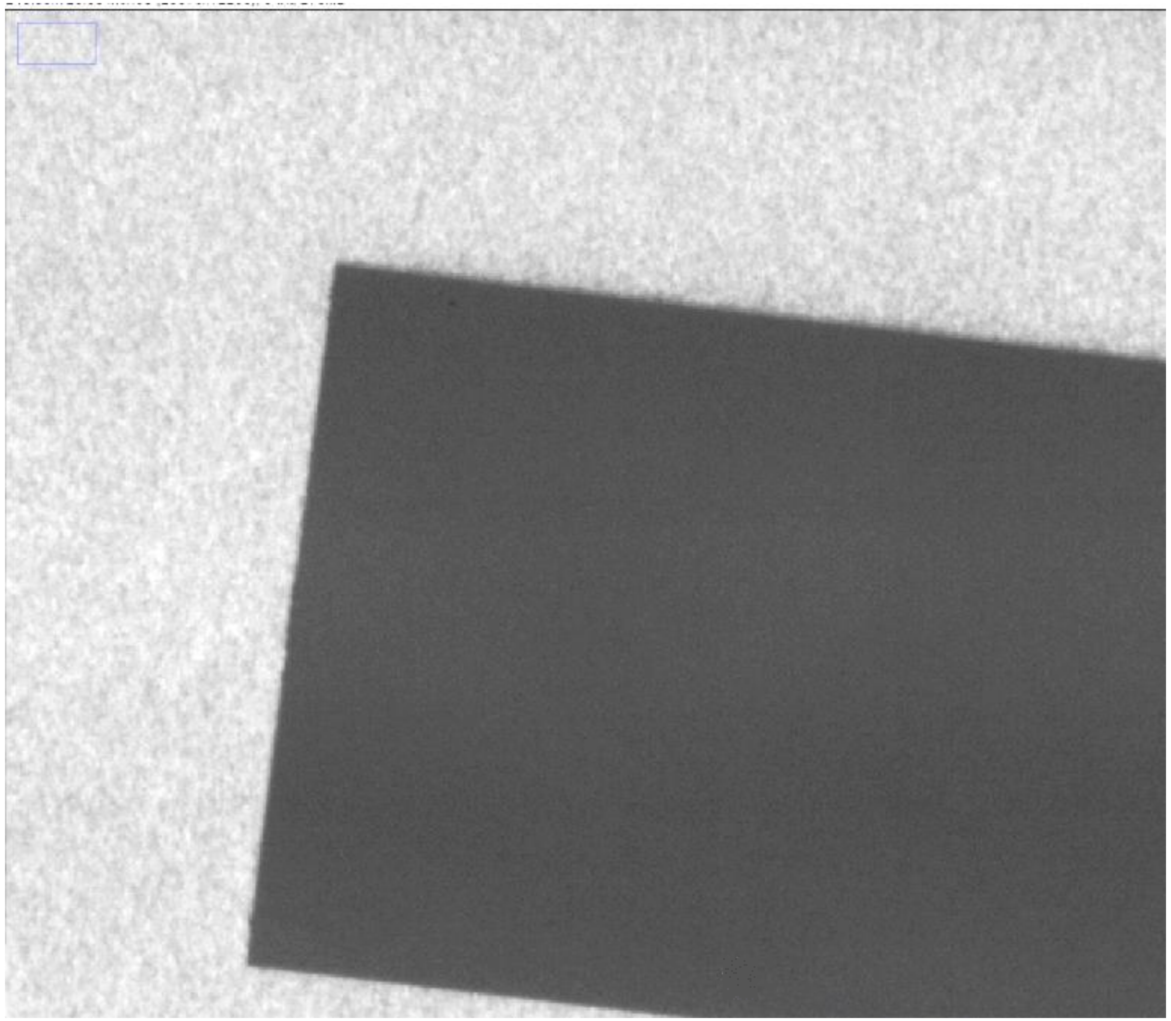
Edge Coat / EBR measurement

Die registration

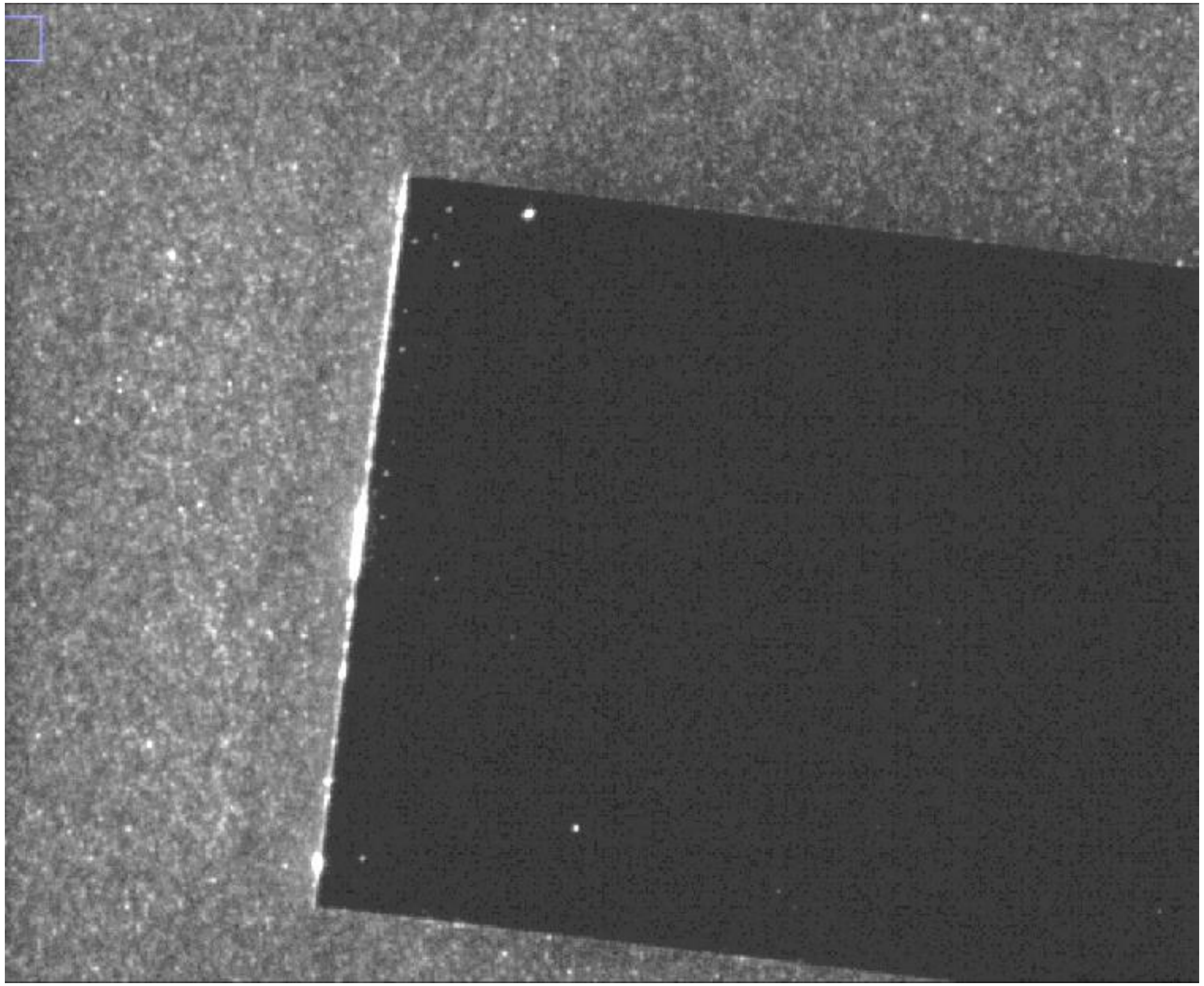
- Bright-field image of populated 300mm wafer (with 775µm thick dies) clearly showing placement errors.



Die cleanliness



Bright-field image of individual die, particles can hardly be seen

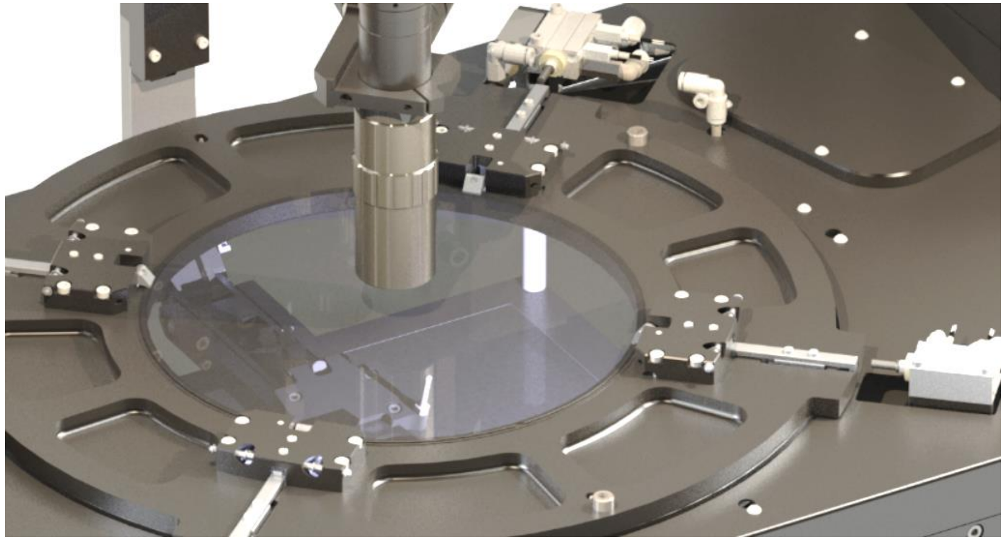


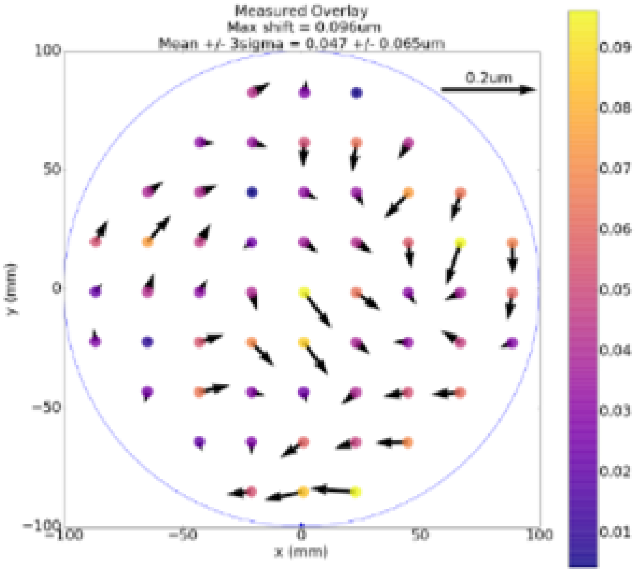
Dark-field image of same die with same particles

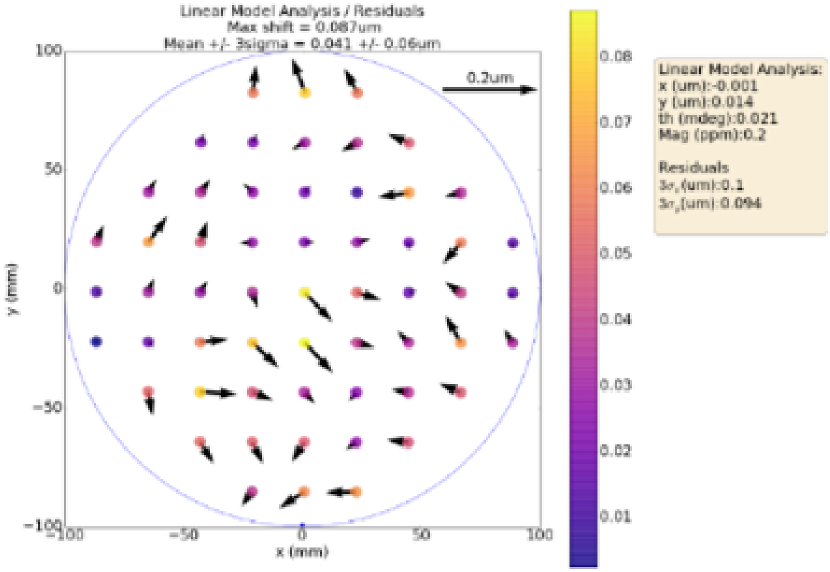
MM300

Integrated Metrology Module MM300

- Ultra-high accuracy IR overlay verification (transmissive/reflective mode) and IR void detection (**>500µm** void sizes)
  - + Multi-point IR overlay metrology (with autofocus)
  - + Throughput optimized (fast and slow recipes (autofocus for each site))
  - + True full-field inspection capability (no blind spots on the wafer)
  - + Resolution: **<10nm**, precision is: **±15nm 3σ**





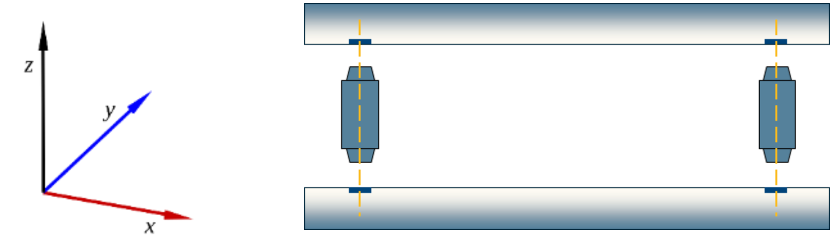


Linear Model Analysis:
x (um):-0.001
y (um):0.014
th (mdeg):0.021
Mag (ppm):0.2

Residuals
$3\sigma_x$(um):0.1
$3\sigma_y$(um):0.094

Often used terms in bonding: alignment accuracy and overlay

Alignment accuracy consists of x, y and theta components
→ Capability to align targets of upper & lower substrate via x-, y-, theta positioning



Inter-substrate alignment (ISA) principle of SUSS MicroTec's W2W bond aligner

Overlay is the vector of the total post-bond alignment error inclusive of all error components (alignment, scaling and residuals) at a specific measurement site

$$\text{Overlay} = \sqrt{\Delta x^2 + \Delta y^2}$$

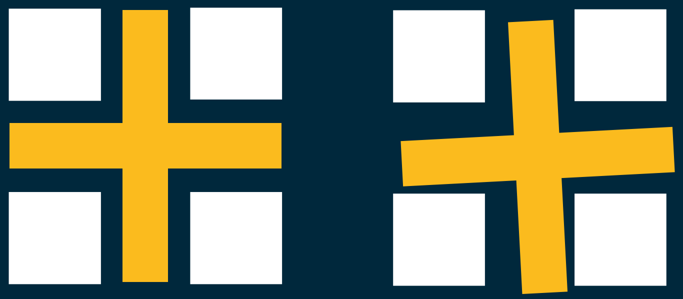
Mean / Max of all overlay vectors across the entire wafer

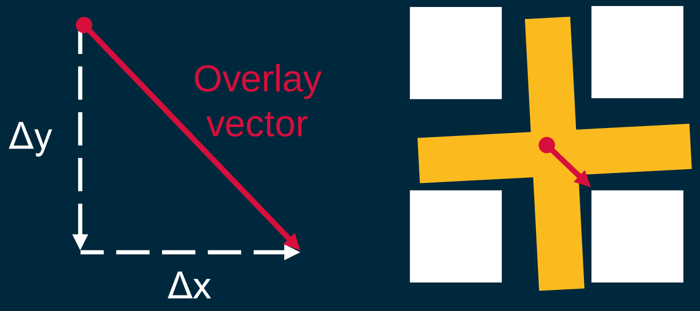
$$\text{Mean overlay} = \frac{vector_1 + vector_2 + vector_3 + vector_4 \ldots + vector_n}{number\ of\ measurement\ sites}$$

$$\text{Max overlay} = \text{Max}\left(\frac{vector_1 + vector_2 + vector_3 + vector_4 \ldots + vector_n}{number\ of\ measurement\ sites}\right)$$

Ideal alignment
→ No shift

Actual alignment
→ x-, y-, theta shift

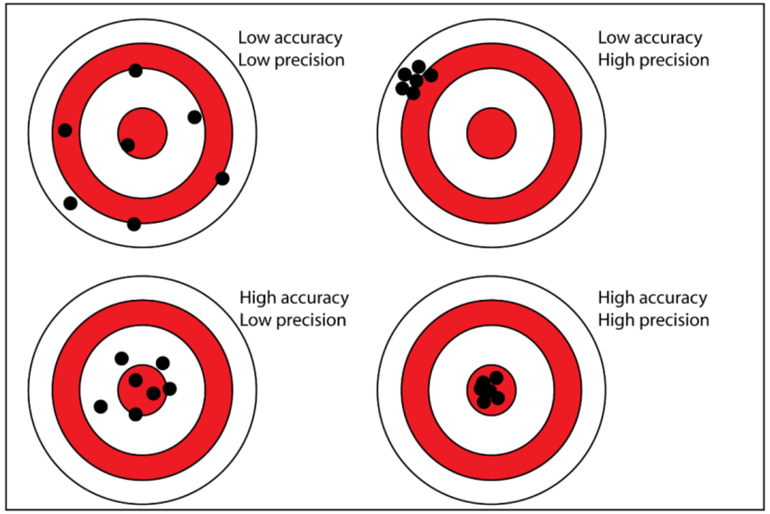


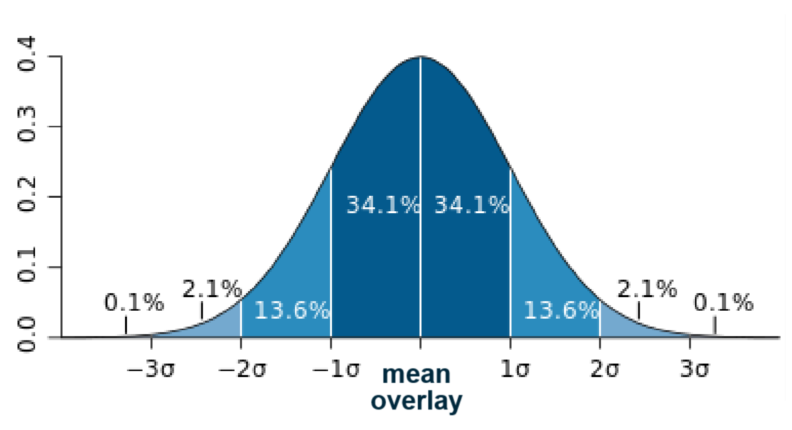


Often used terms in bonding: 3-sigma or 3σ

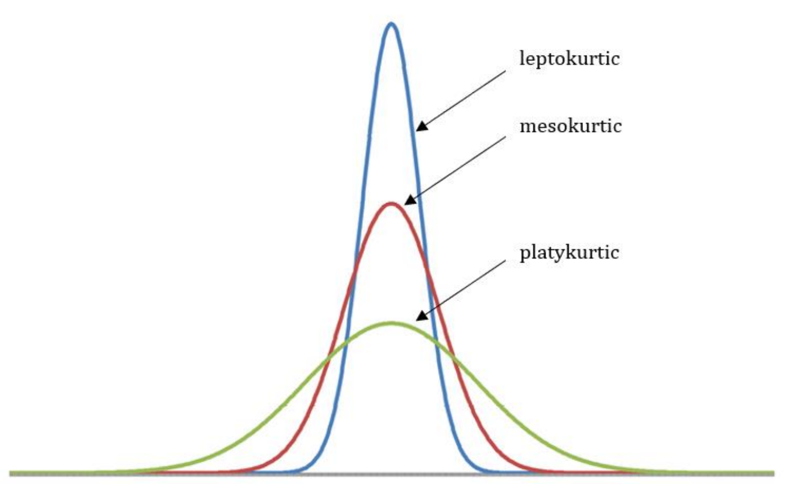
- Overlay precision 3σ describes the distribution curve of all overlay measurements over the wafer (e.g. 148 measurements)
- **3σ represents the range between 99.7% of all measurement points**
- Mean overlay position should ideally be as low as possible
- Tails of distribution should be as short as possible. Preferred is a leptocurtic behaviour (also referred to as “positive kurtosis”)

- In the context of bonding performance, 3-sigma only tells part of the full story
- True bonding and system performance can only be described by **mean overlay + 3σ**





Distribution curve of measurements with mean overlay at its center



Different types of distribution curves

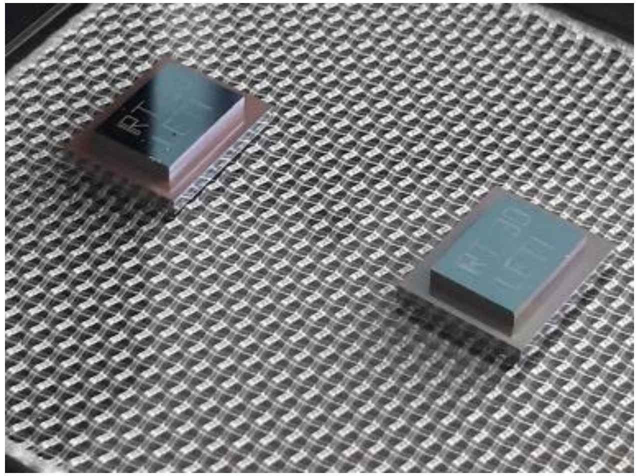
Bonded D2W samples (775µm) inspected via IR microscopes

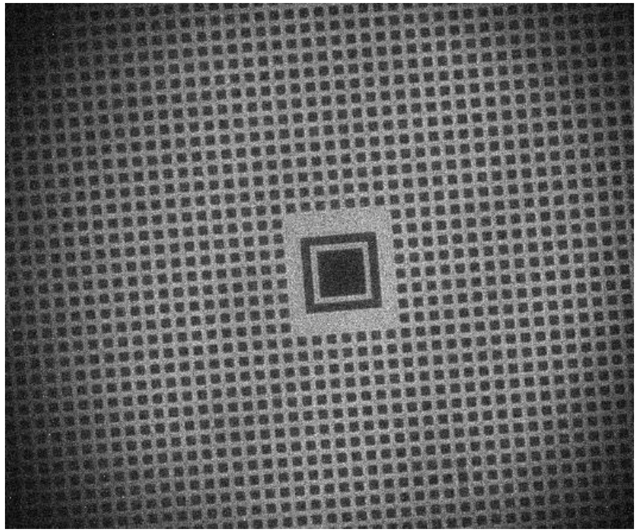
Samples bonded with SET NEO HB die-bonder (D2W)

leti
cea tech

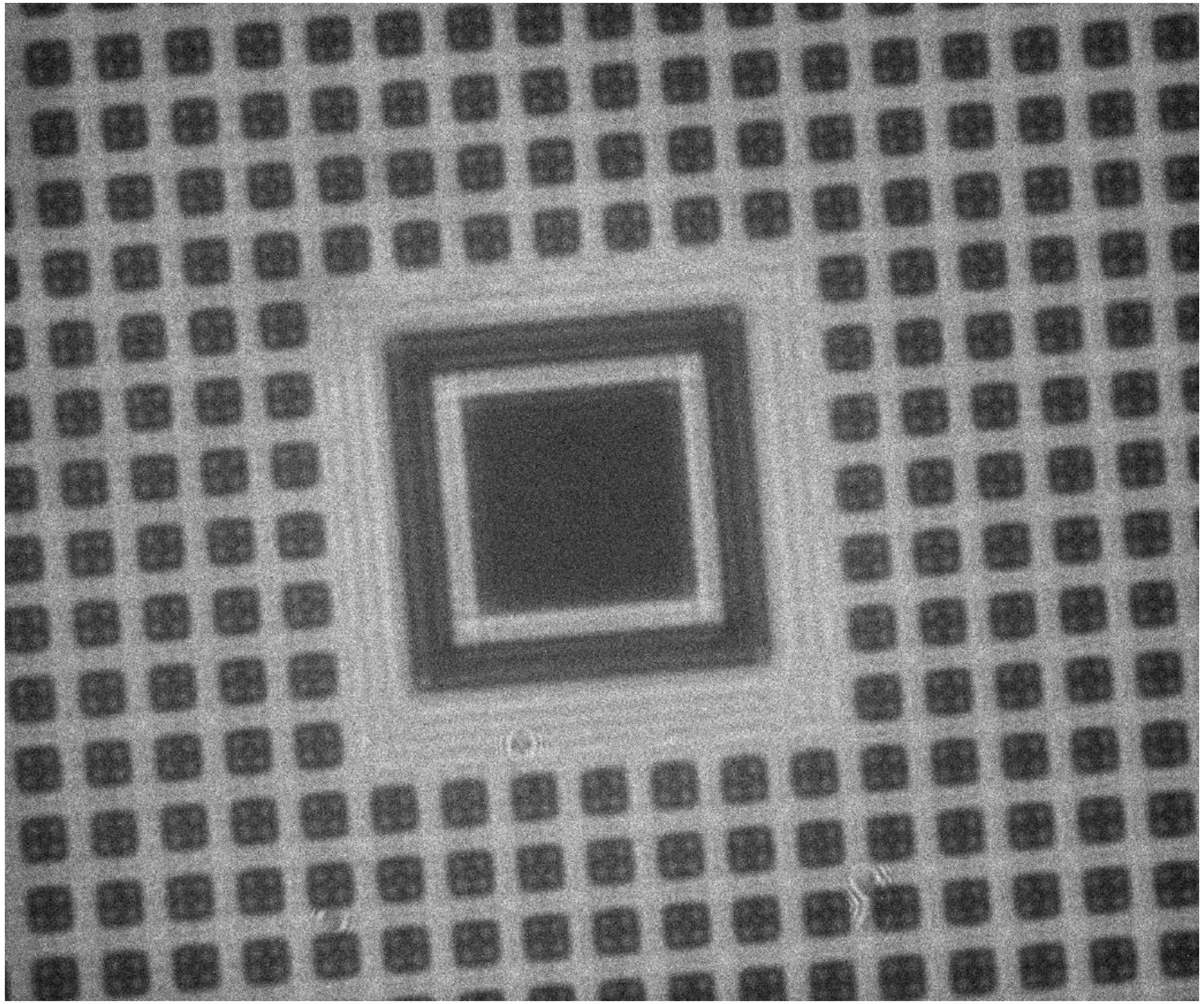
set
Smart Equipment Technology

NANOELEC.





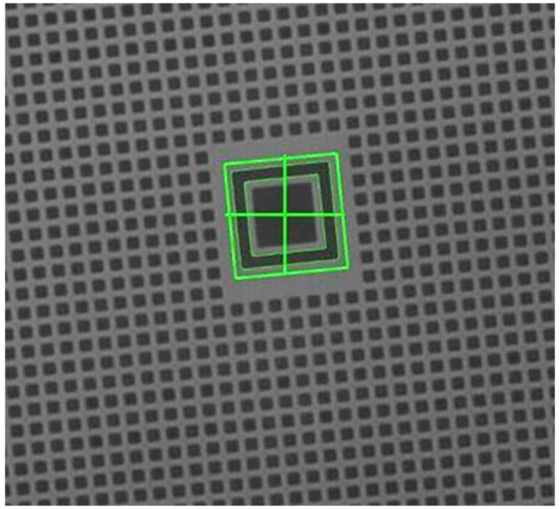
Nikon Eclipse L300N optical microscope (10x objective)



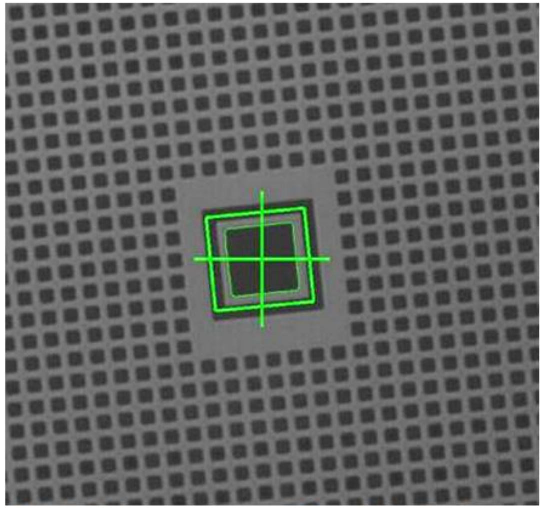
Nikon Eclipse L300N optical microscope (20x objective)

IR overlay measurement of D2W samples using MM300

***Die #1 alignment results**:*
X = 0.068µm
Y= 0.068µm
Theta =-0.683mdeg

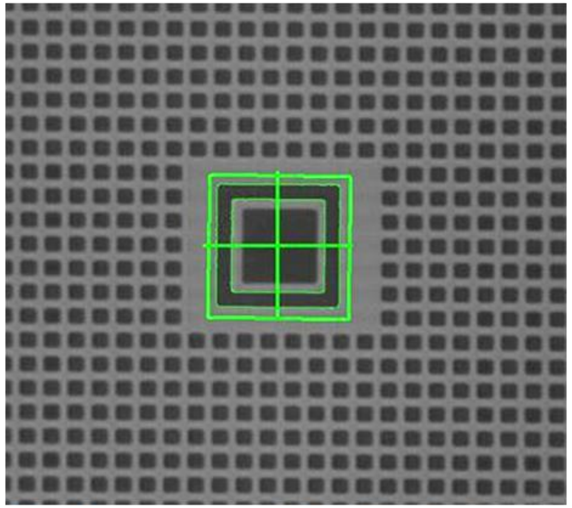


Die #1, outer target (20x objective)

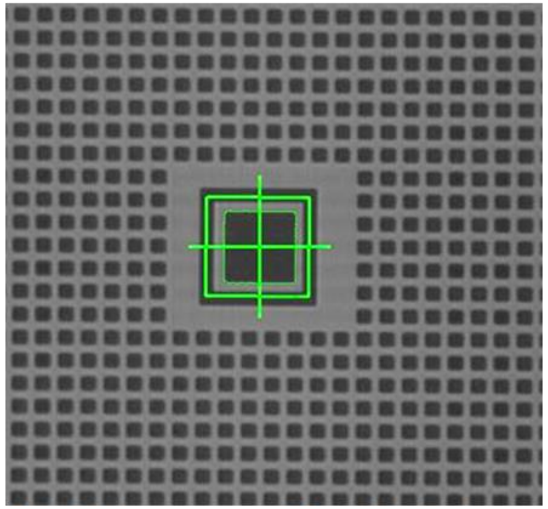


Die #1, inner target (20x objective)

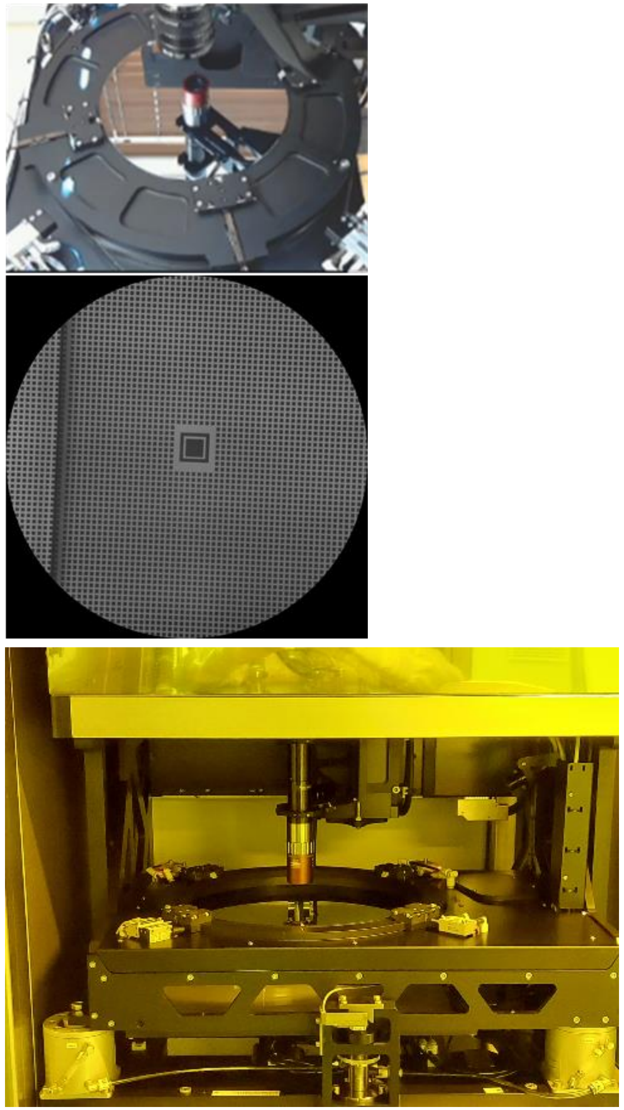
***Die #2 alignment results**:*
X = 0.145µm
Y= 0.224µm
Theta =0.363mdeg



Die #2, outer target (20x objective)

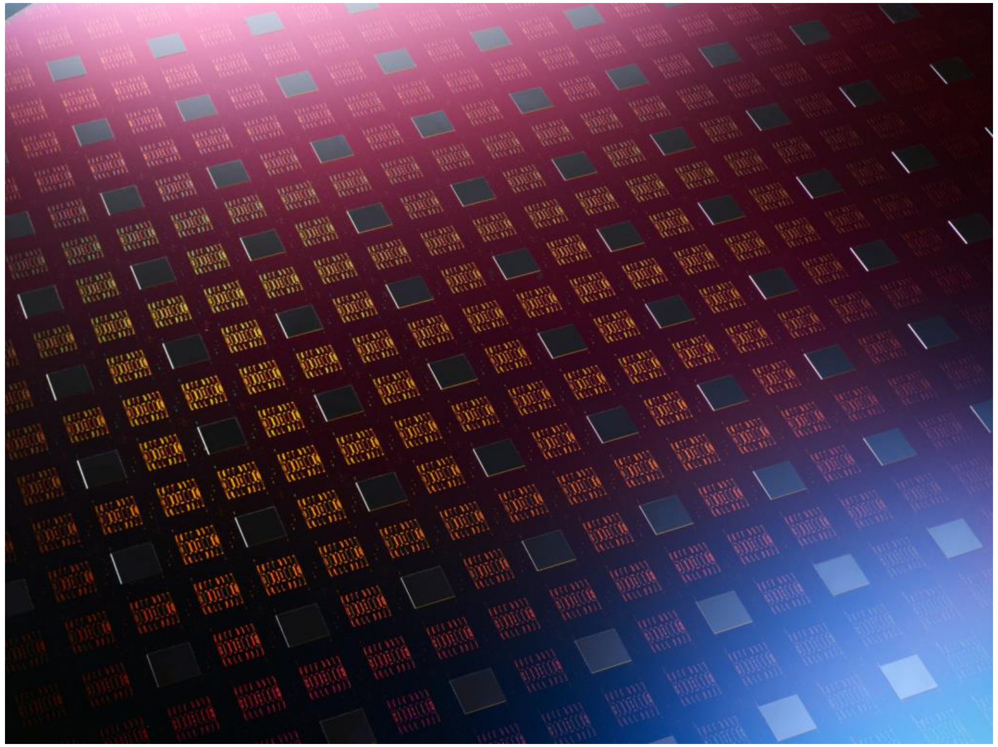


Die #2, inner target (20x objective)



Summary

- SUSS MicroTec has already investigated multiple metrology methods for in-line quality control for hybrid bonding, which are available on request
- Commercial D2W players will most likely face high-throughput challenge for 100% in-line overlay control
  - SUSS MiroTec is working on „overlay only“ HVM platform to meet future high-throughput demands
- Existing metrology solutions have to be adapted and even extended to meet new requirements from D2W applications (die registration, co-planarity measurements, bond strength, etc.)



WWW.SUSS.COM

SÜSS MicroTec

Thank You
for your Attention!

SUSS MicroTec SE
Schleissheimer Str. 90
85748 Garching