Metrology for Hybrid Bonding

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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

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

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

SUSS MicroTec’s solutions for different hybrid bonding processing schemes

**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

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**Surface Preparation**
= Wet Clean & Plasma Activation

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**Pick & Place Bonding**

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**Surface Preparation & Bonding**

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

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
General process flow for W2W Hybrid Bonding

Wafer A
- Particle clean (optional)
- Plasma activation
- Surface hydration

Wafer B
- Particle clean (optional)
- Plasma activation
- Surface hydration

Alignment
- W2W bonding in atmosphere or under vacuum

Metrology
- IR overlay and void
- Offset feedback
- Joining

Annealing
- Single wafer or batch

General metrology requirements:
- Surface roughness
- Copper pad topography
- Cleanliness prior to bonding (particles)
- Voids after bonding
- Post-bond overlay
- Bond strength

AFM
- SPM or AFM
- optical inspection/DI scan
- CSAM or transmissive IR imaging
- transmissive/reflective IR imaging
e.g. Maszara testing
General process flow for Sequential D2W Hybrid Bonding

1. Tape Frame Mounting
2. Dicing
3. Device Wafer 1 Plasma Activation
4. Target Wafer Plasma Activation
5. Particle Removal on Plasma Activation
6. Sequential pick-up & D2W bonding
7. Wafer Hydration
8. Final Annealing
9. Metrology

Subsequent wafer level packaging

Particle Removal on Target Wafer

n>1 Offset feedback
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
  - transmissive/reflective IR imaging with 3D focus capability (multiple die layers)
- Post-bond overlay
  - optical measurement (interferometric)
- TTV
  - optical measurement (interferometric)
- Thin film measurement
  - optical inspection (chromatic confocal)
- Co-planarity measurement
  - e.g. shear testing?
Metrology capability @ SUSS MicroTec

- Thin-film measurement of adhesive layer underneath dies for collective D2W
- Co-planarity measurement of populated wafer (collective D2W) also showing missing die locations 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
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
Often used terms in bonding: alignment accuracy and overlay

Alignment accuracy consists of x, y and theta components.

\[ \rightarrow \text{Capability to align targets of upper & lower substrate via x-, y-, theta positioning} \]

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

\[ \text{Mean overlay} = \frac{\text{vector}_1 + \text{vector}_2 + \text{vector}_3 + \text{vector}_4 + \cdots + \text{vector}_n}{\text{number of measurement sites}} \]

\[ \text{Max overlay} = \text{Max} \left( \frac{\text{vector}_1 + \text{vector}_2 + \text{vector}_3 + \text{vector}_4 + \cdots + \text{vector}_n}{\text{number of measurement sites}} \right) \]
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**
Bonded D2W samples (775µm) inspected via IR microscopes

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

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 MicroTec 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.)
Thank You for your Attention!

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