Die-to-Wafer Hybrid Bonding to Address Next-Gen Electronics Packaging Challenges

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AGENDA

- Introduction to D2W Hybrid Bonding
- Process Flow & Co-Optimizations
- Equipment Solutions for D2W Hybrid Bonding
- Summary

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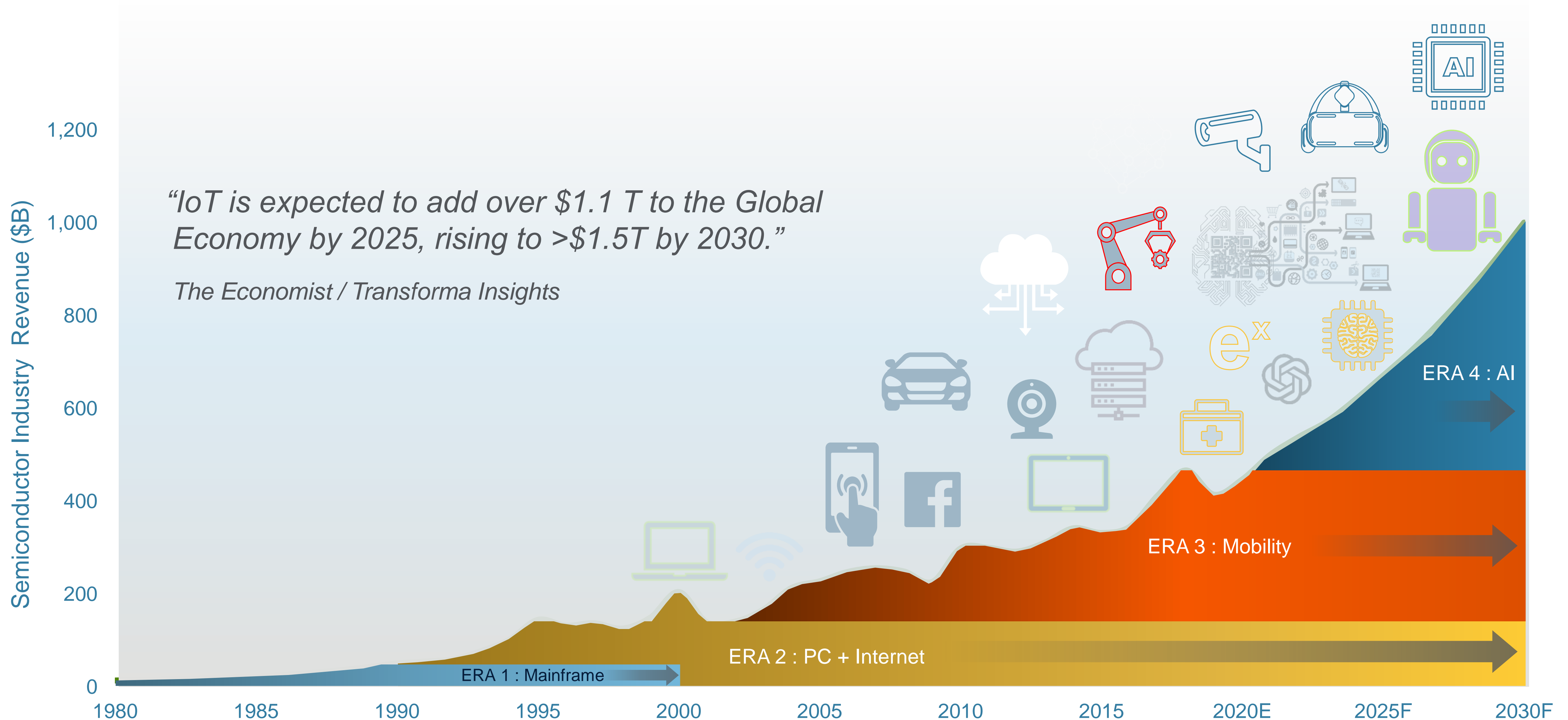
The **BIGGEST** Computing Wave Yet: AI



IoT – Internet of things
PC – Personal computer
AI – Artificial intelligence

Source: SEMI, VLSI, Applied Materials

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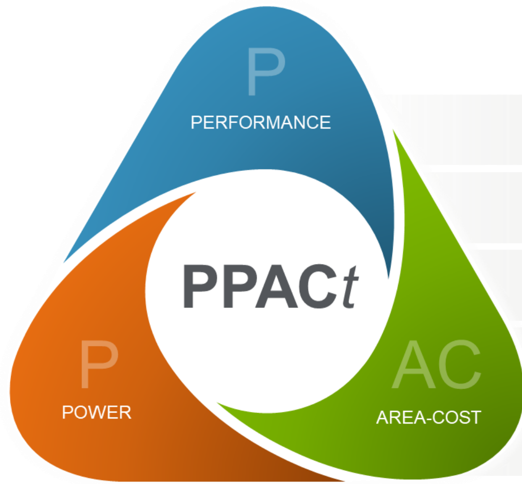
Advanced Packaging | Enabling Heterogeneous Integration

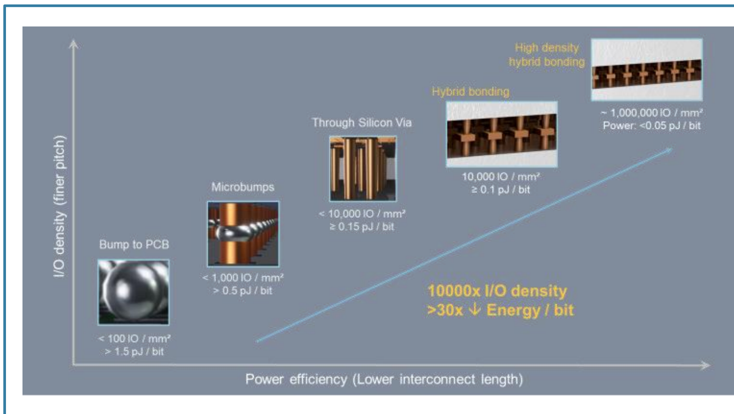


Enabled by

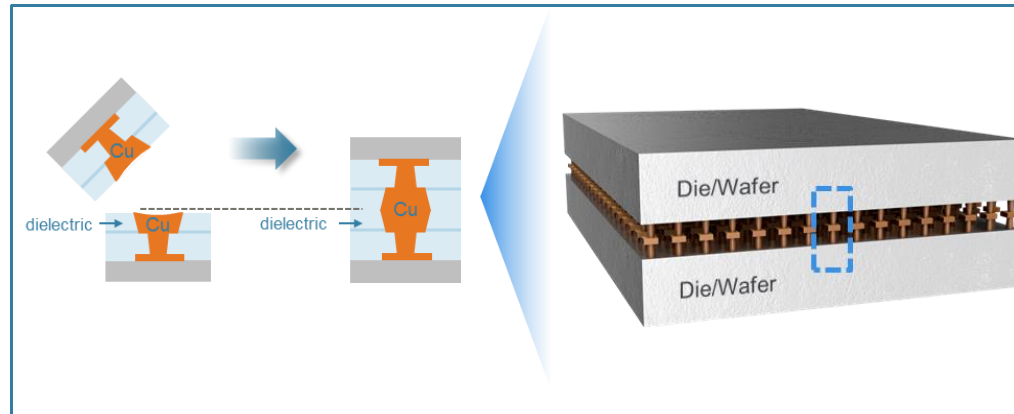
- New architectures
- New structures / 3D
- New materials
- New ways to shrink
- **Advanced packaging**

- AI/HPC is driving need for **higher I/O density**
- **Integrated** logic and memory for higher performance
- Efficient design/IP reuse driving improved time to market
- **Hybrid bonding** is a key enabler for heterogeneous integration

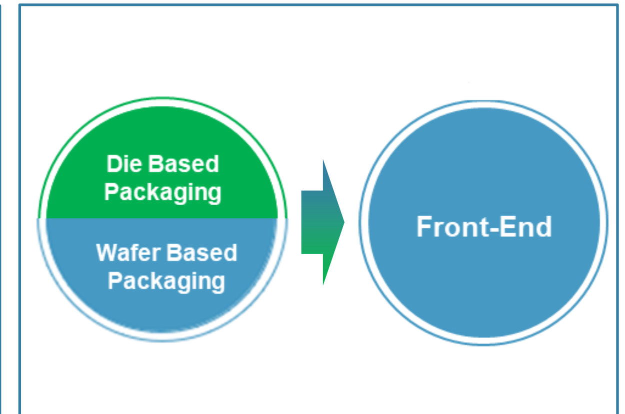
Increasing I/O Density



Extending PPAC*t*



Hybrid Bonding Moving to Front End



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Applied Materials | Broadest Portfolio in Heterogenous Integration

Hybrid Bonding

ILD Dep CVD	Damascene Etch	Barrier/Seed PVD	Cu Pad Fill ECD	Cu CMP (w/Dishing)	Integrated Bonder
Producer **Avila / UHP TEOS**	Sym3 GT	Endura **EnCoRe 2**	Mustang Cu ECD	**Reflexion LK LKP**	Integrated D2W Hybrid Bonder

TSV Formation

TSV Etch (Si/FE films)	CVD Liner	PVD Barrier | Seed	Cu Plating	Planarization
Centris **Sym3 Via Sym3X**	Producer **InVia 2**	Endura **Ventura**	**Nokota Raider Mustang**	**Reflexion LK LKP**

TSV Reveal

Silicon Polish	Recess Etch	CVD LT Passivation	Cu & Oxide Polish
Reflexion LK	Centris **Sym3 Via**	Producer **Avila**	**Reflexion LK**

Bump FanOut RDL

Al Pad / RDL Expose | Develop	PVD	ECD	PR Strip	UBM Etch
Endura **Execta 2 Al**	**Charger**, **Endura**	**Nokota**	**Raider**	**Raider**

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META Center

300mm flows
Integration testing
@ SUNY Albany

Maydan Technology Center

FEOL Product Development

Advanced Packaging Development Center

Heterogeneous integration
@IME Singapore

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NEW
EPIC CENTER
» 180k ft² of cleanroom + supporting labs
» Applied, Customer, University and Partner space
» Operational Q1’26
CURRENT
MTC R&D Fab
» 44k ft² of cleanroom + supporting labs
» Applied only
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Applied + Besi | Accelerating Adoption of D2W Hybrid Bonding

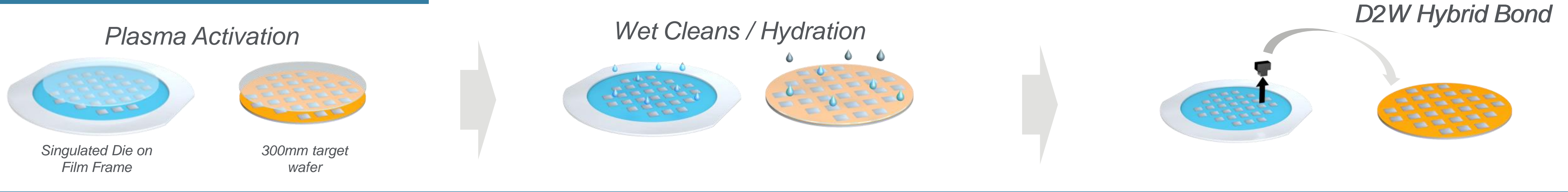
- Front & Back End Process & Equipment Expertise
- Market Leader in Advanced Wafer Level Packaging
- Dedicated Packaging Development Center in Singapore

- Assembly Equipment Process Expertise
- Market Leader in Hybrid Bonding Systems

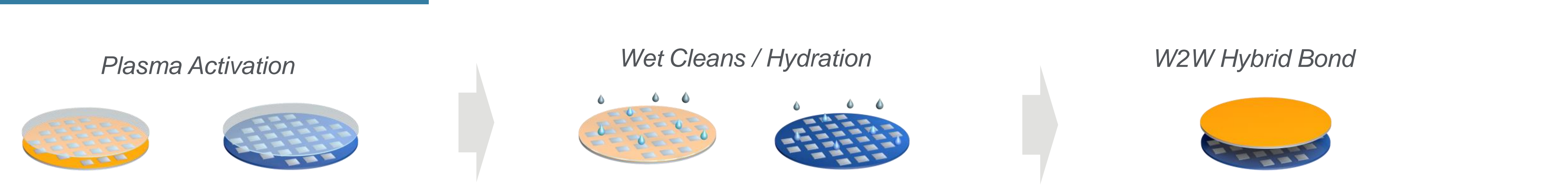
Formation of a Center of Excellence for D2W Hybrid Bonding Announced in Oct'20

Process Flows | D2W Vs W2W Vs. Co-D2W

D2W Hybrid Bonding :



Wafer2Wafer Hybrid Bonding :



Collective D2W Hybrid Bonding :

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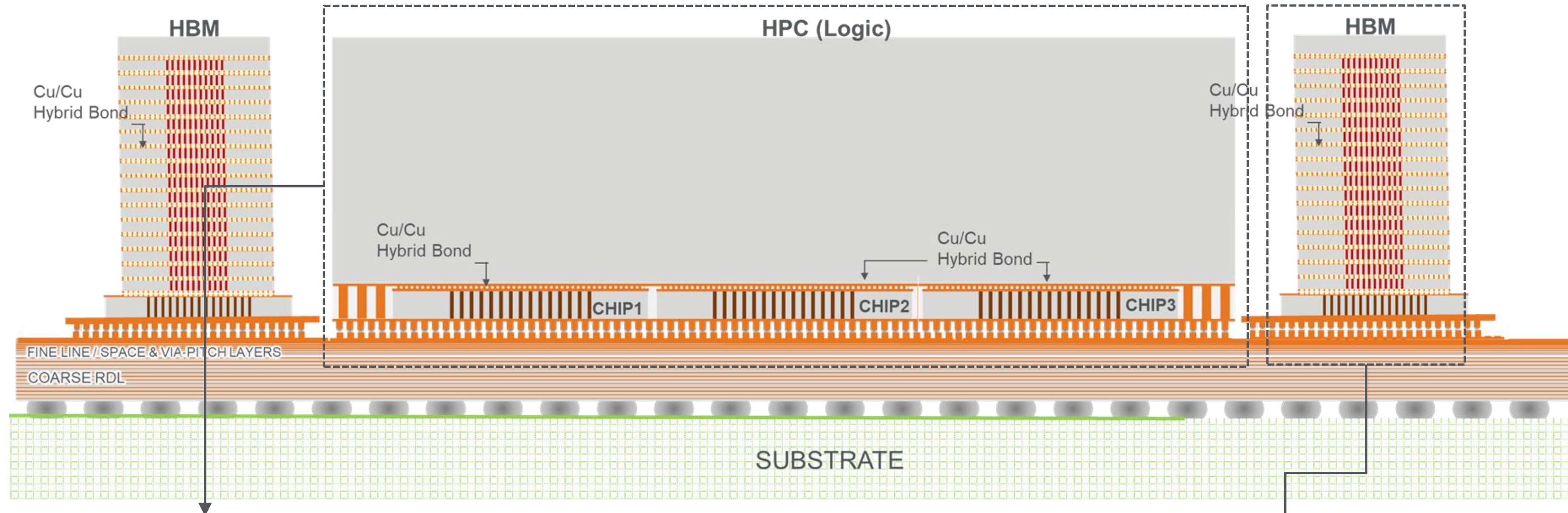
Hybrid Bonding | Comparisons of Key Flows



Advanced Logic

Die2Wafer	✓ Allows for multiple types of Chiplet integration ✓ On the fly binning ✓ Lowest cycle / queue times ✓ Highest accuracy & Yield
Collective D2W	× High cost (Complex process flow/architecture) × Die shift propagation (D2W+W2W) × Die to die thickness variation
Wafer 2 Wafer	✓ Ability to rework × Limited to 2-4 stack × Non KGD process (yield)

Stacked DRAM - HBM

Die2Wafer	✓ Complex Chiplet integration ✓ Lowest cycle / queue times ✓ High accuracy & Yield × Currently limited to >30u die thickness
Collective D2W	× High cost (Carriers + Equipment) × Die shift propagation (D2W+W2W) × Die to die thickness variation × Limited to less complex packages
Wafer 2 Wafer	× Non a viable flow

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Integrated D2W Hybrid Bonders | | Process Flow

1. ILD Dep CVD
2. Damascene ETCH
3. Barrier/ Seed PVD
4. Cu Pad Fill ECD
5. Cu CMP
6. Wafer Singulation
7. Pre-Treatment
8. Hybrid Bonding
9. Wafer Anneal
10. Gap Fill CVD
11. Liner CMP
12. Thru Ox Via ETCH
13. Barrier/ Seed PVD
14. TOV Fill ECD
15. CMP

Pre-Treatment:
- Degas + Plasma Activation
- Wet Clean + Hydration
- Film Frame UV Release

Integrated D2W Hybrid Bonders | Besi 8800 Chameo *Ultra Plus*

- First high-volume die-to-wafer hybrid bonder
- In production since 2022
- 200 nm placement accuracy @ high speed of 2000 CPH
- Designed for use in front-end fab environment
- 100 nm accuracy bonder in development
- Roadmap to <50 nm accuracy

*** Slide Courtesy of BESI*

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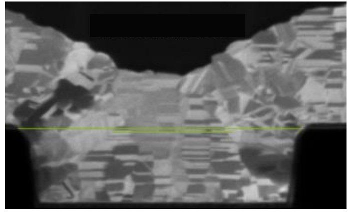
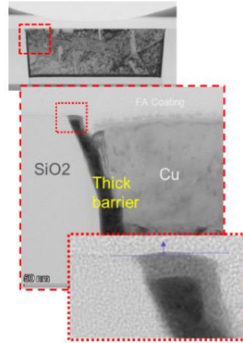
Integrated D2W Hybrid Bonders | | Co-Optimizing of Processes

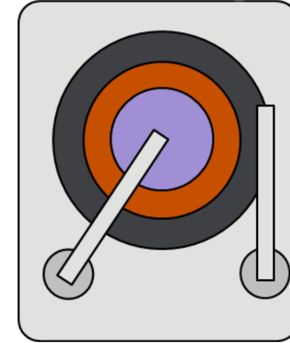
Copper quality and fill



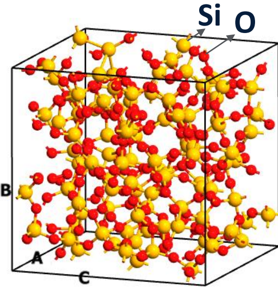
CMP and Dishing



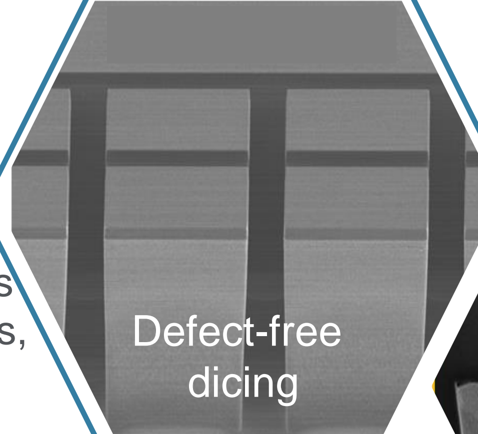
Cleaning



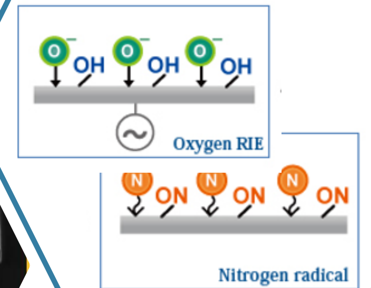
Impact of oxide depostion

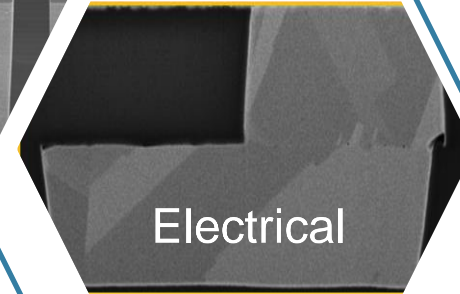


Integrated Process Flow, Low Particles, Inspection

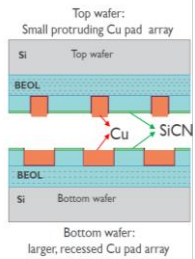


Plasma Activation

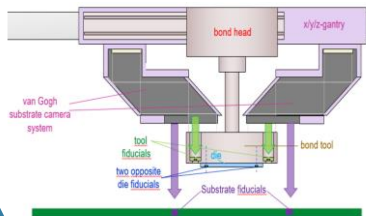




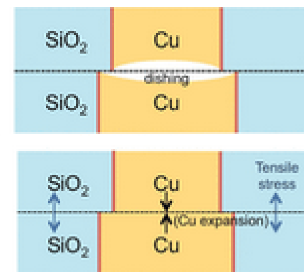
Optimized Bonding Geometry



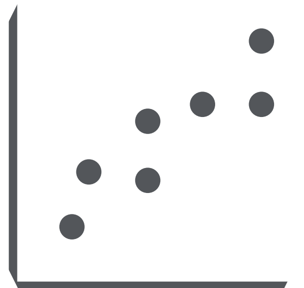
Bonding Process Industrial Solution



Anneal



Reliability



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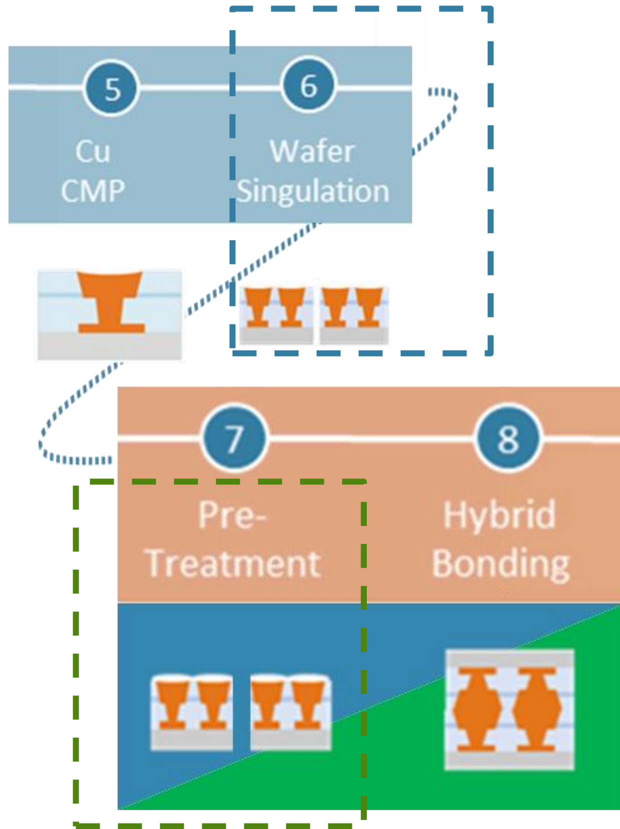
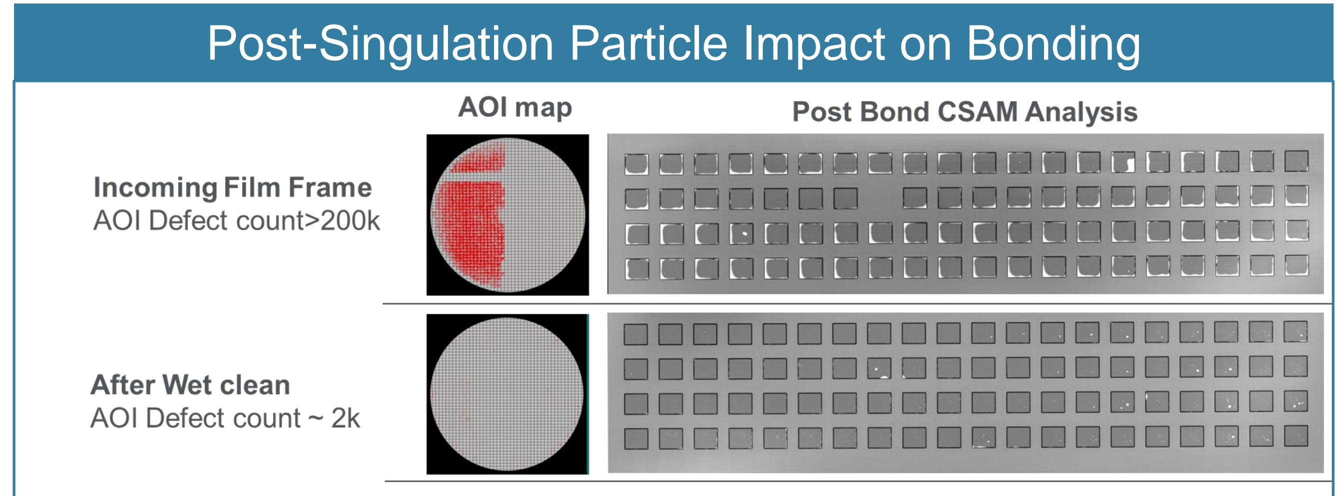
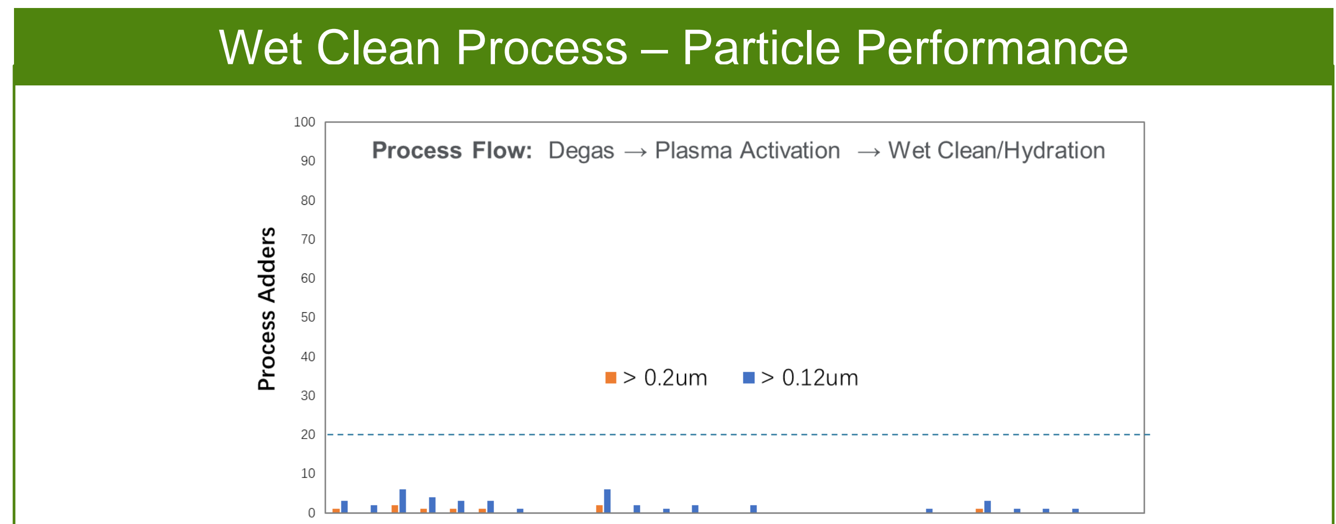
Integrated D2W Hybrid Bonders | Singulation & Cleaning



Post-Singulation Particle Impact on Bonding



Wet Clean Process – Particle Performance



Particle Free singulation process needed for HB. Particle requirements scale with Bond pad size & pitch

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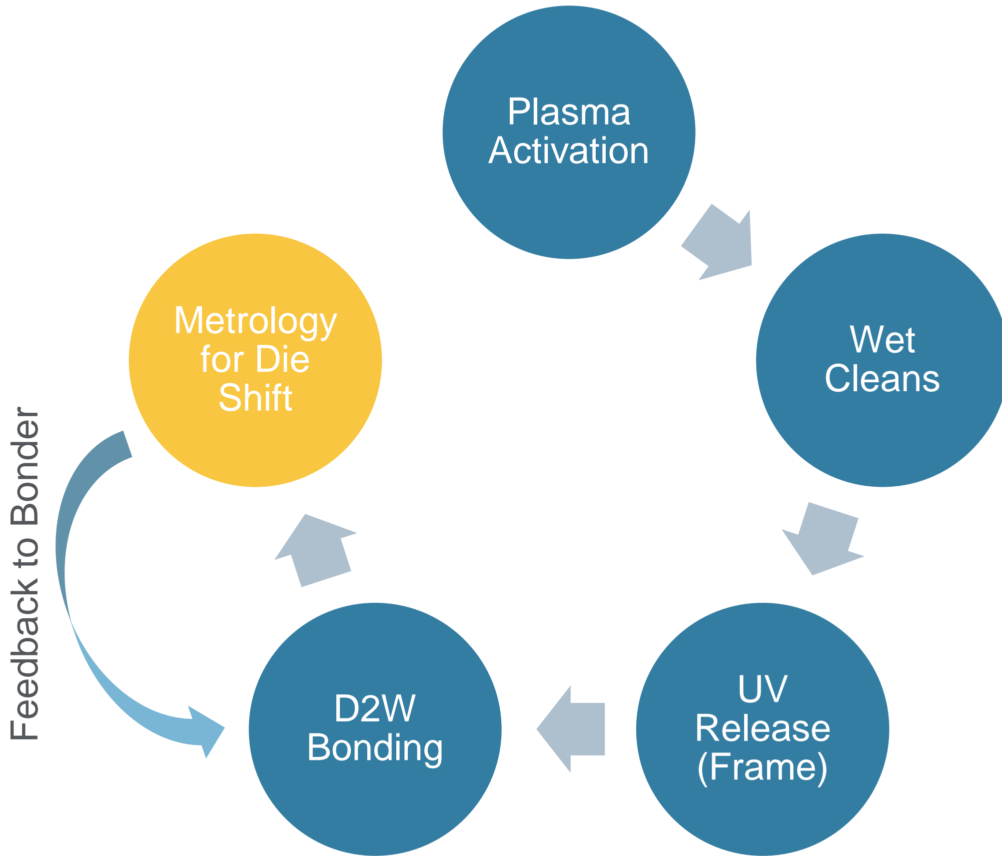
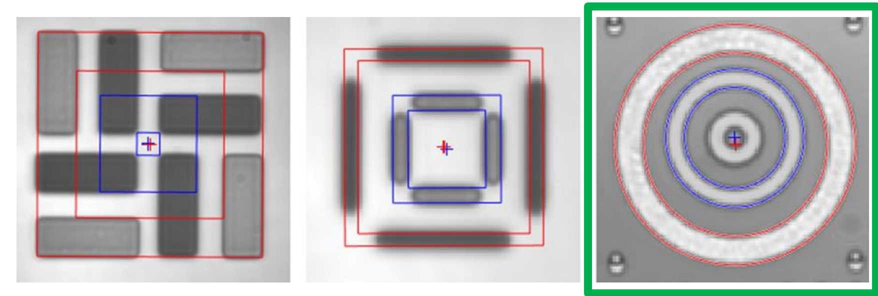
Integrated D2W Hybrid Bonders | Metrology for Die Shift

D2W Hybrid Bonding Flow



Die Shift Metrology Requirements

- Post bond die shift measurement with feedback control for correction critical for maintaining process stability
- The right fiducial design is needed to maximize placement accuracy



- Die shift metrology process performance requirements :

Application	Item	Spec
Overlay Metrology	Precision (3sigma)	20nm
	Accuracy	40nm

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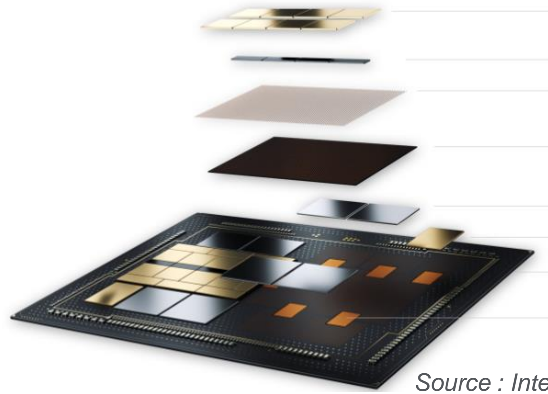
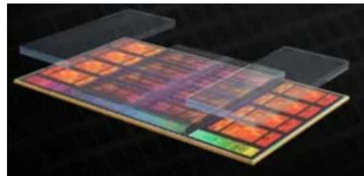
Integrated D2W Hybrid Bonders | Die Management & Scheduling



Source : Intel



Source : AMD

Post Activation Proces Time

Die Per Package

- Roadmap driving need for increased chiplets per package
- Multi-bonder integrated systems with metrology are essential
- Equipment should possess the capability to manage and handle multiple Chiplet sources simultaneously delivered from the fab host
- Effective Software plays a crucial role in managing queue time and scheduling chiplets through the integrated bonder
- Inclusion of Metrology with feedback control is necessary to ensure precise and accurate chiplet placement

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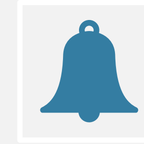
Integrated D2W Hybrid Bonders | Advanced Analytics

- Advanced Data Analytics
- Higher uptime & productivity
  - Improved maintenance
  - First Time Right
  - Output Improvement
- For systems under service

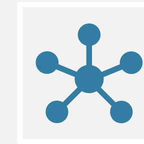
Reports and Dashboards



Notifications

Speed to data

Remote Access

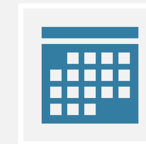


Fleet Analytics

Sharable Models

Excursion Detection

Post Repair Verification



PM Planning

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Summary

- AI chipsets are driving the need for Heterogenous Integration with Die to Wafer Hybrid Bonding
- AMAT / BESI have partnered and setup a Center for Excellence for Hybrid Bonding in Singapore
- D2W Hybrid bonding offers the highest level of flexibility for multi die packages
- Integrated D2W Bonding systems is a requirement to maintain high levels of yield
- The following capabilities are needed for Integrated D2W Hybrid Bonding equipment:
  - Front End Like Substrate Cleaning & Plasma activation processes
  - High accuracy & throughput Bonders
  - Advanced Die scheduling software w/ queue time control
  - Integrated Metrology w/ feedback control
  - Advanced analytics for productivity and uptime

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