

IMAPS DPC 2023

# D2W Hybrid Bonding using high accuracy carrier solutions for 3D System Integration

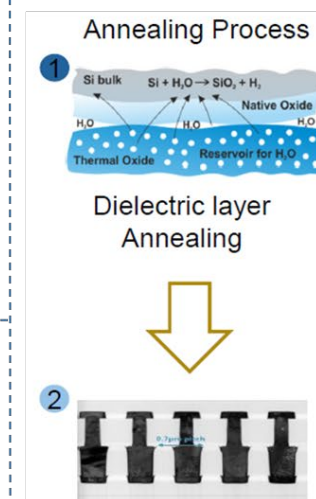
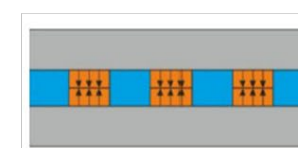
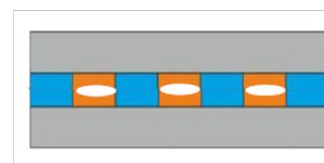
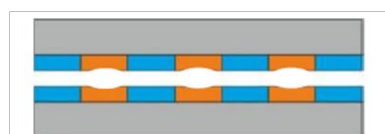
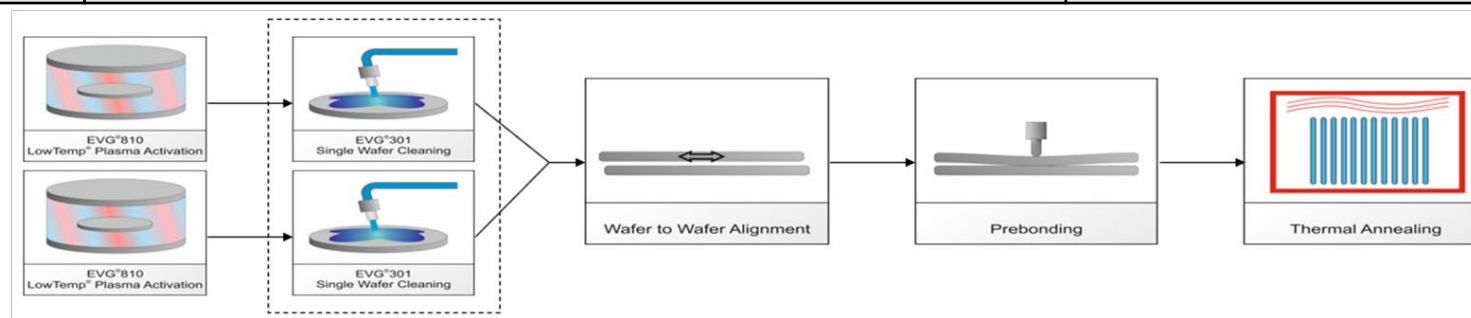
EVG: Thomas Uhrmann, Jürgen Burggraf, Mariana Pires  
ASMPT: Chun Ho Fan, Hoi Ping Ng, Ming Li

# Outline

- Introduction
- Wafer-to-Wafer Bonding vs. Die-to-Wafer Bonding
- Collective Die-to-Wafer Bonding Process Flow
- Process Results – Hybrid Bonding and Multi die transfer
- Conclusion

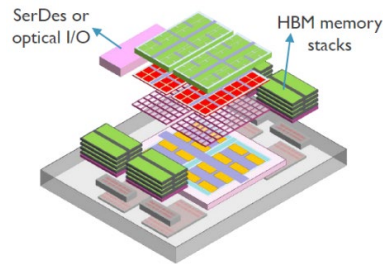
# D2W vs W2W Hybrid Bonding

|                      | Hybrid W2W Bonding                                         | Hybrid D2W Bonding                                                              |
|----------------------|------------------------------------------------------------|---------------------------------------------------------------------------------|
| <b>Maturity</b>      | Wafer Bonding Equipment and Process are matured since 2010 | Process and Equipment maturity is starting to yield but still many difficulties |
| <b>Contact Pitch</b> | <1 $\mu$ m pitch is enabled in production                  | Currently 9 $\mu$ m pitch in production                                         |
| <b>Die Size</b>      | Die Size and Grid Matching required                        | No limitations in die size and system segmentation                              |
| <b>Segmentation</b>  | Each bonding layer consist of one node                     | Each chiplet can consist of a different node                                    |
| <b>Yield</b>         | Cummulative yield of each bonded layer                     | Cummulative yield can be avoided by testing                                     |
| <b>Throughput</b>    | >25 bonds per hour possible                                | Related to chip size and amount of chiplets per system                          |



# Die Bonding Integration | Die-to-Wafer vs. Wafer-to-Wafer Bonding

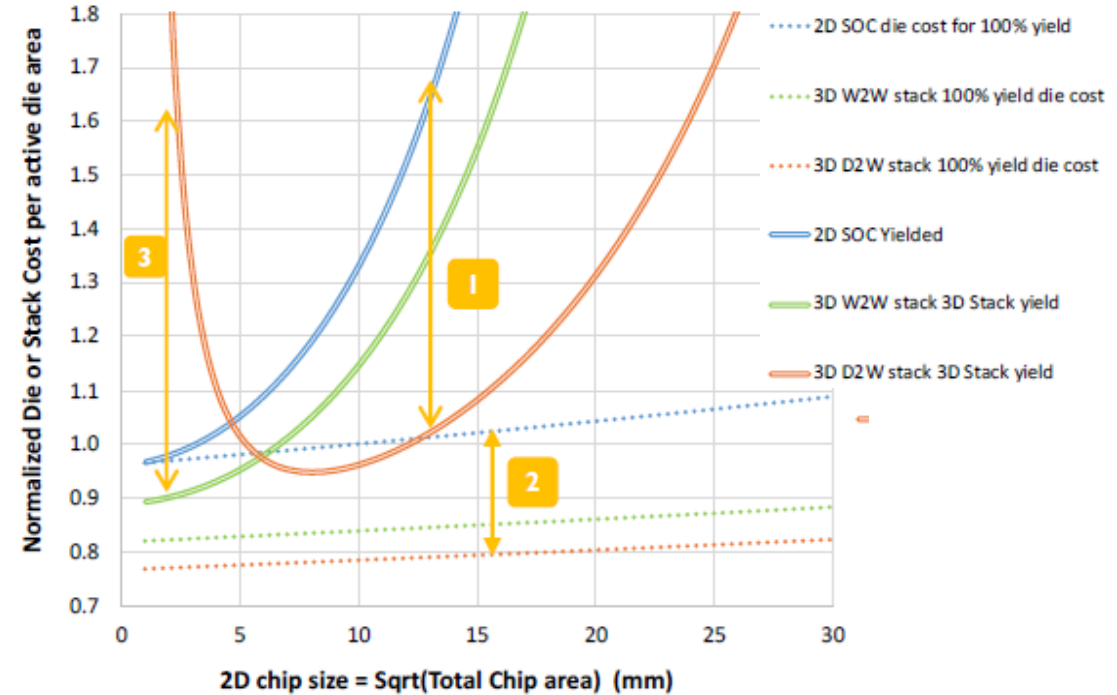
## Die-to-Wafer Bonding



Require larger Die size

→ **High system integration costs**

- Only the „Good“ dies are bonded to the target wafer → High Yield
- Allow stacking of different physical dimensions from arbitrary technologies and substrates sizes.
- Integration of multiple dies onto a single base die of the substrate wafer.



Source: IMEC – 2019 3D & systems summit

- **Costs**  
Increase driven by increased Die size and lower yield  
C2W / KGD integration is favorable for increased Die sizes



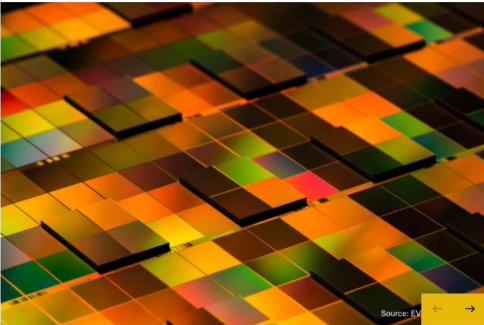
# D2W Bonding | Recent Announcements

|                 | Co-D2W                                             | DP-D2W                                                    | SA-D2W                                                       |
|-----------------|----------------------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------|
| Transfer Method | Collective Die Transfer by Reconstituted Carrier   | Direct placement of activated dies using Flip Chip Bonder | Self Assembly on hydrophilic guiding pads                    |
| Maturity        | Limited volume production proven for several years | Feasibility testing ongoing                               | Experimental results available, Feasibility testing required |

March 2, 2020

## EV Group Establishes Heterogeneous Integration Competence Center

New HI Competence Center to help customers accelerate new product development fueled by heterogeneous integration and advanced packaging



EVG's HI Competence Center is designed to help enable new products and applications driven by advances in system integration and packaging. Shown here: chiplet integration by collective die-to-wafer hybrid bonding.

October 19, 2020

## EV Group Addresses Key Process Gap in Heterogeneous Integration with Collective Die-to-Wafer Hybrid and Fusion Bonding Demonstration

Company successfully demonstrates end-to-end process flow for collective die-to-wafer bonding with sub-two-micron placement accuracy at EVG's Heterogeneous Integration Competence Center™



EV Group successfully demonstrated a complete process flow for collective die-to-wafer (D2W) hybrid and fusion bonding with sub-two-micron placement accuracy. Shown here: individual dies on a wafer after collective die-to-wafer bonding.

December 10, 2020

## EV Group Unveils Hybrid Die-to-Wafer Bonding Activation Solution to Speed Up Deployment of 3D Heterogeneous Integration

EVG®320 D2W die preparation and activation system provides seamless integration with third-party die bonders; completes EVG's equipment portfolio for end-to-end hybrid bonding for 3D/Heterogeneous Integration

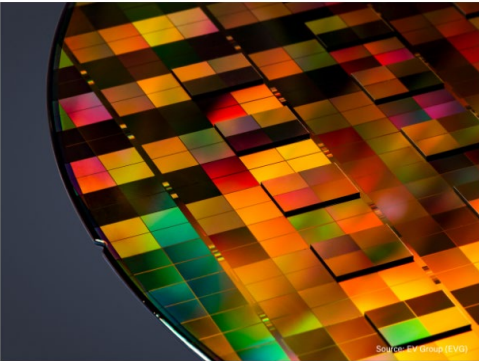


EVG®320 D2W Die Preparation and Activation System

January 29, 2021

## ASM Pacific Technology and EV Group Join Forces to Enable Industry's First Ultra Precision Die-to-Wafer Hybrid Bonding Solutions for 3D-IC Heterogeneous Integration

Joint Development Program will offer highly configurable, ultra-precision end-to-end hybrid bonding solutions to suit various applications, with optimal line balancing and process requirements

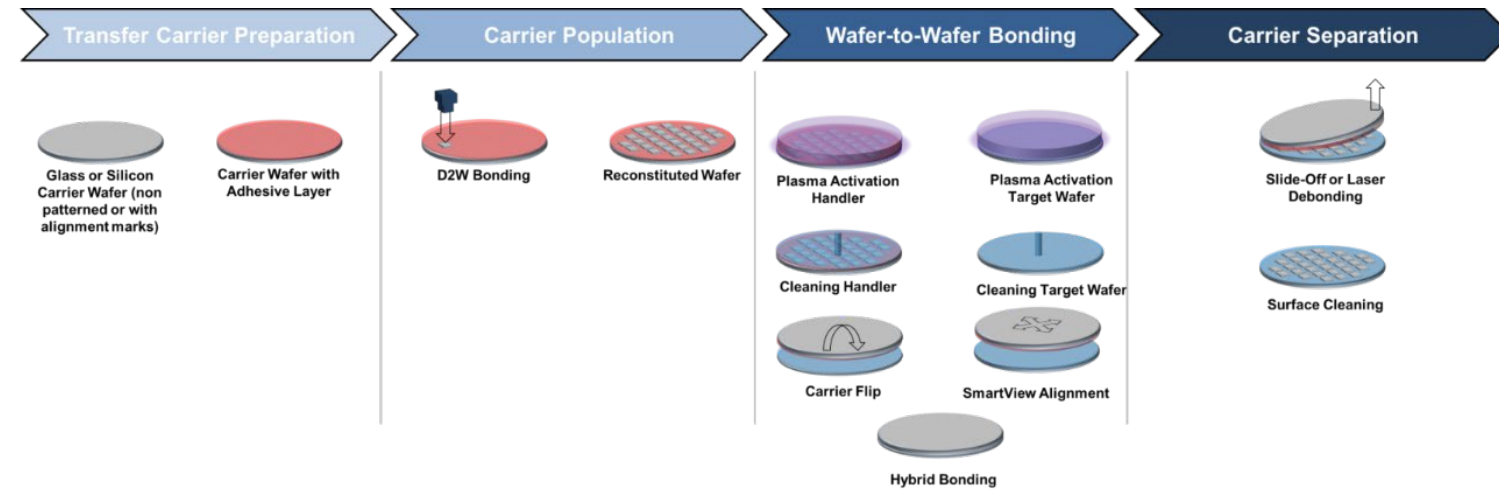


# Hybrid D2W Bonding | EVG Process Support Options

|                        | Co-D2W                                                                                                                                                                                                  | DP-D2W                                                                                                                                                                                                             | SA-D2W                                                                                                                                                                                                              |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Transfer Method</b> | Collective Die Transfer by Reconstituted Carrier                                                                                                                                                        | Direct placement of activated dies using Flip Chip Bonder                                                                                                                                                          | Self Assembly on hydrophilic guiding pads                                                                                                                                                                           |
| <b>Pro's</b>           | <ul style="list-style-type: none"> <li>Proven technology</li> <li>Die Activation and cleaning equivalent to W2W hybrid bonding</li> <li>Oxide management</li> <li>Rework on carrier feasible</li> </ul> | <ul style="list-style-type: none"> <li>Versatile method</li> <li>Die thickness invariant</li> </ul>                                                                                                                | <ul style="list-style-type: none"> <li>Avoids high precision flip chip bonder and potential cost saving</li> <li>Die thickness invariant</li> </ul>                                                                 |
| <b>Con's</b>           | <ul style="list-style-type: none"> <li>Error propagation of D2W + W2W alignment</li> <li>Cost of carrier prep, utilization and clean</li> <li>Die thickness needs to be in narrow range</li> </ul>      | <ul style="list-style-type: none"> <li>Bonding interface needs to be touched</li> <li>Die handling especially for multi die stacks such as SRAM, DRAM</li> <li>Particle management during die placement</li> </ul> | <ul style="list-style-type: none"> <li>High precision die preparation using chemical treated zones</li> <li>Dicing potentially affects placement</li> <li>Die strain is affecting self alignment results</li> </ul> |
| <b>Maturity</b>        | Limited volume production proven for several years                                                                                                                                                      | Feasibility testing required and ongoing                                                                                                                                                                           | Experimental results available, Feasibility testing ongoing                                                                                                                                                         |

# Hybrid D2W Bonding | EVG Process Support Options

|                        | Co-D2W                                                                                                                                                                                                  |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Transfer Method</b> | Collective Die Transfer by Reconstituted Carrier                                                                                                                                                        |
| <b>Pro's</b>           | <ul style="list-style-type: none"> <li>Proven technology</li> <li>Die Activation and cleaning equivalent to W2W hybrid bonding</li> <li>Oxide management</li> <li>Rework on carrier feasible</li> </ul> |
| <b>Con's</b>           | <ul style="list-style-type: none"> <li>Error propagation of D2W + W2W alignment</li> <li>Cost of carrier prep, utilization and clean</li> <li>Die thickness needs to be in narrow range</li> </ul>      |
| <b>Maturity</b>        | Limited volume production proven for several years                                                                                                                                                      |



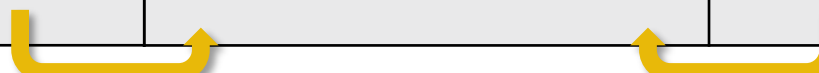
# Hybrid D2W Bonding | EVG Process Support Options

|                        | DP-D2W                                                                                                                                                                                                             |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Transfer Method</b> | Direct placement of activated dies using Flip Chip Bonder                                                                                                                                                          |
| <b>Pro's</b>           | <ul style="list-style-type: none"> <li>Versatile method</li> <li>Die thickness invariant</li> </ul>                                                                                                                |
| <b>Con's</b>           | <ul style="list-style-type: none"> <li>Bonding interface needs to be touched</li> <li>Die handling especially for multi die stacks such as SRAM, DRAM</li> <li>Particle management during die placement</li> </ul> |
| <b>Maturity</b>        | Feasibility testing required and ongoing                                                                                                                                                                           |



# IR Laser Release | Reconstructed D2W Bonding

|                        | Co-D2W                                                                                                                                                                                                  | DP-D2W                                                                                                                                                                                                             | SA-D2W                                                                                                                                                                                                              |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Transfer Method</b> | Collective Bonding (Die Level Bonding)                                                                                                                                                                  | Direct placement of activated dies using Flip Chip Bonder                                                                                                                                                          | Self Assembly on hydrophilic guiding pads                                                                                                                                                                           |
| <b>Pro's</b>           | <ul style="list-style-type: none"> <li>Proven technology</li> <li>Die Activation and cleaning equivalent to W2W hybrid bonding</li> <li>Oxide management</li> <li>Rework on carrier feasible</li> </ul> | <ul style="list-style-type: none"> <li>Versatile method</li> <li>Die thickness invariant</li> </ul>                                                                                                                | <ul style="list-style-type: none"> <li>Avoids high precision flip chip bonder and potential cost saving</li> <li>Die thickness invariant</li> </ul>                                                                 |
| <b>Con's</b>           | <ul style="list-style-type: none"> <li>Error propagation of D2W + W2W alignment</li> <li>Cost of carrier prep, utilization and clean</li> <li>Die thickness needs to be in narrow range</li> </ul>      | <ul style="list-style-type: none"> <li>Bonding interface needs to be touched</li> <li>Die handling especially for multi die stacks such as SRAM, DRAM</li> <li>Particle management during die placement</li> </ul> | <ul style="list-style-type: none"> <li>High precision die preparation using chemical treated zones</li> <li>Dicing potentially affects placement</li> <li>Die strain is affecting self alignment results</li> </ul> |
| <b>Maturity</b>        | Limited volume production proven for several years                                                                                                                                                      | Qualification and ramp up                                                                                                                                                                                          | Experimental results available, Feasibility testing ongoing                                                                                                                                                         |



*Combination of known good dies on carrier with anorganic wafer level pre processing, post processing and W2W bonding*

# IR Laser Release | Reconstructed D2W Bonding

|                 | Co-D2W                                                                                                                                                                                                  | Reconstructed W2W                                                                                                                                                          | DP-D2W                                                                                                                                                                                                             | SA-D2W                                                                                                                                                                                                              |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Transfer Method | Collective Bonding<br>(Die Level Bonding)                                                                                                                                                               | Reconstructed W2W<br>(Anorganic Fill Process)                                                                                                                              | Direct placement of activated<br>dies using Flip Chip Bonder                                                                                                                                                       | Self Assembly on hydrophilic<br>guiding pads                                                                                                                                                                        |
| Pro's           | <ul style="list-style-type: none"> <li>Proven technology</li> <li>Die Activation and cleaning equivalent to W2W hybrid bonding</li> <li>Oxide management</li> <li>Rework on carrier feasible</li> </ul> | <ul style="list-style-type: none"> <li>Proven process</li> <li>High yield, clean process</li> <li>All based on standardized wafer-based manufacturing equipment</li> </ul> | <ul style="list-style-type: none"> <li>Versatile method</li> <li>Die thickness invariant</li> </ul>                                                                                                                | <ul style="list-style-type: none"> <li>Avoids high precision flip chip bonder and potential cost saving</li> <li>Die thickness invariant</li> </ul>                                                                 |
| Con's           | <ul style="list-style-type: none"> <li>Error propagation of D2W + W2W alignment</li> <li>Cost of carrier prep, utilization and clean</li> <li>Die thickness needs to be in narrow range</li> </ul>      | <ul style="list-style-type: none"> <li>W2W bonding process is heavily impacted by die grid and filling factor between dies</li> </ul>                                      | <ul style="list-style-type: none"> <li>Bonding interface needs to be touched</li> <li>Die handling especially for multi die stacks such as SRAM, DRAM</li> <li>Particle management during die placement</li> </ul> | <ul style="list-style-type: none"> <li>High precision die preparation using chemical treated zones</li> <li>Dicing potentially affects placement</li> <li>Die strain is affecting self alignment results</li> </ul> |
| Maturity        | Limited volume production proven for several years                                                                                                                                                      | Limited volume production                                                                                                                                                  | Qualification and ramp up                                                                                                                                                                                          | Experimental results available, Feasibility testing ongoing                                                                                                                                                         |

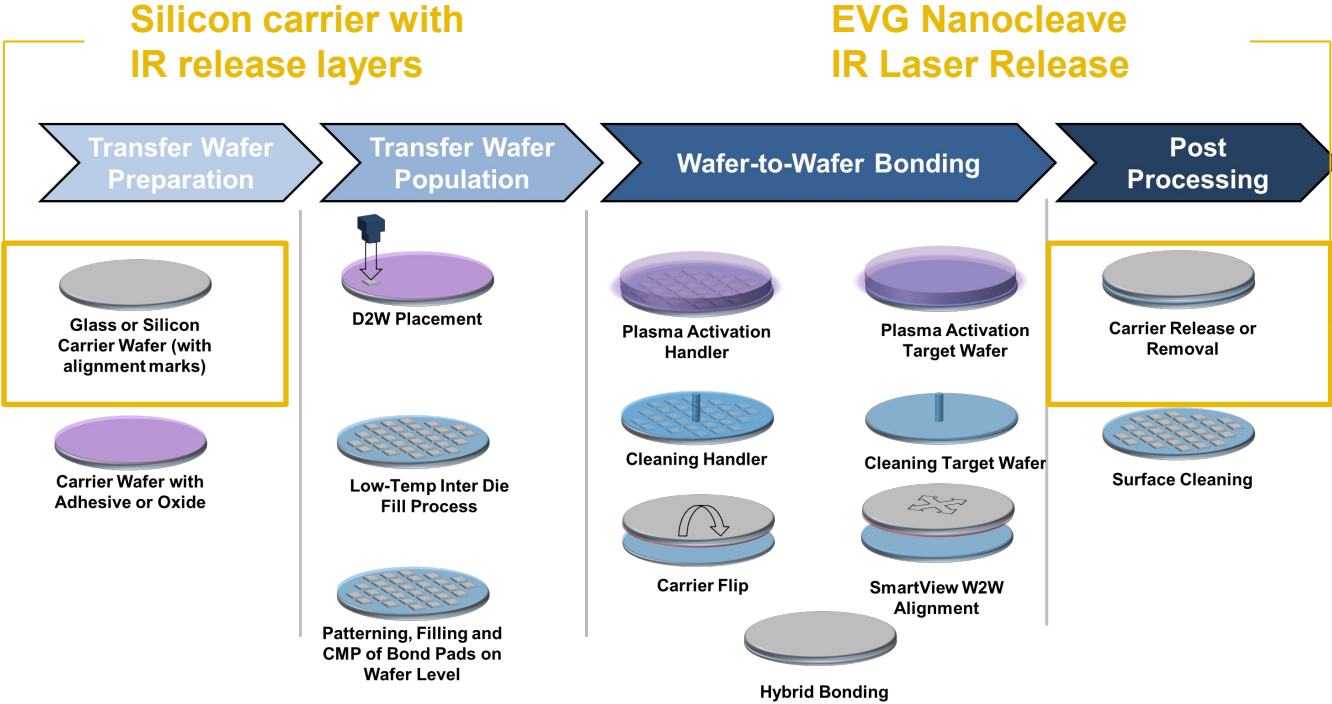


**Combination of known good dies on carrier with anorganic wafer level pre processing, post processing and W2W bonding**



# IR Laser Release | Reconstructed D2W Bonding

|                 | Reconstituted W2W                                                                                                                                                                                  |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Transfer Method | Reconstructed W2W (Anorganic Fill Process)                                                                                                                                                         |
| Pro's           | <ul style="list-style-type: none"><li>Proven technology</li><li>Die Activation and cleaning equivalent to W2W hybrid bonding</li><li>Oxide management</li><li>Rework on carrier feasible</li></ul> |
| Con's           | <ul style="list-style-type: none"><li>Error propagation of D2W + W2W alignment</li><li>Cost of carrier prep, utilization and clean</li><li>Die thickness needs to be in narrow range</li></ul>     |
| Maturity        | Limited volume production proven for several years                                                                                                                                                 |

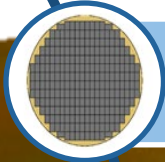


## D2W Bonding – Process Results

# Die-to-Wafer Bonding | Die Transfer Capabilities



Die placement accuracy 1  $\mu\text{m}$   $\rightarrow$  500 nm upcoming



Die Size

600  $\mu\text{m}$  x 600  $\mu\text{m}$  up to 40 mm x 40 mm

GaAs  
Si  
SiC  
GaN

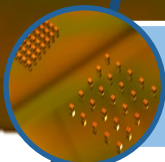
Materials

InP, GaAs, Si, GaN, SiC



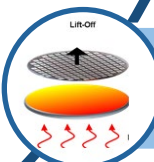
Carrier Size :

200 mm & 300 mm



Bonding Processes

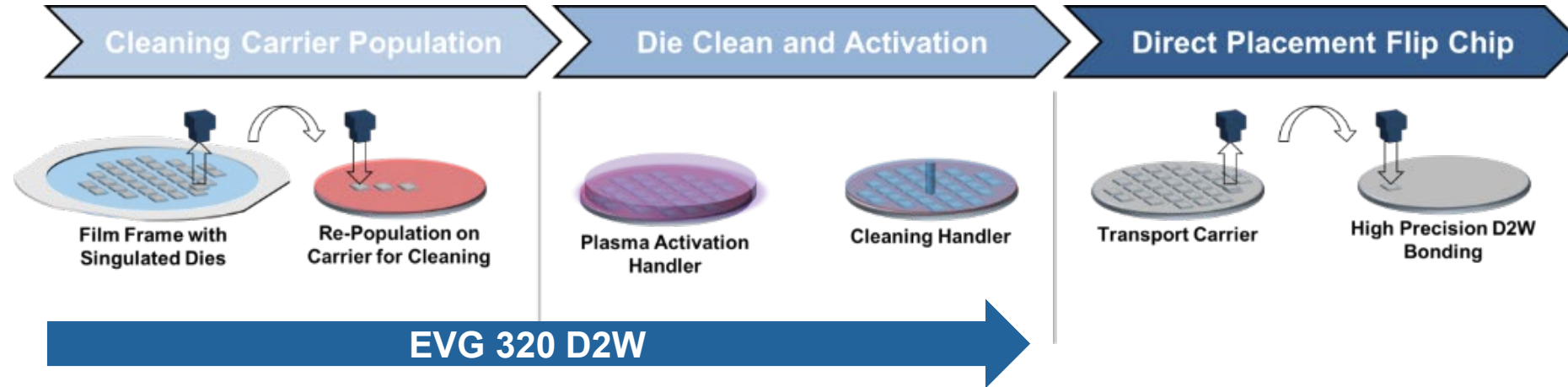
Direct, Metal, Adhesive bonding, Hybrid bonding



Debonding Technology

Thermal Slide off or Laser debonding

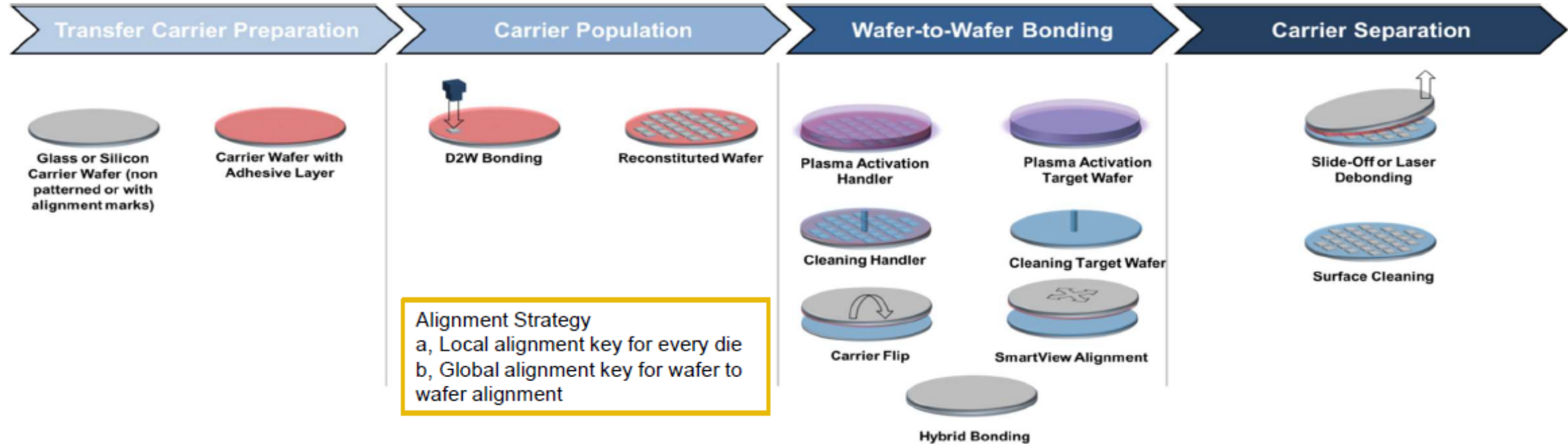
# Direct Placement (DP-D2W) Bonding | Process Flow



| Transfer Method                                                            | Pro's                                                                                               | Con's                                                                                                                                                               | Maturity                                                                                   |
|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| <b>DP-D2W</b><br>Direct placement of activated dies using Flip Chip Bonder | <ul style="list-style-type: none"> <li>Versatile method</li> <li>Die thickness variation</li> </ul> | <ul style="list-style-type: none"> <li>Die handling especially for multi die stacks such as SRAM, DRAM</li> <li>Particle management during die placement</li> </ul> | <ul style="list-style-type: none"> <li>Feasibility testing required and ongoing</li> </ul> |

*Customers would prefer direct placement → Particle / yield issue*

# Collective Die-to-Wafer (Co-D2W) Bonding | Process Flow

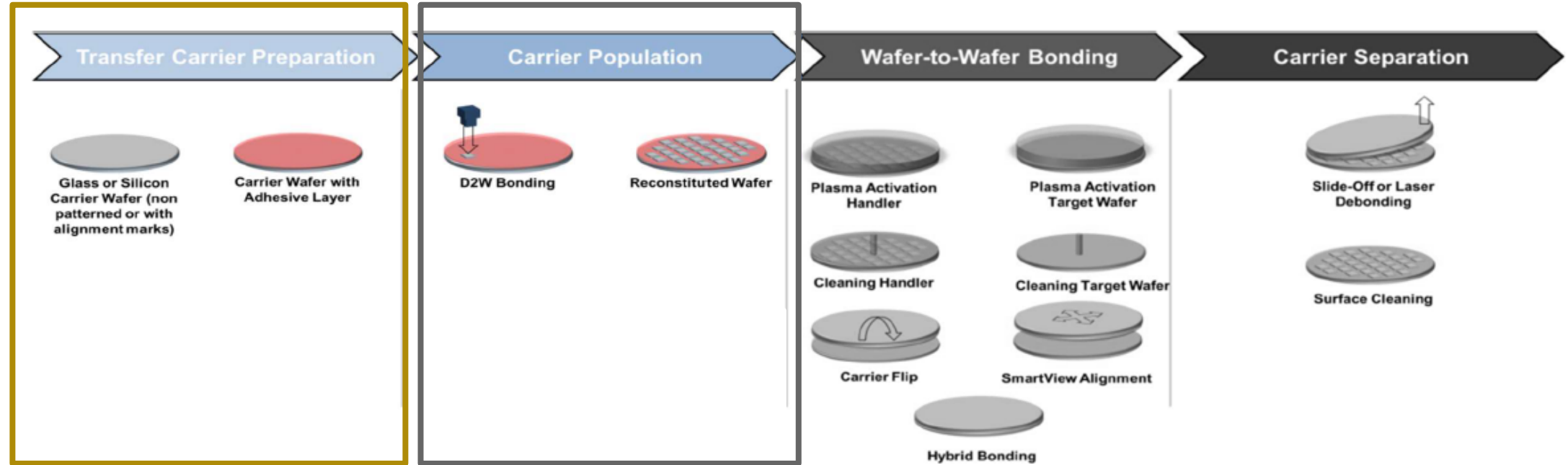


| Transfer Method                                  | Pro's                                                                                                                                                                                                  | Con's                                                                                                                                                                                              | Maturity Level                                  |
|--------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| Collective Die Transfer by Reconstituted Carrier | <ul style="list-style-type: none"> <li>Proven technology</li> <li>Die activation and cleaning equivalent to W2W hybrid bonding</li> <li>Oxide management</li> <li>Reuse of carrier feasible</li> </ul> | <ul style="list-style-type: none"> <li>Error propagation of D2W + W2W alignment</li> <li>Cost of carrier prep, utilization and clean</li> <li>Die thickness needs to be in narrow range</li> </ul> | High Volume production proven for several years |

# Collective Die-to-Wafer (Co-D2W) Bonding | Process Flow

EVG® 101

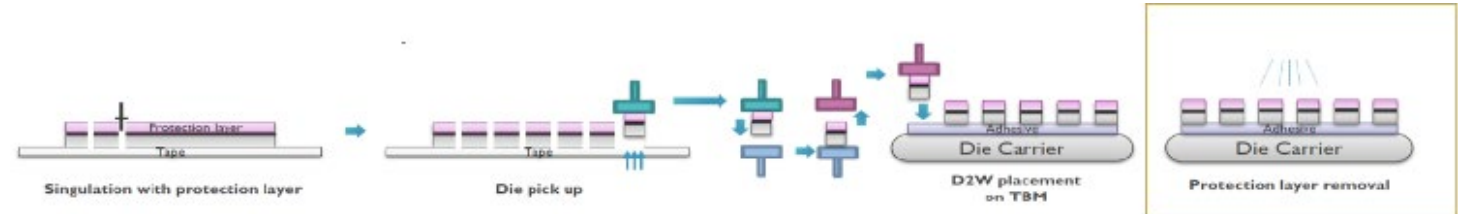
Flip Chip Bonder



EVG® 101



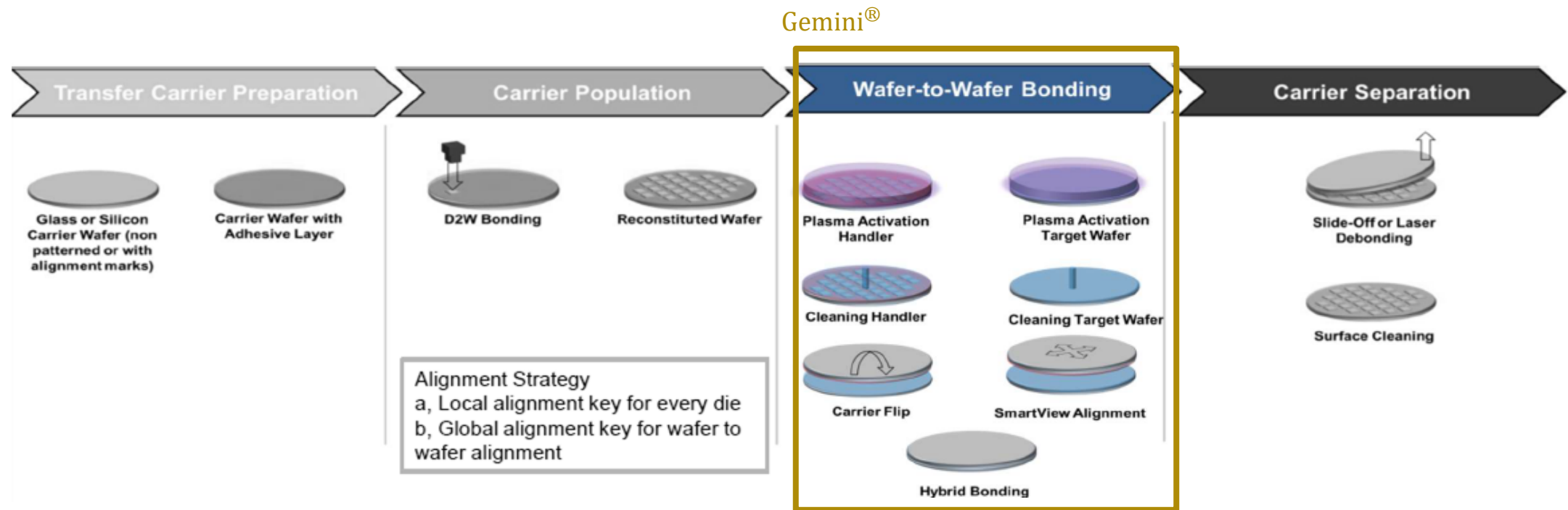
- A protective layer is applied on top of the dies to prevent the contamination of the die surface during the dicing and carrier population processes.



Courtesy of IMEC

# Collective Die-to-Wafer (Co-D2W) Bonding | Process Flow

## Collective Die to Wafer Bonding



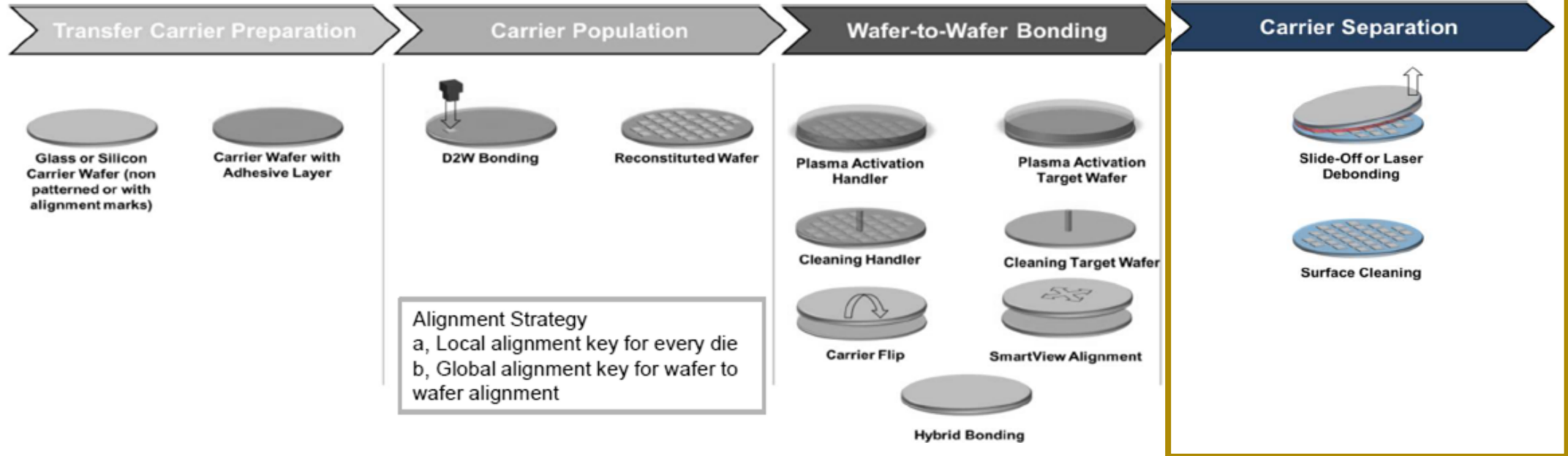
- The D2W bonding is preformed at wafer level using the same W2W bonding systems.

Gemini®



# Collective Die-to-Wafer (Co-D2W) Bonding | Process Flow

Die transfer process

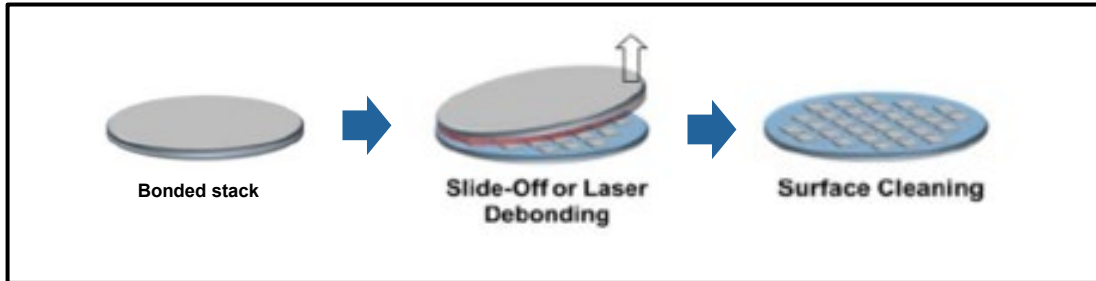


Gemini®

Gemini®

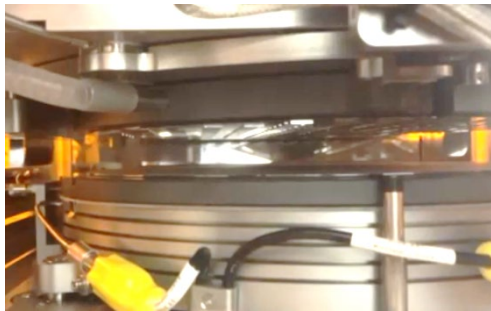


# Collective Die-to-Wafer (Co-D2W) Bonding | Carrier Separation



## Lift-Off Debond

- Process compatible with thermoplastic material and thermo release tapes.
- Debond process < 210°C.
- No specific carrier type is required.

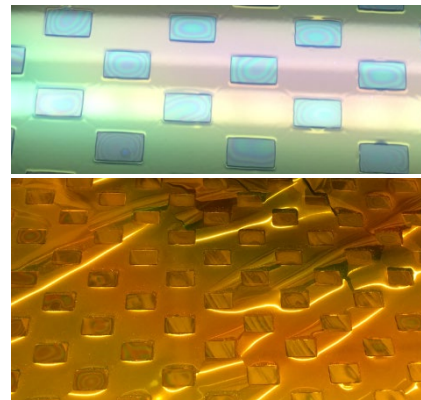


Picture – Lift-off debond process – target wafer with dies on the top chuck.

## UV Laser Debond

EVG®850DB

- RT debond process
- Glass carrier is required.
- Process compatible with adhesive and UV tape

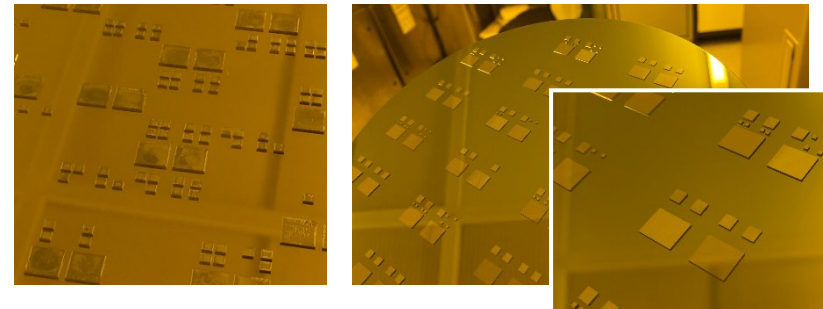


Picture – Bonded stack before and after UV laser exposure.

## Adhesive Cleaning – Target wafer with dies

EVG301®

- Solvent cleaning process.
- Chemistry used for Co-D2W bonding:
  - **Mesitylen (EVG POR)**
  - STW32
  - MEK
  - **IPA (EVG POR)**



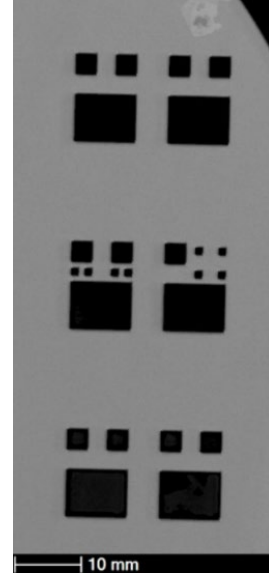
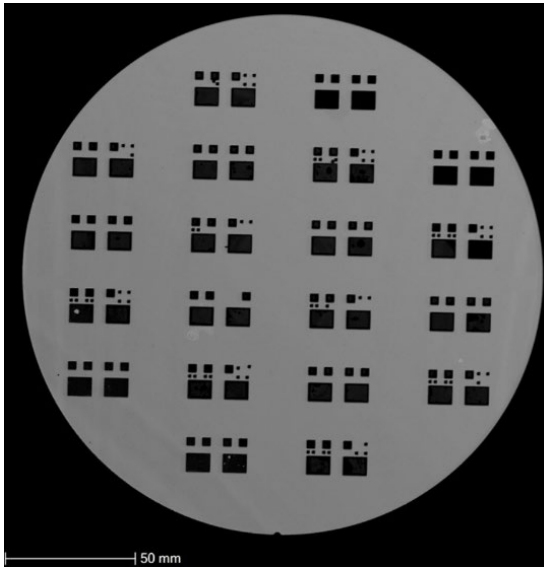
Picture – Target with dies before and after temporary adhesive cleaning.

# Collective Die-to-Wafer (Co-D2W) Bonding | Metrology

## Metrology // Co-D2W Bonding

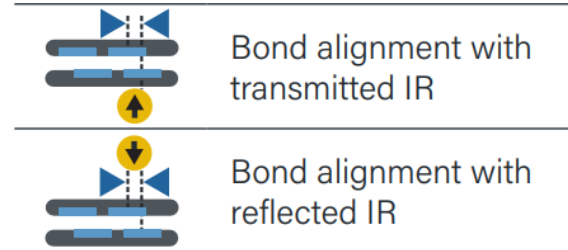
- **Post Co-D2W Bonding inspection:**
  - EVG50® - Die transfer rate
  - EVG40®NT (2) – D2W alignment verification
  - C-SAM – Bond quality

## D2W Bonding interface:

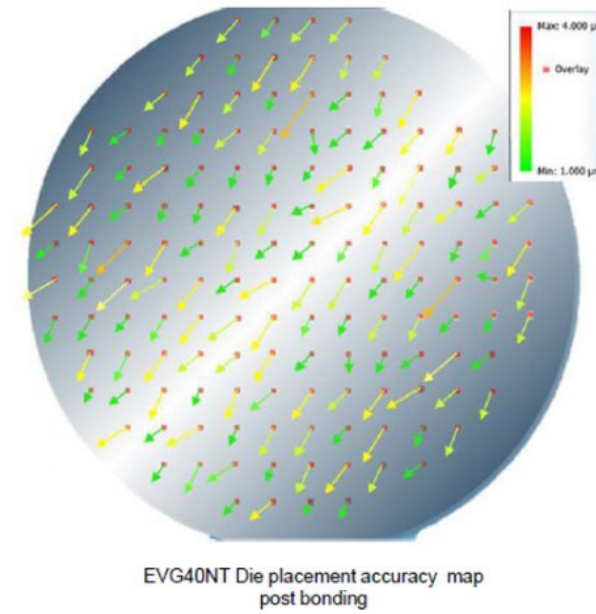


Picture – C-SAM inspection post D2W bonding.

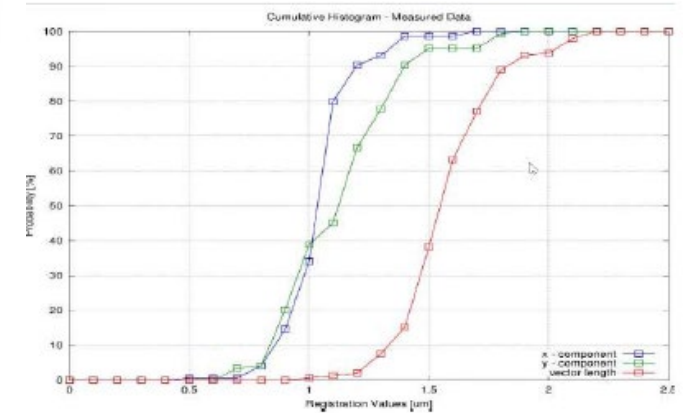
## D2W alignment verification



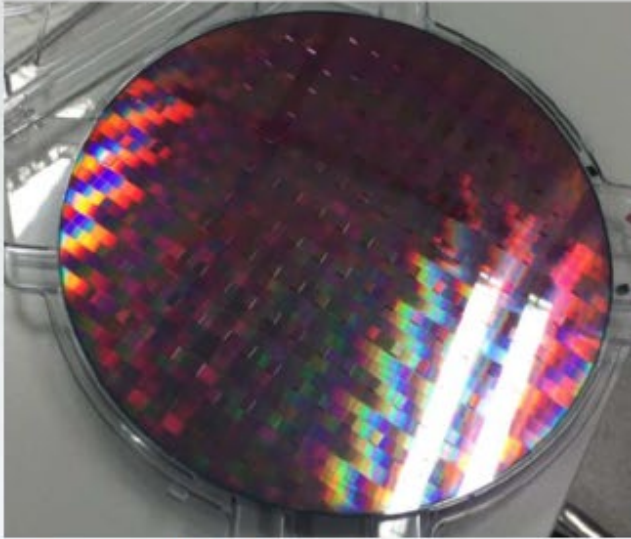
D2W + W2W alignment accuracy can be checked by TIR or RIR.



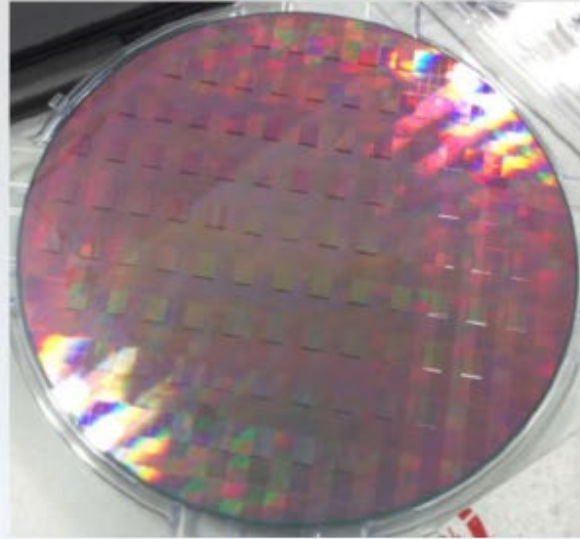
## Post Bond Alignment accuracy Cumulative Plot



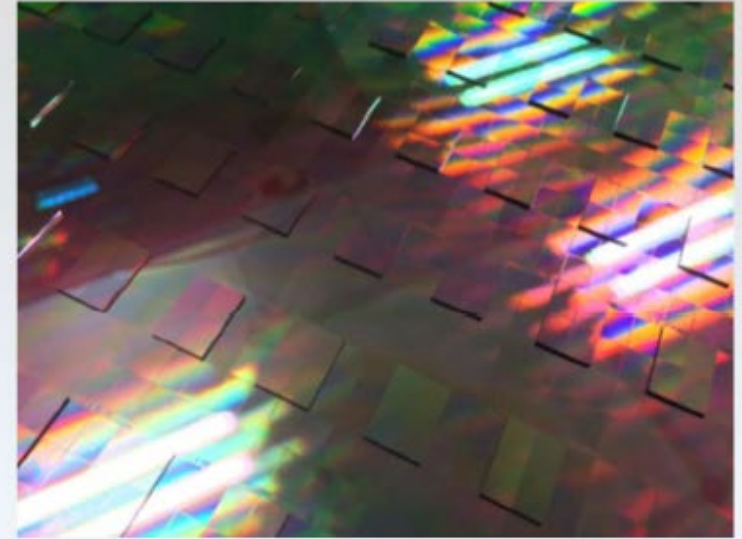
# Co-D2W Bonding | Process Results – Hybrid Bonding



Demonstrator A - 300mm  
Hybrid Bonding, 5 mm x 7 mm



Demonstrator B - 300mm  
Hybrid Bonding, 10 mm x 14 mm



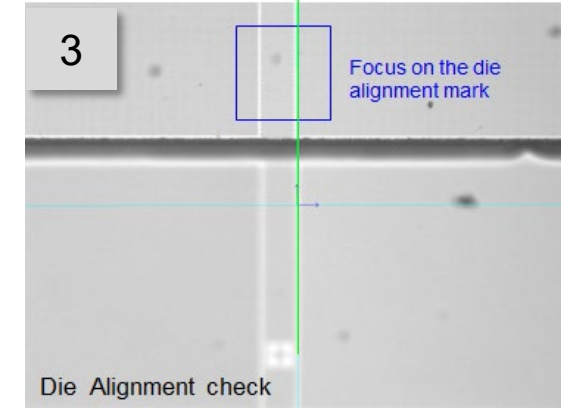
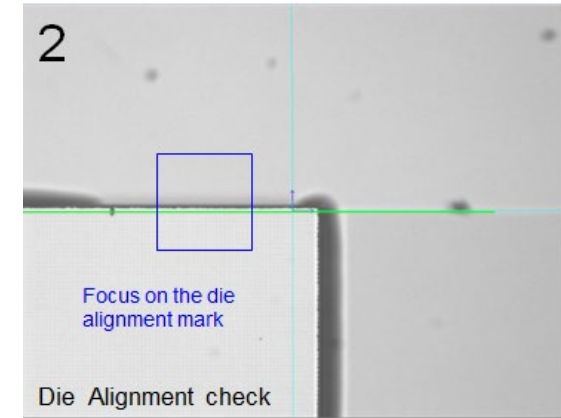
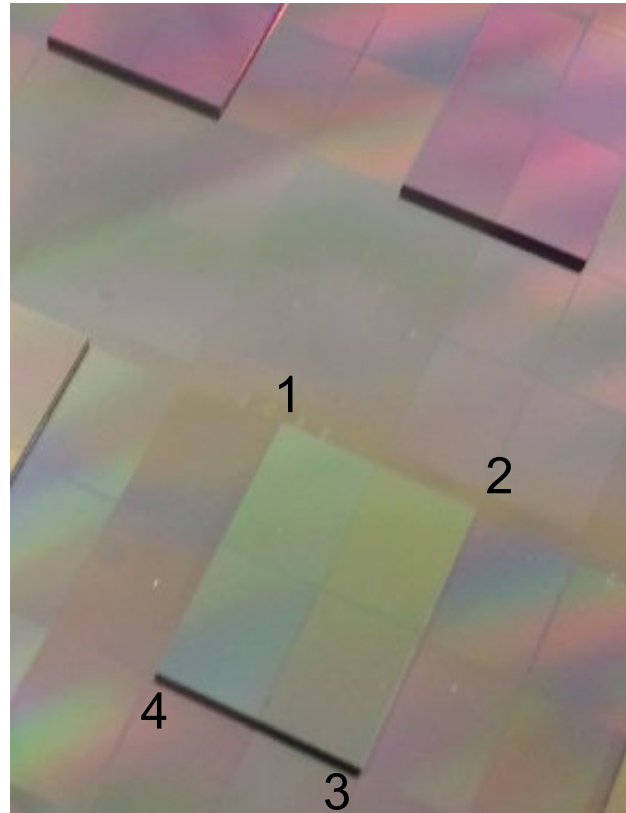
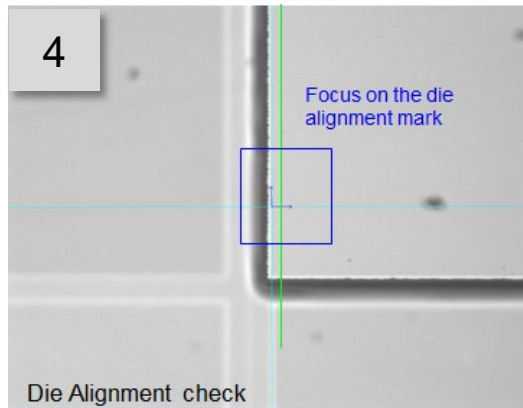
→ Pad Size 4  $\mu\text{m}$  – 1  $\mu\text{m}$



→ Pitch 10  $\mu\text{m}$  – 2  $\mu\text{m}$

\*Substrates provided under IRT Nanoelec program

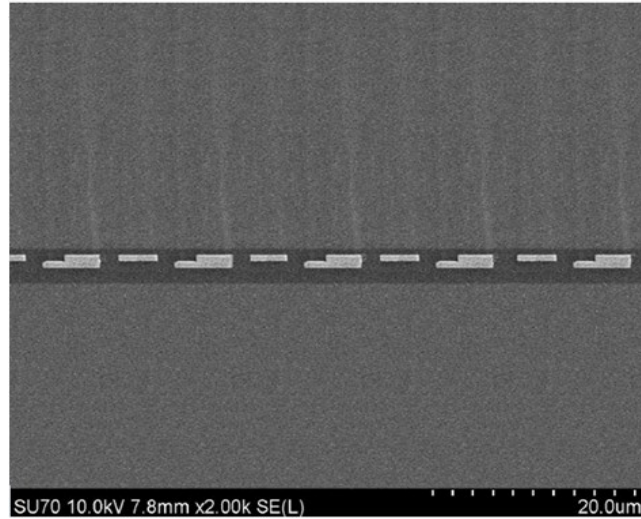
# Co-D2W Bonding | Process Results – Hybrid Bonding



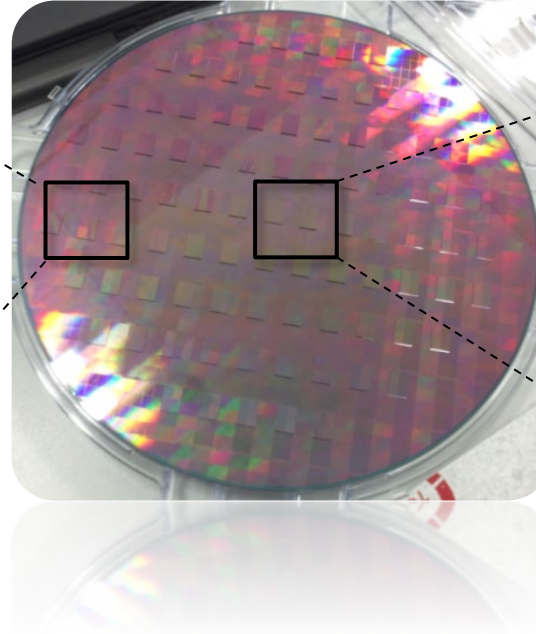
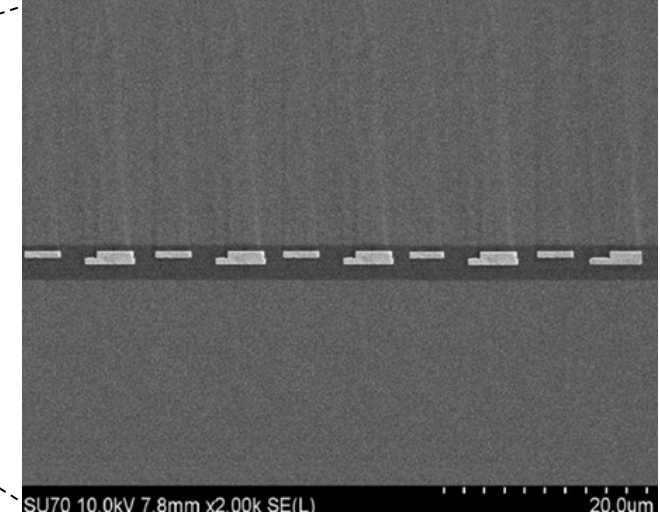
| Demonstrator | Die Dimension | Placement accuracy x 3 $\sigma$ | Placement accuracy Y 3 $\sigma$ |
|--------------|---------------|---------------------------------|---------------------------------|
| A            | 5mm x 7mm     | < 2 $\mu$ m                     | < 2 $\mu$ m                     |
| B            | 10mm x 14mm   |                                 |                                 |

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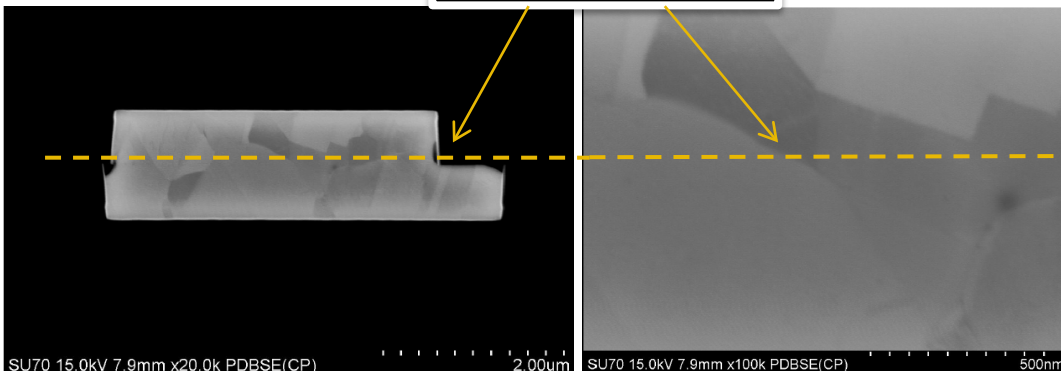
## Edge Die



## Center Die



## Bonding Interface



- High Die transfer rate and alignment accuracy  $< 2\mu\text{m}$
- TEM evaluation of mechanical contact of the bonding pads and Cu grain growth across the bonding interface

# Co-D2W Bonding | Process Results – Multi Die - Direct Bonding

## 2D and 3D Multi Die transfer

C2W Hybrid bonding capability  
Overlay <500nm



2D Multi Die Transfer to substrate



3D Multi Die Transfer to substrate



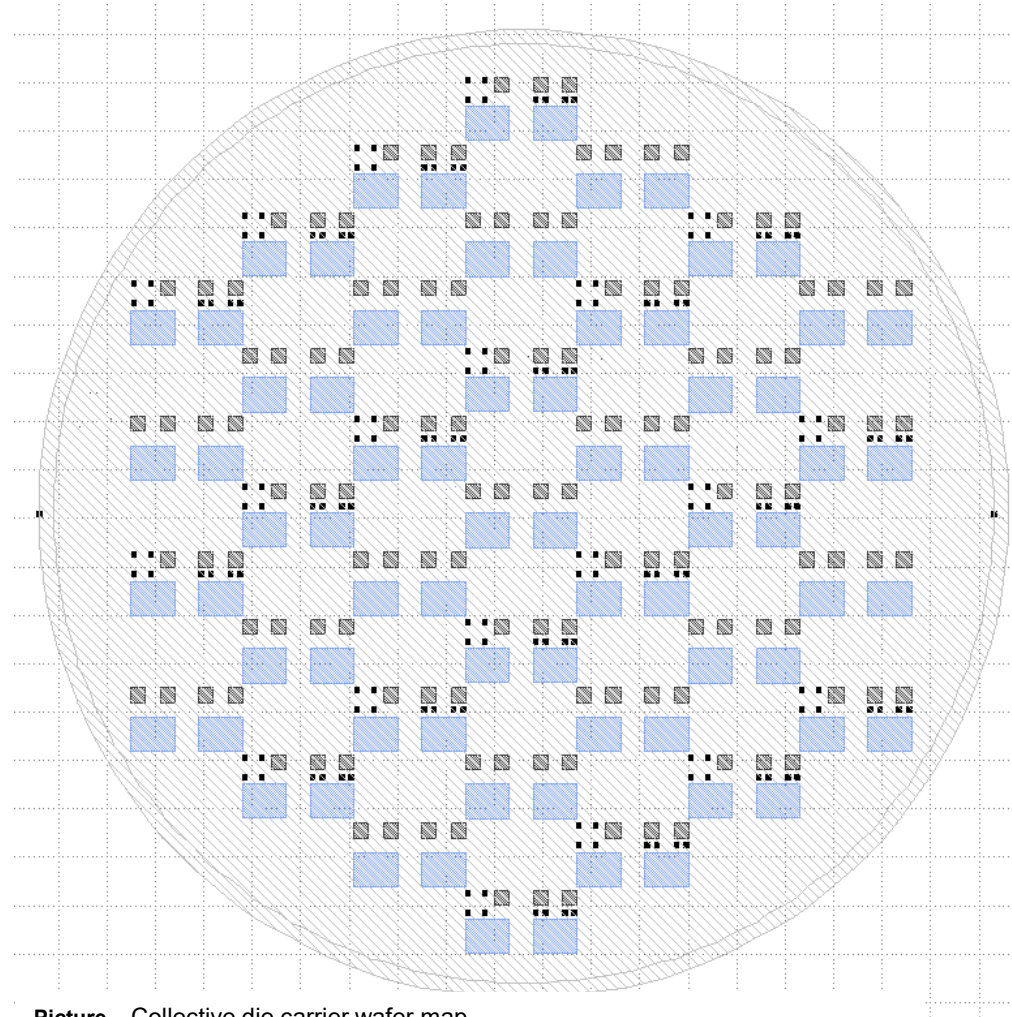
### Demonstrator A

**Target wafer:** 200mm Thermal Oxide wafer

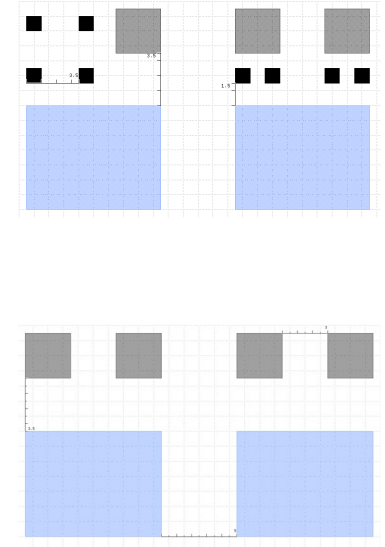
**Collective carrier wafer:** 200mm Bare Silicon wafer

### Die sizes:

- 1x1mm x350µm dies
- 3x3mm x350µm dies
- 7x9mm x350µm dies



Picture – Collective die carrier wafer map.

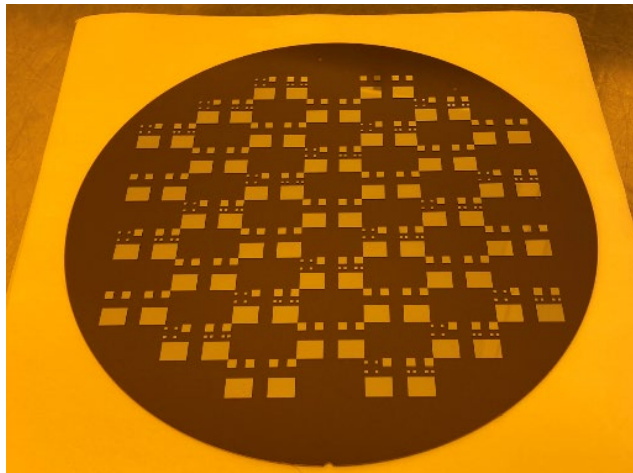


Picture – Collective die carrier wafer map – die detail.

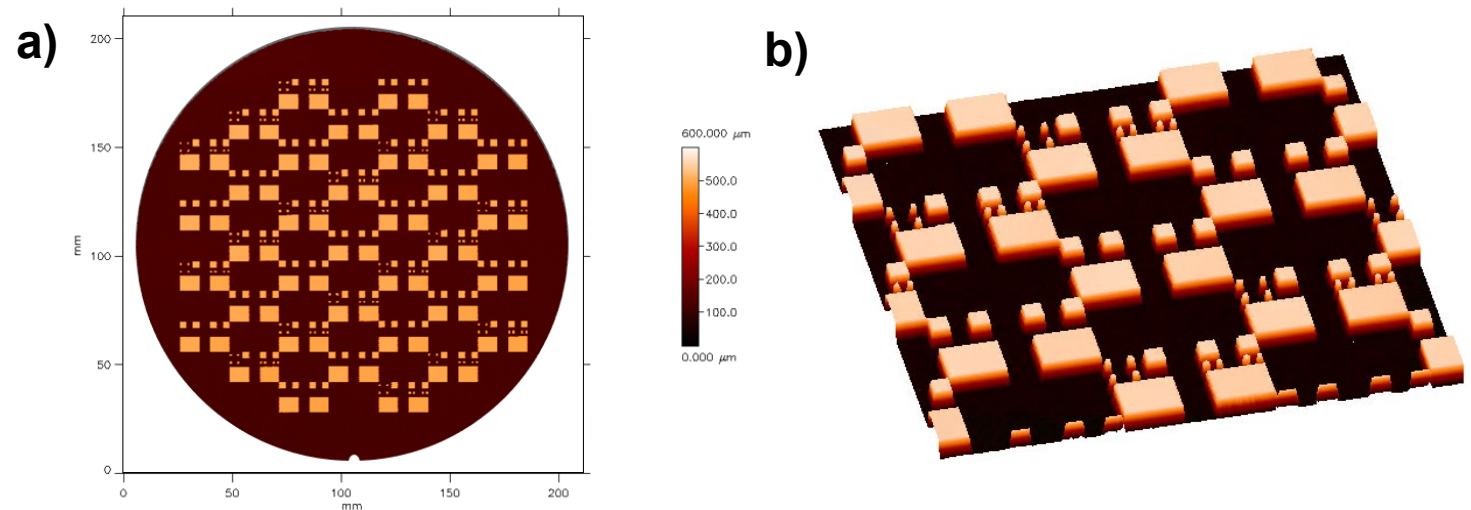
# Co-D2W Bonding | Process Results – Multi Die - Direct Bonding

## Post collective carrier preparation inspection

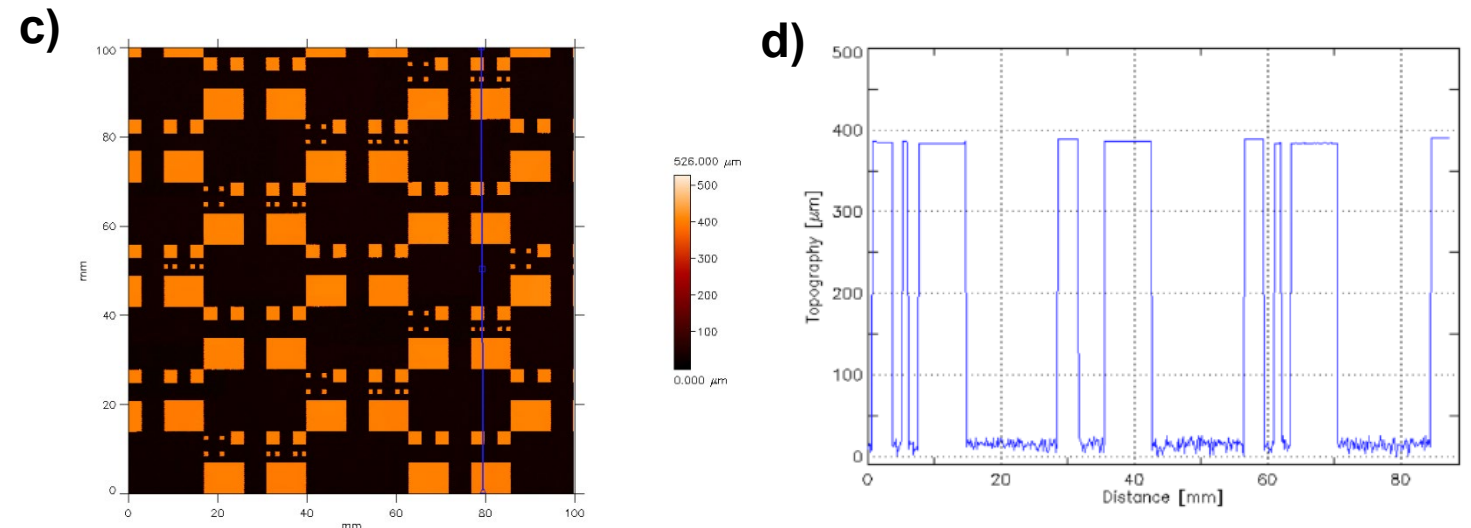
- A high-resolution die height variation (DHV) measurement was performed on the collective carrier with dies after placement using a chromatography sensor to evaluate the die uniformity / distribution.
- A die height variation  $< 3\mu\text{m}$  could be observed after collective die carrier preparation.



**Picture** – Collective die carrier wafers after die placement process.

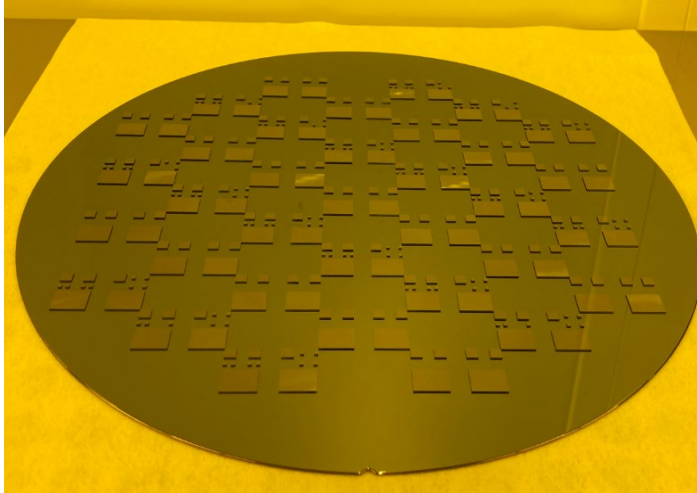


**Die Height variation Measurement** – a): Full scan – 2D collective carrier map; b): Detail scan – 3D collective carrier map.



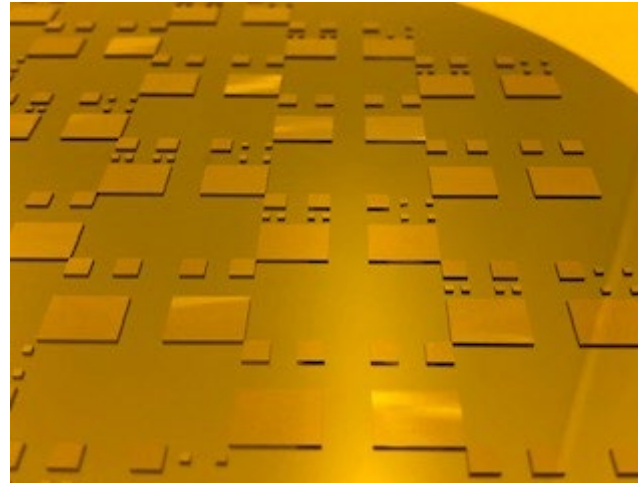
**Die Height variation Measurement** – a): Detail scan – 2D collective carrier map; b): Detail scan – DHV across the blue line.

# Co-D2W Bonding | Process Results – Multi Die - Direct Bonding

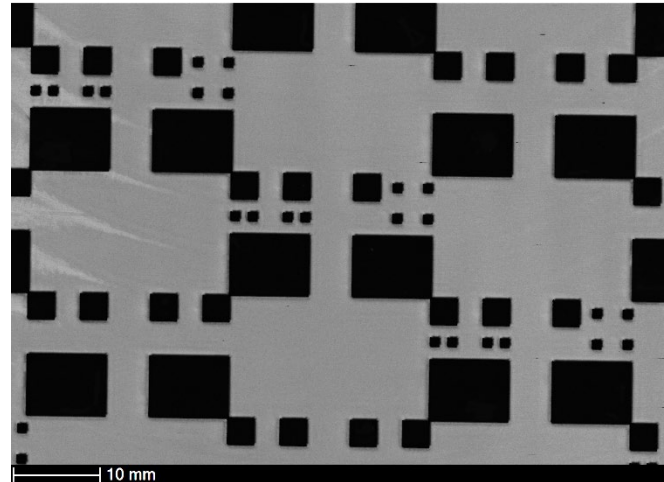


**Picture** – Target wafer with dies after die transfer process.

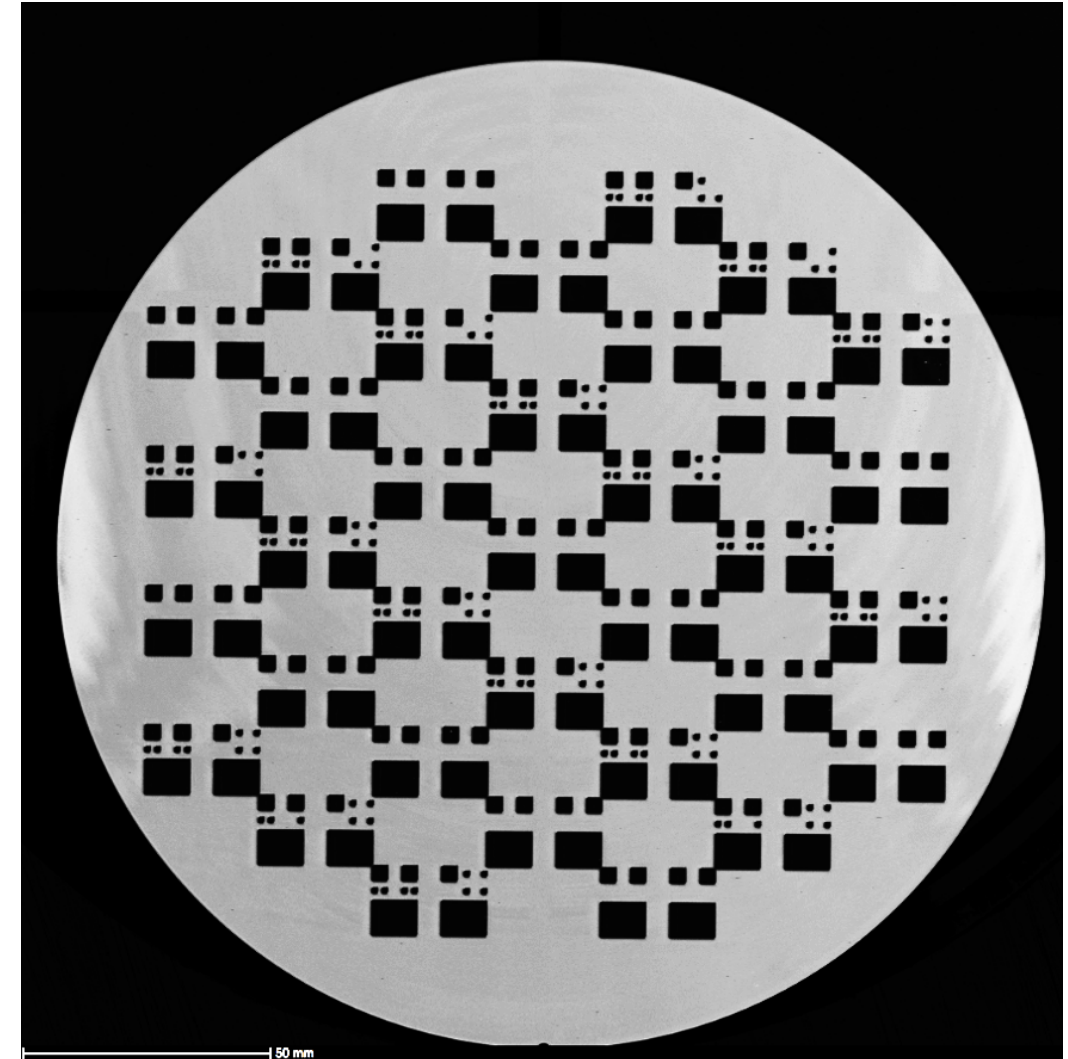
- High transfer yield including high bonding quality based on Scanning Acoustic microscope images (C-SAM) could be achieved.



**Picture** – Target wafer with dies after die-to-wafer bonding process – die detail..



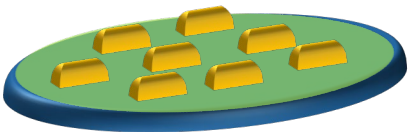
**C-SAM inspection** – Post annealing inspection – detail scan.



**C-SAM inspection** – Post annealing inspection – full scan.



| Bonding Process           | Die Substrate Material | Die Dimension | Target Substrate Material | Bonding Interface | Bonding Parameter |
|---------------------------|------------------------|---------------|---------------------------|-------------------|-------------------|
| Oxide free direct bonding | Si                     | 5 mm x 5 mm   | Silicon                   | SiSi              | RT                |



Collective Die Transfer- Carrier with commercial thermoplastic bonding material

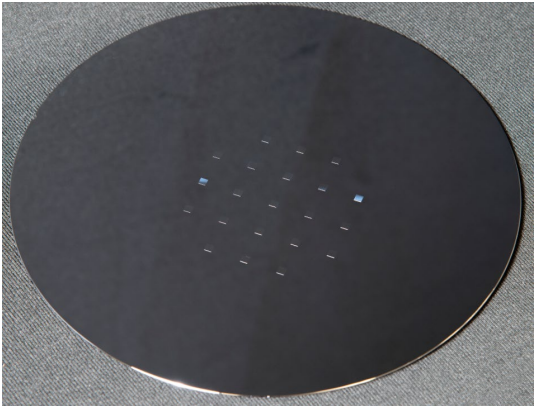
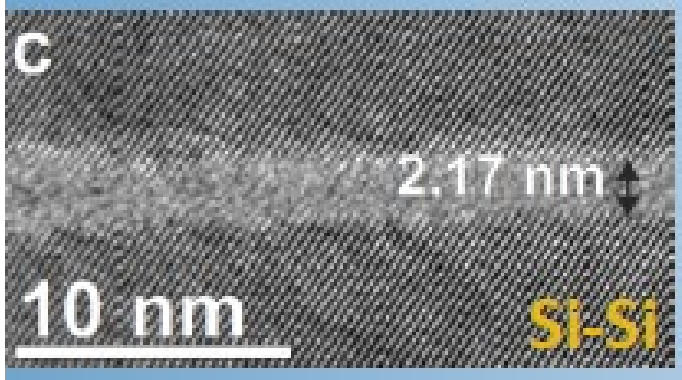
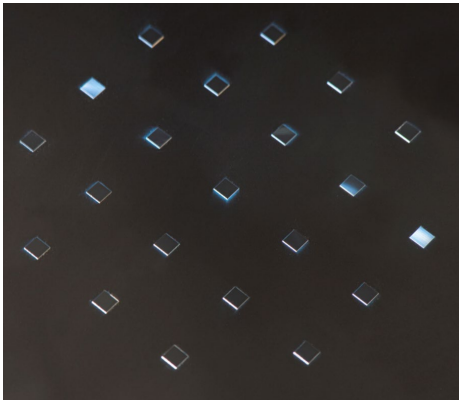


Image – Post Die Transfer and thinning to 10 μm



TEM Cross section Image – post Die Transfer

High transfer yield and high bonding quality based on Scanning Acoustic microscope image and TEM could be demonstrated for collective D2W bonding in Combond.

Expand collective Die to wafer bonding to high Vacuum ComBond technology.

# Summary

## W2W Hybrid Bonding

EVG is market leader for W2W hybrid bonding equipment with more than 80% market share over the last 2 years

EVG fusion and hybrid bonding equipment in W2W bonding is standard process in major IDM and Foundries

Sub 100nm W2W overlay accuracy developed and currently moved in high volume production

## D2W Hybrid Bonding

Several Process Integration schemes are present in the market today with application specific pros and cons

Enabling wafer based cleaning, activation and processing equipment for D2W hybrid bonding for full process transferability from W2W

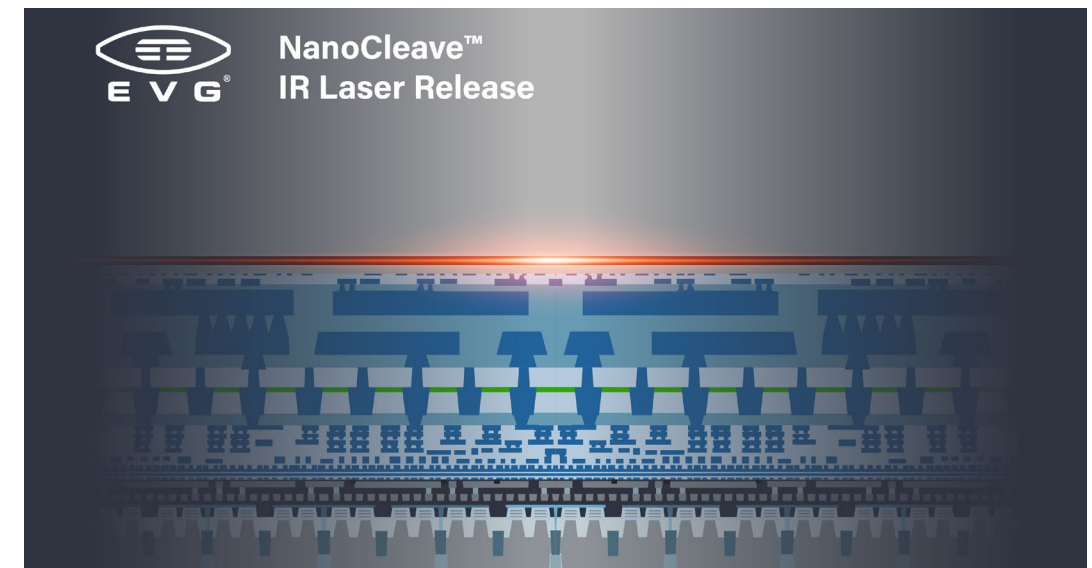
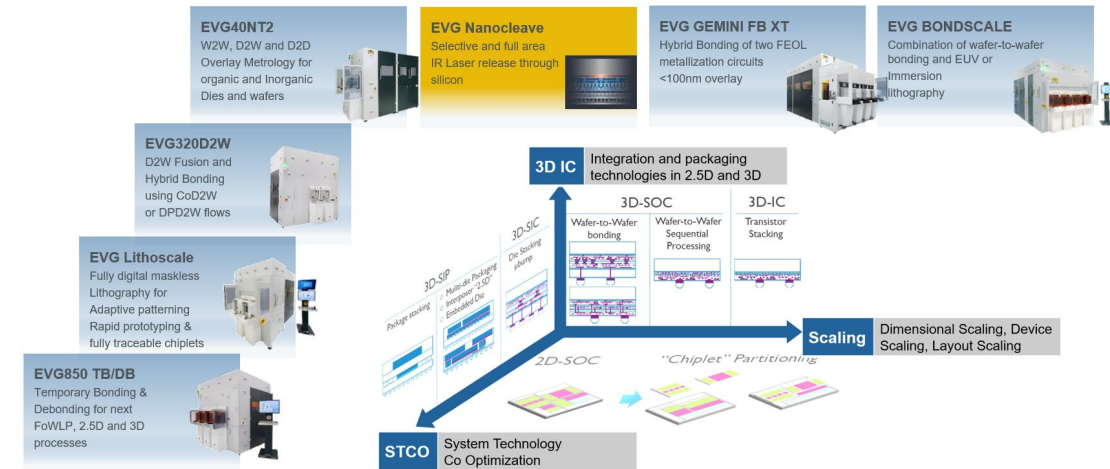
EVG320D2W Fully integrated system solution with standardized process modules

## IR Laser Release – EVG Nanocleave

Novel & universal IR release technology through silicon wafers

Precisely controlled cleaving without IR transmission or risk for product

Inorganic IR release layers with nanometer precision separation trigger





# EV GROUP (EVG)

Get in touch to discuss your high volume manufacturing needs!

THANK YOU!

