Die-to-Die and Die-to-Wafer Bonding solution for High Density, Fine Pitch Micro-Bumped Die

Gilbert Lecarpentier*, Joeri De Vos**

* SET S.A.S. (Smart Equipment Technology), 131 Impasse Barteudet, 74490 Saint Jeoire, France
** IMEC, Kapeldreef 75, Leuven B-3001, Belgium
OUTLINE

- Introduction
- Placement schemes and Bonding schemes
- Die-to-Die Bonding
  - Demonstrator
  - Bonding Process
  - Results
- Summary
GLOBAL ROAD MAP FOR 3D-INTEGRATION WITH TSV
ASSEMBLY TRANSITION ROADMAP IMPACT ON EQUIPMENT DESIGN

Road map shows a migration towards Thermocompression bonding rather than reflow bonding

→ Tougher requirements on bonding equipment
→ Force Increases while pitch and Bump Size decrease
APPLICATIONS REQUIRING HIGH ACCURACY PLACEMENT

IR Sensors

Detectors for IR, UV, X-Ray

Source: Samsung

Optoelectronics Communication Devices

Source: IME

3D Integration C2C - C2W

Source: IMEC

Source: Samsung
PLACEMENT AND BONDING SCHEMES

ALIGNMENT
- Face-to-Face / Flip Chip (F2F)
- Face-to-Back (F2B)

PLACEMENT
- Die-to-Die (D2D / C2C)
- Die-to-Wafer Bonding (D2W / C2W)

BONDING
- In situ Bonding
  - In-Situ Reflow
  - Thermocompression
- Sequential placement followed by gang bonding
DIE-TO-WAFER (D2W) PLACEMENT

😊 Throughput
  • Single Chip Placement

😊 High Yield
  • Known Good Die
  • Good Overlay

😊 Flexibility
  - Component and wafer sizes

😊 Heterogeneity!
  • Different Technologies
  • Different suppliers, …
DIE TO DIE (D2D) BONDING / DIE STACKING

😊 Throughput
- Single Chip Placement
- Multiple Alignment stage capable

😊 High Yield
- Known Good Die
- Good Overlay

😊 Flexibility
- Component sizes (?)

😊 Heterogeneity!
- Different Technologies
- Different suppliers, …
CHIP PLACEMENT

**Face-to-Face / Flip Chip (F2F)**
- Chip must be flipped after pick up prior to being transferred to the bond head.
- Alignment can be made by Inter-Component optics literally at bonding position providing high accuracy placement capability.
- Post bonding testing is difficult.

**Face-to-Back (F2B)**
- Chip can be placed directly after pick up, blind alignment with memorized information is performed.
- For higher accuracy, alignment can still be made by Inter-Component optics in case the via offer good enough image.

Source: SEMATECH

Source: IMEC
DIE-TO-WAFER BONDING
IN-SITU Vs COLLECTIVE, TEMPERATURE PROFILE

Sequential D2W bonding

😊 High Accuracy capability, controlled by the bonder
😊 Time consuming
😊 Landing wafer sees several bonding T-cycles

Collective D2W bonding

😊 Time efficiency
😊 Landing wafer sees only one temperature cycle
😊 Accuracy depends upon pre-attachment method and global bonder

Diagram showing temperature profiles for Sequential D2W bonding and Collective D2W bonding.
DIE-TO-DIE BONDING
DEMONSTRATOR: HYBRID IMAGER

High density 20µm pitch
Applications: FPGA, Fully hybrid imagers

Detector

ROIC

PCB
DIE-TO-DIE BONDING DEMONSTRATOR
μBUMP FULL AREA ARRAY

- Bump diameter: 10µm
- Pitch: 20µm
- Designed to investigate very high bump yield
- Face-to-Face assembly
- 440 long daisy chains of 1766 bumps each

<table>
<thead>
<tr>
<th></th>
<th>Top die</th>
<th>Landing die</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die size</td>
<td>20.2 x 18.7 mm</td>
<td>21.4 x 21.4 mm</td>
</tr>
<tr>
<td>thickness</td>
<td>725 µm</td>
<td>725 µm</td>
</tr>
<tr>
<td># bumps</td>
<td>~ 1000 x 925 bumps</td>
<td></td>
</tr>
</tbody>
</table>
DIE-TO-DIE BONDING DEMONSTRATOR MODULE WITH LONG DAISY CHAIN ARRAY

44 modules (M1 to M44) / die
per module: 5 x 2 interwoven daisy chains of 1766 bumps
→ 440 daisy chains in total / die
Length 1 daisy chain: about 5 cm.

R: NORMAL CHAIN RESISTANCE
S: TO CHECK SHORTS
DIE-TO-DIE BONDING DEMONSTRATOR
μBUMP -- CuSn (Cu Pillar)

D2D Face-to-Face flip chip assembly done at 250°C, 3min, 5MPa
No under fill used to assess stacking yield of μbumps only
Die to Die Alignment, Placement & Bonding was performed on the SET-FC150.

Flexible High Accuracy Die / Flip Chip Bonder

± 1 µm Post Bond Accuracy
Die is vacuum-secured on a Silicon Carbide Pick Up tool
Die is vacuum-secured on a Silicon Carbide Pick Up tool

Parallelism can be actively adjusted by motorized sphere coupled with an autocollimator
ALIGNMENT AND PLACEMENT SEQUENCE

- Die is vacuum-secured on a Silicon Carbide Pick Up tool.
- Parallelism can be actively adjusted by motorized sphere coupled with an autocollimator.
- XYθ Alignment is achieved by inserted microscope between the die and the wafer.
ALIGNMENT AND PLACEMENT SEQUENCE

Die is vacuum-secured on a Silicon Carbide Pick Up tool

Parallelism can be actively adjusted by motorized sphere coupled with an autocollimator

XYθ Alignment is achieved by inserted microscope between the die and the wafer

Bond Head moves down to search contact and Place/bond die on wafer
Supplement to auto-collimator, for components with:
- Low Reflectivity
- Bowed or Warped
- < 2 mm

Laser focus based design
- Focuses at 3 to 8 points, then calculates leveling
- Automated operation
DIE-TO-DIE BONDING DEMONSTRATOR
BONDING RESULTS

- **Copper Cleaning Step**
  - **Process of Record**
  - Temperature elevated after dice are placed in proximity to enable confinement
    - Good bond is achieved
    - Bump resistance 58mΩ

- **No Copper Cleaning Step**
  - **Process of Record**
    - No contact (open circuit)
DIE-TO-DIE BONDING DEMONSTRATOR
Mechanical characterization: shear strength testing

Bump diameter: 7.5µm

Average: 0.385 grf
Std dev: 0.042 grf

Average: 0.452 grf
Increase of 6.7%
Std dev: 0.055 grf

○ Shear tool width: 35µm
○ Shear height: 1µm
○ Shear distance: 50µm
○ Shear velocity: 40µm/sec
○ Touchdown velocity: 40µm/sec
DEMONSTRATOR - DAISY CHAIN YIELD
fixed conditions Cu bump

Daisy chain yield 2PP-measurement on 440 daisy chains with 1766 bumps

Very high daisy chain yield

CuSn bump DOE
No yield influence when
  - TiW OE time by 30%
  - Adding Cu clean

OE = 30% over etch time
DIE-TO-DIE BONDING DEMONSTRATOR
BONDING RESULTS SUMMARY

- Processing scheme 20µm pitch CuSn bumping for 3D stacking
  - POR = TiW/Cu seed, seed ethant B for both bumps;
    Cu clean on Cu bump
  - No yielding daisy chains for Cu bumps not treated with Cu clean
  - Time between Cu clean to assembly: 4 months → no time critical
  - No impact on daisy chain yield when TiW etch time is increased

- High yield numbers (87.5 ~ 99.5%) shown on large area 20 µm bump pitch daisy chains with 10 µm diameter CuSn bumps implies a defect density below 50 for 1 million bumps (< 50 ppm)
IMEC has not disclosed their copper clean process

- SETNA (SET distributor in North America) has developed its own surface preparation system (*Patent pending*)
- It removes native oxide on various metals, and applies a thin passivation layer preventing re-oxidation even at elevated temperature
DIE-TO-DIE BONDING DEMONSTRATOR
BONDING IN NEUTRAL GAS ENVIRONMENT

- Gas confinement made easier for Die-to-Die as bond head and substrate chuck have same or similar dimensions
DIE-TO-DIE BONDING DEMONSTRATOR
BONDING IN NEUTRAL GAS ENVIRONMENT

Gas confinement made easier for Die-to-Die as bond head and substrate chuck have same or similar dimensions

In case of small Bottom die (<20mm) a confinement cover can be used to reduce the window and ensure confinement efficiency even when bond head is not in bonding position
REMOVAL OF OXIDE PRIOR TO BONDING IN-SITU CONFINEMENT CHAMBER (D2D VERSION)

The Semi-Open Confinement includes a Contactless Cover Plate attached to the Bond Head it becomes active only when components are in proximity.

- Process Gas is injected towards the components (programmable gap)
- Exhaust Ring prevents process gas dissemination in the environment
- External Nitrogen curtain prevents Oxygen introduction in the Confinement Chamber
REMOVAL OF OXIDE PRIOR TO BONDING REDUCTION CHAMBER HARDWARE

Photos of the D2D version of the micro-chamber

View of Chuck

View of Bond Head
In the Die-to-Wafer version of the Confinement Chamber, the chamber part is attached to the bond head, the contact less cover function is performed by the wafer itself.

This experimental set up has some challenges:
- Local areas of the wafer see several gas reduction cycles.
- During wafer population, exposed areas oxidize.
DEMONSTRATOR - HYBRID IMAGER
µBUMP ROADMAP

Source: imec
FINER PITCH IMPACT ON BONDING EQUIPMENT

Depending upon bonding process and bump material, post bond alignment requirement is
30 ~ 10% of bump size
(10µm pitch, 5µm Bump)

0,5µm Post Bond Alignment

- Higher Camera Resolution
- Better automatic vision system
- Higher machine stiffness and stability
- Higher Alignment Stage resolution
- Better thermal management
ALIGMENT WITH INTER-COMPONENT OPTICS / FC300R

- Requires machine stiffness/stability and optics resolution adapted to the alignment accuracy target
- Alignment Accuracy at 3 sigma = 0.12 µm
PLACEMENT AT ROOM TEMPERATURE / FC300R

- Automatic Calibration check every hour
- Post Bond Accuracy at 3 sigma = 0.51 µm
THERMOCOMPRESSION BONDING SIMULATION

- Automatic Calibration check every hour
- Placement Accuracy at 3 sigma → X 0.45 µm, Y 0.65 µm
  (TC Bonding simulation at 300°C)

Bond head 50mm / Substrate Chuck 50mm / TC Bonding simulation with Quartz Chips (12x12mm) -- Température 300 °C
SUMMARY

Using the SET-FC150, high accuracy Flip Chip Bonder, Connecting full area µbump array on large 20mm die has been demonstrated using a Chip to Chip, Face to Face (Flip Chip) placement and Thermo Compression process.

Cleaning copper pad/pillar is required to obtain good contact.

µbump roadmap showing bump pitch reduction to 10µm with eventually larger die induces tougher requirement on die parallelsim adjustment, alignment and post bond accuracy.

The new generation bonder FC300R achieves this requirement.
Thank you for your attention
Questions?

Die-to-Die and Die-to-Wafer Bonding solution for High Density, Fine Pitch Micro-Bumped Die

Gilbert Lecarpentier*, Joeri De Vos**

* SET S.A.S. (Smart Equipment Technology), 131 Impasse Barteudet, 74490 Saint Jeoire, France
** IMEC, Kapeldreef 75, Leuven B-3001, Belgium