Temporary Wafer Bonding - Key Technology for 3D-MEMS Integration

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Fraunhofer ENAS
System-Packaging (SP)
Back-End of Line (BEOL)
Outline

- 3D-MEMS integration
  - Motivation and challenge
  - Main processes for 3D-MEMS integration
- Temporary wafer bonding
  - Method (zone bonding process)
    - Device and carrier wafer preparation
    - Adhesive wafer bonding
    - Wafer de-bonding
- Summary and Outlook
3D MEMS Integration

Motivation

- New applications, different functionalities and interaction with environment

→ Demand for Smart Systems

From lateral to vertical integration

- Vertical Integration improves the driving factors: size, cost, speed and power consumption
3D MEMS Integration

Challenge compared to "3DIC"

- Functionalities (optic, mechanic, fluidic + electronic)
- Different technologies, materials and substrates (e.g. silicon, ceramic, glass, metal, polymers)
- Sensible components, hermetical packaging
- TSVs with high aspect ratio and large dimensions
- No Standard solution → depending on the application

MEMS: micromechanics

Principle of integrated MEMS (Sensor + ASIC/Cap)

CMOS based on Image Sensor with HAV TSVs

3DIC

Samsung (16Gbit DRAM)

IBM (TSV in 32nm CMOS)
3D MEMS Integration

Main process steps

Principle

- Combination of different devices (MEMS+ASIC/Cap)
- Creation of miniaturized system

Main processes

- Wafer thinning
  - Form factor/ TSV depth reduction
- Fabrication of through substrate vias (TSVs)
  - TSV etching, isolation and fill with conductive material
- Permanent wafer bonding
  - Realization of mechanical + electrical contact including other functions (e.g. hermiticity, ...)

MEMS wafer

ASIC/Cap wafer

Wafer thinning

TSV fabrication

Permanent wafer bonding

Mounting on PCB
3D MEMS Integration

Main process steps

Permanent bonding

- Bonding without intermediate layer
  - Fusion bonding
  - Anodic bonding
  - Metal/oxide
  - Metal/polymer

- Hybrid bonding
  - Insulating layer
  - Metal layer

- Bonding with intermediate layer

Temporary bonding

- Dry
  - Tape
  - Electrostatic
  - Adhesive

- Wet

Wafer bonding

- Surface activated bonding
  - Glass-frit bonding
  - Adhesive bonding
  - Eutectic bonding
  - SLID bonding
  - Laser bonding
  - TC bonding
  - Reactive bonding

- Thermal
  - Chemical
  - Laser
Temporary wafer bonding - key Technology for 3D-MEMS

Motivation

- 3D integration required wafer thinning
- Thinned wafer: low stability, low bending stiffness and fragile
- Required temporary mechanical wafer support
  → Solution: temporary wafer bonding to fix the device to support wafer
  → Established method in 3D IC

Source: FRT of America LLC

Extreme wafer deflection

Source: ITRI

3D-IC
Temporary wafer bonding - key Technology for 3D-MEMS

Motivation

- Temporary wafer bonding technology important in 3D-IC:

<table>
<thead>
<tr>
<th>Step #1</th>
<th>Step #2</th>
<th>Step #3</th>
<th>Step #4</th>
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<td>TSV Etch</td>
<td>TSV Fill</td>
<td>FEOL 1st</td>
<td>BEOL 1st</td>
<td>De-Bonding</td>
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<td>FEOL 2nd</td>
<td>BEOL 2nd</td>
<td>Thinning</td>
<td>TSV Etch</td>
<td>De-Bonding</td>
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</table>

Source: Yole 2014
### 3D MEMS Integration

#### Main process steps

**Temporary bonding**

- **Permanent bonding**
  - Bonding with intermediates layer
    - Fusion bonding
    - Anodic bonding
    - Metal/oxide
    - Metal/polymer
    - Insulating layer
    - Metal layer
    - Glass-frit bonding
    - Adhesive bonding
    - Eutectic bonding
    - SLID bonding
    - Laser bonding
    - TC bonding
    - Reactive bonding
    - Thermal release
    - Laser release
    - Chemical release

- **Hybrid bonding**
  - Bonding without intermediates layer
    - Surface activated bonding
    - Oxide free bonding

- **Temporary bonding**
  - Dry
  - Tape
  - Electrostatic
  - Adhesive
  - Wet

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Temporary wafer bonding - key technology for 3D-MEMS

**Methods**

Various methods are available with different requirements for thermal, chemical and mechanical stress.

**Traditional methods:**
- Thermal slide, laser release

**Trend:**
- Chemical release with room temperature de-bonding (peel-off)
- Two different zones (zone-bonding)

**ENAS:**
Brewer science ZoneBond® technology with temporary adhesive wafer bonding process
Temporary wafer bonding - key technology for 3D-MEMS

Zone-Bond® technology

Main process steps:

- Preparation device wafer
- Preparation carrier wafer
- Adhesive wafer bonding
- Wafer de-bonding
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**Zone-Bond® technology**

- **Device wafer**
- Spin coating thermoplastic adhesive
- **Cure adhesive**
- **Carrier wafer** with low adhesion zone in the center
- **Flip wafer**
- **Adhesive wafer bonding temperature/ force**

**Temporary wafer bonding**

- **Carrier wafer cleaning**
- **Device wafer cleaning**
- **Mechanical de-bonding at room temperature**
- **Zone edge cut release**
- **Attach on dicing frame**

**Wafer de-bonding**

Source: SUSS microtec
Temporary wafer bonding - key technology for 3D-MEMS

**Device wafer preparation**

- Preparation device wafer (100-200mm) with spin on process using SUSS RCD8 coating system (including hotplate)
- Spin on process with thermoplastic adhesive (ZoneBOND™ 5150), started in wafer center → high viscosity: 10000cp, layer thickness: 15-30µm
- Cure adhesive: 230°C, 2min

Fig.: process flow device wafer preparation
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*Device wafer preparation*

- Layer thickness depends on vacuum chuck rotating speed
  - Thickness 15-30µm required rotating speed of 1000-2000 R/min
- Dispensing quantity: 5-10ml

![Graph: layer thickness in dependence on the rotating speed](image)

Fig.: measured layer thickness (30µm) and homogeneous coated wafer
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**Carrier wafer preparation**

- Preparation carrier wafer (100-200mm) using SUSS RCD8 coating system (including hotplate)
- Dispensing adhesive (ZoneBOND™ EM 2320) on wafer edge
  - Medium viscosity: 400cp, layer thickness: 0.5-3µm
  - Cure adhesive: 220°C, 2min
- Dispensing anti-stick layer (ZoneBOND™ Z1 3500-02) on wafer center
  - Low viscosity: 50cp, layer thickness: 1.5-3nm
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Carrier wafer preparation

- Layer thickness depends on vacuum chuck rotating speed and dispensing quantity

→ Layer thickness of 2µm required rotating speed of 300 R/min with dispensing quantity of 1-2ml

- Adhesive edge width: 1.5mm

Fig.: layer thickness in dependence on the dispensing quantity with constant rotating speed 300R/min

Fig.: carrier wafer after coating with adhesive on wafer edge (1-2mm)
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Adhesive wafer bonding

- Adhesive wafer bonding of device and carrier wafer
- Equipment: wafer bonding system SB8e (company SUSS MicroTec)
- Process parameter:
  - Temperature: 200°C
  - Time: 2min
  - Bonding force: 170 kN/m²
- Forming of two different zones
  - Fragile adhesive region (zone 1) → wafer center
  - Strong adhesive region (zone 2) → wafer edge

Fig.: Wafer bonding system SB 8e

Fig.: Schematic drawing regarding adhesive wafer bonding in the SB8e
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Adhesive wafer bonding

- Characterization adhesive wafer bonding technology
  - Quantitative: IR-Detection
  - Qualitative: Compression shear test
    - Fragile adhesive zone 1:
      Dicing → Yield < 5%
      Bonding strength: 4MPa
    - Strong adhesive zone 2:
      Dicing → Yield > 90%
      Bonding strength: 8MPa

Fig.: IR-Detection after adhesive Wafer bonding w/o defects
Fig.: Shear strength zone 2 (left) and zone 1 (right)
Fig.: Dicing yield zone 1 (left) and zone 2 (right)
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Wafer thinning
- Wafer size: 100…200 mm
- Material: Si, glass, ceramic…

Grinding
- Disco DAG 810 semi automate
- Final thickness: < 50 µm

Spin etching
- HF/CH₃COOH/HNO₃ chemistry
- Stress release after grinding
- Surface quality: \( R_a = 4 \) nm

Chemical mechanical polishing
- IPEC and AMAT Mirra tool
- Surface quality: \( R_a < 0.5 \) nm
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Additional processes

- DRIE etching
- Metallization
- Photolithography
- Wet etching
- Cleaning processes with acids and bases
- … (Processing temperatures up to 250°C)

<table>
<thead>
<tr>
<th>Solvents</th>
<th>NMP</th>
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<tr>
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<td>25°C</td>
<td>30 min</td>
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<td>25°C</td>
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<tr>
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<table>
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<td>KOH (30%)</td>
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<td>2% TMAH (2%)</td>
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**Wafer edge release**

- Thinned wafer stack attach to dicing frame
- Chemical release of the zone 2 direct on tape frame (support with ultrasonic)
- Equipment: cleaning system AR12 (SUSS microtec)
  - Wafer size: 100-200mm
  - Time: 10-20min (depended on zone 2 width)
  - Solvent/ swell: mesitylene/limonene
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**Wafer de-bonding**

- Wafer de-bonding carrier- and device wafer
- Room temperature peel-off process
- Initiation with blade
- Carrier wafer release with flexible plate

**Equipment: wafer debonder DB12T (SUSS microtec)**
- Wafer size: 100-200mm
- Kraft: 100-500N
- Time: 5min

Fig.: schematic drawing to wafer de-bonding

Fig.: wafer de-bonding system DB 12T
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*Device cleaning and handling*

- Cleaning carrier and device wafer
  - Combined puddle dispense- und spray cleaning process
    - Device wafer on dicing frame
    - Carrier wafer single process
- Equipment: AR12 cleaning system (SUSS microtec)
  - Wafer size: 100-200mm
  - Time: 10min
  - Solvent/swell: mesitylene/limonene, IPA
- Thinn wafer handling using electrostatic vacuum chucks

*Fig.: AR12 cleaning system (company SUSS microtec)*

*Fig.: electrostatic vacuum chuck*  
*Fig.: 50µm thinned device wafer*
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Possible scenario for 3D-MEMS Integration

Device wafer with Via first TSV

Temporary wafer bonding

Wafer thinning

Wafer bonding to MEMS wafer
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Summary and Outlook

- Trend: increasing of functionalities in one system and component size reducing → solution: 3D MEMS Integration
- Key technology: temporary wafer bonding
  - High priority in 3D-IC → technology transfer to MEMS devices
  - Complex two-zone approach → Reduction to one zone (new technology called BrewerBond®)

![Temporary Wafer Bonding Diagram]

Source: SUSS microtec
Thank you for your kind attention!

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