Using Low Cost of Ownership Direct Bonding Technologies For MEMS Applications

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VP – 3D Applications, Invensas Corporation
Outline

• Background: ZiBond and DBI

• Key MEMS Requirements

• ZiBond and DBI Attributes

• Summary
Background: ZiBond® & DBI®
Corporate Overview

Incorporated: 1990
Headquarters: San Jose, California
Nasdaq listed: TSRA
Shares Outstanding: ~52 Million
Employees: ~270 (~210 Engineers)
2015 Revenue: $273 Million
2015 Net Income: $117 Million

Mission: Invent, develop, and commercialize electronic interconnect, imaging, and learning technologies to enable efficient, intelligent devices everywhere.
Over 25 Years of Leadership in Innovation & Technology Licensing

Parent Company: Founded in 1990, manages licensing for Tessera’s subsidiaries.

Develops novel semiconductor packaging & interconnect solutions for memory, mobile, computing, and smart object applications.

Develops software and hardware-accelerated computational imaging, computer vision and biometrics solutions for multiple applications.

Develops novel semiconductor packaging & interconnect solutions for memory, mobile, computing, and smart object applications.

Acquired in August 2015
**ZiBond® and DBI® Process: Leverages Existing Infrastructure**

**ZiBond®**

- Homogenous Bonding
  - Dielectric - Dielectric
  - Example: SiO₂ - SiO₂

**DBI®**

- Hybrid Bonding
  - Oxide to Oxide with Interconnect
  - Example: Cu/SiO₂ - Cu/SiO₂

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Courtesy Chipworks

**SEM cross-section of stacked dies**
- 13-Mpixel CMOS Image Sensor
- 90-nm back-illuminated sensor bonded face-to-face with 65-nm image processor
- "up & over" TSVs filled with Cu & appear to be filled simultaneously

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ZiBond Bond Energy

Low Distortion Dielectric Bonding
Very High Bond Energy at Very Low Temperature

Fracture Strength of Silicon

Minimum bond energy for post bond fabrication
DBI® Hybrid Bonding Uniqueness

Electrical Interconnections at Low Temperature without External Pressure Minimizes Stress and Cost of Ownership

Cross-Section after Pick/Place (example)

- SILICON
- CMOS Back End of Line
- Oxide
- METAL
- Oxide
- CMOS Back End of Line

Heating Closes Recess (~ 1 nm / 50ºC)

- SILICON
- CMOS Back End of Line
- Oxide
- METAL
- METAL
- Oxide
- CMOS Back End of Line

Further Heating Compresses Metal w/out External Pressure

- SILICON
- CMOS Back End of Line
- Oxide
- METAL
- Oxide
- CMOS Back End of Line

Spontaneous Chemical Reaction with By products Diffusing Away from Bond Interface
ZiBond® and DBI® Have Widespread Applicability

**ZiBond® and/or DBI Licensees***:
Sony, Silanna Semiconductor (acq. by Qualcomm), Raytheon, Novati, Fraunhofer, Tezzaron, Sandia and MIT LL
Key MEMS Requirements
Example MEMS Process Flow*

- „Typical“ flow requires two bond steps
- Variety of bond options
  - Si Fusion
  - Anodic
  - Transient Liquid Phase
  - Eutectic
  - Metal thermocompression
  - Others ...

* Adapted from “Applying the CMOS Test Flow to MEMS Manufacturing” Mike Daneman, InvenSense, Inc. (http://www.meptec.org/Resources/2%20-%20InvenSense.pdf)
<table>
<thead>
<tr>
<th></th>
<th>Anodic</th>
<th>Glass Frit</th>
<th>TLP</th>
<th>Eutectic</th>
<th>Metal TCB</th>
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</thead>
<tbody>
<tr>
<td><strong>Bonding Temp. (°C)</strong></td>
<td>350 - 450</td>
<td>350 - 450</td>
<td>180 - 300</td>
<td>300 - 450</td>
<td>100 - 400</td>
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<tr>
<td><strong>Post Anneal (°C)</strong></td>
<td>NA</td>
<td>Same as bonding</td>
<td>Higher than bonding</td>
<td>Same as bonding</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Bond Cycle Time (min)</strong></td>
<td>5 – 20</td>
<td>20 – 30</td>
<td>30 – 50</td>
<td>30 – 50</td>
<td>15 – 90</td>
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<tr>
<td><strong>Line Width (µm)</strong></td>
<td>&gt;20</td>
<td>200 – 500</td>
<td>&gt;30</td>
<td>&gt;30</td>
<td>&gt;30</td>
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<tr>
<td><strong>Topography Toler. (µm)</strong></td>
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<td>1 – 1.5</td>
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<td>0</td>
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<tr>
<td><strong>Leak Rate</strong></td>
<td>Low</td>
<td>Low</td>
<td>Very Low</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>High Voltage</td>
<td></td>
<td></td>
<td></td>
<td>Pressure</td>
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*Adapted from EVG’s presentation at MEMS Tech XPOT Semicon West 2015
ZiBond and DBI Attributes
High Throughput: DBI® Wafer to Wafer Bonding

Wafer Alignment in Ambient with Pick/Place Tool

Cross-Section of Wafers Bonding

Wafer to wafer video here
High Throughput: DBI Die to Wafer

Die to Wafer Bonding would be used in MEMS applications where top and bottom die sizes may not match.
Comparing Permeability of Water Vapor in Materials

- Glass seals vary considerably in permeability
  - 10 um seal width does not provide adequate sealing
  - 100 um may suffice, depending on glass properties
- Metal seals demonstrate orders of magnitude better performance than glass
- Depending on applications, either ZiBond or DBI could be used

Hermetic Sealing With ZiBond

- Die Size: 8x8 mm²
- Cavity: 7x7 mm² x 0.1 mm
- Bond ring: 0.5 mm
- MIL STD 883E


Helium partial pressure vs post-helium pressure time for ZiBond bonded silicon cavity to silicon wafer

Expect even better hermetic sealing from DBI (comparable to other metal bond technologies)
ZiBond in MEMS

Photograph of a MEMS cavity wafer encapsulated with ZiBond to a glass wafer for a micromirror application. Inset of a singulated die shows the ZiBond surface.
### Comparing Bond Technologies

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* Ref: Ziptronix internal data; BEOL development facility (Morrisville, NC)
** Preliminary analysis shows equal to/better than Anodic bonding
*** Ref: Slide 15, equivalent or better than similar metal bonding
Summary
Applying ZiBond and DBI to MEMS

- **Wafer / Die Bonding is a Key Technology Enabler** - 2.5D/3D IC, Image Sensors, MEMS / Other Sensors, DRAM, RF ...

- **ZiBond® and DBI®**: Cost effective, low temperature wafer to wafer and die to wafer bonding platforms for wide range of applications
  - In high volume production - Multiple generations of leading smartphones and other consumer electronics
  - RF: Enables reliable bonding and lowers cost for filters and switches
  - Image Sensor: Industry leading backlight illuminated (BSI) image sensor with up to pixel-level interconnect capability
  - DRAM: Thinnest and lowest cost 3D DRAM
  - 2.5D/3D IC: Eliminates microbumps, underfills and improves performance

- **ZiBond® and DBI® for MEMS:**
  - Alleviates temperature, cycle time, pressure or high voltage concerns with current bonding solutions
  - Enables lower cost and reliable MEMS devices