Trends in Wafer Bonding for High Volume Consumer MEMS Applications

Markus Wimplinger – Corporate Technology Development and IP Director – EV Group
Trends in Wafer Bonding for High Volume Consumer MEMS

Outline

- MEMS Market Overview
- Product Trends
- Process Trends
- Equipment Trends
- Conclusion
MEMS Market Overview
Figure 1. The MEMS market is increasingly dominated by consumer applications, which inescapably means high volumes, short product cycles times, and pressure for low costs. Source: Yole Developpement.
MEMS‘ Market Overview

The Growing “Billion Unit” Club

MEMS cumulative shipments for selected companies (Munits)

Yole développement © May 2012
MEMS‘ Market Overview

MEMS devices are manufactured in VOLUME.

- ST Microelectronics is estimated to produce more than $4 \times 10^6$ devices per day (more than 56 devices per second!)
- Bosch is estimated to produce approximately $2.5 \times 10^6$ devices per day
- About $3 \times 10^6$ MEMS Microphones are produced per day.
- Roughly more than 3.5 Billion MEMs devices per year!
MEMS‘ Market Overview

Price is Decreasing Rapidly

ASP evolution for MEMS accelero, gyros & compass in mobiles & Mfg Cost

<table>
<thead>
<tr>
<th>Year</th>
<th>3A ASP ($)</th>
<th>3M ASP ($)</th>
<th>3G ASP ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>$2.7</td>
<td>$0.9</td>
<td>$2.7</td>
</tr>
<tr>
<td>2011</td>
<td>$2.2</td>
<td>$0.7</td>
<td>$2.2</td>
</tr>
<tr>
<td>2012</td>
<td>$1.8</td>
<td>$0.6</td>
<td>$1.8</td>
</tr>
<tr>
<td>2013</td>
<td>$1.5</td>
<td>$0.5</td>
<td>$1.5</td>
</tr>
<tr>
<td>2014</td>
<td>$1.2</td>
<td>$0.4</td>
<td>$1.2</td>
</tr>
<tr>
<td>2015</td>
<td>$1.0</td>
<td>$0.4</td>
<td>$1.0</td>
</tr>
</tbody>
</table>

2010 3G Manufacturing Cost ($) = $2.7
2010 3A/3M Manufacturing Cost ($) = $0.9/0.7
Product Trends
MEMS Product Trends

MEMS Performance Dimensions

- SWPPCCE (Size, Weight, Power, Performance, Cooling, Cost & *Ease of Integration*)
  - For consumer MEMS
    - Cost
    - Size
    - Power
    - *Ease of Integration*
      - *NRE & TTM*
    - Cooling
    - Weight
    - Performance
MEMS Product Trends

• Design Kits (requires standard process)
  – Reduce NRE costs
• Die Shrink
  – Increased die per wafer
• Standard Processes
  – Reduced cost
  – Reduced TTM (time to market)
• Automated Equipment
  – Integrated with shop floor control system
    • Lot tracking
    • Recipe management
  – Cassette to Cassette systems
    • Minimize operator handling
• Control Plans & Systems
  – Metrology
  – Test Structures
  – SPC (statistical process control)
  – Feedback loops
• Yield Analysis
  – Improve yield
• Simplified Packaging
  – Wafer level packaging
• Simplified Test
  – Increased self test
  – Increased sensor fusion for calibration
MEMS Product Trends

MEMS Cost Structure - Process Development

Standard Processes and Platforms

• ST Microelectronics
  – THELMA – Accelerometer & Gyroscopes
  – VENSENS – Pressure Sensors

• Tronics MEMS
  – Inertial
    • Accelerometer
    • Gyroscope
  – Pressure Sensors

• Teledyne DALSA
  – MIDIS™ process for inertial sensors

• X-FAB
  – Pressure
    • Relative
    • Absolute
  – Inertial
  – IR Radiation

• AM Fitzgerald / Silex
  – Rocket MEMS

• TSMC / Nasiri Process
  – Shuttle available
MEMS Product Trends

- Die per wafer
  - Die shrink
  - Bonding line shrink
  - Wafer size increase

Example: Knowles Microphone
MEMS Product Trends

Technical Solutions Adopted in the Inertial Industry

• 2 Market drivers:
  ➢ Reducing cost
  ➢ Smaller packages

• Main techno solution:
  ➢ Smaller die size

ST MEMS Packages Evolution (courtesy of ST)

ASP for motion sensors in cell phones & tablets ($)
Process Trends
MEMS Process Trends

- **Design Kits (requires standard process)**
  - Reduce NRE costs
- **Die Shrink**
  - Increased die per wafer
- **Standard Processes**
  - Reduced cost
  - Reduced TTM (time to market)
- **Automated Equipment**
  - Integrated with shop floor control system
    - Lot tracking
    - Recipe management
  - Cassette to Cassette systems
    - Minimize operator handling
- **Control Plans & Systems**
  - Metrology
  - Test Structures
  - SPC (statistical process control)
  - Feedback loops
- **Yield Analysis**
  - Improve yield
- **Simplified Packaging**
  - Wafer level packaging
- **Simplified Test**
  - Increased self test
  - Increased sensor fusion for calibration

EV Group Proprietary – Prepared for Semicon Taiwan 2013
MEMS Process Trends

MEMS Cost Structure - Process Development

Standard Processes and Platforms

• ST Microelectronics
  – THELMA – Accelerometer & Gyroscopes
  – VENSENS – Pressure Sensors

• Tronics MEMS
  – Inertial
    • Accelerometer
    • Gyroscope
  – Pressure Sensors

• Teledyne DALSA
  – MIDIS™ process for inertial sensors

• X-FAB
  – Pressure
    • Relative
    • Absolute
  – Inertial
  – IR Radiation

• AM Fitzgerald / Silex
  – Rocket MEMS

• TSMC / Nasiri Process
  – Shuttle available
MEMS Process Trends

Wafer Bonding Trends

• From Tried and True
  • Glass Frit (because of line width)
  • Anodic (because of sodium)

– To Metal Bonding
  • Reduced bond line
  • “Hermetic”
  • Conductive – allows 3D Heterogenous Integration

– Process Temperature Reduction
  • Low temperature solder alloys
  • TLP (Transient Liquid Phase) / SLID (Solder Liquid Interdiffusion)
  • Low temperature thermo-compression through surface pre-treatment

Need for more advanced bond alignment
For large dies, no significant savings as the bondline only consumes ~10% or less.

For small dies, huge savings possible.
## ST 3-Axis Gyro Manufacturing Cost Evolution

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS manufacturing cost</td>
<td>$450</td>
<td>$450</td>
<td>$450</td>
<td>$550</td>
</tr>
<tr>
<td>Test &amp; Dicing cost</td>
<td>$50</td>
<td>$60</td>
<td>$70</td>
<td>$80</td>
</tr>
<tr>
<td>MEMS wafer cost</td>
<td>$500</td>
<td>$510</td>
<td>$520</td>
<td>$630</td>
</tr>
<tr>
<td>PGDW per 8-inch wafer</td>
<td>2,900</td>
<td>3,400</td>
<td>4,300</td>
<td>4,900</td>
</tr>
<tr>
<td>Known good dies per 8-inch wafer</td>
<td>2,140</td>
<td>2,510</td>
<td>3,170</td>
<td>3,610</td>
</tr>
<tr>
<td>MEMS die cost</td>
<td>$0.23</td>
<td>$0.20</td>
<td>$0.16</td>
<td>$0.17</td>
</tr>
<tr>
<td>Cost saving</td>
<td>0%</td>
<td>13%</td>
<td>30%</td>
<td>25%</td>
</tr>
</tbody>
</table>
MEMS Process Trends

Process Control Plan

• Define KPOV (Key Process Output Variable(s))
• How will the KPOV be measured?
• What are the specification limits for KPOV?
  – These should be based on the effect on product performance and downstream operations
• What is the capability of the process?
  – Cp and Cpk are techniques for evaluating the capability of a process
• What action will be taken when the process goes out of spec?
Equipment Trends
MEMS Bonding Equipment Trends

• Design Kits (requires standard process)
  – Reduce NRE costs
• Die Shrink
  – Increased die per wafer
• Standard Processes
  – Reduced cost
  – Reduced TTM (time to market)
• Automated Equipment
  – Integrated with shop floor control system
    • Lot tracking
    • Recipe management
  – Cassette to Cassette systems
    • Minimize operator handling
• Control Plans & Systems
  – Metrology
  – Test Structures
  – SPC (statistical process control)
  – Feedback loops
• Yield Analysis
  – Improve yield
• Simplified Packaging
  – Wafer level packaging
• Simplified Test
  – Increased self test
  – Increased sensor fusion for calibration
MEMS Bonding Equipment Trends

HVM Requirements

• Full Automation
  – Lot Delivery
  – Recipe download
  – Cassette to Cassette wafer handling
  – Lot Pick Up

• Integration with shop floor control system
  – Automated recipe Management
  – 100% Tracking
    • Every Operation
    • Every Lot
    • Every Wafer

• Process Variables
  – Input variables
    • Controlled by previous operations.
  – Process variables
    • Controlled by downloaded recipe
  – Output variables
    • Key ones must be measured

• Control Plan
  – SPC
  – Feedback control
MEMS Bonding Equipment Trends

- 100% Tracking
  - Every Operation
  - Every Lot
  - Every Wafer pairing
  - Every bond tool
  - Every chamber

- Allows
  - Sophisticated process control
  - Detailed analysis of any problem that might occur
  - Use of sophisticated software tools, such as “Wafer Sleuth” to analyze data

Example Of “Wafer Sleuth” Analysis Of Positional Data When Troubleshooting Process Variation
MEMS Bonding Equipment Trends

- Process job control (SEMI E40, E94)
- Multi recipe bonding
- Individual recipes and processes down to single substrates slots
  - Operator can choose substrate pairs out of a lot and run specific recipe parameters only valid for the dedicated substrates
  - Bondchuck, process stations (modules) and process sequence can be determined
MEMS Bonding Equipment Trends

- **Process job control** (SEMI E40, E94)
- **Continuous Mode Operation** (CMO)
- **Slot integrity** Slot position of wafers in send cassette = slot position in receive cassette
- **Lot integrity** The system loads the same substrates from send lot #1 to receive lot #1. Even if process times are different due to recipes change for lot #2, subsequently loaded substrates of lot #2 are loaded to its dedicated receive lot #2.
MEMS Bonding Equipment Trends

Full SECS / GEM communications possible
• This allows
  – Compatibility with shop floor control system
  – Automatic recipe download and control
  – Full lot tracking

Data Tracking
• Wafer pairing (which wafer was bonded to which wafer)
• All significant process variables logged
  – Time, temperature, force, vacuum or pressure level
  – Bond tool
  – Bond chamber
Gemini FB – The Workhorse for BSI CIS Manufacturing
MEMS Bonding Equipment Trends

• AVM – Alignment Verification Module
• Integrated in Gemini
• Allows in line measurement of alignment (KPOV)
Conclusions
Conclusions

• MEMS Are In High Volume Production
• Consumer Electronics Are Driving This High Volume
• MEMS Production Is Expected To Continue Growing
• High Volume Manufacturing Has Additional Requirements For Success
• EV Group’s Equipment And Knowledge Are Proven In High Volume
• EV Group Is Ready To Support Your High Volume Production
Trends in MEMS and Wafer Bonding

• Thank You for Your Attention!

• Please contact me if you have any questions.
  • m.wimplinger@evgroup.com
  • +43 (7712) 5311 - 0

• Questions?

• Please visit us at our booth