Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

Michael Shillinger
Vice President of Operations
Innovative Micro Technology
Santa Barbara, CA, USA
mjs@imtmems.com
October 20, 2011
Established in 2000, IMT is a privately-held, profitable company

Acknowledged leader in complex MEMS foundry/contract manufacturing

Offering *flexible turn-key services:*
- Cooperative design for manufacturability
- Process development
- Prototyping
- Volume manufacturing
- Testing
- Metrology/analytical services

**IMT’s Mission:**
- *To enable the shortest time to market and greatest overall value while leading our customers into volume production*
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

• MEMS perform best as fabricated in the clean room
• Airborne contamination generally causes device failure
  – Lead to development of wafer level packaging (WLP)
• WLP forced the need for bond quality testing
  – Hermeticity testing
    • Fine and gross leak verification
    • Gross leaks $> 1 \times 10^{-5}$ > Fine Leaks
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

• Gross Leak Testing Set up (Mil-Std-883G Method 1014)

1) Parts are placed in the preconditioning chamber
2) A vacuum is pulled on the chamber to 5.0 in Hg
3) The Vacuum is maintained for the prescribed time
4) Fluorocarbon FC-84 is pumped into the chamber covering the parts
5) Chamber pressurized to 90 PSIA with N2
6) Pressure is maintained for the prescribed time
7) Pressure vented, fluid drained

1) Parts are placed into the test chamber
2) Temperature is elevated to 125°C
3) Operator views the parts through an illuminated port for 60 sec looking for bubbles
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

• Gross Leak Testing Set up (Mil-Std-883G Method 1014)

Pros:
• Historical Military Specification procedure with abundant data
• Commercial equipment exists for performing this test

Cons:
• Not enough resolution for the small cavity volume of MEMS devices
• Can be destructive for certain types of MEMS devices
• Not wafer level
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

- Fine Leak Testing Set Up (Mil-Std-883G Method 1014)

Step 1: Evacuate chamber
Step 2: Vent Chamber to atmosphere
Step 3: Pressurize chamber with helium
Step 4: Vent chamber to atmosphere
Step 5: Evacuate chamber
Step 6: Residual gas analysis to detect helium
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

• Fine Leak Testing Set Up (Mil-Std-883G Method 1014)

Pros:
• Historical Military Specification procedure with abundant data
• Commercial equipment exists for performing this test

Cons:
• Not enough resolution for the small cavity volume of MEMS devices
• Can be destructive for certain types of MEMS devices
• Not wafer level
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

• Not adequate for MEMS with small device cavities
  – Insufficient resolution

• New testing techniques have been developed specifically for MEMS devices
  – Applicable for other device technologies also
# Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

## Six new testing techniques with more than adequate resolution for MEMS

<table>
<thead>
<tr>
<th>Name of Technique</th>
<th>Basic Principles</th>
<th>Pros</th>
<th>Cons</th>
<th>Wafer or Die Level</th>
<th>Fine or Gross Leak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane deflection</td>
<td>Measurement of membrane deflection to determine hermeticity</td>
<td>Quick, economical, and precise</td>
<td>Requires capital equipment (Wyko Interferometer)</td>
<td>Wafer level</td>
<td>Both</td>
</tr>
<tr>
<td>Radio isotope</td>
<td>Measurement of radio active particles within a cavity</td>
<td>Very precise</td>
<td>Licensing required, requires handling of radioactive material</td>
<td>Die level</td>
<td>Both</td>
</tr>
<tr>
<td>Cumulative Helium Leak Detection (CHLD)</td>
<td>Detection of helium, in a cumulative fashion, using a mass spectrometer</td>
<td>Sensitive, Mil Spec approved</td>
<td>Requires capital equipment (Inficon’s Pernkica 700 Series System)</td>
<td>Die level</td>
<td>Both</td>
</tr>
</tbody>
</table>
**Bonding Reliability Testing for Wafer Level Packaged MEMS Devices**

Six new testing techniques with more than adequate resolution for MEMS

<table>
<thead>
<tr>
<th>Name of Technique</th>
<th>Basic Principles</th>
<th>Pros</th>
<th>Cons</th>
<th>Wafer or Die Level</th>
<th>Fine or Gross Leak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in resistance measurement</td>
<td>Resistance measurement of an in package thermistors</td>
<td>Allows for 100% testing</td>
<td>Requires in package thermistors, requires electrical auto probe system</td>
<td>Wafer level</td>
<td>Both</td>
</tr>
<tr>
<td>Q measurement</td>
<td>Looking at the quality factor of a resonant structure as it affected by gas damping</td>
<td>Quick, economical, and precise</td>
<td>Only works for devices that resonate (i.e. accelerometer)</td>
<td>Wafer level</td>
<td>Both</td>
</tr>
<tr>
<td>Pressurized steam</td>
<td>Inspection of a delidded device looking for in package moisture</td>
<td>Definitive</td>
<td>Destructive, requires autoclave</td>
<td>Die level</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Membrane is formed during fabrication of lid or capping wafers that is ~30 microns in thickness

Membrane deflection for packages in vacuum or pressurized is optically measured with an interferometer
  - Concave membranes = vacuum
  - Convex membranes = pressure

Angstrom resolution

Automated wafer level non-destructive test

In use at IMT for production screening

**Wyko interferometer image of a deflected lid membrane indicating hermeticity**
Membrane Deflection Testing

- Measures both gross and fine leaks
- NorCom Systems
  - Optical hermeticity tester
  - Interferometer with an integrated holographic camera
  - Enables recorded images to be superimposed on live images for comparison
Membrane Deflection Testing

Pros:
• Precise
• Fast
• Low cost
• Wafer level
• Non destructive
• Automated
• Will measure vacuum and pressure

Cons:
• Requires capital equipment
  • Wyko interferometer or LT-550 optical leak test system manufactured by NorCom Systems
  • Device must have a cavity in the lid ~30 microns in thickness and it needs to be opaque
Radioisotope Testing

• Measures both gross and fine leaks
• Similar to helium leak testing
  – Packages are subject to pressurized radioactive gas
• Measures alpha radiation from krypton 85 N2 gas
  – Uses a scintillator
  – Presence of gamma radiation indicates non-hermetic packaging
• Die level testing – higher cost
• Atomic energy license required
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

Radioisotope Testing

Pros:
• Extremely precise
  • Detectability $10^{11}$ KR-85 molecules

Cons:
• Requires handling radioactive material
• Requires an Atomic Energy license
• Expensive test set up
Cumulative Helium Leak Detection (CHLD)

- Only hermetic device testing method currently approved by the military (Mil-Std-750 Method 1071) with sufficient resolution for MEMS
- Die level, sufficient for both gross and fine leak testing
  - Can detect leaks < $1 \times 10^{-14}$ ATM-cc/sec
- Detects krypton, fluorocarbons, argon, and helium
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

Cumulative Helium Leak Detection (CHLD)

Pros:
• Sensitive
• Meets military specification
  • Mil-STD-750 Method 1071

Cons:
• Die level
• Requires purchase of capital equipment
  • Inficon’s Pernkica 700 Series System
Resistance-Hot vs. Resistance-Cold
(R-Hot vs. R-Cold)

- Comparison of resistance of MEMS device or an on board thermistor to baseline resistance
- Screening for low resistance indicates that high vacuum is not present
  - Automated probe station
Bonding Reliability Testing for Wafer Level
Packaged MEMS Devices

Resistance-Hot vs. Resistance-Cold
(R-Hot vs. R-Cold)

• 100% and performed at wafer level
  – Wafer maps generated to indicate pass-fail
  – Ideal for production
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

Resistance-Hot vs. Resistance-Cold (R-Hot vs. R-Cold)

Pros:
• Allows for 100% testing
• Automated
• Wafer level

Cons:
• Requires in package thermistors
• Requires electrical probe system
Q Measurement of MEMS Resonators

- Quality (Q) factor
- Low pressure = low viscous drag on resonating structure
  - High Q factor
- Wafer level test (laser doppler vibrometry or integrated piezo-resistive device)
- Vibration induced electrostatically
- Good for both gross and fine leak testing
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

Q Measurement of MEMS Resonators

Pros:
• Quick
• Economical
• Precise
• Wafer level

Cons:
• Devices applicability
  • Accelerometer
  • Microbolometer

Electron Microscope Image of microbolometer FPA
Pressurized Steam Testing

- Devices placed in autoclave chamber
- Chamber filled with high temperature pressurized steam
  - 130°C at 2.7 ATM and 100% RH for a prescribed time
- Pressurized steam will penetrate into device cavity if the bond is not hermetic
- Devices are de-lidded and optically inspected for moisture
  - Destructive
- Test would be performed in development only
Pressurized Steam Testing

Pros:
• Conclusive
• Equipment is commonly available

Cons:
• Destructive
• Die level
• Not a production test
• Not economical
Bonding Reliability Testing for Wafer Level Packaged MEMS Devices

Summary

• Fine and gross leak testing has been around for many years
• Due to small cavity size of MEMS devices current tests do not exhibit sufficient resolution
• Battery of 2\textsuperscript{nd} generation tests have been developed which work with MEMS and other devices
  – Membrane deflection
  – R-hot vs. R-cold
  – CHLD
  – Q measurement testing
  – Pressurized steam
• IMT currently uses both membrane lid deflection and thermistor measurement screening (R-Hot vs. R-Cold) in production testing of MEMS devices
Thank you for your attention.

Questions??