Ball Grid Array
Assembly Reliability

by
Reza Ghaffarian, Ph.D.
Jet Propulsion Laboratory
(818) 354-2059
Reza.Ghaffarian@JPL.NASA.Gov
Electronic Package Trend
- Package shrink trends/BGA/CSP
- CBGA and BGA definition

Qualification Approaches
- IPC 9701
- CBGA and BGA

Reliability
- Thermal cycle test results
- Thermal cycle/vibration failure mechanisms
- Conclusion

Guides for NASA Missions
Package Miniaturization

QFP 256

CSPs

BGA 256
References

JOSEPH FJELSTAD
REZA GHAFFARIAN
YOUNG-GON KIM

CHIP SCALE PACKAGING FOR MODERN ELECTRONICS

HANDBOOKS

AREA ARRAY PACKAGING HANDBOOK

AREA ARRAY INTERCONNECTION HANDBOOK
CSPs

Grid Arrays

- C4
- Wire Bond
- High I/Os
- Wire bond I/O Limitation
- C4 ceramic, Wafer, Reliability?
- Assembly Robustness

 Leads

- Wafer
- Leaded
- Low I/Os
- No Leads, Reliability?
- Assembly Robustness?

- No Leads

Self Alignment
BGA Balls Collapse

Reflow

63/37 eutectic

PWB

30 mil

16-22 mil

63/37 eutectic
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• **Advantages**
  - Capable of high pin counts
  - Manufacturing robustness
  - Higher package densities
  - Faster circuitry speed than QFP
  - Better heat dissipation

• **Challenges**
  - **Inspection**
    - Routing for high pin count
    - Rework, individual balls
- IPC 9701, Released Jan 2002
  - IPC SM785- Guideline
    - No answer to the question of data for product application
    - Data comparison
  - IPC 9701
    - Details on thermal cycle test and acceptance

- Key Controls
  - Surface finish (OSP, HASL), thickness, 93 mil, NSMD, continuous monitor, etc.

- Five Cycle Conditions
  - Preference 0/100°C

- Five number of thermal cycles
  - Preference 6,000 cycles

IPC 9701- “Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments”
Table 1  Temperature cycling requirements specified in Table 4.1 of IPC 9701

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Mandated Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Cycle (TC) Condition:</td>
<td>0°C ↔ +100°C (Preferred Reference)</td>
</tr>
<tr>
<td>TC1</td>
<td>-25°C ↔ +100°C</td>
</tr>
<tr>
<td>TC2</td>
<td>-40°C ↔ +125°C</td>
</tr>
<tr>
<td>TC3</td>
<td>-55°C ↔ +125°C</td>
</tr>
<tr>
<td>TC4</td>
<td>-55°C ↔ 100°C</td>
</tr>
<tr>
<td>TC5</td>
<td></td>
</tr>
<tr>
<td>Test Duration</td>
<td></td>
</tr>
<tr>
<td>Number of Thermal Cycle (NTC) Requirement:</td>
<td>Whichever condition occurs FIRST: 50% <em>(preferred 63.2%)</em> cumulative failure (Preferred Reference Test Duration) or</td>
</tr>
<tr>
<td>NTC-A</td>
<td>200 cycles</td>
</tr>
<tr>
<td>NTC-B</td>
<td>500 cycles</td>
</tr>
<tr>
<td>NTC-C</td>
<td>1,000 cycles (Preferred for TC2, TC3,and TC4)</td>
</tr>
<tr>
<td>NTC-D</td>
<td>3,000 cycles</td>
</tr>
<tr>
<td>NTC-E</td>
<td><strong>6,000 cycles (Preferred Reference TC1)</strong></td>
</tr>
<tr>
<td>Low Temperature Dwell</td>
<td></td>
</tr>
<tr>
<td>Temp. tolerance (preferred)</td>
<td>10 minutes</td>
</tr>
<tr>
<td>+0/–10°C (+0/–5°C) [+0/–18°F (+0/–9°F)]</td>
<td></td>
</tr>
<tr>
<td>High Temperature Dwell</td>
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</tr>
<tr>
<td>Temp. tolerance (preferred)</td>
<td>10 minutes</td>
</tr>
<tr>
<td>+10/–0°C (+5/–0°C) [+18/–0°F(+9/–0°F)]</td>
<td></td>
</tr>
</tbody>
</table>
Test Vehicles

Type 1 “300” I/Os

- 352 Plastic Perimeter SuperBGA 35 mm
- 352 Plastic Perimeter OMPAC 35 mm
- 361 Ceramic Full Array 25 mm
- 313 Plastic Full Array OMPAC 35 mm

Type 2 “600” I/Os

- 560 Plastic Perimeter SuperBGA 42 mm
- 256 Plastic Gull Wing 30.6 mm
- 625 Ceramic Full Array 32.5 mm
- 256 Plastic Perimeter OMPAC 27 mm

361 I/O CBGA

625 I/O CBGA

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BGA Test Vehicles

a) Type 1 Test Vehicles, 300 I/Os
b) Type 2 Test Vehicles, 600 I/Os

352 SBGA
361 CBGA
560 SBGA
625 CBGA

352 OMPAC
313 OMPAC
256 QFP
256 PBGA
- **Mid Range**
  - Cycle A, -30 to 100°C, 82 min. (2-5°C/min, 10 min. dwells)
  - Cycle B, -55 to 100°C, 245 min. (2-5°C/min, 45 min. dwells)

- **Military**
  - Cycle C, -55 to 125°C, 159 min. (2-5°C/min., 10 min. dwells)
  - Cycle D, -55 to 125°C, 68 min. (high heat/cool, 20 min. dwells)
Weibull, $m=9.1$, $N_0=424$
Weibull, $m=8.4$, $N_0=391$
Weibull, $m=11.7$, $N_0=307$
Weibull, $m=4.0$, $N_0=205$
A Cycle, (-30/100°C)
B Cycle, (-55/100°C)
C cycle, (-55/125°C)
D Cycle, (-55/125°C, Shock)
2-P and 3-P Weibull (Cumulative Distribution Function)

\[
F(N) = 1 - \exp\left[-\frac{(N - N_1)}{N_0}\right]^m
\]

where

- \(F(N)\) is the cumulative failure distribution function
- \(N\) is the number of thermal cycles
- \(N_0\) is a scale parameter that commonly is referred to as characteristic life, and is the number of thermal cycles with a 63.2% failure occurrence.
- \(N_1\) is the failure free cycles for a 3-parameter Weibull distribution
- \(m\) is the shape parameter and for a large \(m\) is approximately inversely proportional to the coefficient of variation (CV) by \(1.2/CV\); that is, as \(m\) increases, the spread in cycles to failure decreases
Failure Mechanisms
Thermal Cycle Only

Global CTE Mismatch
-30°C <> 100°C

Local CTE Mismatch
-55°C <> 125°C
PBGA 313 I/O Failure (-30/100°C)

(-30/100°C, 4692 JPL cycles, failure)
Vibration Setup

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A near-thermal shock in the range of -55°/125°C induced the most damage
- Up to 50% reduction compared to thermal cycle conditions

Assemblies with three levels of rigidity passed a launch environment
- Cycles-to-failure after vibration significantly affected by board rigidity
- >50% reduction in cycles-to-failure for a less rigid board

Failure for thermal cycle were from board/package

Failure for random vibration
- Tensile deformation in high melt balls
- Tensile shear in eutectic solder
● NEPP Web site, BGA Technology Readiness
● http://nepp.nasa.gov/index_nasa.cfm/778
  ○ Search: Reza Ghaffarian BGA NEPP Technology

● Provide Overview of BGA/CSP Technologies
● Key parameters affecting reliability
● Procedures for Qual using IPC/others
● Missions are categorized
● PWB/package assembly/underfill
● Radiation
- **Review IPC Standards**
  - IPC 7095, design and assembly process implementation for BGA
  - IPC 9701
  - www. IPC.org

- **Define Overall NASA Requirements**
  - Radiation, mechanical, thermal, life cycle, etc.

- **Determine Appropriate BGA/CGA/CSP**
  - I/O, build up, solder geometry, materials, heat distribution, etc.

- **Is Package Tech within Mission Env.**
  - Die radiation capability, temp limits including Tg, junction temp.

- **Life Thermal Cycle Qual- 3 times realistic worst case**
Four Mission Categories
- A: Benign thermal cycle and short mission
- B: Benign thermal cycle and long mission
- C: Extreme thermal cycle and short mission
- D: Extreme thermal cycle and long mission

If No Details, Use Rules-of-Thumb
- For A and B, life cycles 100-500 NASA cycles (-55/100°C)
- For C and D, estimate flight allowable temp ranges plus the ground and multiply mission life cycles by 3
**Review Qualification Data by Vendor**
- Most plastic BGAs on polymeric boards have sufficient life cycle to meet the A and B NASA requirements
- Plastic package with large die may be required to qualify for B
- Low I/O ceramic sufficient life for A
- High I/O may not meet either B or even A mission categories

**Most BGA need to be qualified for C and D missions**

**Most Ceramic and plastic CSPs may meet the A mission, but need PQV for B, C, and D missions**

**Package Qualification Verification (PQV) test vehicle**

**Others including Radiation/Vibration/Shock**
SUMMARY

- No Flight Heritage Data Yet
- BGAs and CSPs Less 2\textsuperscript{nd} Level (Assembly) Thermal Cycles Than Leaded Counterparts
- CSPs Have Lower Life Than BGAs
- Perform Tests on Dummy Daisy Chain Package/Board, if in Doubt
- Non-destructive Technique for Interconnection is not Yet Developed
- Most Packages Are Built for Commercial Applications and Many Issues with COTS BGAs/CSPs are similar to those for conventional COTS
Acknowledgments

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In-kind contributions of team members