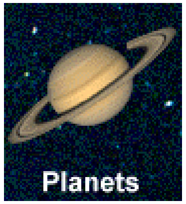
Jet Propulsion Laboratory
National Aeronautics & Space Administration
California Institute of Technology

NEPP



Ball Grid Array Assembly Reliability

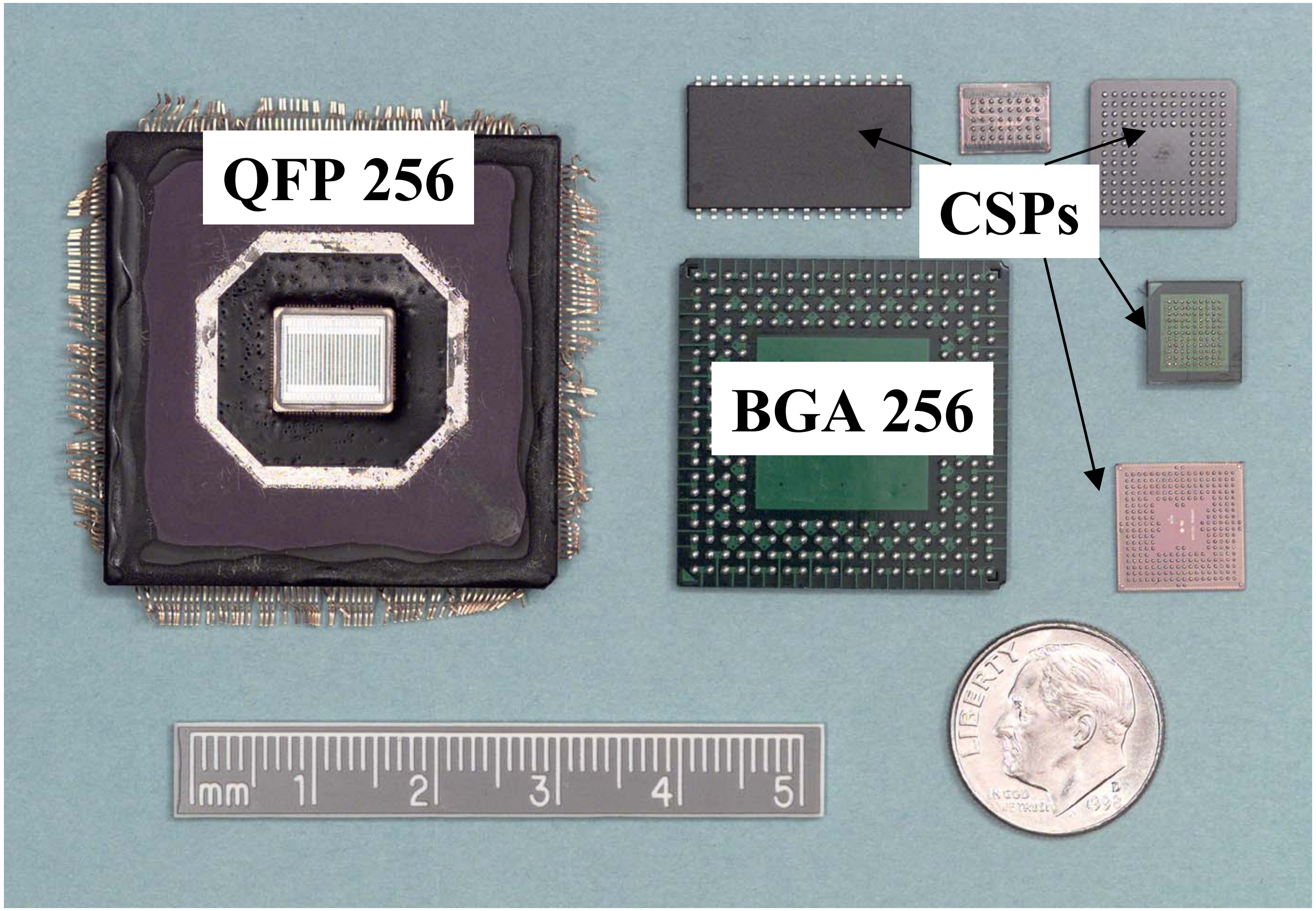
by

Reza Ghaffarian, Ph.D.
Jet Propulsion Laboratory
(818) 354-2059
Reza.Ghaffarian@JPL.NASA.Gov

Outline

- 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



References

JOSEPH FJELSTAD

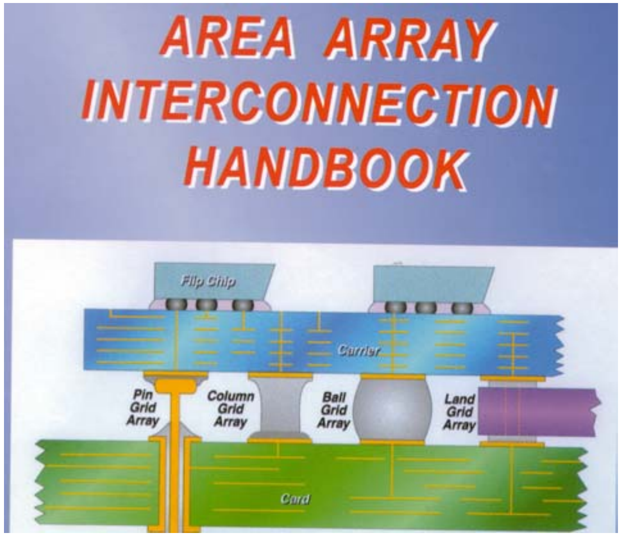
REZA GHAFFARIAN

YOUNG-GON KIM

CHIP SCALE PACKAGING FOR MODERN ELECTRONICS

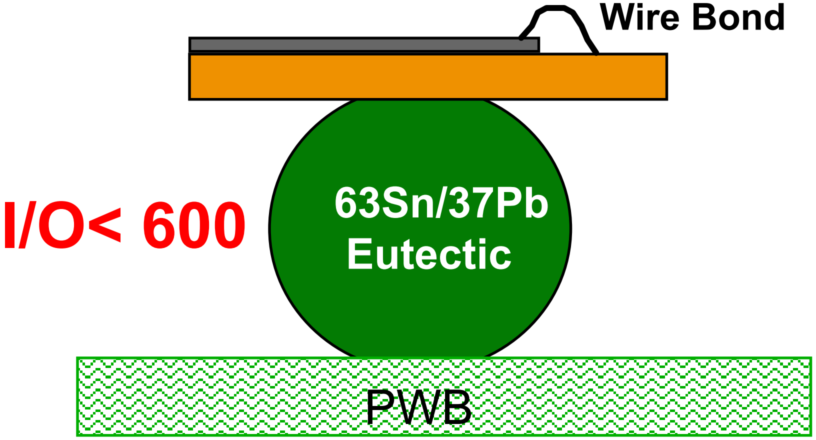
HANDBOOKS

AREA ARRAY PACKAGING HANDBOOK

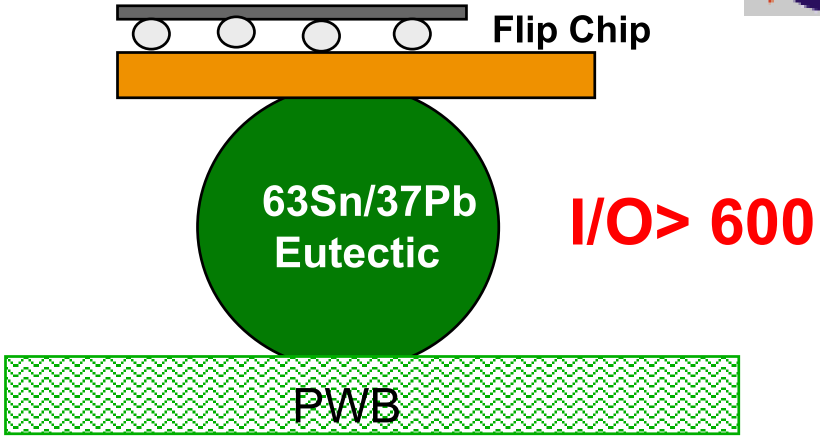


AREA ARRAY INTERCONNECTION HANDBOOK

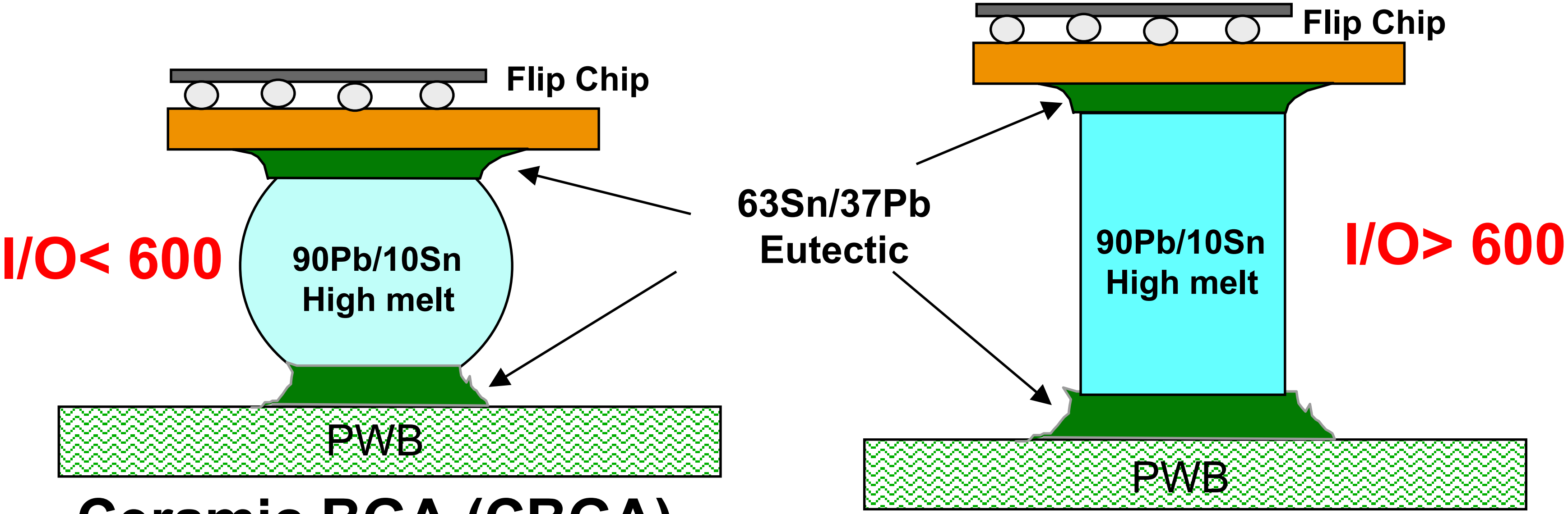
BGA Package Types



Plastic BGA (PBGA)



Flip Chip BGA (FCBGA)



Ceramic BGA (CBGA)

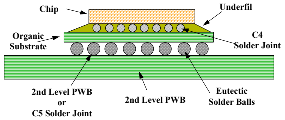
Column CBGA (CCGA)

Reza Ghaffarian

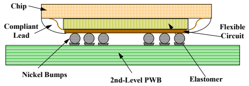
CSPs

Grid Arrays

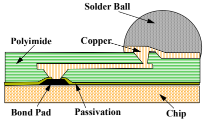
C4



Wire Bond



Wafer

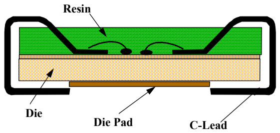


- High I/Os
- Wire bond I/O Limitation
- C4 ceramic, Wafer, Reliability?
- Assembly Robustness

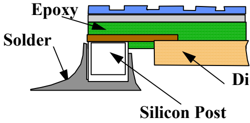
Self Alignment

Leads

Leaded

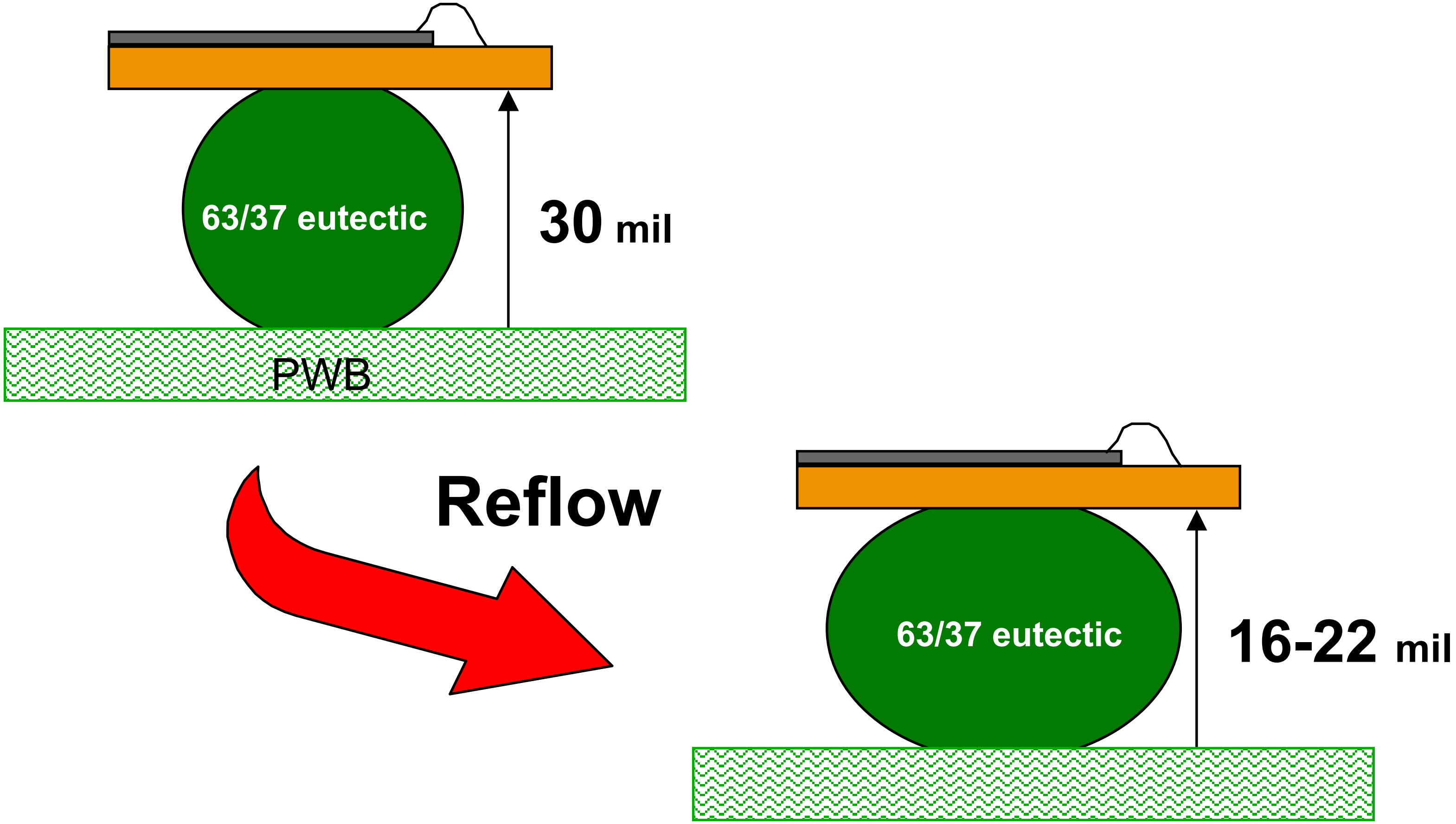


No Leads



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

BGA Balls Collapse



63/37 eutectic

30 mil

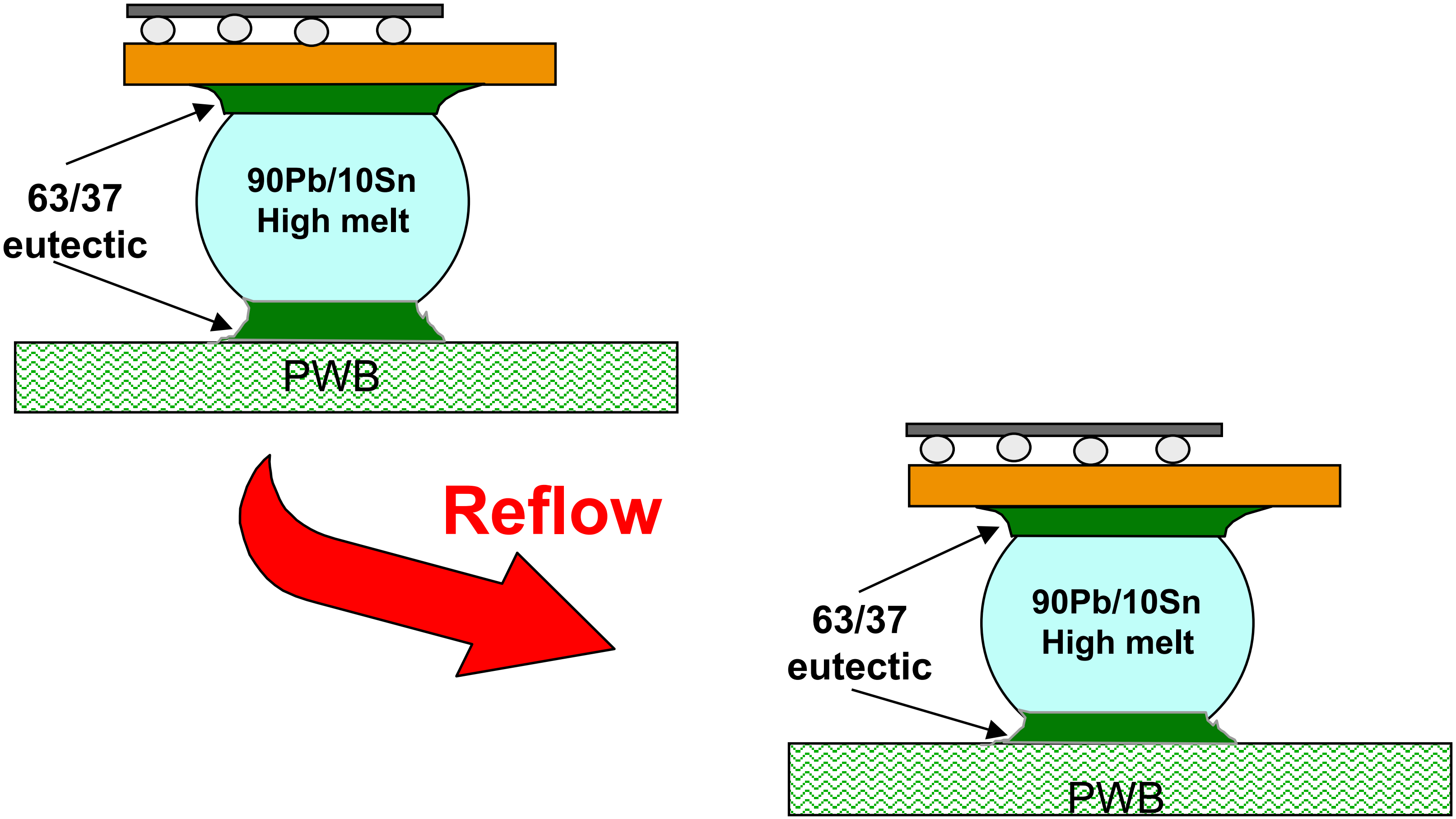
PWB

Reflow

63/37 eutectic

16-22 mil

CBGA Balls Control Height



63/37
eutectic

90Pb/10Sn
High melt

PWB

Reflow

63/37
eutectic

90Pb/10Sn
High melt

PWB

BGA vs QFP

- 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

Qualification- IPC 9701

- 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"

IPC 9701Temperature Cycle Requirements

Table 1 Temperature cycling requirements specified in Table 4.1 of IPC 9701

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

Test Vehicles

Type 1 “300” I/Os

352
Plastic
Perimeter
SuperBGA
35 mm

361
Ceramic
Full Array
25 mm

352
Plastic Perimeter
OMPAC
35 mm

313
Plastic
Full Array
OMPAC
35 mm

361 I/O CBGA

Type 2 “600” I/Os

560
Plastic Perimeter
SuperBGA
42mm

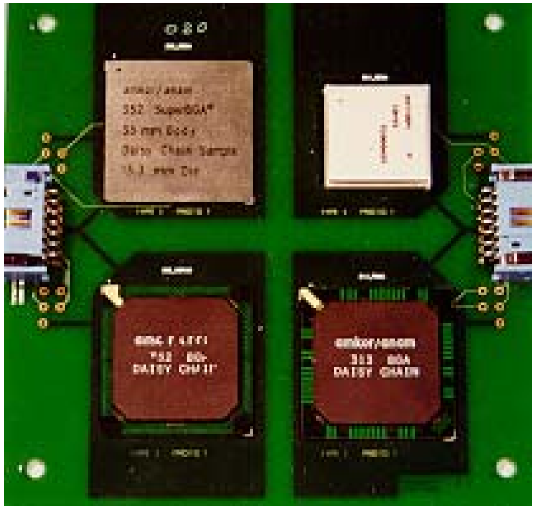
625
Ceramic
Full Array
32.5 mm

256
Plastic
Gull Wing
30.6 mm

256
Plastic
Perimeter
OMPAC
27 mm

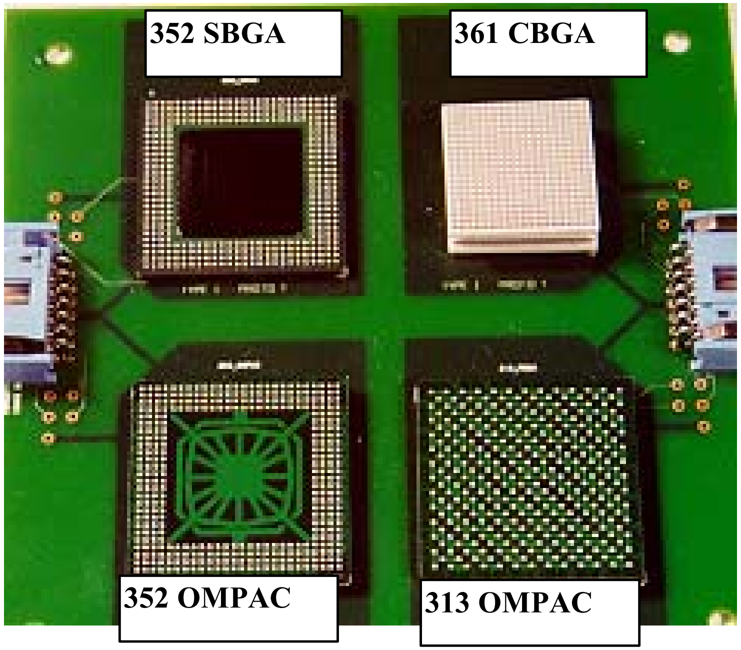
625 I/O CBGA

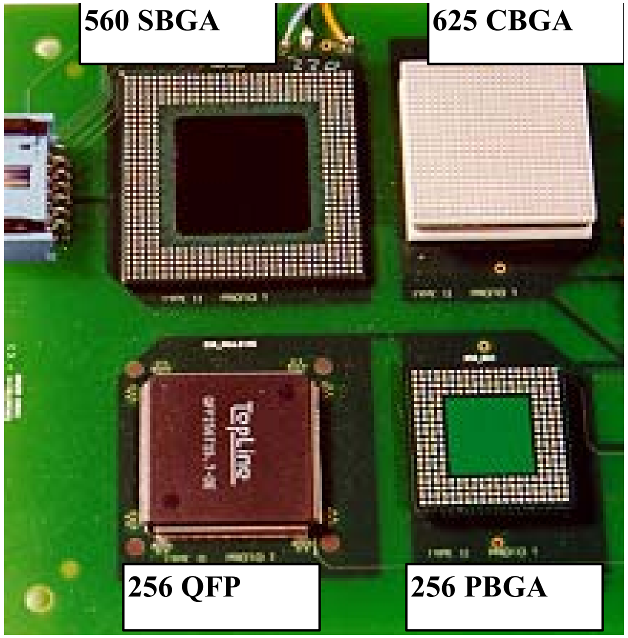
BGA Test Vehicles



a) Type 1 Test Vehicles, 300 I/Os

b) Type 2 Test Vehicles, 600 I/Os



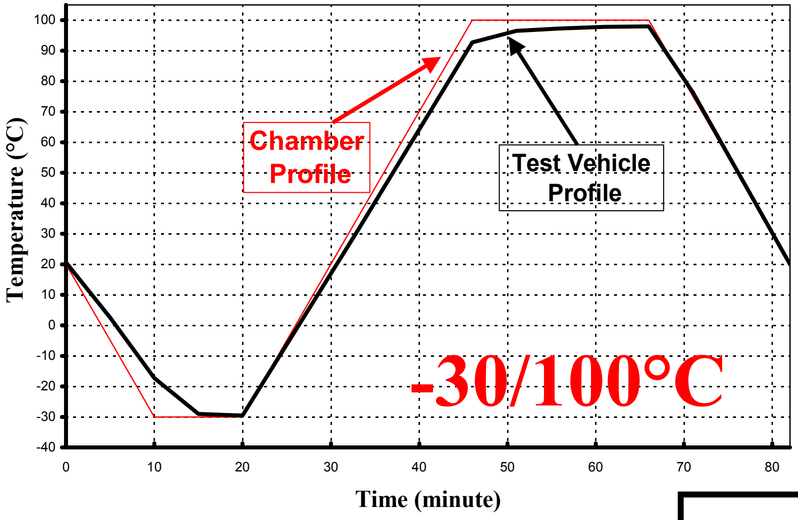


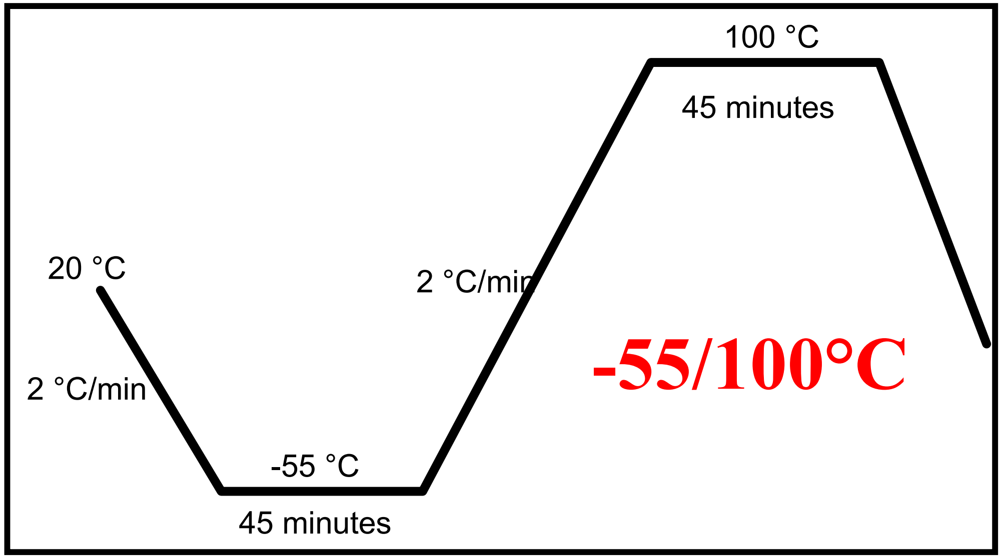
Thermal Cycle Profiles

- **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)

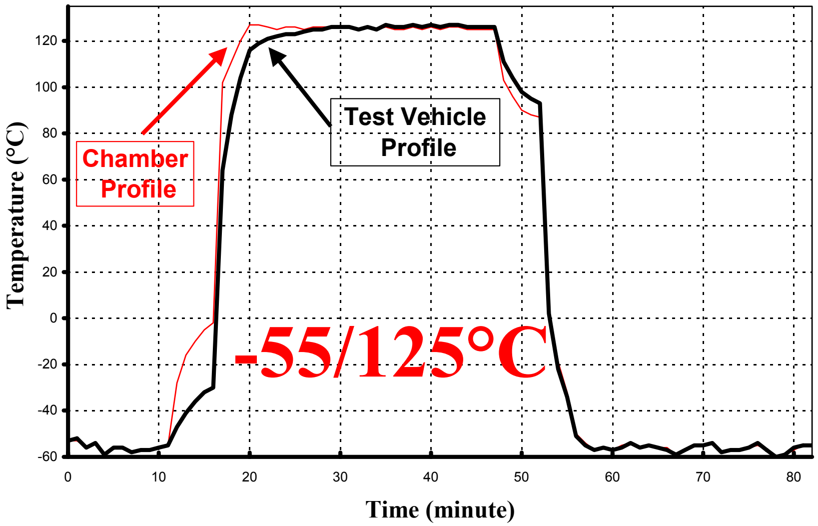
Thermal Cycle Profiles
Mid Ranges

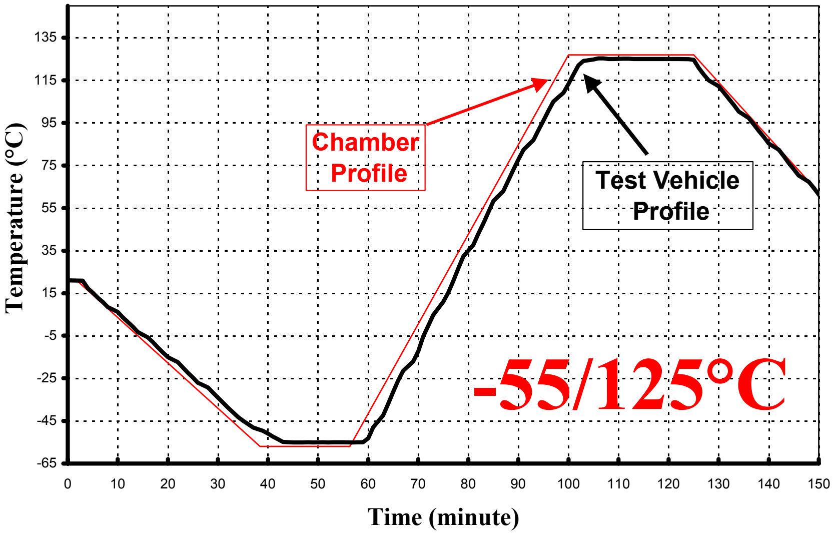


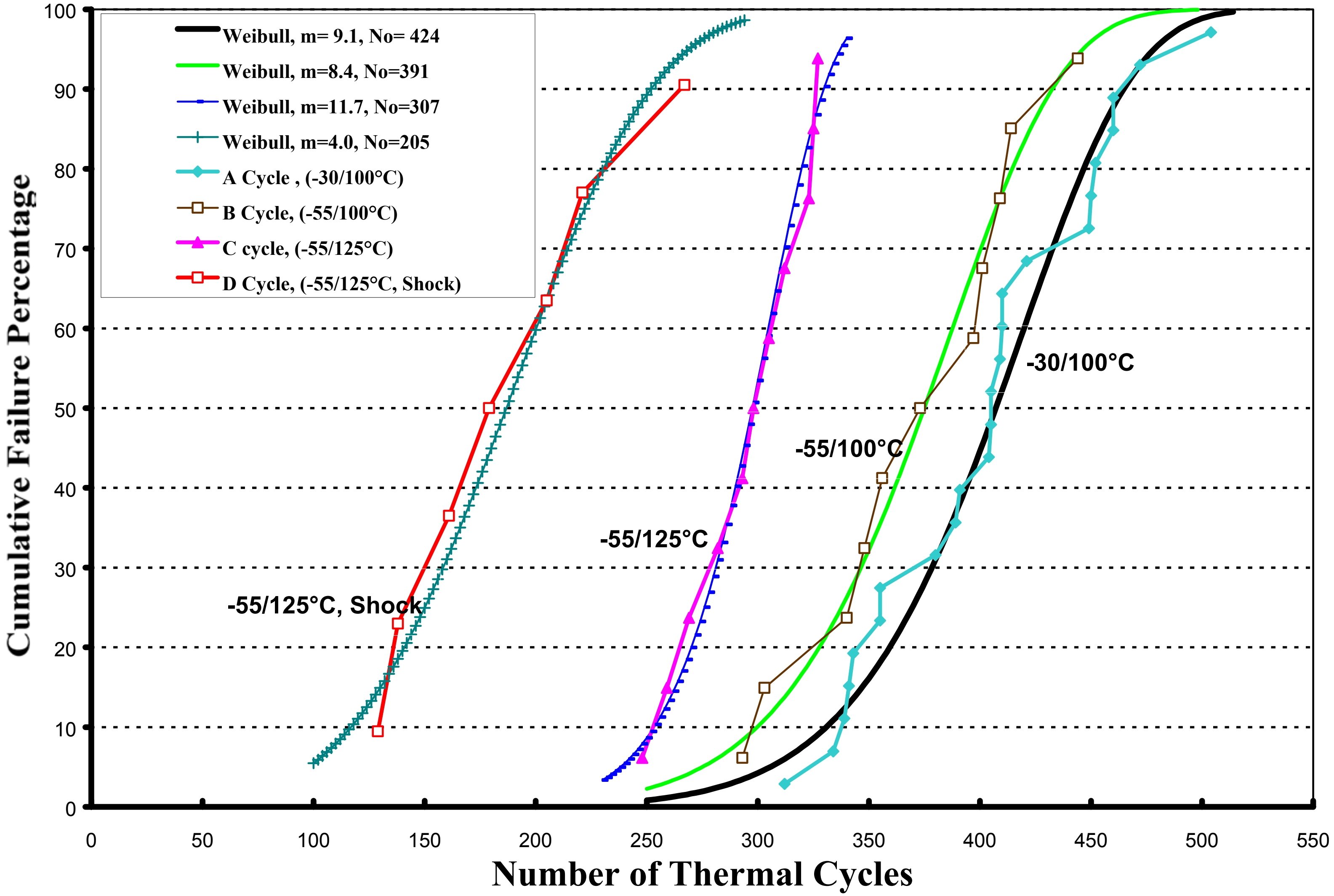


Thermal Cycle Profiles

Military







Weibull, m= 9.1, No= 424
Weibull, m=8.4, No=391
Weibull, m=11.7, No=307
Weibull, m=4.0, No=205
A Cycle , (-30/100°C)
B Cycle, (-55/100°C)
C cycle, (-55/125°C)
D Cycle, (-55/125°C, Shock)
-30/100°C
-55/100°C
-55/125°C
-55/125°C, Shock
Cumulative Failure Percentage
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
400
450
500
550
Number of Thermal Cycles

Weibull CDF

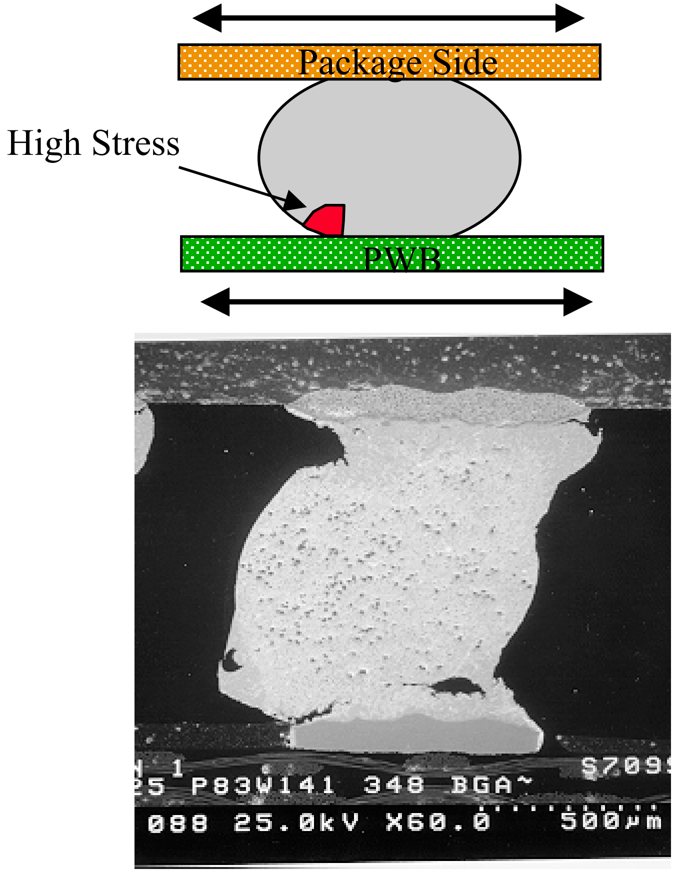
2-P and 3-P Weibull (Cumulative Distribution Function)

$$F(N) = 1 - \exp -[(N - N_1)/N_o]^m$$

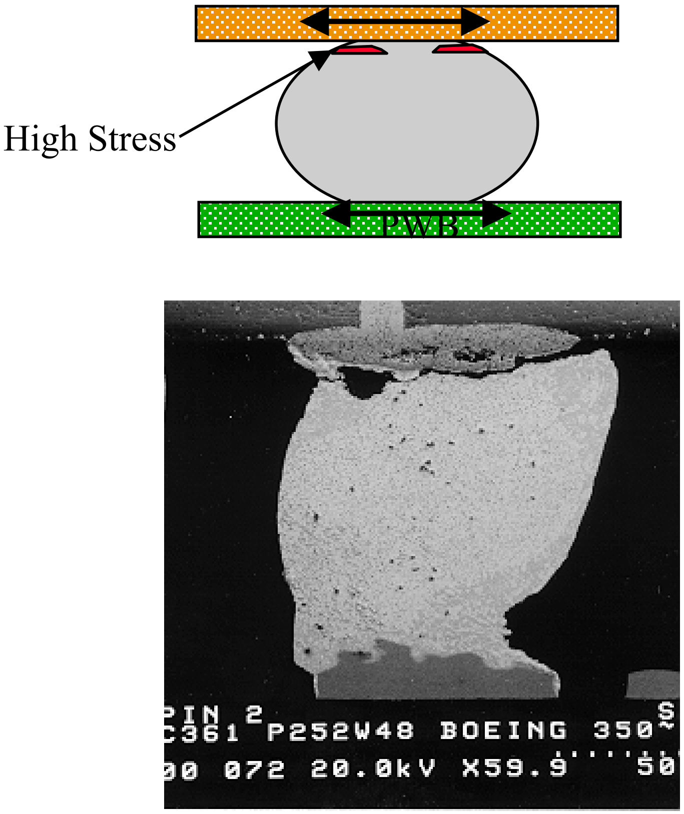
where

- F(N) is the cumulative failure distribution function
- N is the number of thermal cycles
- N_o 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

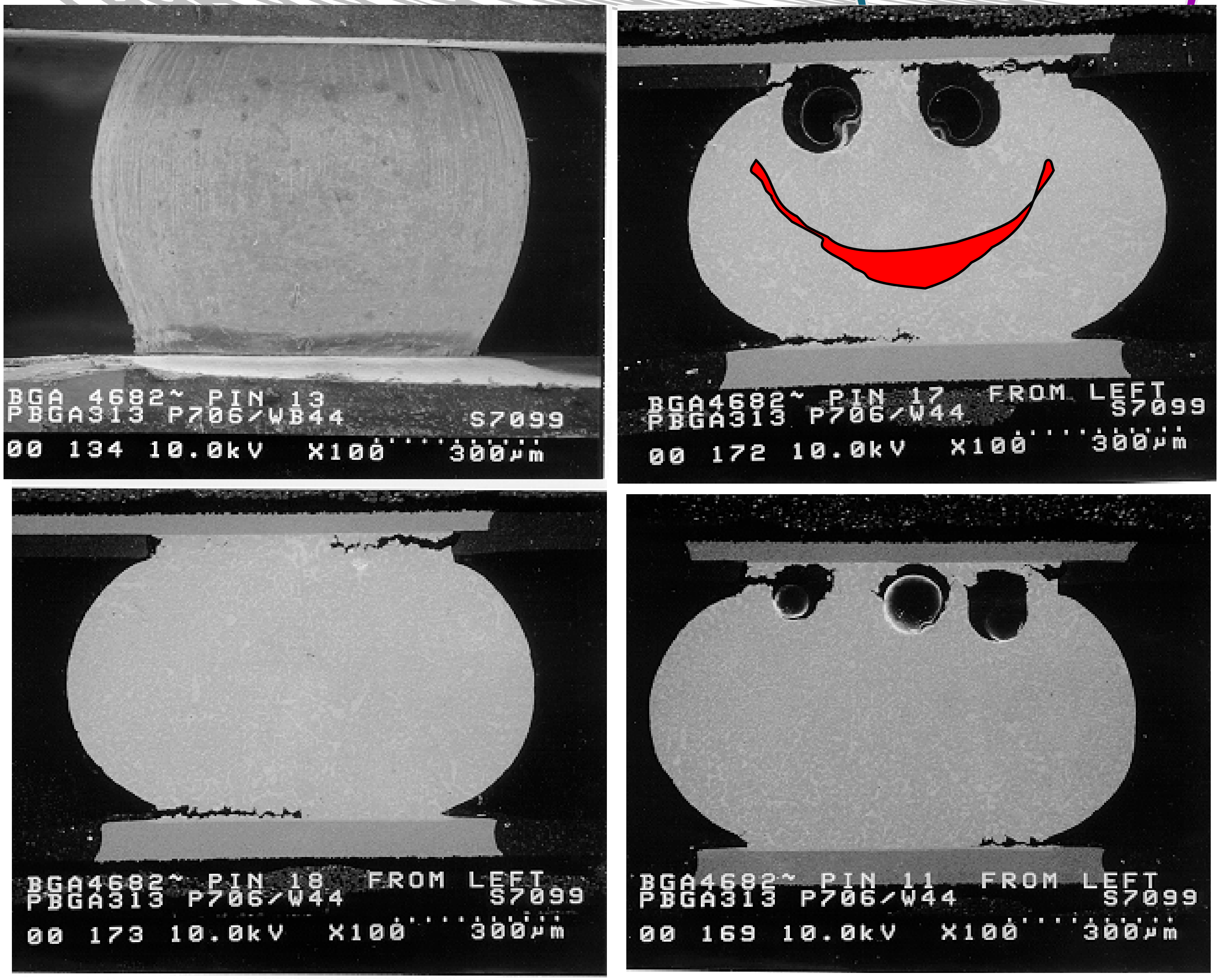


Global CTE Mismatch
-30°C<>100°C



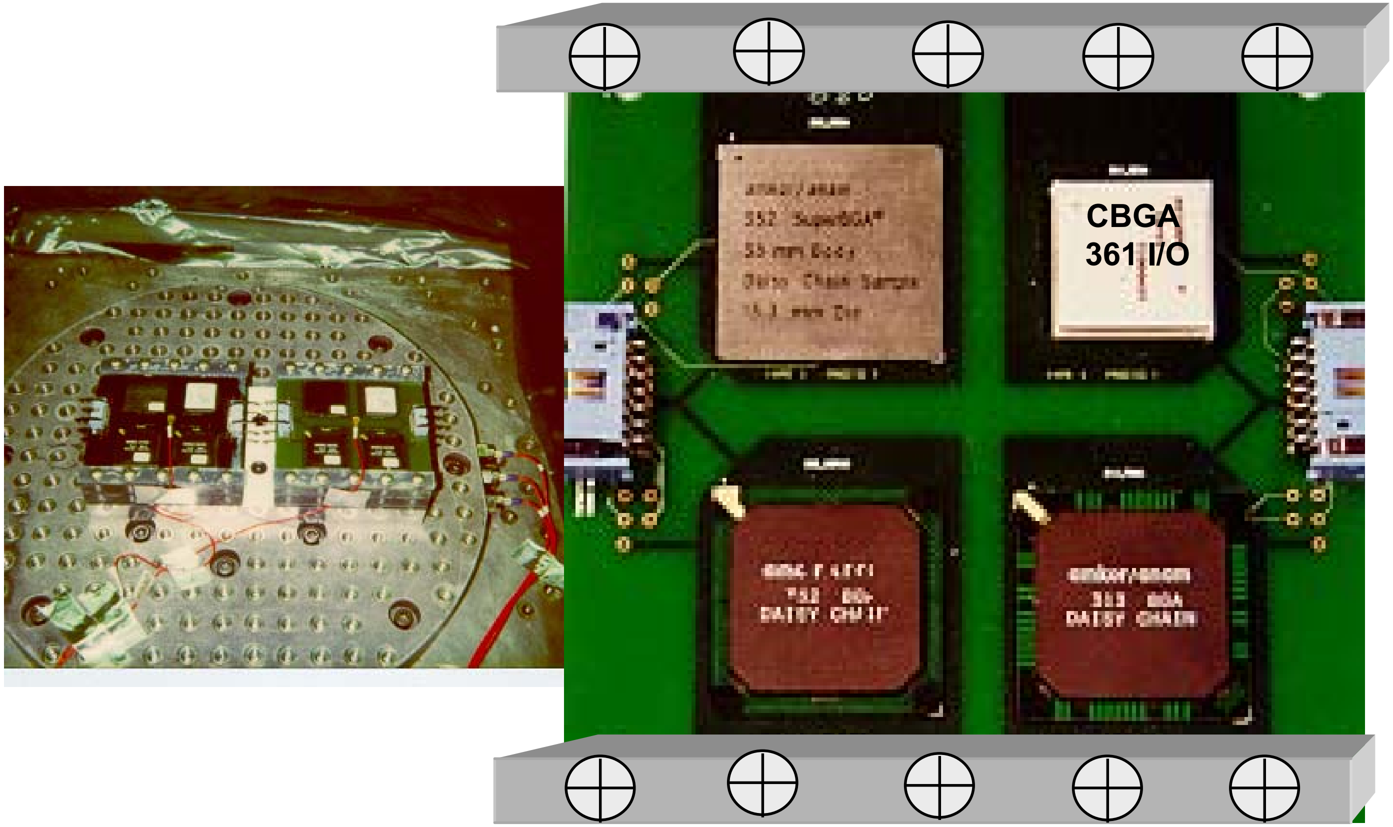
Local CTE Mismatch
-55°C<>125°C

PBGA 313 I/O Failure (-30/100C)



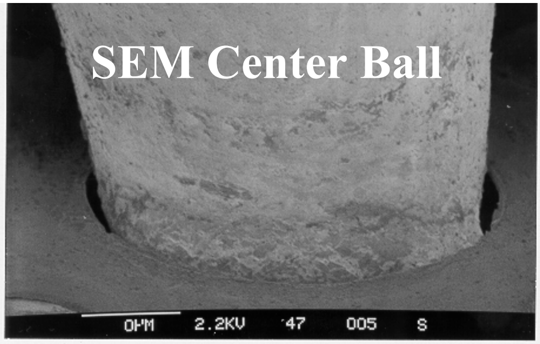
(-30/100°C, 4692 JPL cycles, failure

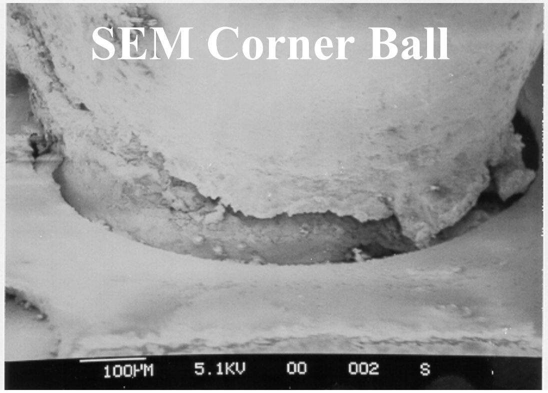
Vibration Setup

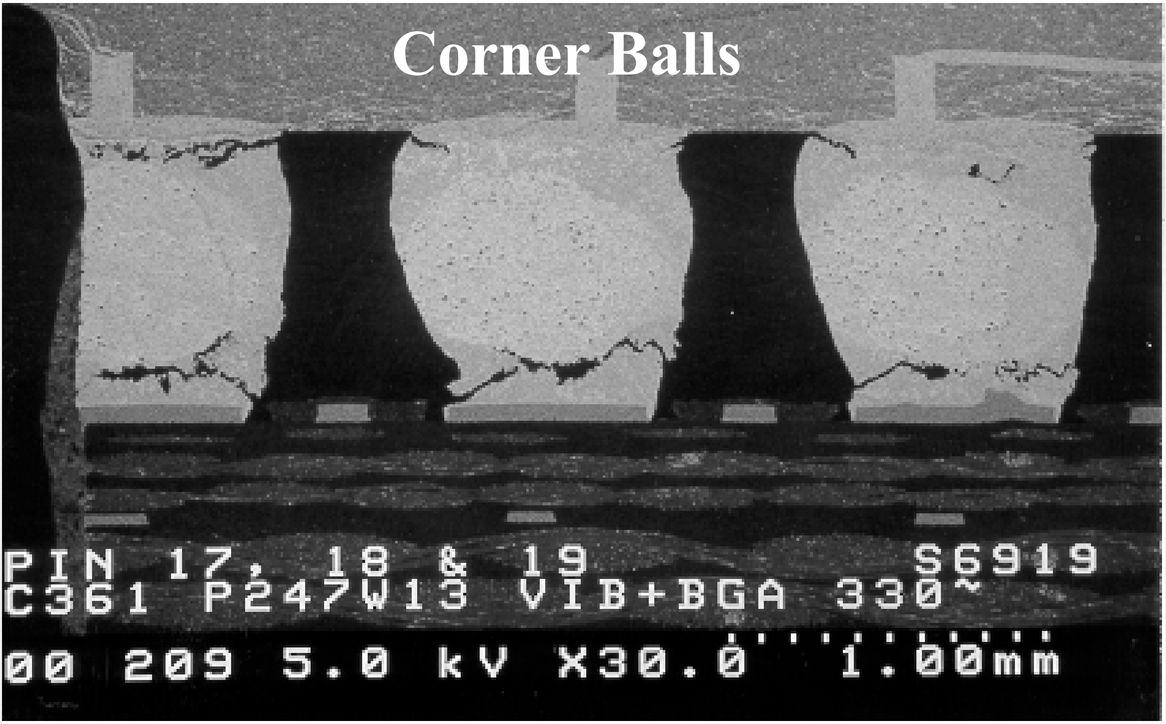


Failure Mechanisms

Vibration + Thermal cycle


SEM Center Ball


SEM Corner Ball


Corner Balls

Conclusions

- 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

BGA Qualification

NASA Missions

NEPP BGA Report

- 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

Qualification -1

- **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

Qualification - 2

- **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**

Qualification - 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 2nd 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

NASA Electronic Part and Packaging (NEPP)

In-kind contributions of team members

BGA CONSORTIUM