Update on High I/O Area Array Packages & Assembly Reliability

by

Reza Ghaffarian, Ph.D.

JPL-Caltech

(818) 354-2059

Reza.Ghaffarian@JPL.NASA,com

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

Microelectronics Reliability & Qualification Workshop (MRQW)
December 8-9, 2009

JPL Space Missions

July 2009

Formulation (5)

Pipeline

Outer Planets (2016)

Exo-Planet (2015)

DESDynI (2017)

SIM (201X)

Soil Moisture (2012)

Implementation (6)

Juno (2011)

GRAIL (2011)

NuSTAR (2011)

MSL (2011)

WISE (2010)

Aquarius (2009)

Operations (19)

Dawn (2007)

Deep Impact (2005) EPOXI

Stardust (1999) Stardust Next

Cassini (1997)

MRO (2005)

Spirit (2003)

Opportunity (2003)

Odyssey (2001)

Kepler (2009)

Spitzer (2003)

Galex (2003)

Voyager 1 (1977)

Voyager 2 (1977)

OSTM (2008)

CloudSat (2006)

GRACE (2002)

Jason-1 (2001)

QuikScat (1999)

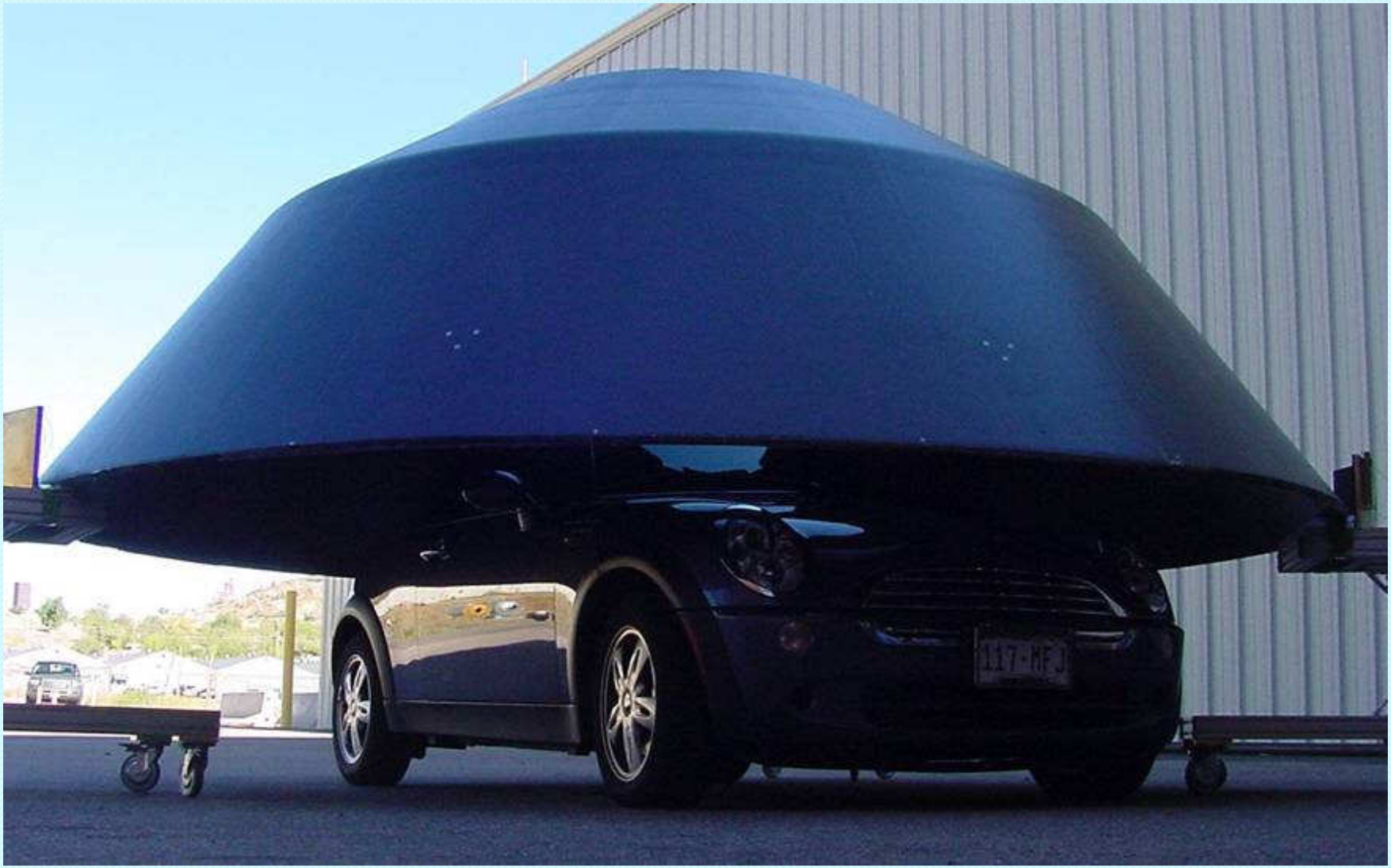
AcrimSat (1999)

Planetary/Mars Astrophysics Earth Science Planetary/Mars Astrophysics Earth Science Planetary/Mars Astrophysics

Mars Science Laboratory (MSL)- Curiosity Rover

- Determine whether Life ever arose on Mars
- Characterize the Climate of Mars
- Characterize the Geology of Mars
- Prepare for Human Exploration

Mars Science Laboratory (MSL)- Curiosity Rover



Reza Ghaffarian

Mars is Cold- Tin Whisker/Pest Lead-free?

SUMMARY OF MARS WEATHER – SOL 1-63

Slight increase in temperature from Sol 1-63 (about 4 degrees)

WIND:

Southerly during the day, Easterly at night. Average wind speed of 14.4 km/h or 8.9 mph

PRESSURE:

Steadily decreasing from 8.5 to 7.85 millibars

AVERAGE VISIBILITY:

Clear to clear with dust haze

AVERAGE MAX

- 30 °C / - 22 °F

AVERAGE MIN

- 79 °C / - 110 °F

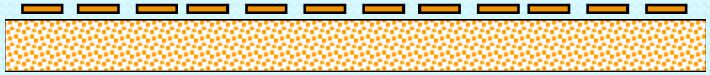
http://www.nasa.gov/mission_pages/phoenix/images/new-latest-images-collection_archive_1.html

Outline

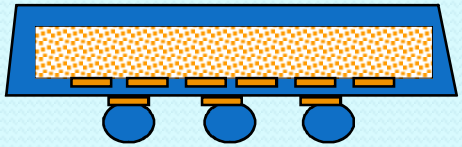
- High I/O BGA & CSP & SMC Packages
  - Assembly characterization
  - Key defects due to manufacturing
  - Reliability- Thermal cycle standard & extreme cold
  - X-ray and optical and inspection results
  - Failure analysis after TCs
- Lead-free
  - Lead-free & high reliability
  - Drop tests for high I/O BGA test vehicle
  - Other activities
- Summary & Future Activities

Advanced Package Concepts

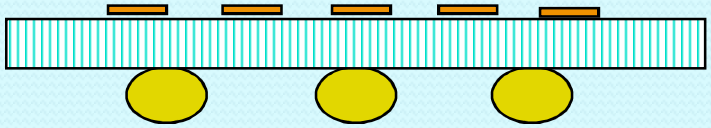
- Die Tight Pitch
- Al Pad- Non Reflow



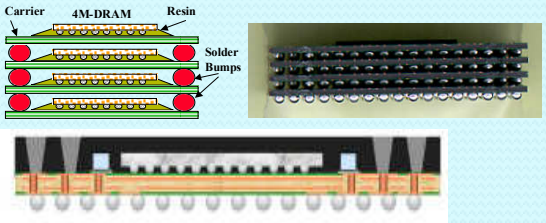
- Wafer
  - Pitch limitation



- Interposer
  - Polymer, Ceramic, Flex
  - Cu:Ni:Au Pad



- Stack
  - die/wafer/package



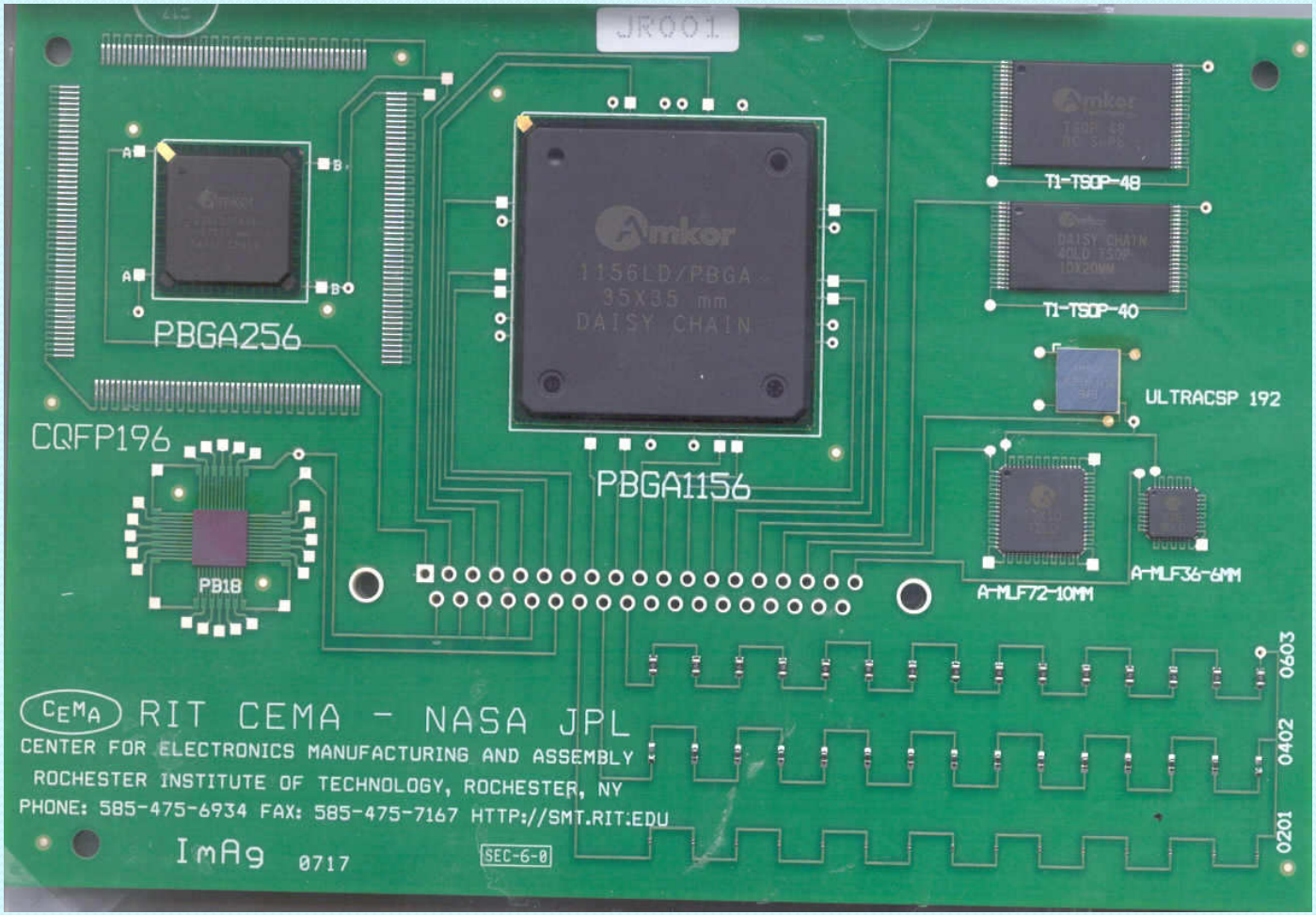
- Norm Pitch for PWB
  - 0.4-1.27 mm

Reza Ghaffarian

Package Trend- PBGA/CGA

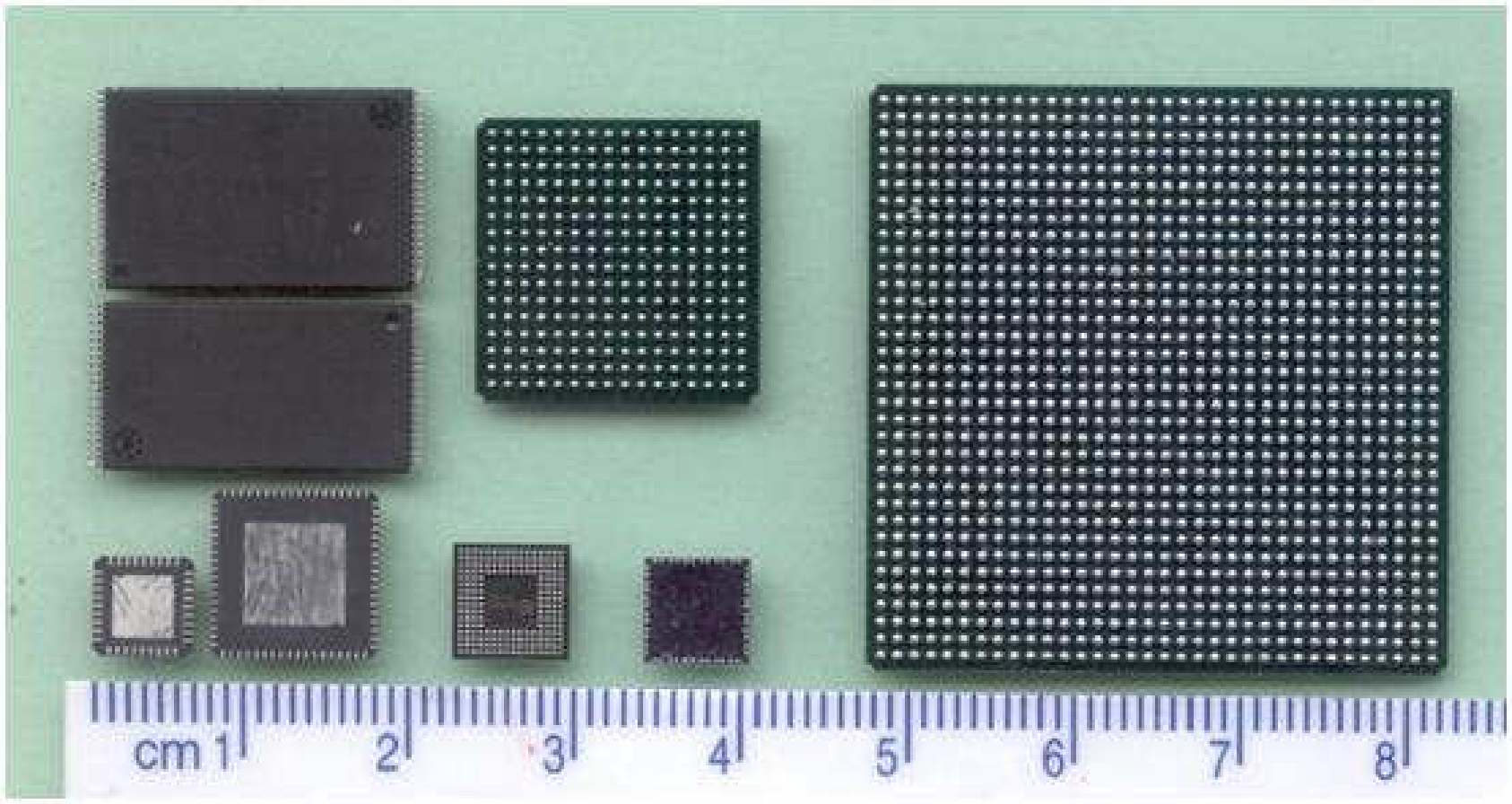
- Plastic Ball Grid Arrays (PBGAs)
  - Peripheral to full array
  - From 1.27mm (50 mil) pitch to 1 mm (40 mil) pitch/lower
  - Wire-bond die (<1000 I/Os) to flip-chip die (>1000 I/Os)
  - Pb-Sn to **Pb-free**
- Ceramic Packages- Hi-Rel
  - CQFP to area array packages
  - CBGA to CCGA/CGA (>500 I/Os?) and LGA
  - Wire-bond to flip-chip die within package
  - Hermetic to non-hermetic package (>1000 I/Os?)
  - Pure column to column with Cu wrap (Six Sigma)
  - Pb-Sn to **Pb-free** (Cu column??)
  - Land grid with conductive interconnect rather **Pb-free** solder

High I/O BGA & CSP/Flipchip/TSOP Packages



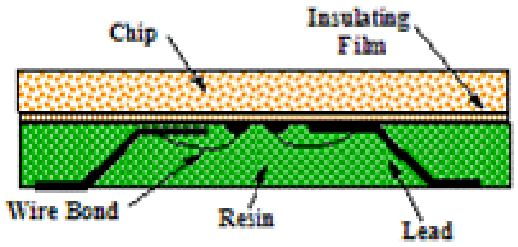
Reza Ghaffarian

PBGA 1156 I/O 1mm /CSP/FC/MLF

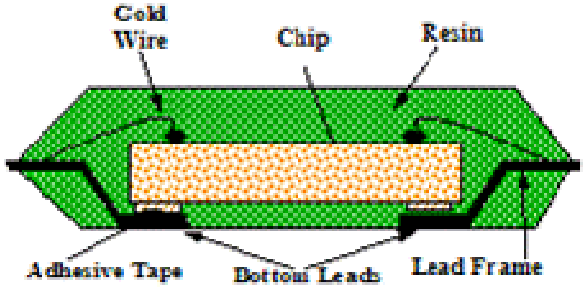


Reza Ghaffarian

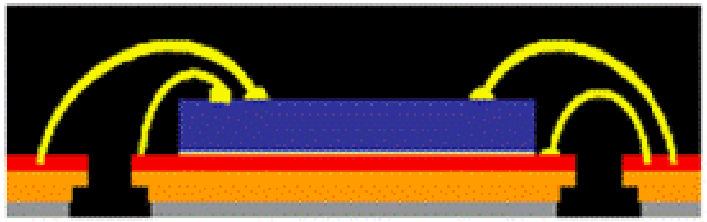
Leadless Package & MLF 36/72 I/Os



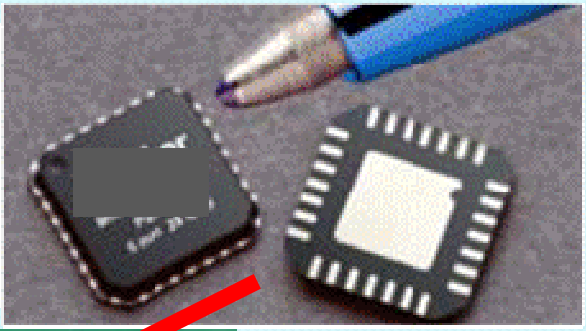
Lead On Chip
LOC

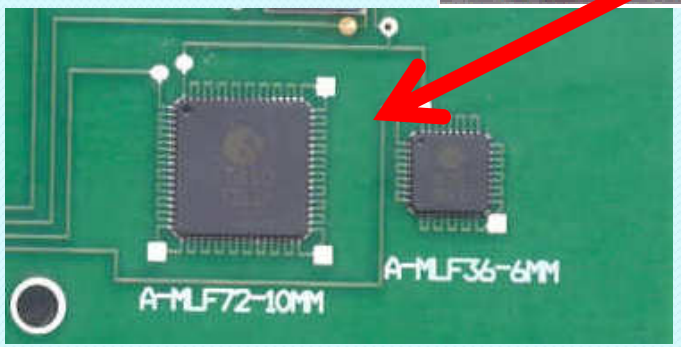


Ultra-Thin-Small-Outline
USON



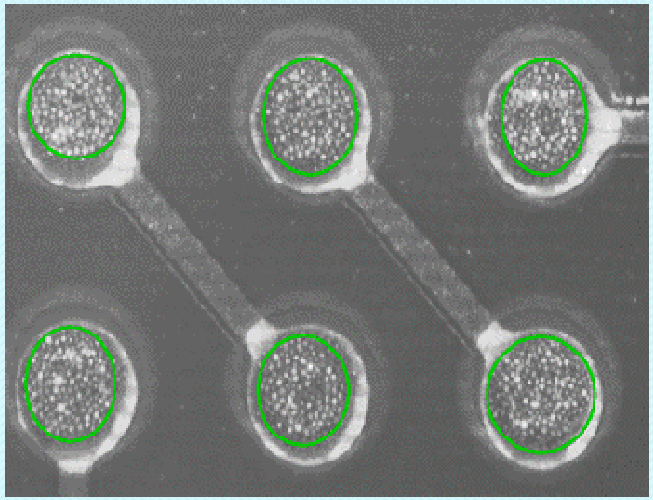
MicroLead Frame®

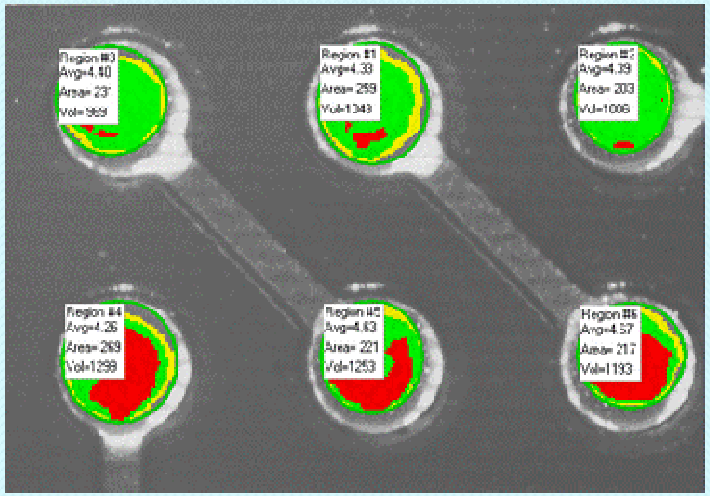


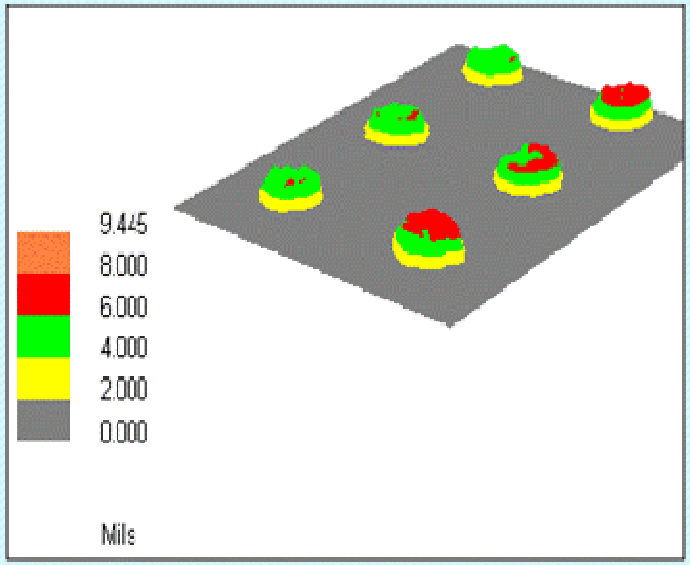


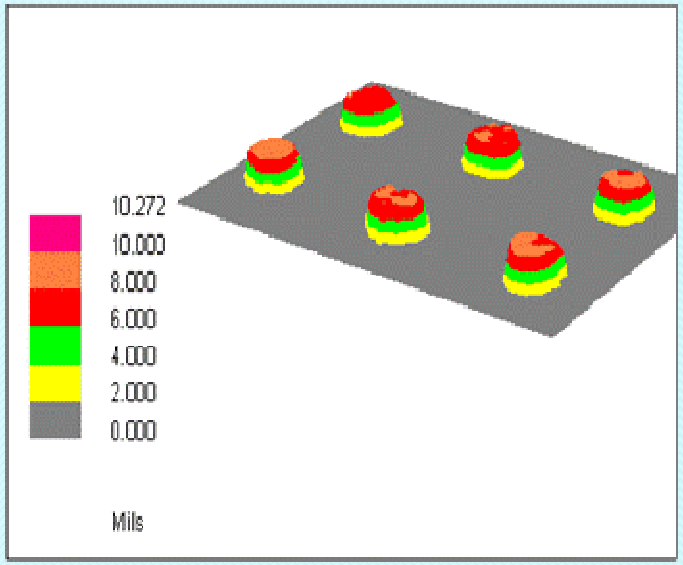
Reza Ghaffarian

Paste Print Quality of PBGA 1156 High I/O 1mm Pitch



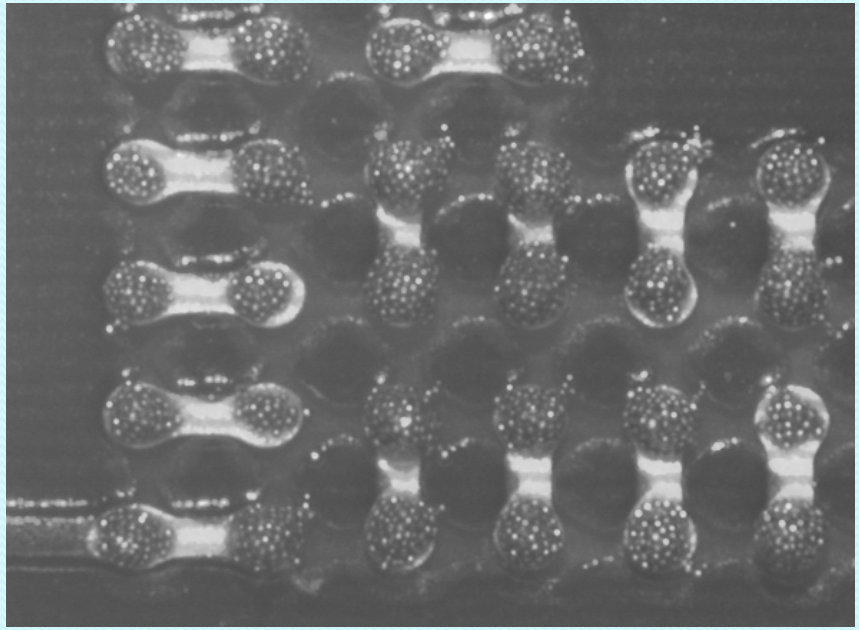


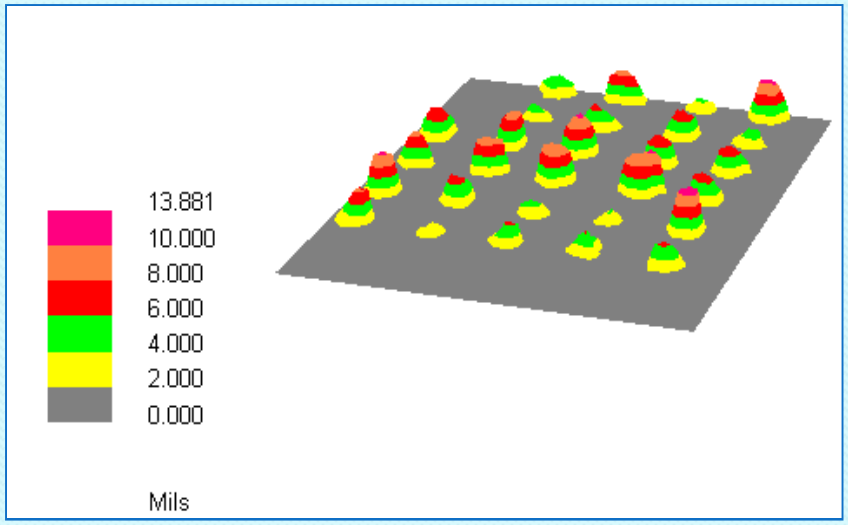


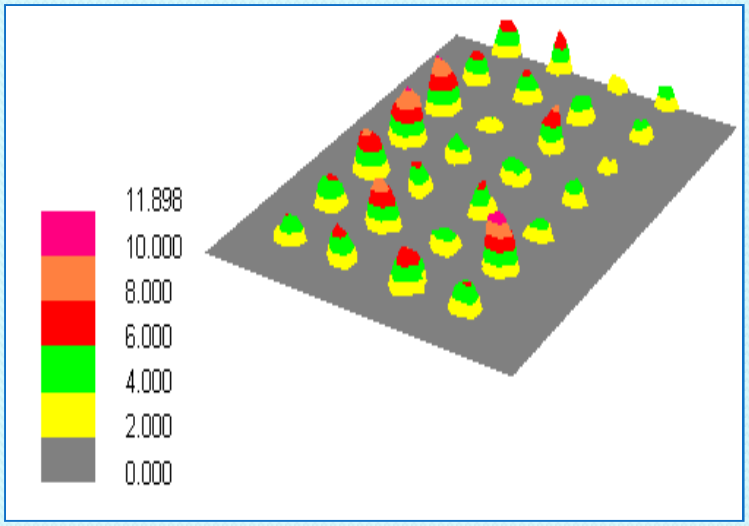


Reza Ghaffarian

Solder Paste Print Quality of CSP 192 I/O 0.4mm Pitch

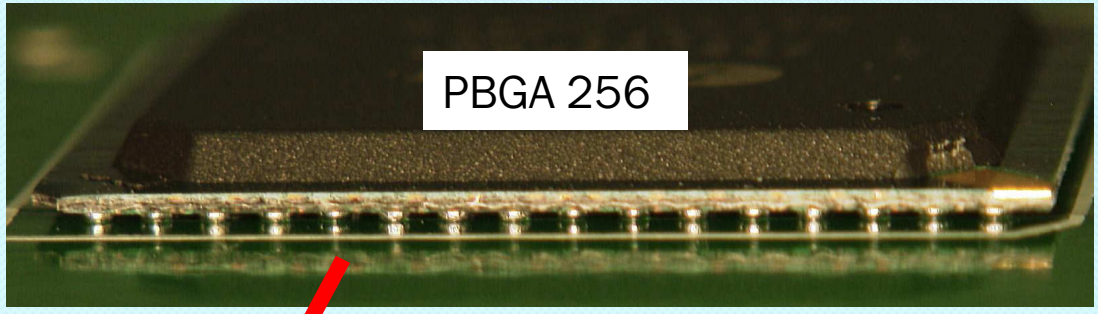


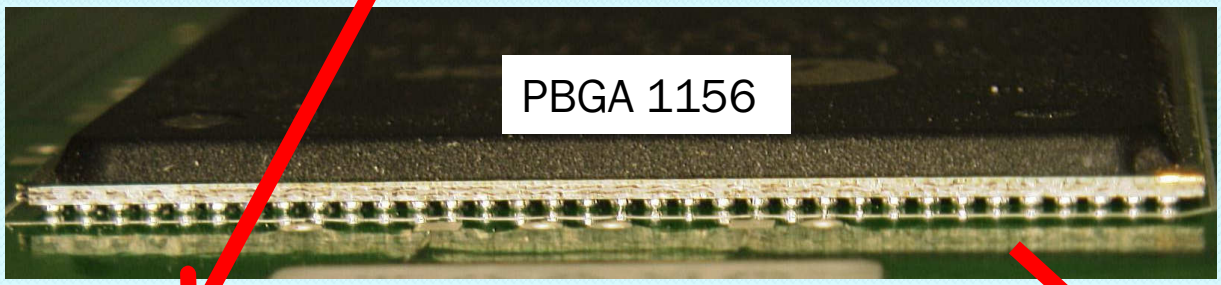


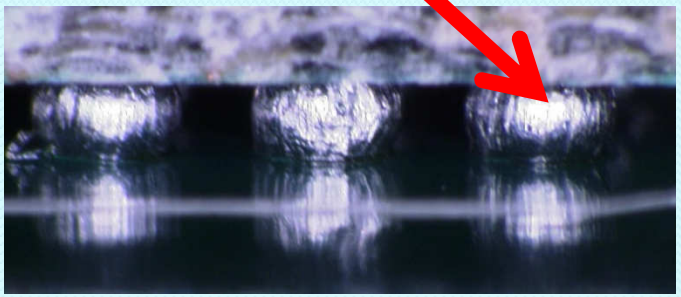


Reza Ghaffarian

Optical Photos of PBGA 1156 & 254 I/O Assemblies

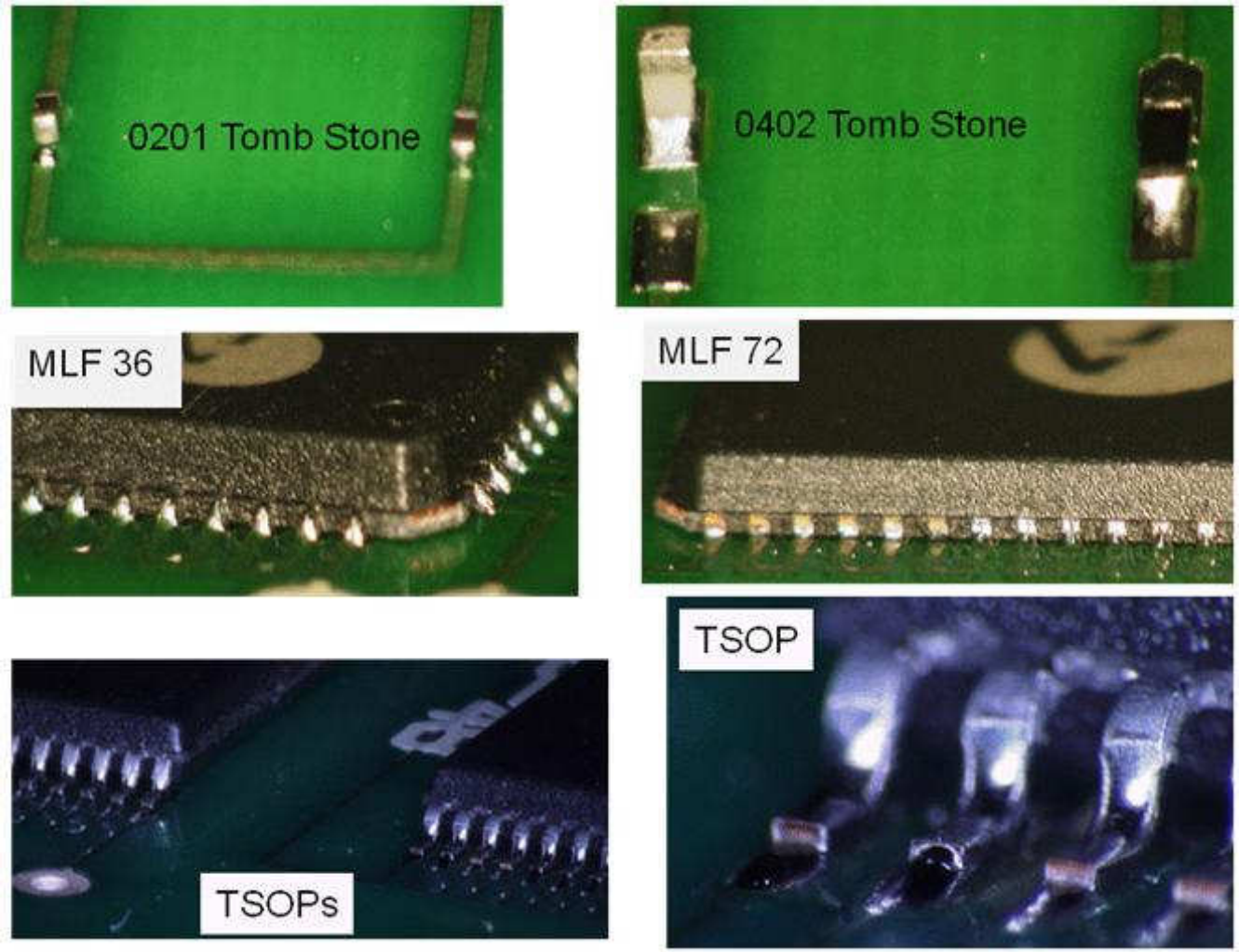






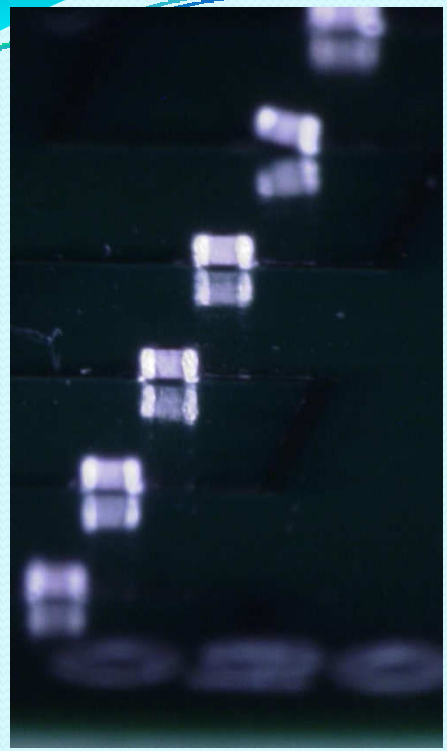
Reza Ghaffarian

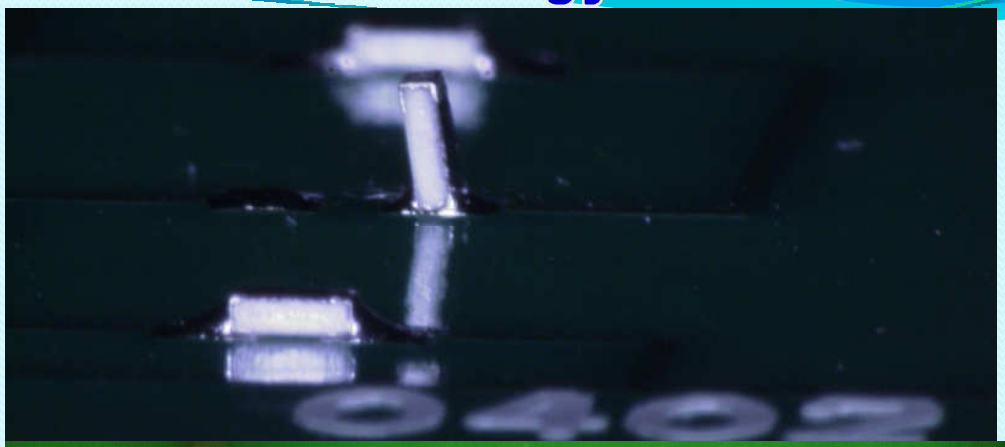
Optical Photos of 0402/0201 MLF 36 & 72 TSOPs

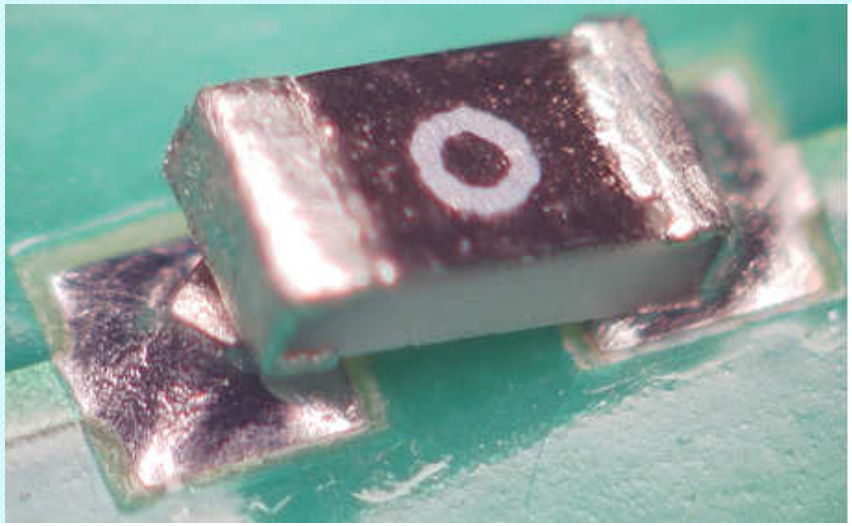


Reza Ghaffarian

0402/0201Tombstone and "Pigyback?" Defects

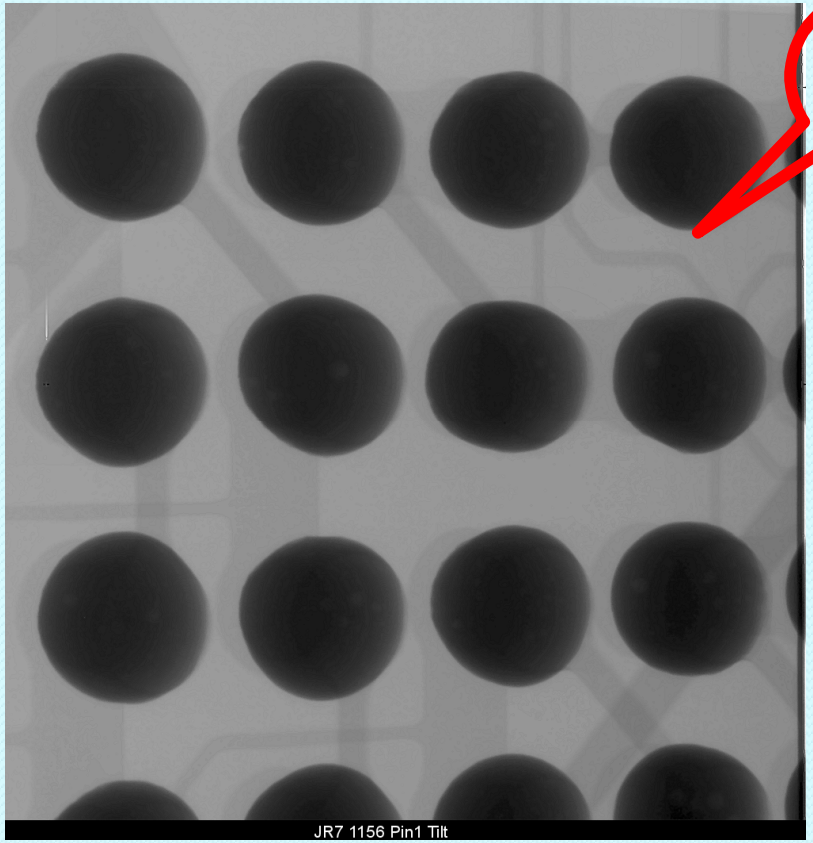


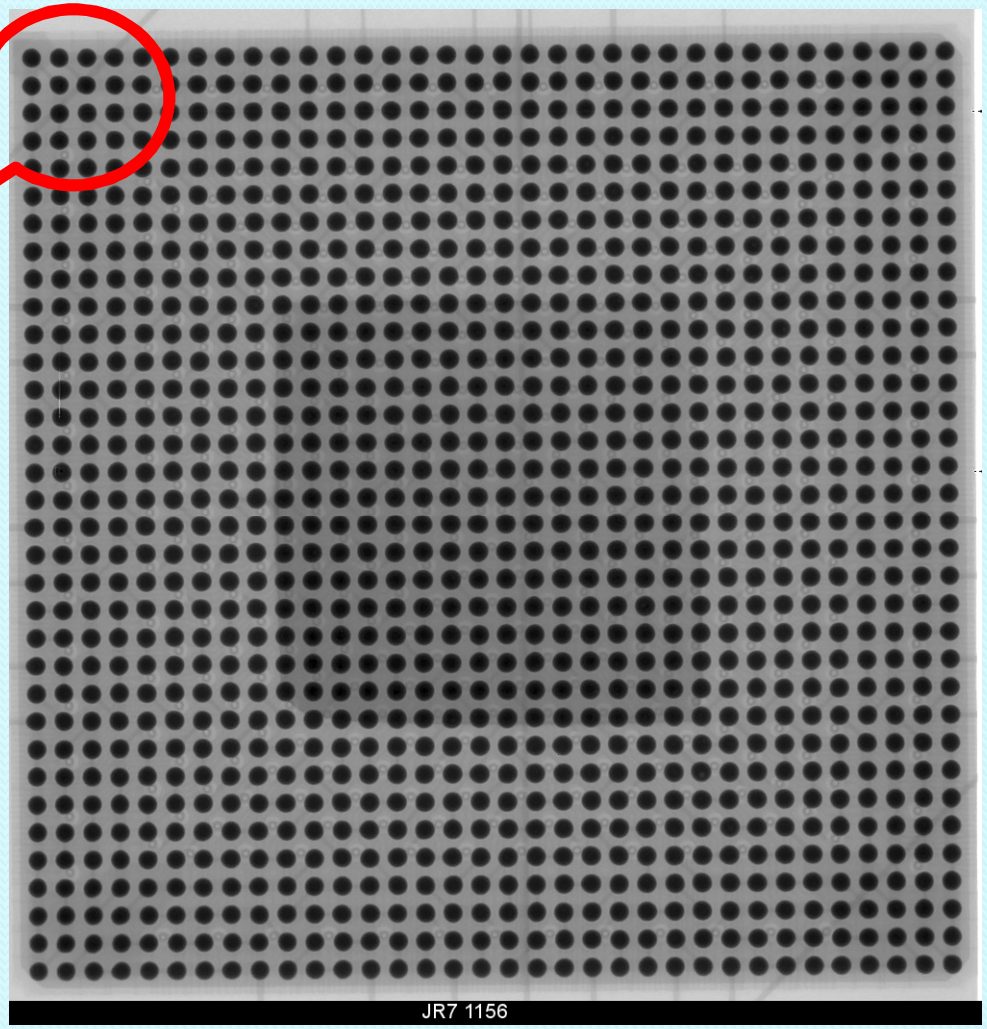




Reza Ghaffarian

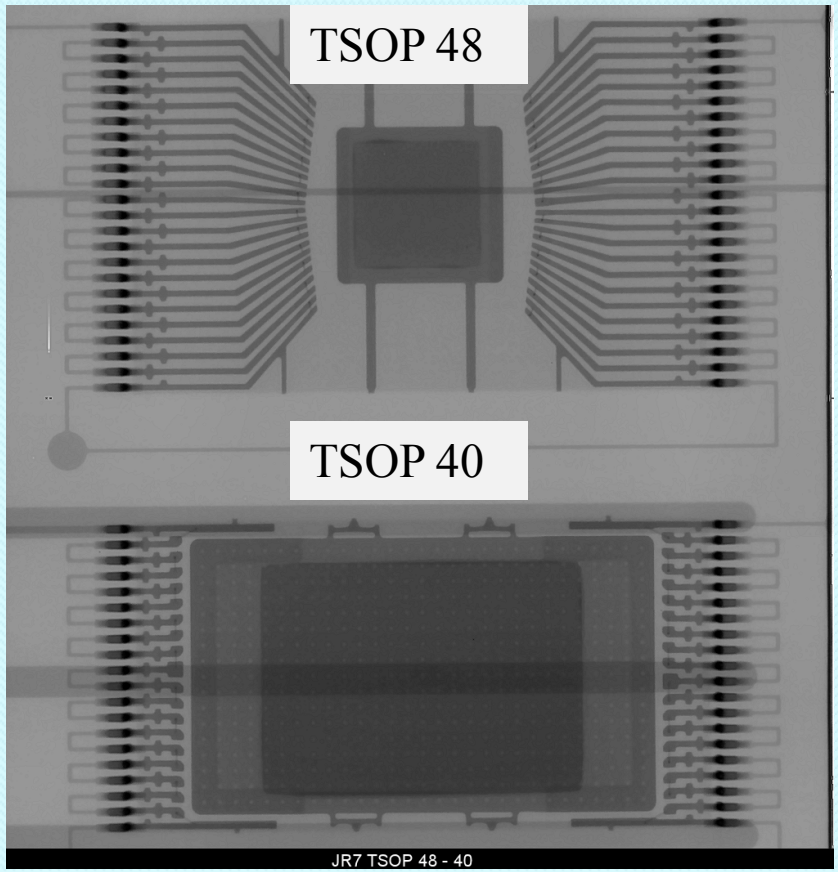
X-ray of PBGA 1154 I/O 1mm Pitch Assembly

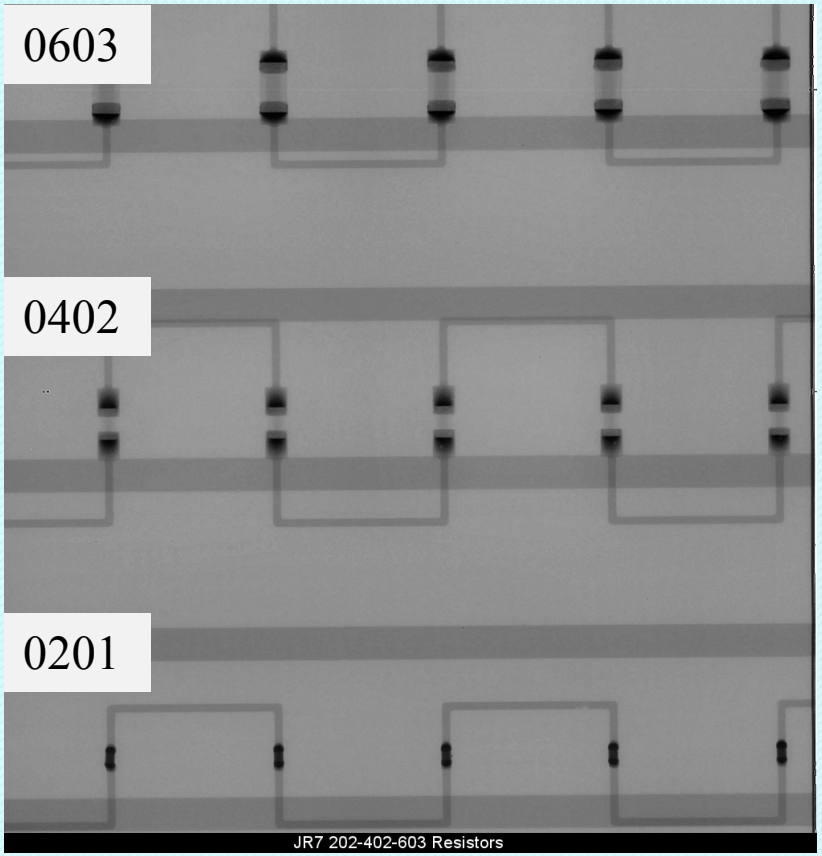




Reza Ghaffarian

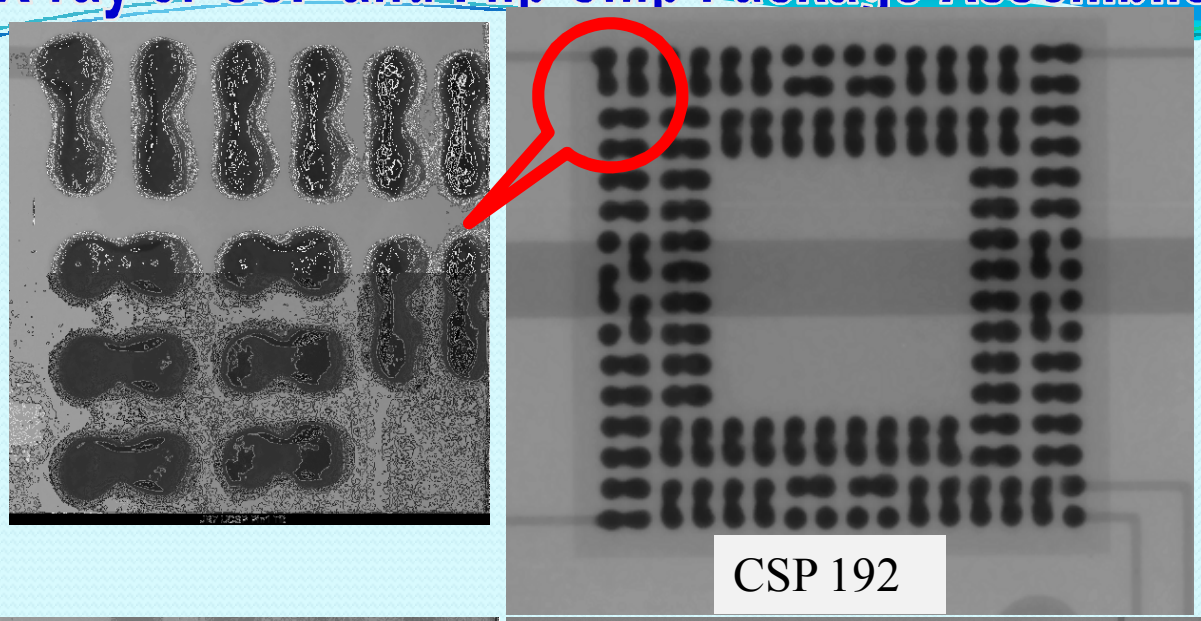
X-ray of TSOPs and Various Chip Resistors

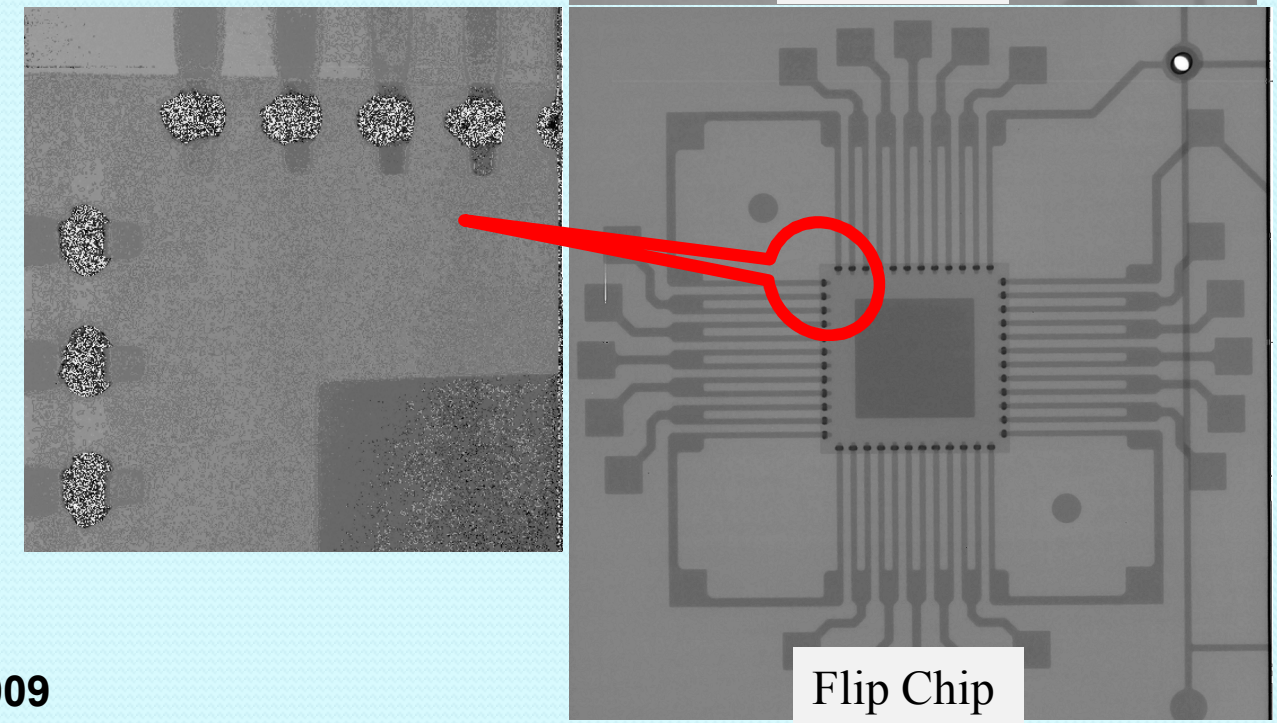




Reza Ghaffarian

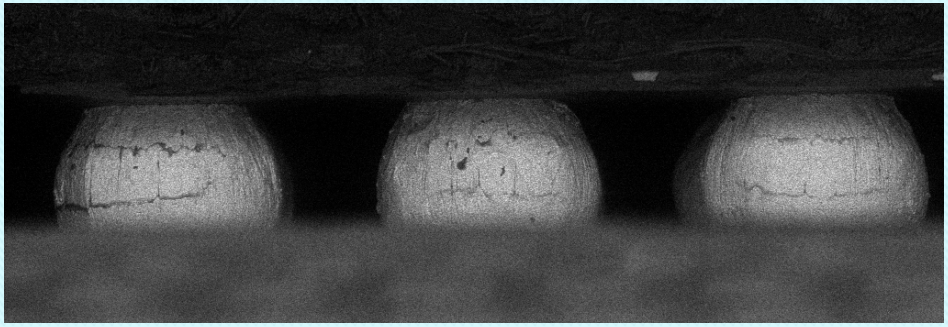
X-ray of CSP and Flip Chip Package Assemblies

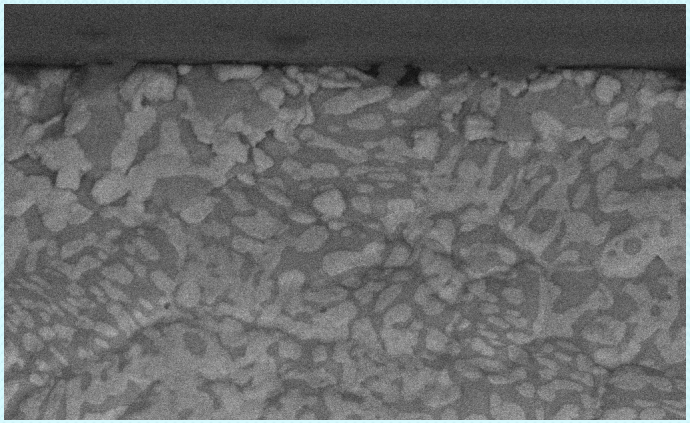


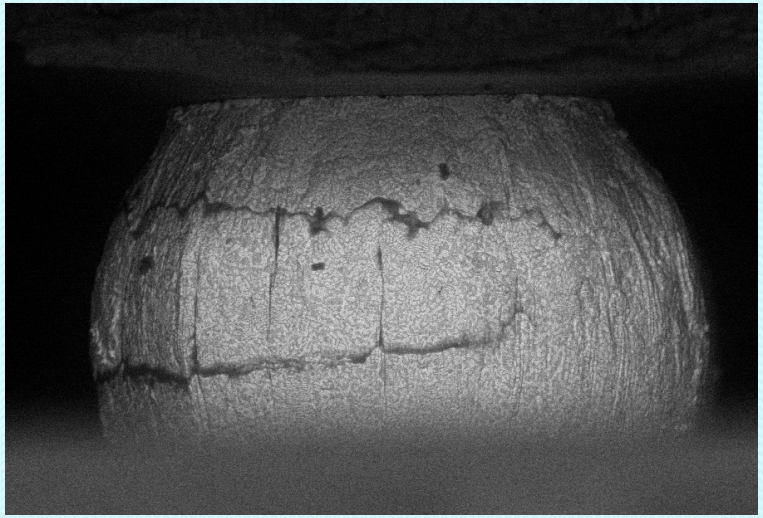


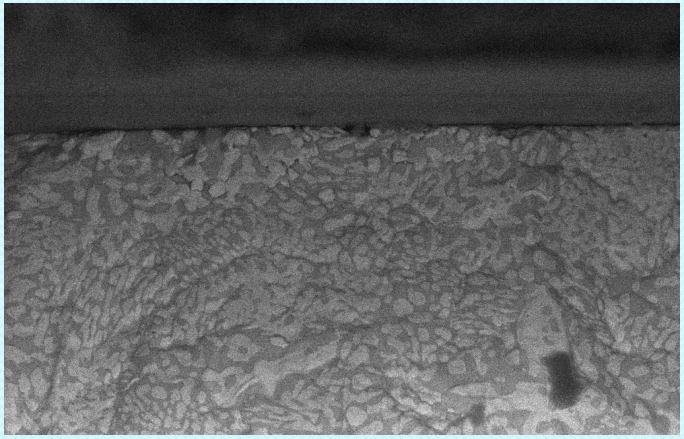
Reza Ghaffarian

SEM Images of Thermally Cycled PBGA 1156 I/O Assemblies



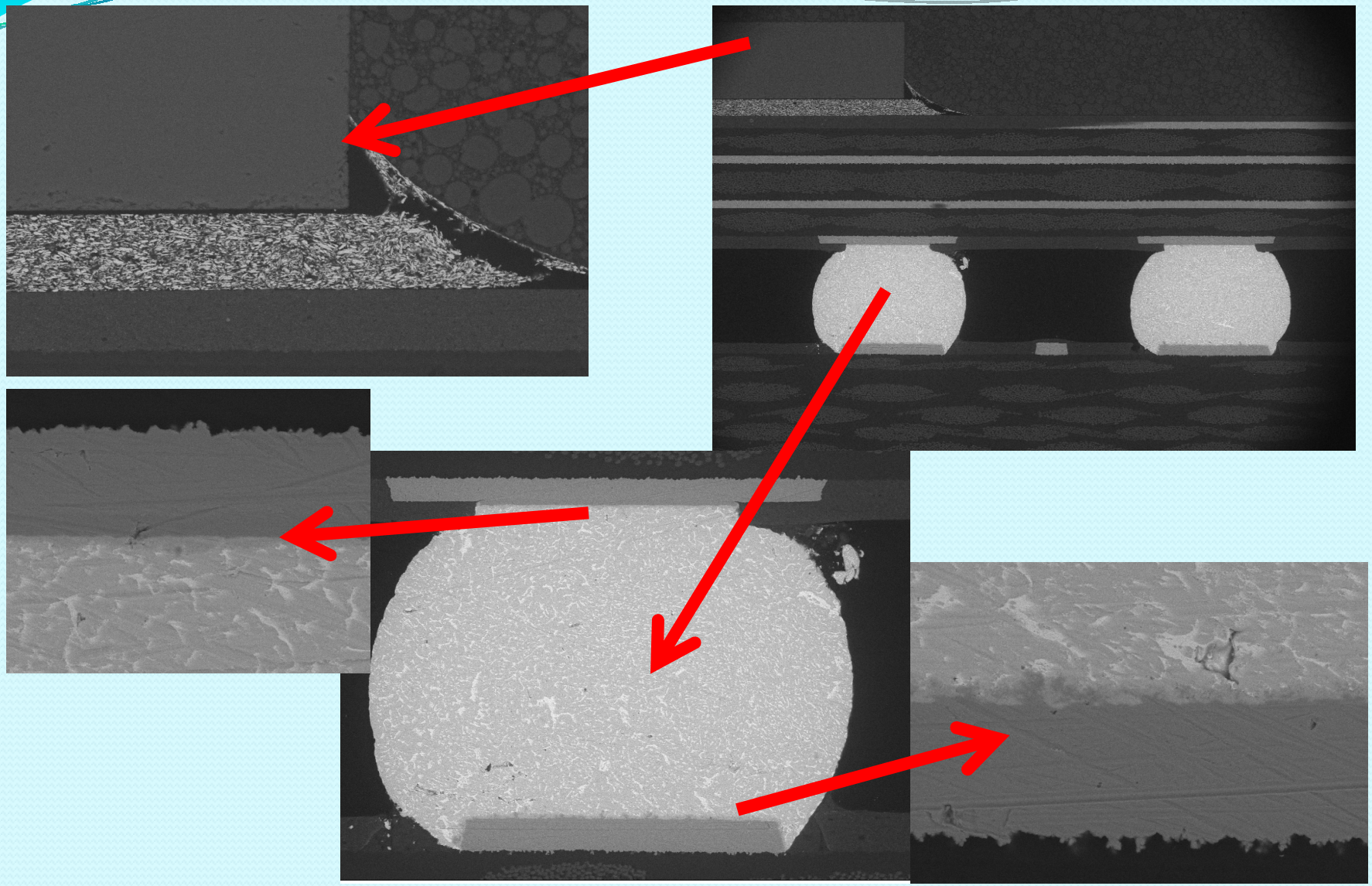






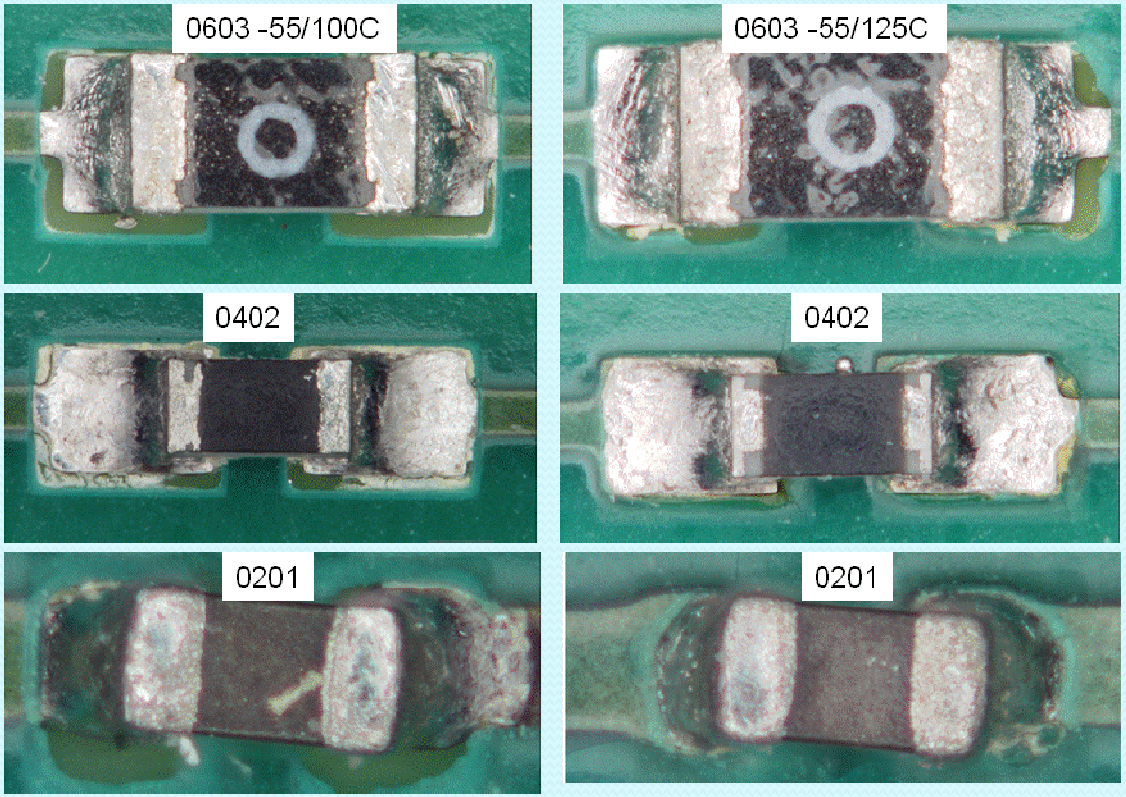
Reza Ghaffarian

X-section Images of Thermally Cycled PBGA 1156 I/O Assemblies



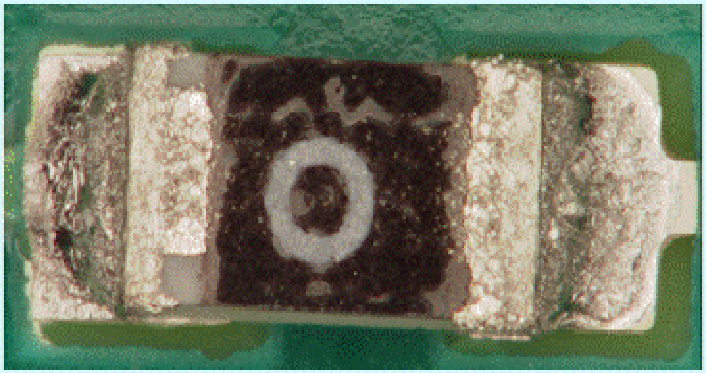
Reza Ghaffarian

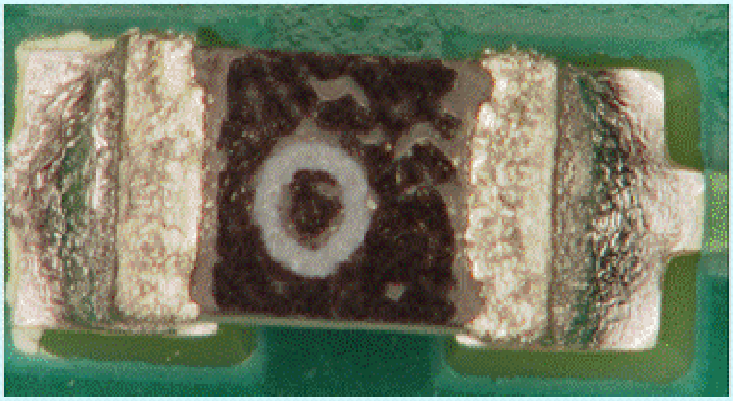
Damage of 0201 and 0402 Resistors under two TCs, -55/100C & -55/125C with the same time intervals

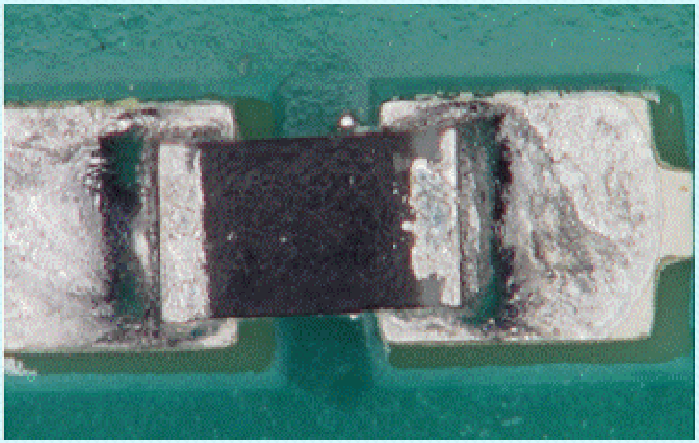


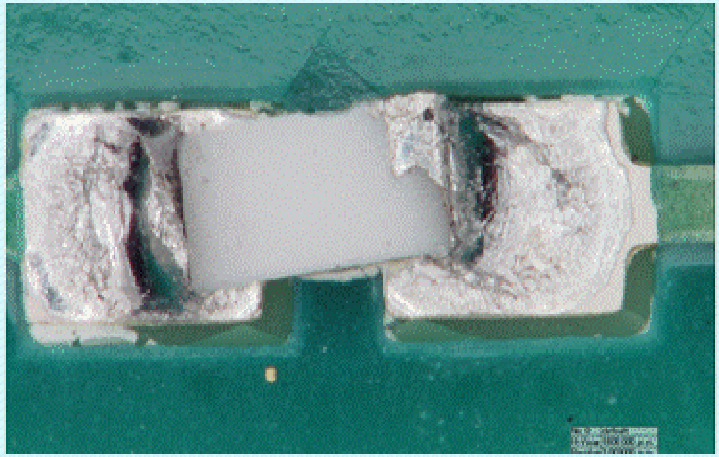
Reza Ghaffarian

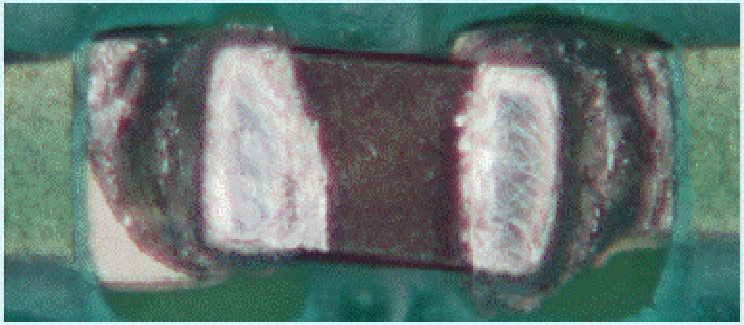
Damage of 0201 and 0402 Resistors under Extreme Thermal Cycle -120/85C

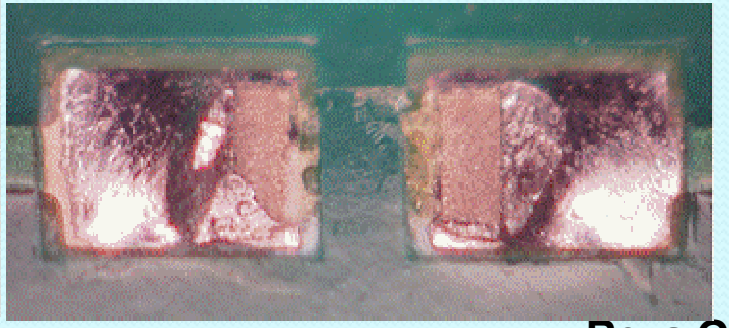




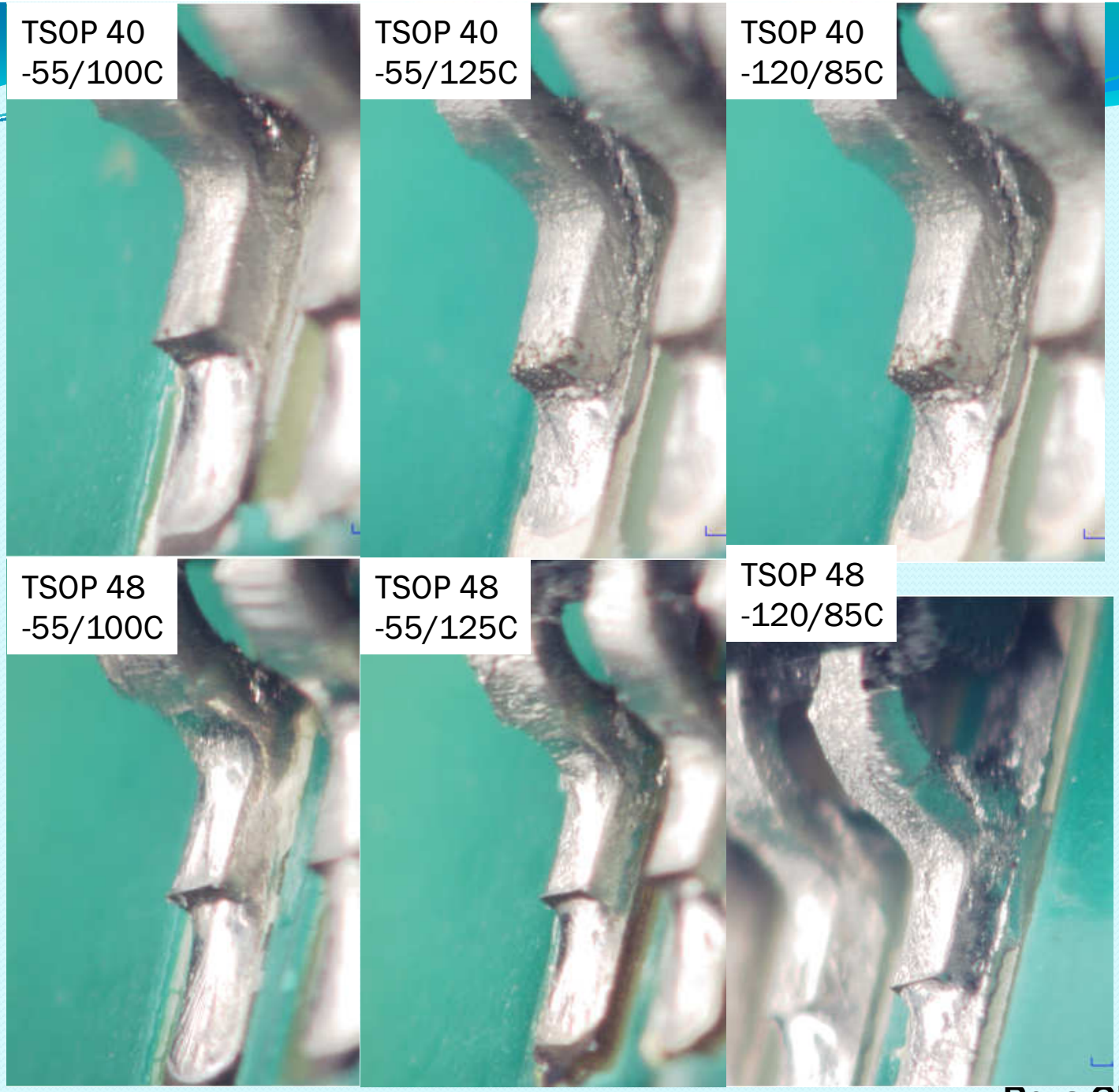








Reza Ghaffarian



Reza Ghaffarian

Lead-free & High Reliability

- Why?
  - "Green" Marketability/Reputation Advantage
  - WEE & REACH! Other Legislation (Waste from Electrical & Electronic Equipment)
  - Implemented – Commercial worldwide /**High Reliability lags**
- Lead-free SAC
  - SAC near eutectic , INEMI/IDEALS/JEIDA
  - Requires reflow temp 235 C (melt 217°C)> Tin-lead 210 C (183 C)
  - Issues with exiting package/assembly – mostly resolved
  - Now, alloy proliferation! – **High Reliability?**
- Package Finish (Tin Whisker)
  - Matte tin (low organic content, grain>1 μm) – **High Reliability?**
- Assembly Reliability
  - Extensive data for commercial/Minimum data & scatter for **High Reliability**
  - Inspection criteria redefinition – Minor for **High Reliability**
  - Mixed Pb-free & Pb – Critical for **High Reliability**
  - Assembly/Rework – Critical for **High Reliability**

Reza Ghaffarian

Lead-free Activities& High Reliability

- **Limited study for High Reliability**
  - NASA NEPP initiated some activity
  - NASA-JPL joint study with RIT on backward/lead-free TC/Drop
  - NASA strong policy for mitigation of Tin Whisker
- **NASA- DOD on Lead-free**
  - Completed comprehensive study, thermal cycle/vibration/shock
  - Continuation on rework- Data being gathered/e.g., presentation at AIMS/SMTA 09
- **Aerospace GEIA Guidelines**
- **Implementation for high-end commercial**
  - Extensive presentations @ SMTA/AIMS/ECTC 2007/2008
  - IBM lesson learned SMTA Oct 2009
- Issues for Hash Environment
  - Reliability, especially mechanical, quality controls, specifications
  - Lead-free alloy proliferation- Chaos!

Drop Tests for As-fab and after 2 TCs

Thermal cycles

-55/100°C

-55/125°C

Drop test parameters

Parameter	Setting
Average peak load	485 G
Time period	3 ms
Height of drop	36 inches
Maximum drop cycles	30
Stand-off height	2 inches

Reza Ghaffarian

Number of Drops to Failure for Different Solder ball/Paste Conditions

Package Type	As Fab Pb/Pb	As Fab SAC ball /Pb Paste	As Fab SAC/SAC
PBGA 1156	2	1	1
PBGA 256	14	16	5
Thickness	0.093	0.063	0.093

TSOPs: No Failure to 30 drops

Reza Ghaffarian

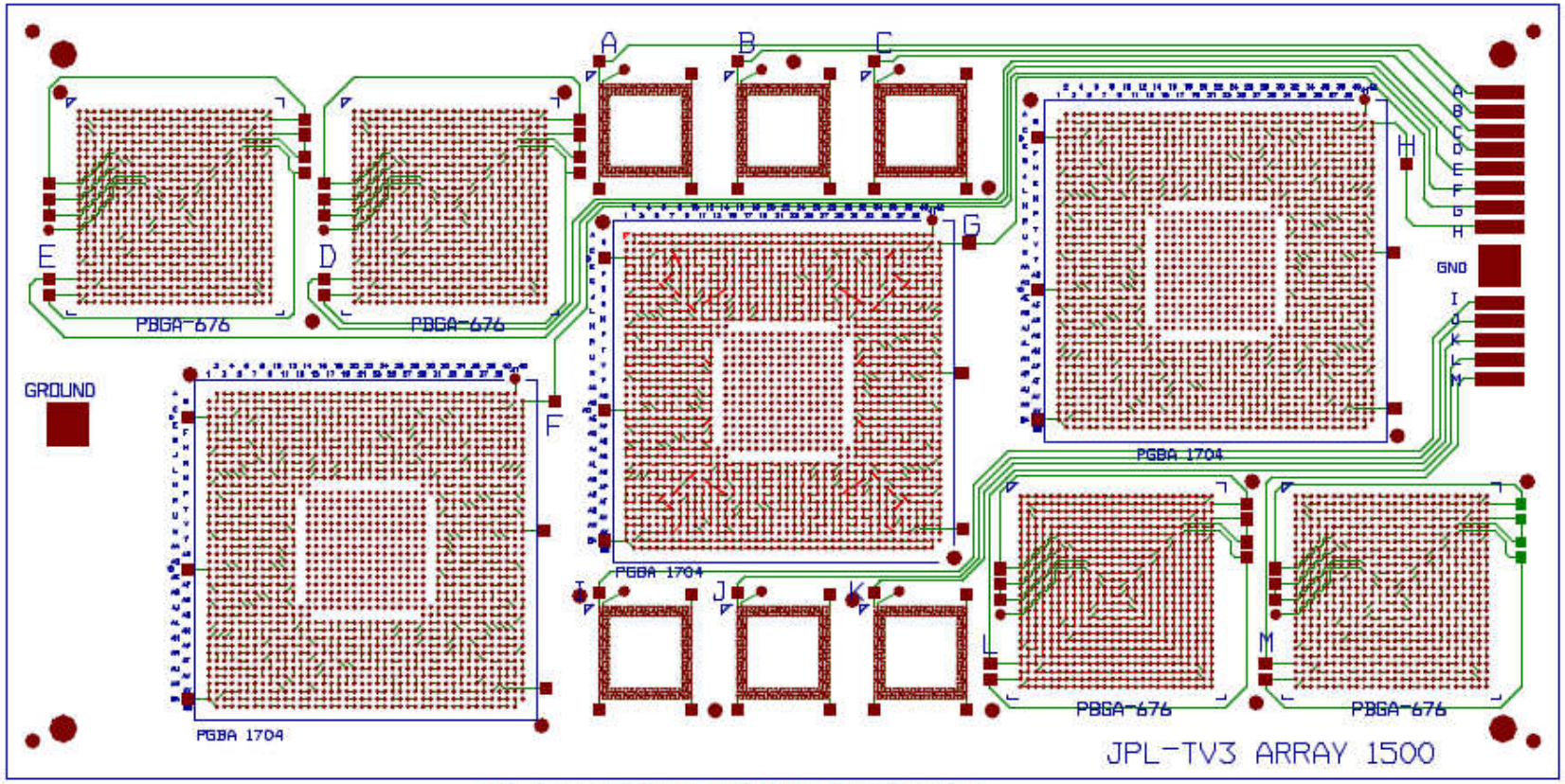
Summary: Tin-Lead Solder: High I/O BGA & CSP/SMC

- **Assemble BGA/CSP/FC/MLF/TSOP/0201-0603**
  - Vapor phase reflow process
  - High I/O BGA 1156 I/O 1mm pitch – No issue
  - CSP- Issue with paste print consistency
  - MLF- Design need to be changed for consistent paste print
  - Often opens for 0201 due to tombstone defects
- **Inspection after cycling**
  - Optical inspection difficult for area array, flip chip , and MLF
  - X-ray, generally difficult to narrow damage level
  - X-ray revealed larger size for TSOP 40 rather TSOP 46

Summary: Tin-Lead Solder: High I/O BGA & CSP/SMC

- **Thermal cycles (-55/100C), (-55/125C), (-120/85C)**
  - Compared damage on TSOP under three TC conditions
  - Compared for 0201 chip resistor
  - Optical/SEM /X-section of BGA 1156 I/O after TCs
- **Drop test @ ~ 500 g**
  - Critical: Package location, type, and size
  - PBGA 1156 at the center failed after 1-2 drops for As Fab
  - PBGA 256 away from the center, better results for comparison
- **Current/Future Activities**
  - More comprehensive study on TC/Drop with RIT University gathered/presented @ SMTA09
  - New test vehicles with >1500 I/Os and fine pitch

New Test Vehicle with >1500 I/O FCBGA & fine pitch CSPs



ALL LAYERS VIEWED FROM TOP SIDE (LAYER 1)

Reza Ghaffarian

Acknowledgment

The research described in this publication is being conducted at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Copyright 2009 California Institute of Technology. Government sponsorship acknowledged.

The author would like to acknowledge industry/university partners. Special thanks to Dr. Ramkumar and students at RIT for extensive drop and thermal cycle characterizations. Thanks also to fabrication and failure analysis lab including Atul Mehta and Ronald Ruiz for their supports. The author also extends his appreciation to program managers at NASA Electronic Parts and Packaging Program (NEPP) including M. Sampson & K. LaBel, Dr. C. Barnes, and P. Zulueta for their continuous support and encouragement.

References

http://NEPP.nasa.gov