Thermal Cycling Test Report for Ceramic Column Grid Array Packages--CCGA

Raymond Kuang, Lijie Zhao
Actel Corp
2061 Stierlin Ct
Mountain View, CA 94043
650-318-4493
Raymond.kuang@actel.com
Lijie.zhao@actel.com

Table of Contents

1.0 Introduction

Traditional Ceramic Quad Flat Pack (CQFP) or Ceramic Pin Grid Array (CPGA) packages are no longer suitable for today's high I/O count FPGA devices. Higher pin-count packages such as Ceramic Column Grid Array (CCGA) become necessary for packaging today's high density FPGA devices. CCGA represents a key leveraging technology that offers high density packaging for high performance FPGA devices at a reliability level that can meet space satellite requirements.

Most space application customers have qualified or started their qualification programs to get CCGA qualified on their flights. There are various column configurations. The most widely used column configurations are 90 Pb / 10 Sn (called 90 Pb / 10 Sn column) and 80 Pb / 20 Sn with copper spiral (called 80 Pb / 20 Sn column) as reinforcement. This paper will discuss the thermal cycle reliability testing of both 1.27 mm and 1.0 mm pitch with both column configurations—90 Pb / 10 Sn, and 80 Pb / 20 Sn with Cu spiral. Mechanical tests such as shock and vibration were not conducted at this point. However, BAE Systems in Manassas, VA, USA (refer as BAE in this report) and various customers have successfully qualified CCGA package technology to meet or exceed the reliability requirements for space class programs.

2.0 Scope

In most applications, thermal cycling is one of the key stress requirements. Actel has selected a 10-layer polyimide board with a 9 in x 6 in test PCB. Refer to the CCGA Package and PCB Matrix Table (page 3) for CCGA daisy chain packages column configuration and PCB layout.

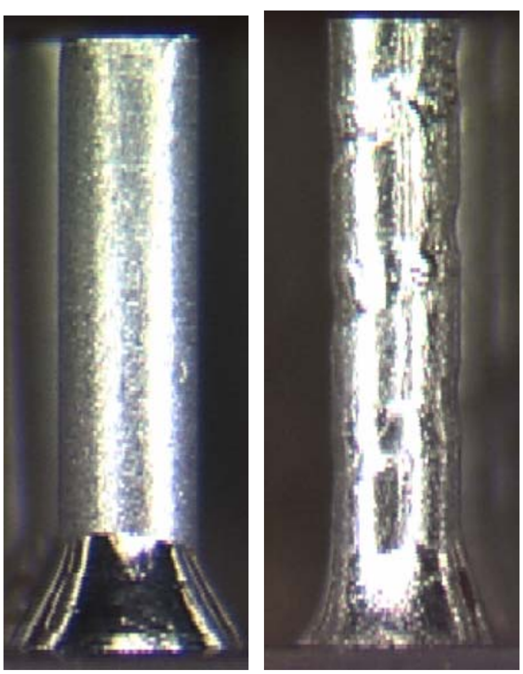


Figure 1: Left—90 Pb / 10 Sn, with 20 mils diameter
Right—80 Pb / 20 Sn column with Cu Spiral, with 20 mils and 22 mils diameter

CCGA Package and PCB Matrix Table

PCB ID	CCGA Package and Column Type	CCGA Package ID	Total Qty CCGA Package on PCB
PCB1	CG624 90Pb/10Sn	242, 245, 141R, 1, 11, 12	6
PCB2	CG624 80Pb/20Sn	160*, 163*, 142*R, 206, 207, 208R	6
PCB3	CG1152 90Pb/10Sn	179,185, 183, 184	6
	CG1152 80Pb/20Sn	216*, 214*R	
PCB4	CG1152 80Pb/20Sn	219*, 220*, 221*R, 175, 177, 178R	6
PCB5	CG1272 90Pb/10Sn	173, 170, 169R	6
	CG1272 80Pb/20Sn	198*, 199*, 201*R	

Notes:
Package ID abbreviation
R = Rework, the testing package has been reworked.
* = Solder column diameter is 22mils

As can be seen from the table above, the matrix compares the effect of 90 Pb / 10 Sn and 80 Pb / 20 Sn column configurations. Even though both columns have been used in various HiRel and space class applications, it is our interests to find out which column performs better in the same given condition. Also, in this table, there are rework parts, and some of 80 Pb / 20 Sn devices with 22 mils diameter parts were included in the test.
The optimized parameters that were used to assemble CCGA to PCB are documented in this report.

3.0 Column Attachment, Test Board Configuration and Assembly

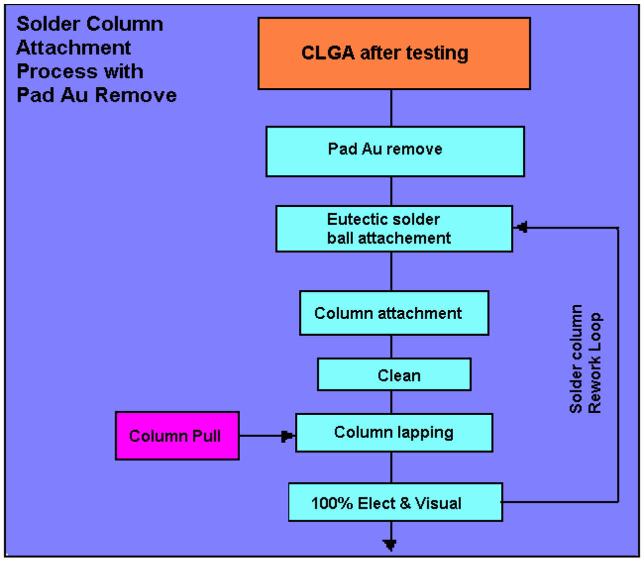
3.1 Attach Solder Column on Ceramic Package

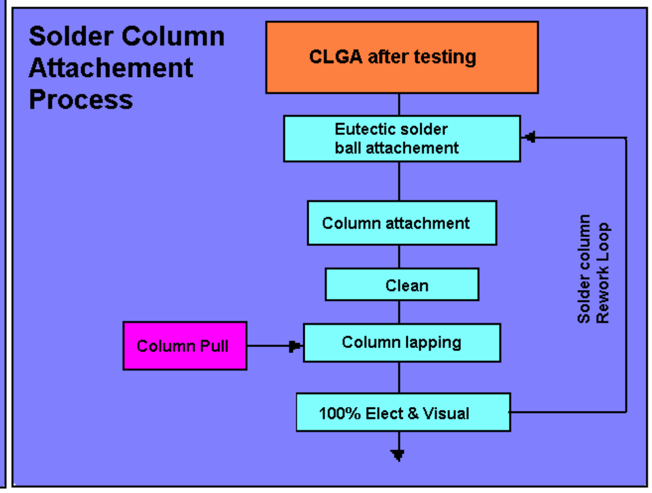
1). CG624 90 Pb / 10 Sn solder column attachment performed at both BAE Systems, Manassas, Virginia and Six Sigma, San Jose, California.

2). CG1152 90 Pb / 10 Sn, CG1272 90 Pb /10 Sn, CG1152 80 Pb / 20 Sn and CG1272 80 Pb / 20 Sn solder column attachment performed at Six Sigma, San Jose.

Solder columns were attached on the ceramic package with Eutectic solder (63 Pb / 37 Sn) by normal reflow. The flowchart below shows two methods of column attachment. The left chart shows the process of land pad gold metallization being removed before attaching column. This method is being used at Six-Sigma for the 80 Pb / 20 Sn with Cu spiral column. The right side chart shows BAE's 90 Pb / 10 Sn column attachment process without land pad gold plating (only flash gold plating) being removed before attaching column.

Note: Removing gold plating should enhance column joint reliability by avoiding rich gold tin intermetallic formation.





3.2 Assembly CCGA on PCB

CCGA package assembly on the PCB was performed in DDI, San Jose. Refer to **APPENDIX B—Board Assembly Parameters** for details**.** It is very important to optimize the board assembly process parameters in order to obtain good and reliable solder joint between the column and PCB. Cold soldering will result in the center column not being properly attached. Over reflow (peak temperature stays too long) will result in dripping of the eutectic solder (Pb 37 / Sn 63) coating from the 80 Pb / 20 Sn column, and column detaching from the column joint on the package side. 3-D X-ray was used during process optimization and final verification. A cross section on both columns has been performed to make sure the solder joints between the columns and PCB land pads are good. See Figure 3 for details.

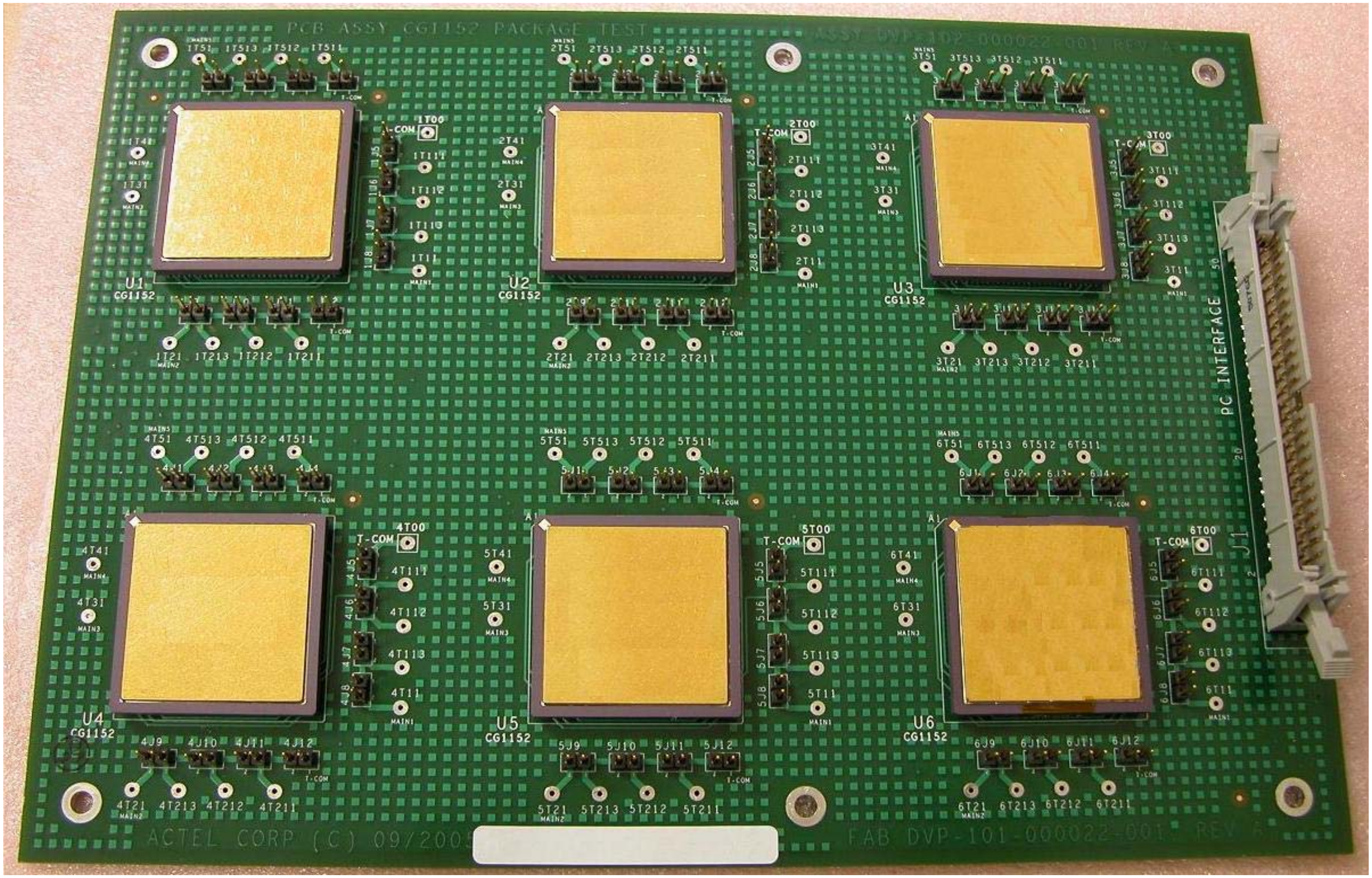


Figure 2: CCGA Thermal Test PCB After Daisy Chain CCGA Package Assembly

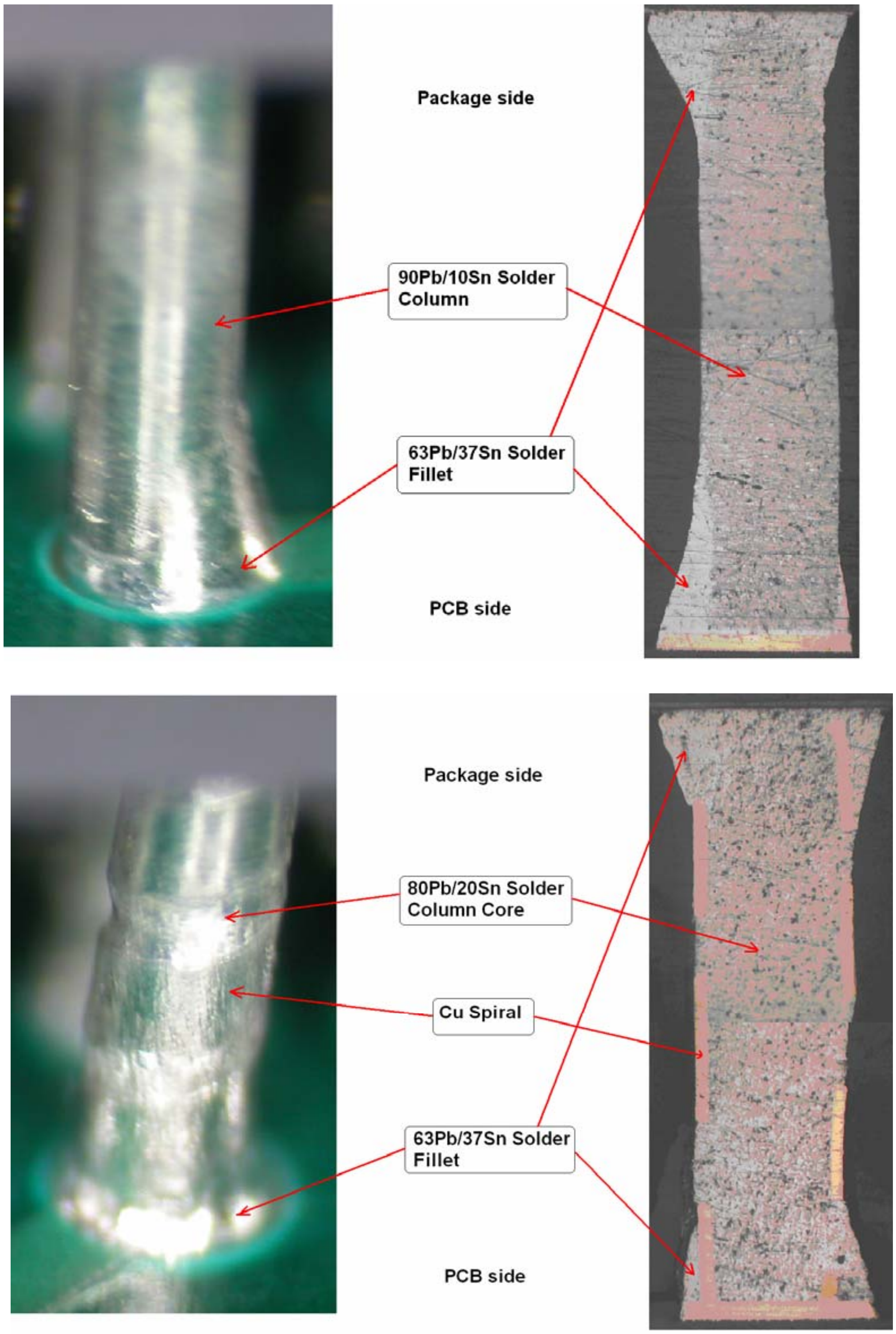


Figure 3:
Top: 90 Pb / 10 Sn Column on PCB and Cross Section After Assembly
Bottom: 80 Pb / 20 Sn Column with Cu Spiral on PCB and Cross Section After Assembly

4.0 Temperature Cycling Test

Thermal cycle testing was performed at Sanmina-SCI, San Jose.

Figure 4 shows the 5 testing PCBs in oven

Figure 4: Testing PCBs in Oven

4.1 PCB Temperature Cycling Profile

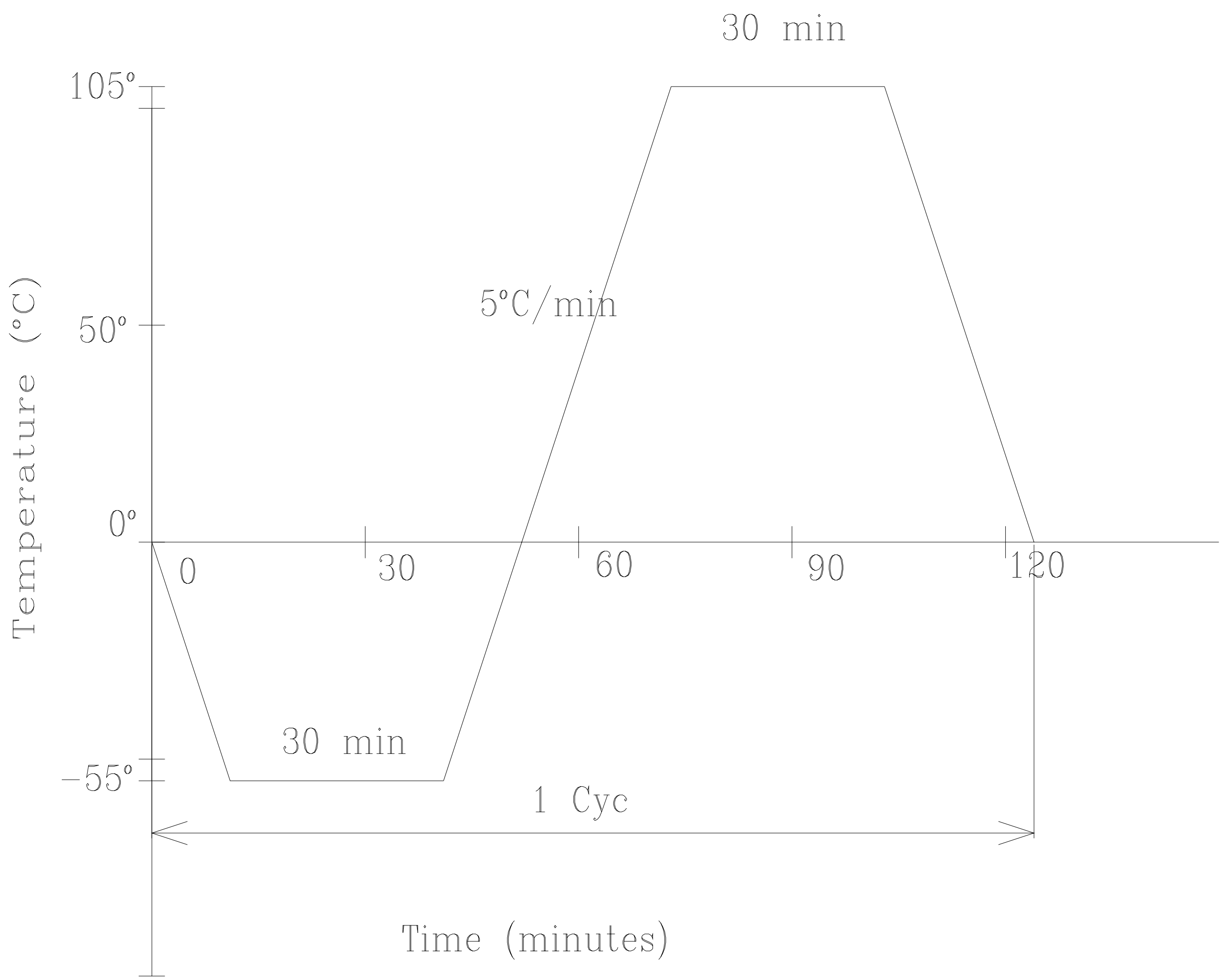
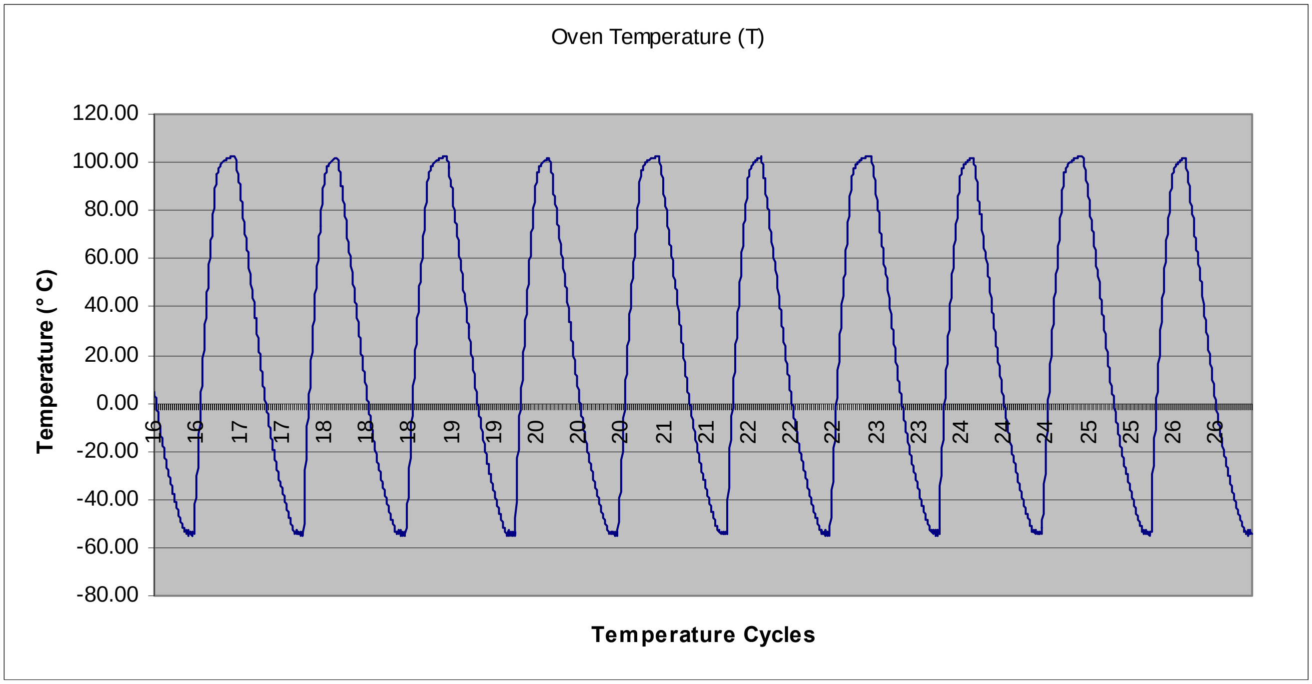


Figure 5: Thermal Testing Temperature Profile

The temperature profile was chosen for accelerating thermal testing and base on end customers application requirement

4.2 Daily Temperature and Loop Resistance Measurement



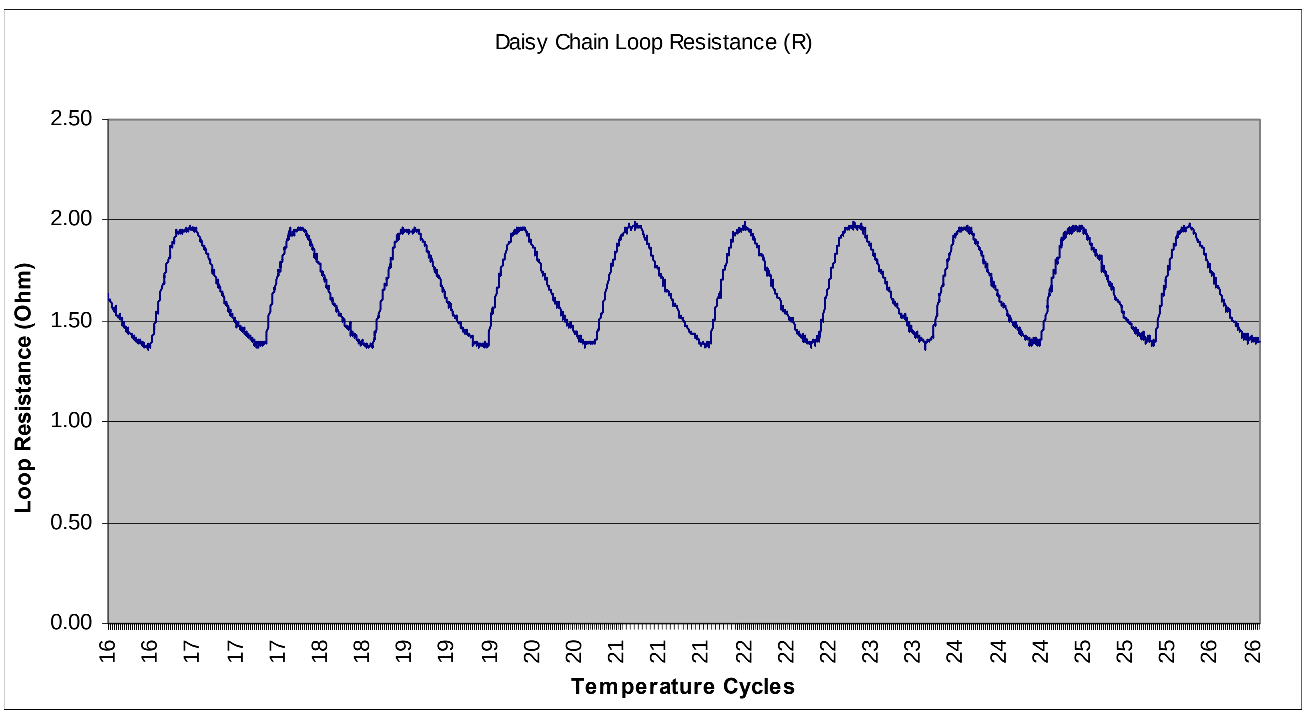


Figure 6: Daily Temperature (first graph) and Loop Resistance (second graph) Measurement

4.3 Test Failure Detecting

Test failed criteria is based on whether daisy chain loops have an electrical resistance over 300 ohms (daisy chain loop open test). Electrical resistance data was inspected daily. Test units were visually inspected every 100 ~ 200 cycles and some pictures were taken. Refer to Appendix C—Solder Columns Pictures in Different cycles. Cross sections have been performed on electrical open failed units. Refer to Appendix D—Solder Column Cross Section Pictures.

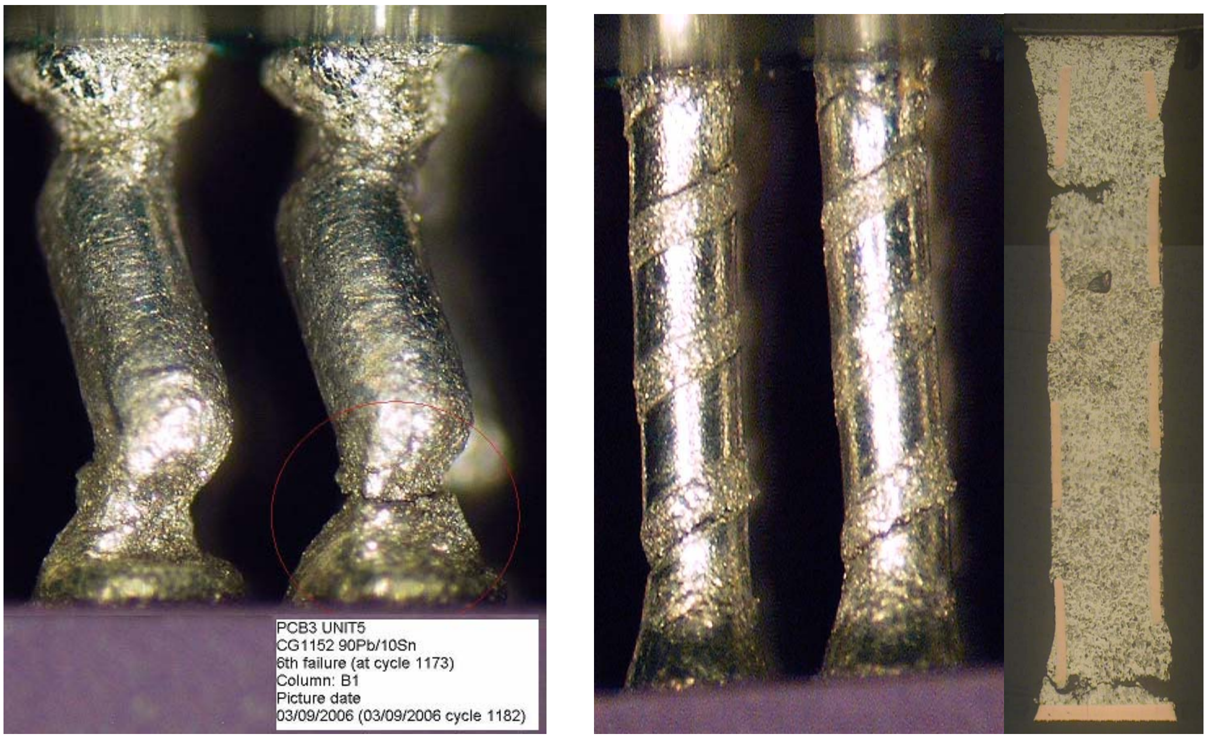


Figure 7: Column failure during temperature cycling

Left side--shows CG1152 90 Pb / 10 Sn typical broken column failure. In this case columns failed at 1182 cycles.

Right side--shows typical 80 Pb / 20 Sn (from CCGA1152) failed at 1212 cycles. In this case, the column did not show the “S” shape stress as the 90/10 column showed. The cross section picture shows the breakdown of the 80/20 column at the PCB side.

4.4 Temperature Cycle Results Table

PCB ID	Package ID		800 Cycles		1000 Cycles		1200 Cycles		1400 Cycles		1600 Cycles		1800 Cycles	
			P ID	Qty	P ID	Qty	P ID	Qty	P ID	Qty	P ID	Qty	P ID	Qty
PCB1	CG624 90Pb/10Sn	242, 245, 141R, 1, 11, 12		0		0	12	1	141R	2	245	3	11	4
PCB2	CG624 80Pb/20Sn	160*, 163*, 142*R, 206, 207, 208R	No failure until test stop at cycle 2313											
PCB3	CG1152 90Pb/10Sn	179,185, 183, 184	183	1	179	2	185 184	4						
	CG1152 80Pb/20Sn	216*, 214*R												
PCB4	CG1152 80Pb/20Sn	219*, 220*, 221*R, 175, 177, 178R.		0		0	177 221*R	2					220*	3
PCB5	CG1272 90Pb/10Sn	173, 170, 169R.		0		0	169R	1	170 173	3	201*R 198*	5	199*	6
	CG1272 80Pb/20Sn	198*, 199*, 201*R.												

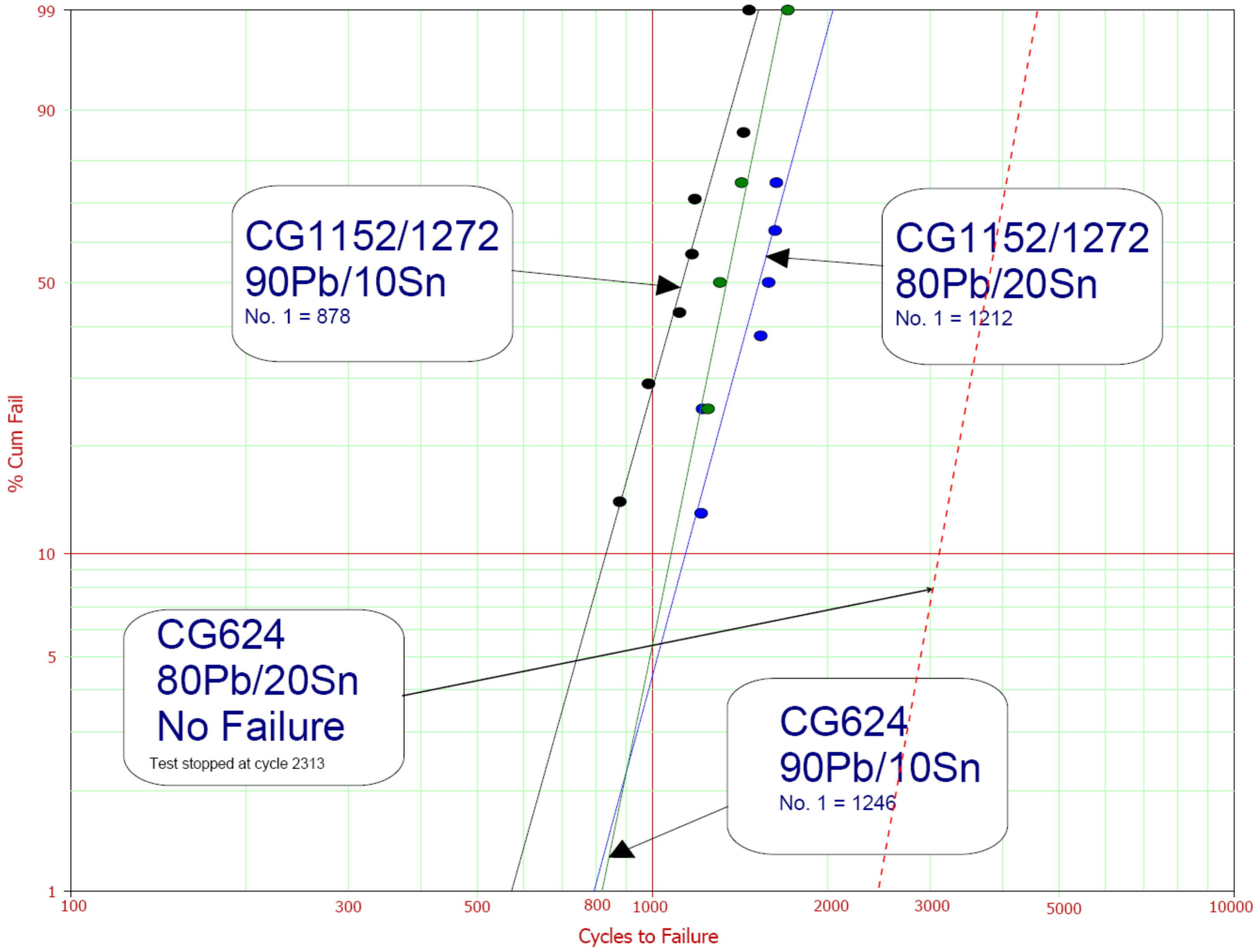
Notes:

1. CG624 90 Pb / 10 Sn, $N_{0.1}$ = 1246 cycles
2. CG1152 90 Pb / 10 Sn, $N_{0.1}$ = 878 cycles
3. CG1272 90 Pb / 10 Sn, $N_{0.1}$ = 1112 cycles
4. CG64 80 Pb / 20 Sn, no failure, Testing stopped at 2313 cycles.($N_{0.1}$ =2313 cycles)
5. CG1152 80 Pb / 20 Sn, $N_{0.1}$ = 1212 cycles
6. CG1272 80 Pb / 20 Sn, $N_{0.1}$ = 1534 cycles
7. Units 242, 1, 160*, 206, 179, 216*, 175, and 219* were cut out for cross section at cycle 1047.

4.5 Temperature Cycle Analysis

Using the raw data collected above, a plot of cumulative fails vs. temperature cycles can be made using a regression analysis on a lognormal probability distribution scale.

Figure 8: Lognormal Probability Distribution of Cumulative Fails vs. Temperature Cycles.



4.6 Temperature Cycle Projections

Using the test results cited in the section above, field life reliability projections can be made. Using the Coffin-Manson equation, the $N_{.01\%}$ derived from the testing can be related to field conditions in order to project the life of the product under given conditions. The Coffin Manson equation is shown in Figure 9 along with a summary of the test conditions.

Figure 9: Coffin Manson Relation, used to relate temperature cycle results to field conditions and a summary of test conditions.

$$\mathbf{A.\ F.} = (\Delta \mathbf{T}_t \ast DNP_t / \Delta \mathbf{T}_f \ast DNP_f)^{1.9} \ X\ (\mathbf{F}_f/\mathbf{F}_t)^{1/3} \ \mathbf{exp}\ [1414\ (1/\mathbf{T}_{max\mathbf{f}} - 1/\mathbf{T}_{max\mathbf{t}})\ ]$$

<u>Where</u> :
N_f = Field Cycles
N_t = Test Cycles
ΔT_t Test Cycle Temperature Range
ΔT_f = Field Cycle Temperature Range
DNP_t = Test Distance to Neutral Point
DNP_f = Field Distance to Neutral Point
F_f = Field Cycle Frequency
F_t = Test Cycle Frequency
T_{maxf} = Maximum Field Temperature
T_{maxt} = Maximum Field Temperature

Test Conditions :

Temp. Range			
-55	105	*160*	*= ΔT_T, ΔTemp for Test*
		12	*= $F_{T,}$ cycles / day for Test*
		378	*= T_{MaxT}, Max Temp for Test*
		21.5mm	*= DNP for Test for CG624***

22.6mm =DNP for Test for CG1152
22.7mm =DNP for test for CG1272

** Note:

Distance of corner pin to the center point of the package (neutral point)

Using this relationship, the test results can be related to typical space satellite conditions, as shown in Figure 8. A more detailed presentation of these results, including more analytical values, is presented in Appendix B.

Figure 10: CGA Field Life projections for some typical Satellite applications based on temperature cycling—for an 80 Pb / 20 Sn column

	Field Cycles (CPD)	Field Temp Range	Field Delta Temp	DNP (mm)	Field Max Temp (C)	N.01 Test Cycles	Acceleration Factor	Projected Cycles	YEARS OF LIFE
CG624	18	20 to 45	25.00	21.5	45.0	2,313	78.88	182,445.8	27.8
CG1152	18	20 to 45	25.00	22.6	45.0	1,212	78.88	95,600.7	14.6
CG1272	18	20 to 45	25.00	22.7	45.0	1,534	78.88	120,999.5	18.4
CG624	12	70 to 85	15.00	21.5	85.0	2,313	110.67	255,970.0	58.4
CG1152	12	70 to 85	15.00	22.6	85.0	1,212	110.67	134,126.9	30.6
CG1272	12	70 to 85	15.00	22.7	85.0	1,534	110.67	169,761.3	38.8

Figure 11: CGA Field Life projections for some typical Satellite applications based on temperature cycling—for a 90 Pb / 10 Sn column

	Field Cycles (CPD)	Field Temp Range	Field Delta Temp	DNP (mm)	Field Max Temp (C)	N.01 Test Cycles	Acceleration Factor	Projected Cycles	YEARS OF LIFE
CG624	18	20 to 45	25.00	21.5	45.0	1,246	78.88	98,282.5	15.0
CG1152	18	20 to 45	25.00	22.6	45.0	878	78.88	69,255.3	10.5
CG1272	18	20 to 45	25.00	22.7	45.0	1,112	78.88	87,712.8	13.4
CG624	12	70 to 85	15.00	21.5	85.0	1,246	110.67	137,889.6	31.5
CG1152	12	70 to 85	15.00	22.6	85.0	878	110.67	97,164.6	22.2
CG1272	12	70 to 85	15.00	22.7	85.0	1,112	110.67	123,060.4	28.1

5.0 Summary/Conclusions:

BAE has completed component and board-level testing for the Column Grid Array (CCGA) package and proved that CCGA technology meets or exceeds the reliability requirements of typical satellite program applications. In addition to BAE's data, Actel has also completed board-level thermal cycle reliability tests for two different column material configurations: 90 Pb / 10 Sn from BAE and 80 Pb / 20 Sn with Cu spiral from Six-Sigma. From a thermal cycling perspective, both columns can meet or exceed the thermal cycle requirement for typical space applications. Following is a detailed summary of thermal cycle test results:

- For CG624 (1.27 mm pitch), temperature cycle data showed 80/20 with a 20 mils or 22 mils diameter column performed better than 90/10 column. So far, up to 2300 cycles (when test stopped), there is no failure in 80/20 column, while 90/10 column failed at 1246 cycles.
- CG1152 (1 mm pitch) first 90/10 column failed at 878 cycles, while first 80/20 column failed at 1212 cycles.
- CG1272 (1 mm pitch) first 90/10 column failed at 1112 cycles, while first 80/20 column failed at 1534 cycles.
- Rework parts performed as well as non-rework parts.
- Vibration test:
  - BAE has done vibration and shock tests and approved that CGA package technology meets or exceeds the reliability requirements for space class programs.
  - Both tests are application-dependent. Customers need to validate their respective programs, taking into account board configuration and specified mechanical conditions.
  - Various customers in the U.S. and Europe have done full qualification on Actel daisy chain CCGA packages, and results meet or exceed their space application program requirements.
  - In this board-level thermal test, Actel did not perform a vibration test. However, Actel plans to do vibration and shock tests sometime in 2007.

Actel is currently offering the following:

CCGA1152, 1272 (1.0 mm pitch) —80 Pb / 20 Sn with 20 mils diameter column from Six-Sigma for 1.0 mm pitch as standard.

CG624 (1.27 mm pitch) —90 Pb / 10 Sn column from BAE, Six-Sigma 80/20(20 mils diameter).

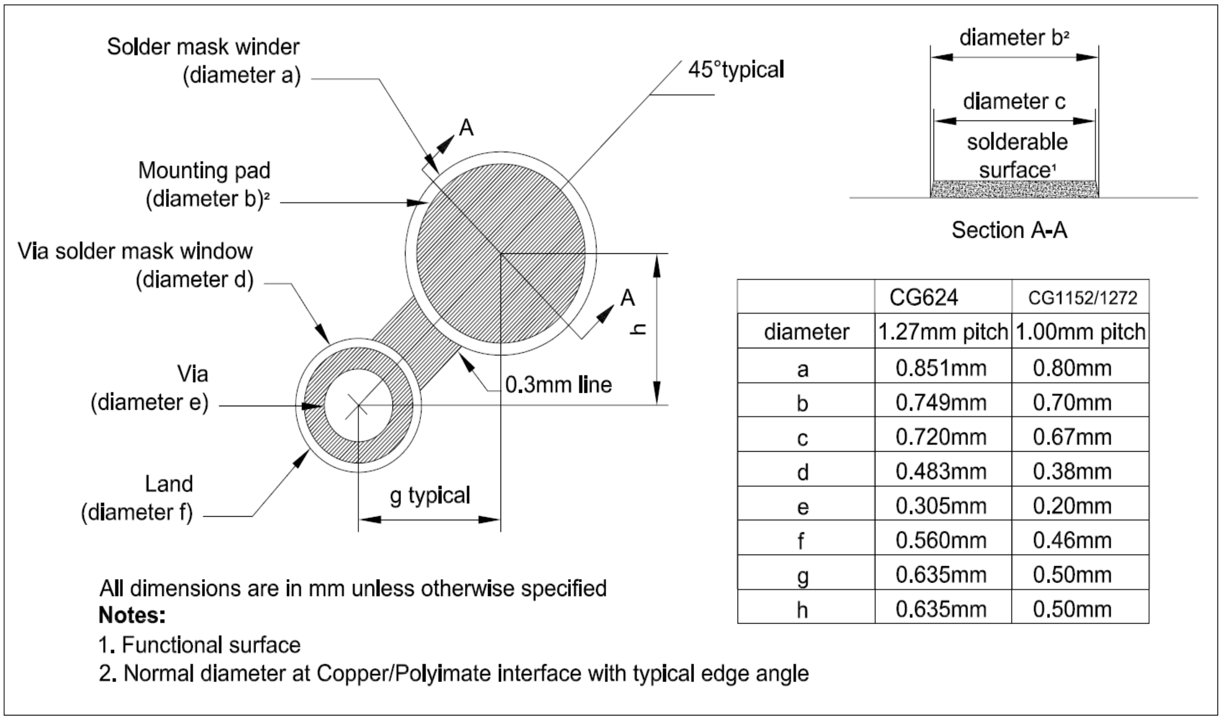
Appendix A—CCGA Package and Test Board Configuration

1. CCGA package and column data

A: CCGA Package Material: Alumina
B: CCGA substrate layers, pad pitch and pad diameter
CG624: layers = 7, pad pitch = 1/27mm, pad dia = 0.86 mm
CG1152 and CG1272: layers = 8, pad pitch = 1.00 mm, pad dia = 0.80 mm
C: Solder column Material, diameter and height
90 Pb / 10 Sn column, dia: 20 mils, height: 2.21 mm; refer to Figure 1
80 Pb / 20 Sn column with copper spiral inside and outer with eutectic solder coating, dia: 20 mils, height: 2.21mm; refer Figure 1
D: Solder fillet material and weight
Material: eutectic solder (Pb 37 / Sn 63)
Weight: 6.5 ~ 8.5 mg/pad
E: Solder column pull Strength: Greater than 1.5 pound/column

2. PCB design data

A: PCB design and Test Method: IPC-9701 Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments
B: PCB size: 9” x 6.5”, refer to Figure A3.
C: PCB thickness: 2.35 mm
D: PCB Layers: 10.
E: PCB material: Polyimide
F: PCB finished type: HASL
G: PCB LGA pad opening: NSMD (non-solder mask defined). Refer to Figure A1. CCGA pad layout dimensions
H. PCB LGA pad solder paste material: Type 798, Water-soluble, Alloy Sn 63 / Pb 37, 89% Metal
I. Daisy chain connection design: Considering most sensitive strength points are at the package corners and silicon die cavity corners, the chain connection is divided into 5 loops. Figure A2 shows CCGA daisy chain package loop connection.



	CG624	CG1152/1272
diameter	1.27mm pitch	1.00mm pitch
a	0.851mm	0.80mm
b	0.749mm	0.70mm
c	0.720mm	0.67mm
d	0.483mm	0.38mm
e	0.305mm	0.20mm
f	0.560mm	0.46mm
g	0.635mm	0.50mm
h	0.635mm	0.50mm

All dimensions are in mm unless otherwise specified

Notes:

1. Functional surface
2. Normal diameter at Copper/Polyimate interface with typical edge angle

Figure A1: CCGA PCB Pad Layout Dimensions

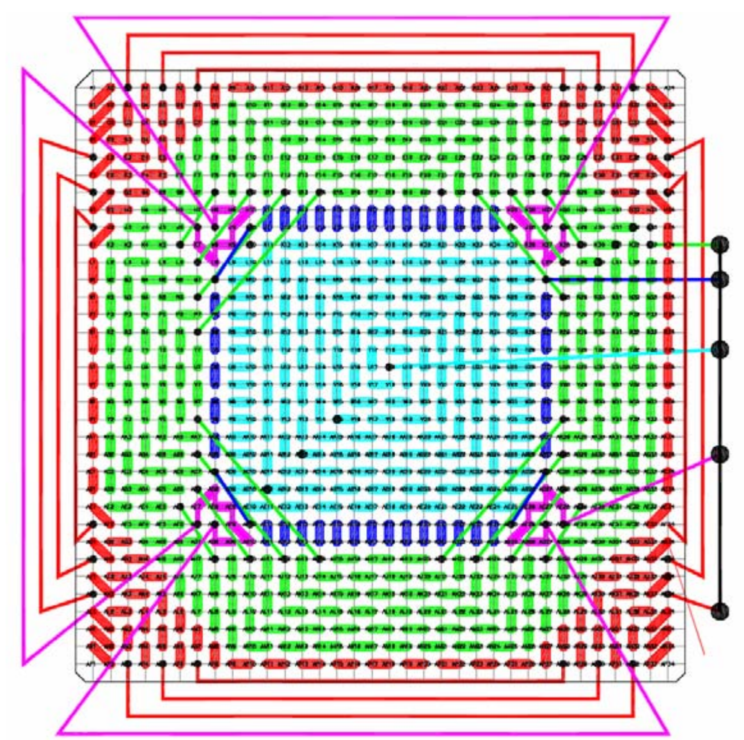


Figure A2: CCGA Daisy Chain Connection

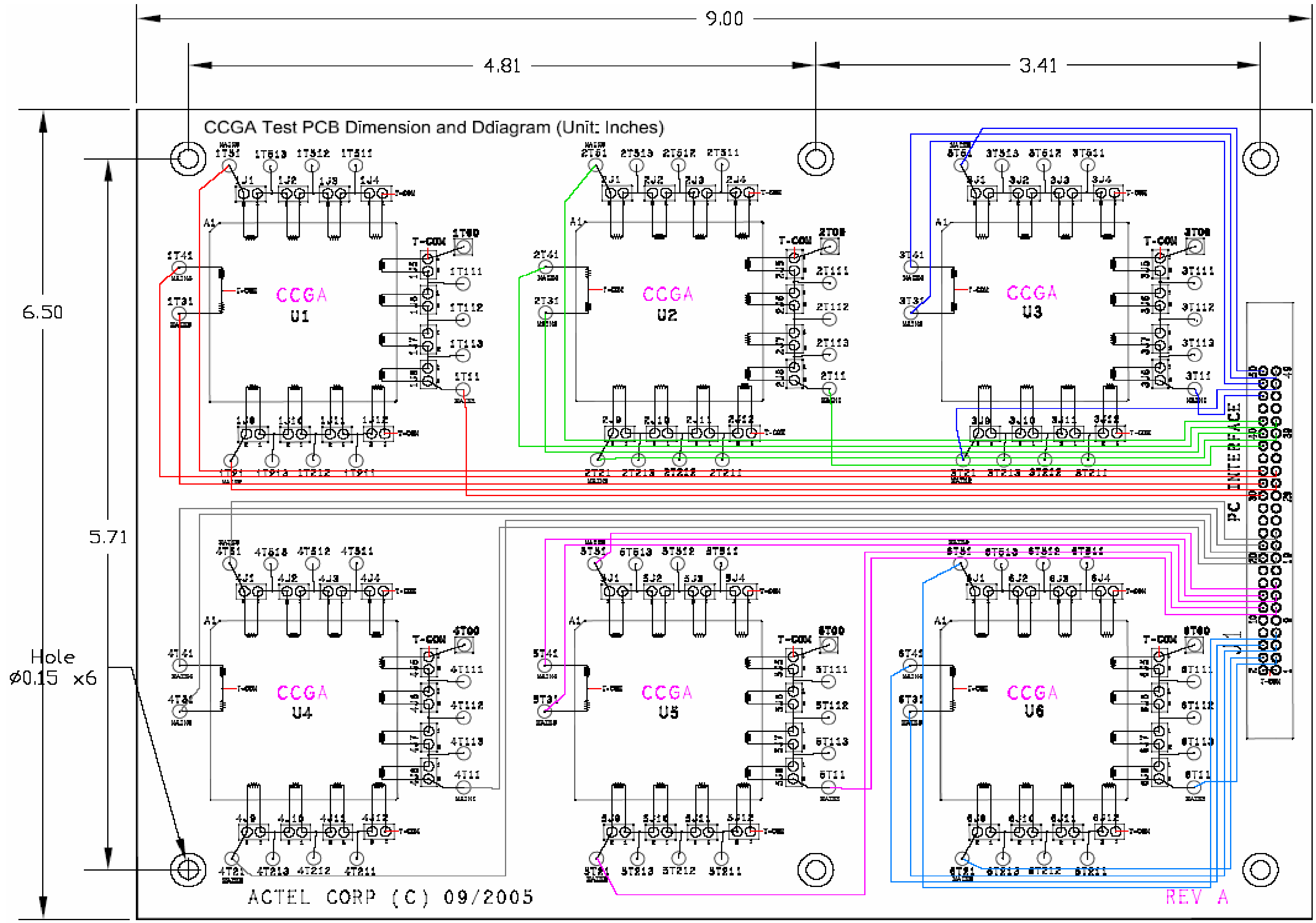


Figure A3: CCGA Packages Layout on PCB

Appendix B—Board Assembly Parameters

1. **Solder Stencil and paste**
   Stencil screen opening
   CG624: 30 x 30 x 7 mils
   CG1152 and CG1172: Ø28 x 6 mils
   Solder Paste: Qualitek, Type 798 Water Soluble, Alloy Sn 63 / Pb 37
   Note: Using circle screen opening (instead of square screen opening) for CG1152 and CG1272 to avoid solder paste bridging for 1.0mm pitch

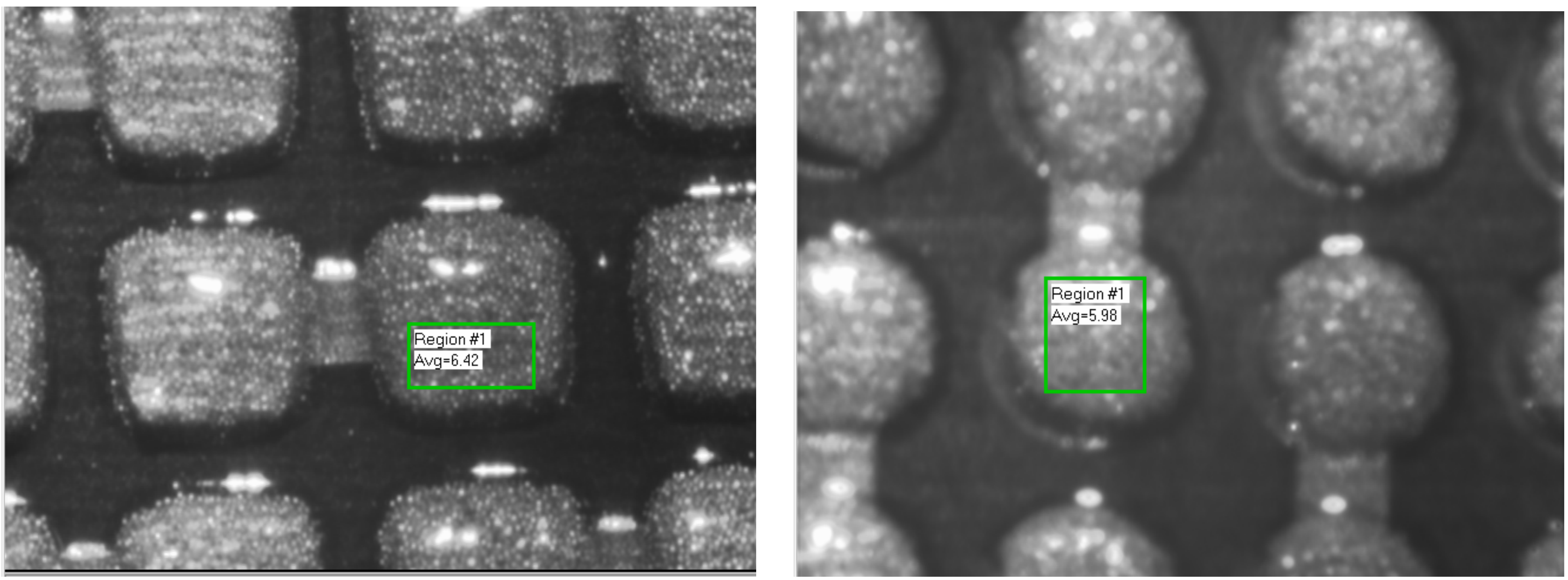
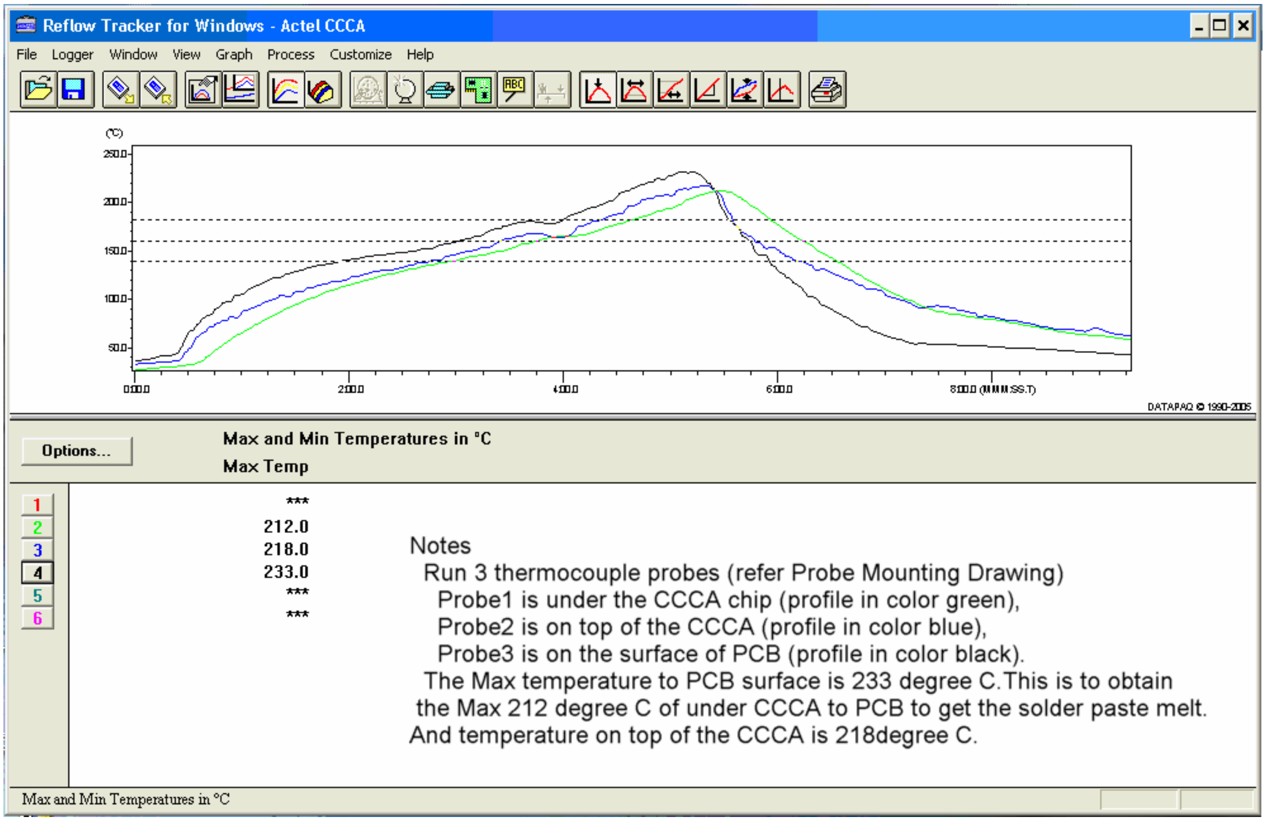


Figure B1. Solder Paste on CCGA624 PCB (left) and on CCGA1152/1272 (right)

2. PCB Reflow Profile



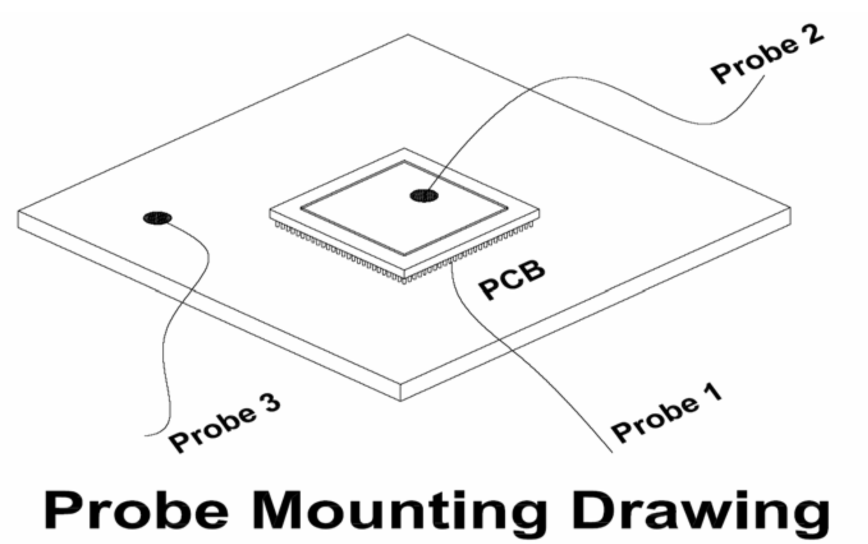
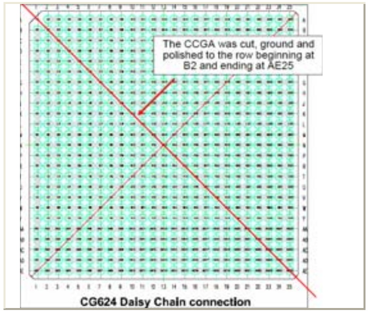


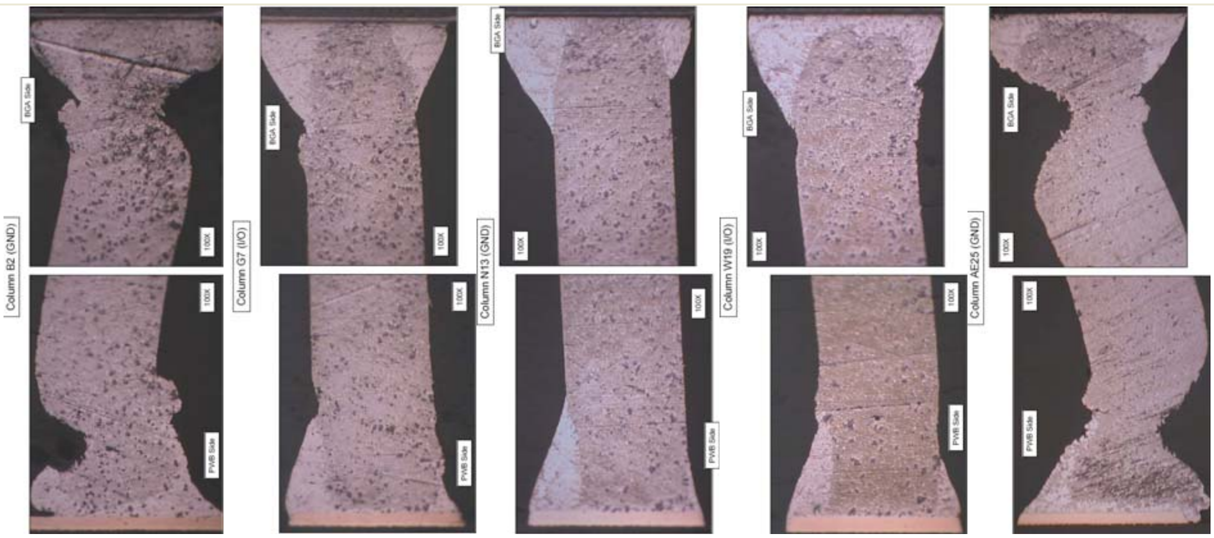
Figure B2: PCB Reflow Profile and probes mounting position

Appendix C—Solder Column Cross Section Pictures at Cycle 1047

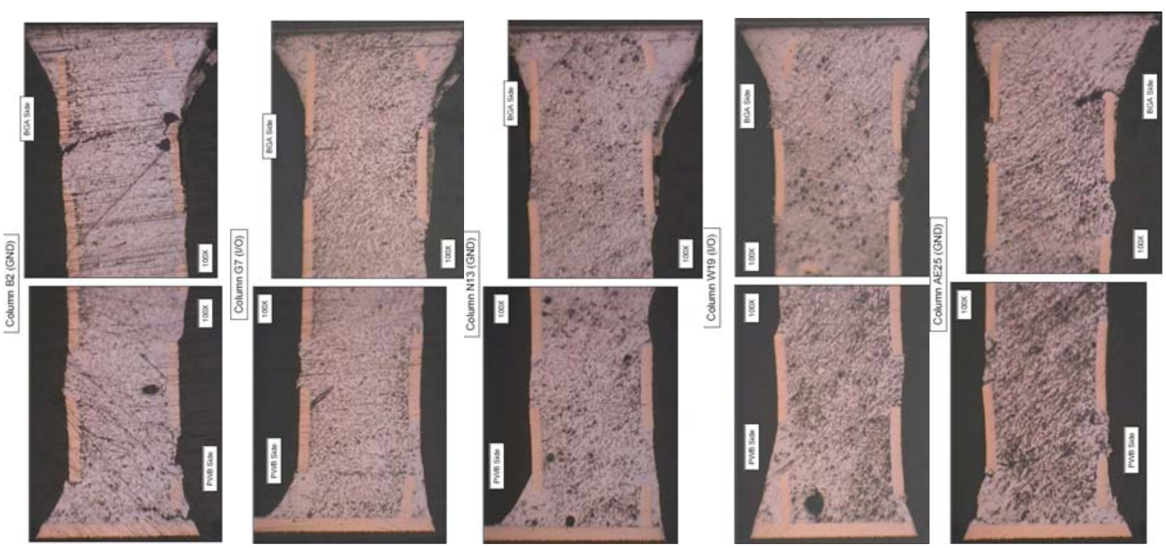
a. CG624



CG624 was cut and ground from left-top corner to right-bottom corner at cycle 1047. (see drawing, left)
5 columns pictures were taken also, from left-top to right-bottom, evenly. Column pins # are B2, G7, N13, W19, and AE25.

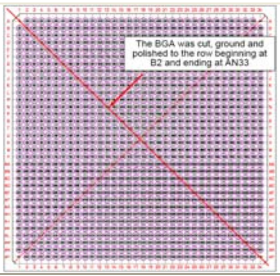


CG624 90 Pb / 10 Sn Column Cross Section (from left to right) pin #: B2, G7, N13, W19, and AE25

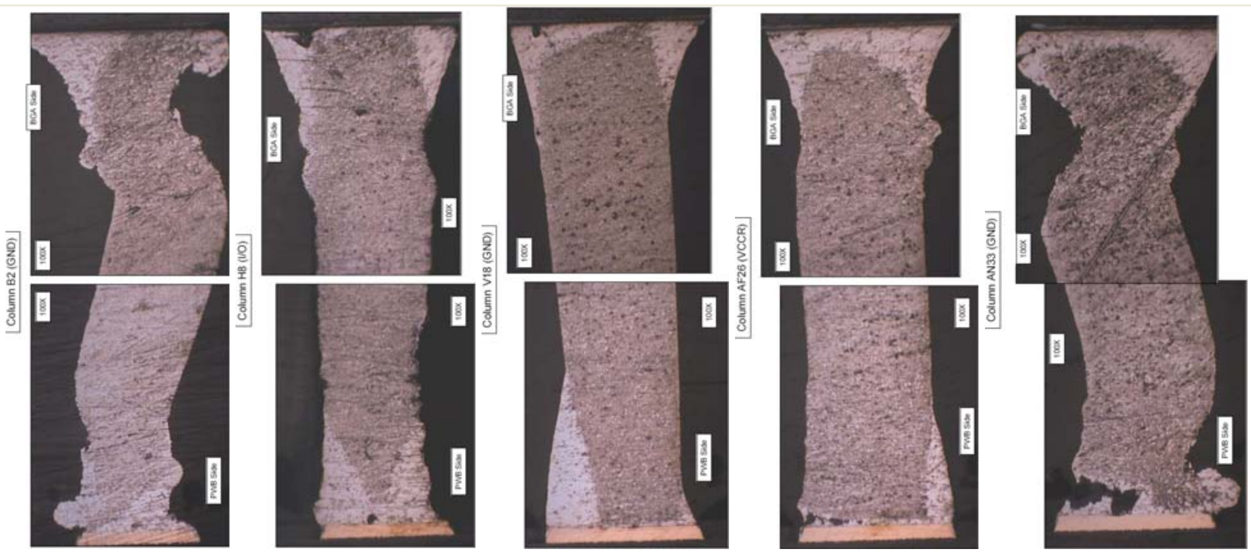


CG624 80 Pb / 20 Sn Column Cross Section (from left to right) pin #: B2, G7, N13, W19, and AE25

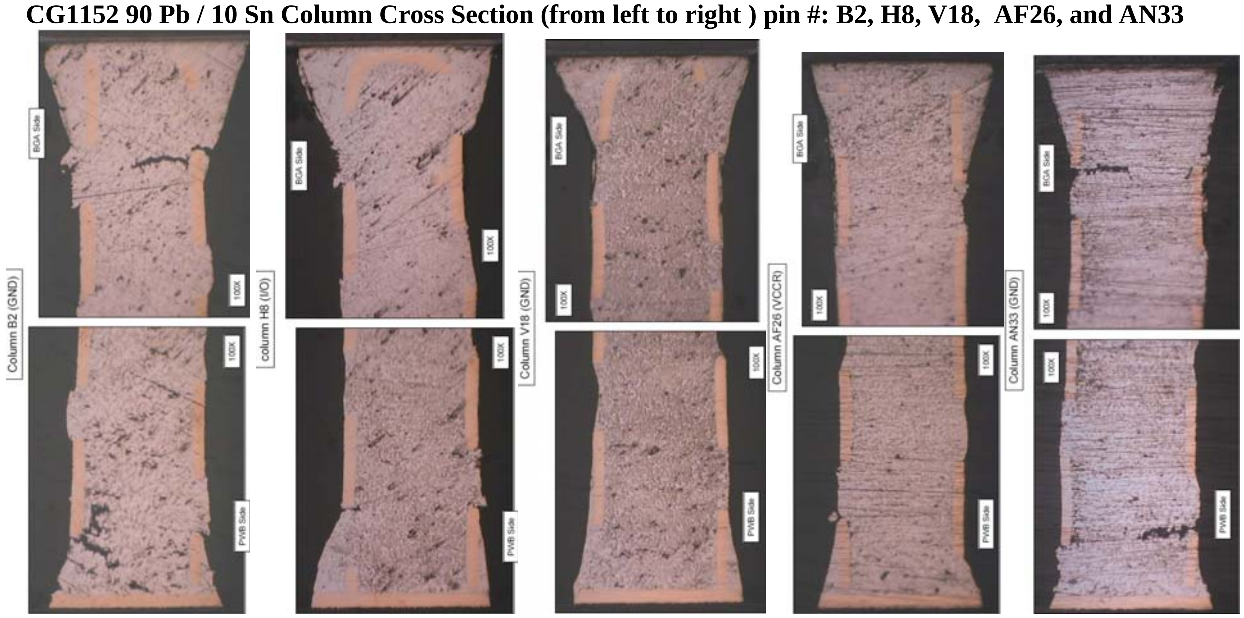
b. CG1152



CG1152 was cut and ground from left-top corner to right-bottom corner at cycle 1047. (see drawing, left)
5 columns pictures were taken also, from left-top to right-bottom, evenly. Column pin # are B2, H8, V18, AF26, and AN33.



CG1152 90 Pb / 10 Sn Column Cross Section (from left to right) pin #: B2, H8, V18, AF26, and AN33



CG1152 80 Pb / 20 Sn Column Cross Section (from left to right) pin #: B2, G7, N13, W19, and AE25

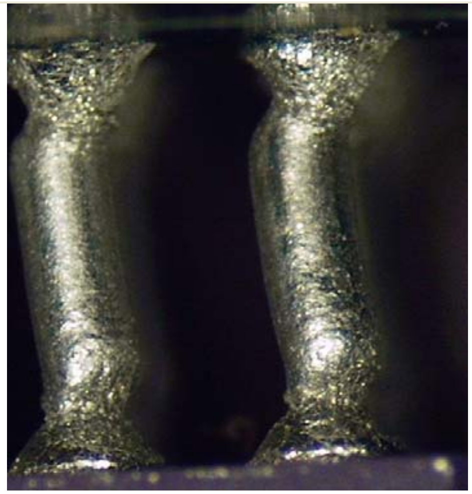
Note:

CG1272 column cross section picture is very similar as CG1152 due to same pitch (1.0 mm). So CG1272 pictures are not included in Appendix C.

Appendix D—Solder Columns Pictures in Different Cycles

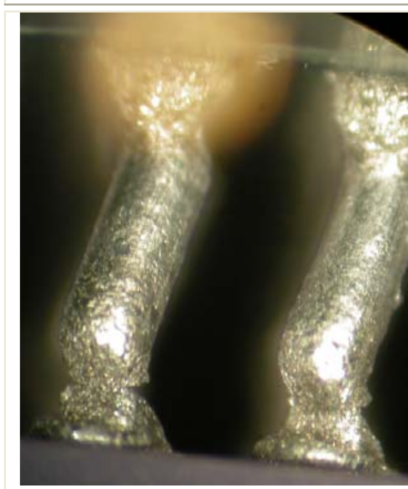
a. CG624 90 Pb / 10 Sn Column

CG624 90 Pb / 10 Sn, Cycle 739



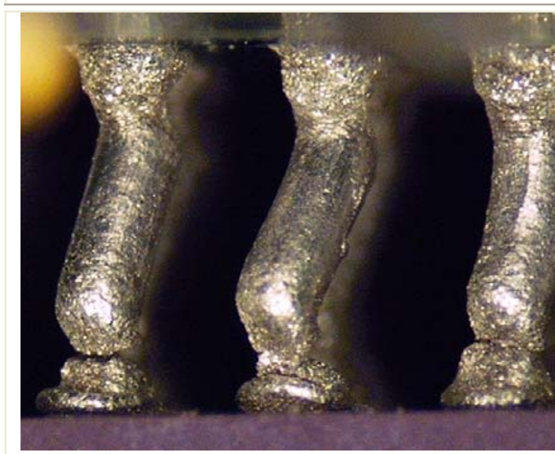
CG624 90 Pb / 10 Sn, Cycle 952

CG624 90 Pb / 10 Sn, Cycle 1052



CG624 90 Pb / 10 Sn, Cycle 1286
1st failure at cycle 1246

CG624 90 Pb / 10 Sn, Cycle 1864

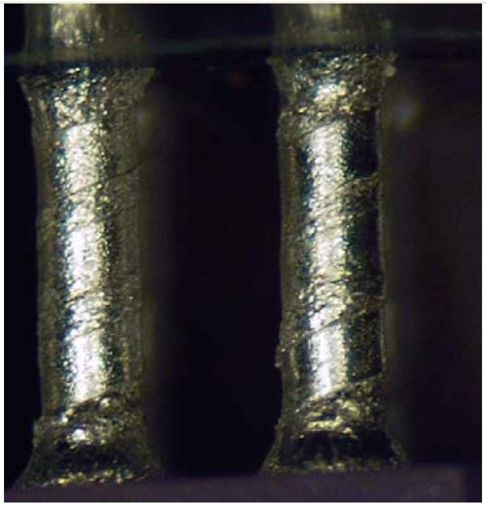


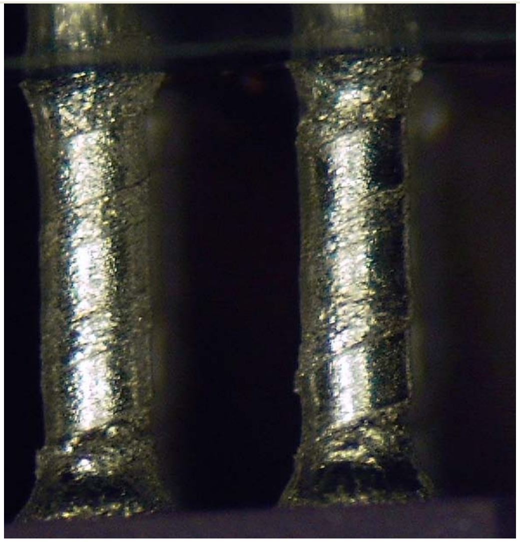
CG624 90 Pb / 10 Sn, Cycle 2150

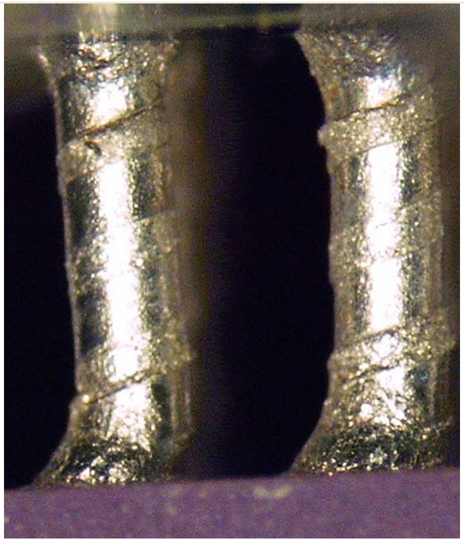
b. CG624 80 Pb / 20 Sn Column

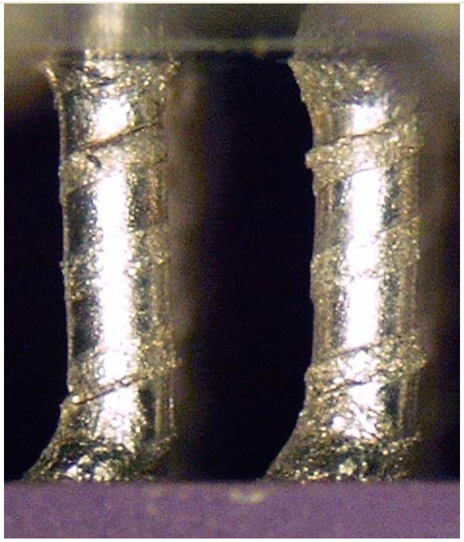

CG624 80 Pb / 20 Sn, Cycle 739


CG624 80 Pb / 20 Sn, Cycle 739


CG624 80 Pb / 20 Sn, Cycle 952


CG624 80 Pb / 20 Sn, Cycle 952


CG624 80 Pb / 20 Sn, Cycle 1864


CG624 80 Pb / 20 Sn, Cycle 2150

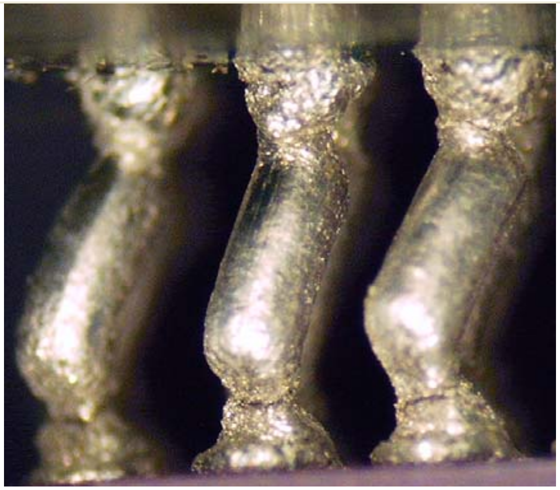
c. CG1152 90 Pb / 10 Sn Column

CG1152 90 Pb / 10 Sn, Cycle 739

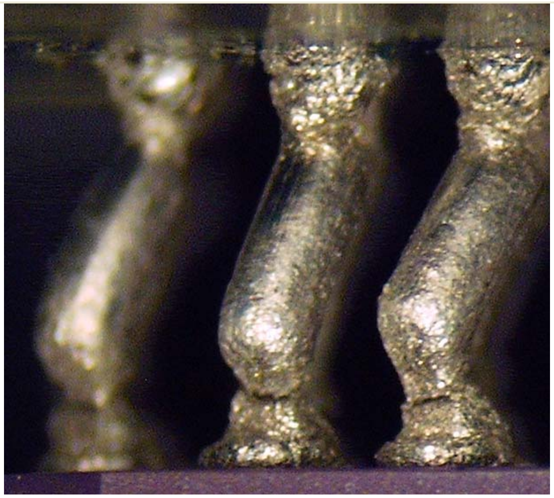
CG1152 90 Pb / 10 Sn, Cycle 882
1st failure at cycle 878

CG1152 90 Pb / 10 Sn, Cycle 1052

CG1152 90 Pb / 10 Sn, Cycle 1286

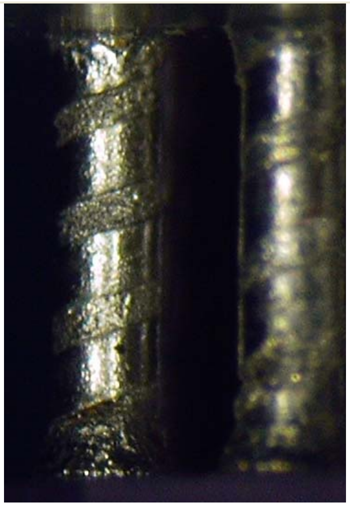


CG1152 90 Pb / 10 Sn, Cycle 1864



CG1152 90 Pb / 10 Sn, Cycle 2150

d. CG1152 80Pb/20Sn column

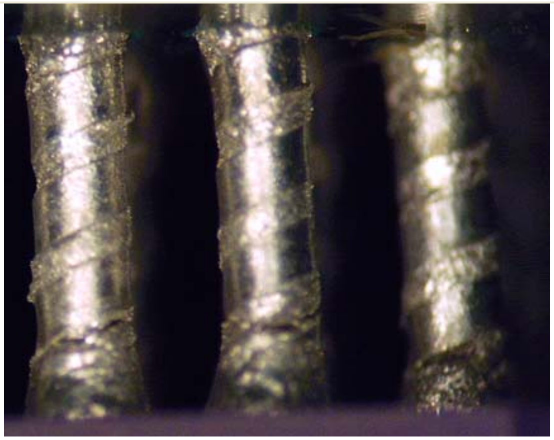

CG1152 80 Pb / 20 Sn, Cycle 739


CG1152 80 Pb / 20 Sn, Cycle 952


CG1152 80 Pb / 20 Sn, Cycle 1052


CG1152 80 Pb / 20 Sn, Cycle 1225
1st failure at cycle 1212


CG1152 80 Pb / 20 Sn, Cycle 1864


CG1152 80 Pb / 20 Sn, Cycle 2150

Note:
CG1272 column pictures are very similar to CG1152 since both have the same column material and pitch. So CG1272 pictures are not included in Appendix D.