Reliability of High I/O High Density CCGA Interconnect Electronic Packages under Extreme Thermal Environments

Rajeshuni Ramesham Ph.D.
Office of Safety and Mission Success
Reliability Engineering and Mission Environmental Assurance Office
Jet Propulsion Laboratory-NASA, California Institute of Technology
Pasadena, CA 91109
Tel: *818 354 7190;* ***e-mail:*** *rajeshuni.ramesham@jpl.nasa.gov*

Abstract

Ceramic column grid array (CCGA) packages have been increasing in use based on their advantages such as high interconnect density, very good thermal and electrical performances, compatibility with standard surface-mount packaging assembly processes, and so on. CCGA packages are used in space applications such as in logic and microprocessor functions, telecommunications, payload electronics, and flight avionics. As these packages tend to have less solder joint strain relief than leaded packages or more strain relief over lead-less chip carrier packages, the reliability of CCGA packages is very important for short-term and long-term deep space missions.

We have employed high density CCGA 1152 and 1272 daisy chained electronic packages in this preliminary reliability study. Each package is divided into several daisy-chained sections. The physical dimensions of CCGA1152 package is 35 mm x 35 mm with a 34 x 34 array of columns with a 1 mm pitch. The dimension of the CCGA1272 package is 37.5 mm x 37.5 mm with a 36 x 36 array with a 1 mm pitch. The columns are made up of 80% Pb/20%Sn material.

CCGA interconnect electronic package printed wiring polyimide boards have been assembled and inspected using non-destructive x-ray imaging techniques. The assembled CCGA boards were subjected to extreme temperature thermal atmospheric cycling to assess their reliability for future deep space missions. The resistance of daisy-chained interconnect sections were monitored continuously during thermal cycling.

This paper provides the experimental test results of advanced CCGA packages tested in extreme temperature thermal environments. Standard optical inspection and x-ray non-destructive inspection tools were used to assess the reliability of high density CCGA packages for deep space extreme temperature missions.

Keywords: Extreme temperatures, High density CCGA qualification, CCGA reliability, solder joint failures, optical inspection, and x-ray inspection.

Copyright 2011 California Institute of Technology. Government sponsorship acknowledged.

Introduction:

Ceramic column grid array (CCGA) technology is an advanced electrical interconnection surface mount electronic packaging process. This advanced CCGA interconnect packaging technology will significantly improve the performance of high-speed systems, the productivity enhancement in manufacturing over manual wire bonding, low lead inductances, and reduced need for use of precious attachment materials such as gold, platinum, etc. The failure mechanisms of advanced CCGA interconnects are dependent on the materials of columns, board, the solder joint at the column/ceramic interface, column/board material interface, and solder reflow temperature, and the solder materials. The most predominant failure mechanisms are solder joint fatigue, interdiffusion, creep, and electrochemical corrosion. Any thermal co-efficient of expansion (TCE) mismatches between the board material and column, column and ceramic substrate causes shear displacement at each solder joint interconnect, which may lead to low-cycle thermal fatigue failure during thermal or power cycling. Reliability may be significantly increased by matching/tailoring the TCE of the substrate material, ceramic material, and the columns materials. The key contributing factors to solder joint fatigue failure are interdiffusion at the ceramic/solder and printed wiring board/solder interfaces, the solder material, dimensions of the contact area, and finally the environment where they are going to be used. Figure 1 shows the schematic of the 80%Pb/20%Sn column with copper spiral configuration in a given CCGA package.

CCGA packaging interconnect technology was first introduced by IBM (International Business Machines) to enhance the reliability of interconnects over ball grid array (BGA) technology.[1] CCGA permits direct electrical connection between a substrate module and a printed wiring board (PWB).

Master [2] has reported the CCGA for flip-chip applications in a temperature range of 0°C to +100°C and -55°C to +125°C. In this study [2], it was demonstrated that the column height and temperature cycling conditions were in agreement with Coffin-Manson relationship. CCGA assembly and rework was described in depth in a user guide published by IBM [1] and also in [3 and 4]. Aero flex has tested 472 pin CCGA daisy chained package in a temperature range of -55°C to +105°C for 500 thermal cycles and observed fractures in solder joints at board side and some also showed higher resistance. [5] Kuang and Zhao [6] have reported thermal test results of CCGA packages which meet or exceed the reliability requirements of satellite program applications. They reported reliability tests for (-55°C to +105°C) two different column material configurations such as 90%Pb/10%Sn (British Aerospace Engineering, BAE) and 80%Pb/20%Sn with copper spiral from Six-Sigma. The results showed that the 80%Pb/20%Sn column material is more reliable over 90%Pb/10%Sn column material. The test was stopped at 2300 thermal cycles and no failures for 80%Pb/20%Sn column materials and the first failure was observed at 1246 thermal cycles for 90%Pb/10%Sn column material. One of the papers by Ghaffarian reported CCGA 717 I/O showed a minimal signs of solder joint damage at 500 thermal cycles from -55°C to +100°C and showed various levels of damage at 1000 thermal cycles with the same temperature limits. The corner columns without staking showed a higher damage level compared to their counterparts with staking. No failures for CCGA 717 I/O assemblies after 200 thermal cycles in a range of -120°C to +85°C and also from -65°C to +150°C. [7-9] Tasooji et al., [10] have reported on the design parameters influencing the reliability of CCGA assembly and a sensitivity analysis was made. Actel have published and presented some of CCGA reliability for space applications. [11 and 12] Lau and Dauksher have reported 1657 CCGA with *lead-free* solder data in ref. [13] Ramesham [14] has recently reported on the test results of CCGA packages which were tested from -185°C to +125°C for 1258 thermal cycles. The first failure was observed around 137th cycle.

Titan (-180°C, for a proposed Titan *in-situ mission*), Europa (-160°C, for a proposed Europa surface and subsurface mission), asteroids such as MUSES-CN (-185°C), comets (-140°C, for a proposed comet nucleus sample return), Earth's moon (recorded temperature on the moon: -233°C to +123°C, moon mineralogy and mapper, M^3), and Mars Exploration Rovers (MER-Spirit, MER-Opportunity) (-120°C to +85°C), Mars Science Laboratory (MSL-Curiosity) (-135°C to +125°C) require operations of thermally uncontrolled hardware under extremely cold temperatures and hot temperatures with large diurnal temperature change from day to night. Planetary protection requires the hardware to be baked at +125°C for 72 hours to kill microorganisms to avoid any biological contamination especially for sample return missions. NASA standards thermal cycling temperature range varies from -55°C to +100°C per NHB-5300.4 (3A-1) (NASA Handbook: Requirements for soldered electrical connections, Dec 1976). Therefore, the present CCGA package reliability research study has encompassed the temperature range of -185°C to +125°C to cover various potential future NASA's deep space missions.

Based on the existing published data to the best of author's knowledge there is no published systematic experimental data for CCGA 1152 and CCGA 1272 available to assess the reliability of CCGA packages in extremely low and hot temperatures such as -185°C to +125°C. Therefore, this paper describes the important experimental test results obtained in this extreme temperature range. Table 1 provides the summary of the literature review of prior and present research study of CCGA reliability in wide temperature range. Table 2 shows the details of the Actel CCGA 1152 and CCGA 1272 CCGA packages. The package size of the CCGA 1152 and 1272 is 35 *35 mm and 37 * 37 mm, respectively with a lead pitch of 1 mm.

Fabrication of Test Boards:

We have used polyimide board material in fabrication of test boards in this study. The board size is 4" x 8" and board finish is Electro less Nickel Immersion Gold (ENIG). The number of layers in the designed test board is 4. The board thickness is 0.093".

The boards were manufactured using a similar process reported by Mehta and Bodie in refs. [3,4]. They have used a processes that was implemented to qualify CCGA package assemblies using printed wiring boards (PWB), daisy chain CCGA packages for JPL/NASA projects. Figure 2 and 3 show the microscopic images photographs of the as received CCGA 1152 and CCGA 1272 packages prior to reflow at various magnifications. Complete CCGA array package has also been shown in the figure 2 and 3 (33 mm x 33 mm). Copper spiral can be seen around the column interconnect material in figures 2 and 3. Using of copper spiral around the column materials would increase the integrity of the column interconnect during the solder reflow process at higher temperature. Copper melting point is significantly higher than the column material. Figure 4 shows the reflow profile that was used to reflow CCGA 1152 and CCGA 1272 packages. Figures 5 show the digital photographs of the CCGA packages (1152 and 1272) after they have been reflowed over the polyimide PWB board. Figure 6 and 7 show the non-destructive x-ray images of the CCGA packages after solder reflow. There were no shorts or over flow of solder materials that can affect the CCGA packages and their reliability. It is clear from the x-ray images that there were no shorts in the packages.

Temperature profile:

Figure 8 shows the thermal cycling temperature profile employed in this experimental study to perform the cycling of the daisy chained CCGA interconnect polyimide test boards. The low temperature of -185°C and high temperature of +125°C were used in this study. The temperature ramp rate was 5°C/min and dwell time was 15 minutes on hot and cold temperature during the thermal cycling.

Testing for overstress interconnect fracture and intermittent failures

There were five daisy chains on the test board for each CCGA (1152 and 1272) daisy chain packages. The value of the daisy chain resistance was in the range ~ 1-2 ohms at room temperature. Thermal cycling test was conducted to assess the reliability of advanced CCGA interconnect technology based on the potential failure mechanisms. The key failure mechanism addressed in thermal cycling is solder joint fatigue fracture at the board and column interface or column and ceramic package substrate surface. The temperature cycling may result in a thermal fatigue of the solder joint and inter diffusion at the substrate/column or column/ceramic substrate interface. The stress depends on the magnitude of the temperature either on the high temperature side or low temperature side, rate of temperature change, and range (Delta T: ΔT) of temperature and also CTE of the materials combination involved in this configuration. High rate of change of temperature (change in temperature/minute) could lead to thermal shock of the advanced CCGA interconnect packages which could have catastrophic effect on the reliability of solder joints. Therefore, low rate of change of temperature (5°C/minute) has been employed in this experimental study. Figure 9 and 10 shows the daisy chain resistance of the same daisy chain as a function of temperatures at various stages of the thermal cycling such as first cycles, 359th thermal cycle and 596th thermal cycle. Resistance of the solder joint increases as the temperature increases and resistance decreased as the temperature decreases. Figure 11 and 12 shows the resistance of solder joints of all the daisy chains as a function of thermal cycles at first cycle, 359th cycle and 596th cycle. There was no change in resistance of all of the daisy chains even until 596th cycle and the test is still continuing. Most of the solder joints have been functioning normally electrically. The CCGA solder joints are robust electrically for 596 thermal cycles. There were no intermittent failures were observed even until 596th thermal cycle.

The CCGA test articles were inspected prior to thermal cycling and later subjected to thermal cycling. The CCGA packages were inspected after 258 and 596 thermal cycles. However, the daisy chains were monitored continuously during the thermal cycling from the beginning of the test. Figure 13 and 14 show the microscopic images of the CCGA1152 and CCGA1272 packages. There was no change in visual appearance of the solder joints. It indicates that the CCGA1152 and 1272 have survived for 258 extreme temperature thermal cycles. Solder joint fatigue started showing up in CCGA1152 package over CCGA1272 under extreme temperature thermal cycling from -185^{o}C to +125^{o}C. The ΔT of this test was 310^{o}C which is significantly higher than military applications (-65^{o}C to 125^{o}C) and NASA thermal cycles (ΔT = 155^{o}C, Temperature range: -55^{o}C to 100^{o}C). Figure 15 shows the microscopic images of the CCGAs that were inspected after 596 thermal cycles. Several micrographs show that the significant damage of solder joints particularly notably at the corners of the CCGA 1152 package as shown in figures 14 and 15. Some of the columns are about to dislodge from their original solder joint position. The fatigue has occurred at the column and board interface and also at the column and ceramic interface per figures 14 and 15. Figures 16 show the higher magnification of the solder joints of CCGA 1272 packages. Figures 16 show no fatigue indications yet with CCGA1272 packages even after 596 thermal cycles.

Conclusions:

X-Ray inspection of assembled CCGA packages have been made before thermal cycling. No anomalous behavior such as shorting or solder overflow observed in the x-ray images. Advanced 1152 and 1272 CCGA packaging interconnects technology test hardware objects have been subjected to extreme temperature thermal cycles from -185^{o}C to +125^{o}C. CCGA packages have been tested from -185^{o}C to +125^{o}C for 596 thermal cycles. The change in resistance of the daisy chained CCGA interconnects was measured as a function of increasing number of thermal cycles. Electrical continuity measurements of daisy chains have shown no anomalies observed even until 596 thermal cycles. Optical inspection of the CCGA boards has been made after 258 and 596 thermal cycles. Inspection of the test hardware has shown a significant fatigue especially at the corner columns of CCGA 1152 packages when compared with the corner columns of CCGA1272 package after 596 thermal cycles. This may be due to the large mechanical stress that exists at the corners of the packages. Catastrophic failures have not been observed yet in both the packages. Furthermore, a process and assembly qualification is required to optimize the CCGA assembly processes to have a long operational life.

Acknowledgements:

The research work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. I would like to thank Atul Mehta, Noly Neverida, etc., for their help in assembling of CCGA packages for this study. Thanks to John Forgrave for his comments and suggestions on the manuscript. MSL project is highly appreciated for encouraging me to work with CCGA tiger team to address rework issues of CCGA and its qualification. MSL effort has generated the interest in me in obtaining the experimental reliability data for higher I/O applications for present and future NASA missions. Russel Kido of Practical Components has been acknowledged for his support during the test board design and fabrication.

References:

1. User's guide, IBM "Ceramic column grid array assembly and rework", July 25, 2002. *https://www-01.ibm.com/chips/techlib/techlib.nsf/techdocs/630AFA7BD7DE3FED87256C0100558D50/$file/ccga.pdf*
2. Raj N. Master, Marie S. Cole, and Greg B. Martin, "Ceramic column grid array for flip chip applications", pages 995-929, IEEE 1995.
3. Atul C. Mehta, "A report on BGA/CGA assembly and rework qualification", August 31, 2007, JPL, Pasadena, CA. (personal communication)
4. Atul C. Mehta and Charles C. Bodie, "Column grid array rework for high reliability", The Annual Pan Pacific Microelectronics Symposium & Exhibit, February 10-12, 2009, Hapuna Beach Prince Hotel, Big Island, Hawaii. Pages: 331-340.
5. Aeroflex Colorado Springs, "Solder column qualification for ceramic column grid array (CCGA), white paper, October 2006. *http://www.utmc.com/ProductFiles/AppNotes/AeroflexCCGAQualWhitePaper.pdf*
6. Raymond Kuang, Lijie Zhao, Actel Corporation, CCGA Thermal Test Report (26 pages) *http://www.actel.com/documents/CCGA_board_level_testing_report.pdf*
7. Reza Ghaffarian, "Effect of area array package types on assembly reliability and comments on IPC-9701A"
8. Reza Ghaffarian, "Thermal cycle reliability and failure mechanisms of CCGA and PBGA assemblies with and without corner staking", 8 pages. (Source: Network) IEEE Transactions on Components and Packaging Technologies, Vol. 31, No. 2, June 2008, pp 285-296.
9. Reza Ghaffarian, "CCGA packages for space applications", Microelectronics Reliability, 46 (2006) 2006-2024.
10. Amaneh Tasooji, Reza Ghaffarian, and Antonio Rinaldi, "Design parameters influencing reliability of CCGA assembly: a sensitive analysis" "IEEE Intersociety Conference on Thermal and Thermo mechanical Phenomena; 56th Electronic Components and Technology Conference, San Diego, California, May 30 to June 2, 2006, 1056-1063.
11. Actel Space Forum, "CCGA package testing data review" Dec 7, 2005 (MRQW 2005). *http://www.aero.org/conferences/mrqw/2005-papers/VIII-3-Kuang.pdf*
12. Actel Corporation, Ceramic Column Grid Array Package, Application Note, September 2003. *http://www.eetkorea.com/STATIC/PDF/200811/EEKOL_2008NOV12_PL_AN_02.pdf?SOURCES=DOWNLOAD*
13. John Lau and Walter Dauksher, "Reliability of a 1657 CCGA package with 95.5Sn, 3.9Ag, and 0.6 Cu on lead free solder paste on PCBS", *J. Electronic Packaging*, 127, 2, pp. 96-105.
14. Rajeshuni Ramesham, "Reliability of ceramic column grid array (CCGA 717) interconnect packages under extreme temperatures for space applications", *Journal of Microelectronics and Electronic Packaging,* 2010, 7, pp.16-24.

Author	[Ref.]	Temperature Range
Ramesham	The reported research	-185°C to 125°C

	work	(CCGA 1152 and 1272)
Master	[2]	$0^{o}C$ to $100^{o}C$
		$-55^{o}C$ to $125^{o}C$
Aero flex	[5]	$-55^{o}C$ to $100^{o}C$
Khuang & Zhao	[6]	$-55^{o}C$ to $105^{o}C$
Ghaffarian	[7-9]	$-55^{o}C$ to $100^{o}C$
		$-120^{o}C$ to $85^{o}C$
Mehta & Bodie	[3,4]	$-55^{o}C$ to $100^{o}C$
Ramesham	[14]	$-185^{o}C$ to $125^{o}C$ (CCGA 717)

Table 1: Prior and present research work and the temperature range used in the respective studies to assess the reliability of advanced CCGA packaging technology for wide temperature range

Package Details	CCGA 1152	CCGA 1272
Who attached?	Six-Sigma	Six-Sigma
Column Composition	80Pb//20Sn	80Pb//20Sn
Copper Ribbon	Yes	Yes
Column Height	2.21 mm	2.21 mm
Column Diameter	0.51 mm	0.51 mm
Column Co planarity	0.15 mm	0.15 mm
Package Size	35 mm * 35 mm	37 mm * 37 mm
No. of Columns	1152	1272
Lead Pitch	1 mm	1 mm

Table 2: Actel CCGA 1152 and 1272 Package Details [1]

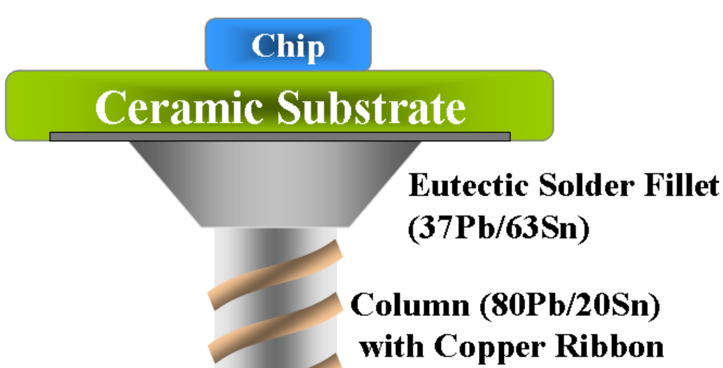

Figure 1: Schematic of a Column in a CCGA Package

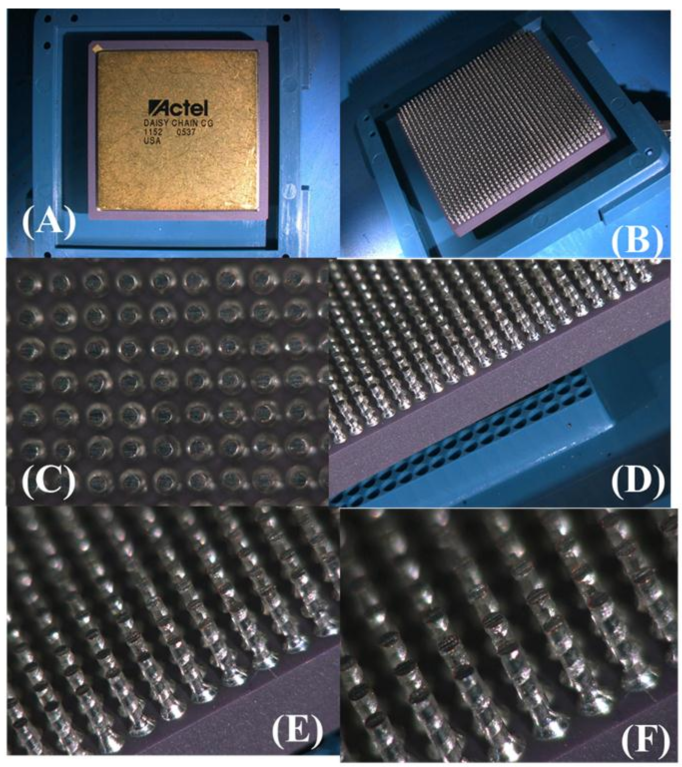

Figure 2: Microscopic images of Actel CCGA 1152 package

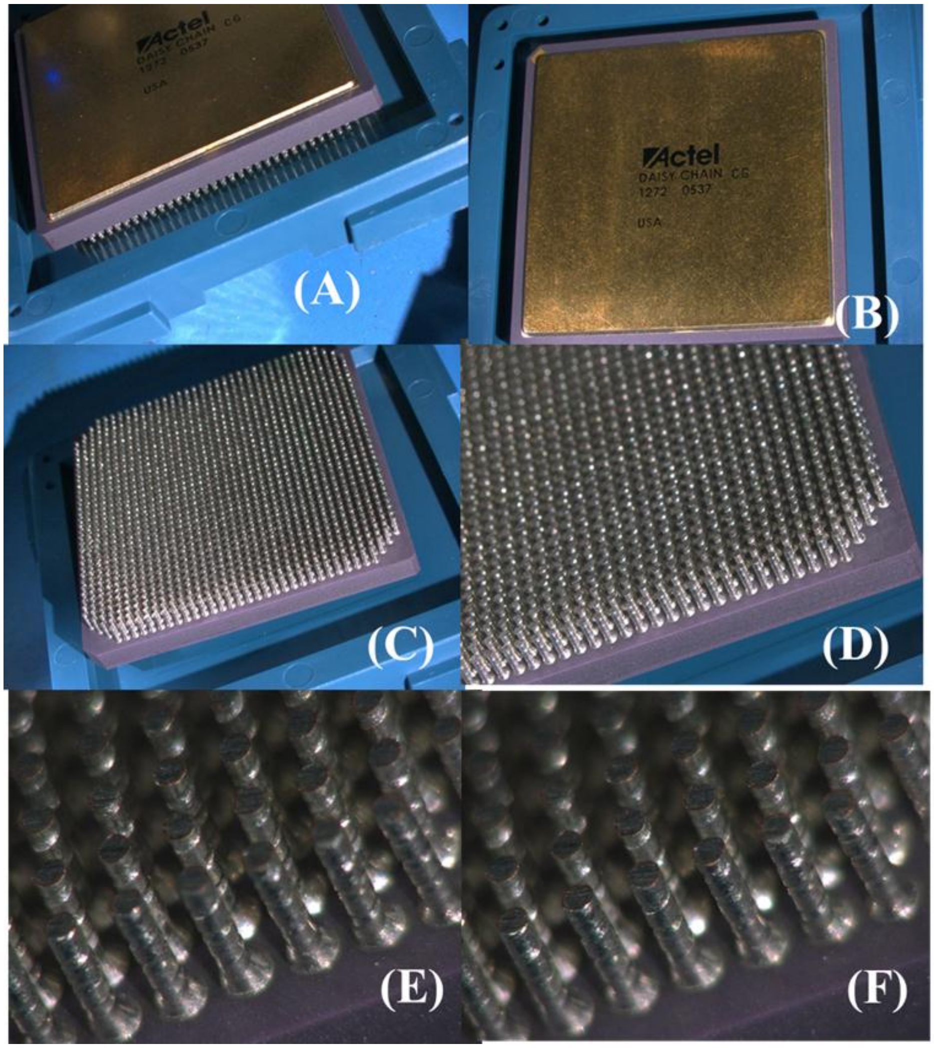

Figure 3: Microscopic images of Actel CCGA 1272 package

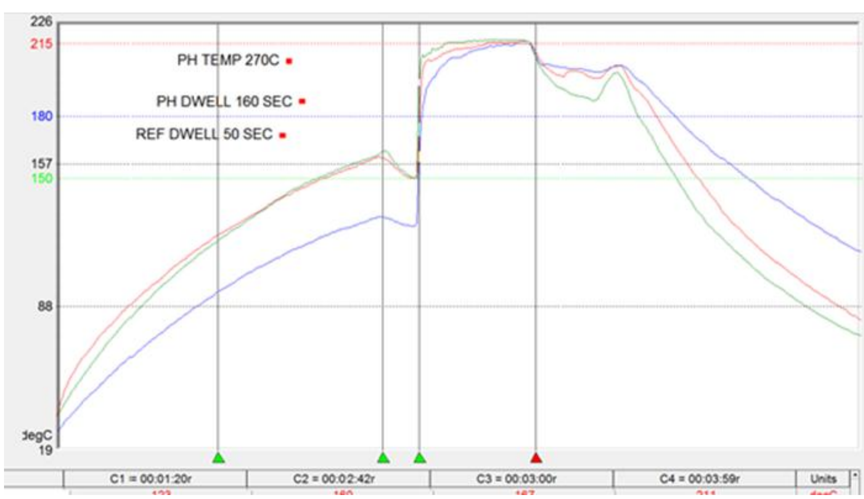

Figure 4: Reflow profile that was used to reflow CCGA1152 and CCGA1272 packages.

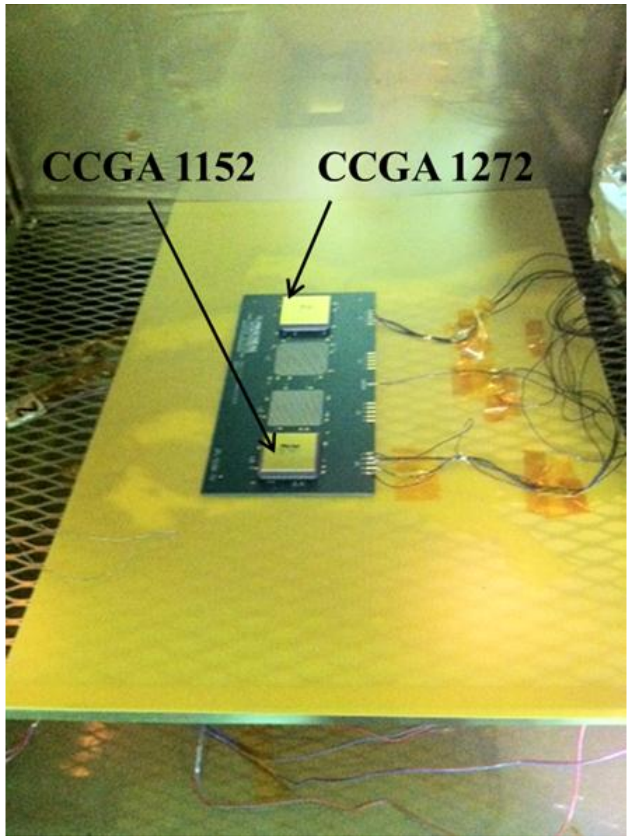

Figure 5: Optical photograph of the test board assembled with CCGA1152 and CCGA1272 packages

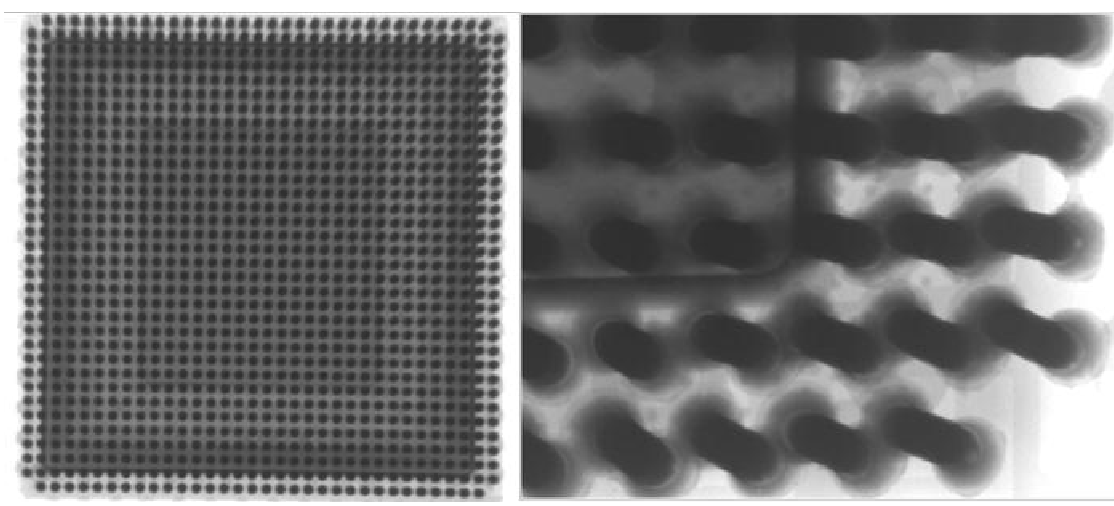

Figure 6: X-ray imaging of the CCGA 1152 assembled board prior to thermal cycling

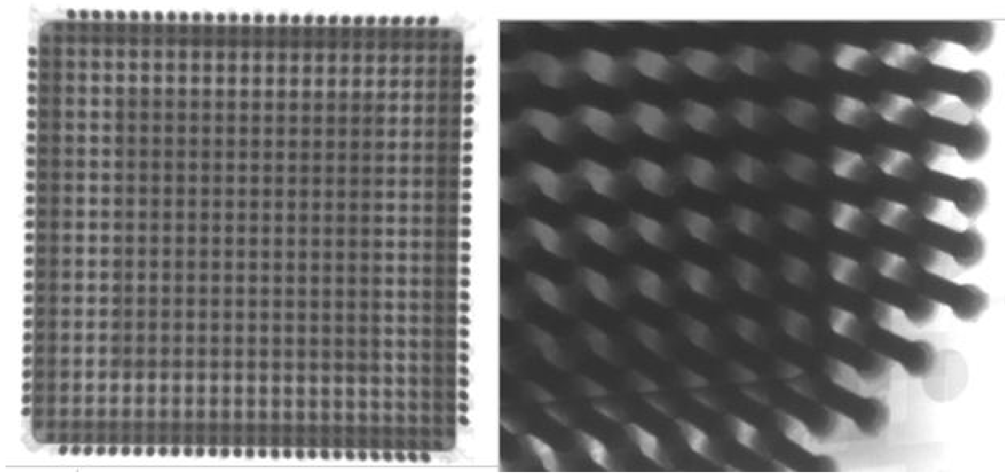

Figure 7: X-ray imaging of the CCGA 1272 assembled board prior to thermal cycling

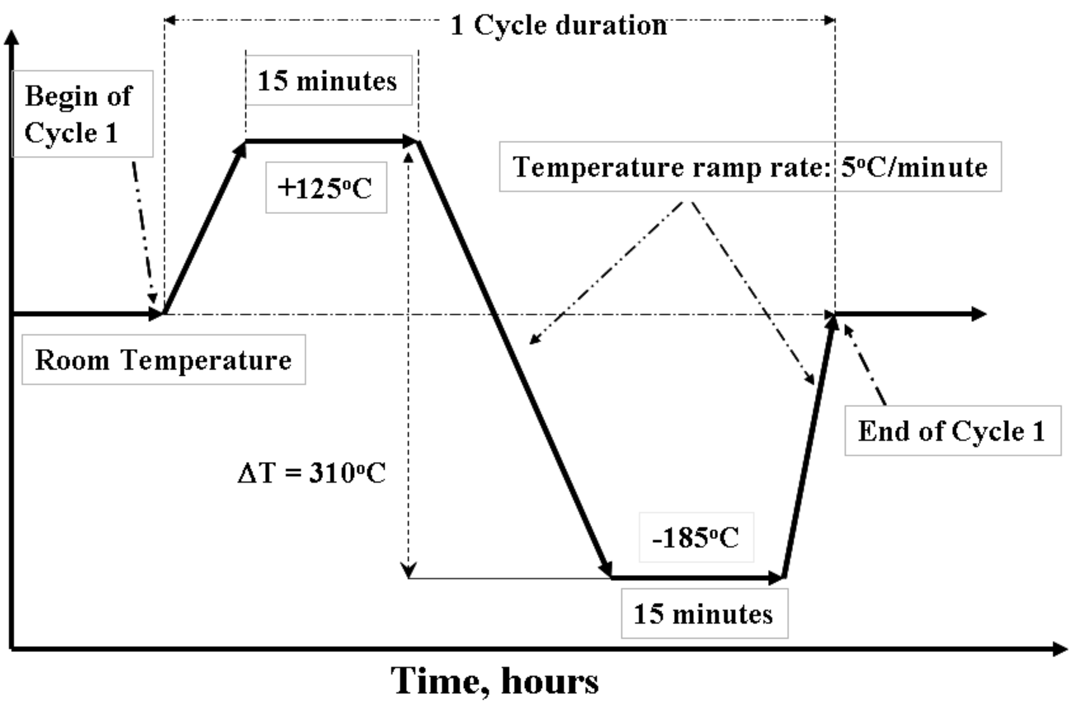

Figure 8: Extreme Temperature Thermal Cycling Profile used in this study

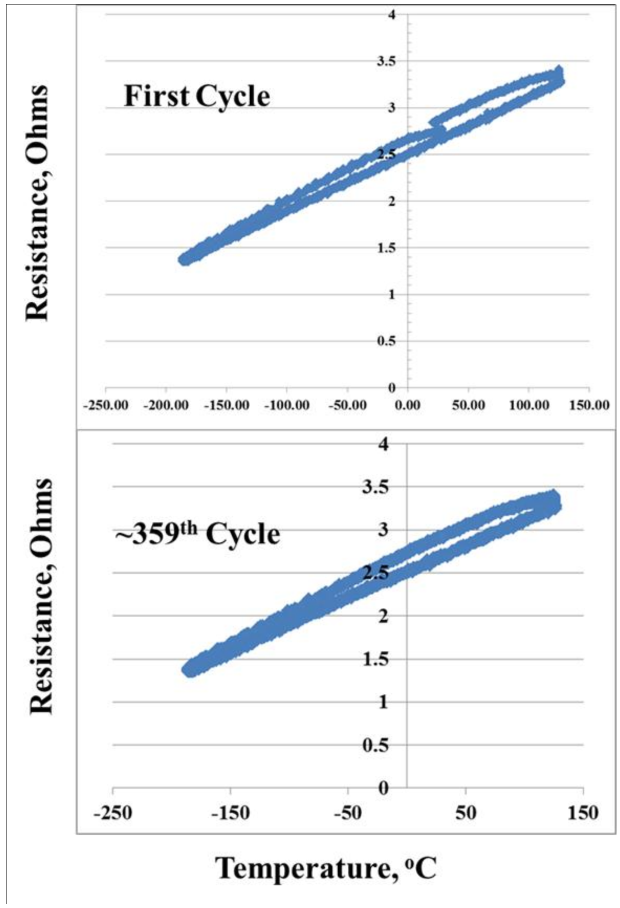

Figure 9: Resistance of one daisy chain during the first cycle and also during the 359th cycle.

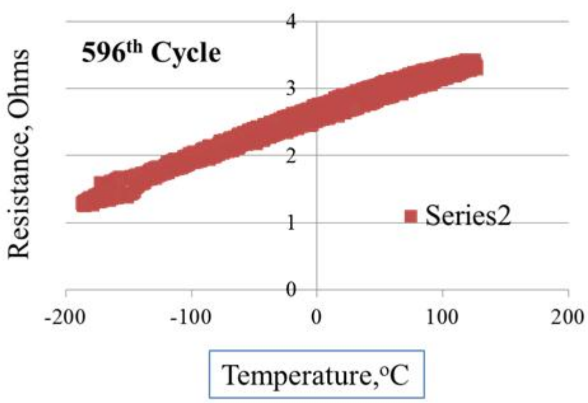

Figure 10: Resistance of one daisy chain during the 596th cycle.

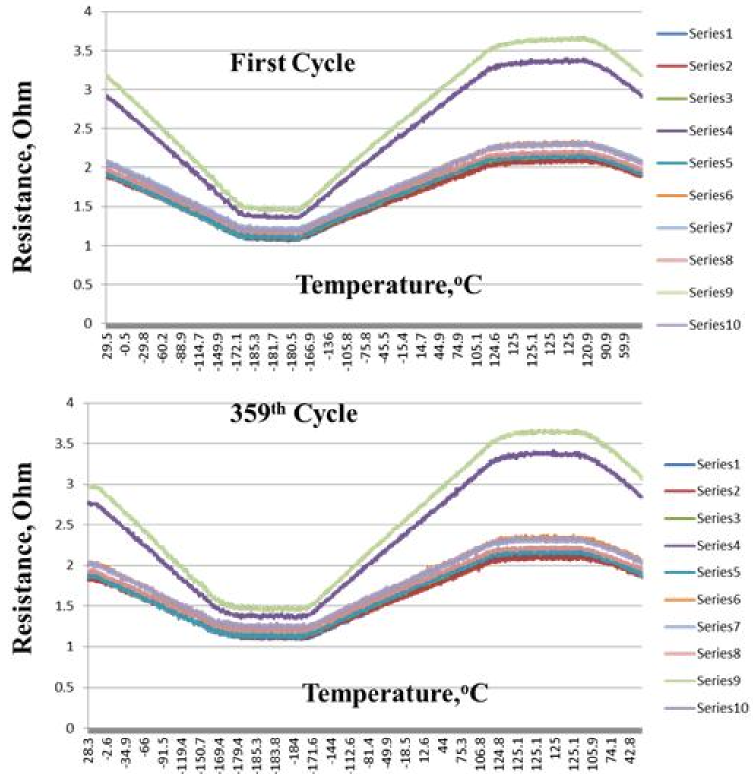

Figure 11: Resistance of ten daisy chains collected during the first cycle and also during the 359th cycle.

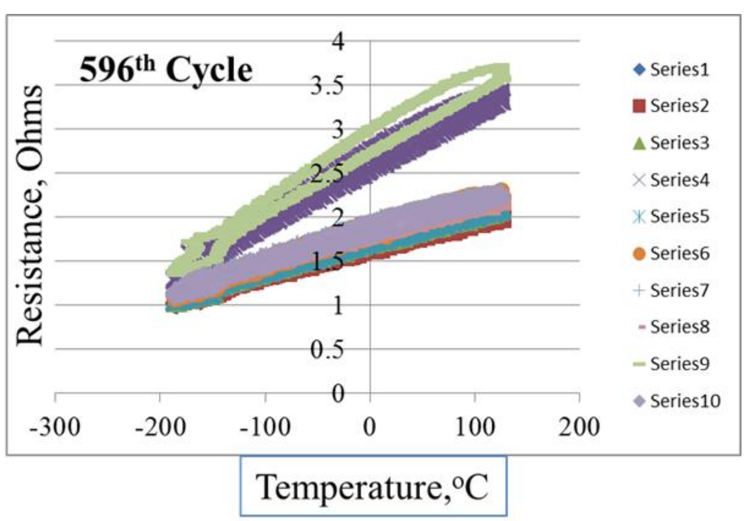

Figure 12: Resistance of all daisy chains during the 596th cycle.

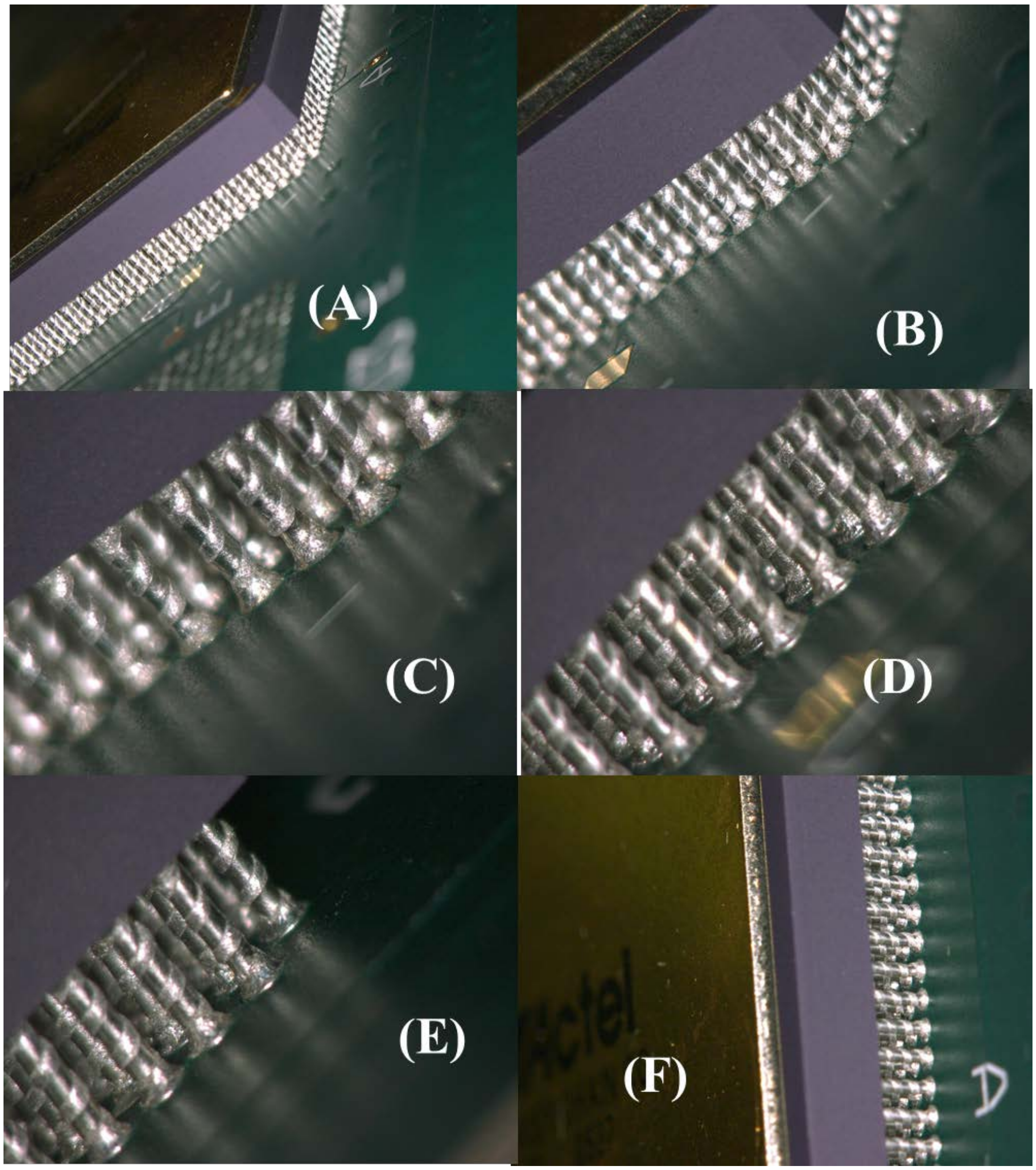

Figure 13: Microscopic images of the Actel CCGA 1152 package after 258 thermal cycles from -185°C to 125°C

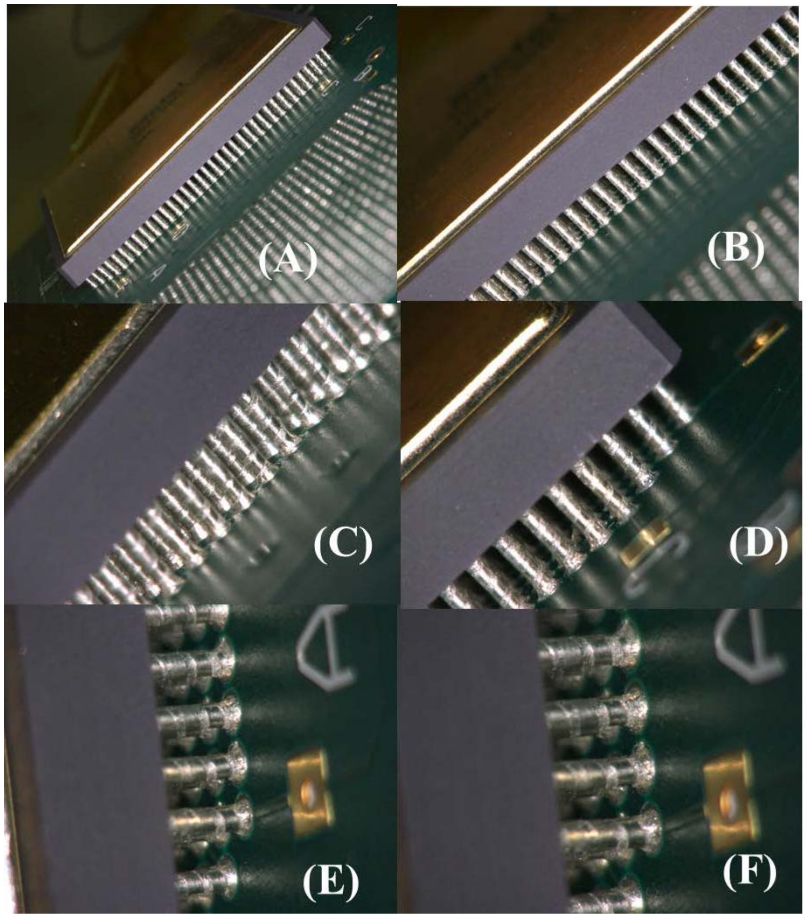

Figure 14: Microscopic images of the Actel CCGA 1272 package after 258 thermal cycles from -185°C to 125°C

Figure 15: Microscopic image of the column which are slightly bent due to thermal cycling. (CCGA1152) for 258 cycles

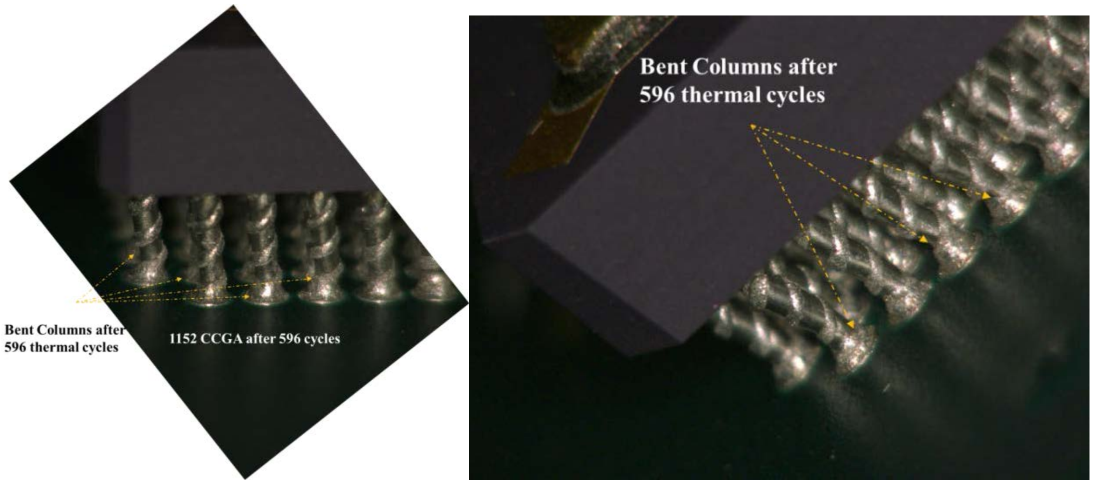

Figure 16: Microscopic image of the column which have been significantly bent due to thermal cycling. (CCGA1152) for 596 cycles

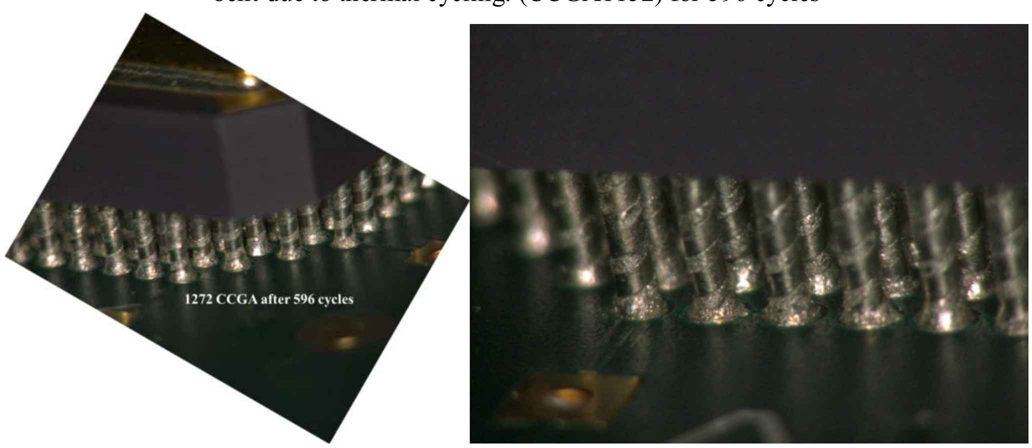

Figure 17: Microscopic images of the column which have not been bent due to thermal cycling (CCGA 1272) for 596 cycles