Cleaning in an HDI World

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Abstract

Recent electronic assembly innovations have produced more performance using highly dense interconnects (HDIs). However, solder paste and flux residues from the assembly process may increase the risk of premature failure or improper functionality. The challenge for OEMs is to qualify products that meet the mean time to failure reliability requirements. To do so, OEMs must understand "how clean is clean enough" under various levels of bias and environmental conditions. High density interconnects render this assessment more challenging as conductors and circuit traces are increasingly narrower.

Highly dense bottom termination components decrease conductor pitch, spacing, and standoff height from the board surface to the bottom of the component. The complexity arises from the variability of components and their function. For example, standoff height isn't an issue with a BGA pitch, while for other components, pitch may not be the issue but stand-off is. Current spacing trends for some component types result in flux residues bridging conductors. The combination of flux bridging a gap and incomplete volatilization under components may expose a reliability risk. Additionally, the low stand-off can result in incomplete cleaning, which is also a significant factor.

Tighter spacing between conductors results in a higher electric field. Past researchers reported reliability risks due to voltage swings, high frequencies, leakage currents, and high impedance. One of the goals of this research is to gain a better understanding of contamination and its effect on reliability. The purpose of this research is to design new test boards and explore a wider range of electrical testing protocols that provide a more accurate correlation and prediction of assembly residues to one or more aspects of long term reliability. The research plans are to conduct a series of designed experiments to learn the effects of various levels of electrical bias on electrochemical migration in the presence of common residue types under different atmospheric conditions. This research paper will study electrical voltage effects on SMT and BGA board designs under various cleanliness conditions.

Keywords: Cleaning, Flux Residues, Leakage Currents, Electro-chemical Migration, Highly Dense Interconnects

Introduction

The design of reliable products requires improved test methods that keep pace with higher functioning electrical circuits. Product reliability is a measure of how well a product performs a specific function, within conditions where the product would commonly be used, and over its expected life time. The reliability of an electronic assembly for its designed purpose determines the overall reliability of the product in which the electronic device is used. Test methods that simulate full operational testing, and can be supported with conclusive data findings, is a needed requirement.

Current industry standards and test methods were designed on circuits with much wider traces between conductors. The smaller conductive spacing for components placed on highly dense interconnects creates a condition where residues can bridge conductors. These residues can create a path for leakage currents, which may affect signal integrity. Surface moisture, as low as a few monolayers, can dissolve trace ions within the residue and through electrostatic interaction between charged ions, trace metals can migrate.[1] Path formation for metal ion migration between conductors can take place from soldering residues, board surfaces and other materials that may absorb or attract moisture.

An unavoidable or unwanted capacitance between the parts of an electronic component or circuit can occur from both non-polar and polar residue that is in the proximity of adjoining circuits.[2] High levels of voltage can render electrical interference from closely spaced circuits. Signal integrity can be interrupted due to unwanted or parasitic capacitance between two components. Parasitic capacitance can distort high frequency signals due to residues interfering with wave paths, which may result in disrupted signal integrity.[3] As circuits increase in density, an accurate correlation of assembly residues and their effects on reliability is missing. The board designs highlighted in this research support a wider range of electrical and chemical testing. The board designs allow for high voltage, low level leakage current, rate of current change, and frequency bias interactions to test the effect of leakage currents and ultimately electrochemical migration.

Research Background

For many years there has been a huge disconnect between the engineers that design the assembly and the chemists responsible for developing assembly materials. In short, engineers and chemists don't speak the same language. In today's HDI environment, this disconnect in language can cause more issues than it solves. The challenges of cleaning smaller pitched components used in the HDI World means that the two disciplines need to collaborate in an effort to better understand how to overcome these challenges.

A design engineer's objective is to place as much functionality in the smallest space possible. The image in Figure 1 is a monochrome of a highly dense circuit design. A solder paste chemist's objective is to design a flux package that will allow an assembler to achieve high process yields while leaving minimal residues post-soldering. The flux residue remaining is intended to be non-conductive. As circuit traces narrow, the surface tension and wetting properties of the flux residue bridges the anode and cathode (Figure 2). Residues underneath low stand-off components do not volatilize as completely and polymerization of the rosin structures may not occur. These residues under bottom termination components are not visible and its effects may not be considered. Researching the effects of these residues may provide a better understanding of the risks and effects under various levels of electrical bias.

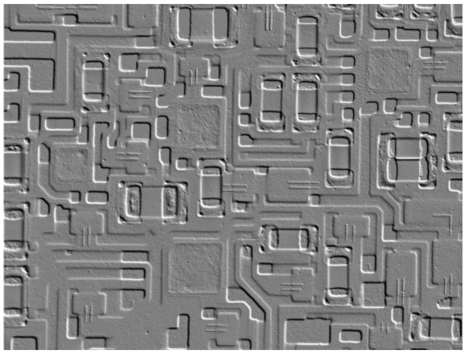


Figure 1: High Density Circuit Design

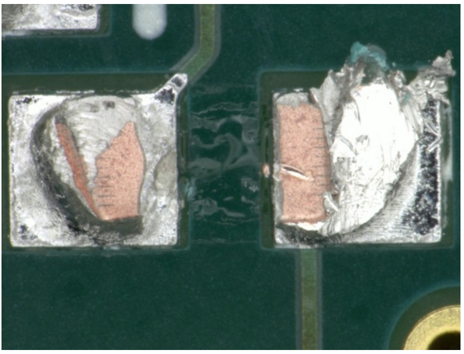


Figure 2: Flux Residue Bridging Conductors after Cleaning

Problem Statement

Larger pitch devices exhibit a lower failure rate due to a comparably lower electric field [Electric Field (E) = voltage (v) / distance (d)]. Smaller and faster circuits exhibit higher current densities, lower voltage tolerances and higher electric fields. As component pitch reduces in size, the use of leadless components increase. High density and high impedance designs are becoming more commonplace. The electric field rises inversely with conductor spacing, which may increase electrical, mechanical and thermal modes of failure. Rates of failure are driven by a combination of temperature, voltage, current and frequency.

The electric field is proportional to the force applied on a metallic ion. Electrical forces applied to a charged particle affects the time it takes for the metallic ion to move through an electrolytic solution. Bumiller, Pecht and Hillman (n.d.) research found a strong correlation between dendrite formation and the electric field.[4] Dendritic growth was found on boards with contamination as low as 0 µg/in^2 Cl levels on boards with less than 2 mil spacing. At contamination levels of 0-2 µg/in^2 Cl, dendritic growth was found on 6.25 mil comb spacing, with infrequent appearances on 12.5 mil spacing, and no occurrence on 25 mil spacing. At 5-20 µg/in^2 Cl, dendritic growth was found on both 6.25 and 12.5 mil spacing, with infrequent occurrences on 20 mil spacing. The research found a strong correlation between contamination levels and the distance between conductors.

Highly dense circuits have a number of reliability risks that must be considered. Higher current densities, lower voltage tolerances and higher electric fields are common place with these circuit designs. On highly dense interconnects, cleanliness is an important consideration even when the residues are deemed "no-clean." The problem is that cleaning highly dense assemblies is very difficult. Improving on current test methods that help assemblers validate good design parameters, and to confirm that levels of cleanliness are sufficient, is increasingly important.

Research Purpose

The IPC-B-52 Test Vehicle (Figure 3) is the most current test vehicle available to evaluate the impacts of flux residues. One of the benefits of the B-52 test vehicle is that it improves flux and cleaning evaluations by adding in cleaning effects and cleaning limitations created by components. However, there are a number of limitations with this design. The B-52 is designed for only low-level leakage current testing and low voltage tests. Small HDI components (01005, 0201, QFN's etc.) are not part of the current board design and are not being characterized currently as part of the B-52 research effort.

Pass / fail criteria used for the B-52 was originally developed from the B-24 test vehicle. The B-24 is an older board design that has no components and uses larger line widths and spacing's. The board designs use a pass/fail at 100 meg-ohm resistance. Visual presence of dendrites and corrosion is based on the same criteria defined within J-STD-004. Visual inspections of the B-52 are difficult because of board layout and large ground planes. As such, it is very easy to miss items that may have impacts on tests. In addition the B-52 only is designed for low current and low voltage measurements, which don't necessarily represent "real world" conditions.

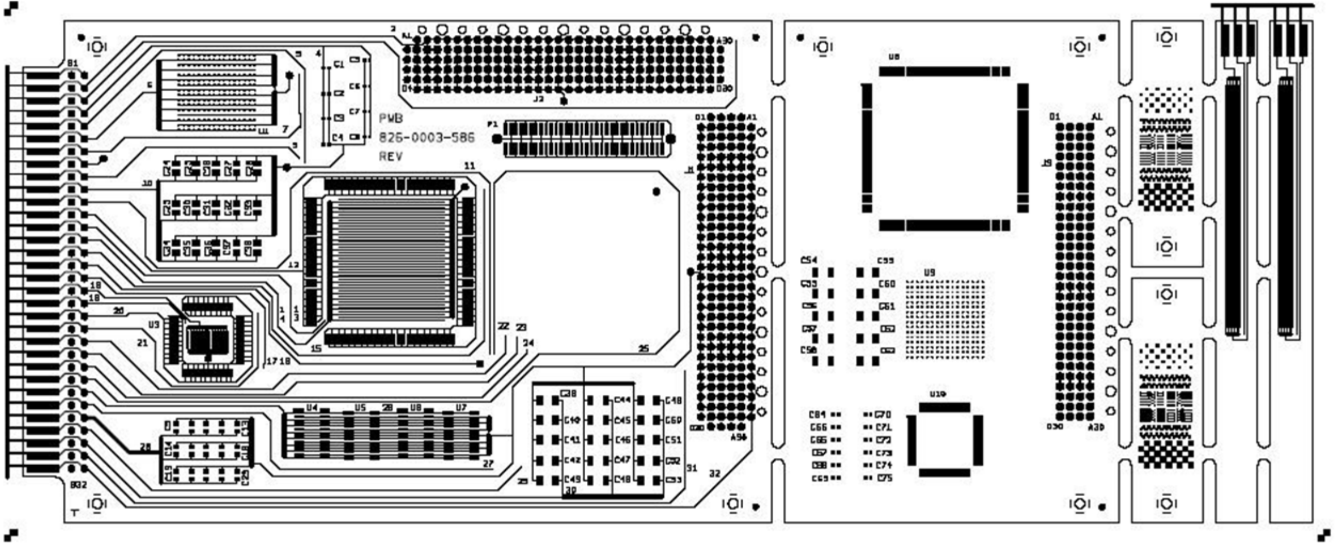


Figure3: B-52 Top View

One of the goals of this research is to design new test vehicles (Figure 4 & 5) that can provide an accurate correlation and prediction of assembly residues and their effects on reliability. The test vehicle designs use specific component types. Within the designs, electrical traces were place in doughnut, cross, and X-design patterns. The research team identified bottom termination components and oriented these components to create a realistic cleaning challenge.

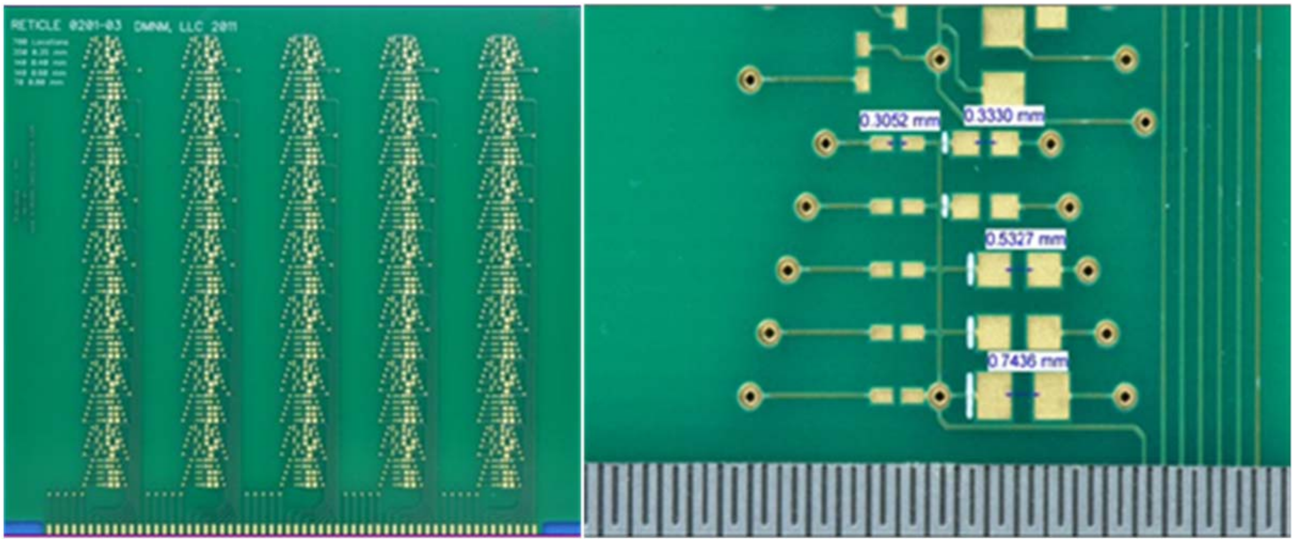


Figure 4: SMT Test Vehicle

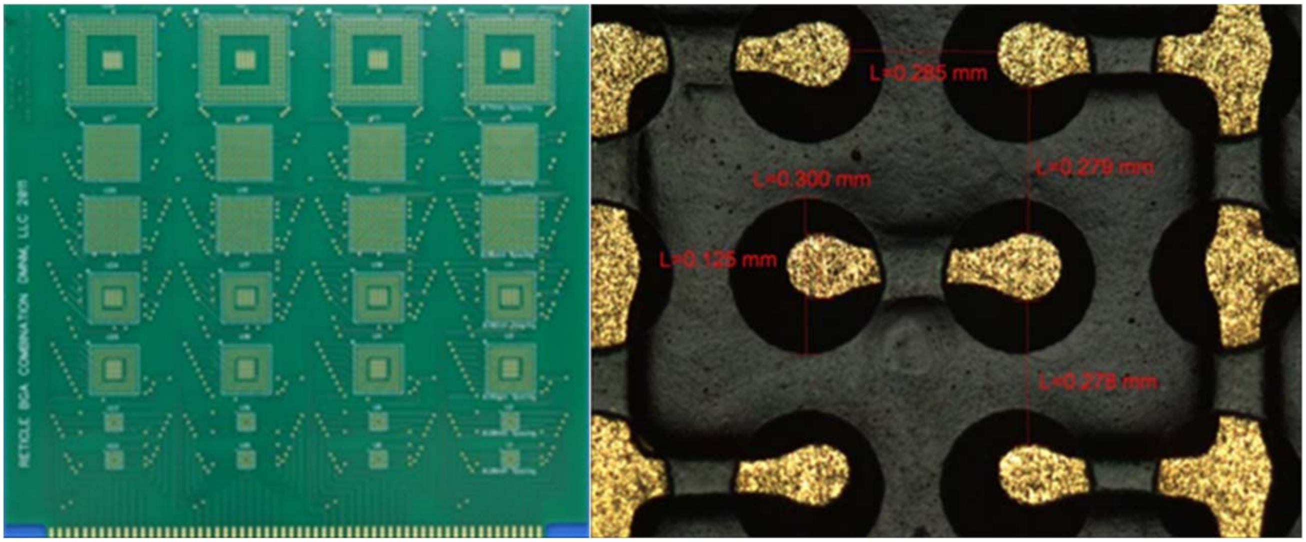


Figure 5: BGA Test Vehicle

Parameters considered when laying out the boards were as follows:

1. Test pattern
2. PCB pad sizes, pitches, and Z-offsets
3. Directional placement (Devices relative to cleaning system)
4. Flux type (Clean & No-Clean)/Flux volume
5. Cleaning chemistries
6. Ionic levels
7. Inspection techniques (Visible, IR, UV, etc.)
8. Organic levels (FTIR, HPLC, GCMS, etc.)
9. Environmental conditions

How Clean is Clean Enough?

The DOE matrix is designed to test the voltage leakage from boards that were not cleaned, partially cleaned and totally cleaned. The larger pitch BGA components also exhibit higher standoff heights. The flux residues on large pitched devices do not bridge conductors. As the density of the interconnect increases and the component size decreases, pitch and standoff decrease. Flux residues on highly dense devices (small BGAs) create the potential for residues bridging conductors, which creates a greater risk for electrolytic path formation and the potential for parasitic capacitance.

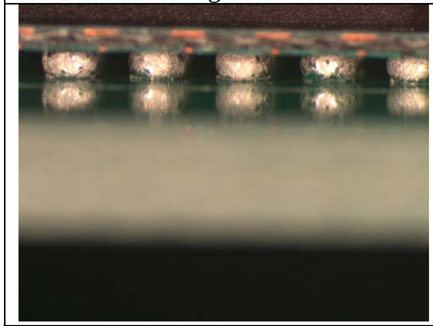
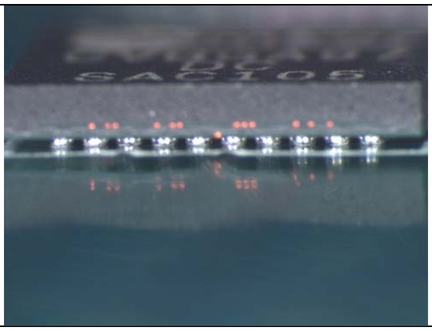
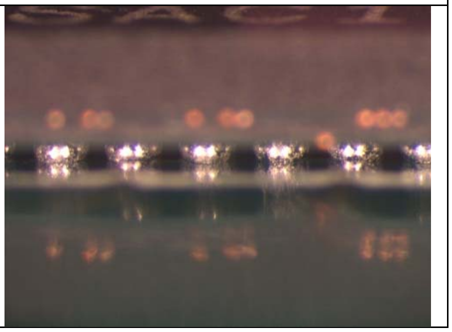
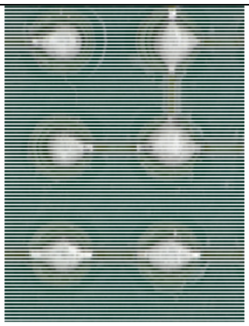
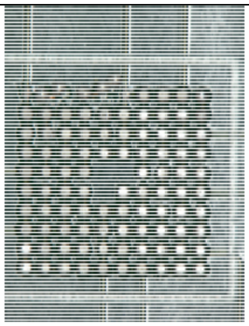
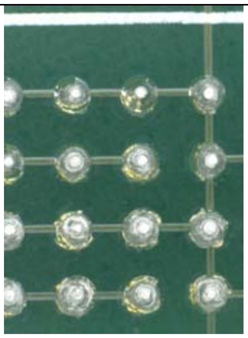
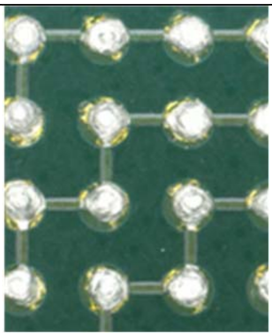
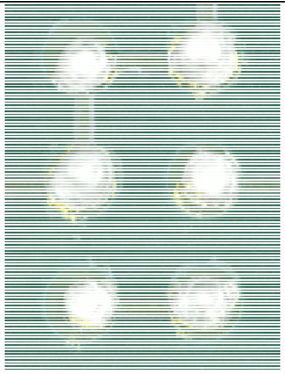
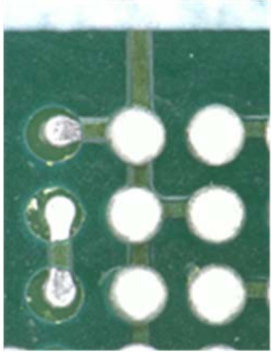
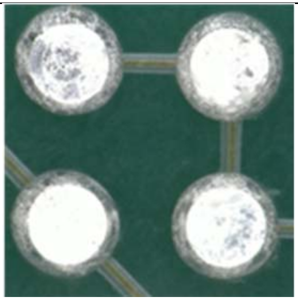
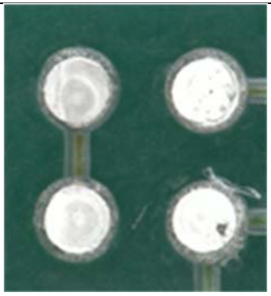
Large BGA	Medium BGA	Small BGA
		

Figure 6: BGA Size Comparisons

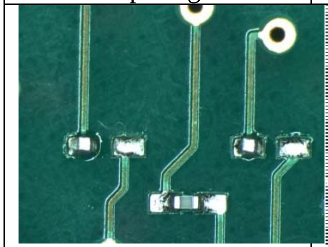
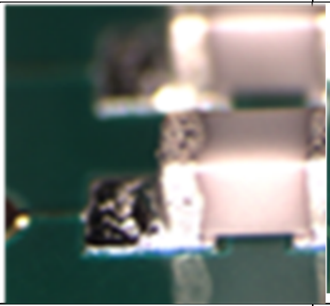
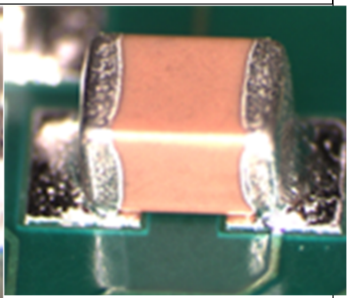
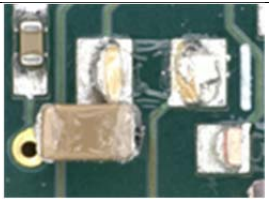
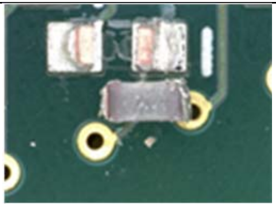
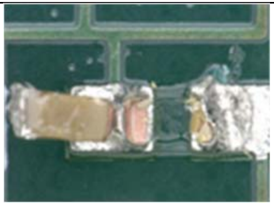
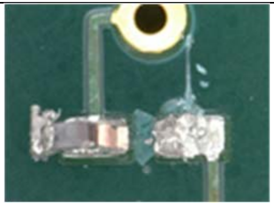
0.70 mm Spacing Not Cleaned	0.53 mm Spacing Not Cleaned	0.46 mm Spacing Not Cleaned	0.20 mm Spacing Not Clean
			

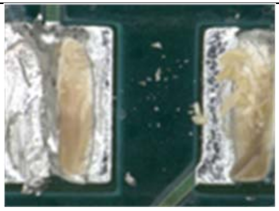
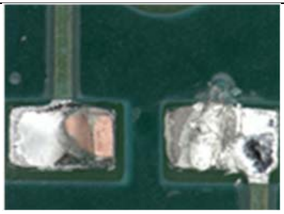
0.70 mm Spacing Partially Clean	0.53 mm Spacing Partially Clean	0.46 mm Spacing Partially Clean	0.20 mm Spacing Partially Clean
			

0.70 mm Spacing Clean	0.53 mm Spacing Clean	0.46 mm Spacing Clean	0.20 mm Spacing Clean
			

Figures 7, 8 & 9: BGA Cleaning Conditions

The SMT boards are populated with small chip cap resistors. These components have minimum pitch and/or spacing barriers. Flux residues commonly bridge conductors. Dependent on solder paste thickness, and how much pressure is used to insert the component into the solder paste, determines the gap or standoff height. Many smaller chip caps have gap heights below 25 μm (1 mil). Residues under these components may create a reliability risk Small capacitors exhibit a small distance between conductors, flux under fills the component and gap height is low. Cleaning the flux residues under these devices is quite difficult. Flux left under the cap is also hard to detect.

2.0 mm x 1.30 mm Spacing	1.69 x 0.71 mm Spacing	1.00 x 0.51 mm Spacing	0.61 x 0.30 mm Spacing
			
2.0 mm x 1.30 mm Spacing 0805 Not Cleaned	1.69 x 0.71 mm Spacing 0603 Not Cleaned	1.00 x 0.51 mm Spacing 0402 Not Cleaned	0.61 x 0.30 mm Spacing 0201 Not Clean
			
2.0 mm x 1.30mm Spacing 0805 Partially Clean	1.69 x 0.71 mm Spacing 0603 Partially Clean	1.00 x 0.51 mm Spacing 0402 Partially Clean	0.61 x 0.30 mm Spacing 0201 Partially Clean

			
2.0 mm x 1.30 mm Spacing 0805 Clean	1.69 x 0.71 mm Spacing 0603 Clean	1.00 x 0.51 mm Spacing 0402 Clean	0.61 x 0.30 mm Spacing 0201 Clean
			

Figures 10, 11, 12 & 13: SMT Cleaning Conditions

Methodology

Two sets of Reticle bare boards were provided to two separate test laboratories to baseline their starting cleanliness. A total of forty boards were provided to Kyzen Corporation. Kyzen utilized a modified version of the IPC-TM-650, method 2.3.28.2 to perform the analysis. The modification consisted of changing the test method specified extraction solution from 90% DI water 10% 2-porpanol to a 25% DI water, 75% 2-propanol. This was done to make the before and after IC analysis comparable by using the same extraction fluids. Tables 1 and 2 report the data findings from Ion Chromatography (IC) analysis per a modified IPC-TM-650 2.3.28.2, as determined by Kyzen. Sixty boards were provided to Precision Analytical Laboratory (PAL). PAL followed IPC-TM-650, method 2.3.28, which is reported in tables 3 and 4. The following tables show the results from both labs. PAL only completed thirty of sixty samples that were provided.

Please note:

1. The limits defined in the following tables (column 2) were a line in the sand and may not be reflective of all electrical applications. They are merely a starting point that will be refined as our research continues and more data becomes available.

2. Values in green were below the established limit. Values in red were above the established limit. Values in yellow were at the established limit. Hence, the term “Stoplight Criteria.” Red for levels that exceed the limit. Yellow levels represent good to cause as residue levels approach the limit. Green represent levels that are below the set limit.

3. WOA-SMT is weak organic acid surface mount; WOA-PTH is weak organic acid pin through hole.

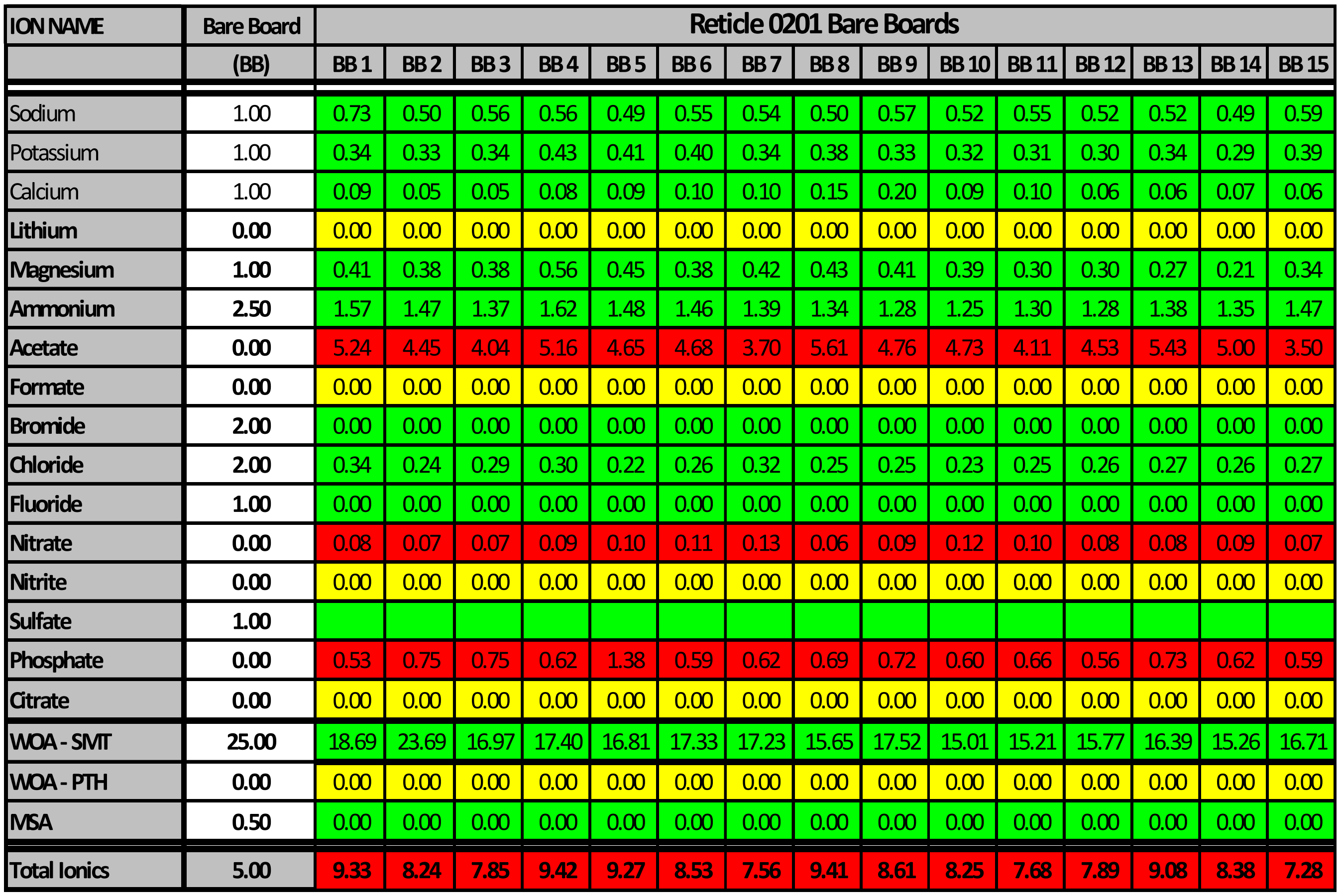
Table #1: Numerical Anion and Cation Residues for Reticle 0201 Bare Boards (BB) – Kyzen. Results are in µg/in^2.

CHEM ID	Bare Board	Reticle 0201 Bare Boards																			
	(BB)	BB 1	BB 2	BB 3	BB 4	BB 5	BB 6	BB 7	BB 8	BB 9	BB 10	BB 11	BB 12	BB 13	BB 14	BB 15	BB 16	BB17	BB 18	BB 19	BB20
Na+	1.00	0.01	0.01	0.04	0.03	0.02	0.03	0.03	0.00	0.05	0.07	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.04
K+	1.00	0.00	0.01	0.01	0.02	0.02	0.01	0.02	0.03	0.02	0.02	0.03	0.06	0.03	0.02	0.03	0.03	0.03	0.02	0.03	0.20
Ca++	1.00	0.00	0.02	0.06	0.03	0.04	0.05	0.01	0.08	0.06	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.15
Li+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Mg++	1.00	0.02	0.04	0.09	0.12	0.18	0.14	0.13	0.16	0.12	0.04	0.01	0.01	0.02	0.00	0.01	0.02	0.03	0.03	0.01	0.08
NH4+	2.50	0.04	0.05	0.04	0.09	0.12	0.09	0.05	0.05	0.03	0.06	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00
CCOO-	0.00	0.98	0.83	0.77	0.87	0.82	0.67	0.92	0.96	0.91	1.78	0.55	0.50	0.55	0.34	0.76	1.30	1.02	1.39	0.76	0.52
COO-	0.00	0.67	0.44	0.46	0.29	0.25	0.23	0.22	0.20	0.19	0.52	0.32	0.30	0.28	0.30	0.29	0.42	0.24	0.27	0.19	0.19
Br-	2.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.60	0.43	0.34	0.12	0.11	0.02
Cl-	2.00	0.25	0.15	0.17	0.20	0.14	0.09	0.42	0.13	0.15	0.22	0.19	0.17	0.12	0.10	0.24	0.08	0.09	0.13	0.09	0.11
F-	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.01	0.00	0.00
NO3--	0.00	0.10	0.29	0.06	0.07	0.08	0.09	0.08	0.07	0.06	0.09	0.07	0.06	0.28	0.04	0.25	0.35	0.27	0.10	0.15	0.45
NO2-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.00
SO4--	1.00	0.36	0.33	0.43	0.37	0.34	0.36	0.34	0.34	0.58	0.33	0.27	0.34	0.31	0.15	0.25	0.18	0.26	0.29	0.32	0.25
PO3--	0.00	0.53	0.31	0.38	0.20	0.40	0.26	0.27	0.28	0.38	0.15	0.15	0.28	0.29	0.11	0.12	0.18	0.12	0.19	0.34	0.21
Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOA-SMT	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOA-PTH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MSA	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5.00	2.96	2.48	2.49	2.28	2.45	2.01	2.49	2.30	2.56	3.30	1.64	1.78	1.94	1.09	2.59	3.03	2.43	2.66	2.10	2.24

Table #2: Numerical Anion and Cation Residues for Reticle BGA Combination Bare Boards (BB) –Kyzen.Results are in µg/in^2.

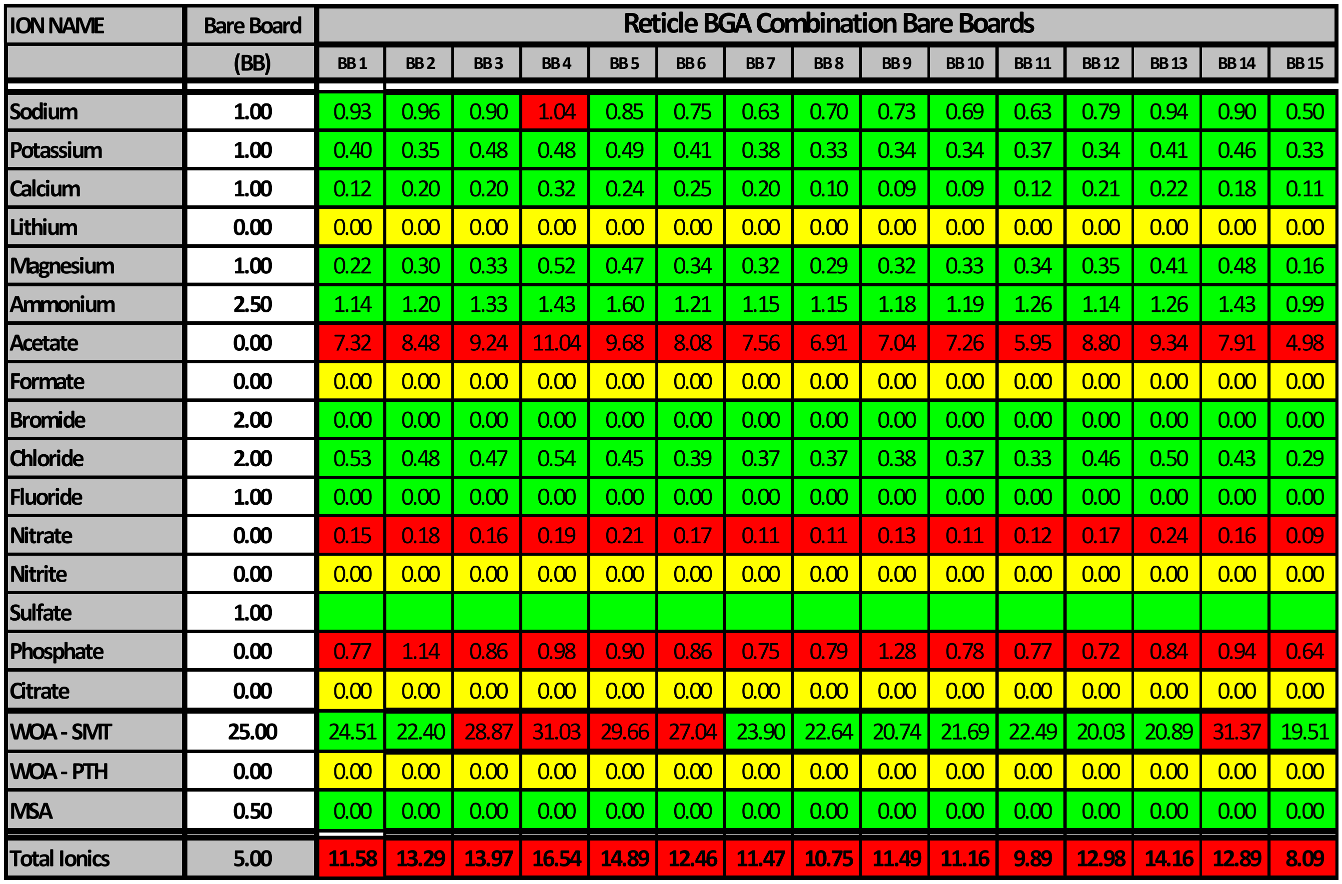
CHEM ID	Bare Board	Reticle BGA Combination Bare Boards																			
	(BB)	BB 1	BB 2	BB 3	BB 4	BB 5	BB 6	BB 7	BB 8	BB 9	BB 10	BB 11	BB 12	BB 13	BB 14	BB 15	BB 16	BB 17	BB 18	BB 19	BB 20
Na+	1.00	0.02	0.03	0.03	0.02	0.04	0.04	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.02	0.02	0.13
K+	1.00	0.03	0.09	0.10	0.06	0.08	0.08	0.02	0.09	0.04	0.06	0.05	0.08	0.14	0.15	0.18	0.10	0.03	0.01	0.07	0.10
Ca++	1.00	0.01	0.03	0.03	0.02	0.02	0.01	0.03	0.01	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.02	0.02	0.06	0.06	0.01
Li+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg++	1.00	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.10	0.24	0.26	0.23	0.13
NH4+	2.50	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
CCOO-	0.00	2.08	1.42	1.86	1.55	1.67	1.54	1.54	1.65	1.36	1.47	1.39	0.46	0.48	0.55	0.73	1.50	0.76	0.74	1.27	1.45
COO-	0.00	0.85	0.71	0.68	0.66	0.61	0.61	0.47	0.60	0.53	0.58	2.58	0.47	0.42	0.43	0.41	0.43	0.38	0.41	0.50	0.39
Br-	2.00	0.05	0.04	0.04	0.05	0.04	0.00	0.08	0.04	0.00	0.05	0.00	0.00	0.08	0.04	0.04	0.00	0.00	0.00	0.00	0.00
Cl-	2.00	0.70	0.35	0.36	0.36	0.22	0.22	0.10	0.25	0.10	0.32	0.22	0.13	0.18	0.19	0.15	0.33	0.19	0.28	0.26	0.47
F-	1.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO3--	0.00	0.55	0.88	0.46	0.11	0.22	0.39	0.38	1.09	0.52	0.90	0.63	0.36	0.63	0.84	0.76	0.09	0.52	0.30	0.10	0.61
NO2-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4--	1.00	0.49	0.29	0.59	0.59	0.52	0.47	0.47	0.57	0.45	0.39	0.35	0.50	0.48	0.43	0.54	0.52	0.51	0.54	0.54	0.60
PO3--	0.00	0.55	0.33	0.32	0.49	0.42	0.29	0.37	0.34	0.50	0.61	0.31	0.35	0.36	0.31	0.56	0.39	0.38	0.39	0.41	0.37
Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOA-SMT	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOA-PTH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MSA	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5.00	5.32	4.19	4.49	3.93	3.86	3.66	3.47	4.68	3.55	4.44	5.58	2.39	2.81	2.99	3.40	3.52	3.06	3.01	3.47	4.28

Table #3: Numerical Anion and Cation Residues for Reticle 0201 Bare Boards (BB)– PAL. Results are in µg/in^2.



ION NAME	Bare Board	Reticle 0201 Bare Boards														
	(BB)	BB 1	BB 2	BB 3	BB 4	BB 5	BB 6	BB 7	BB 8	BB 9	BB 10	BB 11	BB 12	BB 13	BB 14	BB 15
Sodium	1.00	0.73	0.50	0.56	0.56	0.49	0.55	0.54	0.50	0.57	0.52	0.55	0.52	0.52	0.49	0.59
Potassium	1.00	0.34	0.33	0.34	0.43	0.41	0.40	0.34	0.38	0.33	0.32	0.31	0.30	0.34	0.29	0.39
Calcium	1.00	0.09	0.05	0.05	0.08	0.09	0.10	0.10	0.15	0.20	0.09	0.10	0.06	0.06	0.07	0.06
Lithium	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium	**1.00**	0.41	0.38	0.38	0.56	0.45	0.38	0.42	0.43	0.41	0.39	0.30	0.30	0.27	0.21	0.34
Ammonium	**2.50**	1.57	1.47	1.37	1.62	1.48	1.46	1.39	1.34	1.28	1.25	1.30	1.28	1.38	1.35	1.47
Acetate	**0.00**	5.24	4.45	4.04	5.16	4.65	4.68	3.70	5.61	4.76	4.73	4.11	4.53	5.43	5.00	3.50
Formate	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bromide	**2.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride	**2.00**	0.34	0.24	0.29	0.30	0.22	0.26	0.32	0.25	0.25	0.23	0.25	0.26	0.27	0.26	0.27
Fluoride	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	**0.00**	0.08	0.07	0.07	0.09	0.10	0.11	0.13	0.06	0.09	0.12	0.10	0.08	0.08	0.09	0.07
Nitrite	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	**1.00**															
Phosphate	**0.00**	0.53	0.75	0.75	0.62	1.38	0.59	0.62	0.69	0.72	0.60	0.66	0.56	0.73	0.62	0.59
Citrate	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOA - SMT	**25.00**	18.69	23.69	16.97	17.40	16.81	17.33	17.23	15.65	17.52	15.01	15.21	15.77	16.39	15.26	16.71
WOA - PTH	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MSA	**0.50**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Ionics	**5.00**	**9.33**	**8.24**	**7.85**	**9.42**	**9.27**	**8.53**	**7.56**	**9.41**	**8.61**	**8.25**	**7.68**	**7.89**	**9.08**	**8.38**	**7.28**

Table #4: Numerical Anion and Cation Residues for Reticle BGA Combination Bare Boards (BB)– PAL. Results are in µg/in^2.



ION NAME	Bare Board	Reticle BGA Combination Bare Boards														
	(BB)	BB 1	BB 2	BB 3	BB 4	BB 5	BB 6	BB 7	BB 8	BB 9	BB 10	BB 11	BB 12	BB 13	BB 14	BB 15
Sodium	1.00	0.93	0.96	0.90	1.04	0.85	0.75	0.63	0.70	0.73	0.69	0.63	0.79	0.94	0.90	0.50
Potassium	1.00	0.40	0.35	0.48	0.48	0.49	0.41	0.38	0.33	0.34	0.34	0.37	0.34	0.41	0.46	0.33
Calcium	1.00	0.12	0.20	0.20	0.32	0.24	0.25	0.20	0.10	0.09	0.09	0.12	0.21	0.22	0.18	0.11
Lithium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium	1.00	0.22	0.30	0.33	0.52	0.47	0.34	0.32	0.29	0.32	0.33	0.34	0.35	0.41	0.48	0.16
Ammonium	2.50	1.14	1.20	1.33	1.43	1.60	1.21	1.15	1.15	1.18	1.19	1.26	1.14	1.26	1.43	0.99
Acetate	0.00	7.32	8.48	9.24	11.04	9.68	8.08	7.56	6.91	7.04	7.26	5.95	8.80	9.34	7.91	4.98
Formate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bromide	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride	2.00	0.53	0.48	0.47	0.54	0.45	0.39	0.37	0.37	0.38	0.37	0.33	0.46	0.50	0.43	0.29
Fluoride	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	0.00	0.15	0.18	0.16	0.19	0.21	0.17	0.11	0.11	0.13	0.11	0.12	0.17	0.24	0.16	0.09
Nitrite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	1.00															
Phosphate	0.00	0.77	1.14	0.86	0.98	0.90	0.86	0.75	0.79	1.28	0.78	0.77	0.72	0.84	0.94	0.64
Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOA - SMT	25.00	24.51	22.40	28.87	31.03	29.66	27.04	23.90	22.64	20.74	21.69	22.49	20.03	20.89	31.37	19.51
WOA - PTH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MSA	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Ionics	5.00	11.58	13.29	13.97	16.54	14.89	12.46	11.47	10.75	11.49	11.16	9.89	12.98	14.16	12.89	8.09

Table 5: The test matrix used for electrical testing.

Board #	Board Type	Cleaning	Soil	Humidity	Electrical Bias
1	SMT/BGA Board	No-Clean	LF No-Clean		High Voltage (0 -500 Volts)
2	SMT/BGA Board	Partial Cleaning	LF No-Clean		High Voltage (0 -500 Volts)
3	SMT/BGA Board	Total Cleaning	LF No-Clean		High Voltage (0 -500 Volts)
4	SMT/BGA Board	No-Clean	LF No-Clean		High Voltage (0-500 Volts)
5	SMT/BGA Board	Partial Cleaning	LF No-Clean		High Voltage (0-500 Volts)
6	SMT/BGA Board	Total Cleaning	LF No-Clean		High Voltage (0-500 Volts)
7	SMT/BGA Board	No-Clean	LF No-Clean	95/50	High Voltage (0-500 Volts)
8	SMT/BGA Board	Partial Cleaning	LF No-Clean	95/50	High Voltage (0-500 Volts)
9	SMT/BGA Board	Total Cleaning	LF No-Clean	95/50	High Voltage (0-500 Volts)
10	SMT/BGA Board	No-Clean	LF No-Clean	95/50	High Voltage (0-500 Volts)
11	SMT/BGA Board	Partial Cleaning	LF No-Clean	95/50	High Voltage (0-500 Volts)
12	SMT/BGA Board	Total Cleaning	LF No-Clean	95/50	High Voltage (0-500 Volts)
13	SMT/BGA Board	No-Clean	LF No-Clean	Cleaning Setup	
14	SMT/BGA Board	Partial Cleaning	LF No-Clean	Cleaning Setup	
15	SMT/BGA Board	Total Cleaning	LF No-Clean	Cleaning Setup	

Following the printing process, the boards were inspected using Koh Young.

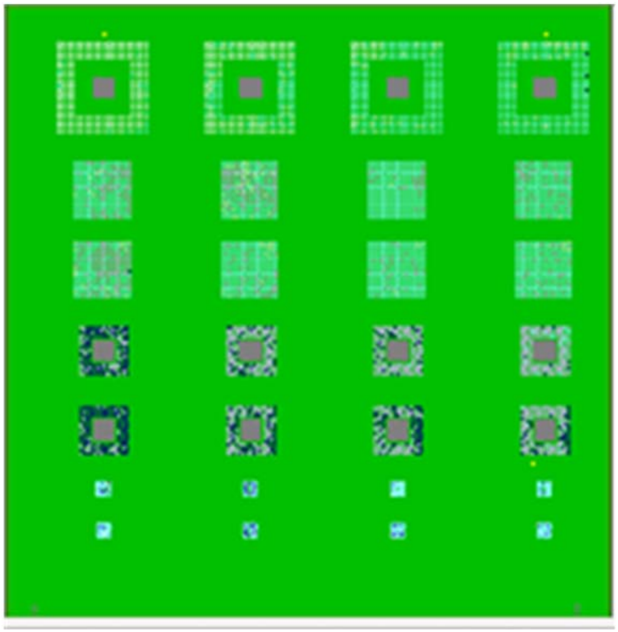
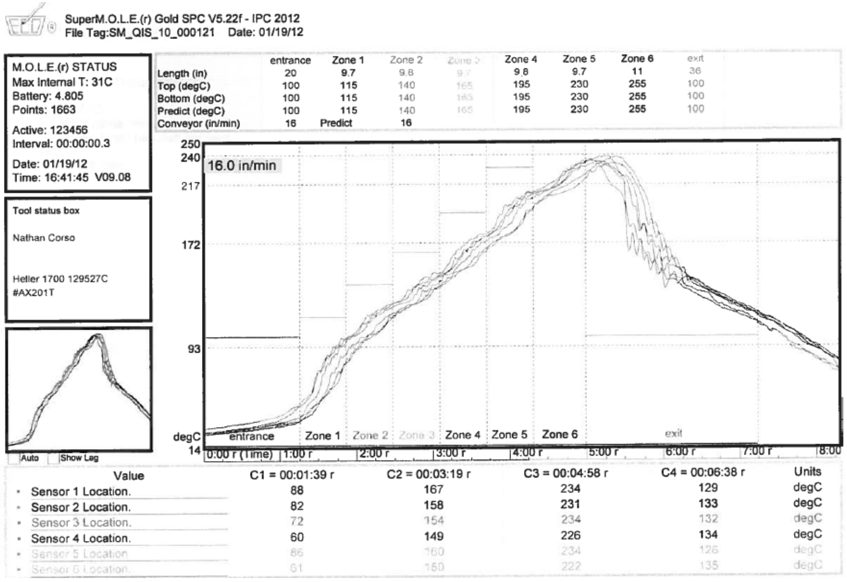


Figure 14: Koh Young Inspection

The boards were reflowed in a nitrogen inerted atmosphere using a spike to ramp reflow profile.



SuperM.O.L.E.(r) Gold SPC V5.22f - IPC 2012
File Tag:SM_QIS_10_000121 Date: 01/19/12

M.O.L.E.(r) STATUS
Max Internal T: 31C
Battery: 4.805
Points: 1663
Active: 123456
Interval: 00:00:00.3
Date: 01/19/12
Time: 16:41:45 V09.08

Tool status box
Nathan Corso
Heller 1700 129527C
#AX201T

	entrance	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	exit
Length (in)	20	9.7	9.8	9.7	9.8	9.7	11	36
Top (degC)	100	115	140	165	195	230	255	100
Bottom (degC)	100	115	140	165	195	230	255	100
Predict (degC)	100	115	140	165	195	230	255	100
Conveyor (in/min)	16	Predict	16					

Value	C1 = 00:01:39 r	C2 = 00:03:19 r	C3 = 00:04:58 r	C4 = 00:06:38 r	Units
Sensor 1 Location.	88	167	234	129	degC
Sensor 2 Location.	82	158	231	133	degC
Sensor 3 Location.	72	154	234	132	degC
Sensor 4 Location.	60	149	226	134	degC
Sensor 5 Location.	86	160	234	126	degC
Sensor 6 Location.	61	150	222	135	degC

Figure 15: Reflow Profile

Figure 16 illustrates the thermocouple position for profiling the boards.

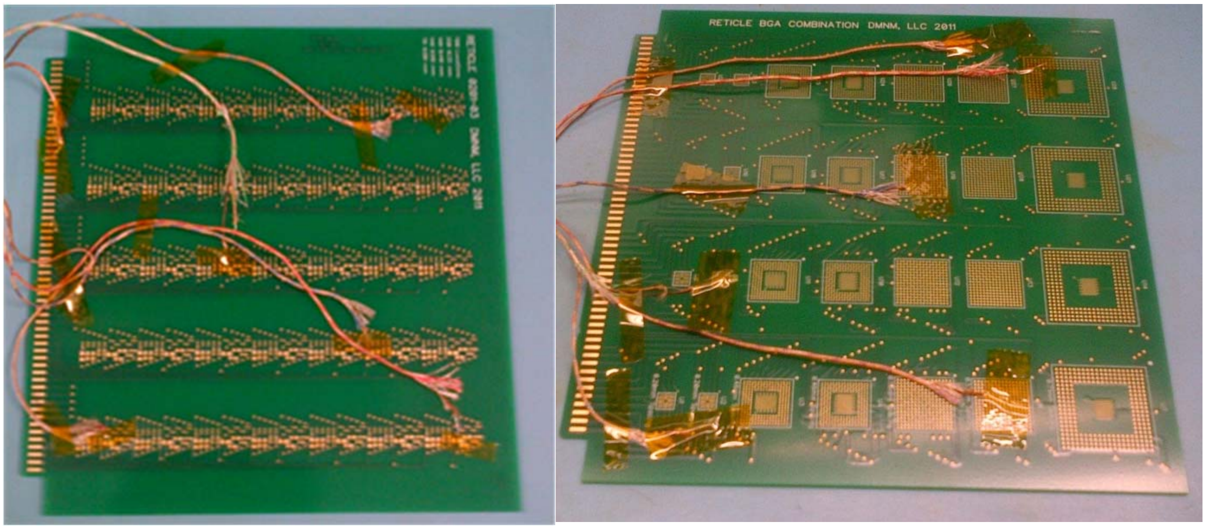
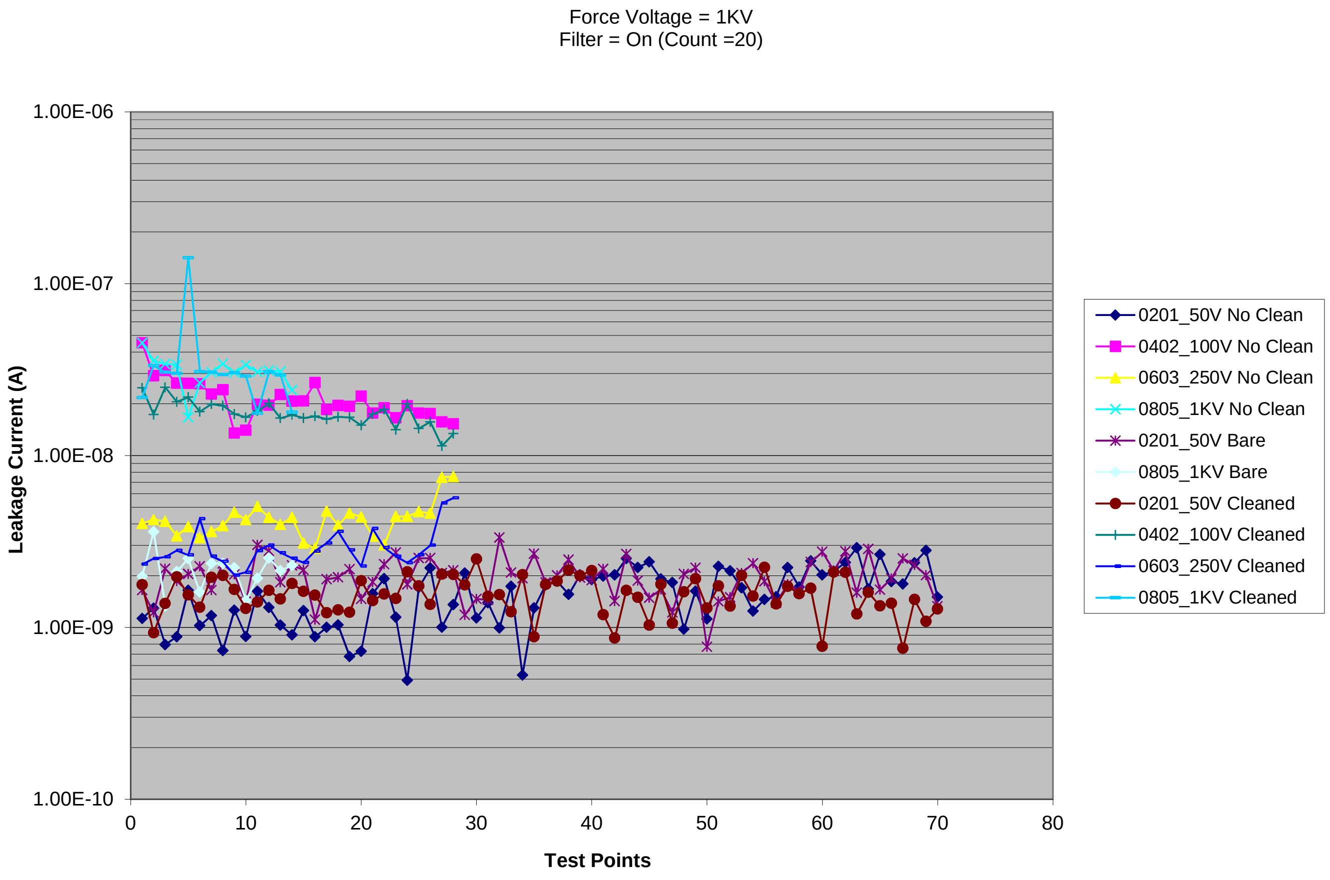


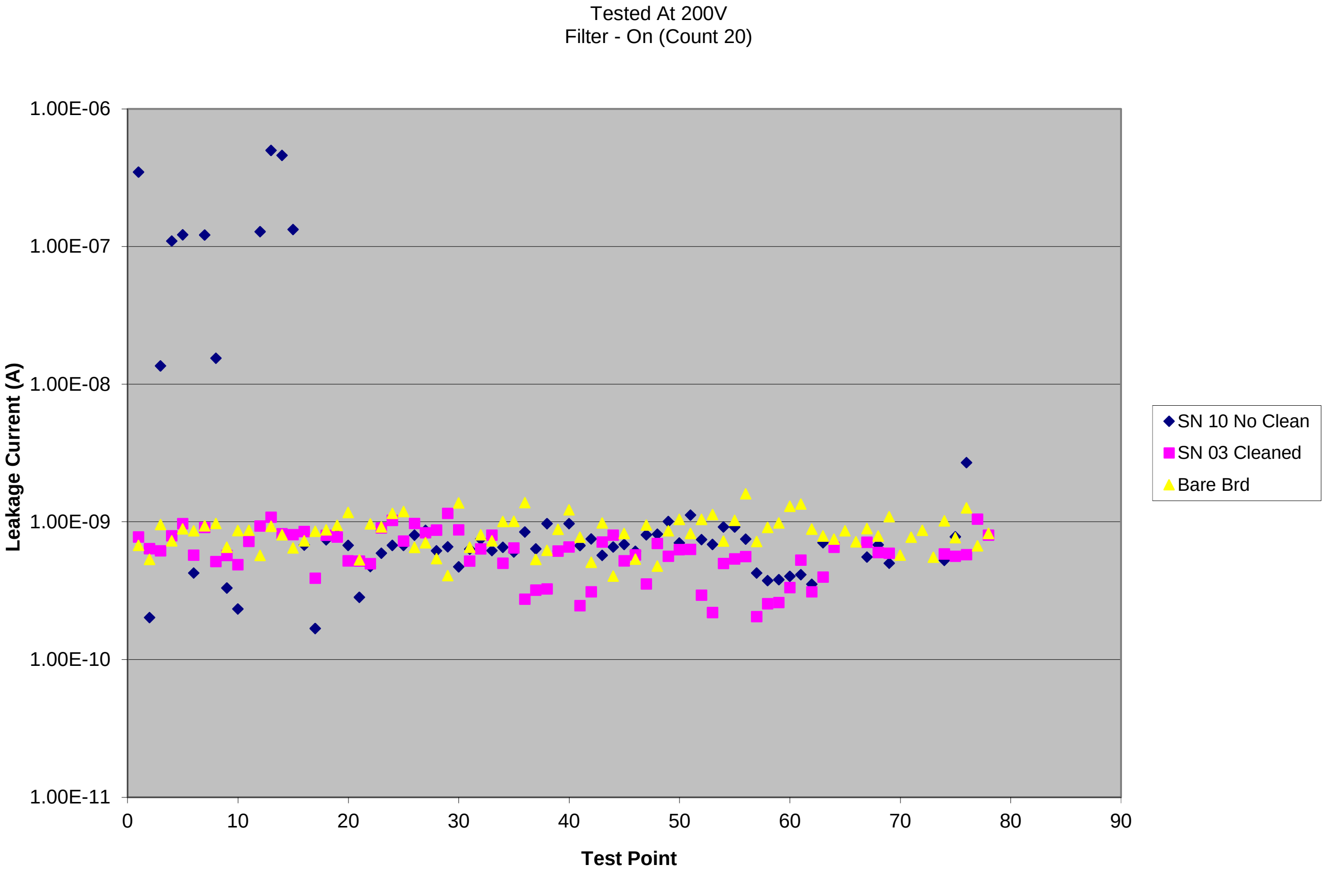
Figure 16: Profiling Boards

The boards were powered up using 20 measurements per point. The voltage applied ranged from 0, 100, 200, 500, 700, and 1000 volts. The voltage time across the component was applied until the device failed, in the event of no failure, the test was ended at 72 hours. No relative humidity was applied to boards 1-6. Boards 6-12 saw a relative humidity of 95% @ 50°C.

Data Findings

The data finds that leakage across the device can be used as a predictor of electro-migration. The data shows no discernible correlation in terms of pitch. The data indicates that when the leakage current moves into the micro-amps and milli-amps range, there is an indication of a current leakage. With the differences in current leakage it may be inferred that there is migration on the BGA and capacitors. The impact of this current leakage will depend on the application, so no general statements can be made at this time. We have shown that the amount of current leakage changes with the ionic contamination. It is beyond the scope of this paper to determine the exact relationship between the two.


Force Voltage = 1KV
Filter = On (Count =20)
Leakage Current (A)
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
0
10
20
30
40
50
60
70
80
Test Points
0201_50V No Clean
0402_100V No Clean
0603_250V No Clean
0805_1KV No Clean
0201_50V Bare
0805_1KV Bare
0201_50V Cleaned
0402_100V Cleaned
0603_250V Cleaned
0805_1KV Cleaned



Inferences from the Data Findings

The new test vehicle provides a higher number of components at different pitches. This provides a better statistical average on a single test vehicle. The layout orientation provides a better, more accurate representation of cleaning. The components are placed at different orientations, which create shadowing issues. By varying the pitch, the test method provides a basis for fluctuating the voltage across the component in the range of nano-amps, into micro-amps, and to milli-amps.

The test vehicle provides can ability to vary the voltage while not increasing dielectric properties. When stepping up the voltage, the test vehicle electric charges does not flow thought the board laminate. This allows for a better research on the effects of voltage when contamination is present.

Assemblies that were not cleaned showed a higher level of leakage current. There were a greater number of pitched areas exhibiting higher leakage current values. Components where leakage occurred exhibit a potential for failure. Assemblies that were partially cleaned compared to assemblies that were cleaned. The test vehicle shows promise in isolating ionic residues and correlating these residues with failure and what causes the failure.

Follow on Research

The genesis behind this research was to develop a test vehicle and method to study the correlation of contamination in the presence of bias. The methodologies used in this study provide the basis for

- Evaluating the cleaning effects and limitations created by components

- Research electrical characteristics in the form of high voltage, leakage current, rate of current change and frequency
- Research different flux technologies and the reliability of residues left on the board following soldering
- Research the effects of partial cleaning
- Research different cleaning agents and their effects on improving reliability
- Research different cleaning processes and their effects on improving reliability
- Development of new evaluation techniques for better isolation and characterization of ionic contamination

Acknowledgements:

The authors are most appreciative to the individuals behind the scenes that contributed to designing, assembling and testing. Individual from I.E.C. Electronics, Indium Corporation, Precision Analytical, and Kyzen Corporation collaborated and worked as a team to complete this phase of the research.

References

1. Bumiller, E. & Hillman, C. (n.d.). A Review of Models for Time-to-Failure Due to Metallic Migration Mechanisms. Retrieved from www.DfRSolutions.com
2. Parasitic Capacitance. Retrieved from http://en.wikipedia.org/wiki/Parasitic_capacitance
3. Schwegart, H. (2011). Contamination-Induced Failure of Electronic Assemblies. Handbook for Critical Cleaning Applications, Processes and Controls. Second Edition. CRC Press.
4. Bumiller, E., Pecht, M., & Hillman, C. (n.d.) Electrochemical Migration on HASL Plated FR-4 Printed Circuit Boards. Retrieved from http://www.dfrsolutions.com/uploads/publications/2004_ECM_Hillman-Bumiller.pdf