APEX EXPO 2012 IPC

Cleaning in an HDI World

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Background

- For many years there has been a huge disconnect between the engineers that design the assembly and the chemists responsible for developing the 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 the smaller pitched components used in the HDI World means that the two disciplines need to be married together to better understand how to overcome these challenges…

Problem Statement

- Higher I/O = tighter pitch
- Higher I/O and lower gap height makes cleaning underneath part far more difficult
- Smaller gaps and spaces tend to be underfilled with flux.
- Flux at the periphery of the part is thinner and tends to be more difficult to clean.
- Flux near center of part tends to be easier to clean, but may also be the most problematic due to insufficient thermal exposure.

Research Purpose

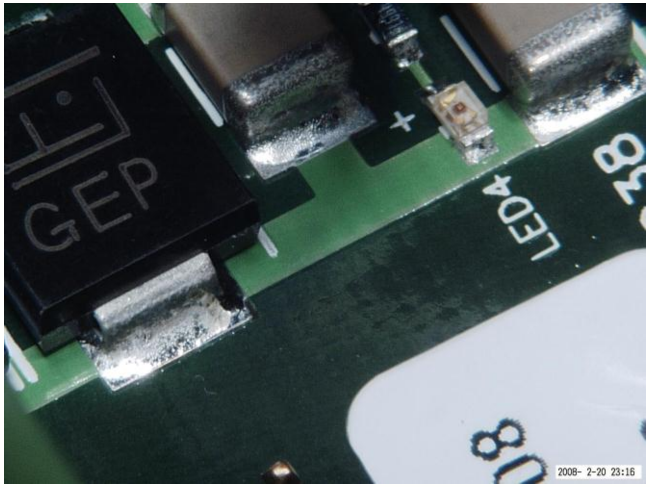
- Build a new test board that provides
  - Accurate correlation and prediction of assembly residues effects on reliability
  - Support for a wider range of electrical / chemical testing
    - High Voltage / Hi-Pot
    - Low Level Leakage Current
    - Rate of Current Change (di/dt)
    - Frequency
    - IC, FTIR, GC-MS, HPLC, etc.

Research Time-Line

- Phase 1 – Test Board Design (Past)
  - ✓ PCB Layout <0.4, 0.4-0.6,>0.6mm
  - ✓ Component Selection: SMT, QFN, BGA
- Phase 2 – DOE Testing (Present)
  - ✓ PCB Surface Finishes (ENIG)
  - ✓ Flux Types (Indium 8.9 HF1)
  - ✓ Cleaning Agents (Aquanox A4625)
  - ✓ Cleaning Machines (Kyzen custom inline)
  - ✓ Analytical Analysis (Kyzen, DRTL, PAL, Foresite)
- Phase 3 – DFM for PCB Designers (Future)
  - Layout guidelines to facilitate acceptable electrical performance.

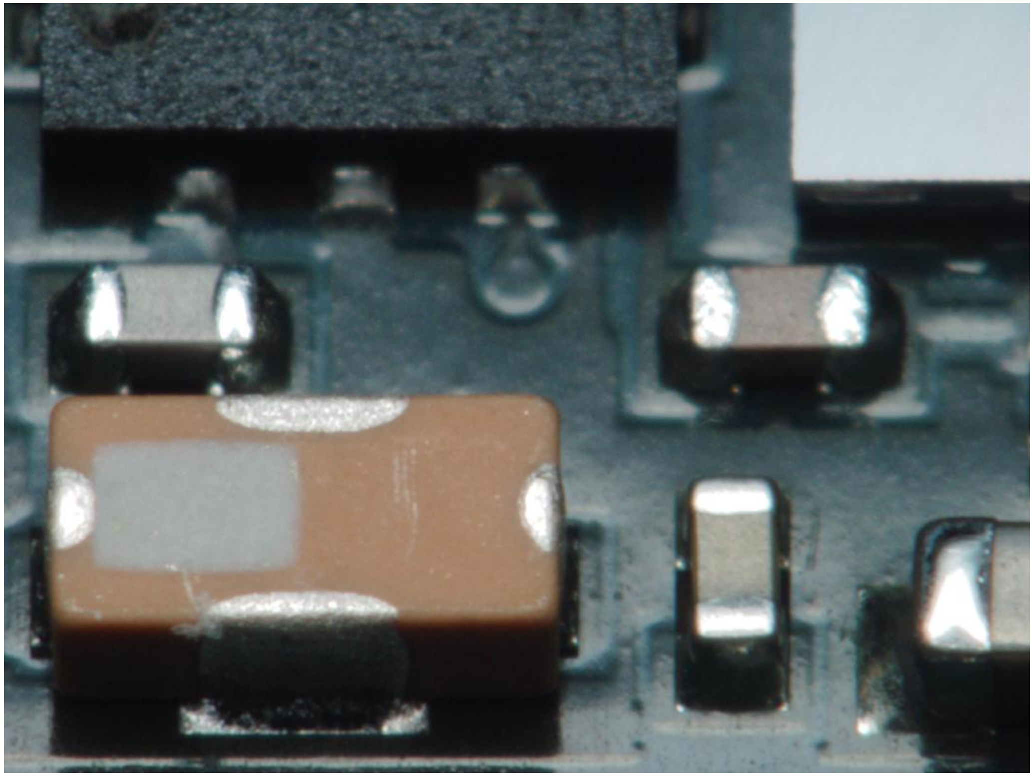
Paper Overview

- Highly Dense Interconnects
- Reliable Product Design
- Research Background
- Problem Statement
- Research Purpose
- How Clean is Clean Enough?
- Methodology
- Data Findings
- Inferences from Data Findings
- Follow on Research



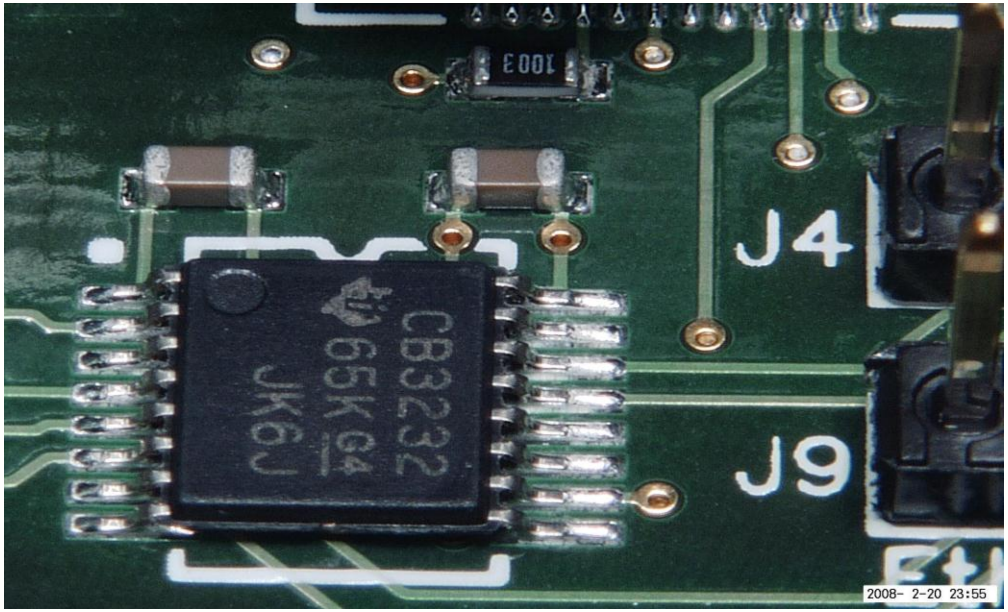
Highly Dense Interconnects

- Contamination may increase
  - Premature failure
  - Improper functionality



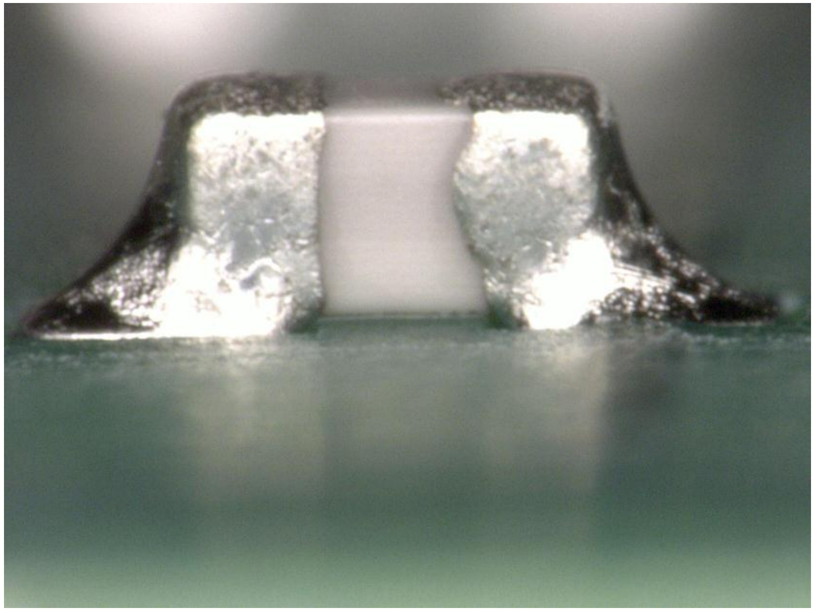
Challenge for OEMs

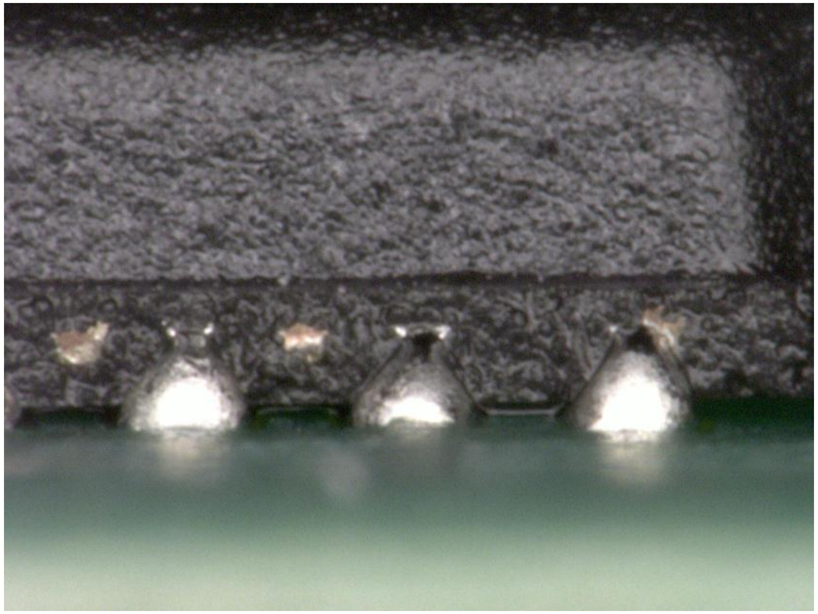
- Qualify a process that meets the end products design purpose
  - Time to failure reliability requirements
- To do so, the OEM must understand
  - How Clean is Clean Enough (i.e. electrical or chemical)
  - How does bias and environmental conditions increase risk



Highly Dense Components

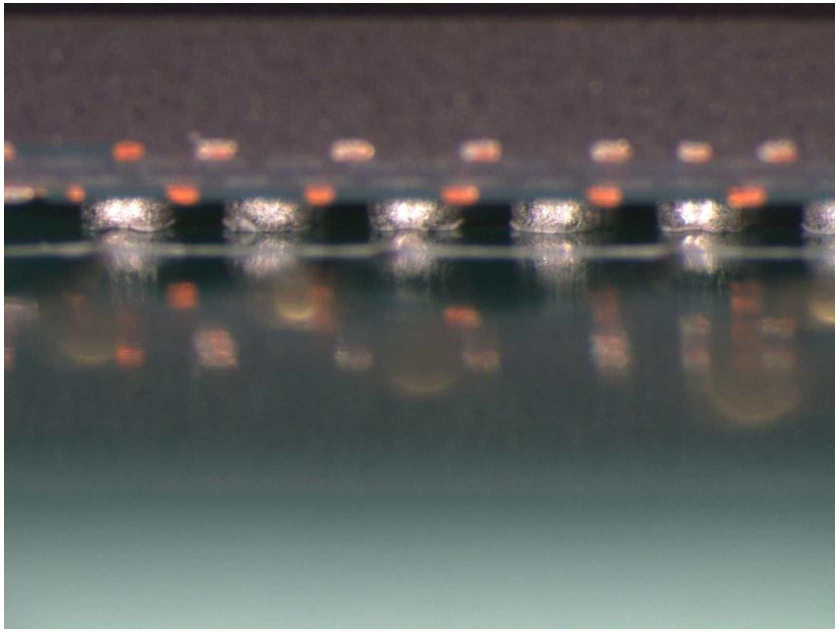
- Bottom termination components
  - Decrease conductor pitch
  - Spacing
  - Standoff height (z-axis)

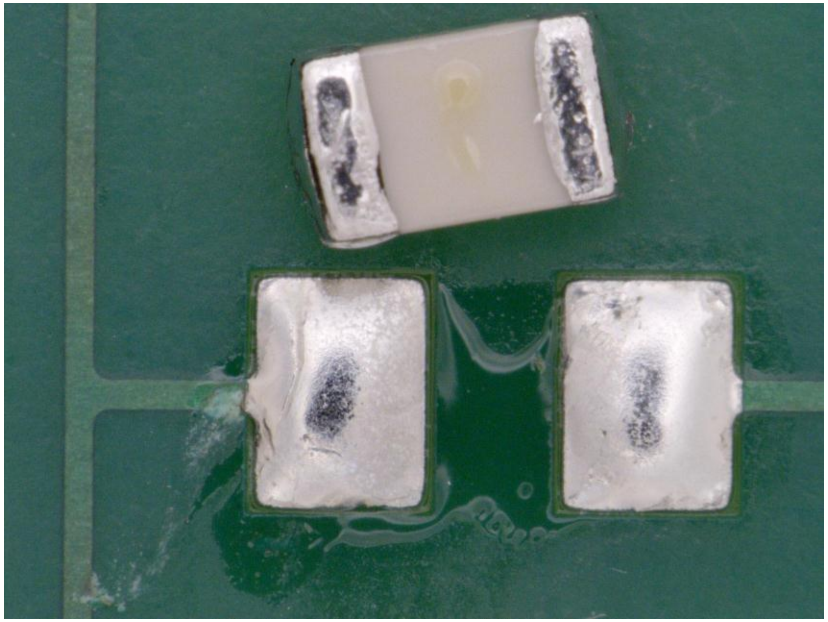




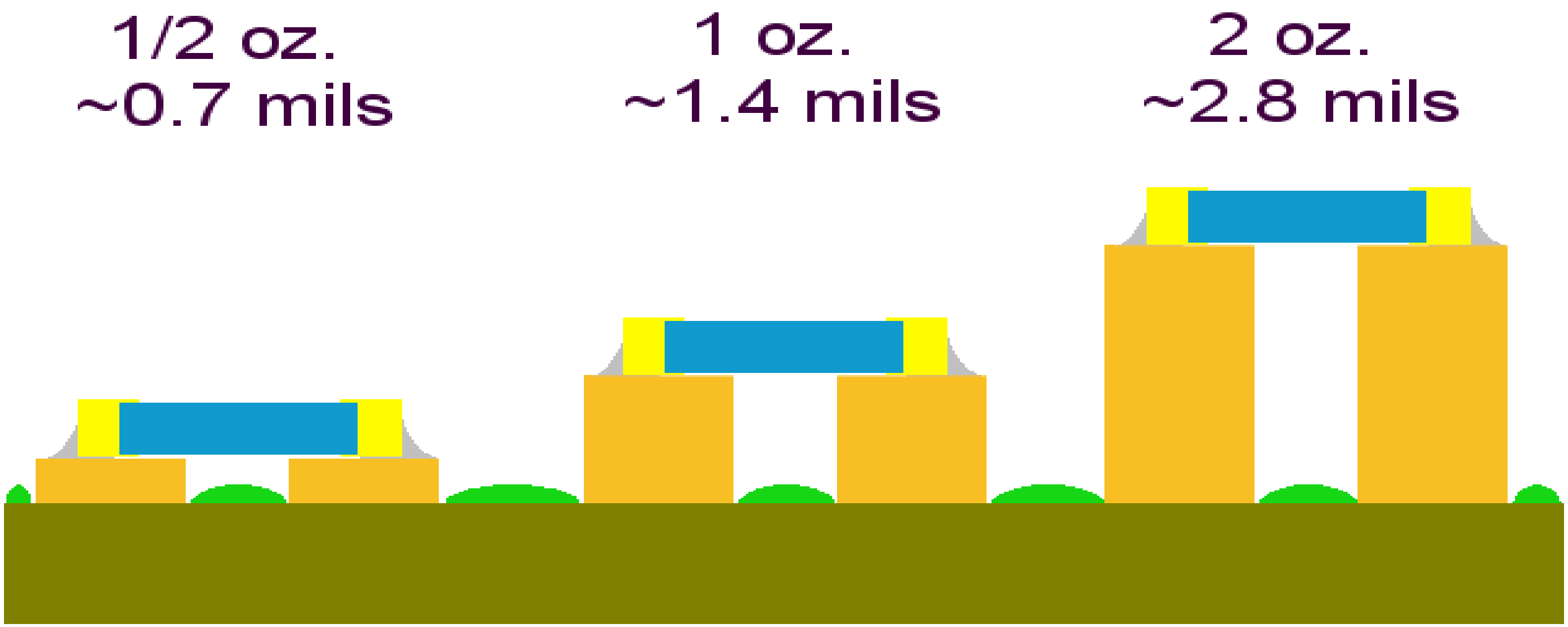
Complexity

- Arises from variety of components and their function
  - For example
    - Standoff isn't a problem for BGAs
    - For other components standoff and pitch are issues

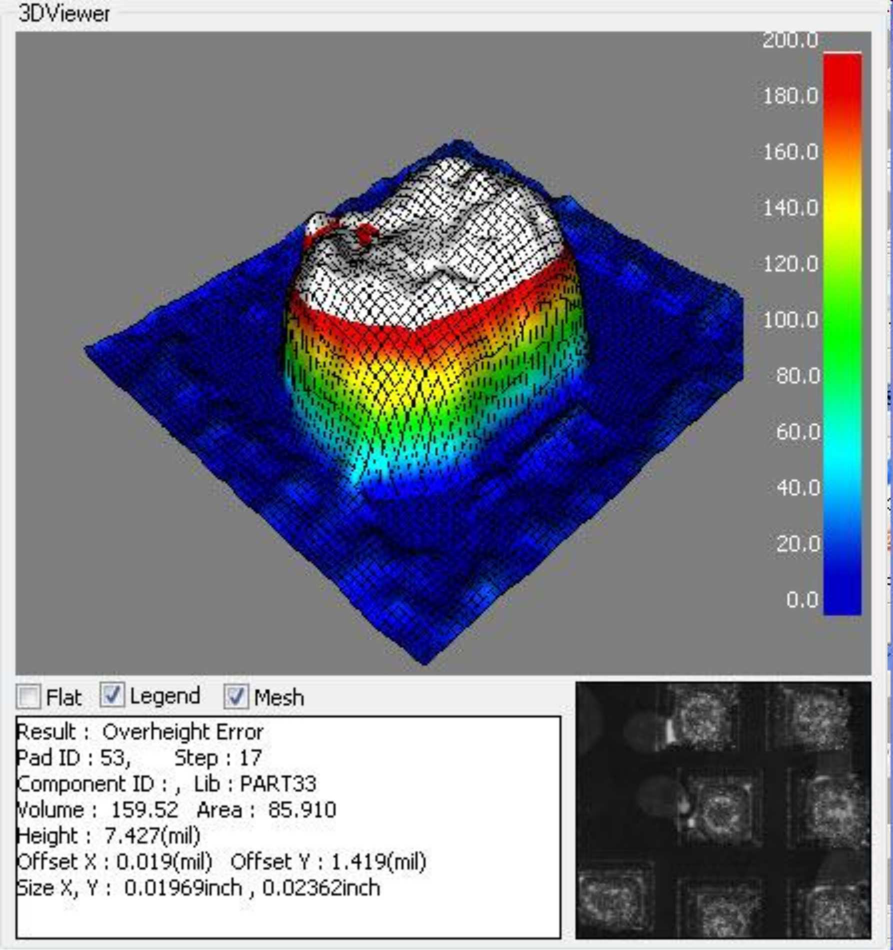




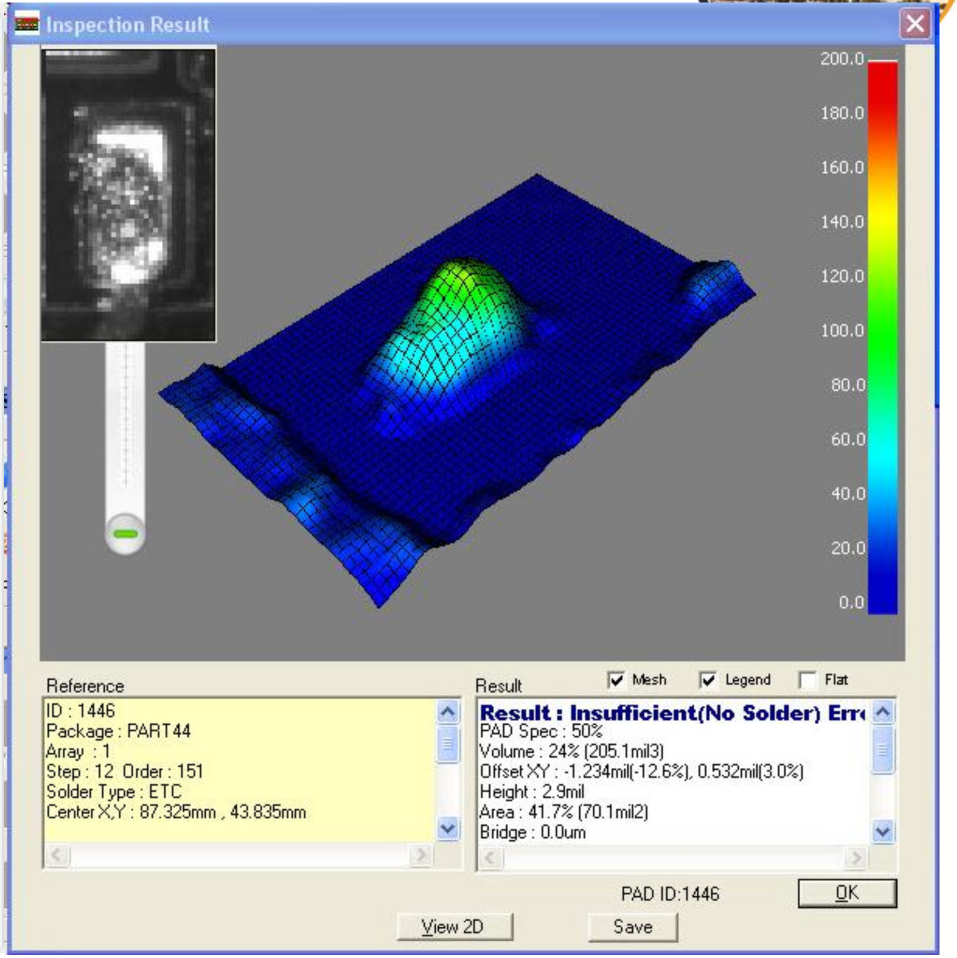
Stand-off(z-axis)



Flux Volumes



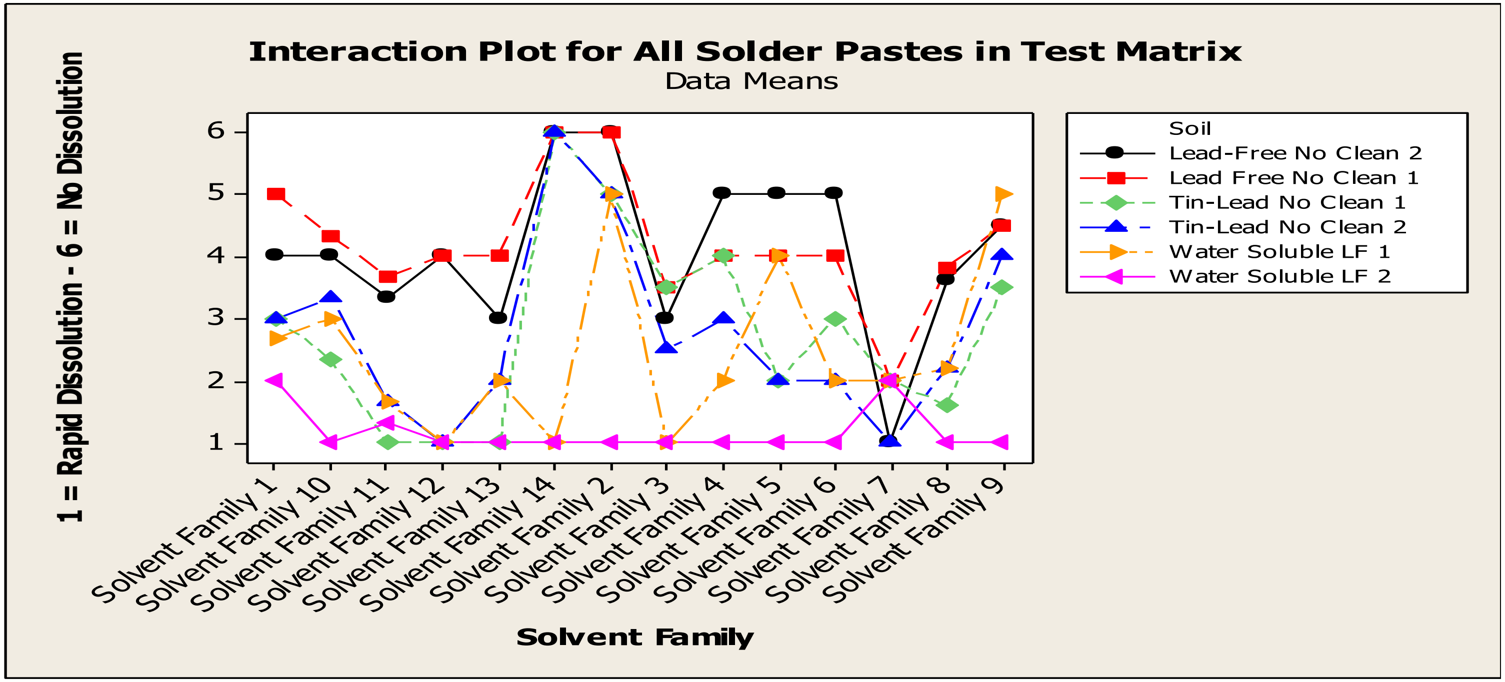
159.52% Volume of Flux on a BGA pad



24% Volume of Flux on a QFN pad

Flux Residue

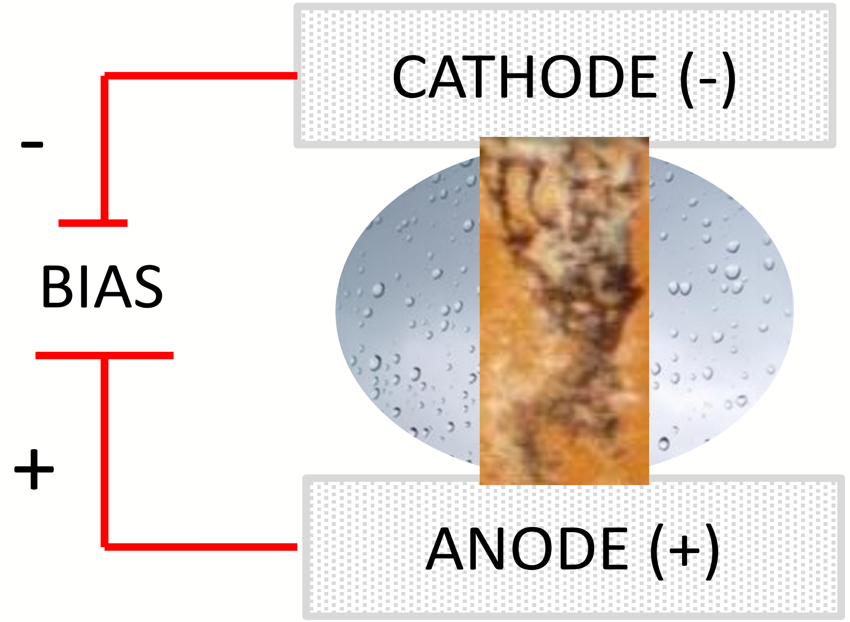
- No-clean solder paste is the Industry Standard
  - Incomplete volatilization under components may expose a reliability risk



Electric Field

- Electric Field increases with tighter spacing

$$E = v/d$$



Product Reliability

- A measure of how well a product performs
  - Specific function
  - Within conditions where the product is commonly used
  - Over its expected life time

Current Industry Standards

- Limitations
  - IPC test methods 2.3.28 (IC) and 2.6.3.7 (SIR)
- Not intended for HDI (<0.4mm)
  - Residues bridge conductors
  - Path for leakage currents
  - May affect signal technology

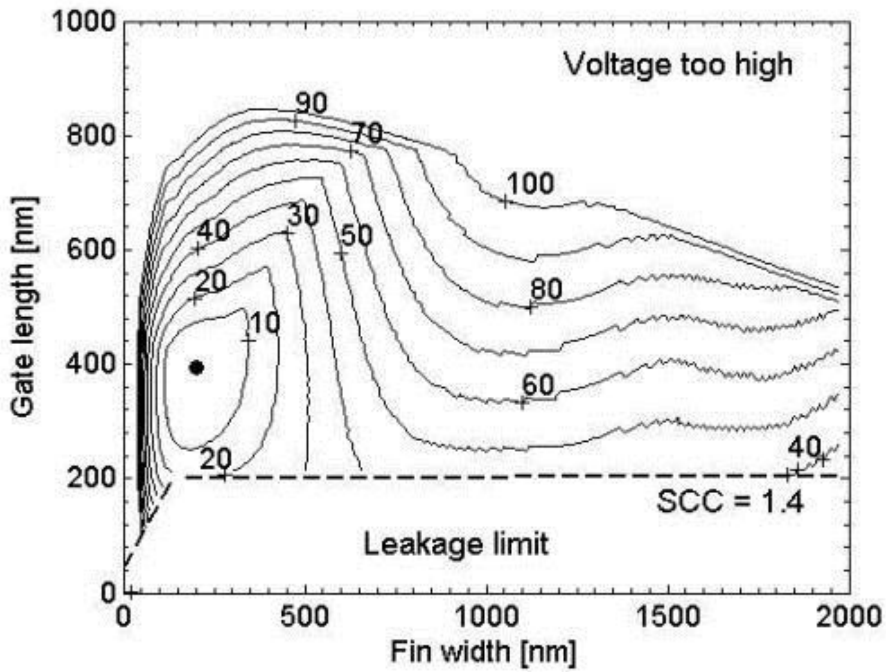
Flux Residue

Electro Chemical Migration

Source: IPC (2007). IPC-5702

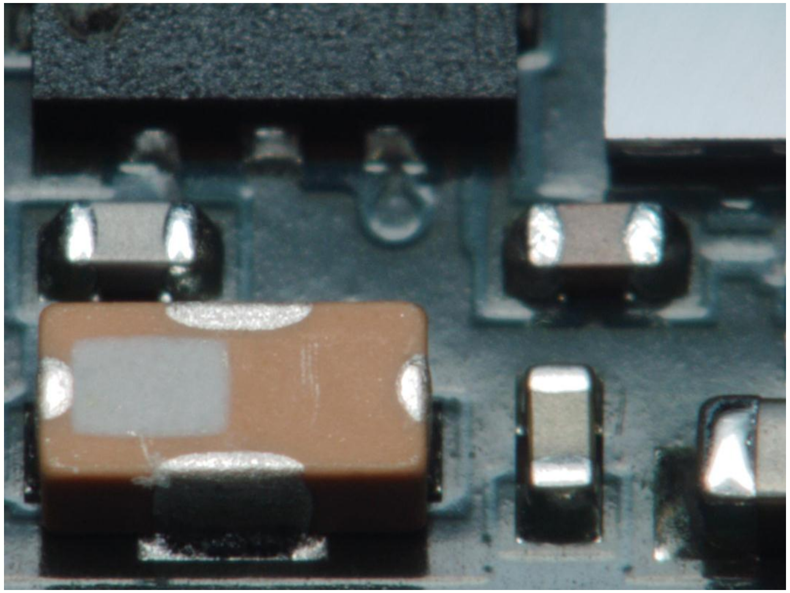
High Frequency?

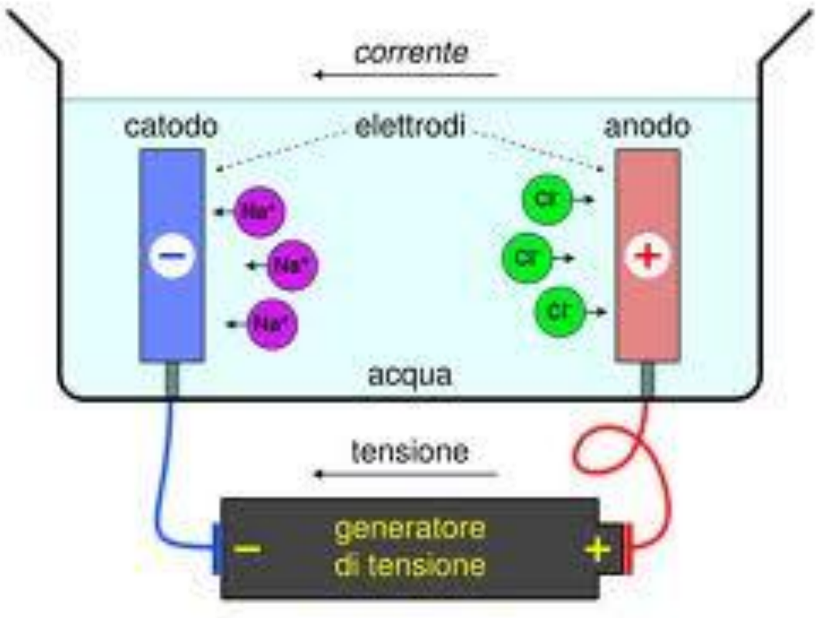
- Unwanted Interactions between circuits
  - Coupling can render electrical interference
  - Signal integrity can be interrupted
  - Residues can interfere with high frequency circuits



APEX EXPO 2012 Research Background

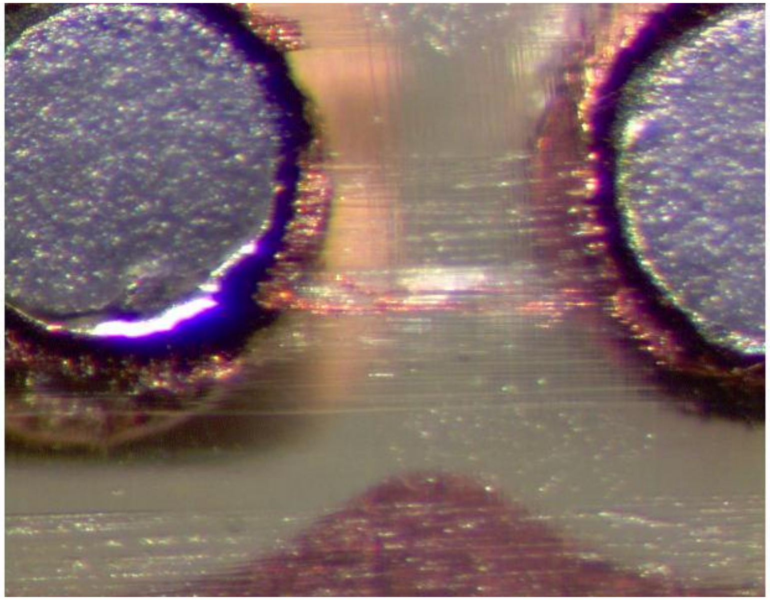
- Disconnect between Electrical Design Engineers and Chemists
  - Voltage, Current, Frequency, etc.
  - Conductivity, Ions, pH, etc.





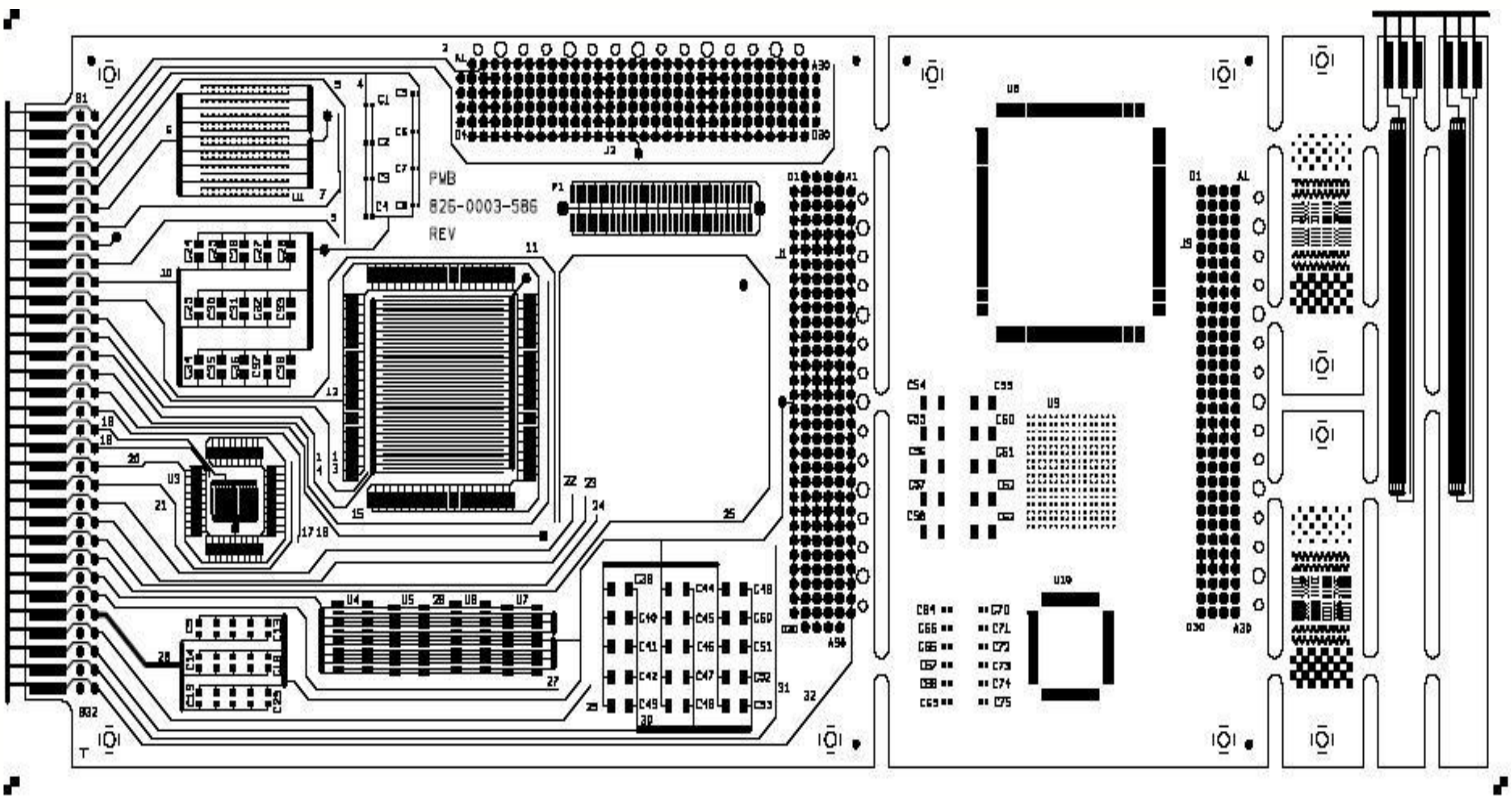
Problem Statement

- Larger pitch devices exhibit lower failure rates
- Smaller / faster devices increase current densities
- Electric field rises inversely with conductor spacing
  - Strong correlation between contamination levels and distances between conductors



B-52 Test Vehicle

- Most up to date industry standard test vehicle for flux evaluation



IPC-B-52 Pro's and Con's

<u>Pros:</u>

- The B-52 improves flux and cleaning evaluations by adding in the effects and cleaning limitations created by components.

<u>Cons:</u>

- Designed for only low level leakage current testing and low voltage tests
  - Unprocessed boards have failed at test voltages above 50 and 100 VDC.
- Not useful for evaluating other key electrical elements that flux residues influence
  - High Voltage / Hi-Pot Testing
  - Rate of Current Change Testing (di/dt)
  - High Frequency Testing
- Small HDI components (01005's, 0201's, QFN's, etc) are not part of the board design and are not being characterized currently as part of the B52 research effort.

IPC-B-52 – Pro's / Con's Continued

Cons - Continued

- Adopted pass / fail criteria is 100 megohm resistance levels and no visual presence of dendrites or corrosion.

- Criteria used for B-52 was originally developed for the B-24, which has no components and much different line widths and spacings.

- Visual inspections are difficult because of board layout and large ground plane. As such, it is very easy to miss items that may have impacts on tests.

New Test Vehicle

- Test vehicle provides a large sampling
  - Better statistical average on single test vehicle
  - Components placed in different orientations
  - Shadowing issues can be tested
- By varying pitch
  - Voltage can be fluctuated across the component
    - Allows for better research on the effects of voltage when contamination is present

SMT Test Vehicle

- SMT Board Design
  - Goal is to provide a more accurate prediction of assembly residues and their effects on reliability

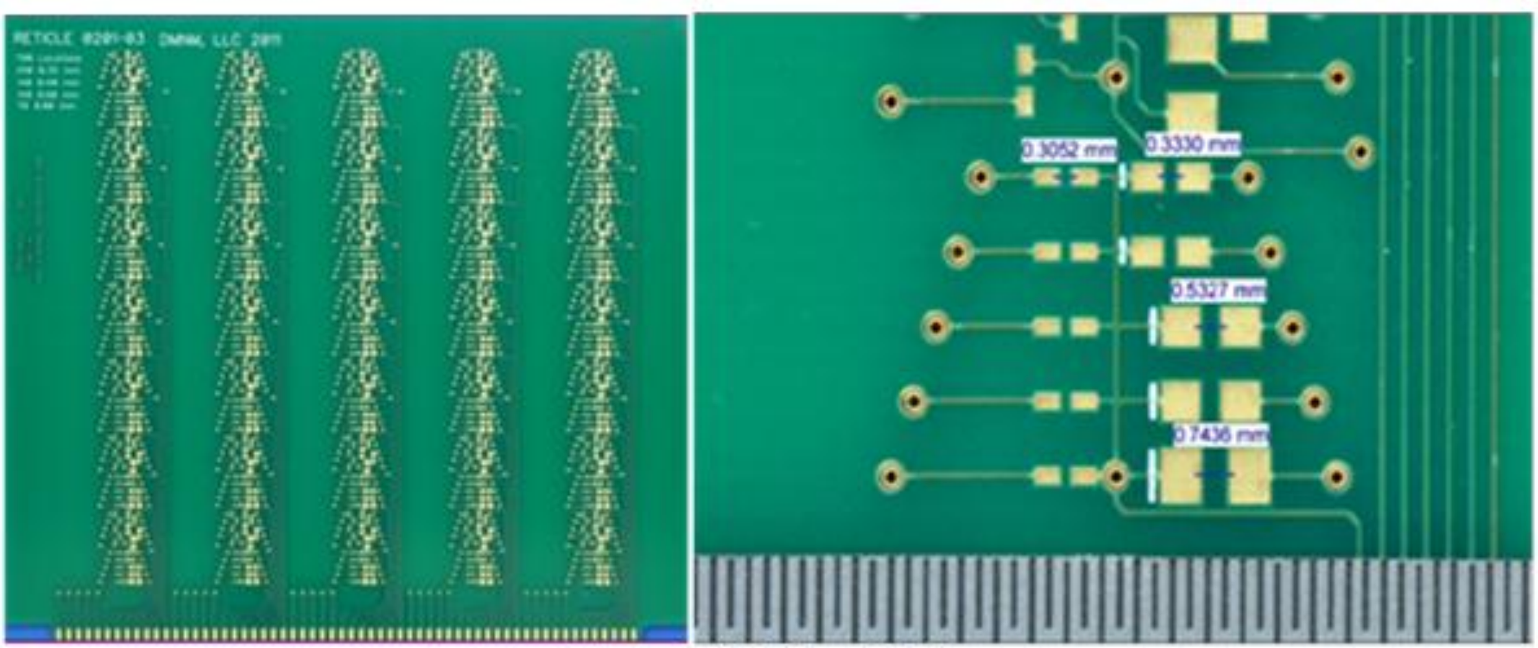
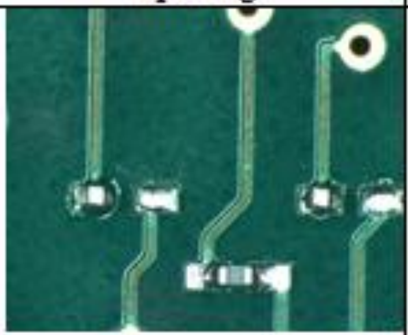
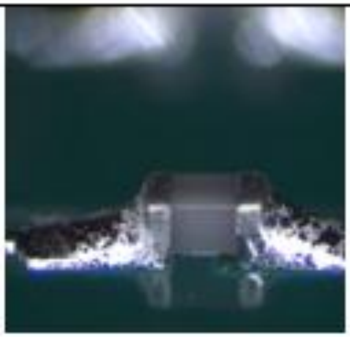
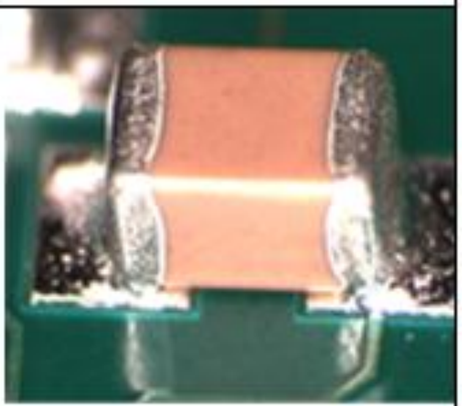


Figure 4: SMT Test Vehicle

SMT Board

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
			

BGA Test Vehicle

- BGA Board Design

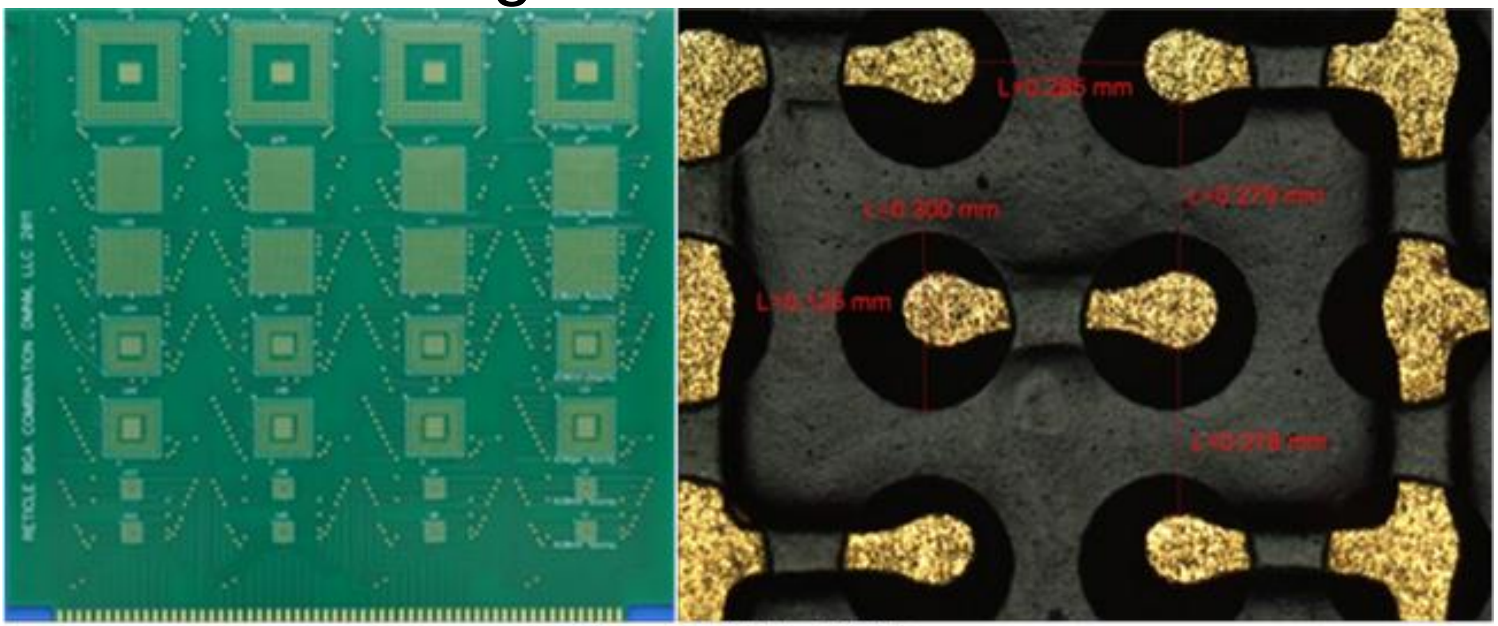


Figure 5: BGA Test Vehicle

BGA Test Vehicle

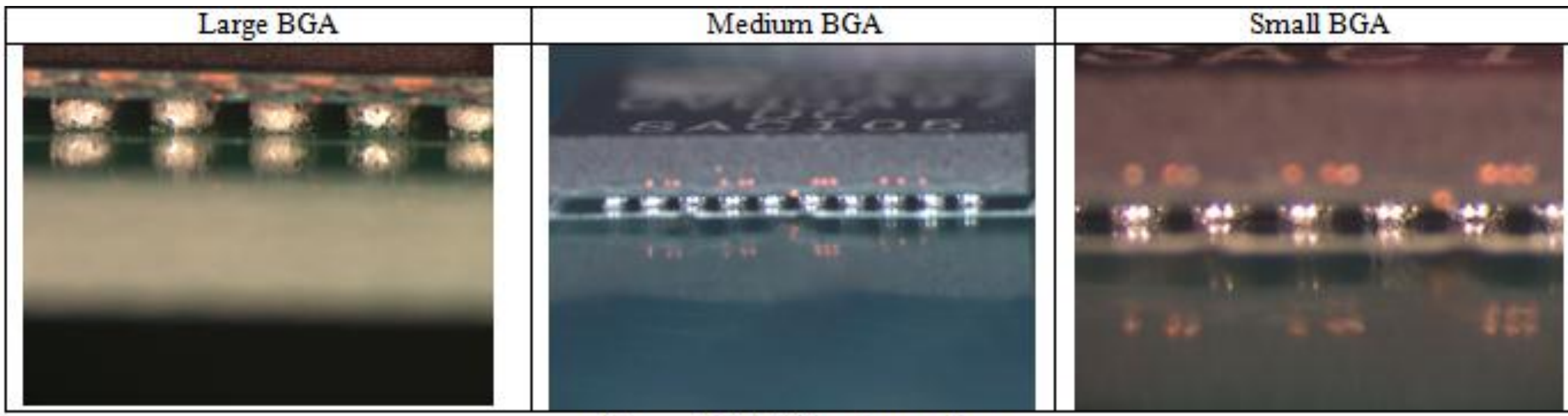


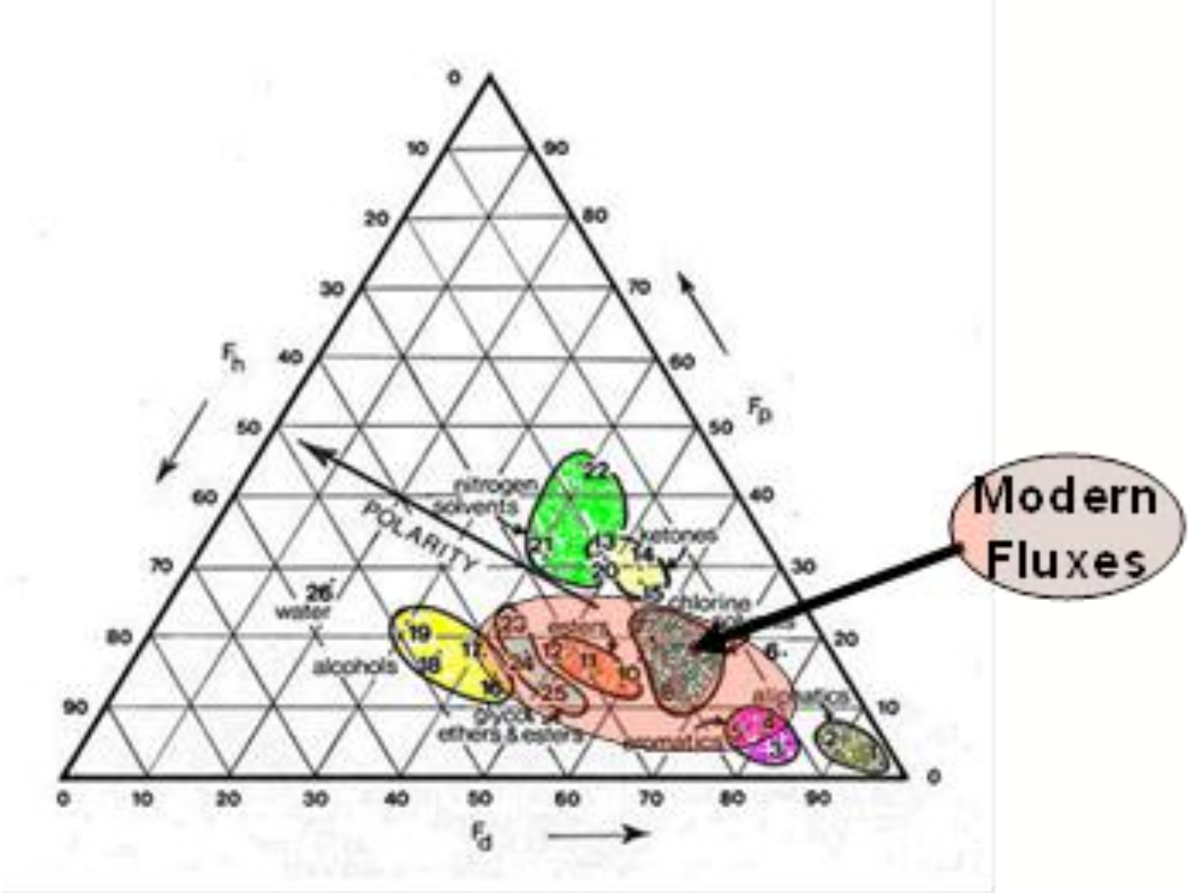
Figure 6: BGA Size Comparisons

Research Time-Line

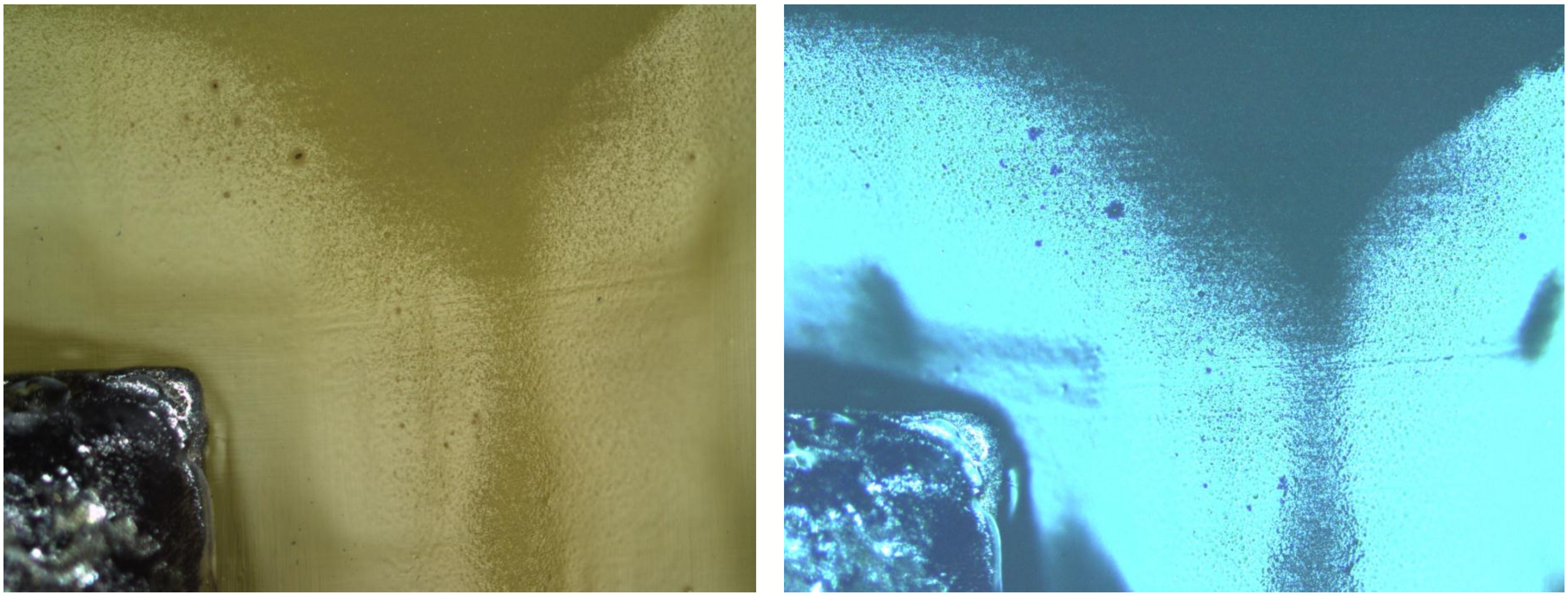
- Phase 1 – Test Board Design (Past)
  - ✓ PCB Layout <0.4, 0.4-0.6,>0.6mm
  - ✓ Component Selection: SMT, QFN, BGA
- Phase 2 – DOE Testing (Present)
  - ✓ PCB Surface Finishes (ENIG)
  - ✓ Flux Types (Indium 8.9 HF1)
  - ✓ Cleaning Agents (Aquanox A4625)
  - ✓ Cleaning Machines (Kyzen custom inline)
- Phase 3 – DFM for PCB Designers (Future)
  - ▪ Layout guidelines to facilitate acceptable electrical performance.
  - ▪ Inspection Criteria(I.e., Visual, Fluorescence, etc.)

Solubility Model

- Expose reflow flux residues to solvent families



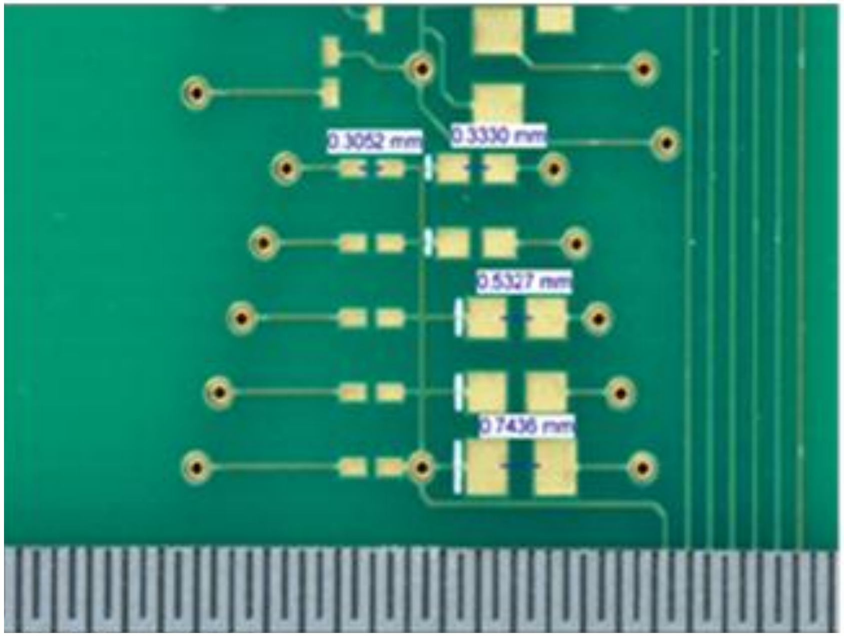
Inspection Technique



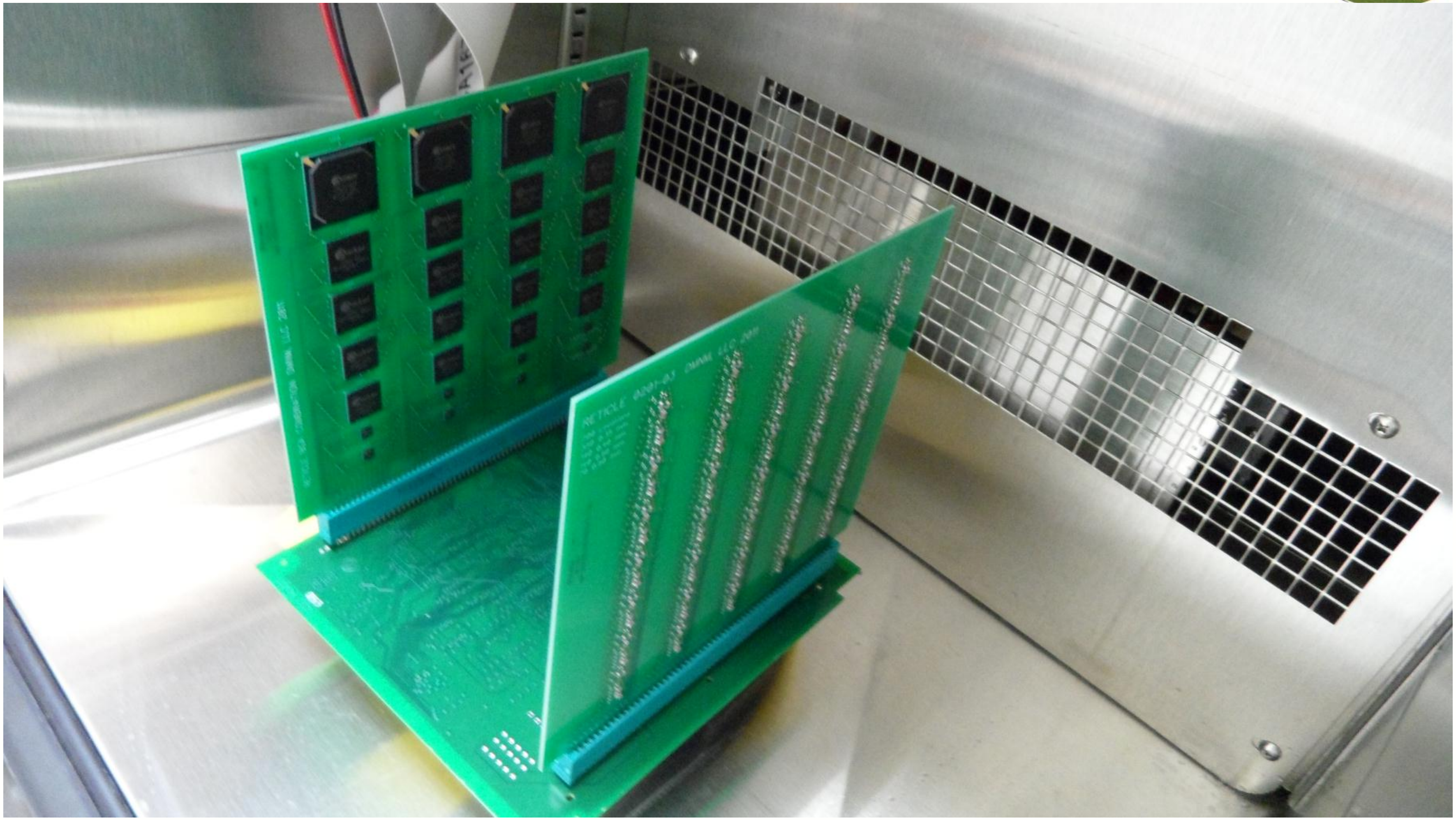
Fluorescence image of flux residue

How Clean is Clean Enough

- DOE tests current leakage from
  1. Boards that were not cleaned
  2. Boards that were partially cleaned
  3. Boards that were totally cleaned
- Voltage was stepped up from Zero Volts
  - 50 volts
  - 100 volts
  - 200 volts
  - 500 volts
  - 700 volts
  - 1000 volts



Test Set-Up



SMT Board

- Visual Inspection per IPC test method 2.6.3.7 (SIR)

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
			

IC Analysis of Bare Boards

- Utilize Ion Chromatography to evaluate ionic cleanliness
  - Anions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2-})
  - Cations (Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+})
  - Weak Organic Acids (Examples: Adipic, Succinic, Glutaric, etc)
- Develop “Stop Light” Criteria for different residues for defined Electrical Characteristics to estimate field performance effects.
  - Criteria may arise for bare boards as well
- Stop Light Model

Green = low level ionics

Yellow = medium level ionics

Red = high level ionics

Note: The following limits may not be reflective of all electrical applications

Bare Boards

- Numerical anion and cation residues for SMT
  - Analysis performed at Kyzen Analytical Lab

ION NAME	Bare Board (BB)	Reticle 020									
		BB 1	BB 2	BB 3	BB 4	BB 5	BB 6	BB 7	BB 8	BB 9	BB 10
Sodium	1.00	0.01	0.01	0.04	0.03	0.02	0.03	0.03	0.00	0.05	0.07
Potassium	1.00	0.00	0.01	0.01	0.02	0.02	0.01	0.02	0.03	0.02	0.02
Calcium	1.00	0.00	0.02	0.06	0.03	0.04	0.05	0.01	0.08	0.06	0.03
Lithium	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	0.02	0.04	0.09	0.12	0.18	0.14	0.13	0.16	0.12	0.04
Ammonium	2.50	0.04	0.05	0.04	0.09	0.12	0.09	0.05	0.05	0.03	0.06
Acetate	0.00	0.98	0.83	0.77	0.87	0.82	0.67	0.92	0.96	0.91	1.78
Formate	0.00	0.67	0.44	0.46	0.29	0.25	0.23	0.22	0.20	0.19	0.52
Bromide	2.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Chloride	2.00	0.25	0.15	0.17	0.20	0.14	0.09	0.42	0.13	0.15	0.22
Fluoride	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	0.00	0.10	0.29	0.06	0.07	0.08	0.09	0.08	0.07	0.06	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
Sulfate	1.00	0.36	0.33	0.43	0.37	0.34	0.36	0.34	0.34	0.58	0.33
Phosphate	0.00	0.53	0.31	0.38	0.20	0.40	0.26	0.27	0.28	0.38	0.15
Citrate	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
WOA - PTH	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
Total Ionics	5.00	2.96	2.48	2.49	2.28	2.45	2.01	2.49	2.30	2.56	3.30

Bare Boards

- Numerical anion and cation residues for SMT
  - Analysis performed at Precision Analytical Lab

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
Sodium	1.00	0.73	0.50	0.56	0.56	0.49	0.55	0.54	0.50	0.57	0.52
Potassium	1.00	0.34	0.33	0.34	0.43	0.41	0.40	0.34	0.38	0.33	0.32
Calcium	1.00	0.09	0.05	0.05	0.08	0.09	0.10	0.10	0.15	0.20	0.09
Lithium	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
Ammonium	2.50	1.57	1.47	1.37	1.62	1.48	1.46	1.39	1.34	1.28	1.25
Acetate	0.00	5.24	4.45	4.04	5.16	4.65	4.68	3.70	5.61	4.76	4.73
Formate	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
Chloride	2.00	0.34	0.24	0.29	0.30	0.22	0.26	0.32	0.25	0.25	0.23
Fluoride	1.00	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
Nitrite	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
Citrate	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
WOA-PTH	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
Total Ionics	5.00	9.33	8.24	7.85	9.42	9.27	8.53	7.56	9.41	8.61	8.25

Bare Boards

- Numerical anion and cation residues for BGA
  - Analysis performed at Kyzen Analytical Lab

ION NAME	Bare Board (BB)	Reticle BGA Co									
		BB 1	BB 2	BB 3	BB 4	BB 5	BB 6	BB 7	BB 8	BB 9	BB 10
Sodium	1.00	0.02	0.03	0.03	0.02	0.04	0.04	0.01	0.01	0.03	0.03
Potassium	1.00	0.03	0.09	0.10	0.06	0.08	0.08	0.02	0.09	0.04	0.06
Calcium	1.00	0.01	0.03	0.03	0.02	0.02	0.01	0.03	0.01	0.03	0.03
Lithium	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	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.01
Ammonium	2.50	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Acetate	0.00	2.08	1.42	1.86	1.55	1.67	1.54	1.54	1.65	1.36	1.47
Formate	0.00	0.85	0.71	0.68	0.66	0.61	0.61	0.47	0.60	0.53	0.58
Bromide	2.00	0.05	0.04	0.04	0.05	0.04	0.00	0.08	0.04	0.00	0.05
Chloride	2.00	0.70	0.35	0.36	0.36	0.22	0.22	0.10	0.25	0.10	0.32
Fluoride	1.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	0.00	0.55	0.88	0.46	0.11	0.22	0.39	0.38	1.09	0.52	0.90
Nitrite	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	0.49	0.29	0.59	0.59	0.52	0.47	0.47	0.57	0.45	0.39
Phosphate	0.00	0.55	0.33	0.32	0.49	0.42	0.29	0.37	0.34	0.50	0.61
Citrate	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
WOA-PTH	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
Total Ionics	5.00	5.32	4.19	4.49	3.93	3.86	3.66	3.47	4.68	3.55	4.44

Bare Boards

- Numerical anion and cation residues for BGA
  - Analysis performed at Precision Analytical Lab

ION NAME	Bare Board	Reticle BGA Combination Bare Boa									
	(BB)	BB 1	BB 2	BB 3	BB 4	BB 5	BB 6	BB 7	BB 8	BB 9	BB 10
Sodium	1.00	0.93	0.96	0.90	1.04	0.85	0.75	0.63	0.70	0.73	0.69
Potassium	1.00	0.40	0.35	0.48	0.48	0.49	0.41	0.38	0.33	0.34	0.34
Calcium	1.00	0.12	0.20	0.20	0.32	0.24	0.25	0.20	0.10	0.09	0.09
Lithium	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
Ammonium	2.50	1.14	1.20	1.33	1.43	1.60	1.21	1.15	1.15	1.18	1.19
Acetate	0.00	7.32	8.48	9.24	11.04	9.68	8.08	7.56	6.91	7.04	7.26
Formate	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
Chloride	2.00	0.53	0.48	0.47	0.54	0.45	0.39	0.37	0.37	0.38	0.37
Fluoride	1.00	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
Nitrite	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
Citrate	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
WOA-PTH	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
Total Ionics	5.00	11.58	13.29	13.97	16.54	14.89	12.46	11.47	10.75	11.49	11.16

APEX EXPO IPC 2013

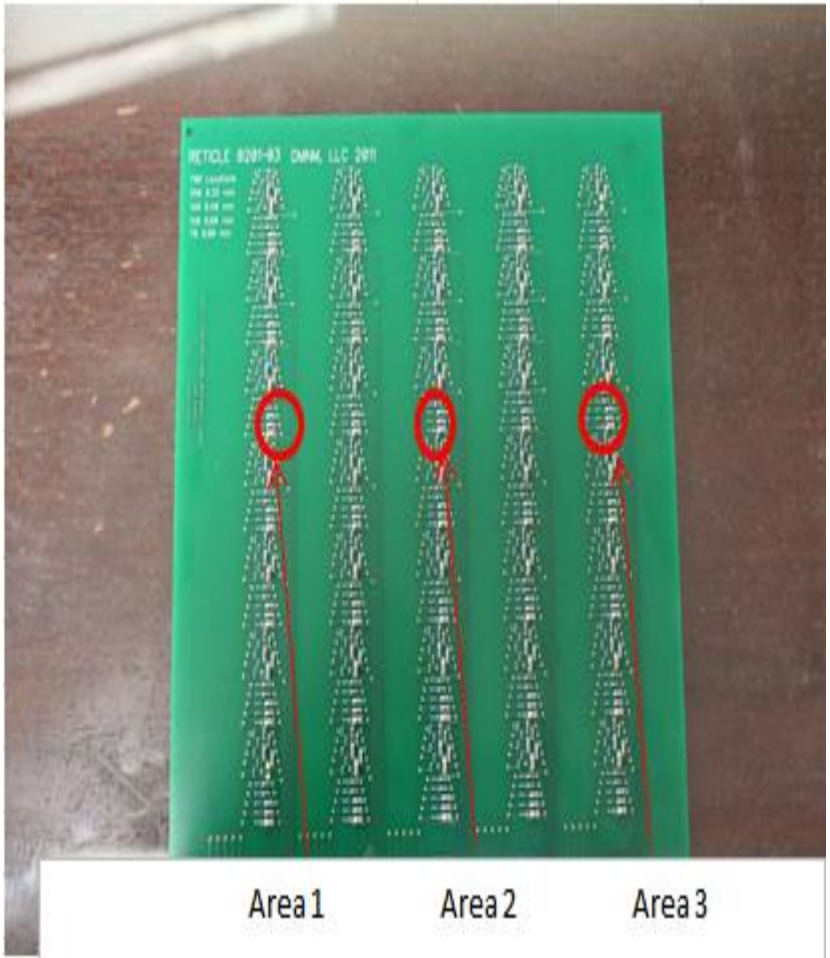
Localized Extractions Data

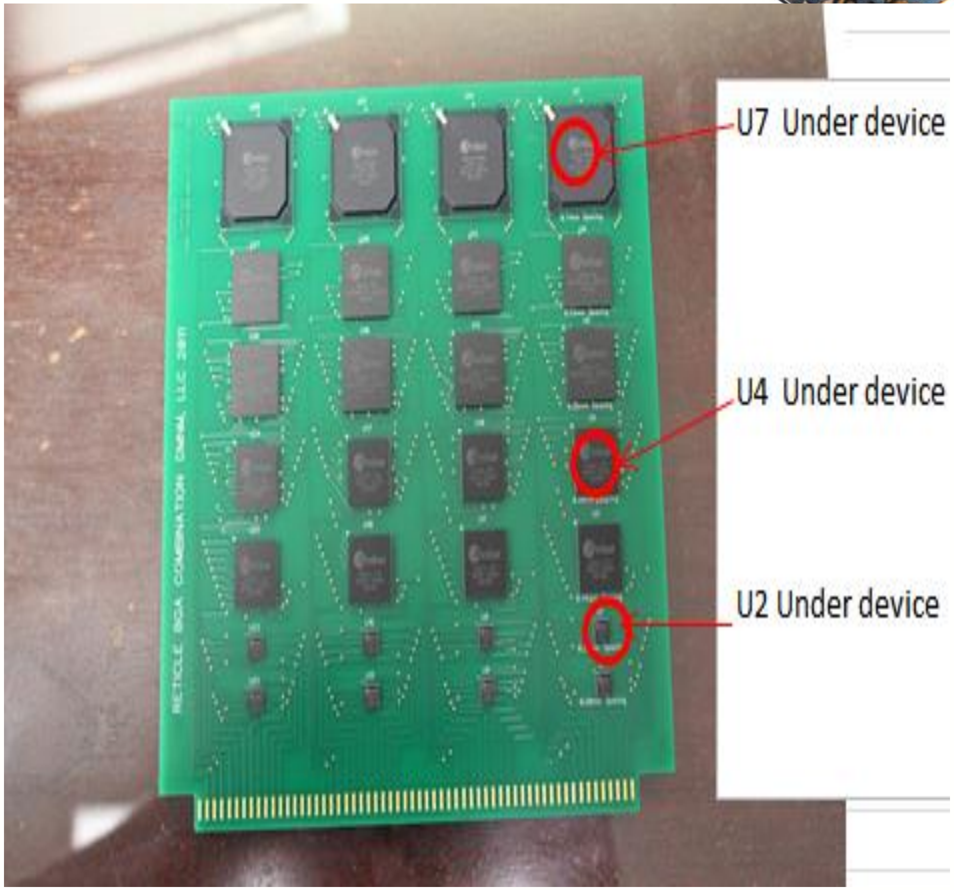
Foresite IC Data

	all values are in mg/in^2 unless noted	Ion Chromatography (Dionex ICS 3000 at Foresite) NA = Not applicable 0 = Below Detection limits of 0.01 ug/in2								
ID#	Sample Description	$C_2H_2O_2$	Cl^-	Br^-	NO_3^-	SO_4^{2-}	WOA	Na^+	NH_4^+	K^+
	Reticle 0201-03 DMNM, LLC 2011									
1	PCBA #7 No Clean Area 1	1.24	0.99	0.36	0.67	1.27	12.33	2.14	0.58	0
2	PCBA #7 No Clean Area 2	1.36	0.81	0.45	0.43	1.04	15.04	2.36	0.75	0
3	PCBA #7 No Clean Area 3	1.53	1.09	0.41	0.57	1.14	13.93	1.99	0.62	0
4	PCBA #8 Partially Cleaned Area 1	2.21	0.85	0.16	0.11	1.05	10.05	2.78	2.88	0
5	PCBA #8 Partially Cleaned Area 2	2.32	0.83	0.19	0.12	0.78	9.58	2.36	2.45	0
6	PCBA #8 Partially Cleaned Area 3	2.27	0.89	0.25	0.11	0.86	8.78	2.54	2.31	0
7	PCBA #10 No Clean Area 1	1.38	1.2	0.31	0.85	2.51	15.24	2..03	0.43	0
8	PCBA #10 No Clean Area 2	1.42	1.13	0.63	0.71	2.45	20.99	2.75	0.51	0
9	PCBA #10 No Clean Area 3	1.36	1.29	0.37	0.65	2.78	17.45	2.33	0.35	0
10	PCBA #11 Partially Clean Area 1	2.04	1.22	0.17	0.28	0.35	9.98	1.05	2.65	0
11	PCBA #11 Partially Clean Area 2	1.98	1.31	0.2	0.25	0.39	10.24	1.28	2.18	0
12	PCBA #11 Partially Clean Area 3	1.85	1.44	0.19	0.26	0.34	9.63	1.36	2.36	0
13	PCAB #12 Clean Area 1	0.12	0.29	0.33	0.14	0.65	5.98	0.88	0.93	0
14	PCAB #12 Clean Area 2	0.16	0.35	0.41	0.11	0.34	4.87	0.96	0.87	0
15	PCAB #12 Clean Area 3	0.18	0.21	0.35	0.15	1.23	5.99	0.78	0.96	0
	Reticle BGA Combination DMNM LLC 2011									
16	PCBA #8 Partially Clean Below U2	1.16	0.82	0.39	0.56	2.95	12.36	2.98	2.54	1.54
17	PCBA #8 Partially Clean Below U4	2.69	1.95	0.31	0.52	2.67	64.67	3.72	5.26	25.5
18	PCBA #8 Partially Clean Below U7	2.77	1.79	0.56	0.48	2.81	39.91	2.39	2.88	8.54
19	PCBA #10 No Clean Below U2	1.38	0.92	0.59	0.42	2.45	18.85	2.35	2.76	0
20	PCBA #10 No Clean Below U4	1.24	1.55	0.63	0.67	2.95	90.35	3.89	3.12	0
21	PCBA #10 No Clean Below U7	1.36	1.62	0.81	0.66	2.23	56.61	2.98	1.69	0
22	PCBA #11 Partially Clean Below U2	1.75	2.78	0.12	0.85	2.29	10.24	2.54	1.45	1.79
23	PCBA #11 Partially Clean Below U4	3.65	1.58	0.18	0.77	3.16	52.98	2.22	1.98	14.4
24	PCBA #11 Partially Clean Below U7	2.88	2.35	0.13	0.59	2.55	43.12	2.16	1.27	15.8
25	PCBA #12 Clean Below U2	0.53	0.53	0.11	0.05	0.36	5.24	0.36	0.55	0.56
26	PCBA #12 Clean Below U4	0.48	0.48	0.15	0.09	0.51	4.59	0.54	0.39	0.95
27	PCBA #12 Clean Below U7	0.61	0.69	0.11	0.04	0.27	5.04	0.29	0.51	0.74

Localized Extractions Sites

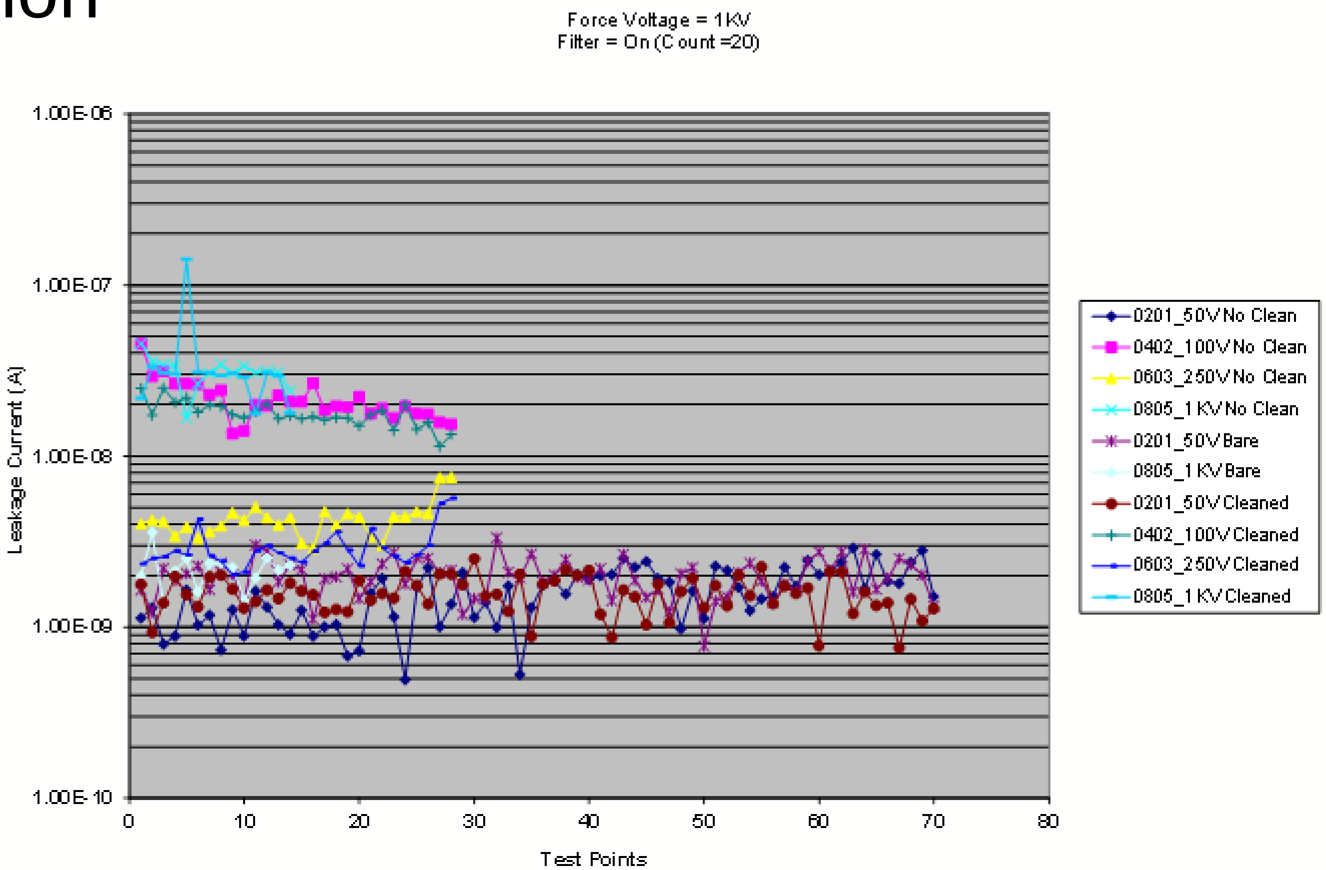
Foresite Extraction Sites





Electrical Testing Data

- Leakage
- Position
- Pitch



Phase III

- Phase 3 – DFM for PCB Designers(Future)
- **Volunteers & Challenges?**
  - Test Pattern
  - PCB Pad Sizes, Pitches, & Stand-offs(Z-axis)
  - Directionality (Devices relative to cleaning system)
  - Type of Fluxes (Clean & No-Clean)
  - Flux Volumes
  - Types of Solvents
  - Types of Cleaning Equipment
  - Ionic Levels?
  - Non-analytical Techniques (Visible, IR, UV, etc.)
  - Analytical Techniques (FTIR, IC, HPLC, GC-MS, etc.)

Questions

- Thank You!