The Failure of a Circuit:
The Reliability Effects of Process Residues

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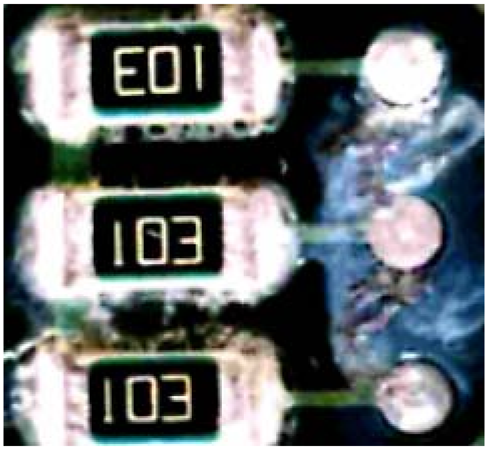

Figure 1

This column will address the corrosive and electrical leakage effects of standard process residues, and the role these residues play in field product performance.

Many elements of today's assembly processes create greater chances for field failures. With major industry changes, such as lead free soldering and continually smaller and more complex circuitry, it is more important than ever to monitor product cleanliness and **be aware of process defects and how to handle them**.

Since the elimination of solvent-cleaned rosin flux, the electronics industry has turned to alternative manufacturing processes such as aqueous clean, water-soluble and no clean processes. The use of these alternate processes has resulted in a growing number of field failures due to corrosion or electromigration issues (Figure 1). This poorer field performance has been directly tied to the changes in process residues (types, levels and reactive states). To improve the way process residues are found and analyzed, tools such as Ion Chromatography (IC) and Surface Insulation Resistance (SIR) testing are used. Foresite's understanding of these changes has come from a 15-year investigation of the failures, process improvement, process qualification, validation and monitoring of these alternative manufacturing methods.

BOARD FABRICATION	COMPONENT FABRICATION	ASSEMBLY PROCESS
• Etch residues	• Plating bath residues	• Solder paste
• Developer chemicals	• Water rinse quality	• Wave solder flux
• Water quality of rinses for inner layers	• Deflashing chemicals	• Cored solder
• Water quality of rinses for outer layers	• Mold release agents	• Rework/Repair operation fluxes
• HASL Fluids (HO) and final rinses	• Preplating oxide cleaning	• Cleaning chemicals
• Alkaline cleaners	• Pretinning flux residues	• Water rinse quality
		• Rework Cleaner
		• Outgassing

Table 1

Sources of corrosive or conductive residues on each assembly come from a variety of process steps and materials. Some of these materials (i.e., flux) are designed to volatilize during soldering to reduce the residue level on the product. Oh, and by the way, nearly all these residues are invisible, <u>especially</u> those that are corrosive. Table 1 lists contaminants and their sources (and this is the short list!).

Electromigration Failures (shorts)

This type of failure occurs when the following key variables are combined:

- a voltage differential (power to ground),
- the transfer fluid (e.g. absorbed surface moisture – in micro-droplet form), and
- a corrosive residue resulting in the deplating of an electrode (anode, i.e., circuit, component lead, etc.) and carrying of the resulting metal salt into solution allowing plating along the current path (dendrite formation as seen in Figure 2).

Figure 2

All three variables must be present before the electromigration failure occurs. With a voltage requirement of as little as 1.5 –2.0 volts to drive the dendrite formation, nearly all electronic circuits are susceptible to this type of failure (as long as the three conditions exist).

Generally, a failure occurs when the spacing between power and ground is connected by a thin layer of moisture. This moisture combines the corrosive residues and the voltage to create a metal dendrite. This conductive metal path creates a short circuit in the field, and the assembly is then returned to the manufacturer where a typical failure analysis is performed.

Failure analysis will often include a SEM/EDX (Scanning Electroinc Microscope/ Energy Dispersive X-ray Analysis) analysis showing the following elements: carbon, oxygen, tin, lead and copper. This elemental investigation provides wonderful photos of the dendrite, and shows that copper, tin and lead metals were the metals creating the short, but it doesn't tell us what caused the dendrite to grow.

We still need to understand the type and level of contamination, as well as determining the sources and why the assembly surface was absorbing moisture. Our focus should not be on which metal created the short (it has to be one of the metals in the area of the failure), but rather, on what corrosive residues caused the dendridic activity and their source. Tools such as Ion Chromatography and SIR testing give a very detailed understanding of the specific residue species, residue amounts and electrical effects in high humidity operating environments.

Figure 2 is an example of a medical device with an electromigration failure. The device, part of a no-clean board assembly, failed in the field due to a large amount of chloride residue from board fabricator processes. The no-clean flux residue did not sufficiently encapsulate enough of the residue to prevent absorbed moisture and the circuit voltage from forming dendrites. Hard (detrimental visible residue, i.e., dendrites) and soft (stray electrical leakage) failures occurred on this device within three months of field operation. Hard electromigration failures are not the only failure type due to residue, electrical leakage failures also seem to increase causing “no trouble found” (NTF) returns from the field.

Electrical Leakage Failures

This type of failure also occurs when the following key variables are combined:

- a voltage differential (power to ground),
- the transfer fluid (absorbed surface moisture – in micro-droplet form), and
- a conductive residue that will carry a current along the current path (no dendrite formation will be seen – Figure 3).

As circuit sensitivity increases (a circuit that can not tolerate more than a .5 meg ohm drift), there is a greater opportunity for a thin layer of moisture and conductive residue to form creating a leakage path bridging the circuits. These electrical leakage failures differ from electromigration failures in that no actual metal migration takes place causing a hard short. This failure mechanism consists only of stray voltage on the surface of the circuit board affecting the sensitive circuit. Moisture is absorbed by the surface residues to create this conductive film but does not contain a level of corrosive residue to cause electromigration. Figure 3 shows an assembly that failed due to electrical leakage of 1.54 volts on a 12-volt input.

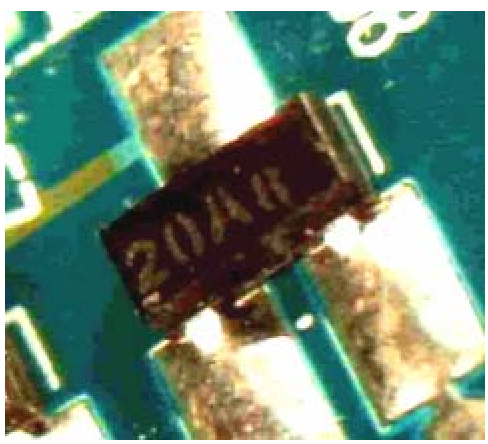

Figure 3

These failures will normally appear as NTF field returns -- a moisture opportunity in the field created the failure. When the failed board is bench tested, it works fine. If the board is returned for an NTF failure, the boards can be placed in a high humidity chamber (65% RH) for a short period of time (4 hours) and retested. If the units fail after this procedure, a leakage problem is the source.

These boards could be baked at 125° F for 3 hours to return them to good working condition, but unless proper corrective action is taken, the boards will continue to fail when exposed to high humidity. A corrective action for these failures is to properly remove or complex the residue.

Why Haven't We Had These Problems Before?

Electromigration and electrical leakage failures have increased dramatically over the last 10-15 years due to the elimination of high solids rosin fluxes. The traditional assembly process left a layer of rosin varnish sealing the area between the circuits. This invisible protection system does not exist with the alternative assembly fluxes in use today. Historically, rosin fluxes contained 25-50 percent solids and required solvent cleaning that reduced the rosin amount by about two thirds. The remaining rosin served as a protective film separating the ambient moisture from the circuitry.

Today's flux technology typically contains less than 1 percent solids and is designed to volatilize during soldering. The remaining residues do not create an insulated barrier between the circuitry.

Lets look at an experiment that will compare the traditional RMA fluxes to the new no clean technology.

Bare Board Cleanliness Experiment

This experiment is an ionic and electrical evaluation of the board fabrication residues and their effect on the electrical performance of no-clean assemblies. This evaluation used the IPC B-24 boards (FR-4 boards with copper traces on one side with a HASL surface finish). One group of boards had the typical cleanliness levels seen on HASL'd bare boards. The other group was cleaned in a saponified aqueous (DI Water) in-line cleaner. The test coupons were wave soldered: one using a no-clean liquid flux (2.5% solids), the other an RMA flux (25% solids), cleaned in a methanol aziotrope (Freon TMS). Two bare board conditions (cleaned and not cleand) were used in the no-clean assembly process. The RMA fluxed test boards were used in the uncleaned, pre-assembly condition.

Ionic and Electrical Analysis

Once the test boards were processed, a surface analysis was performed. The analytical instruments used to determine the ionic cleanliness and rosin levels was a Ion Chromatograph and a HPLC (High Performance Liquid Chromatography) organic system. Ionic analysis was performed per IPC TM 650 2.3.28 and organic analysis was performed per IPC TM 650 2.3.27. ROSE (Resistivity Of Solvent Extract) testing was completed on an Omega Meter 600R per IPC TM 650 2.3.25. The electrical assessment (SIR) was performed per IPC TM 650 2.6.3.3A. Each value represents a mean value of 5 samples for IC and Rosin data and 4 samples for SIR data.

Ion Chromatography and Organic Analysis (all values are in ug/in^2)
ROSE (OM 600R values are in ug/in^2 of NaCl equivalents

IPC – B-24 boards HASLed (all values are in ug/in^2)	**Rosin (abeitic acid)**	**Chloride**	**Bromide**	**WOA**	**OM 600R**
Bare unprocessed boards Standard Process	<0.1	5.79	0.37	<0.1	2.1
Bare Board Cleaned in DI water/saponifier (at DSI)	<0.1	1.12	0.15	<0.1	1.1
No Clean Wave Soldered Standard Process	134	5.12	1.04	34.2	9.2
No Clean Wave Soldered DI water/saponifier Bare Board	153	0.89	1.13	31.4	13.1
RMA fluxed / Solvent Cleaned	2745	18.19	3.71	<0.1	8.3

Table 2

SIR Electrical Assessment (all values are in ohms of resistance)

IPC – B-24 boards HASLed (100 volt test voltage)	Initial Ambient	24 hour 85C/85%	96 hour 85C/85%	168 hour 85C/85%	Final Ambient
Bare unprocessed boards	2.3e10	**8.1e7**	**1.0e6**	**1.0e6**	**1.0e6**
Bare Board Cleaned in DI water/saponifier (at DSI)	3.1e11	1.3e10	2.3e10	6.9e10	3.3e11
No Clean Wave Soldered Standard Process	1.7e11	1.1e8	**1.3e7**	**1.0e6**	**1.0e6**
No Clean Wave Soldered DI water/saponifier Bare Board	2.7e11	2.4e10	3.5e10	1.2e11	3.9e11
RMA fluxed / Solvent Clean	3.9e12	5.6e11	6.5e11	7.2e11	5.1e12

Table 3

(bold faced results indicate values that are below the 1.0 e^8 minimal value defined by J-Std-001 and are considered failures)

What we see in this experiment is a group of bare boards from a standard HASL'd process showing <u>high chloride levels</u> on the surface of the boards from the fabrication process (HASL flux and tap water rinsing). Since the bare boards were dirty (by our standards chloride level > 2.0 ug/in^2) before soldering, the bare unprocessed boards <u>showed hard electrical failures</u> by the end of the first 24 hours and never recovered. The dirty boards had multiple corrosion sites and dendrite growth, but no white residue (no flux residue for water to react with). ROSE data shows similarly low levels for both bare board groups. By comparison, the cleaned bare boards showed <u>low ionic residue levels</u>

(chloride) and passed SIR by performing well with high resistance levels throughout the SIR test, causing no electrical leakage or electromigration failures or growth.

The no clean fluxed and soldered boards (standard HASL bare boards) showed electrical failures by the 96-hour mark that never recovered. These boards also showed multiple corrosion sites and dendrite growth areas, as well as white residue in many areas of the board. The no clean fluxed and soldered boards (DI water/saponifier cleaned) showed no corrosion sites and no metal, migration, along with good electrical performance and white residue. The RMA fluxed and solvent cleaned boards showed good electrical performance and did not have any sites of corrosion or metal migration, but there were a number of white areas on the board surface (moisture reacted with the rosin).

Rose testing showed acceptable levels for the RMA flux, but Ion Chromatography showed very high chloride levels (activator in the flux) for the RMA flux. This indicates that to have good electrical performance for high chloride (corrosive activator residues) levels there must also be a large amount of rosin to encapsulate the residue. ROSE testing showed acceptable levels (by the old mil-spec limits) for the no-clean assembly that failed, and unacceptable levels for the no-clean and RMA assemblies that passed. This supports the discussion that the ROSE testers are process control tools and not a measure of cleanliness that will predict performance.

Conclusions

Dirty bare boards will cause corrosion and adversely effect the field performance of the no-clean electronic assembly in high humidity situations. Good electrical performance occurred with only two conditions, clean bare boards and protective rosin coated boards. These same factors positively affect field performance.

ROSE testing showed that these process control tools are not a measure of ionic cleanliness as it relates to product performance. Moreover, this is only one aspect of the residue effects on electrical performance. There are many other issues still left to address and correct.

Summary

Our industry is just starting to understand the range of effects our process residues contribute to the product performance in the field. Stray voltage on a sensitive circuits should not be allowed on class 1, 2, or 3 hardware, but it is normal practice to allow this to happen.

It is important to note that these failures are not due to problems in the design. Foresite has data on ten-year old designs (no fine-pitch, through-hole technology) that only started having problems when the process recently incorporated water soluble flux and data on old designs that were originally processed with water soluble flux and did not have a problem until recently (soldermask porosity problems trapping more residue).

These are both class 2 and 3 hardware conditions which shouldn’t have performance problems due to process residues. These problems are not design limitations, but process misunderstandings. Remember, not all visible residues are bad and not all visually clean boards are good.

As the electronics industry meets the challenges of the consumer and industrial market, the addition of product features – faster, cheaper, smaller with more gadgets and colors – are expected to continue.

Process residues will continue to cause electrical field failures at an ever growing level if they continue to be ignored or unchecked. We must define and understand the new processing variables that cause the performance failures and document their elimination.

No circuit card assembly should fail because a touch-up operator used an aggressive flux (OA) on a component and then tried to clean off the flux residue with a brush and bottle of water or alcohol; nor should an assembly process be allowed to cause electrical leakage and field failures due to excessive no-clean flux residue on the topside of the board with a poor preheat to activate the flux. We must continue to document what the failure mechanisms are, and the best corrective actions taken. Moreover, we must strive to understand the new critical parameters of the residue type and level in order to have great product field performance as we meet the challenges ahead.

Bio:
Terry Munson is the President of Foresite, Kokomo, IN. He has extensive electronics industry experience in applying Ion Chromatography analytical techniques to a wide spectrum of manufacturing applications. His company, Foresite, is a failure analysis and process assessment facility with expertise in solder joint quality and residue effects on electronic hardware.

Terry currently chairs the IPC Rework Cleaning Task Group and has spent 16 years participating with the IPC task group activities on CFC elimination, no-clean fluxing, and aqueous cleaning.