The Failure of a Circuit:
Reliability Effects of Process Residues

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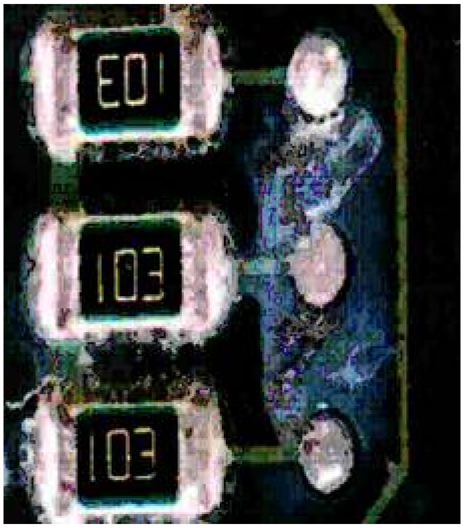
Figure 1



This discussion will address the corrosive and electrical leakage effects of standard process residues, and the role that 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 assembly practices, the electronics industry has turned to alternative manufacturing processes such as aqueous clean, water-soluble and no clean processes for the past 10-15 years. The use of these alternate processes has resulted in a growing number of field failures due to electromigration or corrosion issues. This poorer field performance has been directly tied to the changes in process residues (types, levels and reactive states). Our understanding of these changes has come from our 15 year investigation of the failures, process improvements, process qualifications, validations and monitoring of these alternative manufacturing methods. To improve the way we look at process residues we use tools such as Ion Chromatography (IC) and Surface Insulation Resistance (SIR) testing.

Today's sources of corrosive or conductive residues on each assembly come from a variety of process steps. 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, especially the corrosive ones.

Board contaminants come from the following scenarios (and this is the short list!)

BOARD FABRICATION	**COMPONENT FABRICATION**	**ASSEMBLY PROCESS**
• Etch residues	• Plating bath residues	• Solder paste
• Developer chemicals	• Water quality rinses	• Flux – wave
• Water quality rinses for inner layers	• Deflashing chemicals	• Cored solder
• Water quality rinses for outer layers	• Mold release agents	• Reworked/Repaired Fluxes
• HASL Fluids (HO) and final rinses	• Preplating oxide cleaning	• Cleaning chemicals
• Alkaline cleaners	• Pretinning flux residues	• Water rinse Quality
		• Rework Cleaner
		• Outgassing

Electromigration Failures (shorts)

Figure 2

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

1st is a voltage differential (power to ground),

2nd is the transfer fluid (e.g. absorbed surface moisture – in micro-droplet form) and

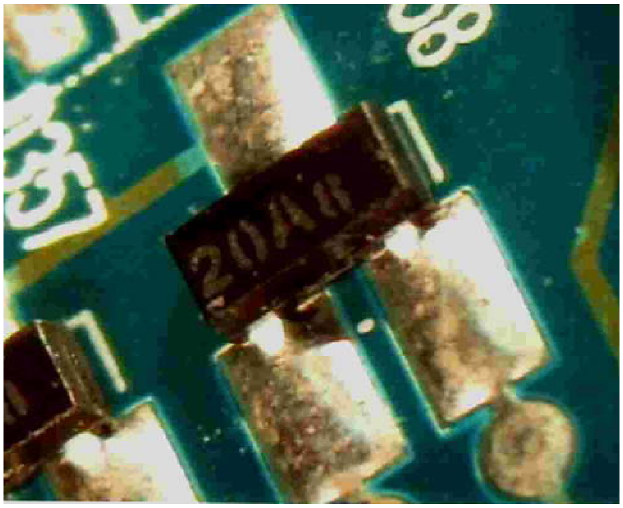
3rd is a corrosive residue that will create the deplating of the anode and carry the metal salt into solution and allow plating along the current path (dendrite formation as seen in the photos).

All three variables must be present in order for the electromigration failure to occur. With a power 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 criteria (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 that combines the corrosive residues and the voltage to create a metal dendrite that shorts the circuit. This conductive metal path creates a short circuit on an assembly in the field, and this assembly is then returned to the manufacturer where a typical failure analysis is performed. This typical failure analysis will often include a SEM/EDX analysis showing the following elements: carbon, oxygen, tin, lead and copper. This elemental investigation provides some wonderful photos of the dendrite, and shows that copper, tin and lead metals were the metals that created the short, but it doesn't tell us what caused the dendrite to grow.

We still need to understand the contamination types and levels, 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 dendrites and where they came from. We have found that tools such as Ion Chromatography and SIR testing give us a very detailed understanding of the specific residue species, residue amounts and electrical effects in high humidity operating environments. Figure 2 is an electromigration failure, of a medical device, that failed in the field due to a large amount of chloride residue from the board fabricator left on a No Clean assembly. The No Clean flux residue was not encapsulating enough to keep the board fabrication residues away from absorbed moisture and the circuit voltage. Hard and soft failures occurred on this instrument within 3 months of field operation. Hard electromigration failures are not the only failure type due to residue, electrical leakage failures seem to increase also (many times they appear as NTF returns from the field).

Electrical Leakage Failures

Figure 3



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

1st is a voltage differential (power to ground),

2nd is the transfer fluid (absorbed surface moisture – in
micro-droplet form) and

3rd is a conductive residue that will carry a current along the current path (no dendrite formation will be seen – see photo).

As circuit sensitivity increases, there is a greater opportunity for a thin layer of moisture and conductive residue to form creating a leakage path (bridging these 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.

These failures will appear as no trouble found (NTF) field returns. This happens because of a moisture opportunity in the field creating the failure. When the failed board is tested on the bench, it works fine. These failures can be placed into a high humidity chamber (65% RH) for a short period of time (4 hours) and retested. If the units fail after this procedure, it is because they have a leakage problem. These failures can be baked out at 125° F for 3 hours to return them to good working condition, but will continue to fail when exposed to high humidity. A corrective action for these failures is to properly remove the flux residue or to complex it somehow.

Why Haven't We Had These Problems Before?

These electromigration and electrical leakage failures have increased dramatically over the last 10-15 years due to the protection that was lost with the elimination of high solids rosin fluxes. Traditional assembly practices left a layer of rosin varnish sealing the area between the circuits. This invisible protection system does not exist in the alternative assembly fluxes. The water soluble and no clean fluxes of today typically contain less than 1% solids. Historically, rosin fluxes contained 25-50% solids and required solvent cleaning. The solid cleaning of these fluxes reduced the rosin amount by two thirds. The remaining rosin was a protective film separating the ambient moisture from the circuitry.

With today's flux technology designed to volatilize at the soldering phase, the remaining residues do not create an insulated barrier between the circuitry. Let us 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' effects on the electrical performance of no clean residues. 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 HASLed bare boards. Another group was of the HASLed B-24 coupons that were cleaned in a saponified aqueous (DI Water) in-line cleaner at Diversified Systems Inc. These test coupons were wave soldered with one of the following fluxes: a no clean liquid flux (2.5% solids) and not cleaned, or an RMA flux (25% solids) and cleaned in a methanol aziotrope (Freon TMS). Two bare board conditions were used with the no clean assembly process, cleaned and not cleaned. The RMA fluxed boards used the not cleaned bare boards.

Ionic and Electrical Analysis

The analytical analysis instruments used to determine the ionic cleanliness and Rosin levels was a Dionex Ion Chromatograph and a Waters HPLC 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 testing was done 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

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

What we see in this experiment is a group of bare boards from a **standard HASLed** process showing high chloride levels 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 showed hard electrical failures 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 low ionic residue levels (chloride) and passed SIR by performing well with high resistance levels throughout the SIR test, and caused 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 of the Experiment are that 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

We, as an industry, are just starting to understand the range of effects that our process residues contribute to the product performance in the field. Stray voltage on a sensitive circuit should not be allowed on class 1, 2, or 3 hardware, but they are. Remember that this is not a failure due to design problems. We have data on ten year old designs (no fine pitch, just through hole technology) that only started having problems when they switched to water soluble fluxes two years ago. We also have data on ten year old designs the switched to water soluble fluxes ten years ago and did not have a problem until a year ago (soldermask porosity problems trapping more residue). These are both class 2 and 3 hardware conditions which shouldn't have these performance problems due to process residues. These problems are not design limitations, but process misunderstandings. Not all visible residues are bad and not all visually clean boards are good.

Our consumers buy electronics knowing it will be outdated sometimes before the 30 day warranty expires, but as long as the product provides the functions (i.e. 386 notebook or a 27 inch TV) and performs well, they don't replace it until it fails. When they do replace it, they remember the product's past performance and all the strange times it didn't work for no apparent reason (not all computer problems are software related). Good field performance will greatly improve brand loyalty in the consumer world.

As the electronics industry meets the challenges of our time, product functions (faster, cheaper, smaller with more gadgets and colors) are expected to continue. Product performance will help us define if we are a throw-away society, or a craftsmanship based one with great products, great performance and ever improving understanding of the needs of the market. As history looks back on this very important time in electronics manufacturing, will it show that we made great advances in the technology bases, or will it show that we struggled through the changes? These change are both environmentally and technology driven. Process residues will continue to cause electrical field failures at an ever growing level if they continue to be ignored or unchecked. It is up to us as an industry to identify the good process practices. Then 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 what are the best corrective actions. 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.