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THE RUSH TO CLEAN NO-CLEAN

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Conductive crystals, white residues, and decreased reliability

The rush to clean no-clean

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Just as the little girl in the 1982 film Poltergeist eerily exclaimed, "they're back," the electronics assembly industry has witnessed the return of a familiar yet unappreciated process step: cleaning.

Once commonplace, then relegated to military and other high reliability applications, today defluxing has once again moved toward the mainstream. The miniaturization of electronic assemblies and their components, implementation of lead-free alloys, combined with improved quality standards and higher reliability expectations have culminated to form a growing demand for ionicly clean electronic circuits.

This paper will review the major causes of residue-related failures including dendritic growth, electrical leakage, and under-coating adhesion failures. Why we clean, what we are removing, and how clean is clean will be presented.

Keywords: Cleaning, Cleanliness, Defluxing, Electro-Migration, Electrical Leakage, Cleanliness Testing

Context

The concept of personal hygiene was greatly enhanced by the Romans in 312 BC with the invention and introduction of public baths. This was further enhanced by the end of the second century AD with the introduction of soap, invented by the Greek Physician Galen.

In 467 AD, Rome fell, as did many of its then modern inventions and influences. This included public baths. The fall of Rome and its public bathing is cited by modern day historians as one contributing factor to the spread of the great plagues of the middle ages and, in particular, the Black Death of the fourteenth century.

Modern day

Today, thankfully, cleanliness has entrenched itself into all aspects of human civilization. In fact, the word "clean" has become part of our modern vernacular. We admonish our boxers to "have a clean fight." We wish upon our favorite sports teams a "clean sweep" When at the doctor we hope for a "clean bill of health" and we hope to "clean up" at the tables in Las Vegas.

This author has spent 26 years in the electronics cleaning industry and has seen many trends. Today's modern cleaning trend is curious. If I ask an audience of engineers "what is the most common flux removed from circuit assemblies today?," I can rely on the consistency of the answers. The most common answer is water soluble (OA). Second to water soluble is RMA. Actually, neither answer is accurate. The correct answer is no-clean. No-clean flux is the most common flux removed after reflow. Why? The answer is ironic.

Déjà vu

To understand why no-clean fluxes are being removed from assemblies after reflow in record numbers we need to understand the history of flux removal and assembly designs from an historic perspective.

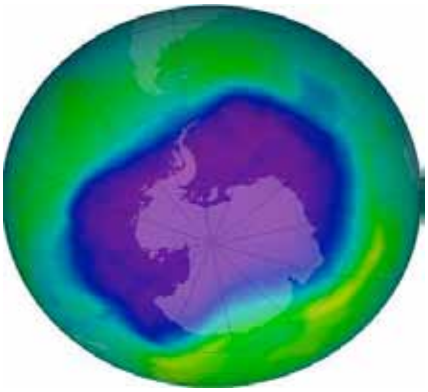

Figure 1. Ozone Depletion, 1989.

Let's travel back in time, specifically to pre-1989. Before 1989, nearly all assemblies were cleaned. Components were "stuffed" into assemblies. Assemblies were soldered, leads were trimmed and assemblies were cleaned to remove the flux residues. Cleaning was an integral part of the assembly process. With few exceptions, assemblies were cleaned using one of three medias; 111 Trichloroethane, Freon TMS (or generic equivalent) or water.

The great buzzkill of the 20th century arrived in 1989 in the form of an international treaty entitled the Montréal Protocol. Apparently, these CFC-based cleaning solvents had been busy destroying the Earth's ozone layer (*Figure 1*) and the United States, Canada and about nine other countries were determined to stop it. As a result, many CFC-containing products were banned under this treaty including the two major cleaning solvents used in electronics production.

Amidst the industry wide panic, fueled by several trade magazines cover pages with their countdown to the end of CFCs came a new technology called "No-Clean Flux." More than just a technology, it was a concept. Reduce the volume, visibility and affect of residues and leave them on an assembly. Problem solved!

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While assemblers of military, medical and other high-reliability products continued to remove flux residues by cleaning their assemblies (using alternative technologies), the greater commercial industry, having no specific mandate to clean, abandoned cleaning by switching to a no-clean process.

This bi-polar approach (cleaning is required/cleaning is not required) was largely successful. No-clean technology, in most cases, left behind mostly benign residues that did not negatively affect most electronics assemblies. In recent years, however, there are a growing number of commercial assemblers that have rejoined the ranks of military and medical processes and turned to cleaning. Our industry is seeing a resurgence of cleaning. Because RMA and OA flux residues have always been removed via a cleaning process, the growth in cleaning is represented by commercial assemblers removing no-clean flux residues. Because there are many times more commercial products being built compared to specifically high-reliability products, the growth in cleaning is no-clean based, hence the fact that no-clean represents the highest share of flux cleaning today.

Houston, we have a problem

As previously mentioned, there is a modern migration toward a cleaning process. No-clean processes have been in popular existence for 22 years. Why now are no-clean processes being replaced with cleaning processes? What changed?

Today, there are two primary problems associated with residues left on a circuit assembly—electrical migration and electrical leakage. These problems are hitting many assemblers hard and, in a growing number of cases, have lead to a rush to clean no-clean.

Electrical migration can occur when three key elements combine on an assembly:

- Voltage differential (power to ground). As little as 1.5 V
- Moisture
- A corrosive or conductive residue

When the three key elements are present with other factors, it is possible to experience electro-migration, commonly in the form of dendritic growth between two electrical connections on the assembly. A dendrite is a metal crystal (*Figure 2*) that forms as metal dissolves at an anode and is electro-deposited at a cathode. The electro-deposited metal takes the form of metal crystals.

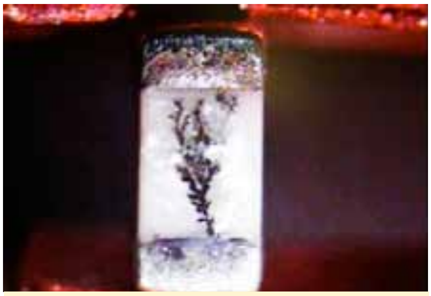

Figure 2. Dendritic growth on component with 5 VDC applied (courtesy Foresite).

Dendrites are harmful because they increase electrical conductivity between two points, causing instrument errors and /or electrical shorts.

The nefarious nature of dendrites comes from the fact that they are extremely slow growing. While rapid dendritic growth can be demonstrated in a lab environment, in a 'normal" environment, they may take from 8-18 months to grow. Unless accelerated age testing (e.g., steam-age testing) is performed, it is impossible to predict the likelihood of dendritic growth until a catastrophic event occurs.

Electrical leakage

The other issue associated with assembly residues is electrical leakage. This is a particularly difficult diagnosis to confirm because the results of electrical leakage tend to be of a temporary nature. At issue is the fact that electrical leakage is a temporary problem. Its affects are witnessed only when the assembly adsorbs moisture. When the moisture is removed, the problem disappears, frequently resulting in no-trouble-found (NTF) field returns. A typical scenario goes like this: An assembly is tested and shipped to a customer in Mississippi in February. The customer begins to use the product, a hand-held portable instrument. By August, the customer notices that the instrument is not working properly and returns it to the manufacturer for inspection. Upon receipt by the manufacturer, the product is tested within the air conditioned and humidity-controlled environment of the test lab. Of course, the problem cannot be duplicated because the humidity-caused moisture has disappeared. This results in a NTF status and the product (and the problem) is returned to the customer. At issue is the flux residue that becomes more active when subjected to moisture, allowing increased conductivity to alter a product's function but not enough to create a short.

Why now? What changed?

As previously stated, we have been using no-clean flux, mostly successfully, for 22 years. Why is our industry seeing an increase in electro-migration and electrical leakage now? The answer is simple. There are two reasons for the increase in residue-related failures. One factor is the implementation of lead-free alloys.

First, let's consider the purpose of flux. Flux reduces oxidation during the reflow process when solder changes from a solid state to a liquid state. The flux's responsibility is to reduce oxidation and to encapsulate the metal salts that form when solder is in a liquid state. Historically, flux had a solids content of 30-50%. A higher solids flux maintains a greater ability to remain useful during the entire reflow process. Today's no-clean fluxes maintain very low solids content, normally 1-3%. Lead-free solder requires a higher reflow temperature compared to traditional 63/37 alloys. An increase of 50˚-60˚C on a low solids content flux may result in the flux volatilizing or polymerizing too early in the reflow process. This action may result in the flux's inability to encapsulate the metal salts that are generated during the reflow process, resulting in unencapsulated metal salts on the surface of a circuit assembly. These metal salts, and other residue species, have the potential, when combined with electrical voltage and moisture to produce a fertile breeding ground for dendritic growth or electrical leakage.

Another contributing factor is miniaturization. Our assemblies are getting smaller and, as a result, the component densities are getting higher. In any reflow process, flux, embedded into the solder paste, oozes from a pad when subjected to heat. Like ice melting on a table, flux will drain from a pad. Historically, this was not a major issue because the assembly's pads were physically far enough apart as to leave a flux-free gap between two pads (*Figure 3*).

As assemblies were miniaturized and component densities increased, the flux residue would spread from pad to pad, forming a bridge (*Figure 4*) of residue between cathodes and anodes.

Even though no-clean flux residues are ionically weak and are hardly corrosive, the physical close proximity between components combined with excessive heat and its negative effects on flux create the perfect storm for potential failures.

Preventing residue-related failures

There are three proven methods to prevent residue-related failures:

1. Remove the electrical voltage. While this method is highly effective, it is absurdly unpractical.
2. Prevent assembly contact with moisture. This is commonly accomplished by the application of conformal coating. Contrary to popular belief, conformal coating, while providing an excellent barrier to fluids, does not prevent all contact with moisture. Over time, moisture can penetrate coatings, (*Figure 5*) resulting in residue-related failures as previously described.

   Even if coatings were to provide an effective barrier to all forms of moisture, coating manufacturers require clean, residue-free surfaces for good adhesion. Failure to provide a residue-free surface can result in coating delamination and/or under-coat corrosion.
3. Remove the residues that contribute to electro-migration and electrical leakage.

With option #1 not on the table and options #2 and #3 all requiring cleaning, it is clear that a cleaning/de-fluxing process is the best method of preventing assembly failures due to electro-migration and electrical leakage.

Additional benefits of cleaning electronics assemblies

In addition to the elimination of post-reflow residue-related product failures, the cleaning of electronic assemblies, while intended for the removal of flux residues, actually provides for the removal of other contamination species. While the emphasis of a cleaning program is flux removal, it is important to consider the many other sources of potential contamination (*Table 1*).

It is highly possible for residues to remain on a circuit board as a result of the board fabrication process. Additional residues may contaminate components from the component manufacturing process. The assembly process, in addition to flux residues, also contributes to excessive assembly contamination by way of machine and human contact. Contact with industrial and human sources can transfer residues that carry a reliability lowering potential.

A robust cleaning process can eliminate all or most of the residues that become stowaways on an assembly during its journey through the fabrication and assembly processes.

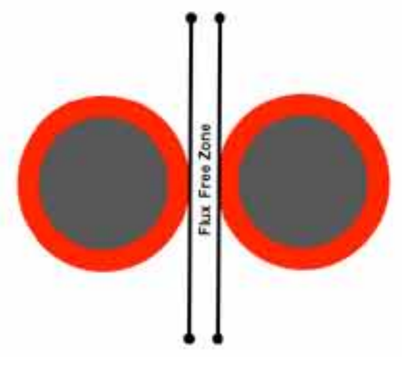

Figure 3. Gap between pads provide flux-free zone.

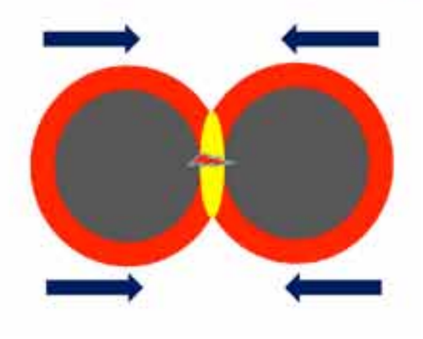

Figure 4. Flux bridge.

Cleaning is an all or nothing proposition

The science of post-reflow cleaning of circuit assemblies is an all or nothing proposition. If you cannot fully clean an assembly, do not clean it. The only thing worse than assembly-related residues on an assembly is a partially cleaned assembly. There are numerous reasons for this. First, the most critical part of a cleaning process often is thought to be the wash cycle. This is not accurate. The most critical function of any cleaning process is rinse.

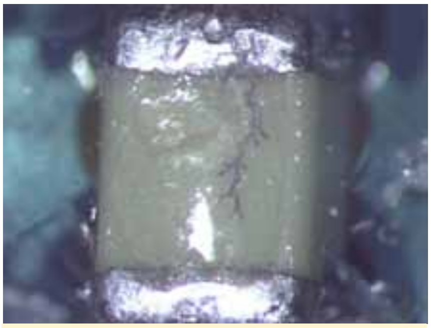

Figure 5. Dendrite grows under conformal coating (Courtesy Foresite).

Defluxing chemicals are highly ionic and corrosive. During a wash cycle, flux and other residues are solublized and held in solution within the wash chemical. After wash, the assembly is covered with wash solution that contains the flux and other residues. If an assembly were removed from a wash cycle without the benefit of rinse, the assembly would soon fail. Solder joints would be attacked, electrical migration and leakage could become rampant. Only a thorough rinse process would adequately displace the wash solution and the residues within it. A high-quality DI water rinsing process will ensure that all solublized residues and the corrosive wash solutions have been removed. Ionic verification of the absence of wash solution during a rinse cycle will confirm that the assemblies are free from wash solution and, one presumes, free from flux and other forms of contamination. A weak cleaning process may actually increase assembly residues and, consequently, the risk of failure.

How clean is clean?

This is one of the most popular questions. The military attempted to tell us in the form of WS6536, MIL STD 2000A and other standards. IPC has told us in the

Board Fabrication	Component Fabrication	Assembly Process
Etch residues	Plating bath residues	Solder paste
Developer chemicals	Water quality rinses	Flux–wave/core
Water quality rinses for inner layers	Deflashing chemicals	Reworked/repaired fluxes
Water quality rinses for outer layers	Mold release agents	Cleaning chemicals
HASL fluids (HO) and final rinses	Preplating oxide cleaning	Water rinse quality
Alkaline cleaners	Pretinning flux residues	Rework cleaner

Table 1. Multiple possible contamination sources.

form of J-STD001-TM650 and other standards. The reality is that these and other standards were written in the 1970s and 1980s.

Consider the magnitude of evolution that has occurred in the design of electronic assemblies over the past 30+ years and ask yourself if you feel comfortable with these cleanliness standards. The real answer relies on another question: what happens if it fails?

A failure in a GameBoy carries far different consequences than a failure on the Hubble Telescope. Mobile phones and defibrillators each have their own unique level of consumer confidence and degrees of liability if failure occurs.

There is considerable debate about which cleaning standard and cleanliness testing method to adopt. Ion chromatography, ROSE testing, SIR, visual and other methods are all valuable tools to determine if an assembly is clean and each carry both benefits and drawbacks. While ROSE testing remains by far the most popular and accessible method of post-reflow cleanliness testing, it is not without its faults. Many assemblers rely on ROSE testing results based on the standards designed in the late 1970s (10 ∫g NaCl/in^2).

The fact is ROSE testers, while fast and inexpensive, are not capable of detecting all forms of possible contamination. Additionally, they assume that all detected contamination is evenly spread across the assembly. In reality, contamination frequently is concentrated in or under high-density assembly areas. For these reasons, one should consider an internal standard that is much lower than the ones published.

How clean is clean? On a ROSE tester, 0.0 is clean. Every value above 0.0 is a step toward possible contamination and related consequences.

Conclusion

Post-reflow residue-related failures are on the rise as are quality expectations. A cleaning process will increase reliability and, therefore, decrease potential assembly failure liability. Cleaning materials and equipment have evolved significantly over the past 22 years. Today's modern cleaning materials and processes provide an environmentally responsible alternative to the processes of the last century. With the ever-decreasing size of a circuit assembly, the increasing densities of components, and the increasing demand for reliability, it is time to return "clean" to the electronics manufacturing vernacular.

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