Critical Parameters of a No-Clean Process

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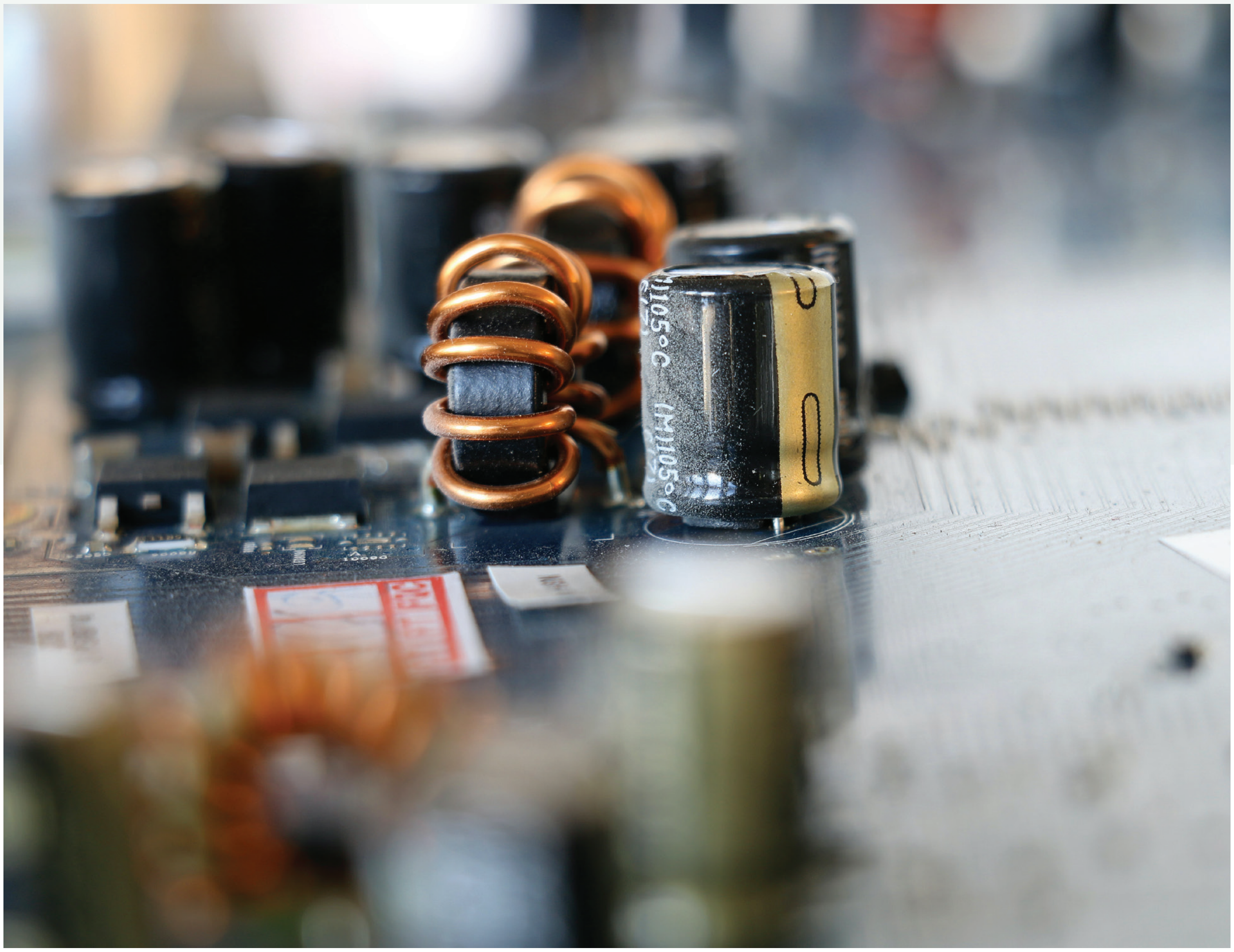

Abstract

The electronic assembly process using low residue flux technology called "no-clean" has captured a large percentage of the assembly processes for electronics used in medical, automotive, industrial controls and sensors, server and consumer electronics markets. No-clean does not mean that the processed electronics will be residue-free, but that the residues are chemically designed to become insulative and electrically benign when they have reached activation temperature. With a no-clean process there are critical parameters that impact electronic performance - in this paper we will discuss the critical parameters that must be taken into account and the problems that can occur, causing intermittent or poor field performance.

Keywords: electrochemical migration, dendrite short, no-clean, SMT, wave solder, selective solder

Introduction

Electronic hardware built with no-clean (low residue) assembly processes have a different set of criteria to achieve good electrical performance in the field. It has been proven that the no-clean process can produce good solder joints and electrical performance with typical soldering and component processing, for both leaded and lead-free assemblies. Since the process does not include any post soldering cleaning steps, residues from all steps of the process collect on the active circuit traces, pad to pad, via to pad, and hole to hole spacing. One major, root cause, no-clean failure mechanism is corrosion, causing dendritic shorting (electrochemical migration) due to contamination from the cumulative process (Figure 1). A second failure mechanism, parasitic current leakage, is also due to contamination from throughout the process. This failure mode does not show visible dendrites or corrosion, but creates poor electrical performance caused by the contamination on and around the components and traces.

We will use the Foresite definition of electronic assembly cleanliness of the printed circuit board assembly (PCBA) - the amount of visible and invisible residue extractable by a water-based extraction, from around each of the active components, circuits, and entrapment locations. The extracted residues are from the collective fabrication, handling, and assembly processes, as found on each component, trace, via and mask area isolated locations, not an overall average for the total circuit board or assembly. The areas between leads, pads, vias or across the body of a component are where electrochemical migration shorting (dendrites) and parasitic leakage occur, even under conformal coating (Figure 2).

One critical step in the optimization of the no-clean process is to understand that the cleanliness level (collection of fabrication and process residues) is not an average overall assessment of the PCBA as one gross value, or average levels of the total board and component surfaces. Cleanliness of a PCBA can be defined as the collective residue on each of the active circuit locations. This can be better understood by evaluating the specific areas of the PCBA in the following locations: bare board (masked and plated areas); SMT top side components; SMT bottom side components; bottom side selective solder leads (contact with the solder wave, or fountain); PCBA bottom side SMT or vias next to the direct contact areas of the solder wave; selective solder areas on top of the PCBA; under connectors or components (for flux residues that were not fully heat activated). Typical contamination-related failures will show up in areas such as sensitive circuits, power circuits or connector locations.

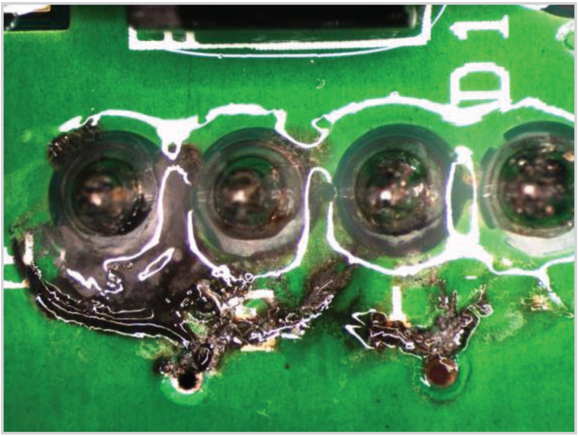

Figure 1 Dendrite Shorting Under Conformal Coating

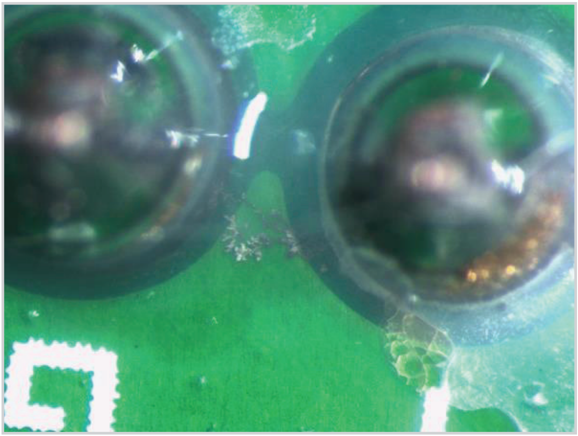

Figure 2 Dendrite Growth Under Conformal Coating

The key areas for cleanliness fall into six areas:

1 **Incoming board and component cleanliness** – contamination consisting of the plating bath and rinse water residues such as HASL flux on the bare board (i.e. ammine hydrochloride in a polyglycol (PEG) carrier) that is rinsed in tap water. Silver, OSP, ENIG and immersion tin are all final finishes that also can leave residues on or in the vias (Figure 3).

Barrel and rack plating of components with methane sulfonic acid (MSA) solution, rinsed in various degrees of deionized water, is a common high volume process. Failures due to dirty components are not as common as failures due to dirty circuit boards, but they are growing in connector areas. These processes can leave high levels of chloride, bromide, sulfate, sodium and ammonium that can cause current leakage and corrosion on powered modules, even in controlled operating environments. Barrel plated components such as capacitors can leave high sulfate residues that when biased in a humid environment (65% RH) will grow a dendrite, even prior to being mounted to a PCBA (Figures 4 and 5).

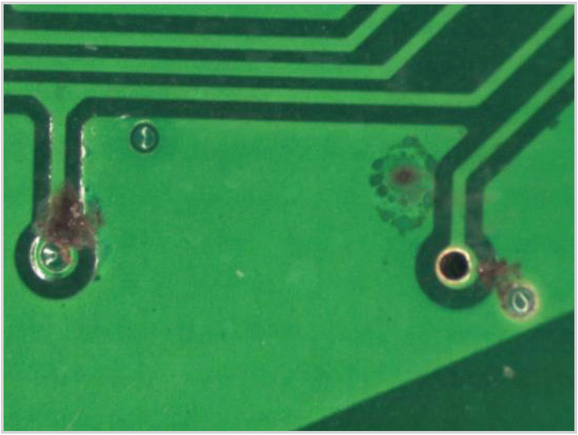
Figure 3 Fab Residues in Vias and Under Mask

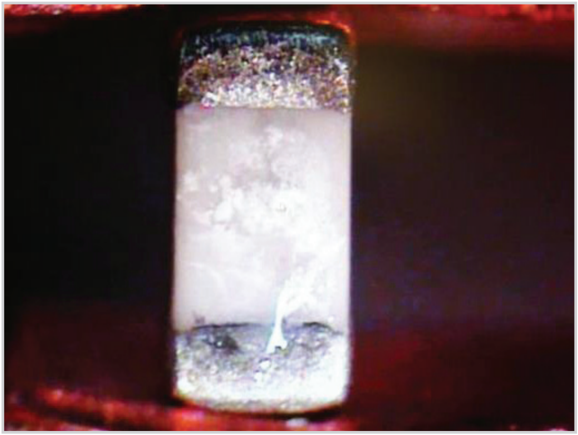
Figure 4 Capacitor Exposed to Humidity

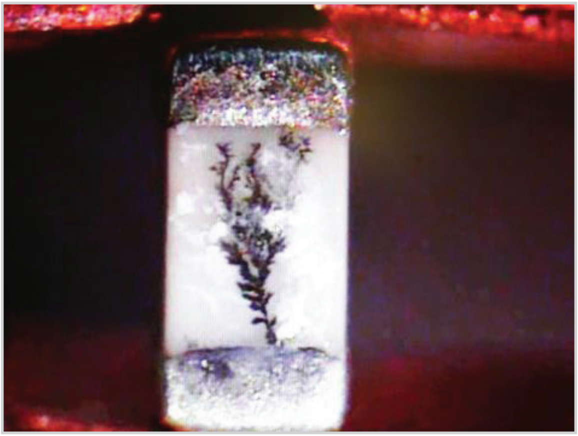
Figure 5 Dendrite Growing on Capacitor

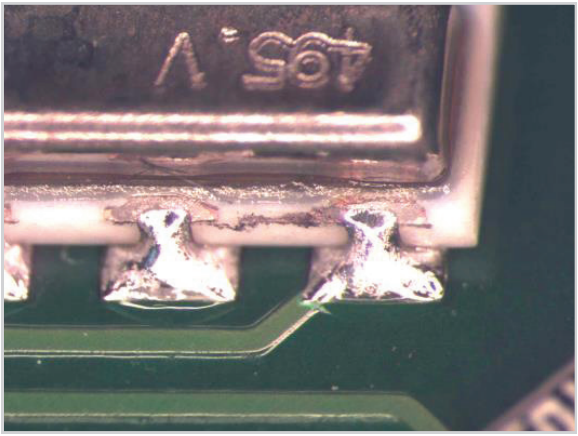
Figure 6 Dendrite on a Component Body

2 **Porosity of the soldermask and non-mask areas** – the porosity of the soldermask is a function of the mask cross linking - when not completely cross linked, masks show an increase in porosity which allows for increased entrapment of flux and fabrication residues. It is difficult to complex this greater volume of flux and the flux will stay moisture absorbing, creating pathways through the mask and even a color change, as shown below (Figures 7 and 8).

Figure 7 Porous Mask Before C3 Exposure

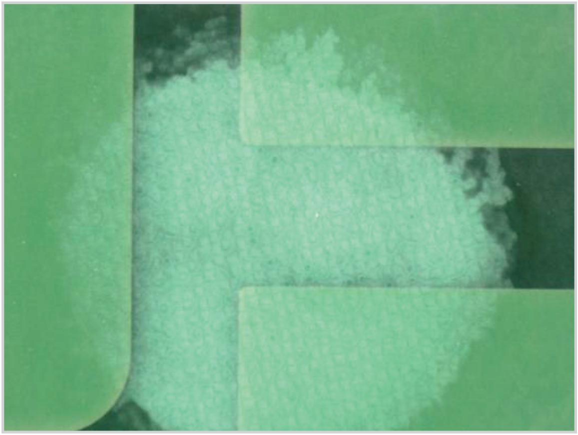

Figure 8 Porous Mask After C3 Exposure

3 Surface mount flux entrapment – on low standoff SMT components, such as QFNs, Power FETs and FLGAs, flux from the solder paste can be trapped underneath, where the solder paste flux hardens over the perimeter edges, trapping the volatiles under the part. This leaves gooey flux that is conductive and corrosive between ground and the back edge of the perimeter pads. These residues will stay gooey and conductive even when the reflow solder reaches liquidous and is held there for 3 minutes (Figure 9). Even though the solder is at temperature, the hard shell that forms at the edge blocks the venting of the volatiles that are designed to separate, keeping them under the component. These components that sit tightly to the board surface, at times within 0.5 mil, are at a great risk of this flux entrapment (Figure 10).

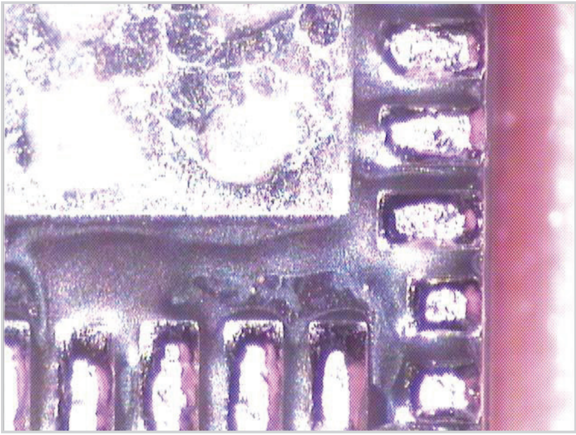

Figure 9 Gooey Flux Under Mechanically Removed QFN, Creating Pathway Between Pads and Ground

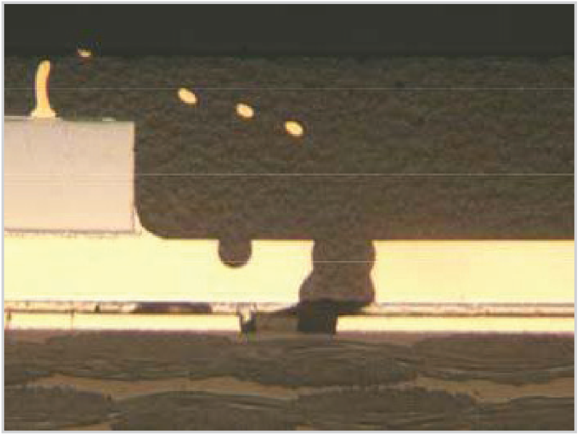

Figure 10 Cross-Section of QFN With 0.5 mil Standoff and Shifting to Reduce the 10 mil Gap to 4 mil

4 **Wave solder liquid flux (sprayed or waved flux application)** - during the wave solder process, flux is applied to the bottom side of the board and up the plated through holes (PTH). Typically the PCBA is placed in a pallet (selective wave solder) to isolate the solder to just the PTH locations (SMT components were already reflowed and need thermal isolation). The pallet is designed to prevent flow of the solder beyond the isolation areas. However, due to the low surface tension, liquid flux can flow beyond the openings with capillary action pulling the flux between the pallet and the bottom of the board (Figure 11). Also, the flux is sprayed up the PTHs and if excessive force is applied, the top side of the component can be flooded (Figures 12 and 13).

a. No-clean liquid flux uses either water or IPA as a carrier. Full heat activation means that the entire volume of flux has reached or exceeded the activation temperature of 150°C for the length of time needed to become a benign residue. Failing this, the raw flux leaves a very corrosive and conductive (moisture-absorbing) residue.

b. No-clean liquid flux is a “low residue” flux after heat activation, not a “no residue” flux. The activators are still organic acid activators that remove the oxides (along with typical other residues like acetate, sodium and ammonium) and, as raw or unreacted flux residue, can be corrosive, causing current leakage problems. Water-based fluxes (VOC-free) have a pH of ~2.5 to 3.5, meaning that they are an acid at ambient conditions and can cause corrosion and dendrites under a biased condition, with ambient humidity over time (1-3 months), or quickly in high humidity conditions.

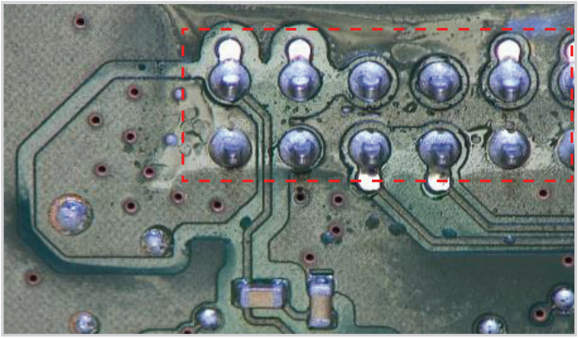

Figure 11 Selective Wave Flux on Bottom Side, Showing Flux Spread Beyond the Pallet Opening (outlined in red)

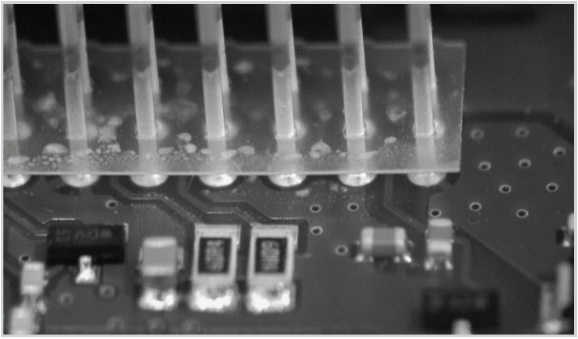

Figure 12 Topside of Connector, Showing Flux on Plastic Surface That Can be Corrosive and Conductive

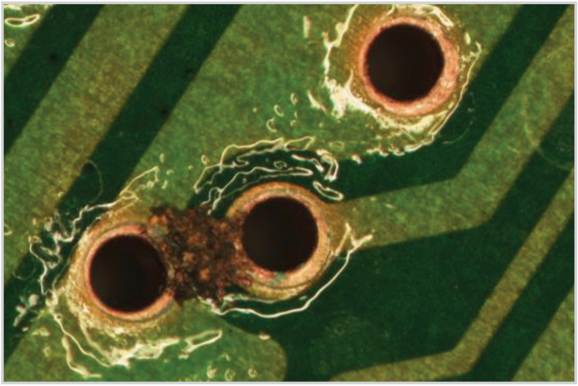

Figure 13 Dendrites Growing Due to Topside Liquid Flux

5 **Hand solder and rework of both SMT/PTH leads** – for both leaded and lead-free solders, the soldering iron heats only the localized lead. Fluxes that travel away from the joint, or additional fluxes used from a bottle or flux pen, do not see sufficient heat to activate and become benign. These fluxes, due to low surface tension, spread into vias, under components and to nearby components. These unheated or partially heat activated fluxes are very moisture absorbing and conductive, causing a large number of industry failures. Many battery connections are hand soldered or selectively soldered into place, with partially heat-activated flux residues left on the bottom surface (or on the top side, trapped under the component structure, shielded from enough heat to reach the activation temperature, long enough to complex the entire volume of flux).

6 **Cleaning** – a no-clean flux is difficult to clean because the formulations are designed to not be easily washed away - adding water to a flux residue by itself can cause early test or in-circuit failures. Batch cleaning with saponification, or inline cleaning with saponification using high pressure, have caused residues to be trapped under components, causing current leakage and performance problems. Cleaning a no-clean flux PCBA requires the removal of the residues from under the components and out of the vias under the components. If not, a white visible residue will result due to the water reacting with the flux residue. This residue is very moisture absorbing and will continue to pull moisture in after it has reacted with the cleaning residues. There are ways to effectively clean no-clean fluxes - it requires chemical contact time, lower pressures and possibly the use of DI water steam. Both inline and batch cleaning leave moisture under components, requiring additional (air dry) time or heated drying before the units are placed into functional performance. Brush cleaning no-clean residues creates a condition where the flux is smeared around and not rinsed/removed, leaving a conductive and even corrosive residue that can cause dendritic failures (Figure 14).

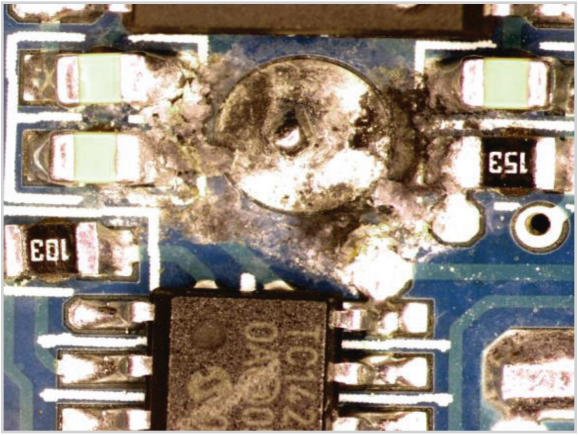

Figure 14 Dendrites Growing Around a Brush Cleaned, Hand Soldered Location

Conclusions

The no-clean assembly process has critical parameters that can impact the potentially detrimental effect of residues on electronic assemblies. By monitoring and inspecting for issues on the production floor, and by learning from no- trouble-found returns, the following cleanliness-related issues can be controlled.

1. **Incoming board/component cleanliness** analyzed in specific areas: vias; mask areas; pad locations; each component (not gross, average measurements), to monitor a variety of plating and rinsing processes.
2. **Soldermask porosity** due to insufficient cross linking from the fabricator that will increase the absorption of fabrication and assembly residues.
3. **Surface mount flux entrapment** under the low standoff components, where the edge of the component/ flux seals in the gooey wet flux, leaving a conductive, moisture-absorbing residue, causing current leakage paths under the component.
4. **Wave solder liquid flux application** on a direct wave solder, selective solder or selective pallet wave solder process, leaving flux that is thermally protected on the top or the bottom of the PCBA. This residue is a moisture-absorbing, conductive and, in worst cases, corrosive residue that will cause reliability problems if not controlled and understood.
5. **Hand solder and rework** of SMT and PTH components, leaving flux that travels to nearby components, vias, pads and leads. Because of focused soldering with a soldering iron and brush cleaning with a solvent, these residues need to be heat activated and not smeared around. The added flux becomes benign by heat activation, just as in the automated processes.
6. **Cleaning of a no-clean** assembly, either as a total assembly in a batch or inline cleaning system, or by brush in localized areas, requires: a) special attention to flux and cleaning residue entrapment under the SMT components; b) complete rinsing.

Use of no-clean soldering processes has shifted the critical parameters of a cleaned assembly (effectiveness of cleaning corrosive residues) to the issues of incoming board and component cleanliness, plus the additional requirement of thermal complexing to create a benign residue for reliable performance in the field. Much of the industry has shifted to a no-clean assembly process, built millions of pieces of hardware and put them into the field with no reported problems - that is great. But the reality of large increases in no-trouble-found returns, or just using SEM/EDS to determine root causes, has not shown when the flux residues are the root cause. Different techniques need to be used and understood to establish the baseline cleanliness and the contributing factors that must be controlled. It typically takes large, critical issues to start down this path of understanding the fabrication/process effects that the residues have on the product performance (Figures 15, 16 and 17).

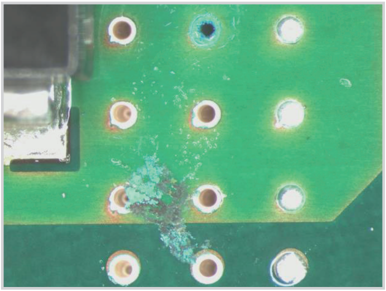

Figure 15 Selective Solder Area Leaving Corrosive Residue Next to the Pallet Isolation Area

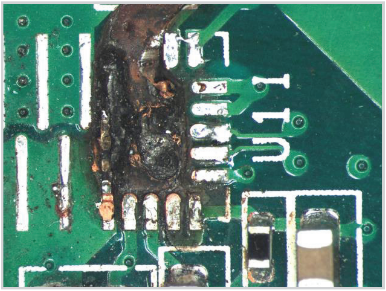

Figure 16 QFN on a Power Device Due to Corrosive Gooey Flux and Residues Trapped Under the Component

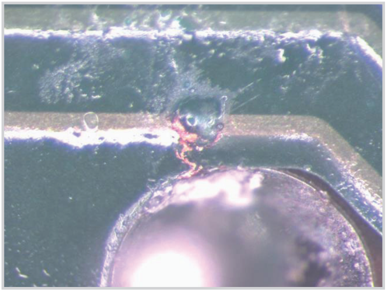

Figure 17 Wave Solder Flux Corroding Open a Trace and Growing a Dendrite Short to Ground on a 3 Volt Circuit