Cleaning Highly Dense Electronic Hardware

by

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Discussion Points

- How Clean is Clean?
- Leadless Components
- Residues Under Bottom Terminations
- Increasing Outgassing Channels
- Static and Dynamic Forces
- Conclusion
HOW CLEAN IS CLEAN?
How Clean is Clean?

- Not easy to determine
- Residues can cause
  - Leakage currents
  - Dendritic growth propagation
  - Failure

Chemical Complexity of a PCB

MOISTURE
SO₂ CO₂
NOₓ

Flux
Laminate
Conformal coating
Adhesives
Metallurgy
Process Chemicals
Metal Finish
Components
Operator

Source: Bruno Tolla, Kester Corp.
Flux components

Solvents
- Alcohols
- Water

Activators
- Organic acids,
- Rosin,
- Amines,
- Halogens

Additives
- Rheological additives,
- Surfactants,
- Dispersants,
- Corrosion inhibitors

Vehicle
- Rosin
- Polyglycols

Fluxes

High T solvent for fluxing byproducts
- Metal protection
- Thermal conduction
- Solder Flow

Remove surface metal oxidation

Restores Metallic surface
- Promotes Solder Wetting
- Oxidation Barrier

Source: Bruno Tolla, Kester Corp.
No-Clean Solder Pastes

- **No-Clean Fluxes**
  - Chemical residues left inside the assembly

- **Reliability depends on**
  - Reactivity of no-clean post-reflow residues
  - Environmental stress

Source: Bruno Tolla, Kester Corp.
High Dense Assemblies

- Cleanliness definition is more challenging
- Site specific problem
  - Residues trapped under component terminations
- Component size reduction
  - Decreases distance between conductors
  - Closer proximity increases electric force
  - Environmental factors can accelerate leakage currents
LEADLESS COMPONENT CLEANING CHALLENGES
Designs are Non-Standard

- The use of BTCs are increasing
- BTCs contain
  - External metallized terminations
  - Planar pad surfaces
BTC Packages

- QFNs packages
  - No solder balls
  - Electrical connection using solder paste

- Package considerations
  - Surface finish
  - Solder paste volume
  - Solder mask definition
  - Thermal vias
  - Solder mask windows
  - Silk screen dots
  - Solder paste flux composition
  - Thermal profile
  - Cleaning
BTC Standoff

As standoff heights reduce, the problem is

1. The level of flux residue under the component increases
2. Flux activators may not properly outgassed
3. Flux bridges power and ground connections
4. The risk of leakage currents increase
Tight spacing between Power and Ground
- Residues trapped under the component can propagate
  - Leakage currents
  - Lead to device failure
Flux Under Bottom Termination

Source: Dale Lee, Plexus
Higher Gaps reduce Residue

NSMD Pad Board Design

No Solder Mask Pad Board Design

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QFN Gap Heights

Source: Kyzen Corp.
Electro-Chemical Failures

- Time delayed effects
- Three conditions must be present
  - Ionic residues
  - Moisture to mobilize residues
  - Bias

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Leadless Component Challenges

- Large thermal mass
- Low standoff heights
- Closer spacing of power and ground
- Channels that can entrap residue
- Seal off flux outgassing channels
- Can leave active flux residue
- Residue is soft and pliable
- Remaining flux activators are easily mobilized with moisture
- Many customers report failures and issues
RESIDUE ENTRAPMENT UNDER COMPONENTS
Soldering Effects

0. Ideal

[Diagram showing ideal soldering process]

1. Gas

The outer area of the paste will melt first and then block the inner gas to escape.

[Diagram showing gas soldering process]

2. Non-wetting

The minimal soldering with the component is caused by non-wetting.

[Diagram showing non-wetting soldering process]

Source: IPC (2015): Silicon Valley IPC Designers Conference
Flux Residues under BTCs

- Low Standoff gap + Thermal Mass
  - Flux outgassing channel is compromised

Source: Texas Inst., by permission
Residue Deposits

- BTC devices fail due to
  - Leakage currents
- Location of dendrites correspond to
  - Trapped flux residues under components
Several low standoff devices were selected to obtain a wide variety of SIR data sets

Devices selected were:

- BGA100 with 0.8mm pitch
- Resistors 2512, 1210 & 0805 passives
- QFN44’s and QFN100’s

Pin out shown is for the A.S.R., 4 channel B24 connector wiring harness (A,B,C,D) – no hard wiring required

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Channel A: To achieve a series of sensors under the QFN100 devices, the board traces form a loop around the central pad terminal and between the loop and the perimeter leads to form the SIR electrical gap spacings.
Activators Studied

- Activator 1 & 2
  - Halogen Free Solder Pastes
    - Failures identified on non-cleaned and partially cleaned test boards

- Activators 3 & 4
  - Halogen-based activators
    - Failures identified by SIR spikes
    - Characteristic of ECM
  - Activator 3
    - Halogen based activator performed well
    - An example of the interplay between chemical reactions, processing conditions and end-usage environments
  - Activator 4
    - Nasty halide based activator
    - Engineered with a subset of halogens in their ionic form
Cleaning Parameters Tested

- Cleaning Conditions
  - No-Cleaning
  - Partial Cleaning
    - Inline spray-in-air, 2 FPM, 3 min wash
  - Total Cleaning
    - Inline spray-in-air, 0.5 FPM, 10 minute wash

- Wash Temperature: 65°C

- Subset of parts where removed during setup to assure partial and total cleaning effects
Activator 1 for QFN 100

Halide Free Solder Paste
Activator 2 for QFN 100

Halide Free Solder Paste

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Activator 3 for QFN 100

Halogenated Solder Paste

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Activator 4 for QFN 100

Halogenated Solder Paste

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Ramp Reflow Profile
Soak Reflow Profile

Fully Cleaned
Partially Cleaned
No Cleaning
Reliability Fundamentals

1. Electrolytic Path formation
   - Residue hygroscopicity and ionicity

2. Electroodissolution
   - Flux corrosiveness

3. Ion Transport
   - Stabilization of charged complexes

4. Electrodeposition
   - Complex reduction at the cathode

5. Dendritic Growth
   - Diffusion-driven from complex supply

Cu(RCOO)₂ + xH₂O + yCO₂ = Cu(RCOOH)₂⁻x(OH)ₙ(CO₃)ₙ⁺xRCOOH⁻

Cu + 2RCOO⁻ → Cu(RCOO)₂ + 2e⁻

H₂O = ½ O₂ + 2H⁺ + 2e⁻ → 2H₂O + 2e⁻ = H₂ + 2OH⁻

3 Basic ingredients: Moisture, Voltage bias, Ions
Reflow Profile

<table>
<thead>
<tr>
<th>Cleaning Method</th>
<th>Activator 1 Ramp to Spike</th>
<th>Activator 1 Soak</th>
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<tr>
<td>NoCleaning</td>
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<td></td>
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<tr>
<td>Cleaning 2 FPM / 3min</td>
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<td></td>
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<tr>
<td>Cleaning 0.5 FPM / 10 min</td>
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INCREASING OUTGASSING CHANNELS
Factors that drive cleanliness are diverse in origin

- Materials Selection: Chemistries of materials within manufacturing process (Flux chemistry, wash solution, etc.)
- Processing Parameters: Settings within manufacturing process (Stencil thicknesses, nozzle pressures, factory environmental conditions, etc.)
- Hardware Selection: Geometric properties of hardware used within design (component standoff height, termination size, shape, and spacing, PCB conductor thickness, etc.)

<table>
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<tr>
<th>Factor</th>
<th>Materials Selection</th>
<th>Processing Parameter</th>
<th>Hardware Selection</th>
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<tr>
<td>Flux Type</td>
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<td>Reflow Temperature</td>
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<td>X</td>
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<tr>
<td>Component Standoff Height</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Paste Volume</td>
<td>X</td>
<td></td>
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<tr>
<td>Venting Paths</td>
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Hardware Selection Can Drive Cleanliness Levels
Increasing Standoff Gaps

Two significant benefits

1. Flux outgassing
   - Flux gases volatize during reflow
   - Flux under bottom termination is reduced
   - Reduced time to clean

2. Benign residue
   - Activators oxide and reduce to a benign residue
   - Activators encapsulated into a rosin or resin shell
   - Lower the risk of electrochemical migration
Low Standoff Height

- Exacerbated by
  1. Thermal mass of solder
  2. Volume of flux blocks outgassing channels
  3. Flux bridges conductors
  4. Both solvents and activators may still be present in residue
Options for Increasing Standoff Gap

- Pad Elevation
- Solder Mask Definition / No solder mask
- Copper Thickness/Weights
- Solder Mask Windows
- Silk Screen Dots
- Copper Buttons
- Reballing
- Pillars
- Preforms
Pad Elevation

- Tin-Lead
  - HASL finish elevated board by 2-3 mils
- Lead Free
  - Planar Finishes
    - No elevation
    - Minimal outgassing channel
    - Flux accumulates under component

Source: www.internationalcircuits.com
Pad Elevation

- Plate thicker pads
Solder Mask Definition

SMD Pads

NSMD Pads

NoSM Pads

Solder Mask Openings

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Solder Mask Definition

- Removal of solder mask
  - Provide an outgassing channel
  - Increase standoff gap
Copper Weights/Thicknesses

- Higher copper weights present more volume for outgassing
  - 1-ounce, 1.5-ounce, and 2-ounce copper
  - Height range: 1.4 – 5.3 mils using 5 mil stencil thickness
  - ~50% of stencil thickness remains as solder after reflow

Solder Mask Not Shown For Clarity
Solder Mask Windows

- Combination of
  - Solder mask windows
  - Thermal vias
Thermal Vias

- Thermal Paddle Vias
  - Provide a flux outgassing channel
  - Reduce flux residues in streets
  - Reduce voids in the thermal paddle

Via Hole diameter 11-12 mils

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Optimal Thermal via diameter

Source: Dale Lee, Plexus
Vias Reduce Voids
Vias Reduce Flux Activity

- OSP Copper
- Test Board #10
- LF NC Solder Paste
- Ramp-to-Spike
- No Silk Screen
- No Cleaning

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<td>-10 Unvented Center Lug</td>
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<td>-12 Vented Pins</td>
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<tr>
<td>(7)</td>
<td>-14 Vented Center Lug</td>
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Silk Screen Dots

- Thermal Pad
  - During reflow, component can draw down
  - Silk screen dots assure minimum standoff height
Copper Button Plate

- Thermal vias plated within the ground lug
- Copper plated elevation at via

Source: Dale Lee, Plexus Corp.
Reballing QFN Components

- Attach high melting spheres to solder pads

Source: Retronix Ltd. www.retronix.com
Pillars

- Similar to reballing, pillars at the corners lift the QFN component

Source: Retronix Ltd. [www.retronix.com](http://www.retronix.com)
Preforms

- Increase gap height
- Flux exhausts during reflow
- Less flux residue
- Easier to clean

Source: Indium Corp.
CLEANING TIME AND FORCE REQUIREMENTS
Engineered Cleaning Agents

- Critical factors include:
  1. Must clean the soil
  2. Must not attack (trash) the assembly
  3. Must have legs (work over extended time)
  4. Must be able to be processed in the cleaning tool
  5. Must not have negative impacts on the environment
  6. Must be safe to use in the assembly environment
  7. Must be cost effective
Normal Clean

- Residues may be trapped
Extended Clean

- Process conditions that render a clean part
Time to Render a Clean Part

- Residue dependent
- Standoff gap dependent
- Impingement energy dependent

Source: Kyzen Corp.
Multiple Cleaning Passes

- Cleaning under low gaps may require
  - Multiple passes in the cleaning machine
  - To fully clean requires
    - Heat to soften residue
    - Flow to wet residue
    - Energy to deliver cleaning agent to the residue
Process Cleaning Rate

- Cleaning agents effectiveness at quickly dissolving residue
- Cleaning machine effectiveness at delivering cleaning agent to soil
CONCLUSIONS
Soil effects

- Residue types can influence the effect on resistance and current leakage
  - Activator packages are designed to react with metallic oxides but can also induce corrosion and electrochemical migration

- Safe residues requires
  - Hydrophobicity ~ do not attract moisture
  - The “right” chemistry: metal complexation effects
    - A zero-halogen activator package is not a guarantee for reliability
  - Volatilization or decomposition at peak reflow temperatures
    - Eliminate as much as possible active residues
Leadless Components

- Higher Standoff gaps
  - Reduce residue
  - Flux activity is lower
  - Easier to wet and clean residue

- Low Standoff gaps
  - Increase the potential for pocket of active residue
  - Longer cleaning time needed
  - Strong mechanical forces needed

- Outgassing channel
  - Allows flux to outgas
  - Reduces the potential for active residue
Reflow Profile

- Most believe that a hotter profile is better for outgassing under low standoff components
  - The data from this study did not show evidence of this effect

- The reflow effect provided interesting findings
  - Zero-halogen activators appear to be more sensitive to reflow conditions
    - Attributed to the thermal instability of activators
  - Halogenated activators
    - Brominated activator showed higher potential to volatilize and outgas
    - Chlorine activator showed electrochemical activity for both soak and ramp-to-spike due to their inherent heat stability
Cleaning effects

- Partial Cleaning
  - Residue left under the component can be detrimental
  - Some activator types are more problematic than others
  - Similar to partial activation of fluxes: Either you or clean well or you don’t

- Total cleaning
  - Improves resistivity values systematically, regardless of the components/chemistries
  - Totally cleaned parts showed good results independent of the activator package
  - Cleaning well can solve the problems of highly active fluxes
Thank you

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Research Sources