Topic Expert Failure Analysis, Method and Solutions

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Overview

- Why are we asked to perform failure analysis?
  - Third-Party Failure Analysis
- General Understanding of Root Cause Failure Analysis
- Case Studies
Why Perform Failure Analysis

– In a production environment the appearance of failures is an unfortunate inevitability.
– In every case Electronic Manufacturers take every precaution to reduce the number of failures that occur in their facilities.
  • This inherently breeds a lack of knowledge and understanding for the evaluation of failures.
  • Since failures are rare it is not financially justified to have a highly skilled and trained dedicated workforce.
– To this end a laboratory that provides the service of failure analysis can be positioned to have all the necessary equipment and resources for the determination of root cause.
– The Universal Advanced Process Laboratory takes this one step further by having the advantage of a research organization as part of its organization as well as a complete prototype manufacturing facility.
– Having experts in PCB fabrication, underfilling, rework, surface mount assembly, wave soldering, stencil printing, encapsulation, reliability testing, PCB design, etc. gives us a unique perspective on failure analysis.
Why Outsource Failure Analysis

• Cost
  – Line down situations
  – New product evaluations
  – Quick turn analysis
• Lack of Analytical Techniques/Understanding
• Lack of Experience with Material and Process
• Non-Biased Evaluation of Issues
Failure Analysis

• Failure analysis of Electronic assemblies requires an understanding of:
  – PCB fabrication
  – Underfilling
  – Rework
  – Surface mount assembly
  – Wave soldering
  – Stencil printing
  – Encapsulation
  – Reliability testing
  – PCB design
  – etc.
Failure Analysis Methods

• Depends upon the type of analysis being conducted
  – Manufacturing failures require an understanding of the process, material systems, components and the issues which drive production related failures.
  
  – Field failures require a detailed knowledge of the environmental applied strains, material interactions and the possible failure modes.
Failure Analysis

• Preparation is a vital part of proper analysis
  – Can involve physical or chemical preparation
  – Often destructive (careful not to affect the failure mode of interest)
  – Often requires a significant amount of analysis time
    • Conversations with customers

• Understanding of the failure conditions and the variables involved
  – Date codes involved
  – Failure rate
  – Design and supplier changes
  – Failure description from customer
    • Example: de-wetting and non-wetting
      – What is the difference?
      – Be careful most don’t know
      – Non-wetting: Mask on pad, oxide, profile (More common failure mode)
      – De-wetting: Black Pad
Lead-free vs. Sn/Pb

• Circuit board issues are the biggest issue in LF and Sn/Pb (could be related to high Tg of LF laminates)
  – This is a big issue for the industry
  – Brittle laminate materials lead to CAF, pad crater, etc.

• Other material issues such as BGA warpage and surface solderability are affected by transition to LF
  – Surface finish

• Manufacturing processes must change to accommodate known LF materials and manufacturing issues
• If you don’t understand the issues then you will not be informed enough to work with your suppliers to resolve problems and drive to solution
Case Studies

• Random sampling of supplier related material issues we have observed that do not have obvious root causes

• If you don’t know the root cause for the failure then;
  • You can’t formulate an effecting corrective action plan
  • You will not be in a position to demand new materials, or reimbursement for lost revenue
  • Risk lost time in manufacturing resulting in missed shipping dates, product launches, etc.

• We don't have much time so only a few topics are discussed here
The Problem: Ag$_2$S formation

- Creates high resistance or electrical opens
Hydrogen Sulfide Gas Exposure ($\text{H}_2\text{S}$)

Drawing of typical resistor construction and exposed Ag area we have identified to show $\text{Ag}_2\text{S}$ whisker formation.
Ag2S source and solution

- Gasket release agents
- Screening of gasket material

Image of sample preparation

Raw Material Black
Raw Material Orange
R10470 Red
R10460 Blue
QFN Failure

- Common issues with QFN’s
  - Thermal pad voiding
  - Process conditions
    - Open or short conditions due to pad design and stencil design
    - Tilted device due to solder volume variations
- Less common issue is related to clock speed variations
  - Exhibits not a true shorting condition
QFN root cause: WS paste used for production, high halide content creates low dielectric strength at T0 and then dendrite growth

defining the future
QFN solution

- No clean solder paste should be used.
- Do not wash these devices
TI published work on voiding in Cu$_3$Sn in 2004.

Many others have also seen it and report it, but often not ‘on the record’.

Consequences & potential severity are commonly underestimated, but Intel started major effort in 2000 (gave up after 2 years).

We have established approach for interpretation & extrapolation to service.

We have developed solder ball test that correlates better with drop than strength testing does.

We can turn the problem on and off and are in the process of filing a joint patent with IBM and Binghamton University.
Board related issues

- Board processing is complicated especially in HDI constructions.
- We have observed numerous failure analysis projects that are related to board construction issues.
- Failure mode determination can be simple
  - ICD
  - Plating
  - Mask on pad
  - IFM
- Root cause and fabrication improvements can be complicated and often beyond the CM.
  - What questions to ask your suppliers?
- The following slides will be related to board issues and will touch on some of the questions that should be asked.
Traces severed at these locations.

X-ray image of shorted electrical network. Green arrows indicate open segment and red arrows indicate the shorted segment.
Back-lit illumination showing a potential conductive filament bridge, imbedded just below the solder mask and highlighted in the image above.
Horizontal section showing location of the filament as seen from the bottom of the board, looking upward. Yellow arrows highlight the filament (foreign material).

Flat section backlit and photographed at two focal depths showing intimate contact (red arrows) between filament, trace, and ground plane. Filament was visually determined to be embedded between the solder mask and L1 dielectric.
Horizontal sectioning and evaluation determined that a thin filament of copper was embedded between the core material (dielectric) and solder mask and making intimate contact between shorted trace and ground plane. A helical shape indicates that the filament was most likely generated during the drill process and redeposited during subsequent processing.
Pad Ruptures

• “Push Button” failures

• Pad rupture is often driven by external mechanical stress, however in order to predict whether the pad is likely to fail we must consider the PCB pad design, substrate material, component design, etc.

• Factors that affect the preferred failure location are;
  – pad diameter
  – solder mask verses non-solder mask defined pad design
  – trace width into the pad
  – and substrate material’s resistance to fracture

• These failure modes will be come more prevalent in lead-free assemblies due to the properties of the high Tg laminate materials
  – Common to hear “we were building with Sn/Pb for years and never had an issue, now that we are assembling with lead-free materials…”
  – Lead-free boards are being used in Sn/Pb military and medical products, higher probability of failure in this mode.
Pad Rupture – Case A

- Dye penetration identified a number of opens in both the OSP and ENIG boards.

- For the ENIG board, three failure types were observed: cracks at the component side, cracks at the PCB side, and fractures under the PCB pads (pad rupture).

- For the OSP assembly the observations were similar, but with only one component-side fracture.

- The mixture of failure modes indicates the problem was mechanical, with the assemblies being subjected to high stresses.
Pad Rupture – Case A

Pad rupture observed for solder joint on OSP assembly.

Pad craters observed in ENIG (left) and OSP (right) assemblies.
Pad Rupture – Case B

Intermetallic fracture

Pad rupture
Pad Rupture – Case C

Component Pad Rupture
Component intermetallic failure
Component Pad Rupture
Component Pad Rupture
Component Pad Rupture
Pad Rupture solutions?

• Board design
  – Solder mask defined pads
  – Placement of components
• Material selection
  – Long list of materials tested within our research consortium
• Adhesive
  – Edge bond, corner bond, underfill
CAF Formation

defining the future
CAF Formation/solutions

Solutions include;
• Working with board supplier to improve drill
• Design spacing for PTH’s and vias with 45 degree offset
BGA Voiding

• Voids due to PCB via-in-pad fabrication issue
BGA Voiding

- Voids due to PCB via-in-pad fabrication issue
- Solutions are obvious but should be discussed with board supplier
- Redesign should be considered
Ceramic capacitor failures

- Fractures in devices
- Design of board must be scrutinized
  - Pad size, mask thickness
  - Proximity to edge of board
  - Orientation
- Board warpage
- Final assembly handling
- Panel singulation
  - Breakaways vs. router vs. pizza cutters
Capacitor failures

- Example of a severe failure on surface mount capacitor

defining the future
Pick and place failures

- Cap fractures
Capacitor failures

• Excellent White Papers
  – KEMET; Ceramic Chip Capacitors “Flex Cracks” Understanding & Solutions by Jim Bergenthal
  – AVX; CRACKS: THE HIDDEN DEFECT by John Maxwell

• These failure modes have been well documented
  – The issue is not with diagnosis
  – The solution can be difficult and complicated
  – Strain gauge analysis
Dendrite formation in botched humidity testing
Wire bond failures of pressure sensor

Fracture initiation site

Area of high rate of fracture propagation

Area of slow rate of fracture propagation
Summary Failure Analysis

- Failure Analysis can be used for production failures to increase yields and improve product reliability.
- Field Failures can be effectively analyzed to determine the cause of failure and aid in accurate and therefore cost effective product recall.
- Failure Analysis can provide the evidence required to support vendor returns in product liability cases.
- Failure analysis is a fast and cost effective method of improving yields and product reliability.
- The ROI (return on investment) in Failure Analysis easily justifies the minimal cost.