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Electronics Manufacturing Insights from ACI Technologies, Inc.

Non-Destructive Test Methods

Failure analysis (FA), by its very nature, is needed only when things go awry. Before any testing is performed on the sample, a decision must be made as to whether or not the sample is allowed to be destroyed in the process of testing. Non-destructive testing can allow for re-use of the assembly since the functionality is not altered, but there still remains the possibility that inadvertent damage can occur through the course of the analysis. If non-destructive testing is preferred, then the following types of analysis can be performed. The testing can be divided into four categories: visual, X-ray (X-ray imaging and X-ray fluorescence), cleanliness (resistivity of solvent extract, ion chromatography, and Fourier transform infrared spectroscopy), and mechanical (non-destructive wire bond pull).

Visual Examination

Optical Microscopy with Digital Imaging

Optical microscopy and photography provide a permanent visual record of the sample, from the point of arrival to the laboratory through each step along the way in the determination of the root cause of the failure. A stereo microscope is used in optical microscopy to give good depth of field when the sample is placed directly underneath the main lens. When used with calibration grids and the appropriate software, images can be captured with scale bars and measurements of features, at magnifications ranging from 7x to 90x.

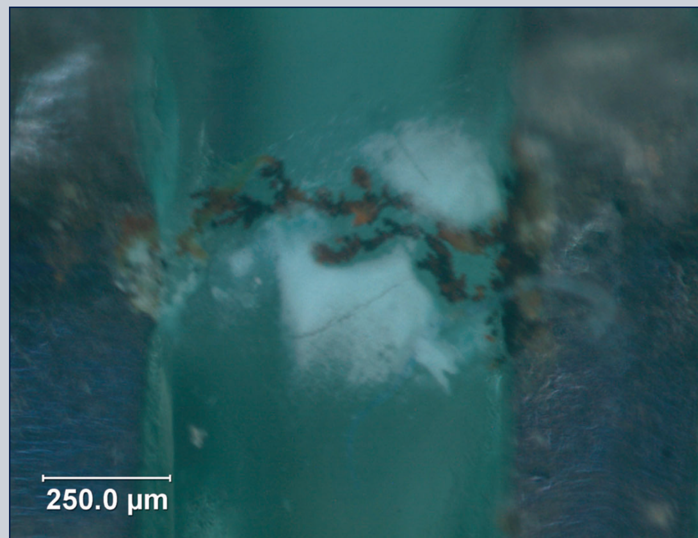

Figure 1: Image of a dendrite growing between two pins causing a short.

Figure 1 shows a case where salt was deposited on an unprotected portion of an assembly and with the addition of high humidity and electrical bias; a dendrite grew between two adjacent conductors and caused an electrical short. This failure was due to exposure to a corrosive environment without adequate conformal coating protection.

Figure 2 shows a partial fingerprint on the assembly, underneath the conformal coating. The oils from the finger print contributed to the poor adhesion of the coating, which in turn led to the dendrite seen in Figure 1.

Figure 2: The oils from this fingerprint contributed to poor adhesion of the conformal coating and led to the corrosion seen in Figure 1.

Optical Inspection System

An optical inspection system is similar to optical microscopy except the lens is placed very close to the board, nearly touching it, and a mirror directs the light path 90°, so that features to the right (or left)

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of the lens can be viewed. Fine features underneath components can be observed, especially the first two to five rows of a ball grid array (BGA) component. The row depth is dependent on the lighting and space beneath the component. The goal is to see if the solder balls have collapsed properly after undergoing the reflow process and if any abnormalities exist, such as contamination or materials bridging leads.

Figure 3 shows a slight misalignment of a row of solder balls. This is acceptable per IPC A-610 Revision D since the BGA solder balls did not violate the minimum electrical clearance. However, it is a process indicator of a potential issue in the manufacturing process due to either manual placement of the BGA or an alignment issue in the pick-and-place system.

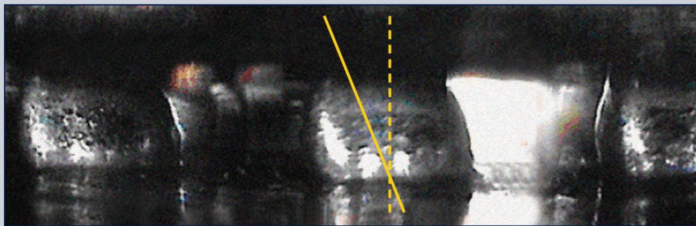

Figure 3: Image of a slight misalignment of a row of solder balls. This is a process indicator that either the manual placement or the pick-and-place system was slightly off.

Automated Optical Inspection

Automated optical inspection (AOI) is used as a process tool for inspection of bare boards, solder paste deposition, component placement prior to reflow, post-reflow component conditions, solder joints, and surface anomalies on assemblies. By programming the features of a good board assembly, comparisons with subsequent assemblies can determine if they pass or fail.

X-Ray Examination

X-Ray Fluorescence (XRF)

XRF is used to identify composition and plating thickness for elements ranging from titanium (Ti, element 22) to uranium (U, element 92). By bombarding a sample with high energy X-rays, "secondary" (or fluorescent) X-rays can be emitted which are characteristic of the atoms present in the sample. Figure 4 shows an XRF spectrum that is indicative of an electroless nickel immersion gold (ENIG) surface finish over copper. Figure 5 shows an XRF spectrum for solder joint composed of tin-lead solder.

X-Ray Inspection

X-ray inspection is used to visualize assemblies by observing differences in density and composition. The denser an item, the darker it appears in the image. Some of the features that can be observed are: cracks, solder joints, traces, vias, voiding within solder joints, and wire bonds. Figure 6 shows a BGA component, where several groups of solder balls have bridged during the reflow process due to solder paste deposition and the thermal profile.

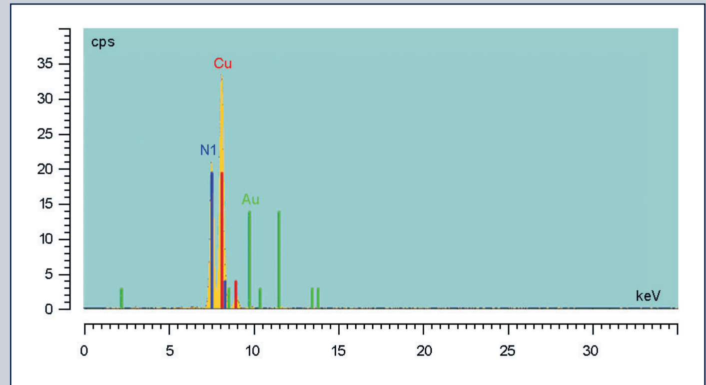

Figure 4: XRF spectrum of an electroless nickel immersion gold (ENIG) surface finish over copper, where copper (Cu), gold (Au), and nickel (Ni) were observed.

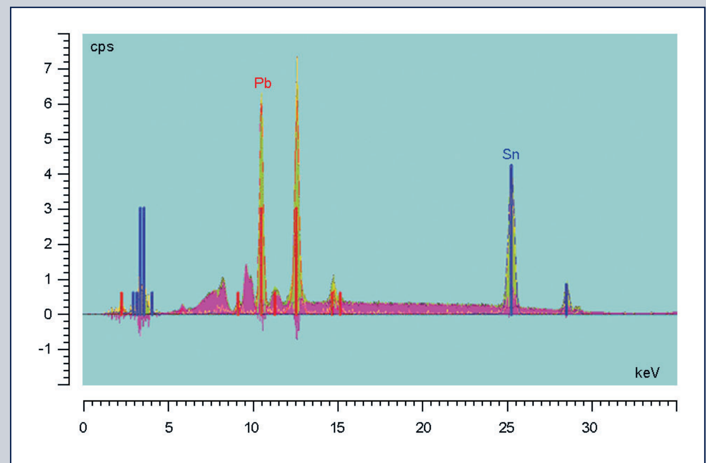

Figure 5: XRF spectrum of a tin-lead solder joint, where lead (Pb) and tin (Sn) were observed.

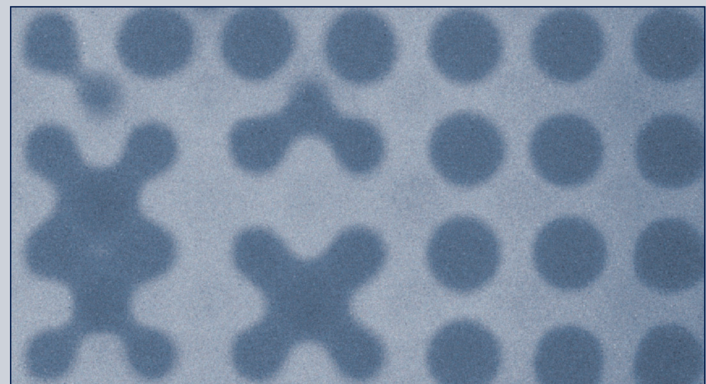

Figure 6: X-ray image of a BGA component with bridging solder balls.

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Cleanliness Examination

To determine if there are ionic contaminants present on the board assembly, there are two methods that give different levels of information: bulk ionics testing and ion chromatography. To determine if there are organic contaminants present on the assembly, Fourier transform infrared spectroscopy can be performed. A spectrum is obtained showing peak location and height which indicate what chemical functional groups (alcohol, epoxy, siloxanes) are present.

Bulk Ionics Testing

The more general method follows IPC-TM-650 2.3.25C, Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract (ROSE) [1], in which a sample is immersed in an isothermal bath (at 35ºC) containing a 3 to 1 solution of isopropyl alcohol to deionized water. Ionic contaminants extracted from the sample pass through a conductivity cell which continuously measures the conductivity of the solution. The conductivity values are integrated over the time of the extraction. The ionic material then passes through a deionization column before being recirculated back into the test chamber. As the ionic materials are extracted from the assemblies, the conductivity (and hence resistivity) of the solution will change dynamically until nearly all of the extractable ionic material has been removed.

Results from dynamic extraction by Ionograph are reported in micrograms of sodium chloride (NaCl) equivalent per square inch. For assemblies soldered using rosin based fluxes, the ionic cleanliness requirement per J-STD-001D is a maximum of 10.06 µg NaCl equivalent/in^2 (1.56 µg NaCl equivalent/cm^2). There is no industry standard for acceptable bulk ionic levels, but it is better to have as low a value as possible. The EMPF recommends Ionograph results to not exceed a level of 2 to 3 µg NaCl equivalent/in^2.

Ion Chromatography

The more specific method of ionic contaminant analysis is IPC-TM-650 2.3.28A, Ionic Analysis of Circuit Boards, Ion Chromatography Method [2], in which the samples are sealed in a Kapak bag with a 3 to 1 solution of isopropyl alcohol to water and heated in an 80 °C water bath for 1 hour to extract any ionic residues. The extract solution is analyzed against known standards to confirm the presence of and quantify each of the following anions: fluoride, chloride, bromide, nitrate, phosphate, and sulfate in units of µg/mL. The surface area is calculated from the board dimensions and the final results are reported in µg/in^2.

ACI's maximum recommended amounts of fluoride, chloride, bromide, nitrate, and sulfate for bare boards are 2, 4, 5, 1, and 3 µg/in^2, respectively. The recommended levels of ionic contamination for populated assemblies will depend upon the application. However, for typical component packages on FR-4 or a like substrate, the maximum recommended amounts of fluoride, chloride, bromide, nitrate, and sulfate are 2, 9, 15, 1 and 10 µg/in^2, respectively. Both sets of acceptance criteria were developed from experience and in conjunction with industry leaders.

An example of an ion chromatograph is shown in Figure 7. The anions in solution are separated from one another by their different rates of interaction with the quaternary ammonium groups in an ion-exchange column. A set of standards is run with the samples to compare elusion times (how long it takes for an anion to leave the ion-exchange column) and corresponds to the identity of the anion. The peaks correspond to different anions passing through an electrochemical detector, which measures changes in conductivity resulting from the flow of ions in solution when moving through an electric field. The level of conductivity is directly proportional to the concentration of the anion, which is calculated by integrating the area under the peaks.

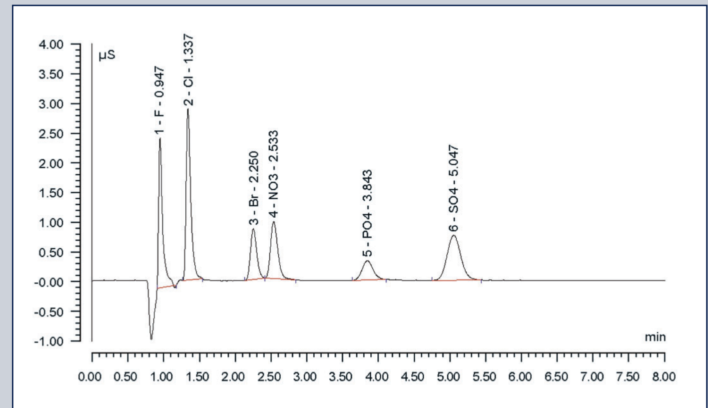

Figure 7: Example of an ion chromatograph showing the presence and separation of the anions: fluoride (F-), chloride (Cl-), bromide (Br-), nitrate (NO3-), phosphate (PO42-), and sulfate (SO42-).

Fourier Transform Infrared Spectroscopy

Fourier transform infrared (FTIR) spectroscopy is used to identify organic materials (those containing mostly carbon) such as: cleaning chemicals, rosins, and polymers used in conformal coatings. FTIR spectroscopy is a technique in which infrared energy is used to excite fundamental vibrational and associated rotational-vibrational modes of molecules in the mid-infrared, approximately 4000 to 400 cm-1. These vibrational modes correspond to molecular structures. Attenuated Total Reflectance (ATR) is a technique used with FTIR, which allows liquid and solid samples to be studied directly without further preparation. In ATR-FTIR, an infrared beam is directed through an optically dense crystal at a certain angle and internally reflects through the crystal, producing evanescent waves. When the crystal is pressed against an infrared active material, the infrared radiation from

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the evanescent waves penetrates typically one to four micrometers into the sample.

Figure 8 shows an FTIR spectrum of an unknown residue rinsed off a board assembly compared to that of a known adhesive compound. The residue was contributing to the poor adhesion of a conformal coating to this assembly.

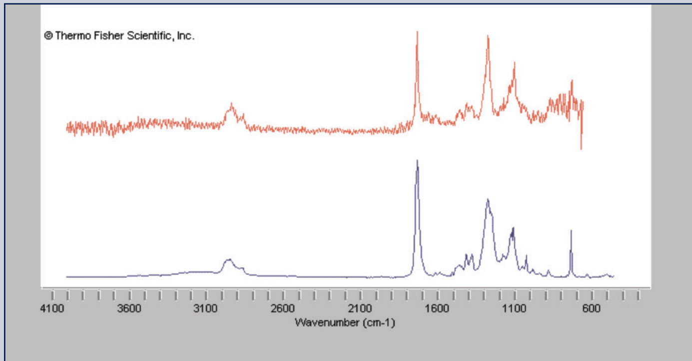

Figure 8: FTIR spectra for an unknown residue from a board assembly (top, red) compared to a known adhesive compound (bottom, blue).

Mechanical Examination

Non-Destructive Wire Bond Pull Test

Method 2023.5 of MIL-STD-883 [3] provides for a Non-Destructive Bond Pull, where an applied stress (measured in grams force (gf) pull) is used to reveal non-acceptable wire bonds while avoiding damage to acceptable wire bonds in a package. This test is intended for “Class S” parts or parts intended for use in the high reliability space flight community [4]. Any bond failures are unacceptable, but based on the program requirements, rework and retest may be acceptable. Table 1 lists the pull forces for a set of standard wire sizes.

Al and Au Wire Diameter (inches)	Pull Force (gf) Al	Pull Force (gf) Au
0.0007	1.2	1.6
0.0010	2.0	2.4
0.00125	2.5	3.2
0.0013	2.5	3.2
0.0015	3.0	4.0
0.0030	9.5	12.0

Table 1: Non-destructive pull forces.

There are conditions for which this test may not be applicable, such as having a high pin count of 84 or more external terminations and small bonding wire pitch at the package post of less than or equal to 12 mils (304.8 μm). Alternative procedures are given to evaluate the wire bonds, such as: review of manufacture quality records and raw material control, a thermal mechanical analysis of the package and the bonds over time and with temperature cycling, and a 100% visual inspection of all bonds. For packages with gold plated posts, a bake test at 300°C for one hour in air or inert atmosphere is performed to test for contamination anomalies in the plating. This bake test calls for 45 bond pulls to destruction per method 2011 of MIL-STD-883 and falls into the realm of destructive testing.

Summary

Non-destructive testing can provide valuable information as to the root cause of failures that can occur in electronics manufacturing. The ACI Technologies facilities are well equipped to assist with non-destructive testing using all of these techniques, along with the skilled staff to provide interpretation of the data, and provide the appropriate recommendations to remedy the conditions leading to failure.

References

[1] “Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract - 2/01.” IPC-TM-650 2.3.25C. <http://www.ipc.org/4.0_Knowledge/4.1_Standards/test/2-3_2-3-25c.pdf>

[2] “Ionic Analysis of Circuit Boards, Ion Chromatography Method - 5/04.” IPC-TM-650 2.3.28A. <http://www.ipc.org/4.0_Knowledge/4.1_Standards/test/2.3.28A.pdf>

[3] Test Method Standards, Microcircuits.” MIL-STD-883. <http://www.dscc.dla.mil/Programs/MilSpec/listdocs.asp?BasicDoc=MIL-STD-883>

[4] “Assurance Issues Related to Electronic Wire Bonds.” NASA Goddard Space Flight Center. <http://nepp.nasa.gov/wirebond/>

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