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Application of ion chromatography to failure analysis of electronics packaging

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ABSTRACT

Ionic contamination is a frequent cause of corrosion failures in electronics packaging. Ionic Cl^- , SO_4^{2-} , Na^+ and K^+ are the species most frequently associated with corrosion and are easily detected by ion chromatography (IC) or other surface analysis techniques (XRF, EDX, etc). This paper will describe a corrosion problem, involving gold-plated copper wires and an automated wire bonding operation, and its solution using IC and Fourier transform infrared (FT-IR) analysis, which showed that the corrosion was caused by ionic NO_2^- and NO_3^- , species which are not easily detected by other surface analysis techniques.

INTRODUCTION

Ionic contamination is a frequent cause of corrosion failures in electronics packaging. Ionic Cl^- , SO_4^{2-} , Na^+ and K^+ are the species most frequently associated with corrosion [1,2].

Corrosion product was found on electronic modules after wire bonding operations, and ion chromatographic (IC) analyses of the modules showed the presence of ionic nitrite and nitrate. The wire bonding operation consists of two steps: stripping of the wire insulation using a direct current (d.c.) arc and ultrasonic bonding of the wire. Using IC analyses the contamination source was traced to the wire stripping operation, which produced NO_2^- and NO_3^- from the NO_2 and water in the air during arcing [3,4]. The wire insulation did not contribute greatly to the formation of these corrosive species.

This paper will show that formation of nitrogen species is directly proportional to the relative humidity and number of arcs. The contamination problem due to wire stripping was solved by installation of a vacuum tube next to the arc to evacuate the corrosive species formed by arcing. The vacuum effectiveness was monitored by collecting the sample in deionized (DI) water and analyzing it using IC.

This paper will also show correlation of IC analyses with micro Fourier transform infrared (FT-IR) analyses of the corrosion/arcing products.

EXPERIMENTAL

Ion chromatography

The ionic contaminants were extracted from the surface of the package by covering it with DI water. The DI water was allowed to remain on the sample for 60 min with periodic agitation. An aliquot was collected and analyzed using Dionex ion-exchange chromatography. Chromatographic conditions used were: sample volume, 50 μ l; separator column, HPIC-AS4A; guard column, AG4A; eluent, 1.8 mM Na₂CO₃-1.8 mM NaHCO₃; flow-rate, 2 ml/min; suppressor, AMMS; regenerant, 25 mM H₂SO₄ at 3 ml/min; conductivity detector.

IR spectrometry

IR spectra were acquired using an IR-PLAN (TM, Spectra-Tech) microscope coupled to a Nicolet 740 spectrometer. The corrosion product was removed from the wires and analyzed in transmission mode; material on gold pads was analyzed in reflectance mode. The IR spectra were acquired at 8 cm⁻¹ resolution using either 128 or 256 scans.

RESULTS AND DISCUSSION

A corrosion product was found on the tips of wires after the wire bonding operation on an automatic wire bonding tool. The process consisted of two steps: stripping the wire insulation using a d.c. arc and ultrasonic bonding of the wires to a gold pad. The corrosion product appeared green and fuzzy and was found primarily on the tips and exposed areas of the wire. The wire was made of gold-plated copper with polyimide insulation. CI analyses showed that the parts with corroded wires had unusually high amounts of ionic nitrite and nitrate. Micro-FT-IR analyses identified the corrosion product as CuNO₃. To locate the source of contamination, the parts were analyzed sequentially using IC before and after the bonding process. There were no contaminants found prior to the wire bonding operation or after a manual wire bonding operation. However, after wire bonding on an automated bonder the parts were found to be contaminated with ionic nitrite and nitrate. Optical inspection revealed that areas surrounded by many bonded wires contained more corrosion than those near fewer wires. In addition, some areas of the part were found to have small droplets of an unknown liquid on their surfaces. The liquid droplets were identified using FT-IR as nitric acid.

Based on the experimental data, the parts were contaminated/corroded at some point during the wire bonding process on the auto-tool. The wire bonding operation on both manual and auto-tools consists of two steps: stripping of the wire insulation using a d.c. arc and ultrasonic bonding of the wire to the pad. The stripping on the manual tool is performed a few feet away from the part, whereas the stripping on the auto-tool is performed directly over the surface of the part being bonded. It was clear that the wire stripping process was the cause of the ionic contamination.

To understand the effect of the wire stripping process, the following experiments were conducted: A small petri dish containing 10 ml of DI water was placed under the wire stripping arc. The wire then was stripped 200 times using standard wire stripping parameters. Simultaneously, another petri dish with DI water (blank) was

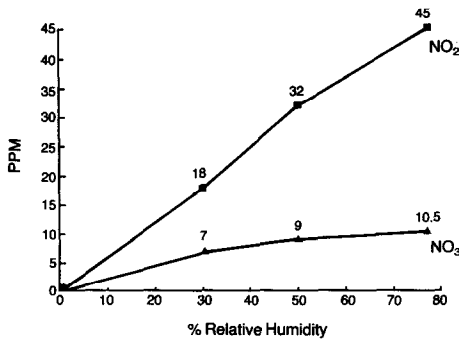


Fig. 1. Concentration of nitrates and nitrites formed during arcing vs. relative humidity in the room.

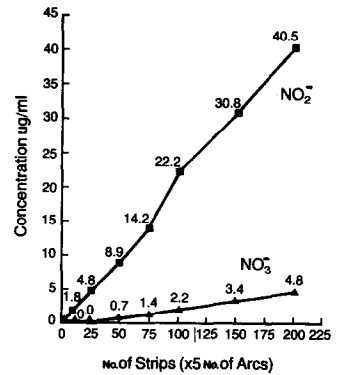


Fig. 2. Concentration of nitrates and nitrites formed during arcing vs. number of arcs.

placed a few feet away from the arcing operation. The water from both dishes was collected and analyzed via ion-exchange chromatography. High amounts of ionic nitrate and nitrite were detected in all samples placed under the arc, whereas none were detected in either blank. These experiments were then repeated with arcing only no wire was stripped. The results were interesting: the wire insulation itself did not contribute to the formation of nitrogen species. Rather, these species were being formed from NO_2 and moisture in the air (acid rain). The formation of nitrate and nitrite ions was found to be proportional to the number of arcs (Fig. 1) and relative humidity. Ionic nitrite could be detected in the water samples using the above techniques after only ten arcs and ionic nitrate after a minimum of 50 arcs. The arcing-over-water experiments were performed on the automated tools, varying the relative humidity in the room from 70 to 35%. The results showed that higher relative humidity produced higher concentrations of nitrite and nitrate (Fig. 2). It has been shown [5] that Cu will corrode [form blue $\text{CuNO}_3\text{-Cu(OH)}_2$ by-product] when exposed to an atmosphere polluted with oxides of nitrogen. With an NO_2 concentration of 8 ppm and a relative humidity of 15%, corrosion can be appreciable and increases with relative humidity. It is also known [6] that positive-polarity d.c. arc at atmospheric pressure yields predominantly a hydrated proton $\text{H}^+(\text{H}_2\text{O})_n$ and some other species, like O^- , NO_2^- , O_3^- , O_3 , NO_2^+ and NO^+ . Combining with water, nitrogen dioxide forms highly corrosive acids that precipitate on the part, causing exposed Cu to corrode.

An attempt to remove the contaminant introduced during wire bonding on the auto-tool using DI water and IPA rinse was unsuccessful. All engineering efforts were then directed toward eliminating or minimizing the source of the contamination. A successful solution to the problem was the installation of a small vacuum tube next to the arc to evacuate by-products away from the part surface. The effectiveness of the vacuum was tested by placing the petri dish with DI water on the automated tool under the arc, performing 200 wire strips with vacuum on, and analyzing the water sample using IC chromatography. No ionic nitrite or nitrate was detected in the samples collected on the auto-tool with vacuum of 15 p.s.i. or higher. The parts wired

on the automated tool with vacuum on had no visible corrosion or droplets of nitric acid.

IC analysis proved to be an indispensable tool for subsequently monitoring the automated operation. Misalignment of the vacuum tube or vacuum pressure lower than 15 p.s.i. lead to insufficient evacuation of the corrosive species, which were easily detected by IC analyses.

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