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In-Situ Thermal Radiographic Failure Analysis of Capacitor Encapsulant Fracturing

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ABSTRACT

Fractures have been observed on polymer tantalum capacitors in a repeatable longitudinal direction along and within the top-region of the molded epoxy encapsulant of sub-contractor SMT (surface mount technology) assembled CCAs (circuit card assemblies).

In-situ radiographic experiments were performed on as-received capacitors using a transmissive x-ray fitted with a heating or hot-stage programmed to simulate SMT production reflow profiles that revealed material forming on top lead frame within the encapsulant below < 232^{o}C.

Visual inspection afterwards confirmed longitudinal fractures were recreated with metal found in the fractures. EDS (energy dispersive spectroscopy) analysis found small amounts of Ag (silver) along with Sn (tin) in the metal.

Failure mechanism attributed to Ag from Ag-adhesives that reacted with the lead-frame Sn-plating, forming a Sn-Ag 3.8% eutectic alloy ~221^{o}C, which expanded and fractured the mold epoxy encapsulant along the top lead-frame in a longitudinal manner.

Key words: in-situ hot-stage radiography, tantalum capacitors, Sn-Ag, mold fractures, SMT reflow profile.

INTRODUCTION

Multiple tantalum capacitors are SMT attached to PCBs. Failures or fractures were observed only at contractor SMT assembly lines and not on RTX lines. Although the CCA capacitors passed electrical tests, a fracture in the capacitor molding encapsulant may compromise the long-term reliability of the capacitor from exposure to moisture, cleaning solutions, corrosive or harsh environments.

FAILURE SIGNATURE

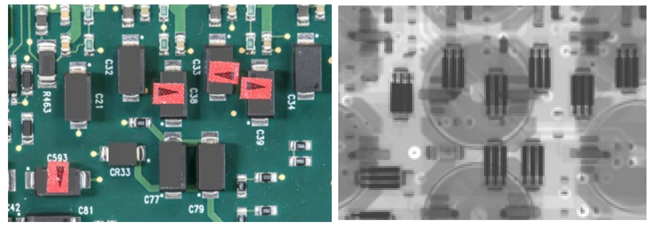


Figure 1. CCA with multiple tantalum capacitors that fractured (L). X-ray was not able to discern fractures or any extraneous metal on or within mold encapsulant (R).

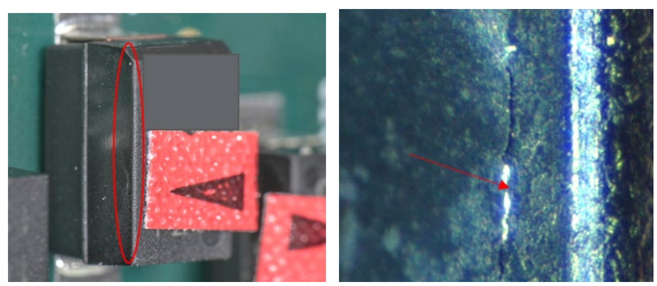


Figure 2. Capacitor (L) and at 10X magnification showed longitudinal fractures along the top and within the molded encapsulant with metal protruding from fractures (R).

ASSEMBLER / SUPPLIER ANALYSIS

Contract assembler and component supplier performed analyses on tantalum capacitors. No as-received capacitors were found with any fractures. No assembly or internal anomalies were reported or observed on capacitors that fractured after SMT assembly. Fractures were attributed from the presence of moisture.[1][2] However, upon revisiting x-ray images, extraneous material was observed on the top lead-frame within the molded epoxy.

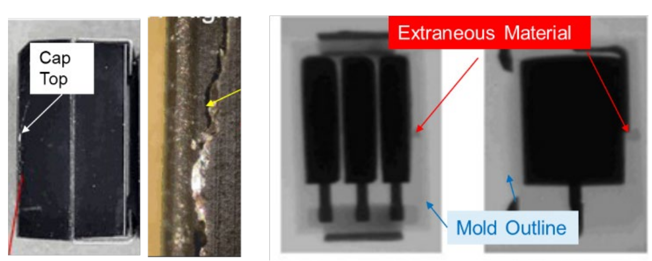


Figure 3. OM-optical microscopy images of longitudinal fractures with metal protruding (L). X-ray images showed extraneous material on top lead-frame within molding (R).

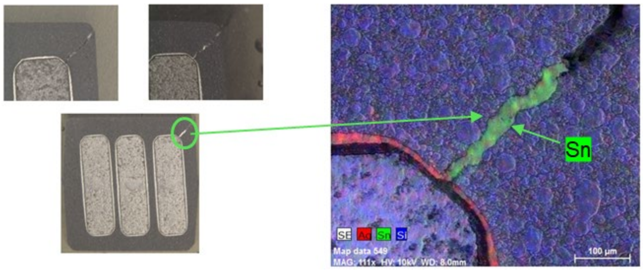


Figure 4. EDS- elemental dot map shows "Sn" in fracture of tantalum capacitor molding encapsulant (R).

RADIOGRAPHIC HOT-STAGE TECHNOLOGY

The "hot-stage" stage installed on the current X-ray machine is used for in-situ radiographic analysis to view the thermal effects on materials within a working area of 50 x 50 x 10mm. The hot-stage can be programmed with multiple various thermal profiles up to 280°C but does not have cooling capability.

In order to try and replicate the failures signatures and failure mechanisms, the X-ray machine hot-stage was programmed with a similar SMT reflow profile used in production to video in-situ, as-received capacitors, under similar production thermal processing conditions.

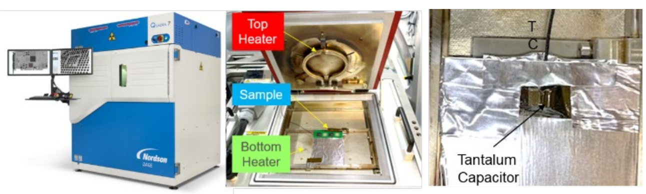


Figure 5. X-ray machine w/ hot-stage inside (L). The hot-stage has a top heater element and a bottom ceramic heater (C). TC-thermo-couple was attached to the back-side of 1 mm thick PCB, opposite device. Other areas not of interest were Al-aluminum thermal tape protected (R).

SMT THERMAL PROFILE

Experiments were performed on as-received capacitors based on replicating the SMT thermal profile used to attach capacitors lead-frames to PCBs pads for production.

The X-ray machine hot-stage heaters were programmed to simulate a production SMT reflow profile as best as possible to radiographically view or video record as-received tantalum capacitors as they would be typically thermally processed in production SMT lines to attempt to recreate or video capture the failure mechanism in-situ or real-time.

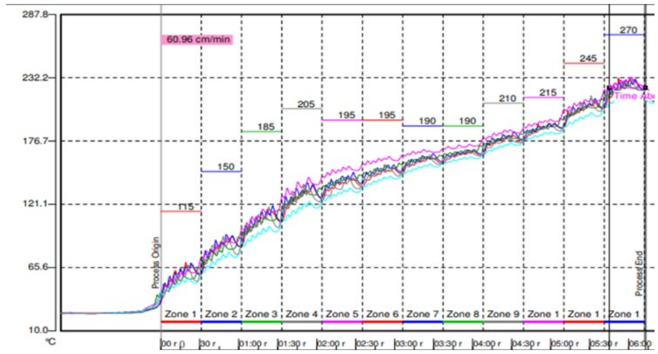


Figure 6. Actual production in-line SMT thermal reflow profile used to base the in-situ simulated thermal reflow profile on X-ray hot-stage.

EXPERIMENT 1:

With hot-stage installed in x-ray machine, one (1) tantalum capacitor was Kapton-tape attached in the normal upright position to a PCB without solder. TC-thermocouple was attached underneath the 8 x 4 x 4 mm tall tantalum capacitor with thermal tape to a 1 mm thick PCB suspended on guides so as to not touch top or bottom heater elements. Hot-stage lid carefully closed and then SMT reflowed.

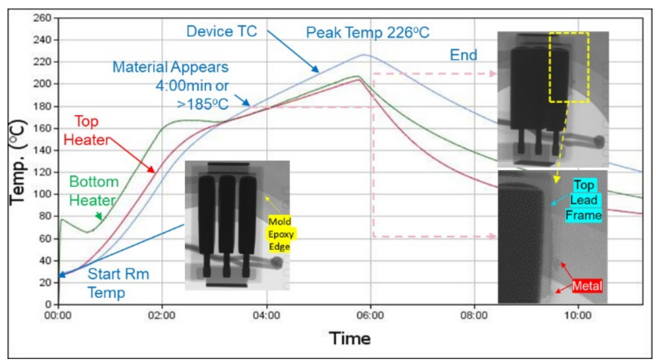


Figure 7. X-ray hot-stage top / bottom heaters and capacitor temperature vs time thermal profiles on 1 device. TC-thermocouple attached on back side of PCB. Material formed on top lead-frame edge, underneath the mold epoxy surface ~ 4:00min, ~185°C .

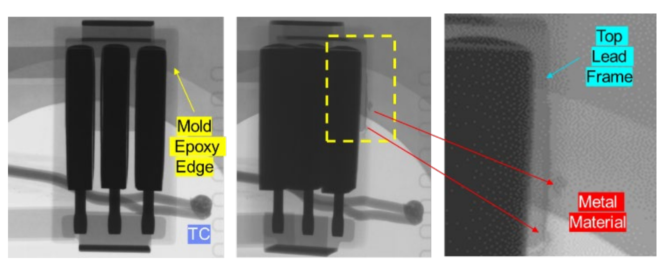


Figure 8. Closer views of capacitor before (L) and during simulated reflow on x-ray machine hot-stage (C, R). Material formed along the of the top lead frame < 232°C.

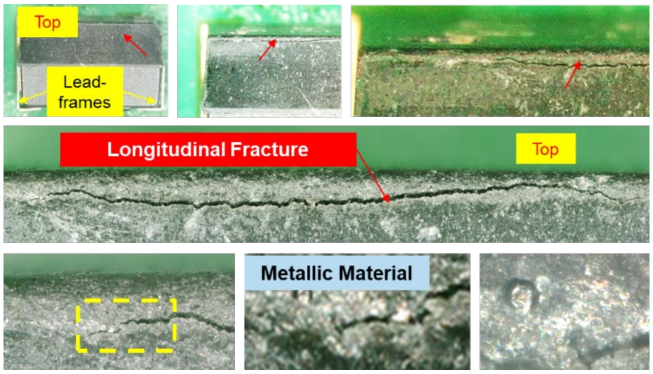


Figure 9. After reflow in X-ray machine. Increasing magnification views show longitudinal fractures were replicated along the top surface within the molded encapsulant with metal observed within the fracture as in previous production failures.

EXPERIMENT 2

Two (2) tantalum capacitors were Kapton-tape attached to a PCB with 1) on its side and 2) in the normal upright position or bottom side down. TC-thermocouple attached opposite the capacitors on PCB backside. Hot stage-lid closed and then thermally processed per same programmed SMT reflow profile.

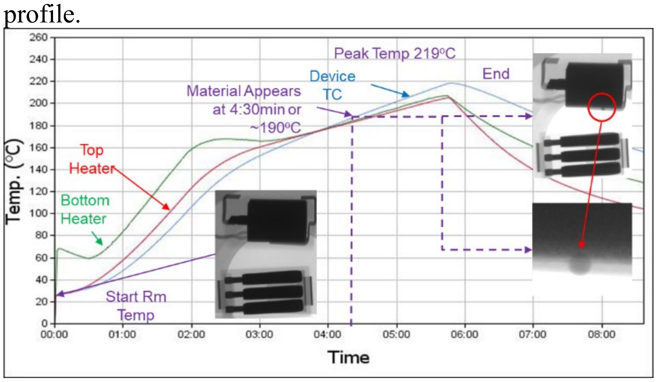


Figure 10. X-ray hot-stage top / bottom heaters and capacitor temperature vs time thermal profiles on 2 devices. Material appeared on top lead-frame edge, underneath the mold epoxy surface ~4:30min, ~190ºC .

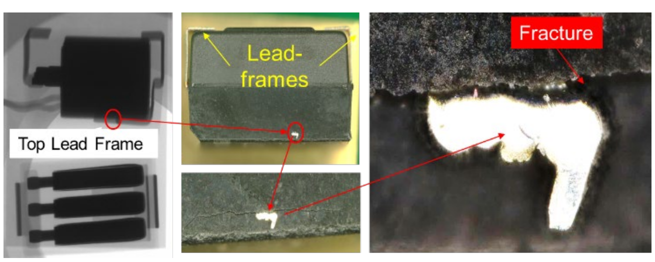


Figure 11. X-ray image after 2nd SMT reflow replicated failure (L). Shows as-received capacitor lead-frames with a longitudinal fracture along the top lead-frame (C). Closer view shows a metallic material emerging from the fracture as observed in previous production failures (R).

TANTALUM CAPACITOR CONSTRUCTION

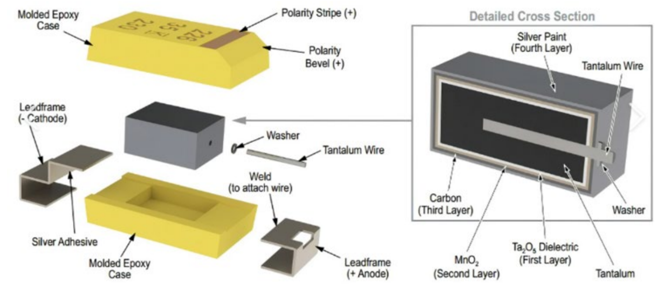
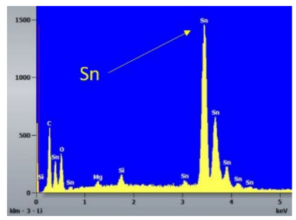


Figure 12. Representative tantalum construction tantalum for reference. Note Ag-silver adhesive used on the lead-frame that was later confirmed to be Sn (tin) plated.



	Weight %
C K	3.67
O K	9.77
Mg K	0.62
Si K	1.15
Sn L	84.80
	100.00

Figure 13. EDS-energy dispersive spectra of the tantalum capacitor lead-frame surfaces, that are SMT reflow attached to PCB pads. Predominantly a Sn surface.

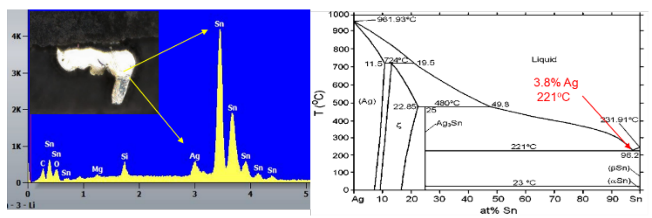


Figure 14. EDS chemical analysis spectra of the metallic material protruding from the longitudinal fracture showed small amounts of Ag along with mostly Sn (L). Ag-Sn phase diagram shows a low temperature Sn-Ag 3.8% eutectic alloy can form ~221ºC (R).

SUMMARY OF ANALYSIS

- Capacitor encapsulant longitudinal fractures were replicated. Ag-Sn radiographically viewed in -situ forming on top lead-frames under simulated SMT reflow profiles.

- Both X-ray hot-stage reflow experiments showed material forming ~180-190^{o} C. Actual temperature at top of device most likely higher since TC was on opposite side of PCB.

- Visual inspection afterwards and EDS confirmed Ag-Sn emerging from the fracture as observed in previous production failures.

FAILURE MECHANISM

Although Ag melts ~ 962^{o}C and Sn melts at 232^{o}C, a small amount of Ag from the Ag-adhesive, formed a Sn-Ag 3.8% eutectic alloy with the top Sn-plated lead-frame ~221^{o}C.

The tantalum capacitor's top lead-frame most likely experienced higher temperatures given its proximity to the top heater and not as thermally protected as the middle lead-frame, where the Ag-Sn alloy formed, expanded and fractured the mold epoxy along the top lead frame in a longitudinal manner.

A slightly lower SMT RF profile temperature thus far, has mitigated this fracture phenomena.

ACKNOWLEDGEMENTS

Mohan John, Pat Lott, Alec Labitt, Christine Carlucci

REFERENCES

[1] EMS Assembly Investigation 05 / 2022
[2] Component Supplier FA Report 07-15-2022,