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A study on electrochemical effects in external capacitor packages

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ABSTRACT

Exposing semiconductor devices with external capacitors to harsh environmental conditions may lead to electrical failures with the formation of conductive paths. This paper presents examples of the analysis of modules with the purpose to understand the respective failure modes. Appropriate sample preparation, sensitive analytical methods like micro-X-ray fluorescence spectroscopy (μXRF), ToF-SIMS, SEM/EDX, X-ray-microscopy as well as micro computed X-ray-tomography (μCT) have been applied to identify the root causes of the electrical failures.

As a main conclusion of these investigations, we found that electrolytes can easily penetrate thermoplastic overmold materials which are typically used by module manufacturers. This can lead to either reversible electrical failures which can be eliminated by drying or irreversible electrical failures because of material migration. The effective failure mode depends on mechanical and climate conditions inside the module which could not be simulated up to now under laboratory but only under application conditions.

1. Introduction

Semiconductor devices are often driven in combination with external capacitors to improve the EMI (= electromagnetic interference) performance (e.g. PSSO-package). During application, the final product module can be exposed to a harsh environment with variable temperatures in combination with increased humidity and ionic contaminations. To protect the microelectronic packages from these environmental influences and to allow a simplified handling and installation, those devices are usually overmolded by module manufacturers. Thermoplastic polymer material, such as reinforced polyamide is typically used for this.

However, as the following analytical investigations show, electrical deviations, like a leakage current occur and can be related to the external capacitor.

This paper reports on comprehensive analysis on such modules. Samples after field application tests as well as new parts and samples after laboratory stress have been analyzed and reliability tests have been performed to confine the failure modes and to specify possible root causes.

2. Initial situation

Application ready modules are usually built up in several steps. First, the IC package leads are bended and it is mounted on a polymer carrier. Then the leads are connected to the module outer contacts like wires by e.g. a welding process. In the final step, the whole component is overmolded by a thermoplastic polymer. For this, typically a reinforced polyamide is used.

Fig. 1 shows a module with bended leads and the contact to the module wires (left hand side) after the overmold process. The ceramic capacitor is attached to the leads by silver epoxy glue and protected with an electronic molding compound (=EMC). A gap between EMC and overmold material is visible directly at the tip of the red arrow. Debris is visible in the support hole.

Typically, modules with a non-conformal behavior showed a leakage current or a short. In some of the cases, this phenomenon vanished after drying the sample which indicates that a permanent metallic bridging did not occur. Tests have been performed to increase the moisture content of the module again after drying and in one case the leakage current came up again. This behavior indicated that electrochemical effects play a major role.

Electrochemical migration (ECM) effects are well described not only in early literature [1–3] which differentiates between metallic electromigration and wet and humid electrolytic electromigration. ECM is characterized by the movement of metal ions between metal conductors, to form dendrites. It is driven by increased temperature and humidity, the presence and strength of an electrical field and possible contaminations such as halogenides. Whereas electromigration occurs within a metal conductor and humidity has no effect on it [4].

But also actual references show that this phenomenon is still worth to discuss. Zuo et al. describe the influence of silver migration

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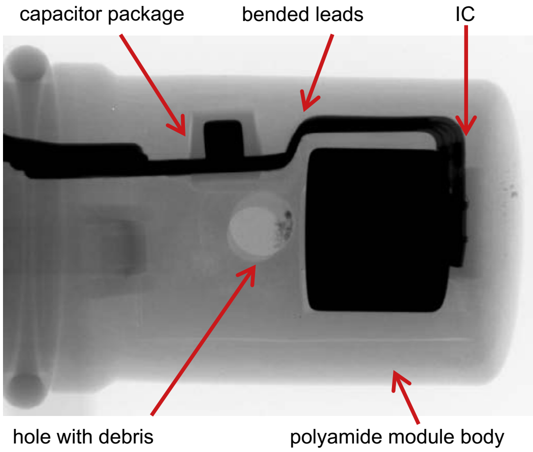

Fig. 1. X-ray-microscopy image of a module after overmolding.

and its micro-mechanism on the reliability of capacitors [5], whereas Riva et al. presents their mitigation solution to overcome the migration problem by a polymer coating [6].

3. Sample analysis

The following examples describe the analysis of samples where an electrical failure was detected in a first instance. Besides standard analytical procedures, we applied methods like micro-X-ray fluorescence spectroscopy (μXRF, linescan after penetration test) and micro computed X-ray-tomography (μCT) to better understand the failure mechanisms.

3.1. Example 1

In this application, two identical devices have been directly installed in an application at two different positions. Only one position was affected (statistically significant). The operating temperature of the not affected module was typically above 100 °C and that of the affected one below 100 °C. The lower temperature supports condensation of moisture, especially in short term use with heating and cooling cycles.

The infrared lock-in thermography (IRLIT) analysis of a package in a different analytical case showed a hot spot at the capacitor position (Fig. 2). Therefore the expectation was that Ag-dendrites at the interface between ceramic capacitor and molding compound are the reason for the electrical failure. After X-ray analysis which did not show any remarkable deviation, the sample has been cracked mechanically to avoid any contamination by sawing (Fig. 3).

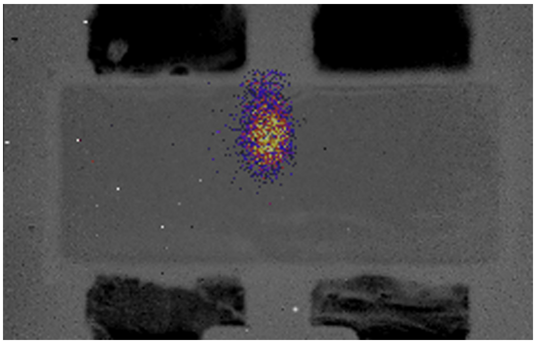

Fig. 2. IRLIT image of a capacitor package.

The SEM/EDX analysis of the capacitor surface (Fig. 4) revealed that Ag-dendrites had covered a large area between the Ag-filled epoxy glue dots (distance approx. 420 μm).

However, no additional elements which could appear as a contamination have been detected. To prove this, on a similar sample which showed the same electrical failure characteristics a ToF-SIMS analysis was performed (Fig. 5).

Again, the Ag-dendrites have been found, but no significant signal intensities of species like chlorine or bromine were detected. In accompanying laboratory "water drop tests" with blank capacitors, we found that even in deionized water dendritic growth takes place in only a few seconds (Figs. 6 and 7).

This result illustrates that a detectable ionic contamination is not mandatory and increased levels of humidity may be sufficient. Similar tests have been performed by Zhou et al., who report the detailed electrolytic reactions and galvanic reactions on the electrodes [7].

The identification of the Ag-ion source was possible after mechanically cross-sectioning and ion-milling of the cross-section surface (Fig. 8). The filler particles of the epoxy adhesive showed clearly the porous structure of corrosion (red arrow), indicating the source of Ag-ions. The EDX map of Ag in Fig. 8 reveals that silver is able to migrate not only along the molding compound ceramic capacitor interface but through the molding compound organic matrix itself. Quartz filler particles are coated with silver and show this circle shaped intensity distribution.

Based on this, several stress tests on module- and package-level, e.g.

- temperature cycling (−50 °C…+155 °C, 30%…60% r.h.)
- THB (18 V, 42 °C, 98% r.h.)
- AC96 (18 V, 106 °C, 95% r.h.)
- HAST (130 °C, 85% r.h., 2 bar overpressure)

and a test where the module is operated above boiling water in steam atmosphere have been performed. Additionally, tests with electrolytes as possible contaminants were carried out. These laboratory tests had the aim to provoke Ag-migration by maximizing the

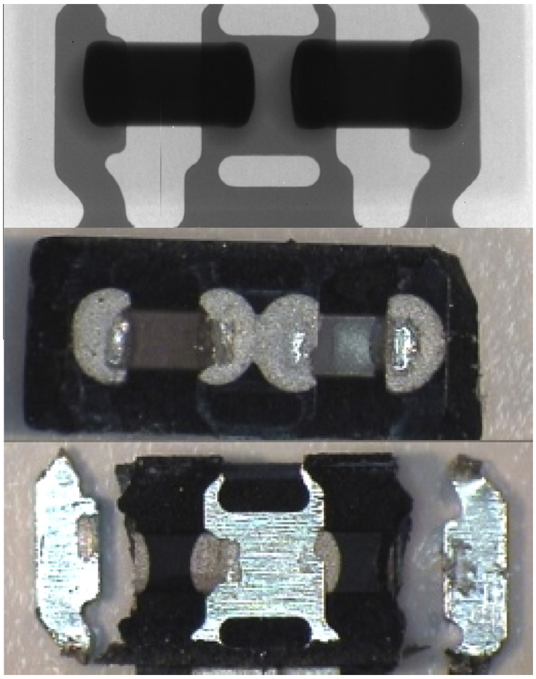

Fig. 3. X-ray-microscopy image and optical image of the capacitor package after cracking.