Microelectronics Reliability xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Identification of foreign particles in packages of failed products by application of our modified failure analysis flow

Rik J. Otte *, Rob F. Fonville, Martin D. Knotter

NXP Semiconductors, Product Diagnostic Center, Gerstweg 2 (FB0.101), 6534 AE Nijmegen, The Netherlands

ARTICLE INFO

Article history:
Received 25 May 2017
Received in revised form 29 June 2017
Accepted 14 July 2017
Available online xxxx

Keywords:
Bond pad corrosion
Molding compound
Foreign particle
Conductive particle
Halogen-containing particle
FA flow

ABSTRACT

In this paper, two Failure Analysis (FA) examples are discussed of products which failed due to an electrical short or open. These cases were analyzed following our modified FA flow, where repeated mechanical polishing and inspection has replaced chemical decapsulation. Foreign particles were found close to the shorted or corroded (high resistive or electrical open) bond pads of these products. Subsequently, these particles could be characterized as Diamond-Like Carbon (10–50 μm diameter) and partially degraded halogen-containing material (80–100 μm diameter), respectively.

By using the modified FA flow in such cases, the actual failure root cause can be diagnosed and the potential sources can be traced back. Finally, the identified sources as well as other potential sources throughout the material supply chain and manufacturing process can be eliminated. Structural application of this improved way of working has led to a breakthrough in our Automotive zero-defect roadmap.

1. Introduction

Standard integrated circuit encapsulating molding compounds consist primarily of SiO_2 filler (70–90%), epoxy resins (3–7%), hardener (3–7%), and additives such as adhesion promoters, flame retardants, carbon black, etc. [1]. Contamination in the production process of the molding compound and during molding may cause systematic and/or random failures in reliability tests or in the field. Two main types of contamination-induced fails can be distinguished: direct fails (e.g. zero-hour electrical shorts) and latent fails (e.g. electrical opens upon aging due to e.g. bond pad corrosion). Direct fails may be screened during final electrical tests. 100% test coverage needs to be implemented to guarantee the performance of all devices. Contamination can be homogenously or non-homogeneously (such as in the case of particulates) distributed. Conductive particles causing direct fails can be relatively small (down to wire pitch in size) and can, therefore, be difficult to detect inline [2]. They can give rise to so-called latent fails if the distance between biased entities decreases beyond a critical point and cause reliability fails due to e.g. dendrite formation. These latent fails usually pass all zero-hour inspections but pose reliability risks. Other examples of latent fails are related to halogen contamination. Halogens present in the molding compound can migrate to (biased) bond pads, and cause bond pad corrosion. Therefore, the halogen contamination level is specified for molding compounds. In the molding compound, the halogen contamination is expected to be homogeneously distributed.

In our investigation of possible causes of bond pad corrosion, we found that the presence of halogen was not the only relevant parameter. Corrosion can only take place if three conditions are fulfilled: die-surface delamination, the presence of moisture, and the presence of a corrosive element such as chlorine which breaks the native aluminum oxide layer (see Fig. 1) [3]. Application of electrical bias on bond pads may accelerate corrosion.

Besides, we found that the results of the standard Failure Analysis (FA) flow is not always conclusive because:

A. Corrosion may be caused by FA sample preparation (artefacts).
B. Corrosion may potentially be mixed up with electrical overstress or other failure mechanisms with a similar fingerprint.
C. Corrosion may be observed, but its root-cause cannot be identified.

In order to allow identification of the particle-induced fails, the standard FA flow has been modified. We first published the modified FA flow for electrical shorts in 2015 [2], after applying this flow to solve a conductive particle related incident (see also Section 4a). In this paper, the standard and modified FA flow are compared for fails related to electrical opens. Two examples of particle induced fails will be highlighted to show the effectiveness and further benefits of the modified flow.

---

* Corresponding author.
E-mail address: Rik.Otte@nxp.com (R.J. Otte).

http://dx.doi.org/10.1016/j.microrel.2017.07.065
0026-2714/© 2017 Elsevier Ltd. All rights reserved.

Please cite this article as: R.J. Otte, et al., Identification of foreign particles in packages of failed products by application of our modified failure analysis flow, Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.07.065

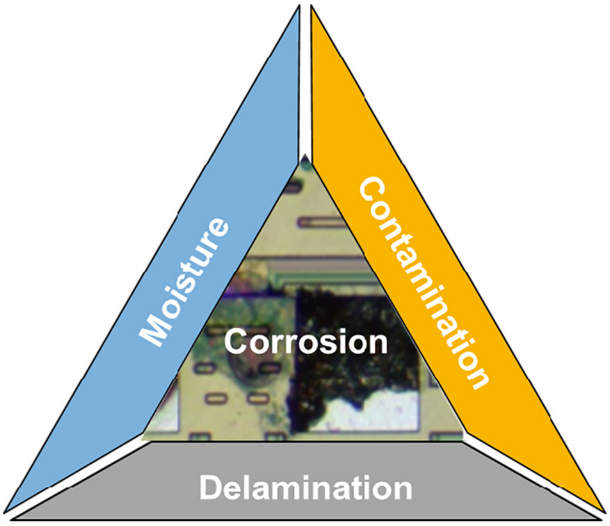

Fig. 1. Schematic representation of prerequisites to bring about aluminum bond pad corrosion; delamination, moisture and a corrosive element such as chlorine (contamination). Optical image of a corroded bond pad after chemical decapsulation in the background.

2. Failure analysis flow

The FA flow to analyze reliability fails is schematically shown in Fig. 2. The standard and modified flow for electrical opens will be discussed in Sections 2.1 and 2.2, respectively.

2.1. Standard flow

As soon as an open connection is electrically observed, and non-destructive techniques like SAM and X-ray analysis point at corrosion, backside decapsulation followed by Infrared (IR) inspection is performed. When interrupted bond pads are found, further front side analysis is carried out by mechanically and chemically removing the mold compound followed by optical inspection, SEM inspection and EDX. Thus, bond pad corrosion can almost unambiguously be established. In other words, there is sufficient evidence that corrosion causes the electrical fail. However, due to chemical removal of the mold compound, the root cause for this corrosion may be lost. To allow root cause investigation, a modified FA flow was required.

2.2. Modified flow

When corrosion is suspected after backside IR inspection (Fig. 2, step 2), the package is mechanically polished and optically inspected whilst polishing (Fig. 2, step 3b). Although this procedure is more time-consuming, it allows inspection of the material removed in the polishing process. Anomalies in the package can subsequently be characterized in step 4.

3. Materials and methods

The samples analyzed in this paper are integrated circuits with shorts, electrical opens or a high resistive paths. The products fail final tests or during exposure to accelerated aging conditions such as Highly Accelerated Stress Test (HAST).

The following tools and methods are used in the FA flow and material characterization. See Fig. 2 for schematic analysis flow:

Step 1

- Electrical verification setups to screen (high resistive) electrical opens and shorts.
- X-ray to non-destructively check for anomalies such as big particles.
- Scanning Acoustic Microscope (SAM) to non-destructively localize delamination.

Step 2

- Mechanical polishing disk setups for backside polishing.
- Infrared (IR) microscope for non-destructive inspection from the backside.

Step 3a and b

a. Facilities and chemicals for decapsulation
b. Mechanical polishing disk setups for backside and frontside polishing.

Step 4 (options)

- Scanning Electron Microscope (SEM) with Energy Dispersive X-ray (EDX) for imaging and semi-quantitative elemental analysis.
- Focused Ion Beam (FIB) to make local cross-sections and perform voltage contrast imaging.
- X-ray Photoelectron Spectrometer (XPS) for surface-sensitive, chemical and electronic state analysis of elements.
- Fourier Transform Infrared (FT-IR) single point ATR crystal for local absorption spectroscopy.
- Confocal µ-Raman for micro spectroscopy down to 1 µm pixel size.

3.1. Particle analysis

Foreign particles found in the failed products can range from a few to hundreds of µms in size. They can be relatively easy or difficult to find, depending on the type of failure mode and specific size. Particles causing electrical shorts between two wires are generally easier to trace down. In such cases, smaller particles can be successfully identified (down to 1050 µm). Particles causing electrical opens may be more difficult to find in this size range, especially when non-destructive techniques such as SAM are unsuccessful in detecting acoustical reflections caused by transitions into the particle's composition or by delamination surrounding the particle.

Localized particles were characterized by elemental and/or molecular spectroscopy techniques. In particular for degraded particles (due to aging), results from multiple complementary characterization techniques may be required. Based on these extensive analyses, faster fingerprinting methods (e.g. by one technique only) can be applied to find the source of the particles.

4. Results

Two examples will be discussed where foreign particles were found during mechanical polishing (Fig. 2, step 3b).

a. Electrical short: conductive particle

Shorted wires were found. By combined mechanical and FIB cross-sectioning in slice-and-view mode, the short was localized (see Fig. 3). SEM-EDX (not shown) revealed that the particle consists of SiO_2 with a carbon and oxygen containing coating. Although EDX can successfully distinguish the different materials in the cross-section, it is not suited to link the material to a possible source. Voltage contrast imaging established that the organic coating is conductive and has shorted the wires. With Raman, the coating appeared to be Diamond-Like Carbon (DLC) material [2].

DLCs include a range of materials varying from diamond (D, sp3 hybridized structure, non-conductive) to graphite (G, sp2 hybridized

Please cite this article as: R.J. Otte, et al., Identification of foreign particles in packages of failed products by application of our modified failure analysis flow, Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.07.065