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Die crack failure mechanism investigations depending on the time of failure

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ABSTRACT

The quality and reliability concern of the die crack failure mechanism needs to be addressed at each step of the supply chain, from the wafer supplier, semiconductor fabrication, package assembly, Tier1 manufacturer assembly, to the end customer application. Finding the critical factors of a die crack is crucial for the root cause investigation, allowing the implementation of accurate corrective actions. The various analytical methods that can be employed are numerous, from standard FA techniques (mainly SAM & fractography) to advanced techniques like TherMoiré Analysis or Finite Element Simulation. Application-level analysis, problem solving and continuous improvement methodologies are also key success factors for such problems: Fault Tree Analysis and Ishikawa diagram will enable complete process assessment, including package and die integrity, assembly process, Surface-mount technology (SMT) process, and stress condition at the end customer application. This paper first introduces the different and complementary FA techniques, then presents three case studies that illustrate the difficulty to identify the cause of such die cracks, as a function of the time of failure.

1. Introduction

The brittle nature of silicon turns the die into the weakest part of the integrated circuit complex object, in terms of mechanical properties. This is obviously a reliability concern that needs to be addressed at each step of the supply chain, from the wafer supplier, semiconductor fabrication, package assembly, Tier1 manufacturer assembly, to the end customer application. In addition to the reliability risk, this is also an economic requirement as compared with the manufacturing yield loss (scrap avoidance), qualification failures (time to market) or customer returns (quality level) it can generate.

There are multiple factors to consider in minimizing the risk of die fracture/cracking in a plastic package: silicon die strength, package integrity, package materials, residual stresses after wafer saw/die attach/die bond/molding process, stress condition on the application board, stress condition at the end customer, etc.

Finding the critical factors of a die crack is crucial for the root cause investigation, allowing the implementation of accurate corrective actions. The various analytical methods that can be employed are numerous [1]. Some die cracks will be easily interpreted and a standard failure analysis (FA) approach will quickly lead to the true cause. But few cases will require extensive application of various FA techniques, and sometimes the expertise of Packaging/Assembly experts.

This paper first introduces the different and complementary FA techniques, then presents three case studies that reflect the difficulty to identify the cause of such die cracks, as a function of the time of failure. Eventually a discussion about the combination of those methodologies and techniques will take place.

2. Die crack investigation

2.1. Non-destructive techniques

2.1.1. X-ray microscopy

The X-ray microscope is a standard piece of equipment in a FA Lab that uses electromagnetic radiation in the soft X-ray band through the specimen to produce a projected image. It is based on contrast imaging due to the difference in absorption of the sample materials. That principle is a limitation with conventional X-ray absorption technique: poor contrast is obtained when imaging low Z materials and their defects as silicon die cracks. However, that technique is critical to assess the quality of the package itself and to allow validating few assembly parameters (die attach coverage, die placement, etc.), valuable in the crack investigation.

The recent increase of the resolution of the X-ray system and the implementation of 3D X-ray Computed Tomography enables the imaging of such defects without any invasive technique, depending of the dimensions of the die cracks.

2.1.2. Scanning Acoustic Microscopy (SAM)

The SAM uses ultrasound waves to assess the package integrity, evaluating the interfaces between materials. Defects linked to the presence of air such as porosity, voids, cracks or delamination will be captured by that technique. Reflection or transmission images can be obtained, and the package can be approached from every direction.

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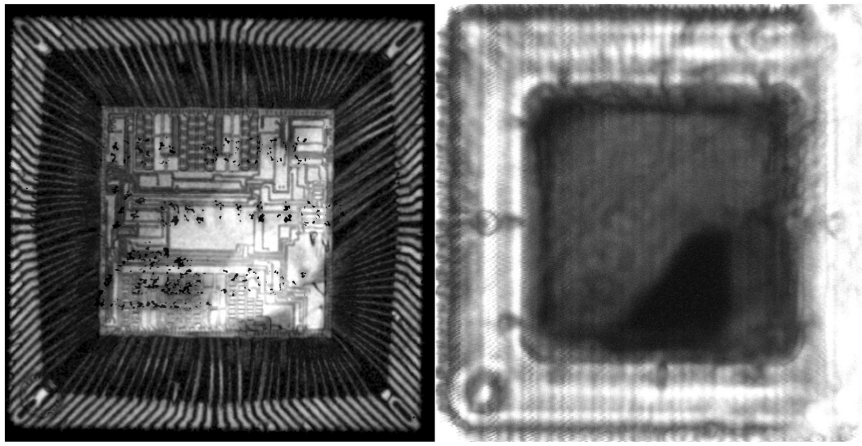

Fig. 1. Die corner crack by reflection/transmission.

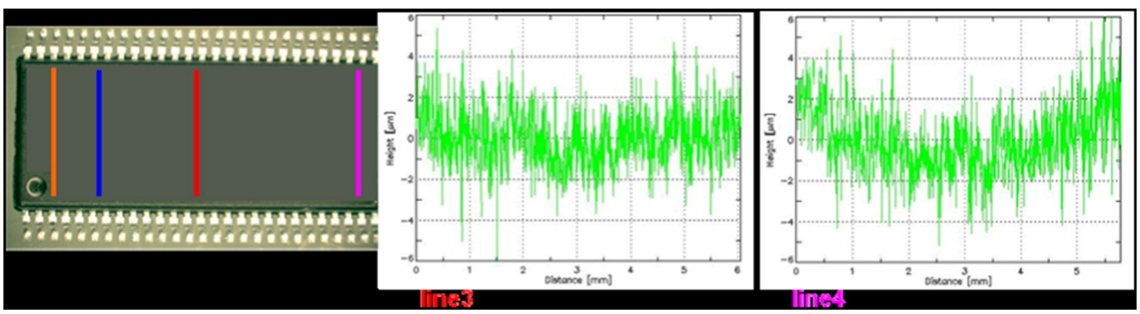

Fig. 2. Contour profile of package: concave warpage.

The different sample materials have a specific acoustic impedance to be taken into account during the analysis.

The nature of a die crack being a fracture of the silicon entails the creation of new interfaces detected by SAM imaging. See Fig. 1 with an example of signal amplitude images obtained on a die corner crack.

2.1.3. Optical profilometry

That non-contact interferometric-based method allows characterizing surface topography. A typical OP analysis provides 2D and 3D images of a surface, roughness statistics, and feature dimensions. It is useful to obtain package surface profile and detect convex or concave warpage.

In Fig. 2, the warpage indicated a thermo-mechanical stress applied to the package during heat excursion of packaging and SMT process.

2.1.4. TherMoiré Analysis or Topography and Deformation Measurement (TDM)

That metrology solution utilizes the shadow Moiré measurement technique to characterize out-of-plane displacement with time–temperature profiling. The sample mechanical behavior can be finely analyzed during a thermal profile. It aims at reproducing real-world processes and operating environments, taking into account the interactions between materials, packages, substrates and complete assemblies. Fig. 3 shows an example of TherMoiré Analysis at the BGA device level.

2.1.5. Electrical fault localization techniques

Few techniques are available to assess the electrical behavior of the faulty devices. In addition to pure electrical measurements (and one can expect parametric or gross functional failures with a die crack), a first information of the spatial location of the die crack itself can be

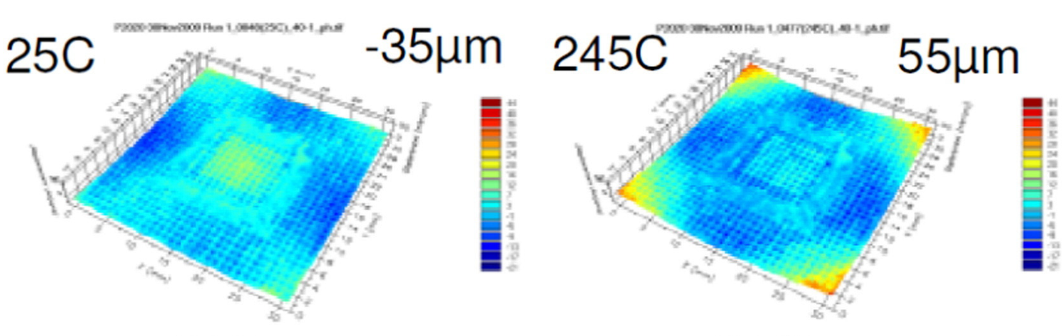

Fig. 3. TherMoiré warpage analysis on a BGA package.

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