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An Overview of Scanning Acoustic Microscope, a Reliable Method for Non-destructive Failure Analysis of Microelectronic Components

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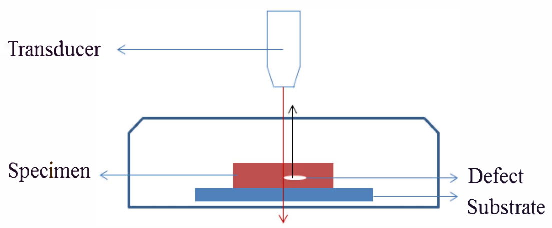
Abstract

In a highly competitive and demanding microelectronics market, reliable non-destructive methods for quality control and failure analysis of electronic components are highly demanded. Any robust non-destructive method should be capable of dealing with the complexity of miniaturized assemblies such as chip-scale packages and 3D IC stacks. Scanning acoustic microscopy (SAM) is indeed one the best non-destructive tools for failure analysis purposes. It is also a useful technique for imaging the morphology, location and size distribution of defects in different microelectronics components. SAM can detect delaminations at sub-micron thicknesses. It is also one of the only available techniques capable of efficiently evaluating popcorning in PBGA's and is a also useful device to detect sub-micron air gaps. SAM can also be used to measure the thickness of an internal layer of material. Overall, SAM is an efficient tool for evaluating such a wide range of different defects in printed circuit boards, underfills, BGAs, wire bonds, discrete components, and wafers. In SAM a focused sound is directed from a transducer at a small point on a target object, as is schematically shown here. Sound, hitting a defect, inhomogeneity or a boundary inside material, is partly scatted and will be detected. The transducer transforms the reflected sound pulses into electromagnetic pulses which are displayed as pixels with defined gray values thereby creating an image.



This article aims at giving an overview of scanning acoustic microscope (SAM) and explaining its operating principles and its limitations. A few examples are also given for further clarification.

Introduction

Microelectronic assemblies are normally very complex in the sense that lots of components are gathered in a relatively small volume fraction, under different stresses and failure modes. The defect in microelectronic components could be due to temperature cycles, mechanical stresses as well as corrosion and electric fields. Delamination between UF and the substrate, bump dielectric damage, dielectric delamination, Lid delamination, solder extrusion, solder fatigue, voids in UF, cracks in UF, incomplete wetting, delamination within substrate, and solder collapse are only a few failure mechanisms that are observed in a microelectronic assembly [1]. Figure 1 shows schematic of a package with location of some frequently observed failures.

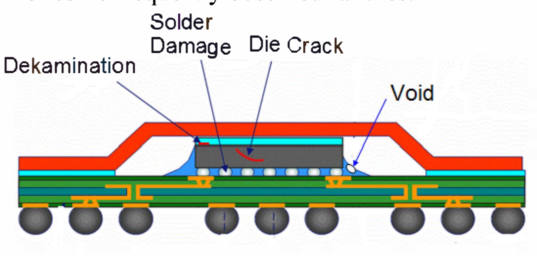


Figure 1: Schematic of a package with location of some failures

There are lots of methods for failure analysis of damages in microelectronic packages, including but not limited to: optical microscopy, laser decapsulation, wet etch decapsulation, SEM microscopy, TEM microscopy, X-ray, and scanning acoustic microscopy (SAM). The problem with most of these methods is the fact that they are destructive. This means that there is always possibility that the damage itself will be gone during preparation. Besides, most of these destructive methods need time consuming and sophisticated sample preparation. So, in most cases, it is crucial to study cracks and other damages with a non-destructive technique. Among different non-destructive methods, scanning electron microscopy (SAM) is the most widely used techniques. SAM provides nondestructive imaging of defects and delaminations in die and package materials. Even though it is a complex technique, requiring greater skill and experience for operation and interpretation of the results, it still provides some advantages over other available NDT technologies which makes it an excellent choice in some applications. For example, SAM is highly sensitive to the presence of delaminations and air-gaps at sub-micron thicknesses and is particularly useful for inspection of small, complex devices. SAM can also be used to measure the thickness of an internal layer of

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material. The reflected signal in SAM can also be used in production of three-dimensional images from defects. Another important feature in SAM is the possibility of having information from different layers in materials.

Fundamentals of SAM

Figure 2 shows a picture from SAM. The transducer in this microscope is the most important part of the device. In case the transducer sends an ultrasound signal with a specified frequency to the sample. The chosen frequency depends on the materials and the information needed. A fraction of the incident acoustic energy is reflected when there is a change in the density of the material and the reflected signal is detected by the same piezoelectric transducer and converted back to an electrical signal. The echo signal is then analyzed and is used to form images of internal structures and defects [2].

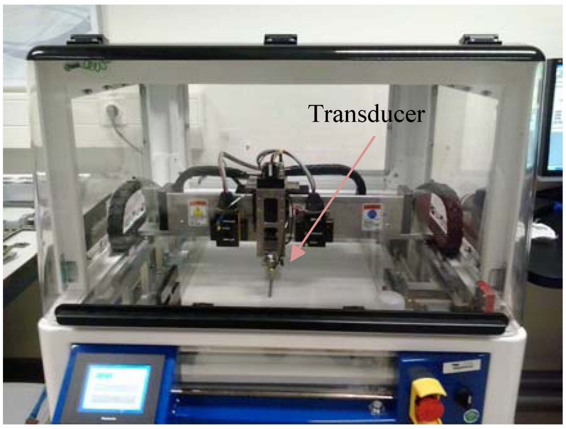


Figure 2: Scanning Acoustic Microscope (SAM), available in TNO Eindhoven, The Netherlands.

Three main types of analysis modes are available in SAM; named as A-scans, B-scans, and C-scans. Each one provides different information of the cracks and defects in samples. These analysis modes are briefly explained here: The A-scan is the echo signal over the thickness of the sample. Using A-scan, one can properly focus the transducer. A schematic of A-scan is shown Figure 3. Changing the position of transducer would change the amplitude of signals. When the signal amplitude is maximum, the transducer is focused. The B-scan is a cross-section of the sample and it provides visualization depth information within a sample. It is a very good feature when it comes to the evaluation of defects in cross section. A C-scan is typically the type of analysis which gives 2D images of the specimens. Images in the C-scan mode can be obtained from a specific depth in the samples. It is also possible to have images from different depths in one scan, as is shown in Figure 4. This is called Tomographic Acoustic Micro Imaging (TAMI).

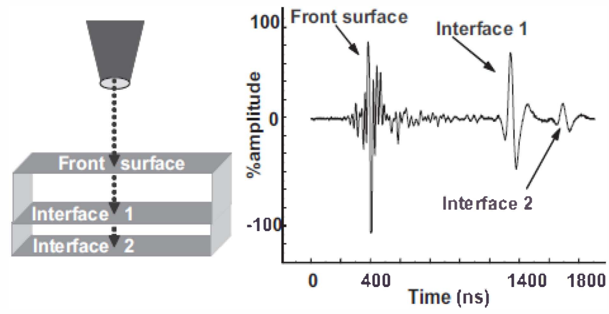


Figure 3: A-scan over the thickness of the sample [2].

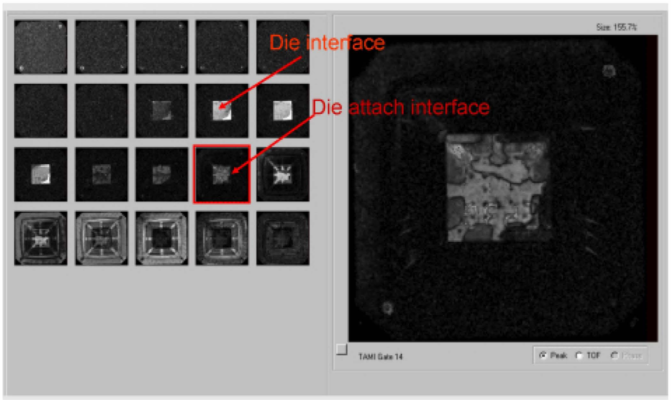


Figure 4: Tomographic Acoustic Micro Imaging (TAMI) mode in SAM [3]

Applications of SAM

SAM in principle can detect die tilt, solder ball joint geometry, underfill coverage, popcorn cracks, package voids, underfill delaminations, cracks, voids, bonded wafer voids, solder cracks and a number of other process originated defects. Some of the more commonly examined components and packages include: Bare printed wire boards (PWBs), Bonded wafers, Capacitors, Ceramics, COB (Chip On Board), CSP (Chip Scale Package), Flex circuits, Flip chips, MCM, (Multi Chip Module), PBGA (Plastic Ball Grid Array), PDIP (Plastic Dual In-line Package), PLCC (Plastic Leaded Chip Carrier), PQFP (Plastic Quad Flat Pack), Smart cards, SOIC (Small Outline Integrated Circuit), and TSOP (Thin Single Outline Package). A few practical examples are given from defects, which can be analyzed by SAM.

Example 1: Dielectric Delamination due to Sawing

The constant need for the reduction in spacing of metal interconnects for a better die performance, has led semiconductor industry to replace traditional silicon dioxide dielectrics with low-k materials [4]. Use of materials with a k value lower than SiO_2 has reduced the capacitance of the interconnect structure. The interaction of these materials with the dicing blade, used in traditional mechanical dicing, however, results in delamination, micro-cracking, and chipping. This is due to the brittleness and fragility of the low-k silicon materials [5]. Due to these specific characteristics, the blade sawing is not an option for manufacturers. Lasers could have provided significant benefits because of the lack of mechanical stress that is primarily responsible for crack formation. However, lasers induce heat damage and a brittle recast layer, causing chipping and delamination. New dicing processes are based on a short-pulse laser beam to initially groove the upper layers, followed by blade sawing. SAM analysis is an extremely valuable tool to study dielectric delamination. Figure 5 shows the SAM result when this type of defect is present in a flip chip. It is typically located at the die edge and propagates into several rows of bumps. One noticeable feature that frequently occurs is the disappearance of the bumps from the image.

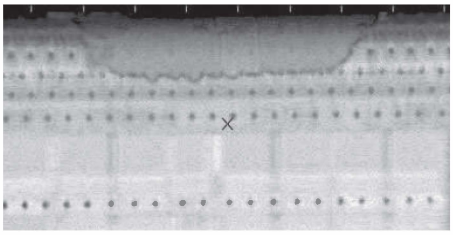
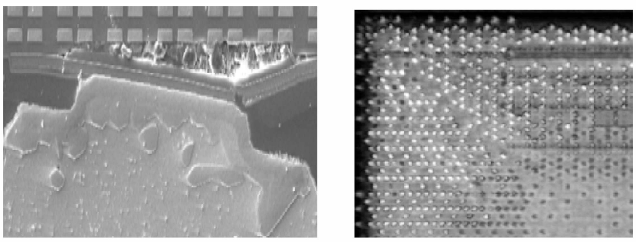


Figure 5: SAM image of a flip chip with cracking in the low k dielectric layers [2]

Example 2: White Bump Defect

Sometimes stresses between chip and substrate are so high that a fracture between dielectric layer and the solder ball take place (See Figure 6a). This defect is named white bump, because under SAM it looks like white dots, as shown in Figure 6b.



a b

Figure 6a) shows fracture at the interface of solder ball and the dielectric and 6b) is how it looks like under SAM [6]

Example 3: UF stress induced ILD delaminationm

After underfill curing (at ~170°C) when a package is cooled to room temperature, large shear and peeling stress occur due to thermal expansion mismatch between Si die and organic substrate. Also a package might undergoe thermal cycles during service. This thermal shear stress can lead to delamination between ILD layers [7]. This delamination often occurs at the die corner and in the vicinity of the outermost solder bump. SAM is a very useful to dtudy this defect. Figure 7 shows an example and how it looks like in SAM.

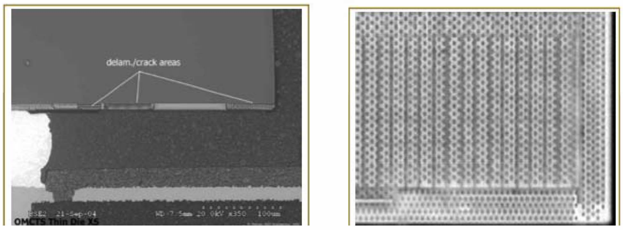


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Figure 7a) shows ILD cracks and Xb) how it looks like under SAM [7]

Example 4: Voids in UF

Voids and delaminations are frequently observed in microelectronic packages, resulting in a significant decrease in the reliability of the system. Voids and delaminations could occur during manufacturing or thermal cycling processes [8]. Figure 8 represents voids in the cured underfill material, observed by SAM. The void that appears white is located at the top of the underfill—the interface with the chip. The black void occurs at the bottom of the underfill, where the latter interfaces with the substrate.

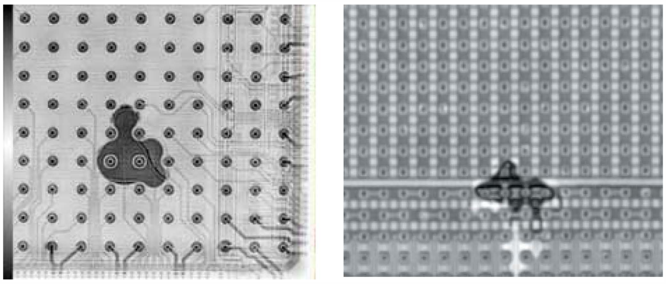

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Figure 8: Two underfill voids observed by SAM. Void above the underfill is white, while the other one below the underfill is black [8,9]

Example 5: Popcorn Defect

If plastic packaged parts have been manufactured or stored under humid conditions, absorbed moisture turns to steam when heat is applied, resulting in the formation of some bumps. The phenomenon is named 'popcorn effect' [10,11]. An example is shown in Figure 9.

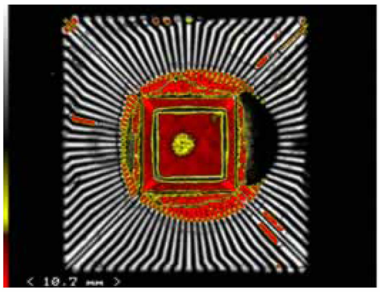

Figure 9: Popcorn effect in pachages [10]

Conclusions

A short review of Scanning Acoustic Microscope (SAM), its fundamentals and applications is given in this paper. SAM is a very useful non-destructive technique for failure analysis of different defects in a wide range of components in microelectronics industry. In contrast to destructive techniques, this method is relatively faster and it gives much more information from different layers in the sample. SAM is also capable of giving information over the cross section the specimen, which makes it an ideal method to study the thickness of layers and delaminations inside material. Underfill delaminations, voids, white bumps and popcorn defects are only a few examples of defects which can be efficiently detected and analyzed by SAM.

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