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A Comparison of Acoustic and Infrared Inspection Techniques for Die Attach

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A Comparison of Acoustic and Infrared Inspection Techniques for Die Attach

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Abstract

Acoustic scanning and infrared imaging are two non-invasive die attach inspection techniques. Acoustic scanning provides information by emitting an acoustic pulse into a sample and analyzing the reflected waves. Based on the geometry and physical properties of the materials, details of the interior of the sample can be seen. Voids, delaminations and heterogeneities can be detected. Infrared imaging is used to examine the temperature of the chip surface while dissipating power. Depending on the geometry and thermal properties, areas with large voids or delaminations can often be detected. It is useful to compare the two techniques to understand the limits of detection capability. Samples were examined with both techniques and the resulting images compared. The acoustic technique could find small voids and heterogeneities, but infrared imaging could not. However, delaminations of the epoxy appeared in the infrared images as hot regions on the chip surface.

This is a preprint of a work-in-progress paper that will be presented at
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1. Introduction

Die attach inspection techniques have become more important as demands on die attach performance have increased. The role of the die attach can be complex since it must fulfill structural, electrical, thermal and material compatibility requirements. With chip manufacturing technology improvements, an entire complex system can reside on a single die. The expense of such a chip may justify 100% inspection during manufacture. This, along with the increased demands on the die attach, have created a need for non-invasive inspection of the die attach joint to find voids, delaminations or material heterogeneities. For production applications, the inspection must be fast, easily quantified for pass/fail decisions and independent of operator skills. In the development stage of a project, where time per sample is not as important, the inspection technique must reveal fine details of the die attach to aid the engineer in resolving design and process problems.

Two non-invasive die attach inspection techniques are acoustic scanning and infrared imaging. Acoustic scanning provides information by emitting an acoustic pulse into a sample and analyzing the reflected echoes. Based on the geometry and physical properties of the materials, details of the interior of the sample, including voids, delaminations, or heterogeneities, can be revealed. Infrared imaging is used to examine the temperature of the die surface while it is under power. Depending on the geometry and thermal properties, areas with large voids or delaminations can often be detected.

Each technique has advantages and disadvantages. For inspections on a manufacturing line, the infrared technique is more practical. It is fast, the results are easily quantified and operator training is minimal. It cannot, however, detect small flaws in die attach. In the development stage of a project, acoustic images can reveal problems that cannot be seen in an infrared image, Unfortunately, the acoustic technique may require that the sample be immersed in a liquid, which risks contamination. For those reasons it is useful to compare the two techniques to understand their limits.

This paper discusses specific experimental results. Silicon chips were epoxied on copper slugs with flaws intentionally designed into the epoxy. Acoustic and infrared techniques were used to inspect the parts, and the resulting images were compared. It was found that although the acoustic technique could find small voids or heterogeneities, the infrared imaging could not. However, delaminations of the epoxy were apparent in the form of hot regions on the chip surface.

2. Description of the Techniques

2.1. Acoustic Imaging

There are three basic acoustic inspection methods: **resonance**, **pulse** and **acoustic emission**. Pulse methods, which are the subject of this work, are the most versatile for non-destructive diagnostics and die attach inspections [1]. In the pulse method, a piezoelectric transducer is situated above a sample. The transducer sends pulses of ultrasonic waves through a liquid couplant and into the sample. Between pulses a receiver listens for echoes reflecting from the sample. In the pulse-echo method, the transmitter and the receiver are the same piezoelectric transducer. The frequency of the ultrasonic waves may vary from 15 to 100 MHz (the later being a more recent capability). The higher frequency produces shorter wavelengths, which can typically resolve smaller defects [5].

The liquid couplant is required between the transmitter and the sample so that the ultrasonic waves are not reflected by the sample surface. The couplant must have the correct characteristic impedance (The speed of sound in a material multiplied by its density). When an ultrasonic wave encounters a boundary of two materials with different characteristic impedances, a portion of the wave is reflected. Water is often used as a couplant since it has a characteristic impedance close to that of many solids [4]. Conversely, air's characteristic impedance is several orders of magnitude lower which leads to nearly 100% reflected waves. Some low frequency techniques (20-30 kHz) do not require couplants [1], but these longer waves can only find very large defects.

It is this characteristic impedance mismatch that allows us to find defects within the sample. When the ultrasonic wave is traveling through the solid die attach material, and it encounters a void or region with a much lower characteristic impedance, it is partially reflected. If, however, the void fills with a well-matched couplant, the impedance mismatch is reduced and the void may go undetected. In the case of epoxy loaded with metal or ceramic fillers, undesirable characteristic impedance combinations may occur, making acoustic imaging of defects impossible. In some cases it is possible to see variations in the particle distribution throughout a joint if the epoxy mixture is inhomogeneous (see Figure 1).

Figure 1: Acoustic C-scan of a diamond-filled epoxy joint. Significant movement of the diamond particles occurred when the die was pressed into the paste. Variations in the diamond distribution indicate the distinct locations of the paste dispensing.

Since the layers of material are at varying distances from the transducer, the reflected waves from the layers are received by the transducer at different times. By capturing a time slot of data, planes within the sample may be selected. If the speed of sound in each plane is known, the locations or thicknesses of the planes may be determined [2].

C-scan is a convenient pulse-echo, data reduction technique which presents the inspector with a plan view of the sample. The strength of the received signal is plotted over the x and y directions. For example, a gray scale plot might indicate solid regions as black and voids as white. By capturing various time slots of C-scans, a 3-dimensional image of the sample can be constructed, but this can be a difficult and time-consuming task.

The planarity of the sample's layers is critical. For example, if the die is out of parallel with the substrate by more than 2 degrees, or if the top of the die is covered with a non-planar encapsulant, C-scan results may be meaningless. Similarly, if the roughness of any surface is greater than the acoustic wavelength, the images may be distorted. For these reasons the operator must be highly skilled to adjust the equipment and interpret the results.

Acoustic Imaging Advantages:

- Can see interior details.
- Material properties not required to get useful images.
- Good image details.
- Powerable parts not required for imaging.

Acoustic Imaging Disadvantages:

- Sample usually immersed in couplant.
- Planarity of the layers is required.
- Surface features may distort image.
- Impedance of materials may not be appropriate.
- Requires skilled operators.
- Low sample throughput.

2.2. Infrared Imaging

Infrared temperature sensing is used in many research, military and commercial applications. Infrared detectors are popular because they provide an inspection technique that is non-destructive, non-invasive and easy to use.

Infrared detectors rely on the Plank and Stefan-Boltzmann laws which provide an expression for the total radiant emittance of energy from a body. These laws consider the absolute temperature of a material, and consequently, the length of the electromagnetic waves that it emits. Since every material has an emissivity or reflectance, which affects the radiant emittance, these laws may be modified for a particular material. They may be expressed either in terms of emittance or photon energy [3].

There are two basic types of infrared detectors. **Thermal detectors** rely on changes in the detector material properties with temperature. **Photon detectors** are composed of semiconductor materials which release electrons based on photon absorption. The flow of electrons can then be related to the surface temperature.

The largest unknown in infrared imaging is the surface emissivity, which can range from a value of 0 for perfectly reflective surfaces, to 1 for a "black", totally absorbent and perfectly emissive surface. This property must usually be supplied by the user before the infrared equipment can yield accurate surface temperatures. Some infrared systems can calculate the surface emissivity through a series of calibrations at known temperatures. A surface with a low emissivity is very hard to measure because it reflects the surrounding environment, contaminating the infrared signal. Unfortunately, the metals found on the surface of most die have very low emissivities. However, the encapsulants commonly used for die coating have very high emissivities leading to good results.

Infrared images are typically presented as plan views of the imaged surface. Temperature scales are depicted with a color or a gray scale image. A centigrade scale is used in this paper's figures.

Infrared Imaging Advantages:

- No couplant required.
- High sample throughput.
- Easily quantified for pass/fail decisions.
- Minimal training required.
- Geometry and planarity are not critical.

Infrared Imaging Disadvantages:

- Need to determine surface emissivity.
- Surface must have adequately high emissivity.
- Must power part to generate temperature gradient.
- Examines die surface, not interior.

This short paper compares pulse-echo acoustic imaging to a photon detection infrared inspection through a simple experiment.

3. Experimental Samples

The samples used in this comparison consisted of silicon chips epoxied to copper slugs. The epoxy joint incorporated intentional flaws of various sizes. The objective was to evaluate the possibility of finding these flaws with the two inspection techniques.

The silicon chip was 15 x 15 x 0.5 mm. Its top surface had a thin film of tantalum nitride with a pair of gold bus bars on opposite ends of the chip. This generated uniform heating when a voltage was applied. It is important to note that the chip did not have any features on or within the top surface which could disturb the acoustic waves. During infrared imaging, the chip was powered at roughly 50 watts while the copper slug was cooled by a refrigerated cold plate.

Silver-filled epoxy film preforms (ABLESTIK'S ECF563) were used to bond the chip onto a 25 x 25 x 3 mm copper slug. The cured epoxy thickness was 0.05 ± 0.01 mm. A plastic pin grid array package, epoxied to the copper slug, allowed wire bonding and power distribution to the chip.

Defects were designed into the epoxy before the chip was attached. This was done by "cookie cutting" voids of various diameters - 0.5, 1.0, 2.0 and 3.5 mm - out of the uncured film with a hand punch. One sample was prepared with a triangular section removed from the center of the film so that a void tapering from 5 to 0 mm in size could be examined (see Figure 2).

In order to examine the characteristic delamination failure that might occur at the corners of a chip, one sample was made by cutting off two corners of the epoxy - one portion larger than the other. On another sample, an adhesive failure was simulated by applying a small amount of silicone grease

on two opposite corners of a chip. In this case the epoxy was not removed, but it is unlikely that it adhered to the chip in these locations.

All acoustic images were made at Precision Acoustic Devices, of Fremont, California, with their own custom built equipment. Their 25 MHz pulse-echo equipment was configured to generate a gray scale C-scan of the epoxy joint. The samples were coupled to the transmitter with water. In these C-scans, the lighter regions are stronger reflections indicating voids or delaminations.

After the acoustic inspections, and before the infrared inspections, the chips were sprayed with a very thin coat of flat black paint to provide a high emissivity surface.

The infrared images were made in our lab using an AGEMA Thermovision ^{R} 870 thermo-electrically-cooled photon detector. The temperature scale is shown at the top of the figures. Since we are interested in finding flaws, the absolute temperature is not as important as local temperature gradients. Temperature gradients in the silicon indicate lateral movement of heat around epoxy flaws.

Figure 2: Infrared and acoustic images of an epoxy joint with a triangular portion of epoxy removed.

4. Results

4.1. Voids

Acoustic Images The larger voids (2 and 3.5 mm diameter) are easily seen in the acoustic images (bottom of Figures 4 and 5). The 1 mm diameter voids reflected a much weaker signal (bottom of Figure 3) but are visible in the original prints. The smallest voids (0.5 mm diameter) could barely be detected in the C-scans, and are not shown here. It is possible that a portion of the void was filled by epoxy resin during cure; in the original prints it was possible to see that a small portion of resin was squeezed into the void. The light areas seen in Figures 4 and 5 near the perimeter of the chip, are probably due to epoxy thickness variations, and not delaminations.

Infrared Images The larger voids are obvious in the temperature map of the chip's surface. In Figure 5 the 3.5 mm diameter voids have caused obvious hot spots. The 2 mm diameter voids are also visible in the infrared image of Figure 4. In the infrared image of Figure 3, the 1 mm diameter voids can not be seen. Although there may be a slight increase in the overall temperature of the chip, indicating a die attach problem, the infrared image provides no indication that 1 mm diameter voids are present. Since the infrared detector views the top surface and not the bondline, thermal spreading in the die and slug obscures the finer details. This is expected since the diameter of the smaller voids is comparable to the thickness of the silicon.

If the silicon were thicker, it would be even harder to detect small voids. This would also be the case with higher thermal conductivity die attach materials, such as solders.

4.2. Delaminations or Poor Adhesion

Acoustic Images An extreme case of corner delaminations can be seen in Figure 6, which was the sample with epoxy missing in two corners. The air gap between the silicon and copper generated a very high reflected signal.

A more realistic case is shown in Figure 7. Here, the adhesive failure in the two corners can be detected by the slightly less intense acoustic reflection. This type of failure is typical of delaminations due to expansion mismatches or poor adhesion to the chip or copper.

Infrared Images In Figure 6 the corners with missing epoxy are easily seen in the infrared images. This is expected since the large air gap effectively insulates these corners. In the adhesive failure case of Figure 7, the infrared image indicates a small temperature gradient which leads to a higher overall chip temperature. However, it would be impossible to conclude that the problem was caused by corner delaminations in this chip, based only on the infrared image.

Figure 3: Infrared and acoustic images of an epoxy joint with two 1 mm diameter voids.

Figure 4: Infrared and acoustic images of an epoxy joint with two 2 mm diameter voids.

Figure 5: Infrared and acoustic images of an epoxy joint with two 3.5 mm diameter voids.

Figure 6: Infrared and acoustic images of an epoxy joint with the epoxy removed at two corners.

Figure 7: Infrared and acoustic images of a die attach joint with silicone grease applied to the chip in two corners, leading to poor adhesion at the corners.

5. Conclusions

Two die attach inspection techniques, acoustic C-scan and infrared imaging, were compared to determine the size of silver-filled epoxy flaws that could be detected. The following conclusions can be made from these experiments:

1. Using a 25 MHz signal, the acoustic technique was able to find voids as small as 1 mm in diameter. It was not possible to see 0.5 mm diameter voids clearly.

2. Infrared images detected voids of a 2 mm diameter and larger. Smaller voids could not be seen distinctly. However, overall chip temperature increases due to small voids could be detected, indicating possible die attach flaws.

3. Severe delaminations, created by removing epoxy, could be seen easily by both techniques.

4. Poor adhesion could be detected acoustically only by skilled operators, but would not be obvious to the untrained eye.

5. Poor adhesion was not obvious using infrared imaging; however, overall chip temperature did increase.

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