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Cover

38 Wafer Cleaning and Surface Prep: Evolution to Revolution

Most cleaning challenges are evolutionary as structures get smaller and specs get tighter, but a revolution is in the making, brought on by a variety of new materials, new integration schemes and process flows.

The Raider HT single-wafer cleaning system is a high-throughput platform designed to provide high-performance cleans for FEOL, BEOL and WLP applications. Advanced process software and metrology features monitor and control critical processes that ensure the performance and repeatability critical for single-wafer processes. *(Source: Semitool)*

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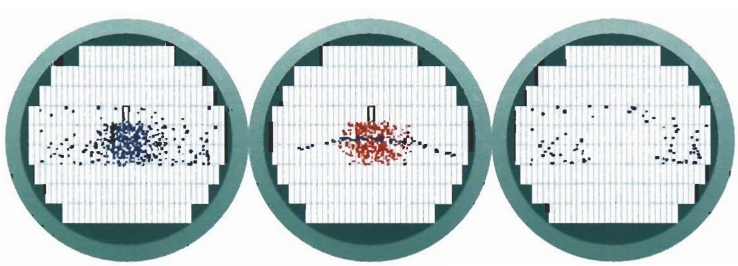
Features

Review Reduction Process



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Contamination in process materials can cause device failure and impact yield. But standard certificates of analysis (COAs) for new materials may not be as reliable as you think.

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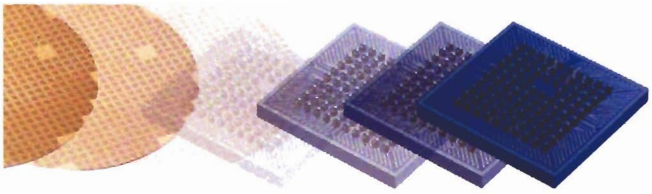
Able to image the interface between the package and die, acoustic imaging detects defects, contamination and molding compound issues.



Acoustic Detection of Package Contamination

Able to image the interface between the package and die, acoustic imaging detects defects, contamination and molding compound issues.

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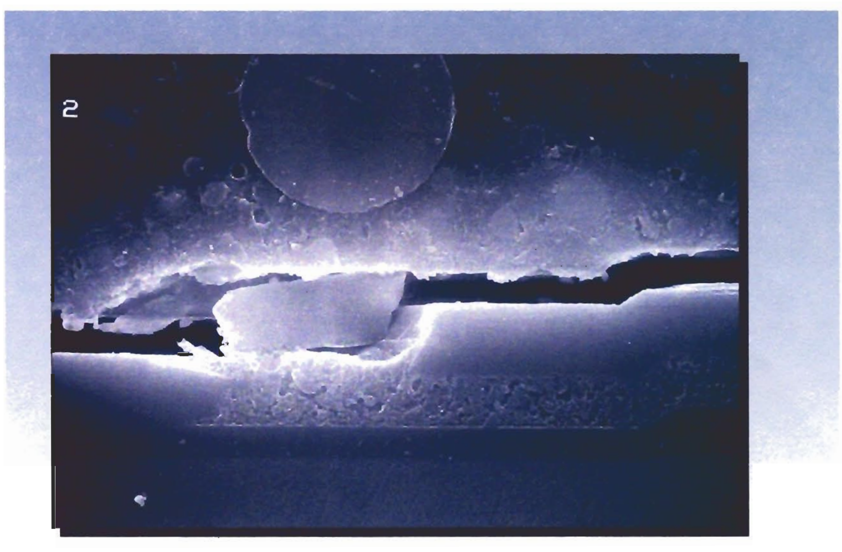
A pulse of ultrasound launched into a sample by the transducer of an acoustic microscope sends back return echo signals only from material interfaces — not from homogeneous materials. If the sample is a plastic encapsulated microcircuit (PEM), the first internal interface encountered may be the interface between the molding compound and die face.

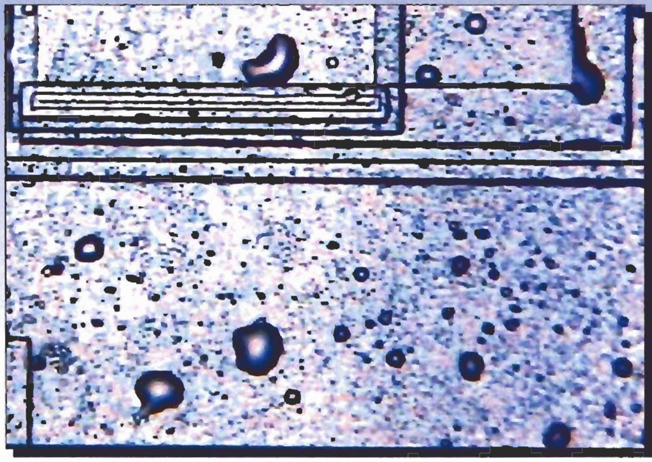
How the ultrasonic pulse interacts with this interface depends on the acoustic impedance (material density × acoustic velocity) of each of the two materials at the boundary. If the molding compound is firmly bonded to the die face, the difference in acoustic impedance between the two materials will be moderate, and a return echo signal of moderate amplitude will be generated when ultrasound strikes the interface. The single image pixel made from this echo signal will probably appear gray (or some other mid-scale color) in the acoustic image. If the entire die face is well bonded, the color of the die face will be uniform.

A delamination between the molding compound and die face drastically changes the behavior of the pulse. A delamination is generally considered to contain air or another gas, so the first interface is now between the molding compound and a gas. The gas will have a vastly lower density and smaller acoustic velocity than a solid. The acoustic impedance of molding compounds, metals and all other solids is measured in units called megaRayls, but the acoustic impedance of air and other gases is around 410 Rayls — a Rayl being one-millionth of a megaRayl.

The relatively enormous difference in acoustic impedance between the molding compound and air in the delamination means that virtually all of the ultrasound is reflected as an echo. The fact that the acoustic impedance of air is less than that of plastic means that the echo polarity/phase is shifted by 180°, resulting in an inverted (or negative) echo. The amplitude of this echo is very high; on many of the color maps used on acoustic microscopes, this high-amplitude inverted echo will be shown as a red pixel. Because delamina-



1. SEM of a sectioned sample showing the delamination between the particle-filled molding compound (top) and the die face (bottom). *(Source: Riga Analytical Lab Inc.)*



2. Microdroplets were found on the inner surface of the molding compound after dry separation. *(Source: Riga Analytical Lab Inc.)*

3. Surface of the die after dry decapping. Small irregular areas are the residue of a contaminant. Auger electron spectroscopy showed the presence of silicon, carbon and oxygen, suggesting that the contaminant may have been a silicone. *(Source: Riga Analytical Lab Inc.)*

tions and other gap-type anomalies have high-amplitude reflections, it has become a more or less accepted convention to display the defects in red.

Over the past several months, numerous PEM samples imaged at our applications laboratories, SonoLab, have generated unusual images in which only part of the delamination is red. The remainder of what appears to be an ordinary delamination is seen as white in the acoustic image. In the color map being used, red indicates a reflection that is both high in amplitude and negative in its polarity -- negative meaning that the pulse traveled from a material of higher acoustic impedance to a material of lower acoustic impedance. In the same color map, white indicates a reflection that is both high in amplitude and positive in polarity, usually meaning that the pulse has traveled from a material of lower acoustic impedance to a material of higher acoustic impedance. The initial question confronting technicians whose job it is to interpret the acoustic image was "How can a delamination between two solid materials possess both positive and negative polarities when, in the case of a possible delamination, the acoustic impedance is unlikely to be greater than that of the molding compound?"

Part of the delamination might be filled with air, and part might be filled with an unknown material that would produce a distorted echo having both positive and negative attributes.

What the unconventional red/white delaminations suggest was that part of the delamination (red) might be filled with air, and part might be filled with an unknown material that would produce a distorted echo having both positive and negative attributes. The unknown material would be considered a contaminant, possibly a thin fluid layer.

The red/white delamination images were obtained during routine imaging, where the return echoes were gated on the delamination. Gating in this case means that a time window was set up to use return echoes from a depth just above the top surface of the die to a depth just below the top surface of the die. Such gating is a standard procedure used to exclude features from other depths from the acoustic image.

An obvious potential contaminant was moisture that could have entered into the delamination. If the gap were filled with water, it might produce the unusual images that had been observed. Sample packages were therefore baked at 125°C for 24 hr, but the red/white appearance of the delaminations persisted. Whatever the contaminant was, it had not been removed by baking.

To obtain a more definitive evaluation of these delaminations, a small group of PEM packages was sent to an independent analytical laboratory. This group of samples included packages with red/white delaminations, as well as a control sample with no delamination. The laboratory was asked to cross-section samples to verify the presence of the delamination and disassemble the samples under dry conditions, examining them optically for residue on the die surface. The laboratory was also asked to perform an elemental analysis of the suspect die surface areas.

One delaminated sample was cross-sectioned through the center and lightly etched for SEM imaging (Fig. 1). Imaging showed that the delamination between the molding compound and die face was as little as 0.6 µm thick. Gas-filled delaminations and other gaps down to 0.01 µm uniformly reflect virtually all of an ultrasonic pulse, so the thickness of this delamination was not significant.

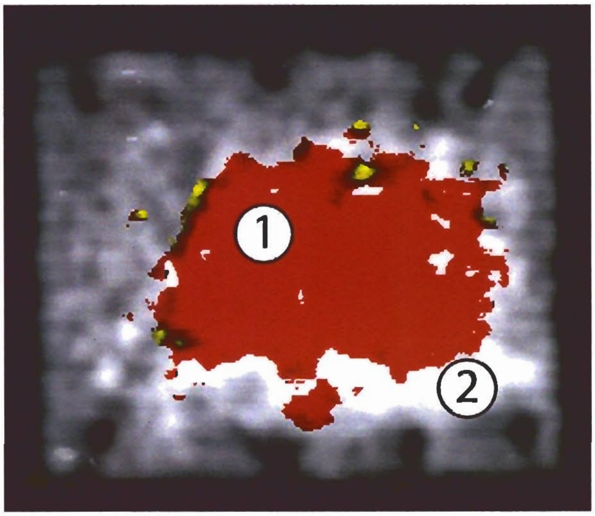
The cross-section did not reveal the presence of a contaminant, because the contaminant was most likely removed during preparation of the sample.

Another delaminated package was disassembled by a dry separation technique to give access to the die surface and inner surface of the molding compound. An examination of the inner surface of the removed molding compound revealed micro-droplets of a colorless fluid (Fig. 2). Because there was no evaporation of this fluid after some hours of exposure at room temperature, it was concluded that this fluid was not water alone. The plastic surface was then examined by energy dispersive X-ray (EDX) analysis. In the vacuum chamber, the fluid evaporated and phosphorus was detected on the surface of the plastic. Since phosphorus is hygroscopic, its presence may have prevented the water from initially evaporating. The source of the phosphorus is unknown, as it is rarely used in molding compounds.

The possibility exists that silicone from this source is making its way onto the die face before encapsulation.

The die face was examined next (Fig. 3) by Auger electron spectroscopy (AES). A dry residue was noticed on the die face. The AES surface analysis of the residue on a bond pad was carried out first without treatment, and then after ablative sputtering with argon ions to remove 20 and 50 Å of material. Comparison with a similarly evaluated control sample showed that carbon, oxygen and silicon were all present in greater concentrations than in the control sample. Identification of the residue as an organic compound suggested that the fluid contaminant in the delamination may have been any of various types of silicone, whose molecules consist of SiO and an organic radical. A silicone is used as a releasing agent in the molding process to facilitate ejection of the parts. The possibility exists that silicone from this source is making its way onto the die face before encapsulation. Bromine was also present in the EDX analysis, because it had most likely leached out of the molding compound.

This analysis does not prove conclusively that the contaminant is silicone, or that its source is the releasing agent, but it does provide an answer that fits very well with the acoustic data. The acoustic pulse used in imaging encounters, in order, the plastic molding compound, which has a lower acoustic impedance of ~4.5 megaRayls; the organic fluid, which, if it is silicone, has an acoustic impedance of ~1.5 megaRayls; and the silicon of the die, which has a much higher acoustic impedance of ~20 megaRayls.



4. Acoustic image made at the depth of the top surface of the die. Red area (1) is an air-filled delamination that stops further penetration of ultrasound and gives a high-amplitude negative echo. The white area (2) that partly surrounds the delamination results from a distorted echo created by a thin layer of fluid contaminant.

Figure 4 shows a red/white delamination image. In the center of the delamination, the ultrasound encountered an air gap adjacent to the molding compound, resulting in a negative echo. The ultrasound does not proceed any deeper because it is totally reflected at this interface. In the white area adjacent to the red area, the ultrasound encountered a very thin fluid contaminant layer that separates the encapsulant and die. This layer produced a distorted echo whose attributes are not clearly positive or negative, and in these cases, the algorithm displays these echoes as white.

The research carried out on these samples demonstrates that delaminations in plastic encapsulated microcircuits may harbor contaminants that produce an otherwise unexpected acoustic signature. The acoustic microscope operator who encounters a "red/white" delamination may be able to at least tentatively identify the contaminant as water if it disappears after baking, and tentatively identify it as an unknown fluid if it does not disappear. The operator can also help determine whether a feature is a contaminant by looking at the echo waveform and noting the distortion resulting from the combination of positive and negative attributes. This ability to more finely discriminate the conditions at a delamination may provide clues for manufacturing engineers on how to more accurately monitor and improve manufacturing processes. **SI**

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