3D acoustic images expand their usefulness

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3D acoustic imaging is useful for measuring the heights of bumps on BGAs, flip chips, and other devices. But it can also be used to image and quantify depth/height variation of features within a particular sample.

Three-dimensional acoustic images, like three-dimensional light images, differ from their two-dimensional counterparts by displaying the z dimension in addition to x and y dimensions. The first 3D acoustic images were made around by 20 years ago at Sonoscan, who invented the technique. The technology can display the surface topography of a sample, or its internal profile at a desired depth.

The C-SAM® acoustic micro imaging tools that make the 3D images have a transducer that pulses ultrasound at a given frequency at or into the sample thousands of times a second as the transducer scans back and forth above the surface of the sample. A pulse of ultrasound leaving the transducer travels first through a water couplant, supplied constantly by a water jet attached to the transducer. Every time ultrasound exits one material/fluid and enters another, some of the ultrasound is reflected to the transducer; as a result, a portion of the pulse is reflected by the water-to-sample surface interface. The rest of the pulse crosses the surface interface and travels deeper into the sample.

In most acoustic imaging, the concern is with the amplitude of the returned echoes from the interior of the sample. A well bonded interface between silicon and epoxy will reflect a small amount of the pulse. The amount of ultrasound reflected causes a specific amplitude in the return echo. The echo amplitude is measured and then displayed in the acoustic image by an assigned color value for that amplitude. The highest amplitude echoes essentially indicate 100% reflection and are produced only by the interface between a solid and a gas. All gap-type defects meet this definition. By measuring the amplitude of the reflected signal and identifying those having near-total reflection, an acoustic micro imaging (AMI) tool can detect voids, cracks, non-bonds and other gap-type anomalies that threaten the longevity of a part.

3D imaging, however, cares about the position in time of a reflection from a given plane such as the surface of the sample. By measuring the distance, in time, from the end of the transducer to the front surface, AMI can assign a color value to each location in time that the front surface occurs. In this way a color representation of the topography is made. Plastic BGA packages, for example, are notorious for having internal defects that disturb the flatness of the package's surface. By assigning a color to each height variation, the locations of surface disturbances are easily detected. The same method can be used to image unpopulated printed circuit boards to ensure that they are flat enough to avoid placing stress on connections. Samples imaged in 3D are viewed at an angle from the vertical perspective in order to make local height differences visible.

Recently the method has been used in a different role - measuring the height, before substrate attachment, of the solder bumps on BGAs. A precise vertical range is set - in acoustic terms, a gate. If the tops of all the solder bumps fall within the small vertical range defined by the gate, successful bonding of all bumps to the substrate is more likely.

The basics of imaging rounded bumps are essentially the same as for imaging flat surfaces. The sides of the bump may send back little or no signal, but in this

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investigation, they are not the area of interest. The color of the top of the bump is what matters, because it indicates whether the top lies within the narrow vertical range for successful bonding. Interpretation of the image is simplified by software that stretches the image of each solder bump vertically. If the solder bumps were imaged in their actual height, the gate in which the top should lie would be tiny and hard to see. Stretching each bump vertically does not change the measurement, it simply makes the results easier to interpret.

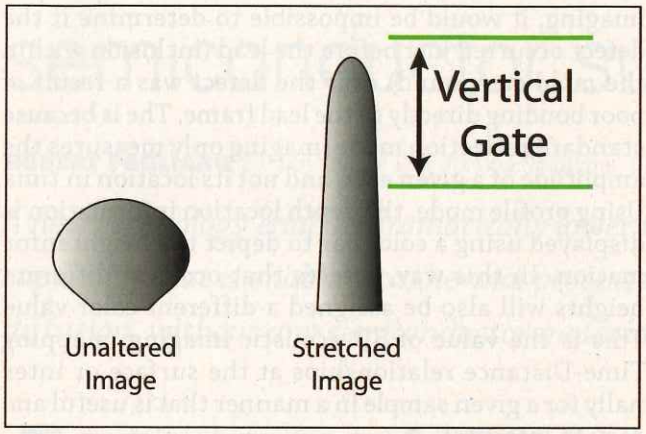

FIGURE 1. 3D imaging stretches the bump image to make accept/reject determination easier.

FIGURE 1 shows an acoustic side view image of a solder bump in its unstretched form, and the stretched form of its acoustic image. (Acoustic side views of internal features can be made by Sonoscan's Q-BAM™ imaging mode, designed for non-destructive cross sectioning.) Even after the image is stretched, it may represent a vertical extent of only several microns. If bumps were imaged without vertical exaggeration, distinguishing accept from reject might be very difficult or even impossible. The amount of stretching needed for the bumps on a particular part type of BGAs, and the vertical extent of the gate that will yield the best results can typically be determined from previous experience with a BGA. Overall, what matters is not the precise configuration of the gate but ensuring that all bumps are very close to each other in height.

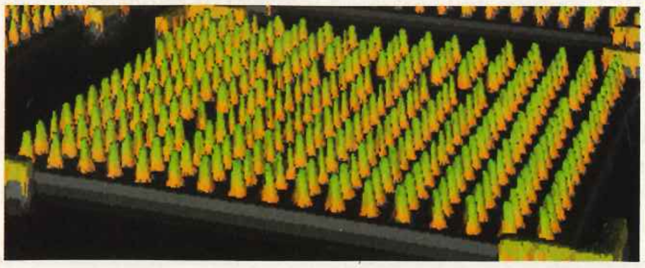

FIGURE 2. Stretched acoustic image of bumps on one BGA.

FIGURE 2 is the stretched 3D image of the solder bumps on one BGA before placement onto a PCB. The desired condition is that the top surface of the bump lie within the thin horizontal slice colored green in the image. **FIGURE 3** is a magnified view of a small section of Fig. 2.

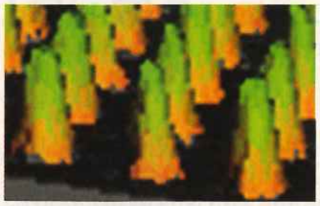

FIGURE 3. Small portion of Fig. 2 magnified.

All the bumps in this BGA have tops that lie within the vertical "green" gate. There are no bumps toppled by other colors, a condition that would reveal that the bump might not bond to the substrate as well. The black areas in the figure are locations where no bump is present. BGAs like this are loaded into JEDEC-style trays and imaged in large quantities. Identification and removal of BGAs having one or more unsuitable bumps can be automated. The failure criteria are completely customizable depending on the level of tolerance a particular sample is held to.

FIGURE 4. Small portion of a BGA having unacceptable variation in bump height.

FIGURE 4 is a small portion of the 3D image of a BGA where results were not quite so uniform. The desired color for the top of each bump here is red. As shown red is the top color on many of the bumps, especially in the left half of the image. But elsewhere there are bumps with pink, orange and other top colors. This is a BGA that may not make good contact with the PCB. Further down the assembly line this sample would likely experience immediate or early electrical failures due to attachment issues.

Location information can become useful to large scale production companies that are trying to understand their process better. If there are trends that suggest a specific location on the BGA is having a bump height problem, then there maybe something related to the process, handling, or materials being used that could be causing the issue. The measurement can be taken simultaneously while scanning in standard reflection mode. There is no addition in scan time or reduction in UPH to make this measurement.

3D imaging can also be used to depict strictly internal features. The operator sets two vertical values - an internal gate - to define the top and bottom of the desired depth measurement. This mode is known as profile mode imaging. When imaging in profile mode, only the echoes that occur within the depth of the gate are used for imaging. Signals outside of the gate are ignored. Because this is 3D imaging inside the part, the variation is measured relative to the top surface of the part.

3D acoustic imaging is useful for measuring the heights of bumps on BGAs, flip chips, and other devices. But it can also be used to image and quantify depth/height variation of features within a particular sample. Measuring the distance of each of the thousands of x-y locations across the entire top surface of a tilted die can reveal how much of a threat to longevity the tilt is. It may even be helpful to stretch the image vertically to make so that the tilt could be easily seen to the human eye. Depending on the gate and depth chosen for a given profile mode image, it is possible to discern defects that occur at different height locations. This can be useful by showing that two similar looking defects may not be occurring at the exact same depth within the part. For example, you may have a void within the molding compound just a few microns before the lead frame. In standard reflection mode imaging, it would be impossible to determine if the defect occurred just before the lead (inclusion within the mold compound) or if the defect was a result of poor bonding directly to the lead frame. The is because standard reflection mode imaging only measures the amplitude of a given echo and not its location in time. Using profile mode, the depth location information is displayed using a color bar to depict the height information. In this way, defects that occur at different heights will also be assigned a different color value. This is the value of 3D acoustic imaging: mapping Time-Distance relationships at the surface or internally for a given sample in a manner that is useful and easy to interpret. ◆