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Defect detection in die stacks with acoustic imaging

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A new simulation technique makes imaging easier and faster for stacked die and other multi-layered structures.

Manufacturers of stacked die configurations have a strong interest in learning by non-destructive means whether a device contains defects such as delaminations, and exactly where the defects are. The standard method for nondestructive imaging and analysis of internal structural defects in other component types has long been acoustic microscopy, but stacked die have always presented a problem because their multi-layer structure makes accurate acoustic analysis difficult. After years of work in collaboration with the Technical University of Dresden, Sonoscan has recently unveiled a simulation technique that makes imaging easier and faster for stacked die and other multi-layered structures.

Challenges for imaging stacked die

Acoustic microscopes use a scanning transducer that switches thousands of times a second between pulsing ultrasound into a sample and receiving the return echoes. This is known as reflection-mode acoustic imaging. The general behavior of ultrasound when pulsed into a sample is straightforward: when the focused beam strikes the interface between two dissimilar materials, it is partly reflected and the remainder is transmitted deeper into the sample. However, it is virtually 100% reflected at an interface between a solid material and the air in a delamination, crack, void or other gap. In the case of an air gap interface there is no further ultrasound transmission deeper into the sample thereby blocking reflection mode views of deeper structures.

Ultrasound behaves in this way in all of the many electronic components that are imaged acoustically. What makes stacked die dramatically different is that there are many layers causing reflections and if the layers are equal thickness, as in many devices such as memory chips, the echoes can overlap making it difficult to distinguish the individual layers. In addition, since the signals from deeper layers are weaker than those from the top layers due to reflection losses at each subsequent interface it may be harder to identify the relevant echo.

Creating the simulated die stack

In order to help image individual layers of a stacked die sample the simulator tool uses construction information from the sample to predict the echo patterns that will result from using a pre characterized transducer in the C SAM acoustic microscope. In the block diagram below, the operator places virtual defects at any or every layer of interest and then the program calculates the echo patterns for each condition. The construction data includes thicknesses and properties of each layer. If exact properties are not known there may be some error in the result, however, the program will still give the analyst enough information to make the imaging task more efficient.

An engineer who needs to inspect the die in a stack for gap-type defects can use the simulation module, which has two main functions:

â€¢ It allows the engineer to create a simulated die stack that is as similar as possible to the physical die stack that he needs to image.

â€¢ It allows the engineer to acoustically image the simulated die stack that he has created.

To create the simulated die stack, he needs to know the part construction of the physical die stack: the material characteristics and the precise thickness of the various layers, for example.

By entering these values into the simulation software he creates the virtual die stack. **Figure 1** is the diagrammatic side view of a die stack, showing the individual die and die attach layers. In making the virtual die stack using the simulator, the operator will enter values that create highly reflective simulated defects, typically one defect at each interface. The simulated defects are shown in gold in the diagram. In the simulation, these gaps will reflect ultrasound just as real defects do. They are typically staggered from left to right to avoid overlap and to identify the individual layers.

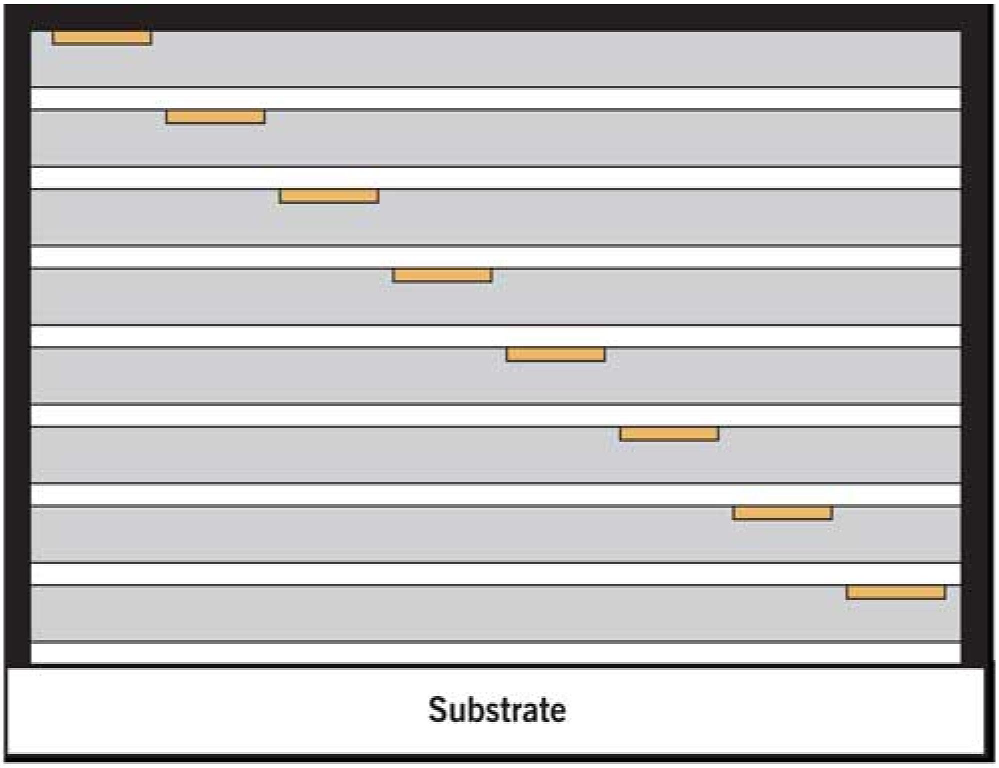

Figure 1. Diagrammatic side view of a typical die stack, showing the numerous material interfaces. Test stacks generally have gaps (gold in diagram) etched into the top of each die.

When the simulated die stack is complete, the engineer will select the ultrasonic transducer that best images this particular sample.

He will gate the A-scan echoes (echoes from all interfaces below a single x-y position) to isolate the defect that he has placed, for example, on top of die #3 when entering values to create the virtual die stack. Gating is accomplished by moving two vertical bars on the on-screen echo waveform to enclose the precise echo depth that will be encompassed in the acoustic image. Echoes reflected from the gated depth are used to make the image; echoes from other depths are ignored.

Next he will move to the C-scan imaging mode using the simulated data, which uses the virtual transducer to scan the area of interest that includes the defect at die #3. This will produce a visible acoustic image of the simulated defect. Here he can begin to optimize the gate (i.e., adjust the vertical bars) by moving slightly off the defect, noting changes in the waveform and then moving back onto the defect. By repeating this process he can find the depth range that provides the optimal image of the defect that he has simulated.

Imaging the physical die stack

At this point the simulation has, for the moment, done everything it can do. The engineer turns now to the physical die stack and places it on the real stage of the microscope. His parameters â€” focusing, gating â€” have already been defined by the simulation. and are transferred from the simulation software to the real-world Sonolyticsâ„¢ software used to operate the acoustic microscope. When he gates on die #3 in the physical sample he may or may not find a defect, but he will be imaging the interface at the top of die #3 where a defect would lie.

He can optimize the gate and the focus to improve the image of the real interface at die #3, gather a VRM (Virtual Rescanning Module) file, and then transfer the VRM file back to the imaging portion of simulation module to apply the powerful imaging techniques available in the module to the real (as opposed to simulated) data in the VRM file. He may find, for example, that the simulator gate was a bit to the right or left, compared to the gate in the physical sample. By moving back forth between the simulation module (to improve gating) and Sonolytics (to improve focus), he will obtain the best possible acoustic image of the features in the real sample. When the optimal image has been obtained, several advanced imaging modes can further enhance the image.

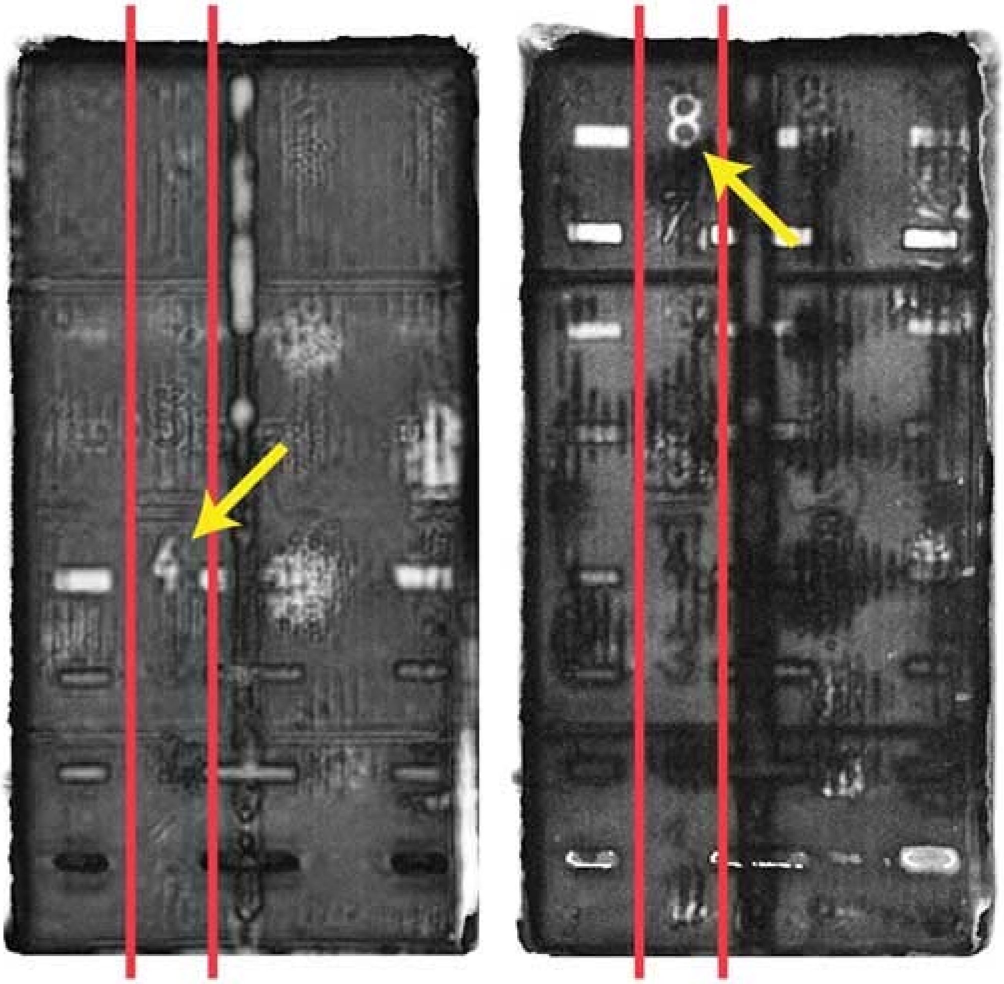

Figure 2. Right half of an 8-die test stack, imaged with parameters derived from the simulation, and gated and focused on die #4 and #8 (at the bottom of the stack). Red bars enclose the vertical columns of all eight numerals. Gated and focused numerals are bright; the others are dark or not visible.

Figure 2 is the acoustic image of die layers #4 and #8 in an eight-die stack whose imaging parameters were defined using the simulation program. Each silicon die is 75mm thick, and the adhesive between the die is 40 microns thick. These die stacks were made for testing purposes. Each die contains two types of gap-type features:

> â€¢ An identifying numeral from 1 to 8 etched into top surface of the silicon. This numeral identifies the die. Die 1 is at the top of the stack, and die 8 at the bottom. The interface between the epoxy die attach material and the shallow gap creates a highly reflective interface. As described earlier for the simulated stack, the numbers are staggered left to right to avoid overlap.
>
> â€¢ Three etched slots arranged in a line across the width of the die. Like the etched numerals, each group of slots is staggered.

The stack was not encapsulated, but was covered by a 100 micron layer of foil that was attached to the top die by 11 microns of adhesive.

The key identifier for each die is the numeral. When the operator has completed the simulation program and is accurately focused and gated on a given die, the numeral (in the case of this die stack) will appear relatively bright, while the numerals identifying other layers will appear dark.

The two pairs of vertical red bars in Fig. 2 identify the vertical rows of numerals. At left, the test stack is focused and gated on die #4, whose numeral is bright. The other 7 numerals are either darker or not visible. In the image at right, die #8, at the bottom of the stack, is in focus and accurately gated. In a non-test sample, the results of simulated imaging would give parameters that would gate and focus accurately on each die, even though it has no identifying marker.

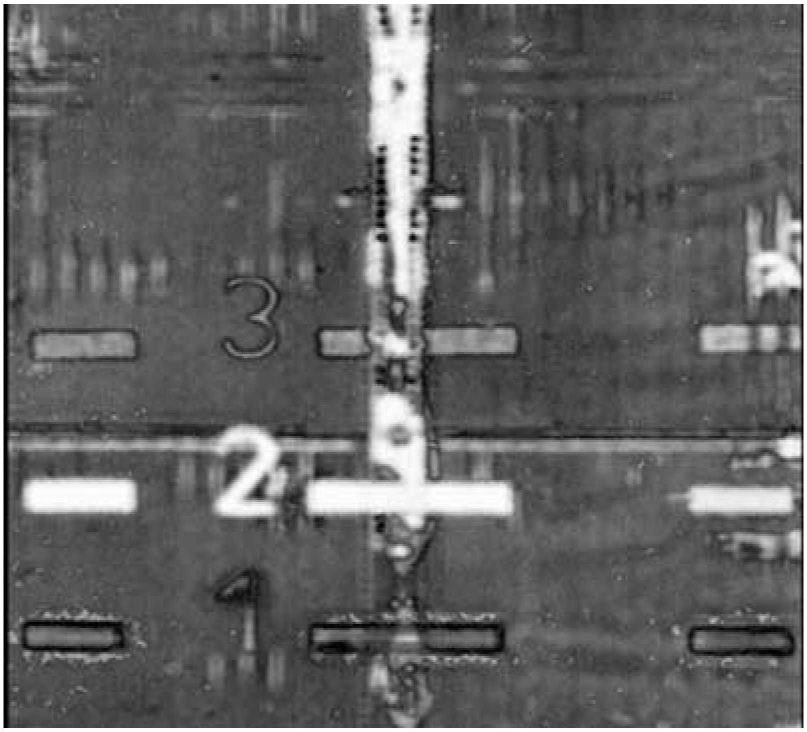

Figure 3. Detail of the same test die stack gated and focused on die #2.

Figure 3 is a portion of an acoustic image gated and focused on die #2. The numeral 2 is bright, and the numerals 1 and 3 are visible. The numerals on layers 4 and above, however, are not visible.

The method can be used on die stacks both before and after encapsulation, although imaging through encapsulation will limit imaging to lower acoustic frequencies. The chief advantage of the simulation module is that it greatly accelerates the task of finding the optimum gate for imaging a specific depth of interest. It might be possible to find this gate working only with the physical die stack, but the work would be very tedious, not intuitive and very time-consuming.

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