Analysis Of A Previously Shipped Part – The Virtual Sample

By Tom Adams and Lawrence W. Kessler

A new mode of acoustic micro imaging has recently been developed that permits users to collect and store 100% complete acoustic data throughout the entire volume of a sample such as an IC package. From only one scan sequence, acoustic data are stored in a matrix file from which any of more than 20,000 different acoustic micrographs can be constructed. After a sample has been scanned (in the new mode), the sample can be shipped to a customer, put into service or be subjected to other forms of testing; however, the total sample acoustic data will remain for later analysis. Any feature within the sample can be imaged at any time as though the sample were still on hand – in other words, a "virtual sample" has been created. The implications of this capability are profound. For example, it permits the user to examine the virtual sample and reconstruct features not paid attention to or focused on before the sample was used in an application. In addition, the mode can be used to enhance the detection of subtle material properties or bond quality features.

Basics of Data Collection

In the acoustic imaging process an ultrasonic transducer scans over the area of the sample, but at any given moment it is positioned above a single x,y point. At this point, the transducer focuses a pulsed ultrasound beam into the sample. Some short time later (microseconds or less) echoes from the various features along the beam within the sample return back to the transducer, where they are collected. The system that performs this imaging is referred to as the C-mode scanning acoustic microscope, or C-SAM®.

Since the sample has a finite thickness, echoes from various depths (z) arrive at the transducer at slightly different times. In other words, the pattern of echoes through the part from a single x,y point on the surface has a time/depth dimension. This pattern of echoes is called the A-Scan, and is visible as an oscilloscope trace that shows echo waveforms at progressive depths within the sample. The echo pattern is sharpest at the focus of the transducer. Outside the focus region the echo pattern is distorted and the image becomes progressively more blurred.

In typical usage, a standard C–Mode image is produced in which an x-y two dimensional display is made of the echoes coming from a selected depth; in this mode only part of the A-Scan echo pattern is used – generally because only a single depth within the sample is of interest. In the standard C-Mode, the C-SAM system selects only those echoes falling inside a time window (for example, 1.2 to 1.25 microseconds) corresponding to the depth of interest. Selection of this time window is called "gating". The C-Mode image is made by applying the time window to all of the x-y positions. This is referred to as a time-domain image (as distinguished from frequency-domain images, to be described below.) Then at each x-y position only the peak intensity value and the polarity of the echo within the gate is displayed; information about other echoes is lost.

In the standard C-Mode, information about the sample is limited by the parameter restrictions of the original scan. Since the A-Mode is not saved, the data cannot be re-gated, nor can the echoes be reprocessed to create different image information. But the standard C-Mode is very useful and has been the "norm" since acoustic micro imaging was developed.

Rescanning Without The Sample

In the new acoustic micro imaging mode a "virtual sample" is created. After creation the virtual sample can be rescanned at any depth with any gate and any focus position. The echoes can be digitally processed, frequency filtered, etc., to bring out subtle bond quality or material property information. The new development is known as the Virtual Rescanning Mode™ (VRM) and is a major breakthrough because it can record the entire A-Mode patterns for every volumetric element (voxel) of the sample. In the VRM mode, the C-SAM quickly scans the actual sample at increasing depths. Instead of collecting only the peak value of a single echo, however, the VRM collects the actual echo waveforms of all the echoes at each x-y location. From all of the focused segments of A-Scan data at each depth a master A-Scan is created for each x-y position. When the entire sample has been scanned, all the A-Scans for the sample are preserved as the matrix file. Collectively this data constitutes the virtual sample, which can be rescanned in an infinite number of ways. The mode is, with some justification, referred to as a four-dimensional technique because the matrix file contains x, y, and z data as well as time data.

Early field experience shows that the matrix file can be extremely useful. If, for example, the field failure of an IC package occurs, engineers can use the virtual sample acoustic file for comparison studies. It can also be used to interpret changes in a package after thermal stress testing even if a defined defect has not yet occurred.

Frequency Domain Imaging

The transducers used in acoustic micro imaging range in frequency from 10 MHz to 300 MHz and above. In conventional acoustic imaging, the choice of transducer determines the spatial resolution, penetration, and other parameters; if a sample is scanned with a 50 MHz transducer, one cannot manipulate the image data to produce a 10 MHz image or a 100 MHz image, because the acoustic pulses themselves do not have sufficiently wide frequency content. However, the data file created by the Virtual Rescanning Mode makes this kind of manipulation possible, within limits. Data collected at 50 MHz can be used to create images showing the sample at frequencies from 30 MHz to 70 MHz, and data collected at 300 MHz can be used to create images showing the sample at frequencies from 225 MHz to 375 MHz. But large excursions in frequency – for example, using a data file collected at 10 MHz to create 300 MHz C-Mode images – are not possible. The same sample can, of course, be physically scanned with a variety of transducers.

Because the new mode collects all waveforms from all regions of the sample, it can also accommodate the changes in frequency that may occur during reflection. For example, a pulse of 15 MHz ultrasound launched toward a material interface (molding compound to die face, for instance) may be reflected with a different frequency content than originally pulsed, and this change – not otherwise detectable - may be indicative of the interface condition. The echo waveforms can be filtered by a Fast Fourier Transform (FFT), also called a Frequency Domain algorithm, to isolate a given frequency. A Fourier Transform decomposes the waveform into sinusoids of different frequencies. It identifies the different frequency sinusoids and their respective amplitudes. Frequency Domain imaging is valuable because specific features may yield more information at one frequency rather than another. The FFT filtering brings out image detail that may not be seen at all with conventional time-domain imaging.

Producing Images from the Data File

Images produced from the time-domain VRM mode do not necessarily look different from conventional C-mode images, except that accuracy and resolution are maximized for images from any depth. The chief advantage over standard imaging is the ability to create at will any image from any other depth, including 2-dimensional and 3-dimensional images. Achieving the same volume of data by conventional imaging would be impossible.

Figure 3 shows the reconstructed C-SAM image of a portion of a flip chip package, along with FFT-filtered images at 141, 167, 175, 195 and 226 MHz. Bright solder bumps in the C-Mode image are defective, probably because of cracks in the passivation layer rather than disbonding or cracking of the solder joint.

Each of the FFT-filtered images shows the virtual sample as it is imaged by echoes at a given frequency. One advantage of this type of imaging is that different acoustic frequencies are sensitive to different features within the sample. Overall, the lines of metallization on the chip are more sharply defined in the FFT-filtered images than they are in the multi-frequency C-Mode image. There are differences in contrast in the FFT-filtered images – for example, the solder bump defects are bright in some, dark in others.

It appears that the higher frequencies within the spectrum of frequencies reflected from within the sample are reflected from a slightly deeper level. Thus in Figure 3 image F, at 226 MHz, is actually imaging at a level slightly deeper than image B at 141 MHz.

Summary

The newly developed Virtual Rescanning Mode changes the nature of acoustic micro imaging by vastly broadening its ability to collect, analyze and display data. Previously developed modes have provided numerous methods for displaying acoustic data from specific regions of a sample in two or three dimensions. The new mode allows the collection of data from all regions of the sample and the display of that data with unprecedented flexibility.

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Figure captions for Virtual Rescanning Mode: Total Acoustic Imaging Of A Shipped Part:

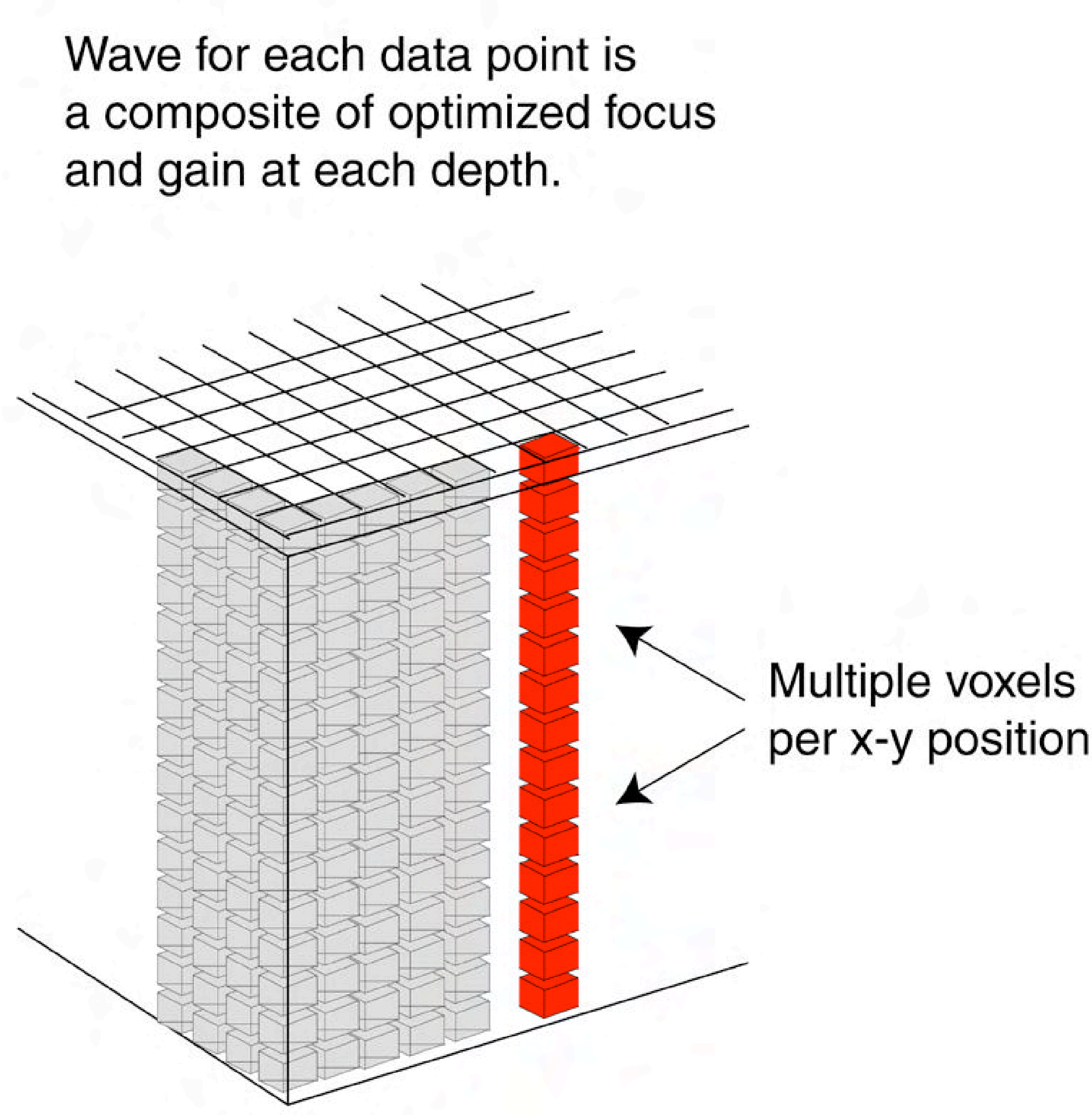

Figure 1 - Multiple scans of a sample at increasing depths permit the creation of voxels, which can be thought of as the acoustic properties of a sample at multiple depths and over the time required for ultrasonic transmission through the sample. Focus and gain are optimized for each scan depth. From the master data file containing all voxels for a given sample, any acoustic image displaying internal features at any region can be made, even after the physical sample has been disposed of.

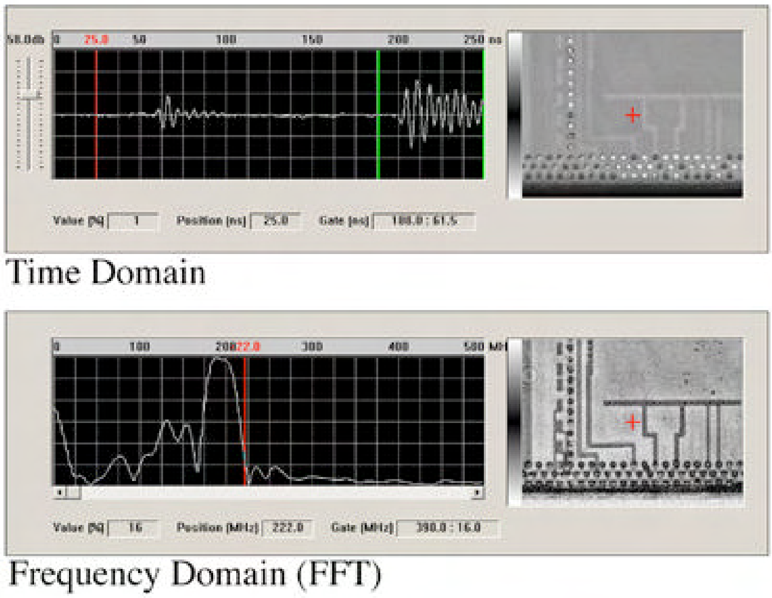

Figure 2 - One benefit of using a data file is speed. Since no physical scanning of the sample is involved, moving the gate (green lines) instantly produces a new C-Mode image (top right). Making an FFT image (bottom right) by moving the red bar to the frequency of interest takes a few seconds.

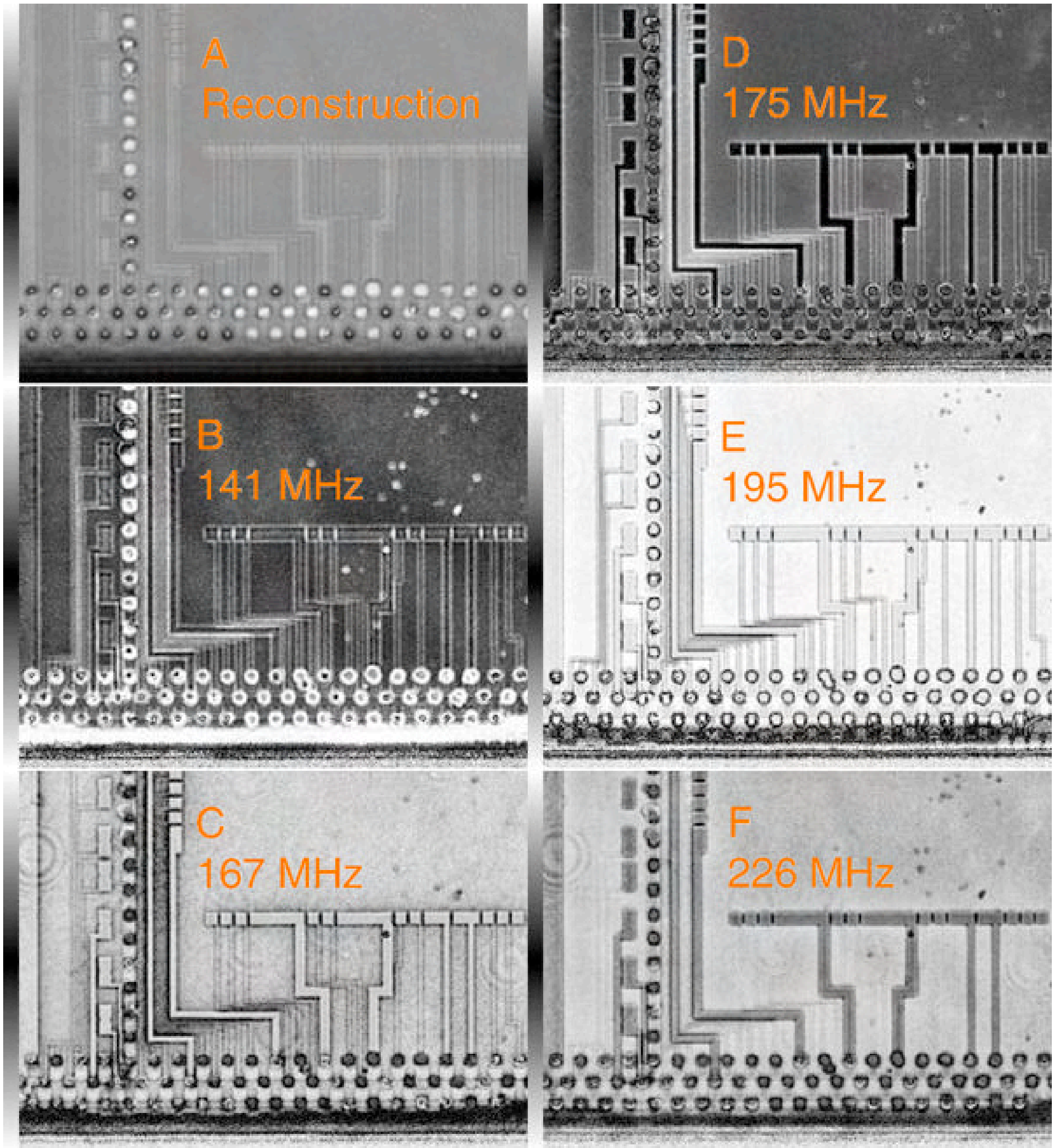

Figure 3 - The image at top left (A) is the rescanned C-Mode image of one portion of a flip chip. This image contains all of the ultrasonic frequencies reflected from the gated depth. B through F are FFT-filtered images containing only echoes ranging from 141 to 226 MHz. Contrast varies from frequency to frequency, and metallization on the chip appears variously dark and light. But the FFT-filtered images give better contrast (and better resolution) for such details. In addition, it appears that higher-frequency echoes such as 226 MHz reflect from slightly deeper in the sample. Overall, individual frequencies are more sensitive to particular features in the sample, thus allowing great versatility in problem solving. These are two of a sequence of 26 FFT images made using a 230 MHz transducer.

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Contact information:

Sonoscan, Inc.
2149 E. Pratt Boulevard
Elk Grove Village, IL USA 60007
Phone: 847 437-6400
Fax: 847 437-1550
E-mail: info@sonoscan.com

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