TECH SPOTLIGHT

DEPTH-BY-DEPTH ACOUSTIC INVESTIGATIONS

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Acoustic microscopy is the general term applied to high-resolution, high-frequency ultrasonic inspection techniques that produce images of features beneath the surface of a sample. The scanning transducer of an acoustic microscope pulses VHF or UHF ultrasound into the sample and collects the return echo signals. Because ultrasonic energy requires continuity of materials to propagate, internal defects such as voids, inclusions, delaminations, and cracks interfere with the transmission and/or reflection of ultrasound signals. Compared to conventional ultrasound imaging techniques, which operate in the 1 to 10 MHz frequency range, acoustic microscopes operate up to and beyond 1 GHz, where the wavelength is very short and the resolution correspondingly high.

Acoustic microscopes are practical tools that can be applied to a broad range of problems that previously had no solutions, and they have been especially useful in solving problems with new high-technology materials and components.

If the characterization must be nondestructive (often the case when subsequent destructive analyses are planned), acoustic micro imaging is a logical choice. To characterize the material or materials in a sample, it is often useful not simply to collect data from the whole thickness of the sample, but also to investigate the sample one depth at a time. Whether the sample is a homogeneous material or an assembly of multiple materials, sampling by depth may make it easier to detect flaws.

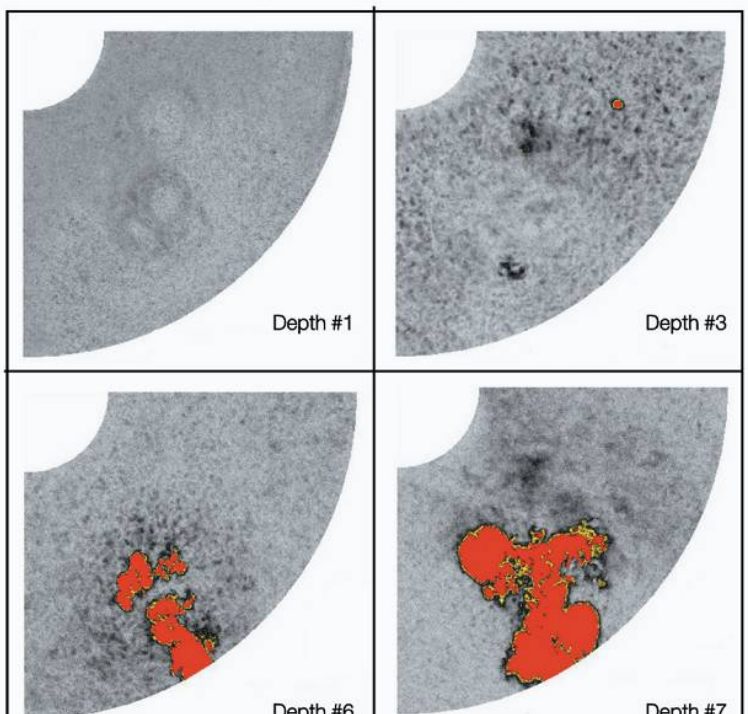

Fig. 1 — Acoustic images at depths 1, 3, 6 and 7 in a ceramic sample. Dark areas and red areas are defects.

Sampling by depth

Sound travels through most production materials rapidly, so the return echo signals arrive back at the transducer and are collected only a fraction of a microsecond after ultrasound was pulsed into the sample. The echoes are returned by material interfaces within the sample. These interfaces may be depths at which two solid materials are bonded, or they may be air-filled gaps such as cracks or delaminations. Materials that are homogeneous and that have no gaps send back no return echo signals. On the other hand, if there are material interfaces at multiple depths, echoes may be received from all of the depths. When these echoes are converted into pixels, the resulting acoustic image may be somewhat confusing because the echoes are being returned from several depths simultaneously.

This problem is solved by setting an electronic gate that accepts return echoes only within a more or less narrow time window that corresponds to the depth of interest. The result is that echoes from interfaces both above and below the designated depth are ignored. Electronic gates can be set for increasing depths to produce a series of acoustic images that show internal features depth by depth.

Characterizing ceramics

This is the procedure that was developed in Sonoscan's applications laboratory to make the four acoustic images shown in Fig. 1. The material was a high-performance ceramic which, if free from internal anomalies, would have essentially no internal material interfaces, and would thus produce a sequence of featureless acoustic images.

The sample was 8.93 mm thick. For acoustic imaging, the depth was divided into 14 segments. Seven of these segments were imaged acoustically, all from the same side of the sample. The seven time windows and transducer focus were centered at these depths: 0.75 mm, 1.30 mm, 1.85 mm, 2.40 mm, 2.95 mm, 3.50 mm, and 4.05 mm.

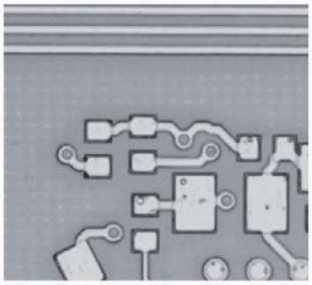

Fig. 2 —The surface (Depth 1) of a printed wiring board. Bond pads and traces are white, which means a high amplitude reflection of ultrasound.

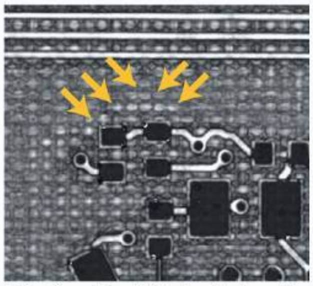

Fig. 3 — Depth 2, just below the surface. Bond pads are now below the gated depth and appear dark.

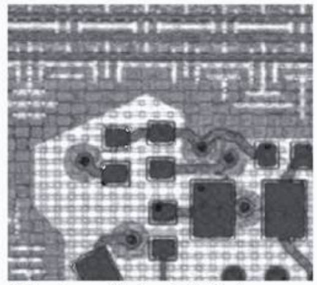

Fig. 4 — At depth 3, features higher up are all dark shadows, but a copper ground plane (white) begins to appear.

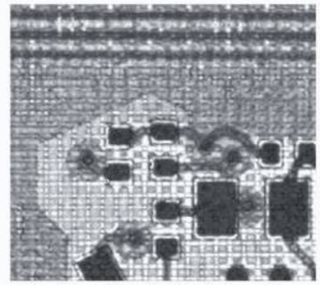

Fig. 5 — Depth 4 is below the traces at top, and partly below the ground plane.

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Each window (or "slice") encompasses about 0.2 mm vertically.

• **Depth #1** is nearest to the top surface, and no gross defects are visible. The indistinct, more or less circular features represent local differences in material density. In the acoustic image, these differences are translated into differences in signal amplitude and thus modest differences in color.

• **Depth #3** shows significant variations in material density, seen in the variable gray and black features, and also a small bright red feature. In the color map for this sample, red represents the highest signal amplitude, consistent with an interface between a solid material (the ceramic) and air. Signal amplitude is at its maximum at a solid-air interface because of the extreme differences in acoustic properties of the two materials. The red feature, then, is a small air-filled void in the ceramic. Some of the even smaller very dark features may also be voids.

• **Depth #6** shows the beginnings of major internal defects. The red areas are large voids (or perhaps different parts of a single multi-depth void). The numerous small dark features probably include both tiny voids and variations in density.

• **Depth #7** shows that the red void area is considerably larger, and there are significant areas of small dark features.

To make this sequence of acoustic images, software designed at Sonoscan guided scanning of the physical sample to collect all of the return echo signals from all parts of the sample. This data set was saved. In the meantime, the physical sample was subjected to other tests. The data set was then used to make the acoustic images to show the sample's internal features before it was altered by later tests. This virtual sample method means that a part that has been altered or destroyed by testing, or shipped to a customer, can be imaged at various frequencies and in different imaging modes even if the part itself is not on hand and no longer exists in its original state.

Figures 2 through 5 are the acoustic images of a printed wiring board that has traces and bond pads but no components. Unlike the ceramic sample – which was designed to be completely homogeneous – the printed wiring board has material interfaces at every depth, even if the interfaces involve only the fiberglass weave pattern. The printed wiring board contains no obvious defects, but illustrates how the acoustic data can change with depth.

Figure 2 is a surface acoustic image of the printed wiring board, meaning that the ultrasonic echoes are gated at the surface. However, ultrasound is not reflected like visible light, and some of the ultrasound is sending back echoes from just below the surface, especially in the weave pattern. The bond pads and traces are white because they are within the gated depth and reflect ultrasound brightly.

In Figure 3, the same printed wiring board has been imaged by gating the echoes at a depth just below the surface, but not including the surface. The bond pads look black because the return echoes are collected from a depth below the bond pads; this makes the bond pads show up as dark acoustic shadows. However, note that the traces leading from the bond pads are mostly white because they are slightly deeper and are inside the gated depth. Note also the small bright areas (arrows), as yet unidentified, in the weave near the bond pads at the upper left.

Figure 4 shows an acoustic image that is gated at a slightly deeper level within the board, and the visible features have changed markedly. The bond pads and associated traces are now entirely black – meaning that ultrasound is being reflected from a depth beneath them. The scattered small white features in Fig. 3 are here resolved into a brightly reflective copper ground plane. The weave pattern has also changed its pattern of reflectivity.

In Figure 5, the echoes have been gated at a depth almost beyond the ground plane, which is somewhat darker but still reflective. Other features, including the horizontal traces at the top of the image, are above the gated depth and are imaged as acoustic shadows. To image this depth, ultrasound waves must make a round trip through the very inhomogeneous weave; as a result, image resolution is beginning to be degraded.

Depth-by-depth imaging such as this has been successful on diverse samples, including composite tensile test bars, multi-layer composite structures, a six-layer stack of silicon wafers, and many other samples involving ceramics, metals, and polymers.