TECHNICAL SPOTLIGHT
ACOUSTIC IMAGING TECHNIQUES EFFECTIVELY MAP BURIED LAYER CONTOURS

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On The Cover:
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Acoustic microscopy advances enable mapping of the point-by-point contour of tilted or warped interfaces, as well as individual material layer thicknesses.
Acoustic microscopes pulse ultrasound into a sample and use the return echoes to find and image cracks, delaminations, and other gap-type flaws in manufactured parts and products. New developments in microscope technology, such as those taking place at Sonoscan Inc., enable mapping of the point-by-point contour of tilted or warped interfaces, as well as individual material layer thicknesses.

If all layers are flat and parallel to each other, the acoustic image map of any internal interface will contain uniform color pixels because they are all the same distance from the scanning ultrasonic transducer. However, an assembly may contain interfaces that are tilted or warped, as shown in Fig. 1. In some instances, both warped and tilted interfaces are present in the same assembly.

In many applications, design constraints require these buried layers to be flat, horizontal, and of uniform thickness, although acoustic imaging may show different internal geometry. For example, power insulated gate bipolar transistor (IGBT) modules often struggle with buried layers. Fast-switching IGBT modules are frequently used to handle heavy loads in critical applications such as railroad engines, heavy mining equipment, and electric automobiles. Due to high current levels, the silicon die that actually performs the switching must disperse large amounts of heat.

IGBT modules are designed so that heat flows downward through ceramic plates called rafts to a metal heat sink that dissipates heat into the surrounding air (Fig. 2). If the heat sink, raft, and die are all horizontal and parallel, and if there are no voids (air bubbles) or other gaps in the solder bond, heat will flow downward (arrows in Fig. 1) at the designated rate. However, if voids are present or the raft (and perhaps the die itself) are tilted, heat flow will not meet specifications, likely causing the die to overheat and fail electrically.

Acoustic microscopes can image internal material interfaces fairly quickly because the transducer that pulses the ultrasound and receives the echoes from the internal features moves laterally at speeds that can exceed 1 m/s. In addition, the speed of ultrasound through production materials such as metals, ceramics, and polymers is typically measured in thousands of m/s.

Because most sample thicknesses are measured in millimeters, the pulse is launched and echoes are received in a few millionths of a second. Consequently, the moving transducer can receive echoes from thousands of locations per second as it scans. Echoes may come from a solid-to-solid material interface, or in the case of gap-type defects, a solid-to-gas (e.g., air) material interface. Each location contributes one pixel to the sample’s acoustic image.

IGBT modules are imaged by scanning the transducer, which is inverted, across the surface of the metal heat sink at the bottom of the assembly. Because the transducer’s ultrasound needs to be coupled to the surface, contact is maintained by a water plume. At each location, the return echo’s amplitude provides information about the two materials at the interface. Solid-to-solid interfaces tend to have lower amplitude echoes. Solid-to-gas interfaces reflect virtually 100% of the ultrasound and thus produce much higher amplitude echoes. Solid-to-gas interfaces reflect virtually 100% of the ultrasound and thus produce much higher amplitude echoes that become bright white pixels in the acoustic image. While imaging the depth in a sample where two solid materials are supposed to be joined, there should be no white areas indicating voids, delaminations, or other gaps.

The elapsed time from pulse launch to echo return is also measured and recorded. This indicates that the image comes from within the vertical extent of the depth of interest (known
as a gate) defined before transducer scanning begins. Because the acoustic velocity of the material or materials is known, the elapsed time of an echo’s travel from an interface within the gate can be converted into distance. The precise depth of the echo at each location can thus be known by using a program called the time difference mode—and the range of depths can be displayed by a sequence of pixel colors.

Figure 3a shows a time difference acoustic image of the area of one warped ceramic raft in an IGBT module. The image was gated to include the solder layer and top surface of the raft beneath the solder. The transducer pulsed ultrasound into the module from below, and the time difference mode mapped the surface of the warped raft. Where the raft surface is highest, the solder is thinnest. A 2D side view image through this IGBT module would look something like the diagram in Fig. 4, where solder thickness varies. In the diagram, black items indicate voids in the solder.

In Fig. 3a, solder is thickest (and raft surface lowest) in the magenta region near the lower right corner. Solder is thinnest (and raft surface highest) in the small red region at the upper left. Tilting and warping of the raft diminishes its heat-flow uniformity. In some IGBT modules, the raft is warped rather than simply tilted.

The red features away from the upper left corner indicate voids in the solder. In both the ceramic raft and voids, red areas identify items in contact with the heat sink through which the ultrasound was pulsed. Each void blocks heat flow and, collectively, may reduce flow to critical and undesirable levels.

Figure 3b uses colors to identify the local depth range of the solder. During inspection, this type of map makes it easier to pinpoint unacceptable solder thickness. The same technology is used to examine internal material interfaces in a much different application—manufacturing polycrystalline diamond (PCD) material for use in cutting tools such as oilfield drill bits.

The material is made by sintering a layer of PCD on top of a tungsten carbide layer. The tungsten carbide (WC) makes the tool stronger and adds to its footprint, making it easier to mount. These sintered layers form a wafer that can be cut into individual tool bits, with the top PCD layer used to perform the actual cutting.

The desirable outcome of sintering is a wafer with a uniformly thick layer of PCD on top. Such a wafer, whose layers are shown in Fig. 5, can be electromechanically sliced into the maximum number of tool bits for a given application. Wafer price depends on the number of good tool bits that can be cut from it. Tool bits where the PCD layer varies as little as possible from the
ideal thickness are desirable because any cutting tool breakdown requires an expensive and time-consuming repair.

Imaging wafers acoustically produces a map showing the local depth of the interface between the PCD and WC, i.e., the PCD thickness. Figure 6 shows the acoustic images of two 55-mm wafers. Each color represents a vertical extent of 0.05 mm. The ideal thickness for this application is roughly 0.60 mm, represented by the boundary between the brown and pale blue regions on the two wafers.

The left wafer features many obvious variations in PCD thickness over short distances. Over the whole wafer, PCD thickness ranges from about 0.45 mm to 0.80 mm. The thickest region is near the center, represented by the magenta color. The result is that only a small portion of this wafer is usable. In contrast, the wafer on the right features a total PCD thickness variation of just 0.20 mm, offering a significantly larger area to be sliced into tool bits.

In both the IGBT sample and the diamond sample discussed here, one face of the buried layer is flat and horizontal—i.e., the top of the PCD wafer, and the top of the IGBT module’s solder where it interfaces with the rigid metal heat sink. If a buried layer were distorted on both of its surfaces, this acoustic method could image both of the buried layer’s surfaces in separate images and map the thickness of the distorted buried layer. ~AM&P

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Fig. 5 — Side view diagram of a portion of an ideal polycrystalline diamond/tungsten carbide wafer.

Fig. 6 — Time difference mode images of two wafers exhibiting extreme variation in PCD thickness (left), and much less variation with far more usable area (right).