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# Bodo´s Power Systems®

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# Inspecting IGBT Modules

## *Ultrasound or X-Ray?*

*An IGBT module that passes electrical tests might contain between-layer defects capable of causing overheating and electrical failure during service. Engineers responsible for long-term reliability have multiple options for determining whether gap-type defects are present. For example, they can physically section the IGBT and use an optical microscope to look for delaminations, voids and similar gaps. One drawback is that they might not section in a plane that intersects a defect. The IGBT, whether defects turn up or not, is destroyed.*

*By Tom Adams, consultant, Sonoscan, Inc.*

Two good nondestructive methods are x-ray and acoustic micro imaging using a  Sonoscan C-SAM® system. Both will image the interior of the IGBT module without destroying it, but with very different results. X-ray and acoustic microscopy are rightly considered complementary methods.

An x-ray tube emits photons that, like visible light, are part of the electromagnetic spectrum. X-ray photons have much higher frequencies and much shorter wavelengths than the photons of visible light. “Hard” x-rays (shorter wavelengths, higher energies) are used in imaging. “Soft” x-rays hardly penetrate metal materials at all.

An x-ray beam traveling through a material is absorbed to some extent by that material - which means that eventually, if the material is thick enough or “dense” enough, all of the energy in the beam will have been absorbed and no energy will emerge from the far side of the material for imaging. When an x-ray beam is transmitted through a sample containing multiple materials having different densities, the intensity of the emerging beam at any location depends on what materials it has traveled through.

Unlike x-rays, ultrasound is not part of the electromagnetic spectrum but is mechanical energy. When a C-SAM® system pulses ultrasound into a material, the pulse travels as a wave that causes motion in molecules. Part of pulse may be scattered in a variety of directions. Some of the pulse energy may be absorbed by molecules, especially molecules such as polymers that are long, twisted, and flexible. The ultrasonic energy causes bending of the molecule. Most production materials transmit ultrasound adequately for imaging. Rubber, on the other hand, is an example of a material that absorbs ultrasound rapidly, although thin samples of rubber have been imaged. The least absorbing material is  crystalline diamond.

Acoustic images display internal material interfaces - a metal to polymer bond, for example - because material interfaces reflect ultrasound back to the transducer for collection. The reflected pulse reports the amplitude of the echo caused by a material interface, the polarity of the interface, and the travel time. Solid-to-solid interfaces have more or less moderate amplitudes, depending on the properties of the two solid materials.

The result is very different when an ultrasonic pulse strikes a solid-to-gas interface, such as the interface between a metal and an air-filled void, because these interfaces have the highest amplitudes.  Typically >99.99% of the energy that has struck the interface is reflected back toward the transducer. Suppose there is a gap <1µ thick between the ceramic layer and the solder in an IGBT module. When the ultrasonic pulse strikes the top of the gap - i.e., the solid-to-gas interface - >99.99% of the pulse energy is reflected. A tiny fraction of the pulse might cross the gap and encounter the gas-to-solid interface at the bottom of the gap, where >99.99% of the the very feeble pulse might be reflected.

The transmission of ultrasound through a given material depends much less on the mass density of the material than does the transmission of an x-ray beam. In some materials such as ceramics, high porosity (i.e., the inclusion of large numbers of microscopic gap-type features) can scatter ultrasound and limit acoustic imaging, but these pores do not alter the inherent density of the solid material.

In the imaging of IGBT modules, there is thus a considerable difference in the information obtained by x-ray and ultrasound: x-ray displays variations in material density, while ultrasound displays differences at internal interfaces.

If there is a delamination, for example, between a ceramic layer and the heat sink, or more precisely between the ceramic layer and the solder that bonds it to the heat sink, here is what each method will see:

- X-ray photons traveling through the delamination will encounter only less overall density than the photons that pass through other areas of the module. The difference is that for a distance of perhaps 0.5mm the beam travels through air instead of solder. This difference is so slight that the delamination will typically be invisible in the x-ray image, and it is not possible to determine that a once bonded interface is now delaminated. For a gap-type defect to be visible to x-ray, the gap needs to be thick enough, and the IGBT module needs to be thin enough, for the gap to cause a visible difference in attenuation of the beam.
- Ultrasound will be almost completely reflected by the initial solid-to-gas interface of the gap. Reflection is nearly total whether the thickness of the gap is 1 cm or considerably less than 1 micron.

Figure 1 shows the x-ray (top) and acoustic (bottom) images of the same IGBT module. The acoustic image was gated to use only the return echo signals from the interface between the round disks and the substrate. The x-ray image encompasses the entire thickness of the module.

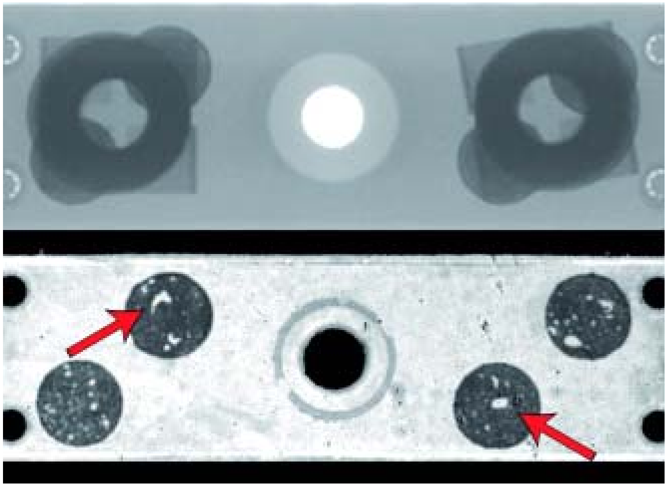

*Figure 1: X-ray image (top) and acoustic image (bottom) of an IGBT module. Arrows mark gap-type defects.*

The x-ray image therefore shows the square outlines of the chips at the top of the assembly, as well as the circular disks and larger holed disks. The acoustic image, gated on a single significant interface, reveals numerous white gap-type defects between the circular disks and the substrate. Two of the gaps are marked by arrows in Figure 1. These gaps mostly lie directly below the chips and will block thermal dissipation to the heat sink. Probably these gaps are best described as delaminations, since they are very thin. Because they are thin, they represent an insignificant loss of attenuation to the x-ray beam, and do not appear in the x-ray image.

The ways in which ultrasound and heat react when they encounter gaps is important in understanding IGBT modules. A gap such as those in Figure 1 reflects 99.99% of the ultrasonic pulse if the gap is, say, 1 millimeter thick. It reflects the same 99.99% if the gap is 1µ thick, or even less. The reflection occurs at the solid-to-air interface; essentially none of the pulse crosses the gap to be reflected from the air-to-solid interface on the other side of the gap. Laboratories that text plastic-encapsulated microcircuits (PEMs) to determine their Moisture Sensitivity Level routinely cross-section the PEMs in order to view delaminations and the like optically. But they image the PEMs acoustically before cross-sectioning because they know that some gap-type features are too thin to be seen by a light microscope after sectioning.

In some IGBT modules, x-ray is able to image gap-type defects. This is true only if there is missing material and if the gaps are relatively thick - i.e., bubble-like voids rather than delaminations or disbonds a few microns thick. The thickness of the gap needs to be large relative to the whole thickness of the module.

The IGBT module shown in Figure 2 is small and relatively thin - considerably smaller and thinner than a typical high-power industrial IGBT. The entire module is about 5.0mm thick; the die attach layer is about 0.5mm thick, or about one-tenth of the thickness of the module, and the voids in the die attach are also about 0.5mm thick.  In the x-ray image at bottom, the voids are visible as lighter areas, but the contrast is poor. X-ray must travel through the entire IGBT, and is not easily restricted to a single depth. In the acoustic image (top), the voids appear bright white because echoes from the specific depth were used to make the image, and because the voids reflect 99.99% of the ultrasonic pulse, just as they would if their thickness were as little as 1µ. Thick voids are sometimes seen in modules where a die is tilted and the die attach is therefore of uneven thickness.

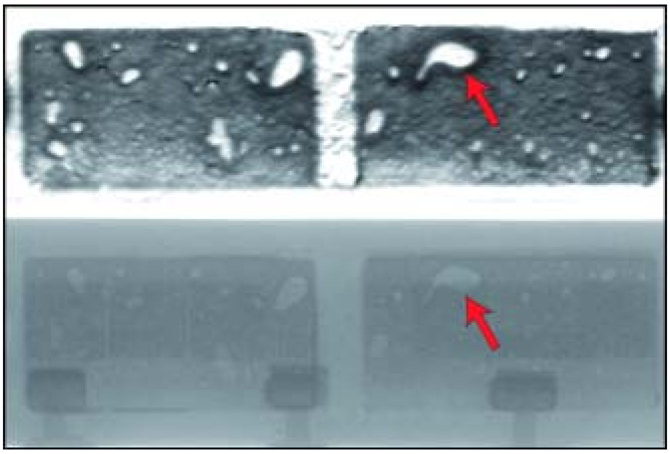

*Figure 2: A very thin IGBT module in which relatively thick voids are visible in the acoustic image (top) and, very faintly, in the x-ray image (bottom).*

The x-ray image (bottom) shows most of the same gaps because they are thick enough to cause a significant change in attenuation. The contrast is much less than the contrast in the acoustic image, even though the contrast has been enhanced here for publication. Since it incorporates the entire thickness of the module, the x-ray image also displays overlying structures (at the bottom of the image) and, very faintly, the chips above the die attach. Some of these structures effectively lower the local attenuation loss from the voids, and make some of the voids difficult to see.

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