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IGBT Modules Benefit from Inverted Acoustic Inspection

When a high-current IGBT module experiences sudden electrical failure in service, the consequences are generally expensive and sometimes dangerous. Because they are used as high-speed switches for heavy power and current, IGBT modules play demanding roles in transportation (electric railways, electric autos), mining and other industries.

By Tom Adams, consultant, Sonoscan, Inc.

Makers of IGBT modules go to great lengths to build long-term reliability into their products, but during assembly of a module there is the opportunity for anomalies to be formed that are not easily detected by most test methods. The anomalies are collectively called gap-type defects. These defects include voids (in solder, for example), delaminations between materials, and cracks. They have two characteristics that can lead directly to a sudden failure during system operation:

1. they block heat being dissipated from the chip transistor. Because they handle varying loads of high current, IGBTs require very efficient heat dissipation.
2. they tend to become larger as a result of thermal excursions during service, and are then capable of blocking more heat flow.

Such defects can and do cause sudden field failures. The challenges for IGBT module makers are to avoid defects through good process control and to find and remove defects before they arrive in customers' hands. Gap-type defects are not detected by electrical tests, x-ray or other routine test methods. They are, however, made visible and characterized by acoustic micro imaging, which employs very high frequency ultrasound These defects reflect more than 99.99% of an ultrasonic pulse that strikes them as an echo signal. The echoes are used to create the acoustic image.

Many makers of IGBT modules, however, can't use acoustic micro imaging systems because the ultrasonic transducer must be coupled to the surface of the sample being inspected by water, and because to date all transducers have been designed to pulse downward. They must therefore scan the top side of the unencapsulated module, but for many modules putting the topside circuitry in contact with water is considered too risky.

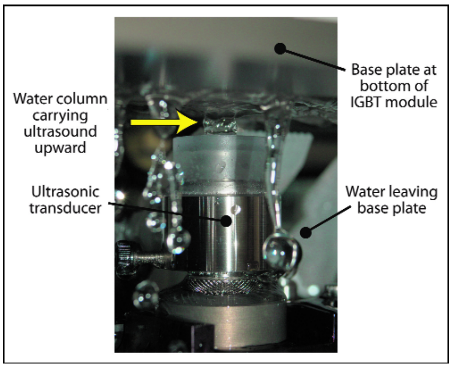

Figure 1: Pumping water upwards, the transducer assembly maintains a constant column of water as it scans the bottom surface of an IGBT module

This obstacle to long-term reliability has been removed by Sonoscan engineers, who have developed an acoustic micro imaging system that inverts the transducer [Figure 1] and places it under the IGBT module's base plate, where it scans the surface at speeds that can be >1m/s as it scans. The inverted transducer pulses ultrasound into the module and receives return echoes at thousands of x-y locations per second. It is coupled to the base plate surface by an inverted water jet that creates a constant column of upward-flowing water (arrow in Figure 1) that reaches the base plate surface but no other part of the module. For applications that require it, the inverted transducer can be moved to the top side and aimed downward to perform the same operations and collect data with the same speed and efficiency.

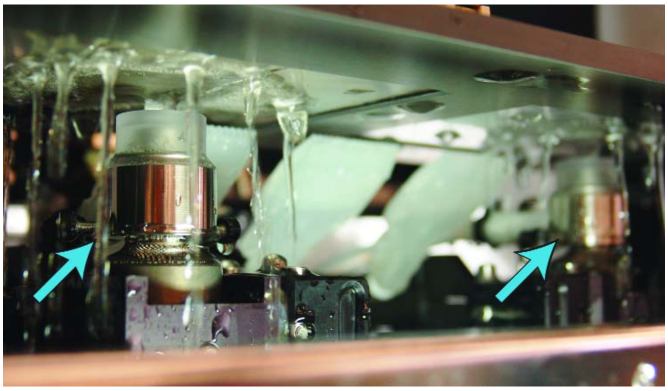

Figure 2: To boost throughput, the system can have two transducers, each scanning its own module

From its vantage point beneath the module the transducer can image internal features at any level, up to and including the IGBT transistors and their attachments. For higher throughput, the system can be equipped with two inverted transducers that image two IGBT modules at a time [Figure 2].

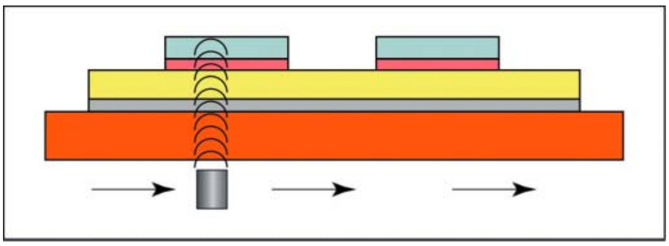

Figure 3: Simplified side view of a module. The scanning transducer sends thousands of pulses per second into the bottom of the module and collects echoes from material interfaces, including the interfaces associated with gap-type defects

Each transducer pulses ultrasound into the base plate of its module. The overall operation of one inverted transducer scanning the bottom side of one module is shown diagrammatically in Figure 3. As the ultrasound propagates upward, it is to some degree reflected by each material interface that it encounters. At the interface between the base plate and the ceramic plate or "raft" above it, a portion of the ultrasound will be reflected back to the transducer and a portion will cross the interface and travel upward. The percent of the ultrasound that will be reflected by striking this interface can be calculated from the density and acoustic velocity of the two materials. The portion of ultrasound that crosses this interface will travel upward and, barring interference from defects, will be in part reflected by the next material interface.

The exception to this pattern occurs when ultrasound strikes a gap-type defect, or more precisely the interface between the solid material it is traveling through and the air or vacuum in the gap. More than 99.99% of the ultrasound is reflected back toward the transducer for collection. In reflection-mode acoustic imaging, the brightness of a feature is determined by the intensity of the returning echoes. Echoes from gaps such as voids, delaminations and cracks are therefore bright white. Echoes from well bonded solid-to-solid interfaces are some shade of gray.

For IGBT modules, this means that the inverted ultrasonic transducer can display anomalies such as voids or cracks in the adhesive bonding the base plate to the raft, delaminations between any two elements, voids or delaminations in the die attach of the transistors, and other anomalies.

The echoes sent back from various levels within the IGBT module arrive at the transducer at different times. A single acoustic image is typically "gated" on a particular time interval representing the targeted depth in order to avoid using echoes from all depths and thereby creating a potentially confusing acoustic image. The gate may be as thin or as thick as desired. For example, when looking for voids or other defects in a solder layer bonding the base plate to the raft, the operator may gate on the top surface of the base plate and the bottom surface of the raft in order to image the whole thickness of the solder. Alternately, he may gate on a thinner portion of the solder region.

Figure 4 is the acoustic image made by the inverted transducer system of one of four units in an IGBT module. This image was gated on the interface between the base plate and the solder layer bonding the base plate to the ceramic raft. The image encompasses roughly half of the thickness of the solder. The material interface between the base plate and the solder is medium to dark gray. At the lower left the solder extends across an intended gap between this raft and the one to the left.

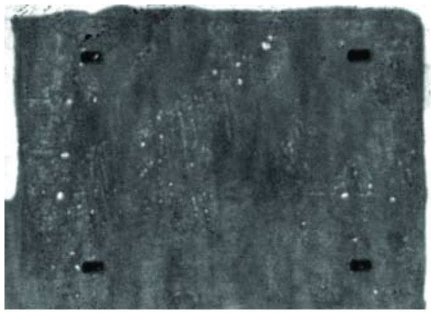

Figure 4: Acoustic image gated on the material interface between the base plate and the solder adhesive. The four dark objects join the base plate to the ceramic raft; the numerous white dots are voids in the solder

The four darker features, one near each corner, are posts that mechanically join the raft to the inner surface of the base plate. The numerous small white features are voids in the solder; these are probably air bubbles that were trapped in the fluid solder. Examination of the next level that was imaged - the second portion of the solder thickness - showed few additional voids and, more important, no large voids. Thus the voids seen in Figure 3 constitute most of the voids in the solder, and these voids lie close to the base plate. Although numerous, they are small, and may pose little risk to performance.

Figure 5 was gated on the die attach below the components at the top of the module. Like Figure 4, Figure 5 was made by pulsing ultrasound into the base plate. In this case the ultrasound traveled through the base plate and rafts to the die attach. Gating selected only echoes from the die attach level for imaging.

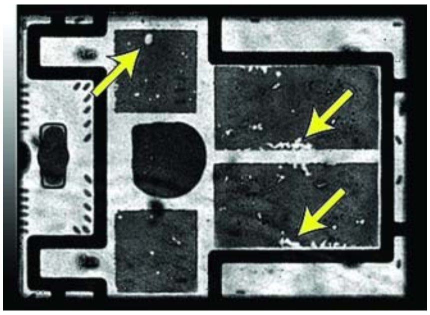

Figure 5: Scanning the bottom surface of the module gave this acoustic view of the die attach level. Arrows mark delaminations and voids that can cause field failures

The straight black lines are intentional gaps between the rafts. Because the echoes were gated on the die attach that is farther from the transducer than the raft, ultrasound returning from the die attach is blocked (reflected back toward the top of the module) by these gaps. The x-y coordinates corresponding to the gaps thus have no echoes, and appear black. The phenomenon is sometimes called an acoustic shadow.

The four rectangular features in Figure 5 are the medium gray tone resulting from the material interface between the die attach material and the die itself. Interrupting this medium gray tone are several much brighter areas that are voids or delaminations (marked by arrows in Figure 5). Although these defects are small, they pose some level of risk in an IGBT module, in part because they will probably be exposed to thermal variations that will cause them to expand. As their areas grow larger, the amount of heat they block will increase. All four of the rectangular components have such defects. The dark, nearly circular feature in Figure 5 is probably the outline of excess solder outflow from a small rectangular component.

IGBT modules are imaged acoustically at various stages of assembly. Rafts are sometimes imaged alone in order to look for internal defects, or to image the attach of components. Most frequently acoustic imaging is carried out on the completed module, with base plate attached, but before encapsulation. Defects found at this point can be remedied by rework. The module can also be imaged by the inverted transducer after encapsulation because the base plate is not encapsulated. Imaging after encapsulation may be helpful in diagnosing the cause of a failure, and is useful as a prelude to destructive physical analysis.

Summary

Overall, the inverted ultrasonic transducer gives the opportunity to inspect nondestructively the internal features of IGBT modules and to identify and rework those modules where anomalies capable of causing field failures are found. Because the inverted transducer can image features at any level, including the die attach and die at the top of the module, it makes possibly risky inspection from the top side unnecessary.

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