Acoustic Determination of IGBT Module Solder Thickness

A color map has the advantage that specific colors can be assigned to thickness ranges

Under ideal conditions, the solder pad immediately above the heat sink in an IGBT module will be free from any voids or disbonds, and will be of the same specified thickness over the whole area of the pad. Voids and disbonds in the solder reflect heat back toward the die, an undesirable situation in a module where the thermal budget has been carefully designed. Uneven thickness of the solder can also cause thermal problems.

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Sonoscan has recently developed and incorporated into its P300™ Acoustic Micro Imaging system a technique known as the Time Difference Mode that evaluates the thickness of the solder at each of the thousands or millions of x-y coordinates scanned by the moving transducer. During the same scan the transducer also performs normal reflection-mode acoustic imaging to find voids and other gap-type defects. Internal features such as voids are imaged in the same frame as the thickness data. The two simultaneous processes are described below.

Imaging Voids and Other Internal Features

As the transducer raster-scans the surface of the IGBT module's heat sink, it alternately pulses ultrasound into the module and receives the return echoes. It performs both functions thousands of times per second while scanning. Software records and measures echoes received and assigns a proportional color to each echo. The pixels from each coordinate make up the acoustic image of internal features.

Ultrasound pulsed into the module is reflected by material interfaces, but not by homogeneous materials. In a defect-free IGBT module there are several material interfaces at various depths. In addition, there may be defects such as voids that present their own additional interfaces. In order to avoid imaging too many interfaces at once, the return echo signals are generally selected by arrival time to image only a specific depth. The whole thickness of the solder layer, for example, can be imaged by selecting echoes whose arrival time indicates that they were reflected from a depth between the heat sink and the material on the other side of the solder layer. Technically, gates are set at the two desired depths, the heat sink to solder interface and, in the case of the IGBT module described here, the solder to copper interface. Only echoes whose arrival times indicate that they lie between these two gates are used to make the acoustic image. Echoes from other depths are ignored.

Figure 1 is the acoustic image, made by pulsing ultrasound through the heat sink, of three solder pads on a fairly large IGBT module. As described above, gates were set at the solder to heat sink and solder to copper interfaces in order to image the whole thickness of the solder.

The solder itself appears gray in Figure 1 largely because the gating includes the solder to copper interface which, like most interfaces between two bonded solid materials, appears gray because the echoes are of medium amplitude. The irregular white features in the solder are voids. They are white because the solder to air interface at the top of each void causes it to reflect nearly 100% of the ultrasound and thus produce the highest amplitude echo signals. To judge the impact of the voids on thermal dissipation, it is often desirable to measure the total area of the solder pad occupied by voids. In Figure 1, the areas of the three solder pads, left to right, are respectively 7.62%, 9.51% and 3.72% occupied by voids.

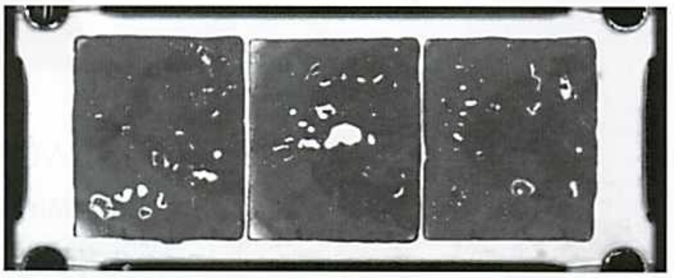

Figure 1: In this acoustic image, white features are voids in the solder layer.

Evaluating Solder Thickness

As the transducer scans the module, software looks for echoes from the two gates that have been set, one at the heat sink to solder interface, and one at the solder to copper interface. Between these two gates, software records medium-strength echoes from solid to solid interfaces (gray) and high-amplitude echoes from solid to air interfaces (white).

But it can also measure in nanoseconds the time that is required for ultrasound to travel between the two strong echoes, and thus evaluate the distance between the gates and their respective depths. The difference between these two depths is the thickness of the solder at any given x-y coordinate.

The two waveforms in Figure 2 display the amplitude of ultrasound reflected from each of the various internal interfaces. Made by pulsing ultrasound into a single x-y position and collecting return echoes from all depths, the waveform lets the operator position gates precisely. Between these two gates lies the solder layer.

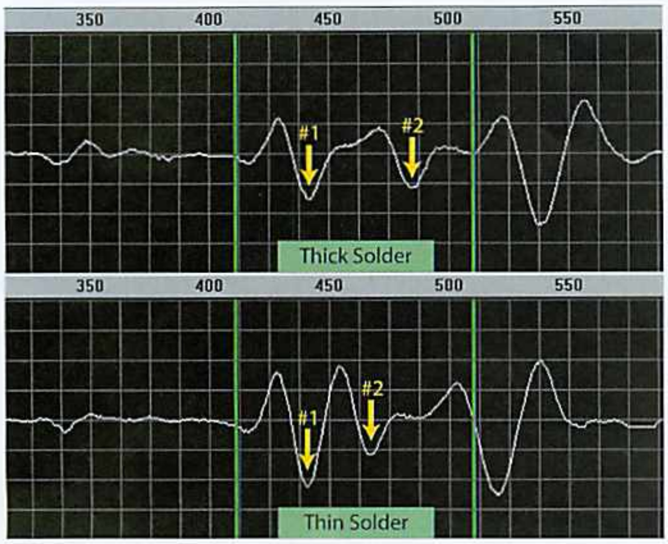

Figure 2: As solder becomes thinner, the peaks representing the heat sink (#1) and the copper (#2) grow closer together.

The two waveforms in Figure 2 were obtained from two different locations on the middle solder pad shown in Figure 1. The waveform marked "Thick Solder" is from an area where the solder is quite thick, while "Thin Solder" is from an area where the solder is much thinner. In both images, #1 identifies the interface between the heatsink and the solder, while s#2 identifies the interface between the solder and the copper. The scale at top measures the time difference between the two echoes in nanoseconds. Where the solder is thin, markers #1 and #2 are much closer together. The waveform thus shows not only the amplitude of the echoes, but also - by the location of the peaks - the distance between the two interfaces, and thus the thickness of the solder. In regions where the solder is extremely thin or absent, the two echoes merge into a single echo. A color map can be used to assign colors to the various thicknesses.

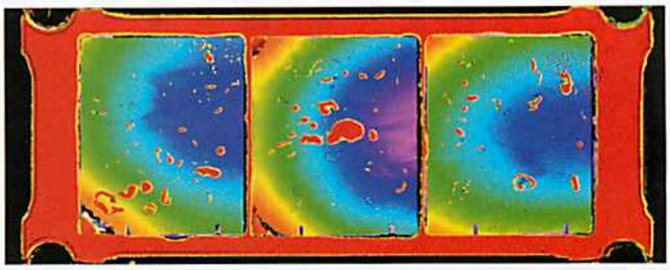

Figure 3: Voids in the solder are red. A continuous-spectrum color map identifies solder thickness from thickest (dark blue) to thinnest (orange and red).

Figure 3 shows the same portion of the IGBT module as Figure 1, but includes solder thickness data along with internal defects. The color map used here employs a continuous spectrum. Regions of solder having the greatest thickness are pink. This thickness is seen only in the second pad from the left. In the solder pads imaged here, the solder generally becomes thinner as you move to the left - dark blue, light blue, green, and eventually red. Some of the upper left and lower left corners have small areas of red and black. In these regions, the distance between the two gates is very small.

Note that most of the voids are red, although some of the smaller voids appear other colors such as green. The voids that are red are close to the heat sink to solder interface, and there is very little solder above them. It is possible that these voids (air bubbles) migrated upward to the heat sink when the solder was fluid. Some smaller bubbles remained at lower depths.

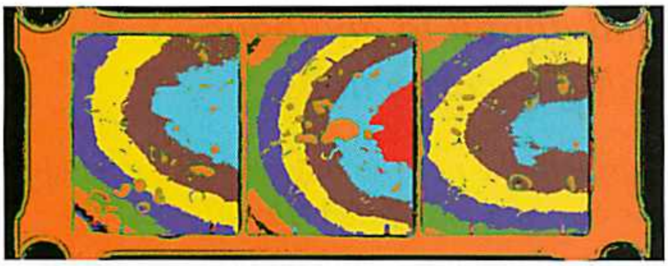

Figure 4: Non-continuous color map makes it easier to identify accept and reject solder thicknesses.

In Figure 4 a color map using arbitrary, non-continuous colors was applied. Each color represents a thickness range. For inspection of modules, such a color map has the advantage that specific colors can be assigned to thickness ranges that are within specifications and to those that are outside specifications. The usual practice is to assign perhaps 9 or 10 colors, of which about 3 are outside specifications. This arrangement makes the identification of a module as accept or reject very simple.

In Figure 4, each color represents a thickness range of about 45 microns. Since there are at maximum (in the center solder pad) a total of 8 colors, the greatest thickness of solder (red) is about 360 microns. Red areas might lie outside specifications, as would the black regions at the left corners of the two left solder pads. Black represents very little or no solder (i.e., a thickness from 0 to 45 microns), as seen in Figure 3. Orange represents a thickness from 45 to 90 microns. The voids nearest in depth to the heat sink also appear orange because, like the underlying bonded copper layer, they are very close to the heat sink.

The purpose of the Time Difference mode when applied to IGBT modules is to speed and simplify the inspection process. The thickness ranges are specified by the user of the system. If all colors displayed in the image match the colors in the color map that indicate acceptable solder thickness, the module is accepted.

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