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Light and sound: LEDs seen acoustically

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Many LED failures are the result of voids or other gap-type anomalies that block heat flow from the die.

A few years ago, the only commercial class of LED devices - HB-LEDs - was typically manufactured for applications requiring high reliability. The goal in most applications was to have few field failures, or at least few early-term field failures. Most HB-LED appliances were consequently fairly expensive.

Recently, however, the world of commercial LEDs has split into two parts: High power LEDs, which continue the tradition of reliability and high brightness in applications that require those characteristics, and mid power LEDs, which fill less demanding roles and tend to have lower initial costs. The principle behind mid power LEDS is that consumers will accept a somewhat higher failure rate in appliances having relatively large numbers of LEDs. The gradual loss of light output is balanced by the lower replacement cost.

Recent work has also shed light on the typical mechanisms of failure in both types of LEDs. Most failures in LEDs generally are related to power supply problems, but many failures are the result of voids or other gap-type anomalies that block heat flow from the die. Not surprisingly, there is good correlation between the total voided area beneath the die and the LED's junction temperature.

Acoustic micro imaging, usually in an automated format, is widely used to ensure LED quality, but with some changes to accommodate the new lower-price market. LEDs can be inspected acoustically in wafer form, as singulated devices before lens placement, and after lens placement by pulsing ultrasound into the heat sink at the bottom of the device (in failure analysis, they may also be inspected by grinding down much of the lens and pulsing ultrasound from above).

The primary change is that singulated mid power LEDs destined for lower-priced applications often need less intensive acoustic inspection. A percentage of such LEDs may be placed in trays and scanned by a system such as one of Sonoscan's C-SAM® tools, but this done as a non-destructive monitoring step to ensure that large numbers of defective devices are not slipping through rather than as 100% inspection to remove all defective devices. High power LEDs, however, may require 100% acoustic inspection.

The chief structural concerns in both mid power LEDs and high power LEDs are defects that are capable of blocking heat flow from the die. At a much lower power level, the situation is similar to that of IGBT modules, where heat from the die must reach a heat sink below the die to be dissipated. IGBTs generate far more heat than LEDs, but like IGBT modules both LED classes must dissipate heat downward. The lens above the LED is a very poor thermal transmitter.

In some designs the LED may be attached directly to the metal heat sink by a layer of solder. More often there is some type of printed circuit board between the die and the heat sink, with a thermal interface material (solder, grease, epoxy or an adhesive) between the die and the printed circuit board and between the printed circuit board and the heat sink.

Gap-type defects anywhere along the path from the die top the heat sink are the chief targets of acoustic imaging at these depths. A delamination or void as thin as 200Å will reflect virtually all of the ultrasound that strikes it; it is also a very efficient blocker of heat. The various gap-type defects have various somewhat overlapping names: a delamination suggests an interface that was once bonded but was somehow pulled apart; a void suggests a flattened (probably) air bubble; a non-bond suggests two surfaces that should have been bonded but never were, perhaps

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because of contamination of one of the surfaces. The actual etiology of a gap-type defect may more likely be revealed by knowledge of the processes used in packaging the LED than in observing the defect's structure.

FIGURE 1 is a high-resolution acoustic image of the solder layer between the substrate and the heat sink of an LED. The transducer of the acoustic micro imaging tool traveled back and forth just above this wafer at a speed that can exceed 1 m/s. Each second the transducer repeated its pulse-echo function thousands of times, pulsing ultrasound into the wafer and receiving the return echoes from material interfaces - homogeneous materials generate no echoes. The amplitude of each echo is recorded, and will determine the pixel color for that x-y location. Most material interfaces are between two solids, reflect roughly 20% to 80% of the ultrasound, and in monochrome images produce dark gray to light gray pixels.

FIGURE 1. Red regions in this acoustic image are voids in the solder bonding the heat sink to an LED.

In the polychromatic color map used here, only in the white areas is the solder bonded to both the substrate and the heat sink. Red regions are not bonded, and thus contain an air gap and reflect virtually all of the ultrasound. More than half of the intended contact area is not bonded, a situation that might be acceptable for a mid power LED, but not for a high power LED. If the non-bonded area grows in size -- as they tend to do after thermal cycling -- this LED may overheat and fail. If it is a mid power LED assembly, though, the failure of some units may have been anticipated and overall performance may remain within acceptable limits.

When ultrasound and heat encounter the interface between a solid and a void, they react in somewhat different ways. A pulse of ultrasound is almost entirely reflected, with no change in its velocity. Essentially none of the pulse crosses the interface. Heat too is reflected, but also retarded. None of the heat crosses the the gap by conduction, although some heat may cross the gap by convection if the gap is filled with air. If the heat is reflected into a heat-retentive material, that material will heat up.

FIGURE 2 is the acoustic image of a single high power LED from which most of the lens above the die has been ground away to permit a less distorted acoustic view of the die and the die substrate. There is still some distortion caused by the remaining lens material; the die is actually rectangular, for example. But the critical depth - the interface between the lens and the die substrate - is clearly visible. In the color map used here, red indicates the very high reflection from a gap-type defect or delamination, in this case the interface between a solid (the lens) and the air in the gap. Like the red regions in Fig. 1, this delamination reflects nearly 100% of the ultrasound. What this image reveals, then, is that the lens is separated from the substrate by a gap. In itself, this

FIGURE 2. Removing part of the lens revealed the red delamination that could expand under the die.

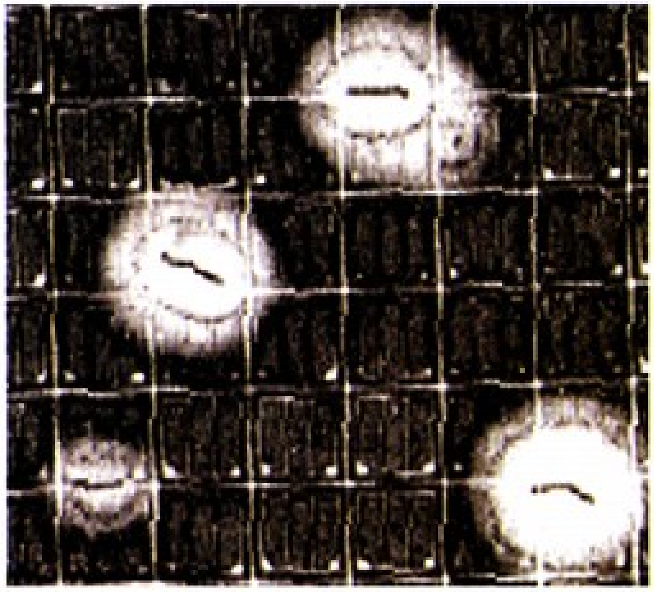

FIGURE 3. On this LED wafer, loose particles caused the rounded white voids.

delamination is relatively unimportant as a blocker of heat, because it lies beside and not below the die. But gaps such as this one tend to grow when exposed to thermal cycling; if this gap grows, it is likely to expand under the die and block significant heat. It if grows large enough, it can cause the die to overheat and fail.

Both high power and mid power LEDs are also imaged acoustically in wafer form in order to find widespread defects as early as possible. **FIGURE 3** shows one depth in one region of an HB-LED wafer. The circular or oval white areas formed as follows: at one point in the placing of layers on the wafer, small elongate structures broke free and moved away from their original positions. When the next layer was put down, these structures prevented some points on the layer from reaching the intended depth and thus caused a rounded air-filled void to form. The void is white where there is an interface between the air and the solid layer above. During later handling, smaller particles moved around in the free space of the void until they became trapped under the lower "ceiling" near the edge of the void. These particles form a broken ring around the particle that created the void. They are dark because the interface is between the solid "ceiling" and the solid particle. ◆