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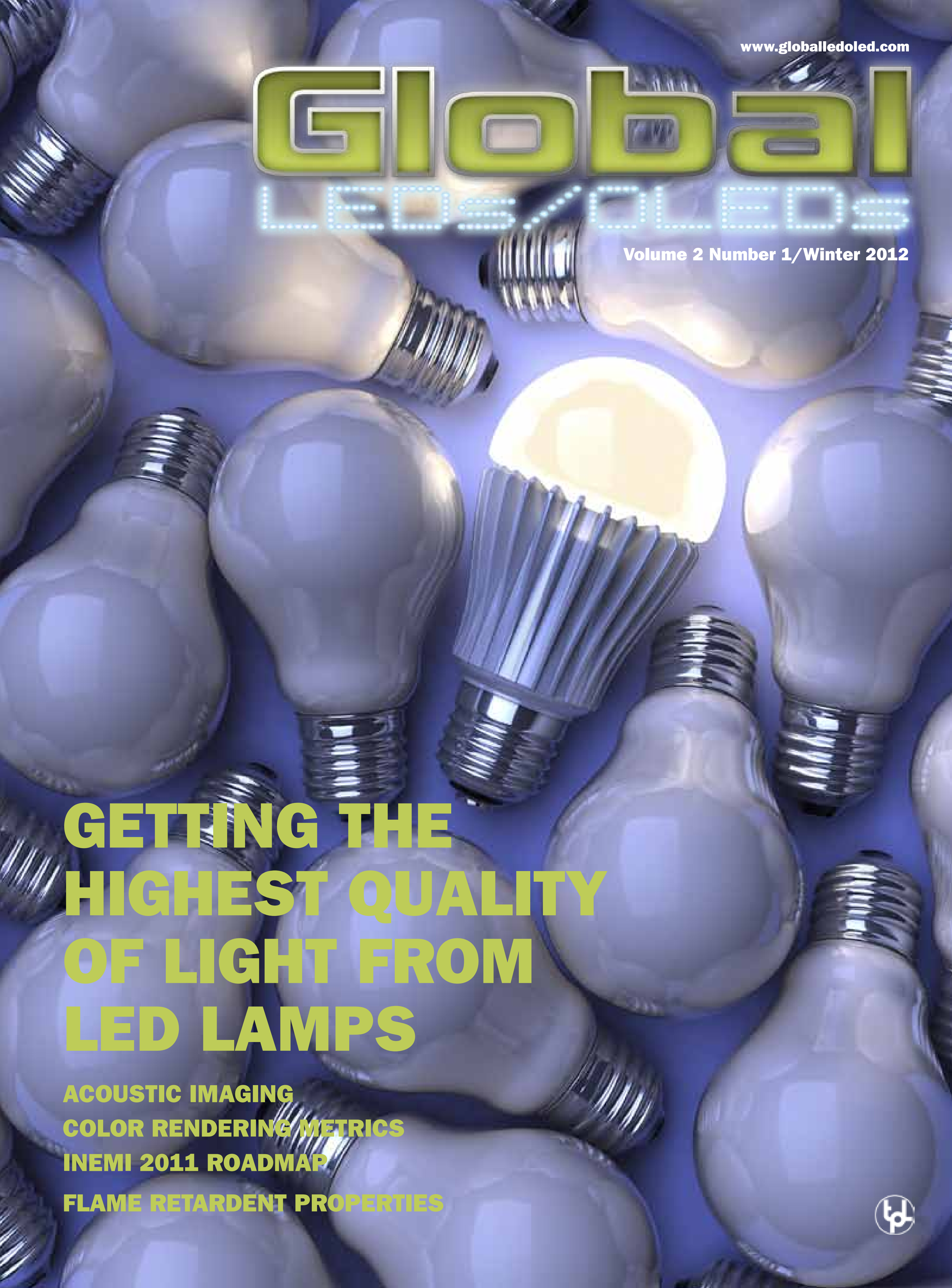

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Acoustic imaging keeps HB-LEDs cool

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The thermally conductive pathway from the LED to its external heat sink is being non-destructively made visible by acoustic micro-imaging in order to find and eliminate gaps that will reflect heat back to the thermally-sensitive LED.

Keywords: metal-core pcb, thermal grease, ultrasonic pulse, scanning transducer, acoustic microscope, acoustic image, electrolytic capacitor, ceramic chip capacitor

Over the next several years, the global market for SSL (solid state lighting), HB-LEDs in residential and commercial applications, will be defined by countless purchase decisions that will be made by an exponential amount of buyers. The buyers will primarily be looking for an acceptable combination of price and longevity. They will expect HB-LEDs to be more expensive than conventional light bulbs, but they will demand in return a longer life span.

Successful HB-LED manufacturers will aim neither too high nor too low. They will avoid making 50,000-hour HB-LEDs that are unacceptably expensive, as well as suspiciously cheap LEDs that will burn out too soon.

Dissipation of heat from the HB-LED will probably be the largest contributor to the reputation of a particular product. The HB-LED has an optimal temperature range for its operation. Operating above this range makes the HB-LEDs less efficient and less reliable. The polymer lens above the HB-LEDs is a poor thermal conductor, so most heat dissipation is downward, through intervening layers to a heat sink exposed to the atmosphere.

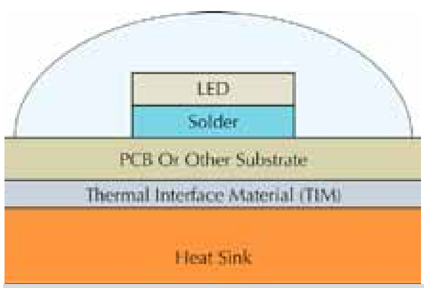

Figure 1. Diagrammatic side view of a typical HB-LED assembly, showing internal interfaces.

How many materials the thermal energy from the LED passes through depends on the design. In the simplest arrangement, the LED might be soldered to the heat sink. Another option is that there might be a metal-core printed circuit board between the LED and the heat sink; this common design is shown in *Figure 1*. At each material interface is a thermal interface material (TIM) of low thermal resistance (*Figure 1*).

Solder, thermal grease, epoxy and adhesives are frequently used TIMs, and several other TIMs are being introduced or are in development. The whole thermal pathway from the HB-LED to the atmosphere must dissipate heat at a rate sufficient to hold the HB-LED within its desired temperature range.

The layered structure of the HB-LED package means that the internal structure can be imaged in detail by an acoustic microscope. Acoustic microscopes pulse high-frequency ultrasound into samples and receive echoes from the material interfaces a few millionths of a second later. The echoes contain various types of information about the interfaces, but no echoes are returned from homogeneous materials. A pulse of ultrasound sent into a homogeneous material will produce echoes from the top and bottom surface of the sample, but not from the interior.

When the scanning transducer of an acoustic microscope moves over an HB-LED assembly, it receives echoes at each of thousands of x-y coordinates per second. From these the acoustic image is built up. A single acoustic image is generally limited to a single depth of interest. In HB-LEDs, the depth is usually an interface. This interface could be the die attach bonding the HB-LED to the PC board, an interface within the PC board, or the interface between the PC board and the heat sink.

Most well-bonded interfaces appear in some shade of gray in the acoustic image. The exact degree of reflection determining the shade depends on the acoustic properties of the two materials at the interface. The degree of reflection can be calculated from these acoustic properties. If there is a uniformly good bonded interface between the die and the die attach material, it will be uniformly gray in the acoustic image. Another interface—between the die attach material and the PC board, for example—will probably be a different shade of gray because the two materials involved are different. The two most important interfaces in an HB-LED are typically between the die and printed circuit board and between the printed circuit board and the heat sink.

However, gaps are also possible within the body of the printed circuit board (PCBs). In general, FR4 printed circuit boards are not easy to image acoustically because the fiberglass weave scatters ultrasound, but in very thin PCBs scattering is much reduced.

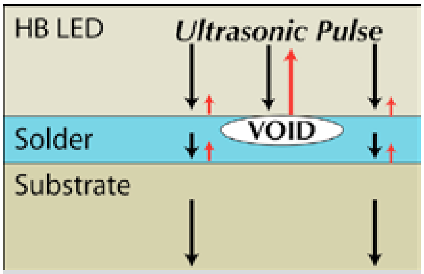

Figure 2. Bonded interfaces transmit a portion of an ultrasonic pulse and reflect a portion, but gaps reflect virtually all of the pulse.

The big threats in layered structures are gaps. A gap may take the form of a delamination, a void, or a crack. Even gaps of very small area may be dangerous because gaps sometimes grow in size when exposed to thermal cycling, mechanical shock and other factors. Gaps are also by far the strongest reflectors of pulsed ultrasound. A gap between two materials, even if it is <1 micron thick, reflects > 99.99% of the ultrasonic pulse. In an acoustic image, gaps are bright white and therefore conspicuous. A void in solder may appear as a white circle or oval. *Figure 2* shows the inside view of a pulse moving downward. It is partly reflected from well bonded interfaces (small red arrows), but it is almost totally reflected from the interface between a solid and a gap. Another defect below the void shown in *Figure 2* will not be imaged because no ultrasound will reach it.

Gaps are also very efficient reflectors of heat. Heat travels downward from the HB-LED by both conduction and radiation, radiation being less efficient. At the interface between a solid material and a gap, instead of crossing the gap, virtually all of the heat is directed back toward the HB-LED that is designed to operate within a defined temperature range.

Acoustic microscopes have a long history in looking for gaps in the layered materials of all sorts of semiconductor packages, and are now being used for similar reasons to inspect HB-LEDs. During product development, the purpose of imaging is to guide the selection of materials and the refining of processes. During production, imaging is used to ensure that unwanted gaps are not occurring. When a part has failed, acoustic imaging is often used to collect internal data nondestructively.

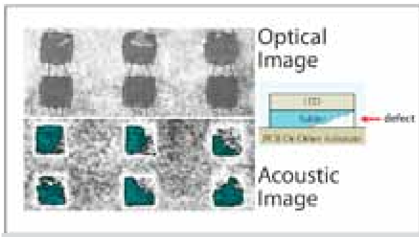

Figure 3. Acoustic image shows attachment (blue) of small array of HB-LEDs to substrate. Non-blue areas of each HB-LED are not attached.

Figure 3 shows the optical view of a part of an array of HB-LED chips, and acoustically the bonding of the HB-LED chips to the substrate. The acoustic image was made by ultrasound pulsed through the overmolding and the HB-LED chip. The return echoes were selected by their arrival time to image only this depth. The interest was in investigating the condition of the solder joining the chip to the copper.

The color blue in this image indicates a good bond. However, significant areas in all six of these bonds are gray and white, indicating a gap. Note that the surface of the substrate is similarly mottled. In the diagram in *Figure 1*, this defect would be represented by lack of contact, and perhaps loss of solder, at the TIM #1 layer. Such significant defects at the solder level would be likely to cause overheating and failure of the chip.

The acoustic image of these six HB-LEDs does not tell why gaps are present, but they show that the gaps tend to occupy a fairly large percent of the intended bond area. If such gaps occurred during production, it might be wise to verify that a material (the TIM or die attach materials, for example) has not changed from previous lots.

The ongoing evolution of HB-LEDs has created a second area where acoustic imaging may contribute significantly to reliability and longevity. Currently, most HB-LEDs drivers use electrolytic capacitors. These capacitors are seen as a potential weakness because early failure of the capacitor can cause the driver and thus the HB-LED to fail. Some HB-LED drivers, however, are moving to newly available high-capacity multi-layer ceramic chip capacitors (MLCCs).

Electrolytic capacitors cannot practically be imaged acoustically, but MLCCs are one of the items most frequently imaged acoustically. Millions have been imaged at Sonoscan's headquarters applications laboratory. The purpose is to find internal flaws (voids, delaminations, cracks) that may grow and cause unanticipated failure. Typically, dozens or hundreds of MLCCs are placed on a tray and imaged at once. MLCCs have a layered structure of electrode and dielectric, but the two materials are so thin and have such similar acoustic properties that the acoustic image looks much like the acoustic image of a homogeneous material—if there are no defects. Voids and other gaps stand out sharply. In MLCCs, the danger posed by these gaps is electrical failure.

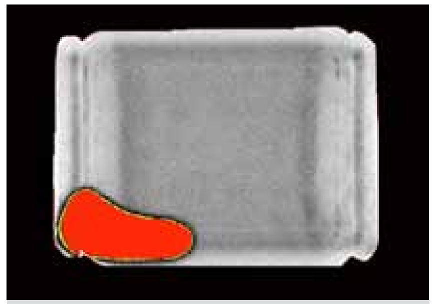

Figure 4. High-capacity multi-layer ceramic chip capacitors in HB-LED drivers can be screened acoustically to remove those with defects such as this large delamination.

Figure 4 is the acoustic image of an unmounted 50-volt capacitor, part of a lot of capacitors that were imaged before surface mounting in order to screen out future failures. The prominent red feature is a large delamination within the capacitor, very likely to cause electrical failure in service.

Delaminations and other gap-type defects that can disrupt the dissipation of heat from IGBTs are hard to detect by most methods, but because even very thin gaps are very efficient reflectors of high-frequency ultrasound, acoustic microscopes are able to image and analyze these potentially dangerous flaws.

Tom Adams is a freelance writer and photographer based in New Jersey, USA. He has written more than 500 articles for technical and scientific trade magazines. His articles have appeared in more than 50 magazines in 15 countries in North America, Europe, and Asia.