

White Paper

When the Lights Go Out: LED Failure Modes and Mechanisms

By Joelle Arnold

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Light Emitting Diodes are the wonder component of electronic devices. Blinking indicators and light sources in every color of the rainbow make the black boxes of our profession capable of communicating with their users.

Have yours "gone out"? It's easy to forget that these optical devices are fundamentally electrical, and the investigation of their failures follows the same rules as any other silicon-based component, with some important modifications. This article will summarize the function and construction of ordinary LEDs, indicate some common failure mechanisms, and introduce the basic fixes appropriate to each type of failure.

What Is An LED?

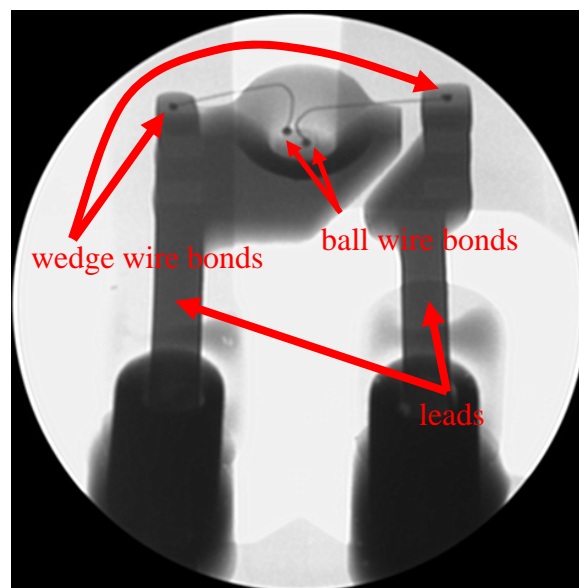
To state the obvious, LEDs are diodes. They are P-N junctions that emit energy at a wavelength that corresponds to visible light when forward biased. Combinations of different semiconductor materials and dopants vary the energy drop across the junction, and the color emitted corresponds to that energy drop. Much work has gone into making every color of the spectrum, and some LEDs incorporate an extra step to mix colors to produce white light. These components use phosphors to absorb blue or ultraviolet light emitted from the die and re-emit it as yellow. Blue and yellow are at sufficiently opposite ends of the visible spectrum to fool our eyes into seeing white light.

LED Construction

The figure on the right is an oblique X-ray micrograph of a through-hole white LED. The through-hole leads travel directly from the board to the die. One lead forms a cone shaped cup on which the die is mounted, the other forms the lead of opposite polarity. This lead is connected to one side of the die with a wire bond, usually gold. The other side can be connected to the lead with another wire bond, as on this LED, or directly through the bottom of the die through the die attach.

What is not visible on the X-ray image is the silicone bead that protects the die. A small drop of the translucent viscoelastic material provides a measure of compliance to the delicate die and wire bonds. In a white LED, the phosphor material is suspended in this silicone.

The entire component is molded into an epoxy casing that provides directionality to the light and further protection to the die and leads.



LED Failures: Degradation

Most LEDs have a natural lifespan that ends in a wear-out mechanism. Defects within the active region can spur nucleation and dislocation growth, and are particularly affected by temperature and current. Phosphors in white LEDs will degrade with time and temperature, resulting in a change of the light color (usually becoming bluer). The epoxy package can yellow with time. While degradation failures are unavoidable, correct LED selection ensures that they will not degrade within the life of

your product. Many LED data sheets will indicate an expected operating life time under normal operating conditions; proper derating and adherence to environmental guidelines will ensure your LEDs outlive your product.

LED Failures: Thermal Runaway

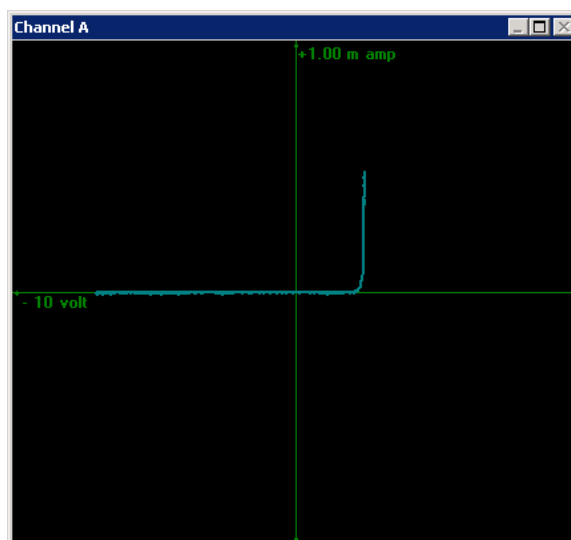
Poorly made LEDs may develop areas of higher and lower resistance (and temperature) within the substrate due to defects, electromigration or incomplete soldering. This may lead to current crowding, which on high power LEDs can cause thermal runaway: increases in temperature result in increases in resistance, which in turn increase the temperature further. Failures of this sort can be solved by selecting an LED rated for high current applications.

LED Failures: Electrical Opens and Shorts

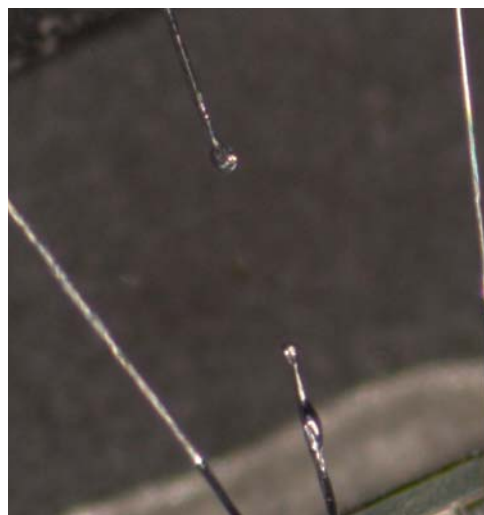
If an LED suddenly goes dark on you, the first course of action is to probe it. An LED is just a fancy diode and it should behave roughly like the curve trace in the figure on the right. Variations in this behavior can suggest the presence of electrical opens or electrical shorts.

One of the major causes of an electrical open in an LED is thermo-mechanical stress of the wire bonds. Often the gap between the wire bond and the die can be viewed under X-ray microscopy or with careful visual inspection.

The coefficient of thermal expansion of the epoxy encapsulant and the silicone bead protecting the die can differ markedly. At elevated temperatures, the differing forces of the expanding materials can pull the wire bond from the surface of the die, especially if the component is heated cyclically or for a prolonged period of time. Eventually, plastic deformation or creep will result in a permanent electrical open. A good way to check for this failure mechanism is to probe the LED at reduced temperatures - one example is to use freeze-spray to contract the coatings when performing this test.

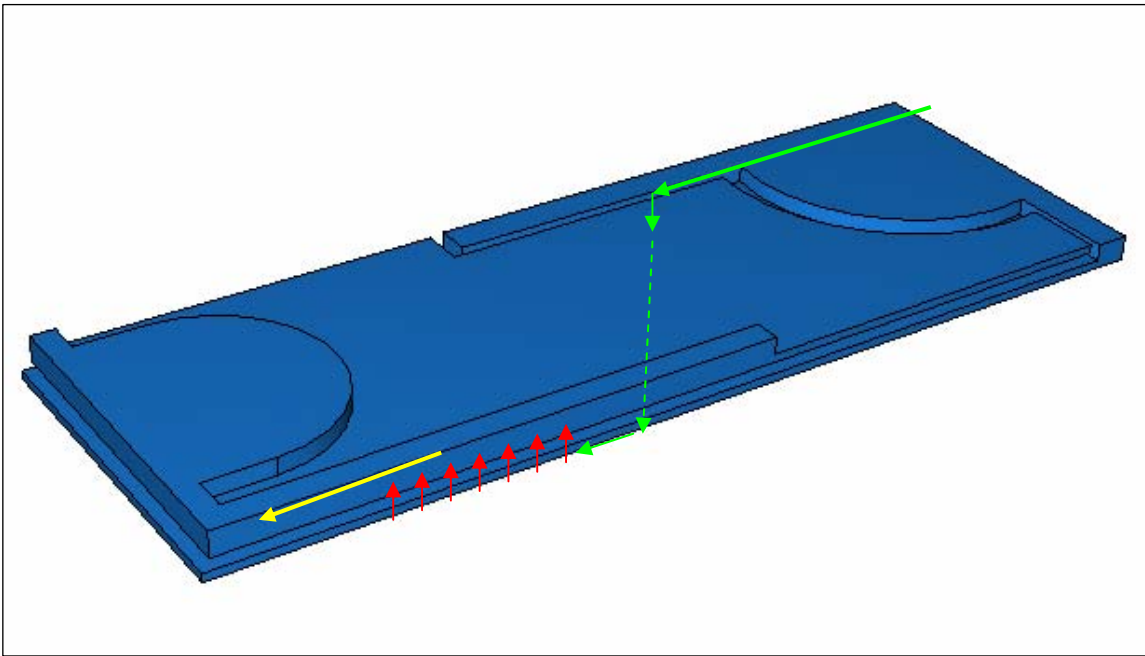


Another cause of electrically open failures, particularly on LEDs with sapphire substrates (most common in blue and white LEDs), is electrostatic discharge (ESD) or electrical overstress (EOS) to the die. The forward biased ESD pulse will pass through the LED without damage, but a reverse biased pulse can prove catastrophic. It is important to check for this failure mechanism in unshielded devices when an open between the die and the wire bond is not visible. One approach is to grind down the hard epoxy housing to the surface of the silicone bead, which is then dissolved with Dynasol or some other solvent. This can be a delicate procedure, as the wire bonds can be prone to breakage, but if successful allows for higher magnification viewing of the die surface and the use of liquid crystal imaging. A backside grind is also a potential option, but also requires care and control to avoid cracking of the die. In regards to electrical opens, EOS can induce fusing of the wire bond due to an overcurrent situation (see image above).



The solution to ESD and EOS events is relatively straightforward. A correctly rated Zener diode reverse biased in parallel with the LED will allow voltage spikes to pass through the circuit in both directions without damage to the LED. Addition of a capacitor to smooth input signal is an appropriate corrective action to prevent EOS failures.

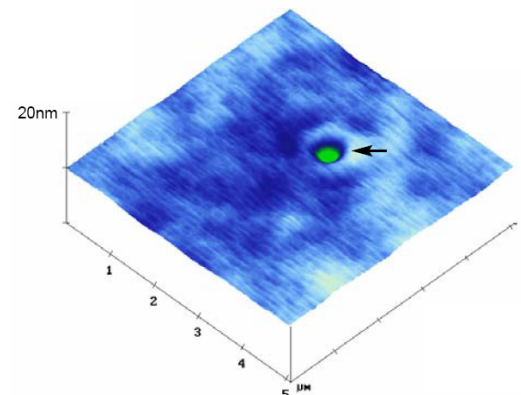
Electrical shorts on LEDs can also occur. These failure modes tend to be more prevalent on-die (one possible path is demonstrated in the below figure), as opposed to within the packaging structure. While there are potentially numerous root-causes of electrical shorts, two of the more common are threading dislocations (also called micropipes or nanopipes) and insufficient or degraded passivation.

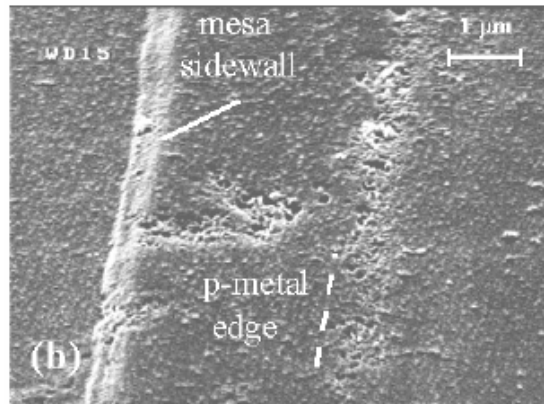


Threading Dislocations (TD)

Threading dislocations form at the interface of the substrate and epitaxial layer. They propagate towards the surface of the epitaxial layer and are often called micropipes or nanopipes because of the open core nature of the defect. Threading dislocations form in highest densities on sapphire based GaN LEDs. The image below demonstrates that Atomic Force Microscopy (AFM) can be used to examine threading dislocations.

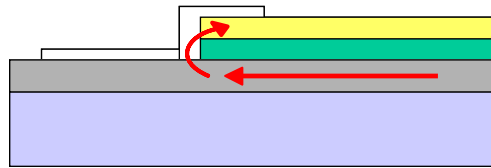
Elevated dislocation density can result in an increase in leakage current during operation. The mechanism at work here is migration of contact metal through the hollow center of the dislocation, creating an ohmic resistance path between the P and N regions of the die. An example of the damage that occurs due to this process can be seen in the figure below, in which pitting near the edge of the P-region has formed due to metal migration through the dislocations.





Glass passivation

Mesa structures, used in some LEDs, are susceptible to elevated leakage currents. In production, the mesa structure will often display elevated leakage before the deposition of a SiO₂ passivation layer. Therefore, the quality of the etching and deposition processes, and the integrity of the resulting passivation layer are critical to preventing shorts. A schematic of one potential leakage path is shown in the below figure.



In Conclusion...

LEDs are simple and ubiquitous components in electronic assemblies. Failures can usually be corrected with subtle modifications to the design. In some cases, the addition of a shielding component may be necessary; in others, selection of a different LED may solve the problem.