DOMINANT™
Opto Technologies
Innovating Illumination

APPLICATION NOTE:

LED Electrical Failure Prevention

Background

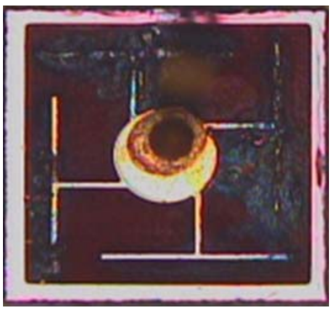
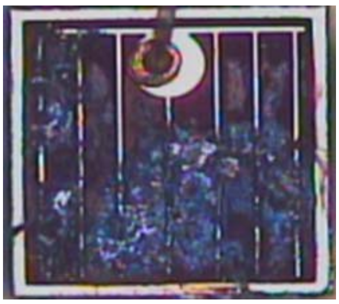
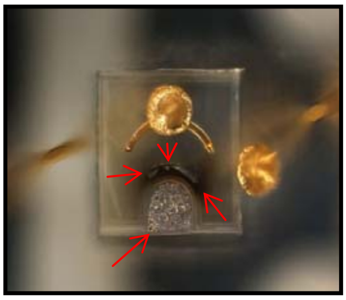
All LED (light-emitting diode) should be operated below the absolute maximum ratings specified in the data sheet in order to safeguard its reliability and service life. Key factors that contribute to LED electrical failure are Electrical Overstress (EOS), Electrostatic Discharge (ESD), Thermal Overstress and Solder Bridging across LED Leads. This application note will cover main known causes that can induce electrical failure in LED and provide guidance and recommendations to prevent it.

A. Electrical Overstress (EOS)

EOS happened when LED is operated above its absolute maximum electrical rating either in a single event, repeated event or continuous in nature. The maximum electrical rated values refer to maximum forward current or maximum forward voltage, maximum surge current, maximum reverse current or voltage, maximum permissible continuous pulse current at specific temperature. All these parameters should be kept below the maximum rated values to ensure that EOS is not experienced by LED.

There are many different sources which can induce EOS including power-on and power-off transients (also known as spikes), inrush current and excessive voltages or currents (also known as overdriving).

Photo below show some example of LED chip damaged due to EOS:

Since EOS event are related to overcurrent or overvoltage, there are two types of protection that are commonly used which is overvoltage protection devices and current limiters.

1. *Overvoltage protection devices*

   Transient Voltage Suppressor (TVS) diodes are commonly a clamp device which kept the voltage through the LED at specific level. This clamp device is connected in parallel with the LED they protect. It could be unidirectional or bidirectional clamp device. This clamp device is always in “off” state during normal operation. During EOS event happens with higher voltage than the clamp device breakdown voltage, it will change to “on” state which clamps the voltage and hence protecting the LED.

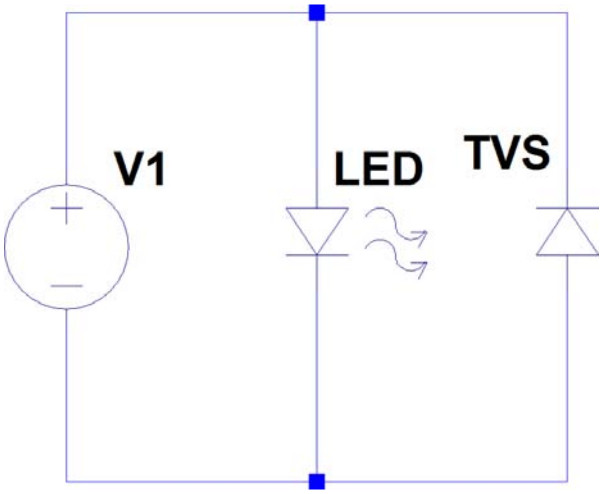


Figure 1: Function of TVS diode

2. *Current limiters*

   Negative Temperature Coefficient (NTC) or Positive Temperature Coefficient (PTC) thermistors are commonly used to control the amount of current flow through the LED. These thermistors are connected in series with the LED they protect and its resistance will change based on the temperature. NTC thermistors change its resistance from high to low when the temperature changes from low to high. NTC thermistor is suitable for protecting against inrush current. PTC thermistors works opposite way of NTC thermistors. Its resistance changes from low to high when the temperature changes from low to high. PTC thermistor is suitable for protecting LED from slow transients.

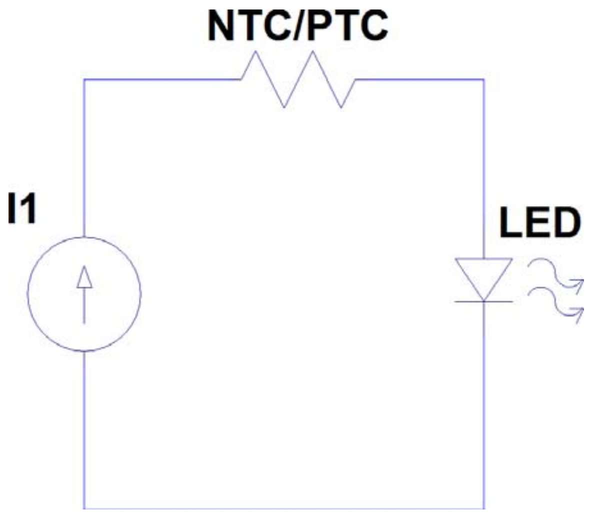


Figure 2: Function of NTC/PTC thermistor

Besides that, a proper driver design is crucial to ensuring that the LEDs are protected from EOS event. It is better to use constant current LED driver with proper voltage/current clamp. Most of LED drivers also equip with open/short circuit protection.

B. Electrostatic Discharge (ESD)

ESD happens when two materials are placed in contact and then separated. When this happens, the electrons are transferred from the surface of one material to the surface of another material. The material that losses electrons will become positively charged and the material that gains electrons will become negatively charged.

ESD damaged is usually contributed by 2 events which are direct electrostatic discharge to the device and electrostatic discharge from the device.

1. *Discharge to the device*

   The most common cause of electrostatic damage is the direct transfer of electrostatic charge from human body to electrostatic discharge sensitive (ESDS) device. This model is named as Human Body Model (HBM).

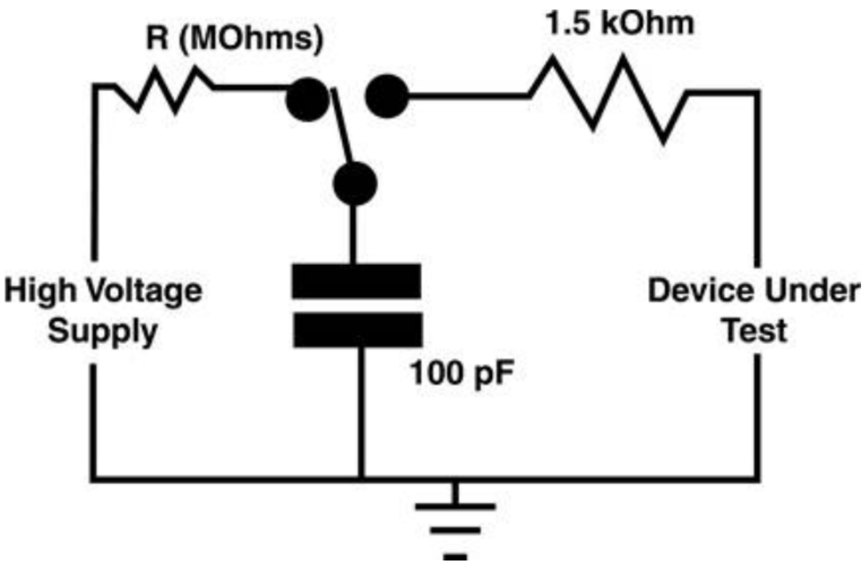


Figure 3: Typical HBM circuit

2. *Discharge from the device*

   ESDS may also accumulate electrostatic charge through handling or contact with packaging materials, working surfaces or machine surfaces. When this charge is transferred to any conductive surface, a rapid discharge may occur from the device to conductive object. The model used to simulate the transfer of charge from an ESDS device is named as Charged Device Model (CDM).

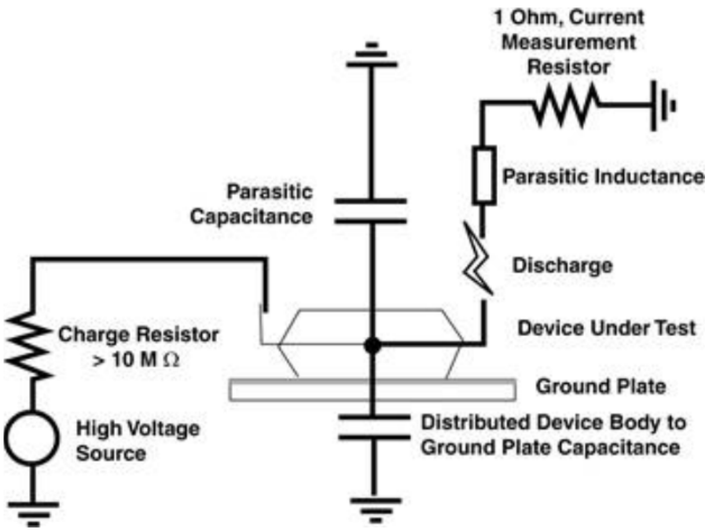


Figure 4: Typical CDM test

All these ESD events normally happened in a very short in duration (a matter of nanoseconds) with significantly higher voltages up to kV range. In order to avoid such damage due to ESD event, Zener diode is the most common overvoltage protection device and is recommend to adopt into the circuit. There are 3 characteristics that need to consider when choosing the Zener diode which is the Zener Breakdown Voltage, Response Time and Placement.

1. *Zener Breakdown Voltage*

   The breakdown voltage should be slightly higher than the total forward voltage of LEDs to ensure the functionality of the circuitry under normal circumstances. When a surge occurs and exceeds the maximum ratings of the LED, the Zener diode will provide alternative path to channel the ESD current.

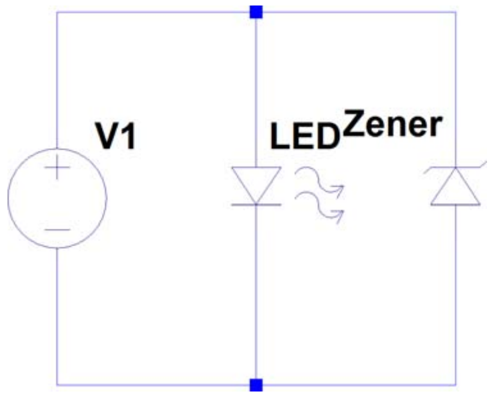


Figure 5: Reversed Zener diode connected in parallel with LED

2. *Response Time*

   The response time of the specific Zener diode must be faster than the LEDs so that the LEDs are protected effectively when there is a high voltage pulse occurs. The response time range has to be in nanoseconds or less. This characteristic has to be considered in both directions from anode to cathode and vice versa.

3. *Placement*

   ESD protection Zener diode normally is placed near to the power supply input in order to protect the whole module. However, the most applicable location is placed as close as possible to the protected component, for instance the LED. Circuit designer should first identify where the most potential damage could come from in order to place the Zener diode at the most optimum location. .

C. Thermal Overstress (Over Temperature)

Thermal overstress or excess heat can cause LED to fail in terms of open circuit failure or short circuit failure. A prolonged thermal overstress can cause short circuit failure due to micro damages or metal migration. A rapid thermal overstress creates an immediate failure in open circuit. Excess heat melts materials, chars plastics, warps and breaks LED dies and worst case fire. In general, LED should not be operated with a junction temperature exceed maximum Junction temperature specified in datasheet.

This excess heat is a form of energy which can be transmitted through various mechanisms from one medium to another in the form of a heat flow. Basic heat transfer mechanism consists of the three types.

1. *Conduction*

   Thermal conduction is a mechanism for the transport of thermal energy that does not require a macroscopic flow of material. The heat exchange takes place between the neighboring particles via vibration energy, for example solid bodies, metal. Energy is also transported through movement of the free electrons. This is the primary mechanism where the heat generated from LED is dissipated via PCB.

2. *Convection*

   This mechanism takes place between a solid body and the surrounding liquid or gas medium. Particles are heated up first and then are transported to the surrounding due to density difference. The fluid on top of a hot surface expands, become less dense and rises. As the temperature of the given fluid mass will increases, the amount of the fluid should increase by the same issue.

3. *Radiation*

   Both conductivity and convection need a medium for the transfer of the heat, however radiation doesn't rely on any contact between the warmth supply and therefore the heated object. The heat is transferred in the form of electromagnetic waves emission.

In LED system, all three mechanisms happen at the same time and thus thermal management must be implemented to transfer the heat from the LED chip to the ambient environment. The thermal management of an LED system can be broken down into three system levels.

1. *LEDs*

   The heat generated in the LED epitaxial layer is transmitted through the package housing via soldered joint and on to the PCB. Selecting a low thermal resistance LED provides better system level heat dissipation. Both Electrical & Real Thermal Resistance value are stated in Dominant LED datasheet.

2. *PCB*

   The heat can be transported to the heat sink by various design measures such as horizontal and vertical thermal conductivity. Horizontal thermal conductivity design can be realize by increasing the size of the copper area. The copper surfaces may have to be supplemented with leads that contribute to the cooling of the component in accordance with the LED housing design. Vertical thermal conductivity design can be improve by introducing thermal vias and reduction in PCB thickness.

3. *Cooling Unit*

   From here, the heat is finally transferred to the ambient environment through heat convection and thermal radiation. Mostly, heat sinks or combination of heat sinks and fans are used as traditional heat dissipation. Additionally, more advanced method such as Peltier cooler, heat pipes can be used where appropriate.

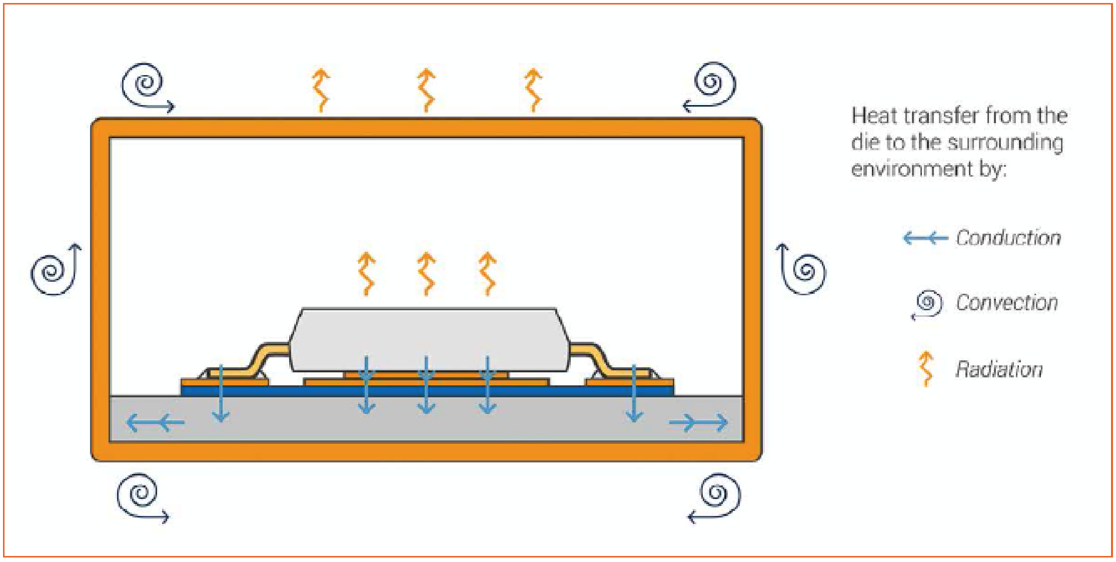


Figure 6: Heat transfer in LED system

D. Solder Bridging

A solder bridge forms when two points on a circuit board that are not designed to be electrically connected are inadvertently connect by solder over the top of the PCB solder mask. This issue can be microscopic in size but even the smallest solder bridge that goes undetected on PCB can lead to short circuit.

There are many conditions that contribute to solder bridging which include:

i. Using excessive solder volume on solder pads
ii. Having a bad seal between a stencil and bare board during printing process
iii. Designing solder pads that are too big in relation to the gap between pads
iv. Poor LED component placement accuracy or having a reduced component lead to pad size
v. Having an insufficient layer of solder resist applied between the pads

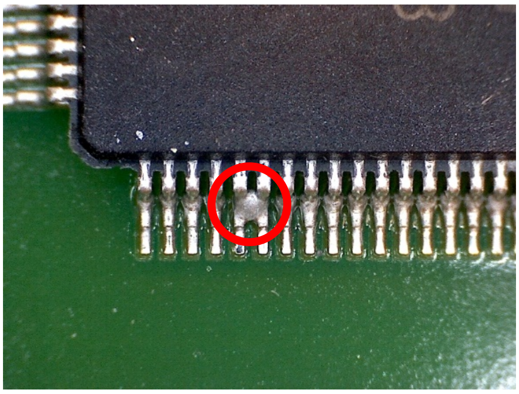


Figure 7: Example of solder bridging of an IC

There are a few common key measures that can be taken to reduce the risk of solder bridging significantly.

1. *Circuit board design*

   Adjusting the aperture width or area ratios and adding solder mask dams in PCB design can avoid the solder bridging.

2. *Reflow profile*

   Soak time is the key in this reflow profile. Increase in soak time will help to equalize the temperature between the leads and solder pads.

3. *Solder stencil*

   Commonly, reducing the solder stencil area to at least 80% of the solder pads total area would be recommended.

4. *Solder paste volume*

   Reducing solder paste volume especially for components will multiple leads help to minimize the risk of solder bridging.

5. *Solder masking*

   Proper application of solder mask will reduce the risk of solder bridging.

Summary

The main electrical failure mode of LED is open or short circuit. Both should be prevented if the above-mentioned safety measures are taken into design and process consideration to avoid EOS, ESD, Thermal Overstress and Solder Bridging. A robust circuit and system design can ensure a safe, reliable and long-lasting LED during application.