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Light Emitting Diodes: Past Present and Future

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Light Emitting Diodes [LEDs] are the energy efficient lighting sources. The demand is increasing year by year. The present talk discusses few technical issues in manufacturing the LEDs from semiconductor chips. The main emission mostly in blue (450nm) which is due to electroluminescence [EL], white LEDs are nothing but the absorption of blue light from semiconductor device which excites the phosphor in the epoxy lens.

The thermal management design of an LED application is very important to ensure its reliability and optimum performance. The maximum junction temperature of the die inside the package is based on the allowable thermal stress of the package material which can not be exceeded to avoid a catastrophic failure of the device. The thermal resistance is the most important parameter that determines the amount of heat dissipates or travels out of the component. The lower the thermal resistance, the higher ambient temperature that the component can operate. The basic concept of thermal management shows the importance of selecting the right materials from the substrate material, thermal interface to the heat sink, or other cooling methods to ensure the device is operating reliably within the expected ambient temperature range.

The thermal resistance of the LED is determined by the effective heat removal. An efficient thermal engineering of the package can also help in reducing the device dimensions thus greatly improving the future scalability of these devices. The thermal resistance of the package needs to be sufficiently low if the advantages obtained at die level are to be maintained at module level.

LEDs are typically driven by ***constant current*** (30mA, 60mA, 150mA, 350mA, 700mA or 1A) drivers. Constant current drivers fix the current of the system and vary the voltage depending on the load of theLED. A typical Filament bulb produces 12 lumens optical output for every watt of electrical input, which amounts to 3% Light & rest 97% is heat. This heat is mostly radiated and the Lamp parts are chosen to withstand this temperature. LEDs are 12 times efficient, being 140 lumens per watt, which translates to 35% light. It still leaves 2/3rds or 65% as heat, which is substantial by any measure. This 65% heat power is absorbed by the LED, the temeperature of the chip rises. LED forward Voltage drop Vf typically 3~3.3V has negative coefficient of temperature, which means, the Vf reduces as it heats up. This results in increased flow of current due to lesser load voltage. This increased current heats it up further and pulls down the Vf a bit more and the viscious cycle repeats till LED fails at high currents. So Current needs to limited to designed value, hence the Constant current driving.

A constant current driver is therefore needed to regulate the current flowing through each LED string of the lighting system to the rated current in order to maximize the illumination level and lifespan of the LEDs for their optimum performance and reliability.

Constant voltage drivers are also used for LEDs, in applications where the load is not known and the LED loads are connected in parallel; such as in coves and signage applications where one can add several the LED loads in parallel across the output of the driver until maximum capacity of the driver supply are reached. Even here current regulation happens by simple resistor or in case of higher power strings, by internal constant current ICs.

The retrofit LED bulbs, Tube lights, Street lights have built in drivers. The downlights and few very high power Streetlights, High bay lights have external drivers to isolate the heating effect mutally. The maximum permissible distance between an LED product and a external driver is dependent on the LED load, the conductor size and driver used. There is no effect if using a constant current driver because it increases the output voltage to overcome any volt drop due to the cable length. The distance becomes a critical factor for constant voltage drivers for covelighting etc where there is a voltage drop due to the load and length of cable. A 24V system are more immune to this drop compared to 12V due to lowered currents for same wataage laoads.

1. LED DIMMING CIRCUITS

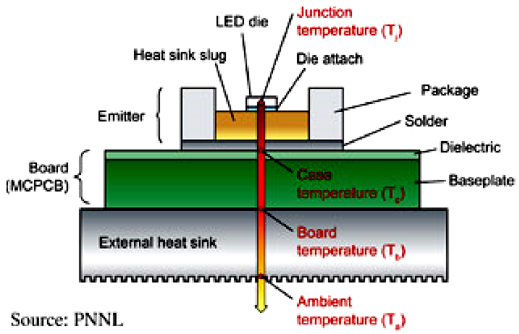
LEDs are dimmed either by Pulse Width Modulation PWM, or by Constant Current Reduction CCR. PWM dimming involves switching current at a high frequency from zero to the rated output current. PWM enables Smooth dimming capability, More precise output levels, Better consistency in colour over various levels. It is Relatively more expensive, has Flicker perceived in peripheral vision if the driver is run below 100Hz frequency, has Stroboscopic effect evident in fast moving environments when the driver frequency is low. It is prone to Electromagnetic Interference (EMI) issues. The

Performance issues arise when the driver is mounted remotely from the light source.

CCR dimming— The lighting level required is proportional to the current flowing through the LED. Current flows through the LED continuously and reduced or increased based on whether the LED is to be dimmed further or is to increase in light output level. CCR dimming is good in Outdoor applications and damp locations, Places that have strict EMI requirements like medical suites, Places where there is a lot of motion and rotary machinery, Applications where the drivers are to be placed at a distance from the light source.

In view of their High efficiency, switching circuits are employed. As a result Low lagging power factors in LED lighting systems are now prevalent, and this can lead to increased reactive power requirements on existing grid networks.

Its well known fact that threat from Chinese CFL was successfully warded off thanks to mandatory provision for High PF CFLs, and it could prove similar manna to block low end products that are positioned a ridiculously low predatory prices, harming healthy growth of Indian LED industry.



Source: PNNL

Fig. 1: Modern Power LED with added Heat Slug for enhanced evacuation of Heat from the LED chip.

Use of Silicon wafers to grow GaN LEDs could lead to drastic fall in cost of LEDs, once uniformity across 12” area is mastered. Silicon has an excellent heat resistance (see graph).Si has best suited coefficient of thermal expansion (CTE). Silicon melts at 1,000 C, its CTE or coefficient of thermal expansion is below 4 ppm/C, and its TC or thermal conductivity is in the 150-180 W/m.k.

In near future, one can build LED driver ICs also into the WLP LED package by etching circuits on the bottom of the silicon lead frame, thereby shrink the size of LED modules into a miniscule.

2. CHALLENGES IN THE PACKAGING OF GAN- ON-SI DEVICES

Direct growth of GaN-on-Silicon substrate is one of the good options to get rid of Sapphire. Yet this will require the reuse of mainstream technologies such as lead frame and wire bond packaging. This is because, GaN-on-Si devices for LED applications require Si substrate removal since light is emitted in the same direction as the substrate. It is a technology challenge for substrate transfer to get the GaN film effectively flipped and electrically connected.

This brings us to option of growing GaN on traditional way, then removing them by LLO (laser liftoff technology) and then transferring it to Silicone substrate using wafer to wafer processes to derive complete package there itself. Wafer-level packaging and advanced technologies such as through-Si vias (TSVs) could offer a solution: they could provide effective means of substrate transfer and allow wafer-level integration of some more packaging elements like optics and drivers.

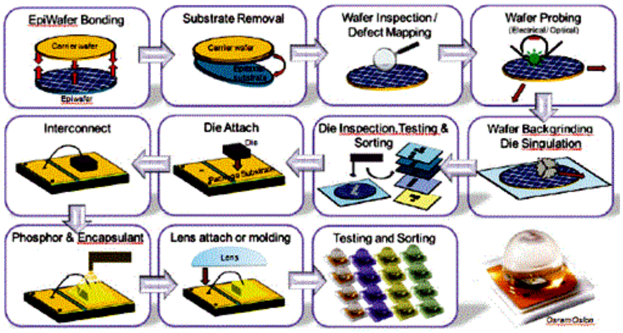


Fig. 2: Typical Single Chip LED packaging Process

Among the cost of ceramic packaging is the highest whereas WLP is the cheapest, with PPA and LCP in the middle. If a ceramic package costs US$0.25, a PPA would be around US$0.06, an LCP would be around US$0.08 and WLP would be around US$0.03.

3. LED BONDING PROCESS

Die Attach Process also known as Die Bond or Die Mount, is the process of attaching the LED chip to the die pad of the lead frame of the package. There are three main stages: First, the adhesive is dispensed on the die pad. Then the die must be ejected from the wafer tape. A push-up needle pushes upward on the die backside to dislodge the die off the wafer tape. Third, a pick-and-place tool picks the die from the wafer tape and positions it on the adhesive. The key factors are:

1. The amount of the adhesive: Although the junction high is 75~145μm, too much adhesive will cause the p-n junction short.
2. Dimension of push-up needle: should fit the chip with tip radiun as 0.25~0.6 mm only.
3. Pick-and-place of the LED Chip is achieved by either antistatic plastic tool which is made of rubber, though tools made of hard materials like tungsten carbide, ceramic, or steel, are also popular.

Alternate is Eutectic bonding, achieved by low melting alloy like gold-zinc alloy is used to affix LED chip to silicon lead frames. While, epoxy glues used in most LED packages melt at 180 C, Eutectic bonding is much better in thermal resistance and does not absorb the emitted light in the package during high temperatures as epoxy. Here to prevent the high melting temperature from destroying the lead frame construction during the bonding process, the LED chip is first bonded on a heat-resistant board and then the board is adhered to the lead frame (ref Cree).

Wire Bond Process comprises of using the gold ball bonding as electrical connection. A gold ball is first formed by melting the end of the wire through electronic flame-off (EFO). Then free-air ball is brought into contact with the bond pad on the chip. The bonder applies pressure, heat, and ultrasonic forces to the ball, forming the bond.

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