International Journal of Luminescence and Applications (ISSN: 2277-6362)
Vol. 5, No. 2, June 2015. Article ID: 082. pp.168-174.

Nuances of Driving LEDs : An Optoelectronic Device

K. Vijay Kumar Gupta

Managing Director, Kwality Photonics P Ltd, Kushaiguda Industrial Estate, Hyderabad-, India

Abstract— *LEDs are low voltage devices. Hence they require a device / power supply unit / driver or integrated electronics that convert mains voltage to low voltage to run the LEDs. Sometimes the driver has electronics that can interpret control signals to dim LEDs. In view of their High efficiency, switching circuits are employed, which come with undesirable issues of ElectroMagnetic Interference & lagging power Factors that need additional circuitry to be mitigated.*

1. INTRODUCTION

Light Emitting Diodes [LEDs] are the current 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 Design of the LED manufacturer. 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.

Why Constant Current Drivers— 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.

Another reason is that, in a production lot the LEDs have Vf spread of 2.9V to 3.5V typically, The Driver voltage is generally designed to meet the highest voltage LEDs. This driver can burn the lower voltage LEDs. Once CC driver is used, same current flows irrespective of LED Vf.

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.

- Where ever possible LED drivers need to be mounted in a ventilated space with access for general maintenance purposes. Outdoor mounted Drivers must have suitable IP (ingress protection) rating. The distance between the driver and the light source needs to be taken into consideration to prevent voltage drop that results in reduced output of the LEDs.

2. LED DIMMING CIRCUITS- PRECURSOR OF INTELLIGENT LED LIGHTS

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.

Traditional mains voltage dimmer (diac & Triac conducting angle dimmers) compatible LED are now common, though need to checked for Reduced dimming range, Flickering of the lamp, and for Inconsistent performance based on the number and different types of LEDs connected to a singleincandescent dimmer

Dimming help Flexibility in usage of space. A brightly lit space for reading or an office space can turn into a presentation/conference area by dimming, Helps designers create ambient lighting presets to create mood settings, Increases productivity by individual control to reduce eye strain and fatigue or to improve concentration, directly Saving energy and Extends life as the LEDs & Phosphor & electronic components run cooler.

In advanced & automated dimming, LEDs are controlled directly by signals coming from the central dimmer or they can be designed to interpret other protocols like 1-10V, DMX, Ethernet or ZigBee signals from the central dimming system. The manufacturers of the LEDs recommend the various protocols their devices can understand. For applications where single colours and white LEDs are used, analogue or PWM dimming protocols can be used to switch or dim LEDs. For intelligent controls like creating dynamic effects, tuning of white etc, DMX or Ethernet protocols can be used. Digital dimming works better with large numbers of luminaires.

3. WHY POWER FACTOR IS IMPORTANT

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.

Real power is defined as the apparent power multiplied by the power factor, where the apparent power is the product of RMS Voltage and RMS current. This relationship indicates that at lower power factors more current is required to provide the same amount of real power. Higher power factor of at least 0.7 for domestic and 0.9 for industrial applications respectively is now mandated by power Distribution companies for all electrical products that operate from the AC power grid. In addition, selecting LED lights with higher power factor minimises the current capacity requirements of front end components in lighting systems. Today most LEDs have power Factor Correction section within the Drivers, though these come at a cost. The mandatory BIS 160201 required compliance on PF limits.

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.

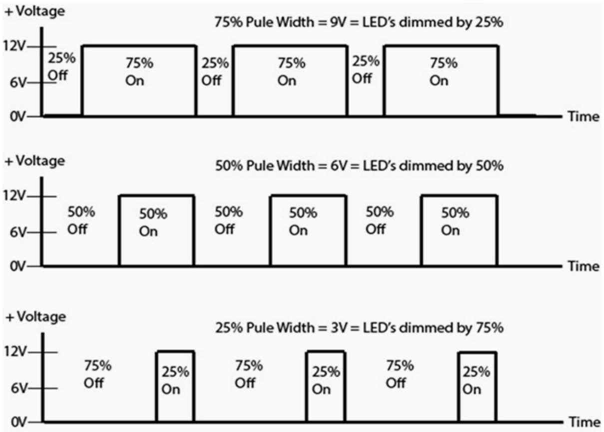


Fig. 1

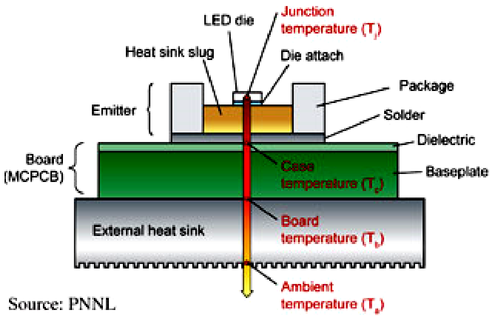


Fig. 2: Modern Power LED with added Heat Slug for enhanced evacuation of Heat from the LED chip.

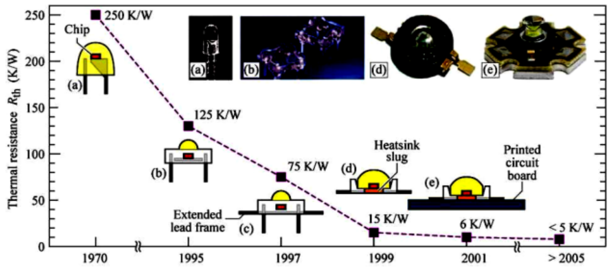


Fig. 11.5. Thermal resistance of LED packages: (a) 5mm (b) low-profile (c) low-profile with extended lead frame (d) heatsink slug (e) heatsink slug mounted on printed circuit

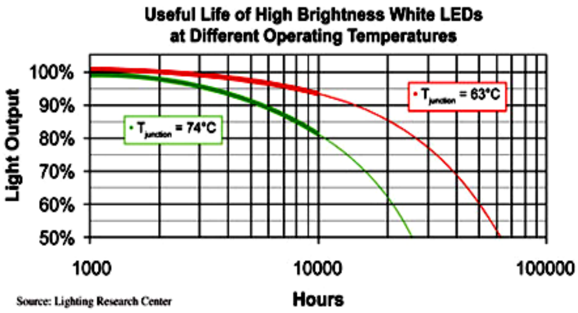
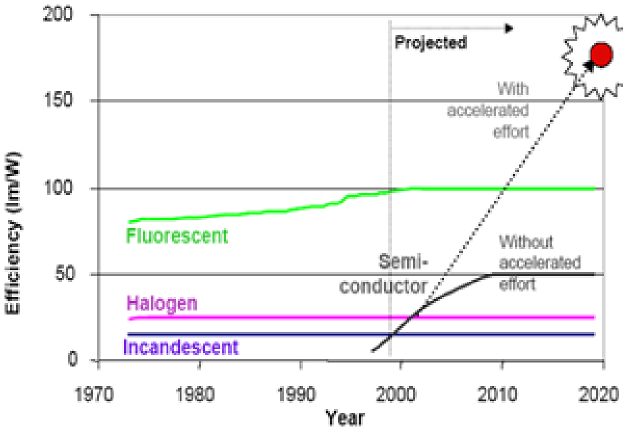


Fig. 4: Modern LED packages reduce the thermal resistance dramatically. In LEDs life is enhanced by 20000hrs with a ten degree temperature reduction



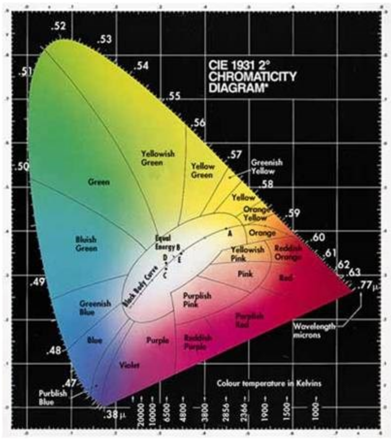


Fig. 3: Evolution of Luminous Efficacy of LEDs and CIE Chromaticity diagram showing Blue-Yellow-White relation

Table 1: Advantages and Disadvantages of analog and PWM dimming

PARAMETER	ANALOG DIMMING	PWM DIMMING
Ease of Design	Easier if controller fitted with analog dim pin.	Requires processer or timers to create PWM input signal.
Relative Cost	Usually cheaper to derive analog input signal.	More expensive to implement PWM input signal.
Shift in Color Temperature	Dimming produces visible color shift.	Relatively constant color over all dim levels.
Dimming range	Fairly limited in most designs.	Can achieve very high contrast ratios.
Flexibility	Changes to dim range hardware adjustable	Changes to dim range possibly software adjustable
Efficacy	Better than PWM at lower dim levels	Lower efficacy at high peak currents
Interaction Issues	No low frequency envelopes of current pulses	PWM presents a low-frequency current draw to the system. This may couple into other circuitry.
EMC	Usual issues with switching supplies	LED shunt FET could exhibit hard edges that can be radiated or conducted.

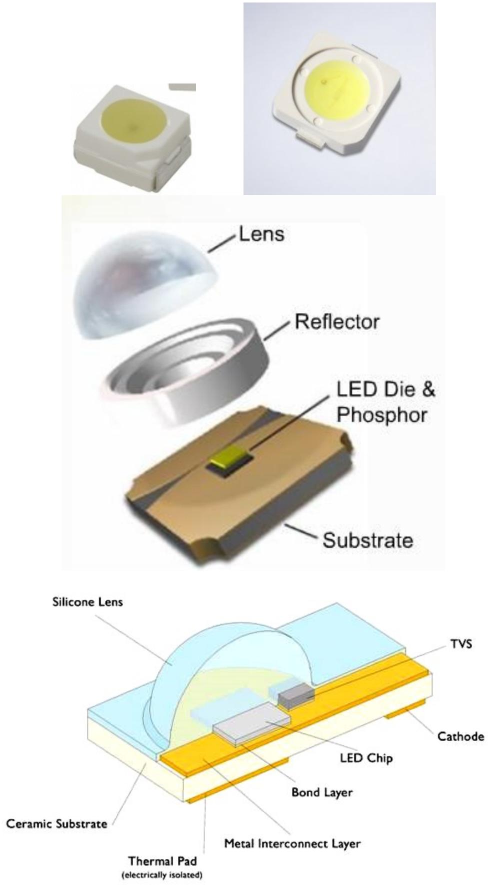


Fig. 5: Traditional LED packages

Currently, *Polyphthalamide (PPA)* is the *major lead-frame material* for packaging low-power chips. The *Ceramic* and *Liquid Crystal Polymer (LCP)* are primarily used for high-power packages. While Ceramic has a good melting point, the ceramic-based lead frame, like PPA and LCP lead frames, has to be made with tooling, hence limiting the frame reduction to miniaturisation micron scale. However, a PPA lead frame, for instance, can be miniaturized to 3mm long by 1.4mm wide at best, holding a 9-mil (0.225 square millimetre) LED chip.

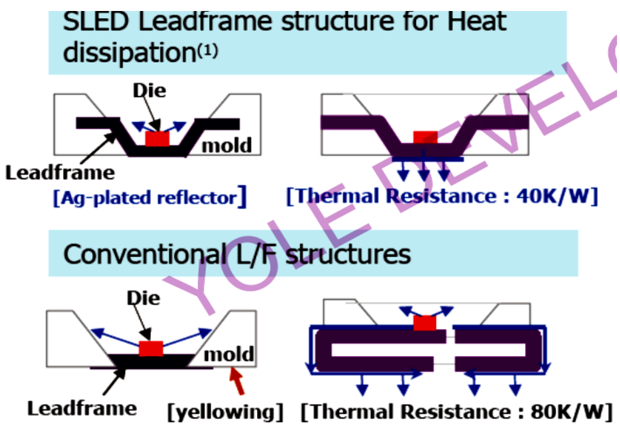


Fig. 6: Silicone Large Wafer technology experience

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.

4. 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.

5. WAFER-LEVEL PACKAGING

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.

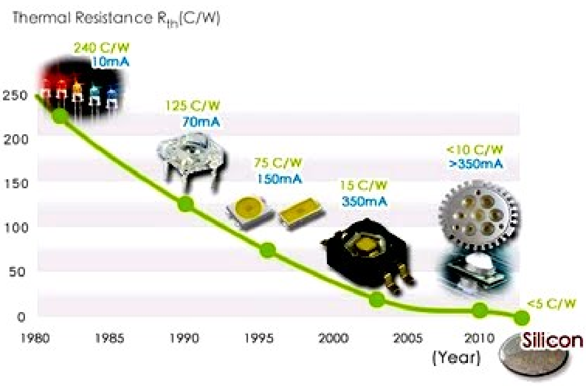


Fig. 7: HB-LED Thermal dissipation capability roadmap: all lead to Silicon WLP (Courtesy of Visera)

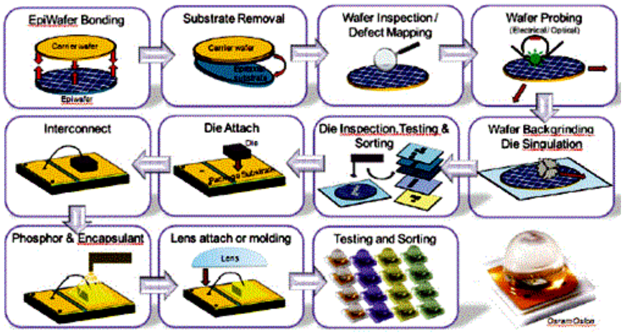


Fig. 8: Typical Single Chip LED packaging Process

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.

6. 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 metallurgical weld between the ball and the bond pad. Then the wire is run to the lead frame, forming a loop between the bond pad and the lead frame. Pressure and ultrasonic forces are applied to the wire to form the second bond. Bonding force of first bond should be fine tune to prevent the stress damage the bond pad and chip.

One can substitute both DieBond & WireBond steps with one step Flip Chip Bonding technique in large chips of high power..

6.1 Encapsulation Materials

The lifetime of LED is not only due to the chip, but also the encapsulation materials. The silicone resin provides many advantages which positively influence the lifetime. Using silicone resin would be very helpful for luminous maintenance.

6.2 ESD Protection

Electrostatic discharge (ESD) may damage chips. To prevent chips from ESD damages, Equipments must be properly grounded & Use wrist band or anti-electrostatic glove when handling the chips.

In solid-state white lighting technology, phosphors are applied to the LED chip in such a way that the photons from the blue gallium nitride LED pass through the phosphor, which converts and mixes the blue light into the green-yellow-orange range of light. When combined evenly with the blue, the green-yellow-orange light yields white light. The notion of multiple colors creating white may seem counterintuitive. In reflective pigments, mixing of blue and yellow yields to green. With emissive light, however, mixing such complementary colors yields white.

In LED manufacturing processes, normal variations in the brightness and exact color LED die and variations in the phosphor coating processes during die packaging lead to variation in the brightness and the “whiteness” of manufactured PCLEDs. During final testing, these LEDs are sorted into different intensity and color bins. Within one intensity bin, some PCLEDs will be a bluer white, others a yellower white, and so on. LED manufacturers need to find applications for each of these bins to keep manufacturing costs under control.

CRI: Another limitation of many PCLEDs stems from how colored objects appear when illuminated by the type of white light they produce. A white light source's ability to accurately reveal colors depends on the number and intensity of the colors contained in the light coming from that source. The red or green objects aren't as vivid when illuminated by PCLED white light made from a mixture of blue and yellow light. New phosphors that can convert blue LED light to other wavelengths besides yellow are now being combined with YAG:Ce to improve the color rendering of blue InGaN PCLEDs.

Another approach to making PCLEDs is to use UV InGaN LEDs and a blend of phosphors that convert the UV into blue, green and red emission which combine to appear white. This approach improves color rendering and can reduce manufacturing variability (range of whiteness) of the light made by the PCLED. Packaging UV LEDs presents more challenges for some of the packaging materials, including lower reflectivity of metal surfaces and mold compounds which reduces brightness and photo-degradation of epoxies and other plastic package parts which reduces LED lifetime. As with research on phosphors for use with LEDs, research on packaging materials better suited for use with UV InGaN LEDs is getting a lot of attention.

Combining phosphors with monochromatic LEDs is not the most energy efficient way to make white LEDs. Phosphors convert higher energy LED light into lower energy, longer wavelength light and the energy difference is lost as heat in the phosphor. The energy difference between absorbed and emitted light is called the Stokes shift. As expected, the Stokes shift is larger (more energy lost as heat) when UV LEDs are combined with phosphor blends than when blue LEDs are combined with YAG:Ce, but since UV InGaN LEDs radiate more optical power than blue InGaN LEDs, both methods make about the same amount of visible light with a given amount of electrical power (Lumens per watt or Lm/W)

7. COMMERCIAL PHOSPHORS SCENARIO

Japan-based Nichia Corp. holds the patent for the dominant phosphor technology known as YAG:Ce (yttrium aluminum garnet with celium). While Toyoda Gosei/Tridonic, GELcore, and Cree hold patents related to phosphor technology, the other major supplier of phosphors to the market is OSRAM. Although Nichia locked up the majority of garnet- based phosphor material combinations, their patent claims failed to mention Terbium (Tb), which allowed OSRAM to lay claim to TAG (Terbium Aluminum Garnet) phosphor technology. Developing and providing advanced phosphor materials to LED manufacturers as an alternative to above.

Alternate to Nichia's patented YAG solution, Intematix' Y460 phosphor is a direct replacement for YAG while its Y450 product is superior to YAG in terms of brightness. The disadvantage of TAG is its conversion efficiency - roughly 80% of YAG. Nichia controls roughly 80% to 90% of the white phosphor converted market, which is also the most profitable segment of the LED market.

The company claims to have delicately manoeuvred around the patent minefield that its predecessors such as OSRAM, Nichia, TG/Tridonic, and GELcore have laid down. To do this Intematix appears to use a different material structure, particle size, and conversion technology -three critical elements that have been scrutinized in past infringement lawsuits (e.g., OSRAM Opto vs. Dominant Semiconductor). First, Intematix uses a silicate-based phosphor rather than a garnet structure, effectively solving the material issue. Secondly, Intematix claims particle size between 10- 20μ, and their average particle size, or D50, is not 5μ, which Osram's patents claim. Finally, with respect to conversion technology (or the way in which the phosphors are excited), Intematix claims their excitation is very different than either YAG or TAG structures. Specifically, the silicate phosphors that Intematix uses prefer to be excited below 460nm continuously to ultra violet (UV) range, whereas the YAG phosphors typically peak at 360nm and 460nm.

8. PHOSPHOR DISCOVERY METHODOLOGY

Until recently, the preparation of phosphor materials was more an art than a science, based on finding crystal structures that act as hosts to activator ions, which convert the higher-energy blue light to lower-energy yellow/orange light. So far, there has been no complete understanding of what make some phosphors efficient and others not. In the wrong hosts, some of the photons are wasted as heat, and selecting the right hosts becomes crucial. UC Santa Barbara has developed science in the form of simple guidelines that would permit the discovery of new and improved phosphors in a rational rather than trial-and-error manner as per Ram Seshadri, professor in UCSB Department of Materials. The results of this research, performed jointly with materials professor Steven DenBaars and postdoctoral associate researcher Jakoah Brgoch, appear in The Journal of Physical Chemistry.

As LEDs tend to get warmer and very few phosphor materials retain their efficiency at elevated temperatures. There is little understanding of how to choose the host structure for a given activator ion such that the phosphor is efficient, and such that the phosphor efficiency is retained at elevated temperatures. However, using calculations based on density functional theory, which was developed by UCSB professor and 1998 Nobel Laureate Walter Kohn, the researchers have determined that the rigidity of the crystalline host structure is a key factor in the efficiency of phosphors: The better phosphors possess a highly rigid structure. Furthermore, indicators of structural rigidity can be computed using density functional theory, allowing materials to be screened before they are prepared and tested. Incandescent lights are 3% efficient and fluorescent lamps are about 20%. LEDs with 40~60 percent efficiency are commercial, the target is to get to 90 percent efficiency which works out to 300 lumens per watt.

Driving White LEDs is another entrepreneurial opportunity for today's engineering students. As LEDs have a very steep Current vs Voltage curve, a small change in voltage (say 0.2V) will change current by more than 100mA which could lead to the LED burnout. Also the LED Voltage drop Vf has negative temperature coefficient which leads to lower Vf as the LED gets warmer during ON condition. Hence, it is imperative to hold the current constant. A simple resistor in series with the LED can absorb the changes in voltage effectively, when the Supply Voltage is far higher than the Vf. But this wastes lot of power in the resistor as heat.

A far more efficient way is to use SMPS also called as LED Driver with current sensing feedback in Buck or Boost modes. Here upto 95% power efficiency can be achieved. Modern Drivers come with power Factor Corrections & EMI/EMC compatibility. Dimmability with triac dimmers as well as Input –Output isolation is also preferred by consumer markets & government regulations.