LED Backlight: LED's potential on the rise and the limitation on the decline

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Abstract
This presentation reviews the current progress in the technology of Light Emitting Diode (LED) as it relates to the LED backlight for Liquid Crystal Display (LCD). A vivid description is given about the performance of LED that is still on the rise and certain limitations of LED that is on the decline.

Objectives and Background
LCD has obtained a big boost from LED backlight and the combination of LCD and LED has resulted in (i) enhancement of image quality (ii) reduction in power consumption (iii) increase in reliability (iv) increase in slimness (v) decrease in weight. On the technical side, substantial problem remains to be solved in thermal management of LED, especially when the demand on brightness is on the increase. Nearly 65% of input power to LED is lost in the form of heat. This shows that there is a huge challenge to be faced and the vast potential that still remains in LED to be tapped. Improvement in the spectrum of white LED is essential. On the marketing side, the cost is the main issue.

The efficacy of LED is galloping. At R&D level Nichia has reported an efficacy of 249 lm/w in low power white LED. This holds big promise for the future. Research and development work in the following areas indicates the potential of LED:
(1) Growth of layers along non-polar axis of Gallium Nitride (GaN) (2) Efficiency roll-off at high current (3) Improvement in quantum well formation (4) Vertical LED structure (5) Quantum dot LED (6) Flip-chip bonding (7) Wafer level packaging (8) Low cost substrate materials (9) Phosphors for Blue LED (10) 6" wafer for manufacturing (11) UV LEDs (12) transparent conductor for p-side (Ga doped ZnO).

Review of latest development

GaN growth: GaN has hexagonal crystal structure and has c-plane as the polar plane as shown in Fig. 1. Currently GaN is grown along c-plane and the polarization field tries to separate the electrons and holes from recombining. Further the defect density is high. GaN grown on m-plane has the potential to enhance the efficacy, especially at high current. GaN has been grown on m-plane by many researchers but the challenge for making them mass producible remains.

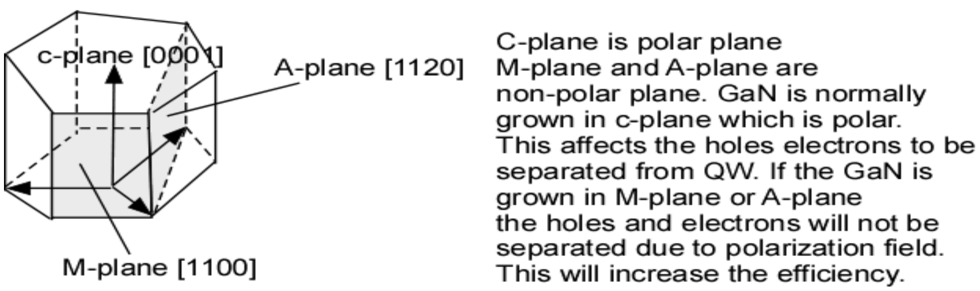

Fig. 1: Hexagonal crystal structure of GaN.

Efficacy roll-off at high current: Present high brightness LEDs have problem of low efficacy in the high current region. As the current is increased (no thermal effect) the efficacy falls off and this is termed as 'droop' or 'efficiency roll-off'. Several reasons are assigned for this behavior and they are (i) Carrier delocalization from In-rich region in quantum wells (ii) Piezoelectric polarization causing electron-hole separation (iii) Auger non-radiative recombination (iv)Electron- leakage to the p-side. The last reason of electron leakage at high current seems to have gained momentum [1,2].

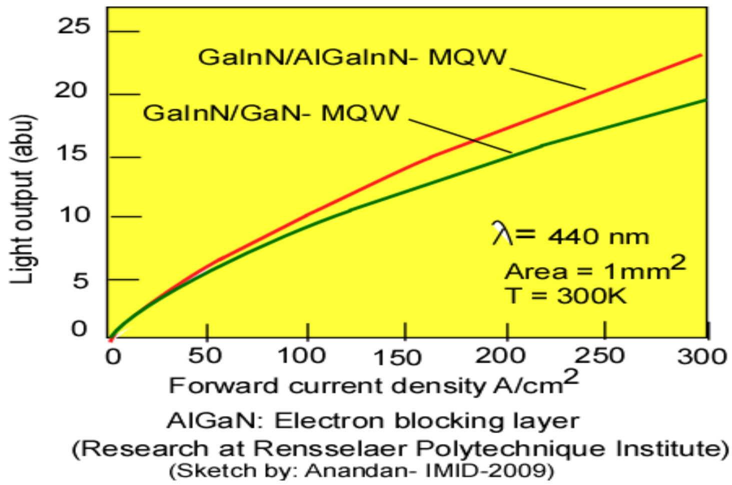

Fig. 2

Researchers at Rensselaer found that there is a polarization mismatch between the layers of quantum well, layers of quantum well barrier and the electron blocking layer. By modifying these layers they obtained 20% higher light output at high injection current compared to the normal GaN LEDs. This is shown in Fig. 2. The modified layer has GaInN/AlGaInN as active region and the electron blocking layer is AlGaN. This theory is disputed by others. The theory of 'droop' is still in debate and nothing conclusive is in sight.

Vertical LED structure: For the purpose of good current spreading, instead of current crowding, and simplifying the processing for establishing n-contact, vertical LED structures have been investigated [3,4]. In traditional GaN LEDs, the direction of electric field between n and p contact is lateral but in the case of vertical LED structure the filed lines are vertical resulting in uniform current density. Eun-Hyun Park et.al employed traditional Saphhire substrate itself for building vertical structure whereas Jun-Seok Ha et.al employed inverted vertical structure with a metal substrate, obtained through a chemical lift-off process and this structure can withstand high current densities due its metal substrate dissipating the heat effectively. This structure is shown in Fig. 3.

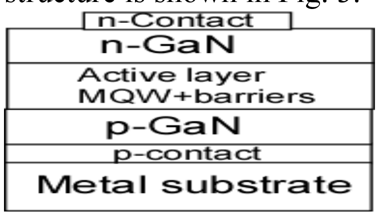

Fig. 3: Vertical LED structure with metal substrate

By virtue of its metal substrate the series resistance and the forward voltage are low and the device could be operated at 1.1 A. This has the additional advantage of low junction temperature.

Flip-chip bonding: Flip-chip bonded LEDs have the advantage of electrode contacts not coming in the path of light rays extracted upwards. Further this technique offers the facility of roughening the top surface for enhancing the extraction efficiency of light. A traditional flip-chip LED is shown in Fig. 4.

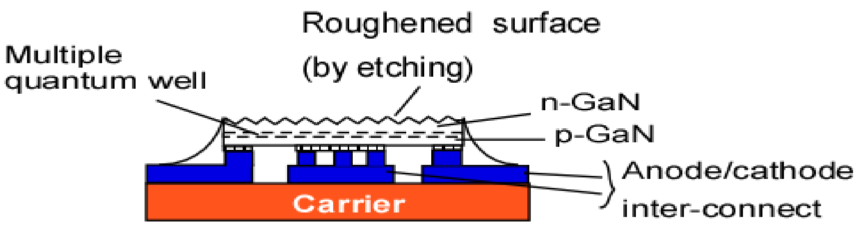

Fig. 4: LED-Flip-chip (Philips)

As could be seen from the Figure 4, an etching process was employed to roughen the surface for light extraction. Development in this technique is aimed at obtaining a low cost process.

Phosphor on Blue LED: The current YAG: Ce phosphor on blue LED lacks rich green and red spectrum. Due to this, the color gamut of white LED backlight is inferior to RGB- white LED backlight. Development of phosphors to enrich red and green spectrum is in progress. The spectrum obtained from an improved phosphor [5] is given below in Fig. 5.

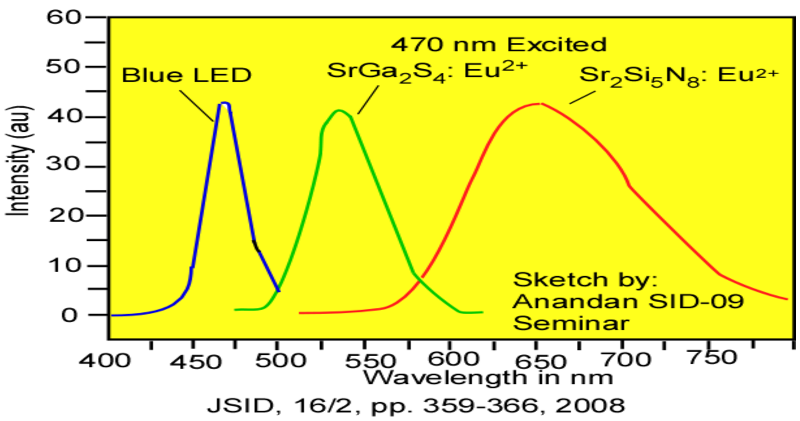

Fig. 5: Spectrum of Two-layer phosphor on blue-LED.

The red and green spectra are rich in color and will match the transmission characteristics of the color filters of LCD. If this type of phosphor is implemented in manufacturing, the industry will eliminate the use of RGB-white LED backlight for obtaining good color gamut. Additionally inventory control becomes easy with only one white LED type instead of managing three types of LEDs.

Low cost manufacturing: The cost of manufacturing LED using sapphire wafer (substrate) can be reduced to one-tenth, if Si wafer is used. The problem with Si wafer is its lattice mismatch and thermal expansion mismatch with GaN. UK based team has successfully overcame these problems by employing SiNx layer over a buffer layer, to develop Si wafer based LED [6] by employing 3"wafer. A company, by name 'BluGlass', is developing glass wafers for manufacturing LEDs. This approach has the potential of further decreasing the price of LEDs. Another approach in cost reduction is through the use of large size wafers. LED manufacturing with 6" sapphire wafer has been demonstrated by Aixtron overcoming the bowing problem. 6" wafers can accommodate large number of chips and thereby reducing the cost of manufacturing.

Thrust on efficacy is relentless: LED Industry is galloping to reach an efficacy of 300 lm/w.
One of the recent works is in the area of doping quantum wells. The industry's practice is the fabrication of quantum wells without doping. In a recent paper [7], n-type doing has been carried out in the fabrication of AlGaInP LED. The advantages of this technique are (i) increased radiative recombination at high injection currents resulting in increased light output (ii) decrease in diode resistance (iii) low heating giving rise to decrease in junction temperature. A 10% increase in light output has been reported.

The light generated inside LED is difficult to extract because of 'index mismatch' problem of compound semiconductor with the surrounding media. Several techniques namely, (a) texturing sapphire substrate (b) using transparent conductor as contact with further texturing of the transparent conductors (c) use of nano-sphere, photonic crystal lattice, micro-ring at the top surface of LED and (d) flip-chip assembly technique have been employed to extract light. One technique [8] being researched upon is the formation of light scattering layer at GaN/Saphhire interface. This has the advantage of 'in-situ' growth of the layer without exposing the wafer to outside environment and a cross-section of the scattering layer is shown in Fig. 6.

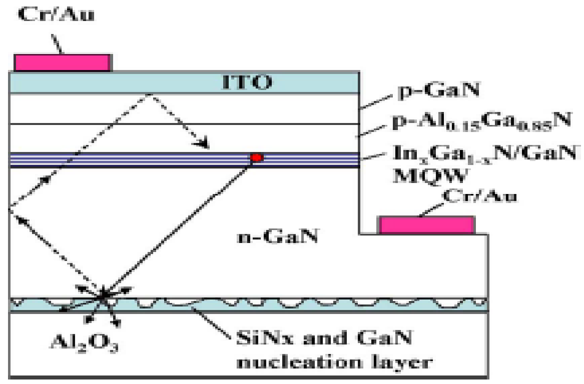

Fig. 6: GaN/Saphhire interface layer for light extraction.

A 15% increase in light output has been reported. Another technique that combines nearly four techniques is of interest. Recently [9] a combination technique that resulted in approximately an increase of 53% in light output is reported. The primary emphasis of this technique is in its double sided texturing of GaN's surface. A cross section of the double sided texturing is shown in Fig. 7:

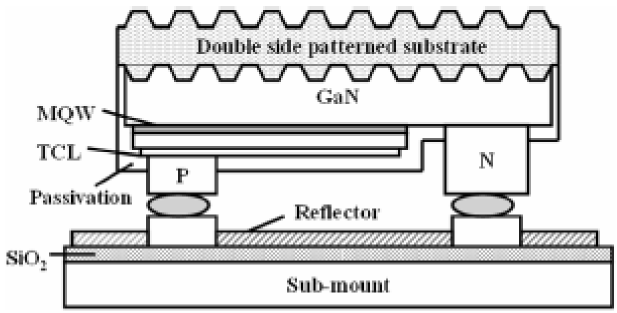

Fig. 7: Flip chip with double side patterned GaN for light extraction.

There are also efforts being directed to the use of GaN wafers instead of dealing with sapphire substrate that has inherent problem of lattice and thermal expansion mismatch. This will reduce the defect density and increase the light output.

Potential of UV LEDs: UV LEDs have not been commercially employed in LED backlight. The current white LEDs, that rely on the blue-light excited yellow phosphor, do not offer good spectrum for obtaining good quality of color pictures. If UV LEDs could be employed with tri-color phosphor blend on the top of UV LEDs, a superior spectrum can be obtained to derive the advantage of high color gamut from LCDs by employing these LEDs in the backlight. Another technique [10] is to assemble near UV LEDs to the light guide to obtain 'color pixel backlight'. This technique can get eliminate color filters in LCDs. The additional advantage of UV LEDs is the absence of 'droop behavior' at high injection current [11] normally encountered by visible LEDs.

3. Impact

The on-going work on LED reveals the vast potential of LEDs for LED backlight. Even though we already saw reports of 246 lm/w at R&D level for low power white LEDs, this does not seem to be the limit. It is certainly conceivable that the efficacy of white LED can reach 300lm/w, with all the improvements coming on board. The junction temperature will decrease and the thermal management problems will be less.

5. References

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