

LED Backlighting of LCDs in Mobile Appliances

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8.1 Introduction

The consumer electronics, wireless appliance, and automotive systems industries all desire enhanced technology for the manufacture of their mid to large sized flat panel displays and have devoted considerable resources to pursuing it.

In reality, this highly sought after technology already exists, in the form of light emitting diodes (LEDs). A type of LED white LED is already standard for small displays precisely because it ideally meets the prevailing desires for miniaturization and superior operating times in cell phones and other small mobile appliances. But LEDs are an increasingly viable solution for mid to large sized displays, as well.

Yet, despite this strong potential for LEDs, the dominant technology for medium and large sized LCDs remains the cold cathode fluorescent lamp (CCFL). Historically, the popularity of CCFLs was driven largely by their superior lumen/cost ratio. But with ongoing (and significant) improvements in LED output, that ratio differential has narrowed considerably, making LEDs a more viable option than ever before. This gap appears poised to continue closing with each succeeding year.

Furthermore, LEDs possess a variety of performance and other advantages compared to CCFLs:

- They are based on semiconductor dies and are therefore *mercury and lead free technologies*.
- They require *no high ignition voltages* to initiate necessary gas discharge, thereby reducing the cost of electronic components, while facilitating electromagnetic compatibility and interference (EMI).
- They possess a *superior color gamut* (range of available colors). In fact, three LEDs of the colors red, green, and blue are able to cover more than 110% of the common color standards for televisions established by the National Television System Committee (NTSC).
- They can be turned on or off (switched) in fewer than 100 nanoseconds, minimizing the blurring effects common to CCFLs as requirements for contrast and brilliance increase.
- They are vibration and shock proof, have exceptionally long service lives, and can operate within a temperature range of -40 to $+85^{\circ}\text{C}$.

This all leads to an obvious question: what is preventing the broader adoption of LED technology for mid- and large-sized flat panel displays? To a degree, it's a result of CCFLs being such an established technology for these applications. Beyond that, the main challenges relate to LEDs' thermal management and, as intimated above, perceptions regarding their cost. Nevertheless, because of the ongoing improvements in overall LED performance and cost, combined with LEDs' their numerous existing advantages compared to CCFLs, LED manufacturers are increasingly optimistic about their ability to further penetrate the market in the near future.

The balance of this chapter delves deeper into the existing and emerging benefits of LEDs for larger mobile appliances, as well as the requirements for BLU systems; the physics of LEDs; and potential LED package solutions for LCD backlighting. The chapter also evaluates the primary potential applications for LEDs, such as cell phones and notebook LCDs.

8.2 Basic Physics of LED Technology

The tremendous advances in bright LED technology are fueling a revolution that has impacted a wide variety of lighting applications. This revolution is particularly driving the development of blue InGaN LEDs, which are poised to open enormous new markets that were previously inappropriate for LED technology, including LCD backlighting, general lighting, and large scale signs and displays for video wall applications.

This section covers the basics of LED physics, beginning with a brief overview of semiconductor diode and current voltage characteristics. This is followed by similarly brief overviews of radiative recombination, semiconductor bulk light extraction, the electro optical characteristics of LEDs, and LED packaging technologies.

8.2.1 History of LEDs

The first LED products were commercialized in the early 1970s. Since then, the luminous flux and efficiency of LEDs have improved by an approximate factor of 20 in each subsequent decade (estimated by authors at OSRAM). Figure 8.1 demonstrates this increase in brightness compared to standard lamp technologies.

In Figure 8.1, it can be seen that LED efficacy has already overtaken that of most of the standard technologies and is still increasing steeply. It goes without saying that a similar decrease can be observed for the cost per lumen.

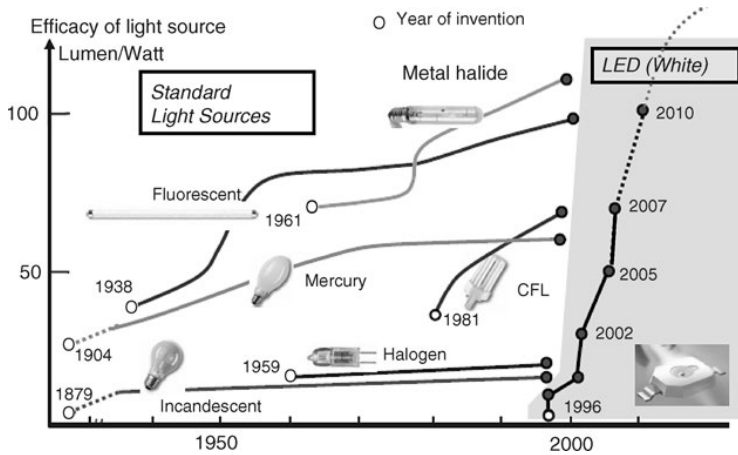


Figure 8.1 Increase of efficacy of different lamp technologies.

8.3 Basic Physics of Semiconductor Light Emission

8.3.1 Semiconductor Basics [1]

In order to truly understand LEDs, it is important to first understand the physics that governs light emission in semiconductors.

Generally speaking, all materials can be categorized as conductors, semiconductors, or insulators, depending on their ability to conduct electricity. The conductivity of a material is a measure of how strongly the material opposes the flow of an electric current. A high conductivity indicates a material that readily allows the movement of electrons. The band theory of materials explains on a qualitative level the differences between conductors, semiconductors, and insulators.

Electrons occupy energy levels from the lowest energies. The highest filled level is called a valance band. Electrons in the valance band do not participate in the conduction process. The first unfilled level above the valance band is known as the conduction band.

Figure 8.2, below, shows the differences between the band structures of metals, semiconductors, and insulators.

Elemental semiconductors are semiconductors in which each atom is of the same type. These atoms are bound together by covalent bonds; these bonds cause neighboring atoms to share electrons, creating the formation of strong bonds.

So called compound semiconductors are formed from two or more elements belonging to groups III and V of the Periodic Table. Other types of semiconductors, called ternary semiconductors, are formed by the addition of small quantities of a third element (AlGaAs is an example of a ternary semiconductor). Likewise, the addition of yet another element results in the formation of quaternary semiconductors, such as AlInGaP.

So called 'doping' p or n type semiconductors can be created by adding atoms to an essentially pure semiconductor material. N type semiconductors are doped with materials that contain an extra electron in the valance band, which is then added to the crystal. The resulting materials are called 'donors'. P type semiconductors, on the other hand, create holes and have one fewer electron than n type semiconductors.

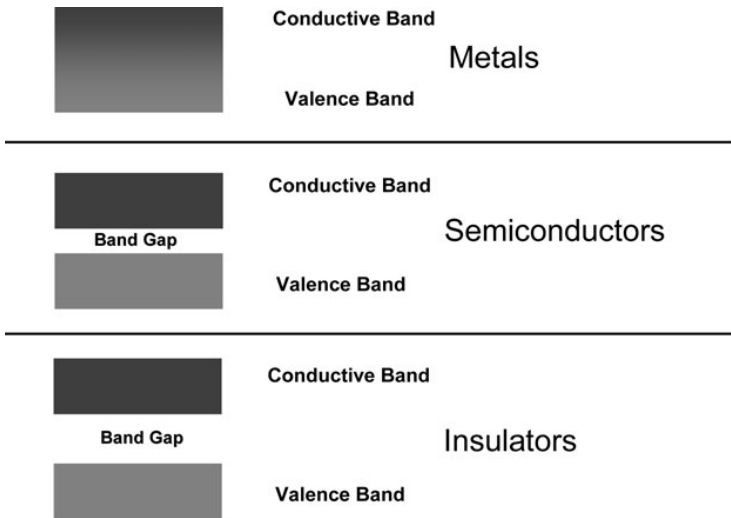


Figure 8.2 Energy band differences.

8.3.2 The p–n Junction and Photons [2, 3]

Semiconductors have a band structure, which refers to the area between the p and n type semiconductor. The injection of electrons into a p type semiconductor is the critical mechanism for LED efficiency. A schematic sketch of the band gap, both with and without forward bias, is shown in Figure 8.3, below. This recombination, in which electrons are injected into the p type semiconductor and holes are injected into an n type semiconductor, results in near band gap radiation. This corresponds to the emission of photons, whose wavelength is correlated to the size of the band gap, and the amount of energy the photon possesses.

Both the band gap and temperature have a significant influence on the probability of radiation occurring, as well as on the wavelength of the emitted photon. The wavelength is determined by the following equation, in which λ is the wavelength of the photon, and E_g the band gap given in electronvolts (eV). The equation reads as follows:

$$\lambda \approx \frac{1.24}{E_g} \mu\text{m}$$

Temperature has a great impact on the statistical distribution of electrons and holes within a semiconductor: the higher the temperature, the larger the local distribution of the electrons and holes. As a result, the temperature influences the radiative recombination between electrons and holes in terms of wavelength (the different ‘distance’ of the band gap) and efficiency (the electrons required per radiative recombination). See Figure 8.4, below, for more detail.

The temperature of this active region is referred to as the ‘junction temperature’. LED efficiency is only a single, albeit important, consequence of this parameter. Another critical consequence relates to lifetime with respect to the degradation of the device. LED encapsulation and the integrity of the housing are especially sensitive to temperature and blue light.

Typical LED efficiencies are shown in Figure 8.5, below.

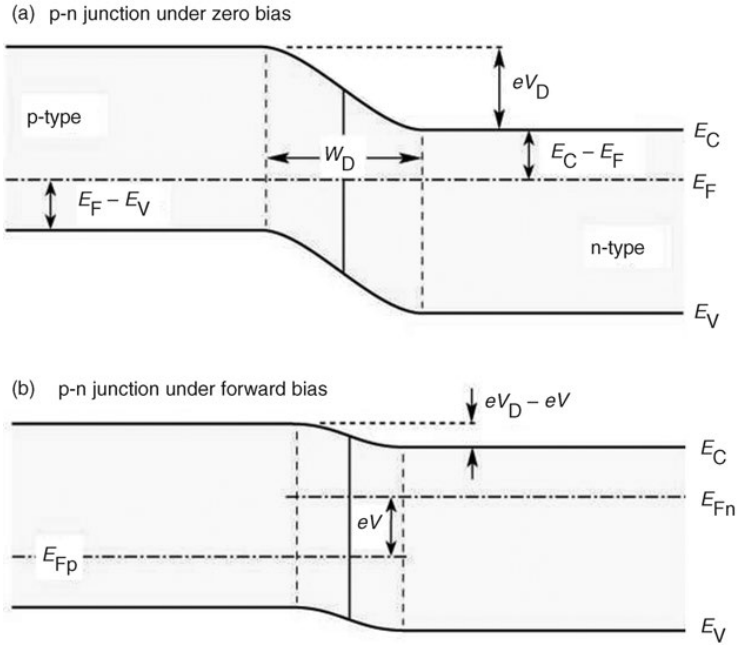


Figure 8.3 The p n junction under (a) zero bias and (b) forward bias. Under forward bias conditions, minority carriers diffuse into the neutral regions where they recombine. Reproduced from [1] by permission of Cambridge University Press.

8.4 LED Efficiency and Light Extraction

One important measure of LED efficacy is the internal quantum efficiency, which refers to the radiative recombination of LEDs the conversion of electrical carriers (electrons) into light (photons). Non radiative recombination refers to the transition of electrons into phonons (heat). Another critically

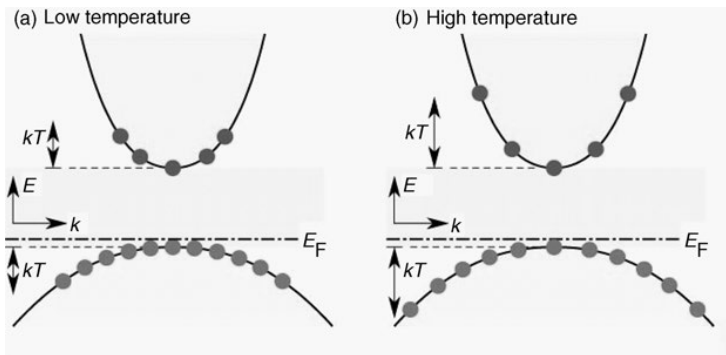


Figure 8.4 Carrier distribution at (a) low and (b) high temperatures. Recombination probability decreases at high temperatures due to reduced number of carriers per d_k interval. Reproduced from [1] by permission of Cambridge University Press.

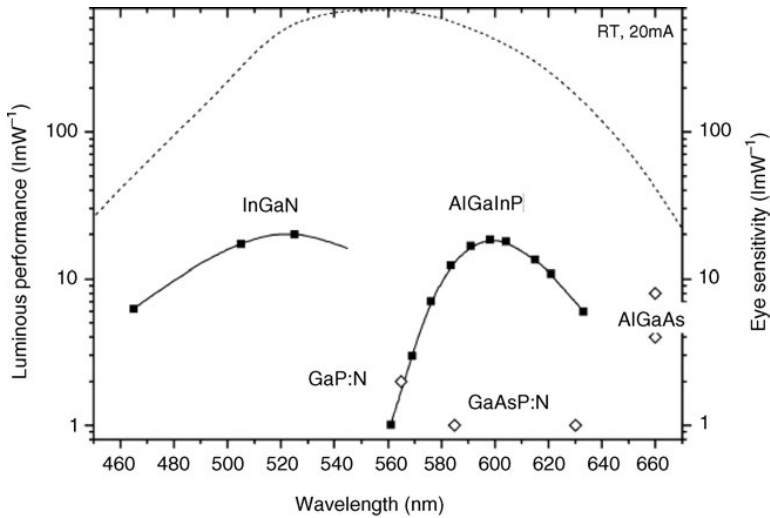


Figure 8.5 Typical efficiencies of LEDs as a function of emitted wavelength (dotted line: eye sensitivity).

important characteristic of LEDs is their so called ‘wall plug’ efficiency. In fact, every process in the LED value chain contributes to this level of efficiency.

Figure 8.6 illustrates the entire process chain for opto emitters, and how each process step contributes to wall plug efficiency.

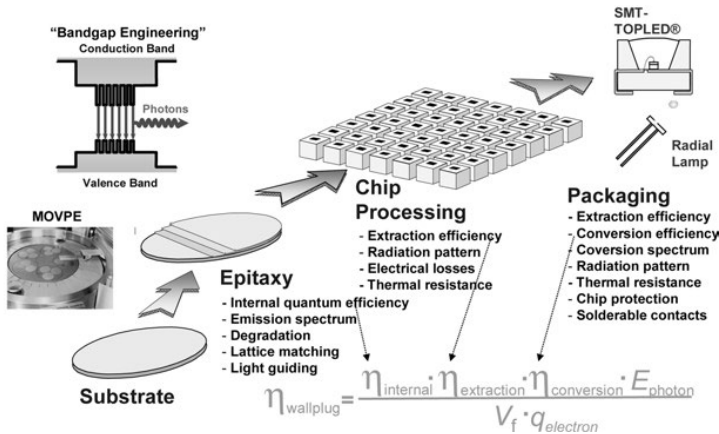


Figure 8.6 Process chain for opto emitters and contribution to wall plug efficiency.

While light can be efficiently generated inside an LED ($\eta_{\text{internal}} \approx 90\%$), due to the large difference in the refractive index between the semiconductor and the surrounding medium, only a small percentage of the generated photons can actually escape from the semiconductor material.

Semiconductor materials have a refractive index of $n = 3.5$, while the surrounding medium has a refractive index of only $n = 1.5$. This means that the semiconductor surface acts as a nearly perfect mirror and, as such, specific actions are required to increase light extraction ($\eta_{\text{extraction}}$).

8.4.1 Chip Technology

The aim of chip development is to increase extraction efficiency. Gains against this goal have been significant in recent years, thanks in large part to the shift from absorbing substrate materials to implementing transparent base material. In addition, extraction efficiency has doubled as a result of breakthroughs that enable the geometrical shaping of chips.

This breakthrough, branded as the ATON[®] chip, was originally dependent on strong reflector designs to propel extracted light to the top of the LED package. So called flip chip technologies were eventually developed to mitigate this requirement. Since then, an ongoing series of additional developments have led to the creation of even more efficient and powerful solutions, such as the Thinfilm chips described in Chapter 9.

8.4.2 Thinfilm and ThinGaN[®] Technology

Common light sources for LED backlighting are based on a new platform generation of high current and high brightness chips, called ‘Thinfilm’ AlGaInP for red light, and ‘ThinGaN[®]’ for blue and green light (Figure 8.7). These chips have inspired several new designs that, in turn, have led to high efficiency and outstanding power levels. Due to their design, these chips are pure top surface emitters with a true Lambertian radiation pattern, offering all of the benefits associated with this property [4–7].

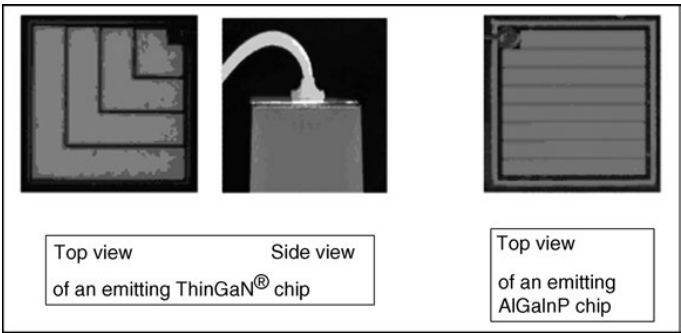


Figure 8.7 Different views of emitting Thinfilm chips.

Readers should note that, in the following sections, ‘Thinfilm’ AlGaInP chips as well as ‘ThinGaN[®]’ are referred to as Thinfilm chips unless otherwise stated.

8.4.3 Design and Manufacturing

Thinfilm chips are manufactured as clip chips, following standard die manufacturing procedures. The top surface is then metallized, after which the chip is literally ‘flipped’ over and attached to a carrier

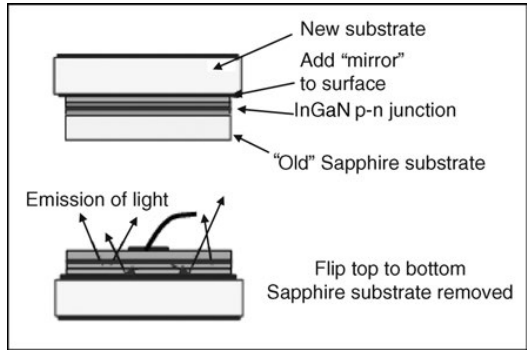


Figure 8.8 Manufacturing of Thinfilm chips.

material. The base substrate material (now on top) is then removed and the newly exposed top surface is roughened (Figure 8.8).

The resulting Thinfilm chip comprises a substrate less thin active layer centered between a rough surface on the top and a highly reflective mirror on the bottom which is attached to the carrier substrate [4].

8.4.4 Benefits

The special design of Thinfilm chips increases optical efficiency (in terms of light output per electrical input power) and decreases forward voltage (otherwise characterized as an increase in electro optical efficiency.)

Because, as previously mentioned, Thinfilm chips are pure top surface emitters (Figure 8.9), the reflector has less importance than in conventional volume emitting chips. Its top surface emission

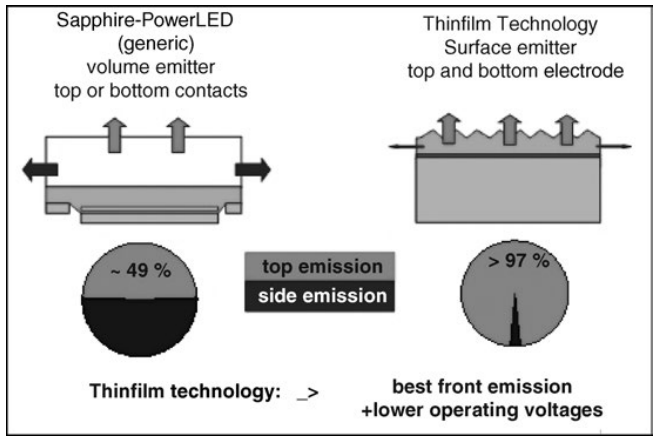


Figure 8.9 Top/side emission ratio of a Thinfilm chip (right) compared to a conventional Sapphire chip (left).

enables excellent optical designs to be implemented for example, the implementation of light spreading optics in LED backlight systems that minimize stray light and avoid hot spots.

As an additional consequence of pure surface emission, luminous flux scales up with the size of the chip. It is therefore possible to implement very efficient large chips for high flux operation at high currents. Conventional volume emitting chips with transparent substrates do not scale up at the same ratio and lose efficiency with increasing sizes [4].

8.5 Packaging Technologies and White LED Light

Almost all LED chips are mounted in packages that provide electrical leads, a transparent encapsulent for light extraction, and a housing body to mount the LEDs. The entire package design typically features surface mount technology (SMT), which enable the LED to withstand mechanical and thermal stress during printed surface board assembly.

8.5.1 Creation of White Light

LEDs emit well saturated colors because they result in the creation of light inside the semiconductor. Because white light is actually a mixture of several colors, there are many ways to create it, all of which are based on additive color mixing. Two of those methods follow.

Method 1 Using Red/Green/Blue LEDs

This method is described in Figure 8.10. In order to achieve the required white color, the brightness of every color has to be adjusted and kept stable. Using this method, all colors contained in the color gamut can be created, defined by the emission spectra of the LEDs.

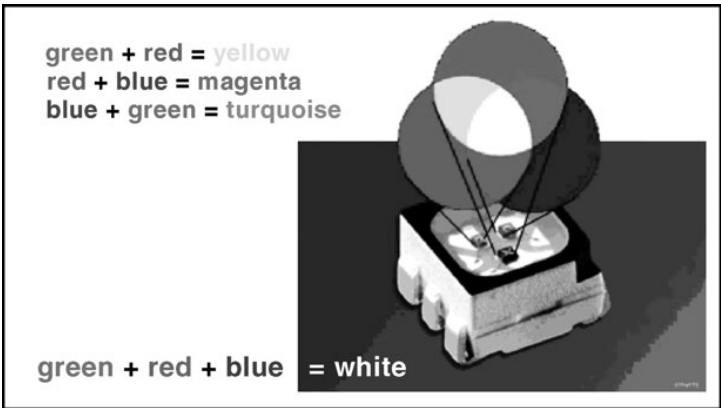


Figure 8.10 RGB color mixing to create white light. (See Plate 8).

In order to achieve a uniform white appearance on a backlight, the light of various LEDs requires mixing, and then needs to be guided through the LCD (Liquid Crystal Display). If the requirements for the white appearance are very tight, it is necessary to stabilize the brightness of each LED, over both temperature and lifetime, by using an optical sensor and an electrical feedback loop.

Method 2 Using Blue LED Emission and Phosphor Conversion

In this method, the white light is once again created by mixing several colors. The light of a blue emitting chip is guided through phosphor particles, which absorb the blue wavelength and emit light in a wavelength range which contains less energy. This effect is commonly called 'phosphor conversion'.

Depending on the requirements, either a yellow emitting phosphor or two (or more) phosphor materials are mixed. This results in light that appears white to the human eye. In commonly available LEDs, the phosphor is mixed in the resin which covers the chip (Figure 8.11). In standard white LEDs, a yellow phosphor is used, and only two colors are combined: the blue color from the LED and the yellow color from the phosphor. For the resulting spectrum, refer to Figure 8.6.

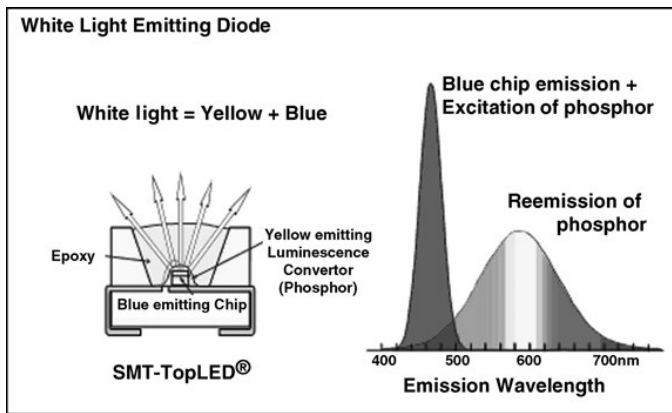


Figure 8.11 Principle of phosphor conversion.

Using this method, the LED manufacturer has to control the amount of phosphor material in order to achieve the desired white color appearance. For the user, the LED can be driven like any LED with saturated colors.

Because a Thinfilm chip emits light only from the surface, phosphor material can be placed only on the top side of the chip. This is called CLC, or Chip Level Conversion. The principle is illustrated in Figure 8.12, below. A thin phosphor layer is placed on top of the chip, which results in a uniform and stable white color appearance. This type of white chip features the highest luminance levels, giving them significant advantages when used in tandem with any kind of optics.

8.6 Requirements and Designs for LED-Based Backlight Solutions

LEDs are often referred to as 'point light sources'. That means that the light of an LED is created in a very small volume, thus it has to be distributed evenly in order to create the uniform backlight

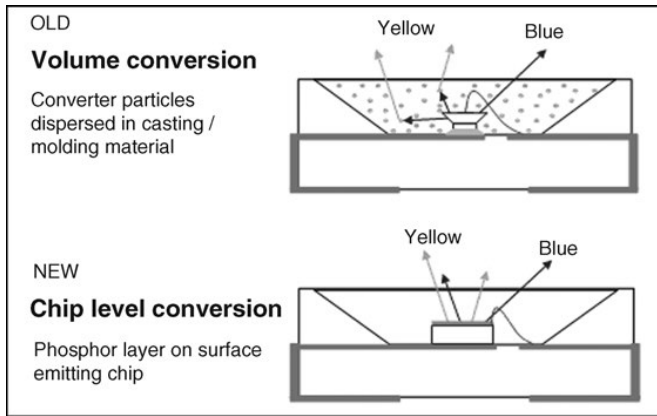


Figure 8.12 Principle of chip level conversion.

illumination necessary for mobile flat panel displays. While this may sound like a disadvantage, it actually results in giving LEDs tremendous flexibility which can be adapted to a variety of requirements and applications. The resulting availability of LEDs in different packages, chip sizes, colors, and brightness helps make them a truly cost effective solution for many kinds of backlight applications.

In general, LED backlight solutions are highly flexible in terms of backlight size, and can be extended to any diagonal. If the same LED packing density (LEDs per unit area) is maintained, then luminance remains constant for all backlight unit (BLU) sizes. To adapt the luminance to specific requirements, either the packing density or the drive current should be changed [8].

8.6.1 Requirements for BLU Systems

While LEDs have yet to become the dominant technology for backlight design, the wide range of actual and potential benefits described above is leading to a growing number of important specifications. In order to target the mass production market, basic guidelines must be established to define the specific requirements of LED backlight units.

These guidelines have already been established for the LED package design of BLU systems, as well as for the semiconductor die.

For example, small backlight applications such as mobile phones and personal digital assistants (PDAs) require luminance levels between 60 cd/m^2 and 150 cd/m^2 . By using either white LEDs or RGB LEDs (depending on the specific requirements of the application), the brightness level of these devices can be modified to the brightness of the environment in which they are being used. This can be realized by adapting the luminous flux of the LED with the help of an ambient light sensor. Ultimately, the resulting brightness is controlled by the size of the die; LEDs enable thickness levels as low as 0.2 mm (with light guides) for the complete backlight system.

As far as larger LCD screens are concerned, the luminance level typically should fall between 200 cd/m^2 for monitor applications and 500 cd/m^2 for large area TV applications, relying on a uniformity of better than 85% in brightness and color. The wavelength ranges of the red, green, and blue LED dies need to be specified in order to achieve a minimum color gamut of minimum 100% NTSC. The mixing ratio of the luminous flux of RGB needs to be chosen for color temperature ranges between 6,500 K and 12,000 K, depending on specifications and customer preferences in different regions.

All LCD backlights, regardless of application, share one requirement: the number of LEDs must be minimized in order to ensure competitive cost levels and high quality backlights with very low levels of failures in time (FIT). Special long life housing materials and robust package and die designs have to be considered to achieve frequently desired lifetimes ranging from 20,000 hours to more than 50,000 hours, depending on the operating conditions [8].

Going forward, it is clear that different LED arrangements and backlight technologies must be developed in order to adapt to BLU sizes and customer requirements pertaining to:

- power consumption;
- brightness;
- thickness of the backlight unit;
- uniformity;
- available space;
- preferred drive conditions;
- cost;
- thermal design capabilities.

8.6.2 LED Component Design

There are two different ways in which the LED components can be arranged (see Figure 8.13):

- by light guide arrangement (left); and
- by direct backlight arrangement (right).

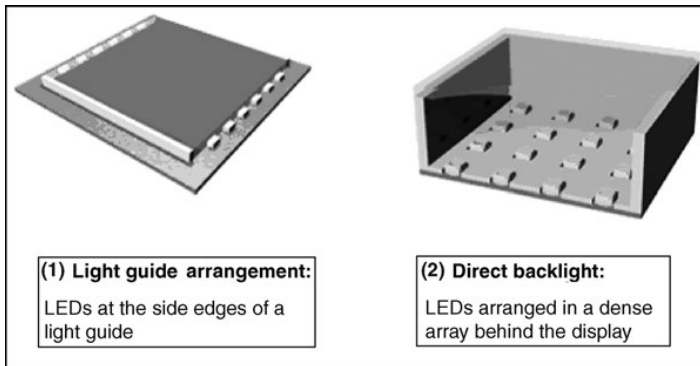


Figure 8.13 Basic LED backlight technologies.

The light guide arrangement (1) leads to very thin (from 0.2 mm to 10 mm) and uniform backlight units. This design will generally yield good optical efficiencies for backlights up to about 20" diagonal.

With the direct backlight arrangement (2), backlight units are thicker (between 25 mm and 40 mm), but result in low power consumption, good thermal design, and excellent scalability. This type of design is practically limitless in terms of the diagonal. Both technologies can be adapted to different specifications and requirements.

Given the nature of LED backlights using multiple primaries with different opto semiconductor devices, a color and brightness control system is highly recommended. This is because LEDs have different thermal and aging behaviors for different wavelengths. To ensure stable white point settings for operating life, a sensor feedback loop is needed [8].

For both design types, an optimization must be found between the following parameters:

- the number of LEDs, which largely determines cost;
- power consumption, which also influences the effort required for thermal management;
- size and thickness, which determine space requirements and brightness/color uniformity.

These three parameters are interrelated, with each one strongly influencing the others. Therefore, it is imperative from the outset of the design process that backlight designers consider which of these characteristics should be emphasized.

8.7 LED-Backlighting Products

The following section discusses LED product solutions for LCD backlighting. First, the different benefits for RGB and white LEDs are discussed, followed by an overview of the Micro SIDELED[®] package, and the benefits of an ambient light sensor.

8.7.1 White versus RGB Backlight Units

As mentioned in the introduction to this chapter, among the advantages of LED backlighting solutions compared to CCFLs are the lack of EMI complications, the color gamut, and the battery life. There are specific LED products that are best suited to generate each of these benefits.

The highest efficiencies for LED packages can be achieved by using a blue wavelength and a converter doped casting material. These GaN based LEDs are covered by a yellowish phosphor coating, which converts part of the blue LED light efficiently to a broad spectrum centered at about 580 nm (yellow). The combination of yellow and blue gives the appearance of white.

Figure 8.14, below, shows the spectral data of white and RGB LEDs. In addition, the $V(\lambda)$ curve is plotted to demonstrate the sensitivity of the human eye.

Since eye sensitivity (in bright environments) has its maximum at 555 nm, the efficiency of any light source is dominated by the intensity in that range. As a result, the efficiency of RGB LEDs is dominated by the emission of the green LED, while white LED efficiency is determined by the conversion of blue LED light into the broad yellowish spectrum.

The impact of LED efficiency on the whole system is covered in more detail later in this chapter.

Another very important characteristic of the whole LCD system is the color gamut. The Commission Internationale de l'Éclairage (CIE) defines a two dimensional color space, which represents all possible colors, visible to the human eye. This CIE diagram can be used to visualize the color gamut obtainable from a particular light source.

In order to evaluate different light sources with respect to the color gamut in an LCD system, it is important to understand the technical background of this technology. As described elsewhere, the LCD system comprises color filters and a matrix display to address each single pixel.

When using white light sources, the spectrum must be evaluated with respect to the transmission spectra of the color filters. After this evaluation, the CIE color coordinates can be calculated and displayed. For a typical notebook display the different color gamuts are shown in Figure 8.15, below, in comparison to the NTSC standard. Comparing these areas, the color gamut can be calculated to be

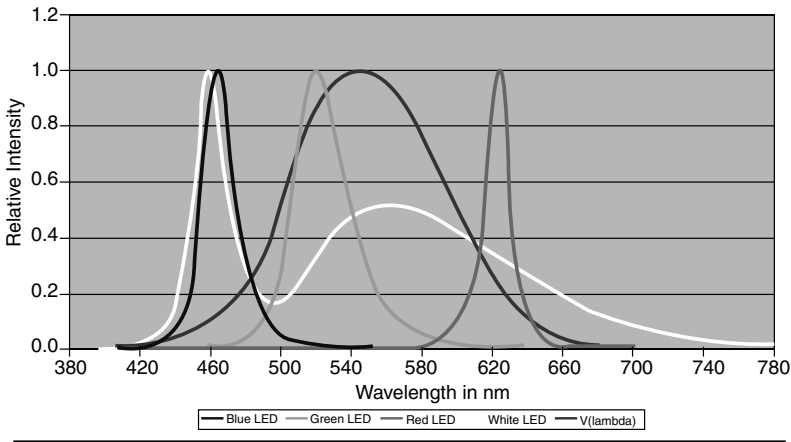


Figure 8.14 Spectra of different LEDs and eye sensitivity.

roughly 45% for CCFLs and marginally higher for white LEDs. The color space for RGB LEDs can be up to more than 110% of the NTSC standard.

This comparison shows that color filters have to be adapted to the light source in order to maximize system efficiency. Otherwise, system efficiency will be reduced significantly. Numerous studies demonstrate that RGB LEDs are the optimal solution for achieving the highest possible color gamut.

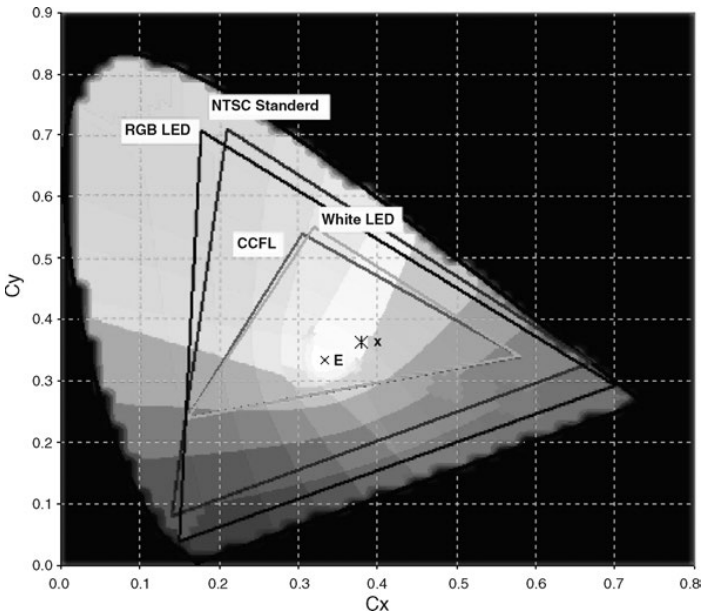


Figure 8.15 Color gamut comparison between different light sources.

These LEDs do not need color filters in a conventional sense. In certain systems, each color is switched quickly on only for a brief period, and only the matrix display defines the color for each single pixel. This approach can reduce costs and the brightness loss caused by the three using color filters. It is important to bear in mind, however, that such an approach requires highly developed electronic devices to achieve optimal results.

8.7.2 Micro SIDELED® (LW Y1SG and LW Y3SG)

Micro SIDELED® is a phosphor converted white LED available in two sizes 0.8 mm (LW Y1SG) and 0.6 mm (LW Y3SG). This small SMD LED emits its light to the side by means of a reflector (Figure 8.16). Therefore, it is fairly easy to direct light into the light guide of an LCD backlight.



Figure 8.16 Micro SIDELED®.

Micro SIDELED® is ideal for notebook applications, and is now a standard product used in small LCDs in cell phones, digital cameras, and other consumer electronics.

There are a variety of shades of white available (Figure 8.17, below). One could use, for example, group 'EL' to achieve a more bluish appearance on the backlight, while group 'JM' would result in a more yellowish hue.

Micro SIDELED® is sorted by its luminous intensity and color coordinates. This kind of binning is very tight. On one reel, there is only a single intensity and a single white bin. Therefore, when using this LED for backlighting, especially in the larger displays common to notebooks, it is strongly recommended to mount only LEDs from one reel. This precaution will help to achieve a good color and brightness uniformity over the backlight and LCD.

When operating the LED, it is recommended to use pulse width modulation (PWM) for the dimming, in order to avoid color shifts (Figure 8.18, below). It is further advisable not to exceed the grouping current of 20 mA for the peak current. The lower the peak current, the better the LED efficiency, which will help reduce power consumption.

LED lifetime is less critical for mobile phones, but it is extremely important for notebooks. In either case, it is realistic to expect similar or better performance than would be expected when using CCFLs for backlighting. This means that an LED lifetime of at least 15 kh is required. This is where the LW Y3SG excels, because it can offer a lifetime of up to 40 kh depending on driving conditions.

Further details of the optical characteristics of LEDs can be found in the corresponding datasheets. For further details of Micro SIDELED®, refer to the datasheet section of www.osram-os.com.

8.7.3 Ambient Light Sensors: Product Introduction

Sensors are now adding functionality, reducing power consumption, and offering more and more convenient features in a wide range of mobile devices such as cell phones, handhelds, and digital

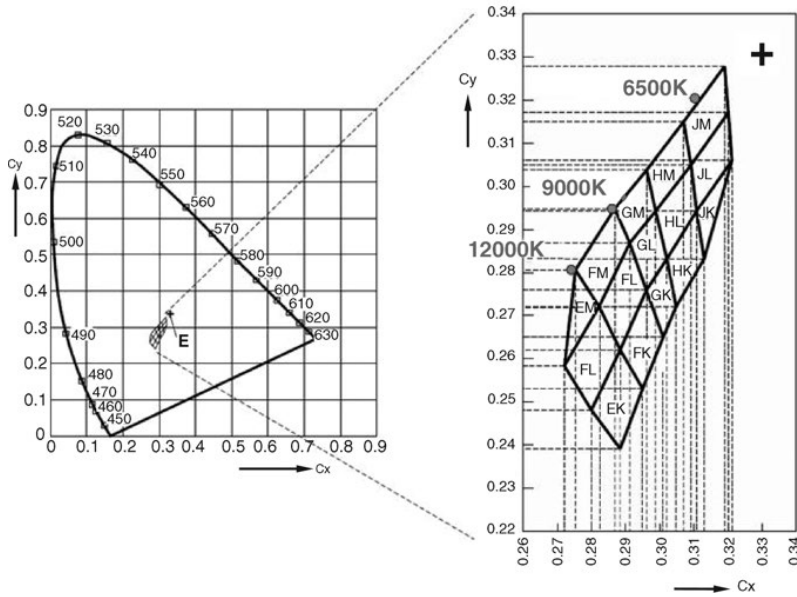


Figure 8.17 Micro SIDELED[®] white binning scheme.

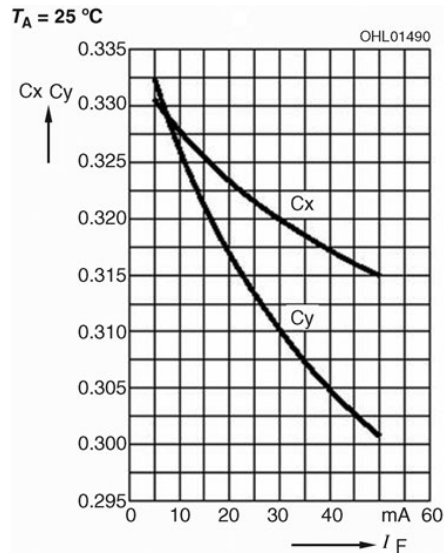


Figure 8.18 White shift versus direct current.

cameras. The most widely used sensors are the ones that adjust display backlighting according to ambient lighting conditions. Comparatively new are orientation sensors that detect whether a mobile device is being held vertically or horizontally

Consider the familiar, ‘real world’ circumstance of taking photographs. Taking outdoor photos with cell phones or even digital cameras is often complicated by bright sun, which can make it difficult to view the device’s display panel. Why? Because the device’s backlighting, quite logically, typically defaults to medium lighting levels in order to preserve battery power. Frequently, this presents no problem. But in cases of bright sunshine or, conversely, extreme darkness, displays are often too dark or too bright to accommodate the desired function.

Ambient light sensors help avoid this effect by measuring the ambient brightness, as perceived by the human eye. This measurement causes the display backlighting to adjust accordingly. The overall result is the more effective use of available power, because, for approximately 40% of the time, the display backlighting is too bright.

The concept of ‘human eye perception’ has been raised more than once in this chapter. It is important for sensors to be sensitive to the same wavelengths that the human eye perceives, because light sources emit more than just visible light; they also emit wavelengths that the human eye cannot see. Normal photo detectors also react to this ‘invisible’ light. They therefore ‘see’ the surroundings brighter than the human eye, and make incorrect adjustments to the lighting (Figure 8.19; Figure 8.20, below). As a result, displays are often too difficult to read.

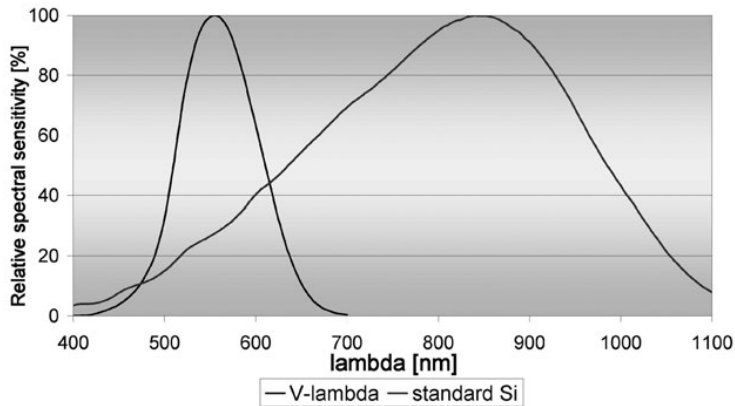


Figure 8.19 Conventional silicon photo detectors (blue curve) are also sensitive to invisible infrared light. The left hand curve shows the spectral sensitivity of the human eye.

Photo detectors have been gradually modified so that their spectral sensitivity (the wavelengths to which a sensor is sensitive) is comparable to that of the human eye. OSRAM was the world’s first manufacturer, with the SFH 5711, to achieve optimum matching with the sensitivity of the eye (Figures 8.21 and 8.22, below). This new sensor measures the ambient brightness perceived by the eye so precisely that the lighting can be adjusted almost seamlessly. Display backlighting can therefore be controlled so that it is always as easy as possible to read. These sensors are consequently also of interest for devices for which energy savings are not the primary concern, such as all types of flat screens and large format advertising panels.

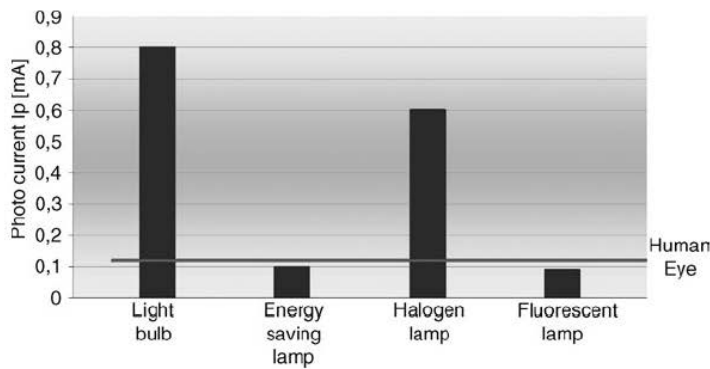


Figure 8.20 Because some light sources emit a large amount of infrared light, a silicon detector receives a much higher signal than an ‘eye like’ detector would.

8.8 LED Backlighting of Notebook LCDs

Notebook users in particular demand long battery life. This is imperative when, for example, working on a long distance flight without an external power supply.

This kind of performance requirement requires holistic energy saving system architecture. At present, the display subsystem accounts for the highest proportion of the power consumed inside a notebook (about 30%). While the LCD itself needs only a small fraction of this power, the backlight consumes a great deal more.

This underscores the great potential of modern and efficient LED technology, which can replace conventional backlighting and lead to a drastic reduction in power consumption, as demonstrated in the following example.

The requirements concerning color reproduction are not very high at the moment so there is no need for RGB backlighting; white LEDs, such as Micro SIDELED[®], can be used instead.

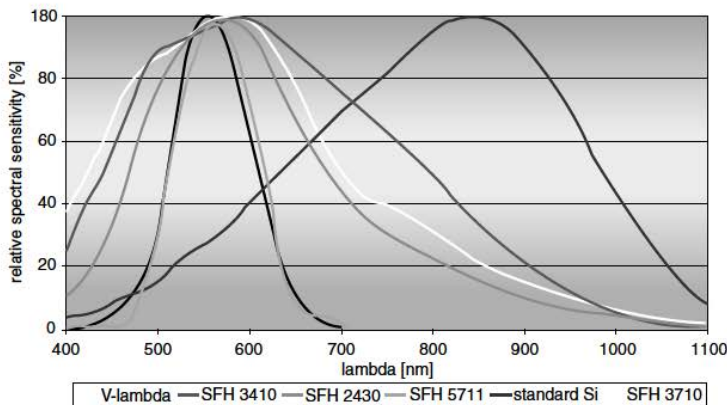


Figure 8.21 Development of ambient light sensors at OSRAM OS. Starting with standard silicon photo detectors, the ambient light sensors were constantly adapted to the sensitivity curve of the human eye. The optimum response is achieved by the SFH 5711.

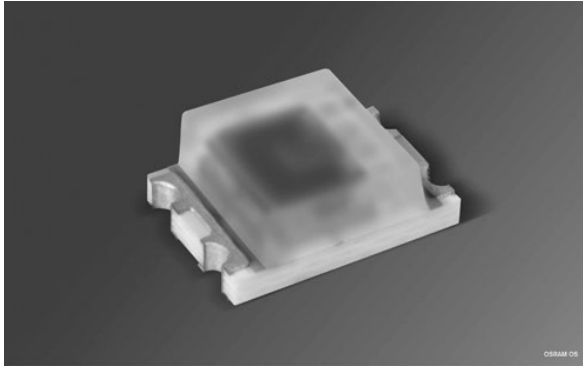


Figure 8.22 SFH 5711, the new ambient light sensor from OSRAM.

Example of Indirect LED Backlighting for a 15.4" Notebook Display

For the following test, two conventional, identical notebooks were used. One was modified with LED backlighting, while the other was not. This affords a perfect opportunity for a direct performance comparison of notebooks with and without LEDs.

An overview of the components is shown in Figure 8.23.

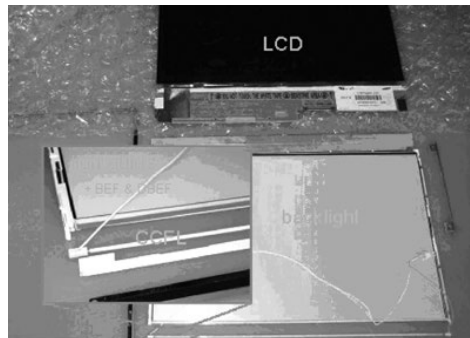


Figure 8.23 Overview of the components.

This picture shows the LCD and the backlight unit as separate entities. The backlight comprises the CCFL and the light guide with its associated optical films (diffuser sheet, brightness enhancement films, etc.).

The retrofit mainly consisted of replacing the CCFL with a PCB strip with a linear LED arrangement. An external power supply was used in this case, but it is generally recommended that the existing onboard voltages in the notebook are used by integrating appropriate LED drivers.

When compared side by side, it is difficult to distinguish between the CCFL and LED versions (see also Figure 8.24, below). This is also verified by the measurement results. For both displays, the same maximum luminance of approximately 180 nits was achieved, with a uniformity of approximately 80% (Figure 8.25, below). The color gamut for both versions was about 45% of NTSC (Figure 8.26, below).



Figure 8.24 Display with conventional backlighting (left) and with LED backlighting (right).

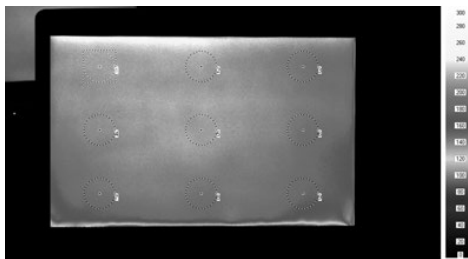


Figure 8.25 LCD with LED backlight: luminance and uniformity measurement.

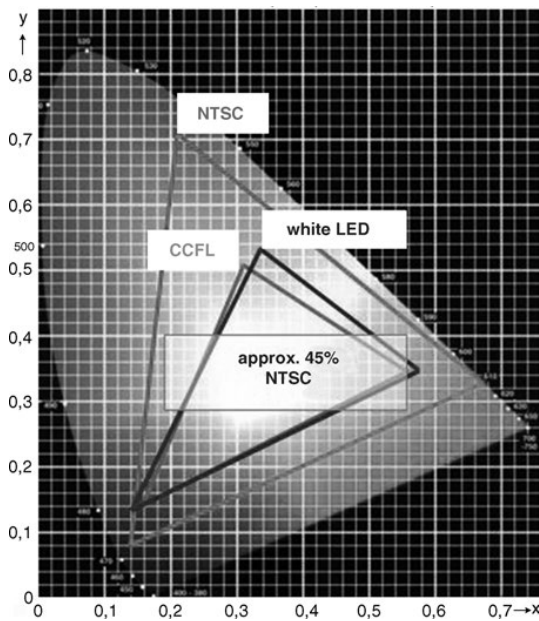


Figure 8.26 Color gamut of CCFL vs. white LED backlighting in notebooks.

In notebook LCD panels, the color filters are overlapping and wider than in desktop panels, which lead to a higher transmission at the cost of a smaller color gamut (Figure 8.27, below).

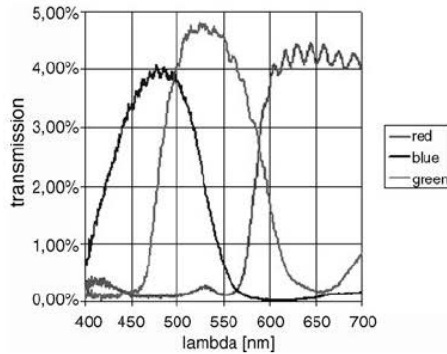


Figure 8.27 Notebook LCD color filters.

Ultimately, the power consumptions for both notebooks were compared. In Figure 8.28, it is apparent that the notebook with LED backlighting consumed significantly less power at all luminance levels.

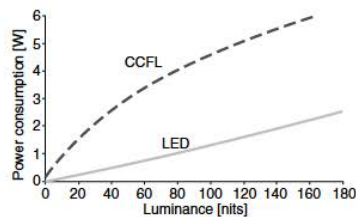


Figure 8.28 Power consumption of CCFL vs. white LED backlighting.

For example, at 60 nits, where the CCFL consumed 3.4 W, the LED power consumption was only 0.7 W. This level of difference can extend battery life by 60 minutes or longer. Combined with an ambient light sensor (ALS) which automatically adjusts the screen luminance, even further power savings are possible.

The table in Figure 8.29 below shows the number of LEDs and typical power consumption levels for various LCD diagonals. Remarkably, the power consumption is less than 1 W at 60 nits for all display sizes.

LCD diagonal	12.1"	14.1"	15"	15.4" wide	17" wide
length	261 mm	286 mm	304 mm	331 mm	382 mm
width	199 mm	214 mm	228 mm	207 mm	245 mm
LED number	40	47	53	53	72
incoupling	at bottom side of light guide				
LED pitch	6.5 mm	6.0 mm	5.7 mm	6.2 mm	5.3 mm
mixing distance	4.6 mm	4.3 mm	4.0 mm	4.4 mm	3.7 mm
LED power at 200 nits	2.3 W	2.7 W	3.1 W	3.1 W	4.2 W
LED power at 60 nits	0.5 W	0.6 W	0.7 W	0.7 W	1.0 W

Figure 8.29 Specification for various LCD diagonals.

8.9 Summary and Outlook

There is ample evidence that LEDs already provide a strong alternative to CCFLs for a variety of LCD backlighting applications in mobile appliances, and that their potential is expanding rapidly. Based on application requirements, the best LED solution can be chosen by considering:

- required thickness of the entire system;
- performance of the LED backlight;
- total power consumption of the light source.

As manufacturers are increasingly realizing, application requirements should also take actual use into account. Consider so called ultra mobile appliances, such as notebook personal computers, which benefit from the lowest power consumption possible in order to extend battery life. For this kind of application, the light source has to be as efficient as possible. As of today, this efficiency can be best achieved with single chip white LEDs, such as white Micro SIDELED[®]. Furthermore, the demand for very small solutions is also growing rapidly. The very low profile of Micro SIDELED[®] (only 0.6 mm in height) makes it very viable where miniaturization is a goal.

As described in this chapter, the achievable color gamut of such solutions is currently limited. For ultra mobile notebook personal computers, the color gamut is not a priority. But, for other applications such as picture processing, gaming, or television, higher color gamuts and, in particular, color saturation are extremely coveted.

The highest possible color gamut available today can be achieved through dedicated RGB solutions. As demonstrated in the CIE diagram above, LEDs can achieve more than 110% of the NTSC standard. If a high on screen contrast is also targeted, direct backlighting solutions made from RGB LEDs can deliver superior results.

The LCD panel set up today uses color filters. As these color filters are limited in transition and are adding several costs, especially for RGB backlighting solutions, sequential coloring should be targeted. Such kinds of solutions would lead to at least double efficiency when compared to solutions using color filters. The main stumbling block for this realization is the switching times of the LC. As each color has to be addressed separately and the picture must not be blinking (also know, as color breakup, caused by three separate pictures in each color), significant improvements have to be targeted at the LC as well. The inherently faster response of optically compensated bend (OCB) LCD panels makes these ideal candidates for use with color field sequential technology.

Furthermore, LEDs possess different temperature and aging characteristics. This means that the white point of the display has to be actively controlled. Brightness and color feedback sensors are state of the art, but the additional costs of the total system have to be considered. All of these factors lead to the assumption that RGB backlighting solutions will primarily target the high end market.

Finally, in order to cover high color gamut needs within low cost applications, in the future so called 'high color gamut white' LEDs are likely to be developed. Such LEDs will consist of a

blue LED and a red and green phosphor. This breakthrough would enable the advantages of a single chip solution (driving, temperature, and aging performance) to be combined. The breakthrough would combine the advantage of a single chip solution in terms of easy operating conditions (like driving), no necessity for feedback sensors, and even high color gamuts in a range between white and RGB LEDs.

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