Ultra-slim LCD TV module using edge-lit LED backlight system

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Abstract

We present an ultra-slim LCD module for 40-inch FHD TV. By employing edge-lit backlight system, module thickness of 10mm is achieved. To satisfy the luminance spec of 450 nits in FHD resolution, it is critical to adopt high efficient LED and optical components.

1. Introduction

Recently the LCD business has been placing greater emphasis on design issues such as slimmer modules and narrower bezels, as well as environmental issues such as mercury-free production and low power consumption. Besides all of the focus on improving LCD image quality, there is a great deal of interest in slimmer LCD modules because form factor is one of the most critical aspects for maintaining LCD's superior position to the much discussed OLED technology. To this point, we demonstrated a 10mm thick 40" LCD-TV module with an LED edge-lit backlight system at FPD International 2007. This set provides a vivid example of what future LCD-TV will look like (see Fig. 1). Specifications for the prototype are shown in Table 1. Without compromising image quality in any way, the 10mm module thickness that has been realized for 40" FHD TVs is now being positioned for the premium market. Even though an edge-lit (wedge-lit) structure is commonly used in notebook PCs and monitor applications, this design cannot be directly applied to large size TVs without a number of careful considerations. Difficulties arise due to lowered mechanical rigidity and insufficient luminous flux. In this article, we will discuss these issues as they relate to ultra-slim technology for large size TVs.

2. Module design and thermal analysis

For an extremely slim module, the first thing we must take into consideration is the design of parts such as the top and bottom chassis because these can make the module more vulnerable to deformities such as bending and warping. When slimming down a large module, it is difficult to maintain a flat shape even in the absence of external force. This situation worsens when the power is on. Heat is generated from the LED light source and concentrated along the edges, before being transferred to other parts such as the light guide plate (LGP), optical sheets, top/bottom chassis, and the middle mold frame. In the steady state, a non-uniform temperature distribution is established, which causes local variations in thermal expansion. Eventually, this will result in complex mechanical distortion. Needless to say, it is important to maintain the maximum temperature below a certain level to meet the reliability criteria.

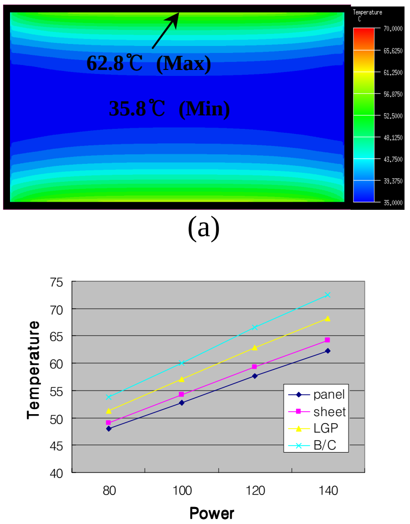


Fig. 1. (a) Temperature distribution of LGP at 120W. The maximum and minimum temperatures are 62.8℃ and 35.8℃, respectively. (b) Maximum temperature vs. power consumption for panel, sheets, LGP and bottom chassis.

To be more specific, a thermal analysis is performed for the 40 inch module and its result is shown in Fig. 1. Note that the energy converted to heat is assumed to be 80% of the input power so the actual dissipated thermal energy for 120W input is 96W. Fig. 1(a) shows the temperature distribution of LGP for 120W input power. The maximum temperature occurs at the center of the LPG edge and the minimum at the center of the module. The temperature difference in LGP reaches to 27℃, which may cause a mechanical distortion. In Fig. 1(b), the plot of maximum temperature vs. power consumption is shown for each component, and the maximum temperature becomes higher in the order of LCD panel, sheets, LGP and bottom chassis. Considering the minimum temperature is almost same for each component, the temperature difference also follows the same order. Usually, the larger the module size, the larger the variation in temperature, so overall distortion occurs readily with larger modules.

It is very difficult to circumvent this problem with an acceptable increase in cost. For example, aluminum could be considered for use as the bottom chassis material, as it has higher thermal conductivity compared to electro-galvanized steel (SECC) and can provide benefits for heat dissipation. However, use of aluminum inevitably results in increased cost and reduced mechanical strength. Some auxiliary parts need to be added to supplement the mechanical strength while maintaining a high level of heat dissipation. Aside from the mechanical rigidity, a thermal spreader is of great help in preventing deterioration of the liquid crystal and for avoiding wrinkles in the optical sheets. These kinds of problems for a slim-edge module quickly become more serious for increasing screen sizes. An optimal corrective approach must be taken from a holistic system perspective in order to pass the various kinds of reliability tests required for mass production. If possible, it is highly advisable to work with the set manufacturer from the beginning of the design stage. Thermal issues are closely related to overall light efficiency and the level of power consumption. Development and use of highly efficient LEDs and optical components, such as the LGP and the system's optical sheets, are key factors for guaranteeing a sufficient level of commercial quality. Active backlight driving is also useful for reducing power consumption and heat generation. These points are discussed in the next section.

3. Results and discussion

LEDs are selected as the optimal light source over conventional cold cathode fluorescent lamps (CCFLs), because CCFLs present serious electrical and optical challenges for application in an ultra-slim LCD-TV module. Unlike a conventional direct-lit type module, the light sources in an ultra-slim panel can only be placed only along the edges of the module. However, tight spacing of CCFLs causes current leakage and a resultant severe decrease in electrical/optical efficiency. Furthermore, discharge instability can result. When applying LED's to edge-lit large TV modules, it is critical to take efficiency into account as the first criterion. This is due to space constraints for LED placement and potentially severe thermal issues. There are many factors affecting efficiency of the LEDs, such as the LED die (size, manufacturer, design, etc.), the package design, and the opto-mechanical characteristics of the module. While LED manufacturers are working hard to increase the performance of their LED chips, it must be noted that packaging technology also has significant influence on the performance of the device. A package with low thermal resistance is critical for best efficiency, control of color shift, increased reliability, and longest life. For edge-type applications, the slug-type package needs to be widely adopted and packaging with ceramic material is highly recommended, even in view of increased cost. Thermal characteristics of LEDs, especially junction temperature, are a critical factor in light efficiency as well as the lifetime of the device. Fig. 2. shows the junction temperature plot with respect to the power consumption. To evaluate the performance difference quantitatively, two kinds of packages with different materials, PPA (Polyphthalamide) and ceramic (Aluminium oxide), are compared. The heat resistance is set to be $R_{th,j-c}$=17[K/W] for ceramic package and $R_{th,j-c}$=30[K/W]) for PPA package, respectively. The junction temperature increases almost linearly with the power consumption and it is seen that the junction temperature is lowered from 78.4℃(PPA) to 73.8℃ (ceramic) at 120W input power. The junction temperature is an important parameter to evaluate the lifetime of LED, as well as the efficiency, and should be kept below some specific value provided by the LED manufacturer.

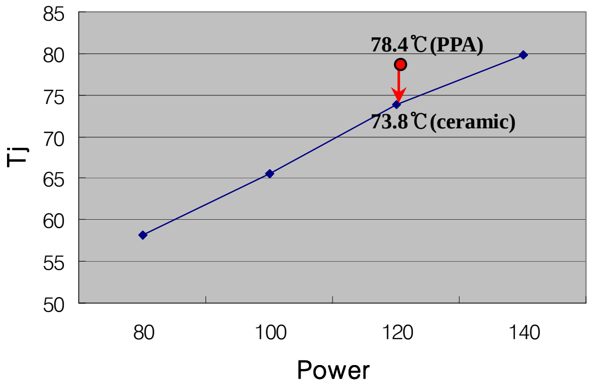


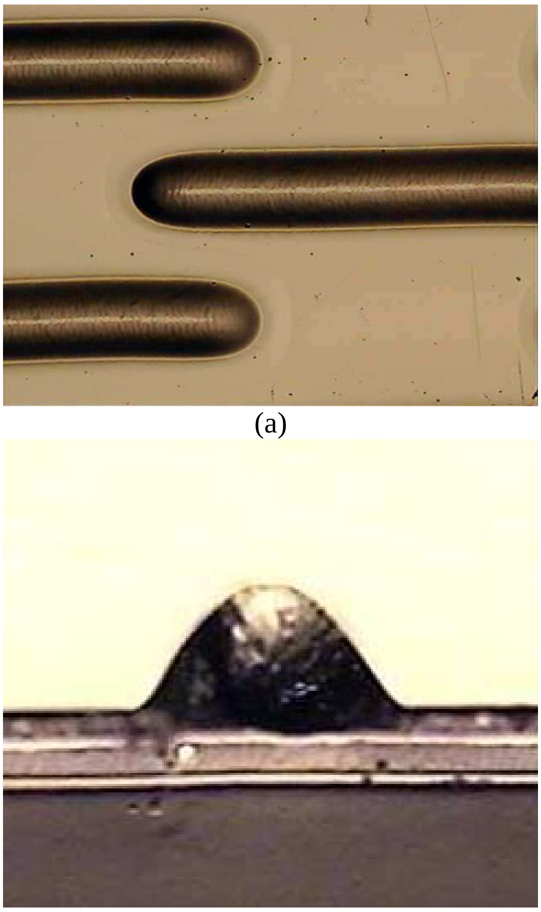
Fig. 2. (a) Junction temperature vs. input power

Also, it is important to consider the method by which white color is produced, as this decision can have a significant effect on color gamut and light efficiency. Table 2 shows a rough estimate of the projected efficiency and color gamut derived from the various methods of producing white light. Note that the efficiency is normalized to the case of the blue chip + yellow phosphor combination. Each method has its own strengths and weaknesses; therefore, selection should be based on the target application and required specifications. For the edge-type TV application, the designer's first priority should be in maximizing efficiency as emphasized above. Case 2 might be most common, due to its simple driving circuit and reasonable color gamut. However, better choices, in terms of efficiency, are cases 3 and 4. Case 4 looks superior to case 3 in that it has better efficiency and a higher color gamut level. However, case 4 may require a color control circuit as would case 5 (RGB LEDs), considering that the blue and the red chips age at different rates and there is a significant difference in the time required for blue versus red chips to reach steady state emission levels.

TABLE 1. Comparison of light efficiency and color gamut for different methods of white color production.

Case	White LED		Efficiency	Color gamut (CIE1931)	Main product
	Chip	Phosphor			
1	Blue	Yellow	100%	<70%	notePC
2	Blue	Red/Green	~75%	~83%	TV
3	Blue	Green/Orange	>90%	~72%	-
4	Blue/Red	Green	>90%	~92%	-
5	Red/Green/Blue	-	~60%	>100%	notePC, monitor, TV

The same argument applies to the LCD's optical components including the LGP and optical sheets. The light extraction pattern of the LGP is formed by a CO_2 laser as an improved method compared to the typical 'scattering ink' pattern seen in screen printing. The resulting microgroove is carefully controlled to provide about 10% higher efficiency level, thanks to its reduced optical loss. As shown in Fig. 3, the microgroove has a well defined shape that reduces the scattering properties. The amount of light extraction is controlled by the pattern pitch, the duty ratio and the width. Also, the angle of the groove will determine the angular profile of the extracted beam. The proper combination of optical sheets is followed by careful application of the LGP to maximize efficiency and to provide best overall appearance.

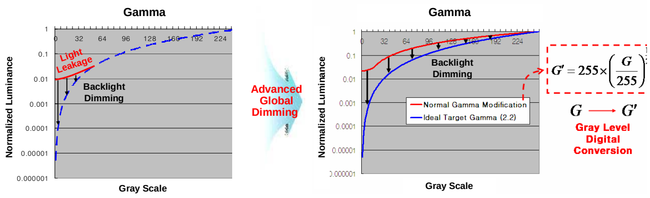

(a)

(b)

Fig. 3. Magnified view of the microgroove patterns in LGP formed by CO_2 laser: (a) top view (b) side view

As a non-emissive display device, an LCD backlight typically consumes constant (maximum) power over time and emits a constant amount of light regardless of the final image seen by the viewer. Even from an early stage, active driving of the backlight has drawn considerable attention, and it has already been adopted for use in some high-end TVs. This technology adjusts the backlight luminance according to the image depicted, which results in reduced power consumption and a great deal of enhancement to the contrast ratio. Active driving technology can be classified by the control method as global dimming, 1-D local dimming, 2-D local dimming, or 3-way local dimming (color dimming). For an ultra-slim module with an edge-lit backlight, global dimming is most appropriate due to its relatively simple dimming algorithm and driving circuit, and in consideration of the physical layout of the light source.

Fig. 4 shows the working principle behind the global dimming technique being used in our edge-lit TV module design. In Fig 4(a), we show the gamma curve of conventional global dimming. Without dimming, the gamma curve follows the red curve at low gray levels due to considerable light leakage. Note that this light leakage can cause significant loss of contrast ratio. Conventional global dimming works in the low gray region mainly for the purpose of increasing contrast ratio, so the amount of power savings is not that significant overall. As shown in Fig. 4(b), with advanced global dimming, the input image data is converted and then transferred to the timing controller just as if the gamma curve were changed to, e.g., 1.8 (red curve) from the ideal value of 2.2 (blue curve). The ideal gamma level is achieved by backlight dimming over the entire gray level range. The difference between the two curves corresponds directly to the amount of power reduction at a given gray level. When this technique is applied, the final gamma curve nearly coincides with the ideal (2.2) gamma curve and results in much higher (dynamic) contrast ratio. Compared to the pixel-compensated global dimming algorithm, which needs memory to store the gray level value for each pixel, this algorithm only requires gray-level averaging with some attention to maximum data level. Therefore, advanced global dimming provides a highly cost-effective, performance-enhancing solution compared to the pixel-compensated global dimming technique. Of course, modifications may be needed to eliminate certain types of artifacts, including darker images in the low gray range and flickering due to abrupt changes in backlight luminance. The amount of power saving is evaluated by measuring the power while playing the standard test image. Compared to the power consumption of 120W (including driver efficiency) without dimming, it is reduced to ~85W (static power – 85.6W, dynamic power – 84.7W) by applying the advanced global dimming. Importantly, the power savings attained by the advanced global dimming technique will also result in a substantial decrease in the temperature of the module.



(a) Conventional method (b) Advanced method

Fig. 4. Operating principle of global dimming technique.

4. Summary

Even though edge-lit backlighting technology is mature in smaller size applications, until now it has not been scalable to large size LCD television. Significant technical barriers must be overcome in order to be able to mass-produce an edge-lit, ultra-slim TV module. First, the module needs to attain a sufficient level of mechanical strength and thermal reliability. Accomplishing this will require panel makers to cooperate more closely with set makers. Secondly, the edge-type TV module must be energy efficient. To achieve this, it is more cost effective to employ an efficient light source and improved optical components than to try to solve the problem simply by way of thermal management. With this point in mind, the edge-lit ultra-slim TV can indeed contribute toward a green TV solution. Finally, our new advanced global dimming technique plays a particularly useful role in reducing overall power consumption, hence increasing efficiency and improving reliability. This technique also provides considerable enhancement to the contrast ratio and results in nearly ideal gamma characteristics. It is expected that the ultra-slim edge-lit TV module will become increasingly popular with ongoing improvements being made in panel transmittance and LED efficiency.