A Color-Filterless LCD by using RGB LED array and lenticular lens array

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Abstract

A liquid crystal display that does not use color filters is proposed. A backlight unit that employs compartmentalized RGB LED arrays and a lenticular lens array is used instead of the color filters in order to direct RGB LED lights into the RGB subpixels. A design of color-filterless LED backlight and experimental results are presented.

1. Introduction

The light energy efficiency of a LCD is as poor as about 5% because most of the lights from the backlight are disappeared during passing through the liquid crystal panel. The polarizer absorbs about 50% of the incident lights and the color filter (CF) absorbs about 70% of the incident light. And so the light efficiency can be improved 200% if the color filter is removed. The field sequential color (FSC) technology is hard to realize because of the color break-up and the fast scan rate as high as 6 times of the conventional LCD.[1-3] Y. Taira proposed an edge-lit color-filterless LCD by using a grating and a lenticular lens array.[4-6] They were successful in removing the color-filter by employing grating, lenticular lens, and directional grating in an edge-lit LCD. However, their method is hard to apply to the direct-lit LCD backlight because there are scattered rays with random directions in the backlight unit.

In this presentation, we propose a direct-lit color-filterless LCD by using compartmentalized RGB LED array and a lenticular lens array. The lenticular lenses image the RGB LEDs onto the RGB subpixels in a one-to-many manner so that the red subpixels receive only red lights from the red LEDs and similarly for the G and B subpixels. Also, the color uniformity was obtained by using a direction-correction diffusing layer that was placed in the position of the color-filter. The principle of operation, simulation, and basic experimental results are presented.

2. Design, Simulation, and Experimental

Figure 1 shows the schematic of the color-filterless LCD. The red lights from the red LED are imaged onto the red pixels by the multiple lenticular lenses and the imaging formula $1/a+1/b=1/f$ holds. There exist multiple units of the above structure in parallel with each other and each compartment is separated with each other by separation walls to prevent light mixing on the same subpixel from adjacent compartments. The LCD may further include a diffusing layer interposed between the CF glass substrate and the R, G, and B liquid crystal subpixels or outside of the front glass in order to make the lights to diffuse and propagate toward the normal direction of the CF glass. The diffusing layer may be formed of transparent resin in which beads or particles are dispersed.

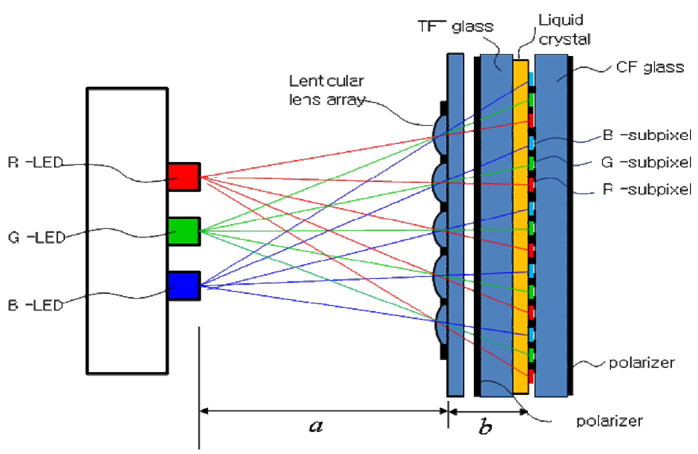
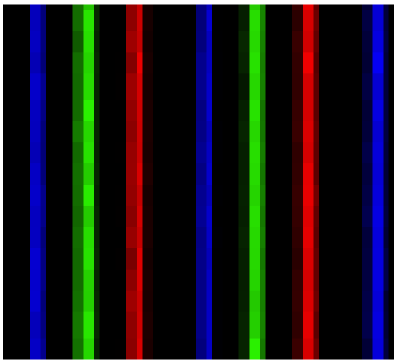


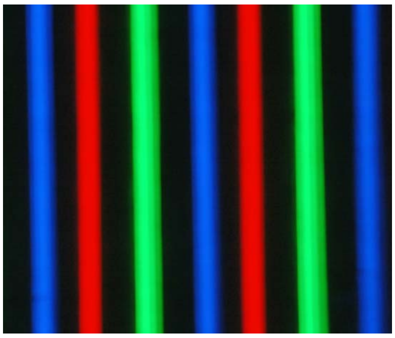
Fig. 1. A schematic of color-filterless LCD by using RGB LEDs and a lenticular lens array.

The lenticular lens sheet can be attached to the rear glass of the liquid crystal panel so that the positions of lenticular lens elements and the pixels coincide with each other.

Figure 2 shows the simulation and experimental results of the system shown in Figure 1. Figure 2 (a) shows the RGB straight lines formed at the position of RGB subpixels and Figure 2(b) shows the RGB straight lines obtained from experimental set up as shown in Figure 1. The spacing between the lines is equal to the spacing of the RGB subpixels and so each of RGB subpixels are illuminated by the corresponding RGB lights from the RGB LEDs .



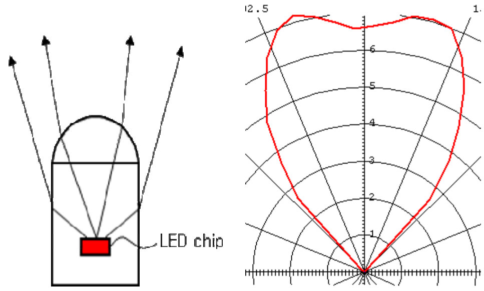
(a)



(b)

Fig. 2. Straight RGB lines formed by the lenticular lens array obtained by simulation (a) and by experiment (b).

The width of each of the lenticular lens element is almost same as the width of the pixel. Since the RGB LEDs are separated by separation walls that are place between the LEDs and the lenticular lens, the lenticular lens array are also grouped in the compartments.



(a) (b)

Fig. 3. (a) An oval type LED and (b) the angular profile of intensity emitted from an oval LED.

Figure 3 shows an intensity angular profile (a) emitted from an oval LED (b). It shows a narrow angular width compared with the Lambertian angular profile from a LED without a coupling lens. This enhances the utility efficiency of light energy by making a best angular width that fits to the compartment in which the light is confined.

The directions of RGB lights from RGB LEDs differ with each other after passing through the RGB subpixels and this may cause the angular color break-up and luminance nonuniformity. This spatial color break-up can be eliminated by placing a diffusing layer between the RGB subpixels and the front glass panel or at the outside of the glass panel. When the diffusing layer is placed outside of the polarizing sheet of the front glass panel the image sharpness may be deteriorated. If the diffusing layer is placed between the subpixels and the front glass panel there should be no polarization change due to the diffusing layer.

Figure 4 shows the expansion of the view angle by the diffusing layer placed outside of the polarizer sheet. When there is no diffusing layer the view angle θ_{out} will be less than 60 degrees. This is too small and so the diffusing layer placed outside of the polarizer sheet or between the subpixels and the front glass panel can increase the view angle up to 180 degrees.

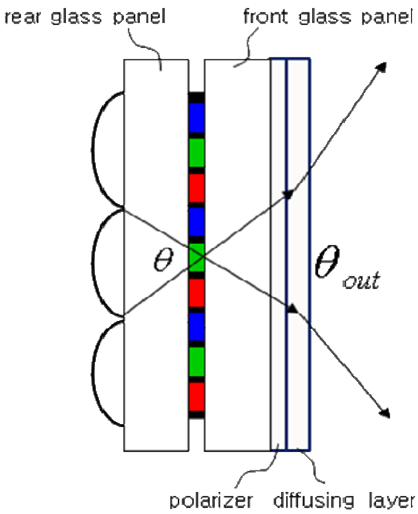


Fig. 4. The expansion of view angle by the diffusing layer placed outside of the polarizer sheet.

Figure 5 shows the layout of RGB LEDs, the compartments, and separation walls. RGB LEDs are grouped and placed periodically along horizontal and vertical directions and the separation walls are placed along vertical directions inbetween the RGB LED groups. The spacing s between the LEDs are determined by the magnification ratio of the lenticular lens and is given by s=Mp, where M is the magnification of the lenticular lens elements and p is the spacing between the RGB subpixels.

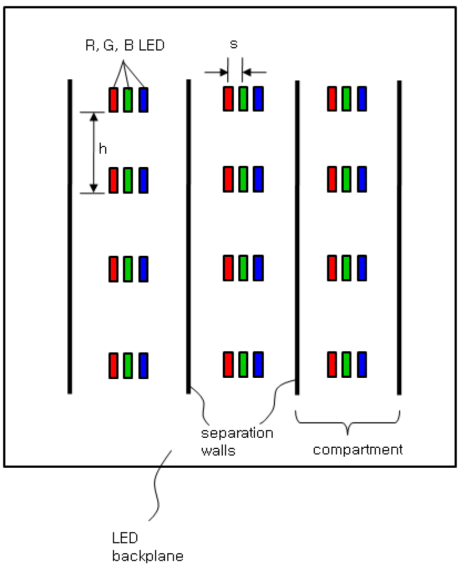


Fig. 5. Layout of RGB LEDs, separation walls, and compartments.

4. Summary

A LCD with no color filter has power consumption as low as 30% of the normal LCD and so the number of LEDs can be reduced to a third of the normal LCD. Also, the manufacturing cost can be reduced much because the color filter process is omitted and also it does not use diffuser plates and prism sheets in the backlight unit. The use of RGB LEDs as light source can extend the color gamut over the conventional LCD using CCFLs so that a high image quality can be achieved.

5. References

[1] Toni Järvenpää, SID Technical Digest, pp82-85(2004).

[2] Fumiaki Yamada, Hajime Nakamura, Yoshitami Sakaguchi and Yoichi Taira, *SID Technical DIGEST*, pp.1180-1183(2000).

[3] Jang Jin Yoo, Jong Hoon Woo, Hyun Ho Shin and Chang Ryong Seo *IDRC03 Digest*, pp.180-183(2003).

[4] Y. Taira, H. Numata, D. Nakano, K. Sueoka, , F. Yamada, M. Suzuki, M. Noguchi, R. Singh, and E. G. Colgan, *SID Technical Digest*, pp1250-1253(2003).

[5] H. Numata, S. Ono, F. Yamada, Y. Taira, US Patent 2007/0139582 (2007).

[6] F. Yamada, S. One, and Y. Taira, *Eurodisplay Digest*, pp.339-342(2002).