Abstract
A color-filterless backlight utilizing reflective and refractive elements in the light guide plate for light extraction and color pixel separation has been integrated with polarization recycling scheme based on wire grid polarizer and quarter wave plate on reflector. All the functional elements modulate and direct light path in a predictable way and therefore can work together properly to improve the efficiency loss at color filter and down polarizer simultaneously.

1. Introduction
Liquid crystal displays have deeply penetrated into the consumer electronic market. Although with highly appreciated image performance, such as viewing angle, contrast and color saturation, the efficiency remains a serious issue to be resolved. Besides aperture ratio of LCD panel itself which is inevitable for active matrix architecture, as shown in Fig. 1, two major sources of efficiency loss are down polarizer and color filter, which in concept take away one half and two thirds of the energy respectively. Both issues are related to the backlight module. The most successful solution for the polarization loss is the DBEF featuring multi-layer of isotropic and birefringent films as a reflective polarizer [1], while wire grid polarizer is being developed with the major barrier in fabrication for large size component [2]. On the other hand, there are two major approaches for eliminating the use of color filers, one is sequential color illumination, and the other one is spatial color pixelized backlighting. The former one needs the support of fast switching liquid crystal, where blue phase LC has been considered as potential solution. The latter one requests components for separating color illumination spatially, where diffraction grating [3] and architecture with spatially separated RGB LED [4] have been proposed.

2. System Architecture and Simulation
The schematic diagram of the backlight architecture is shown in Fig. 2, which can provide pixelized illumination to eliminate color filter, and possesses polarization recycling to reduce loss on down polarizer. For pixelized illumination, RGB LEDs are used as the light source for a side edge type structure. The collimating lens and lenticular array on the top surface of the light guide performs the color separation and makes the pixelized illumination [5]. The v-groove on the bottom surface is the light extraction pattern for the light guide.

However, there has not been total solution to resolve both polarization and color efficiency issues. When combining technology for both issues, the major consideration is the mechanism for light path control must be compatible. For example, the polarization recycling mechanism involving scattering for depolarization will not be compatible with the color separation for pixelized illumination using refractive and reflective element. In this paper, an backlight architecture considering both pixelized illumination and polarization recycling is proposed, and the prototype has been built up for performance evaluation.
Based on the normal specification of the display unit for an intelligent mobile phone, a 3.7" size 480x800 pixelized backlight has been designed and prototyped. Two sets of RGB LEDs have been used for a sufficient illumination, one for each side edge illumination of a symmetrical light guide. Each set include two red LEDs, two green LEDs and one blue LED for a RGBGR full pixel configuration. The reflective cavity surrounding each LED is used for modulating the angular profile of light source for the uniformity on the backlight surface. The top view and side view of the arrangement are shown in Fig. 3(a) and (b) respectively.

The LEDs are located at the focal plane of the collimating lens, and the pitch and focal length of the lenticular array are optimized for the required pixel specification. The shape and density of the v-groove is then optimized majorly for the uniformity. The polarization also play important role in uniformity design. The wire grid polarizer has been set as linear polarizer with two orthogonal axes having 100% and 0% reflectance, and the quarter wave retarder has been set as ideal retarder with 0.25 wave retardance in the ray tracing program LightTools™. Fig. 4 shows the distribution of the v-groove on the bottom surface of the light guide, and it shows that the density is higher at the center due to double side edge light source arrangement. Fig. 5(a)-(c) shows that the pattern of emerging light from the top surface of the backlight unit for red, green and blue color, and it indicates that the illumination has been pixelized.

Figure 3. (a) Top view (b) Side view of the backlight module

Figure 4. Distribution of V-groove on the light guide

Figure 5. Light pattern on the exit of the backlight for (a)Red (b)Green and (c)Blue

Figure 6. Simulated illuminance distribution on the backlight unit
Fig. 6 shows the simulated illuminance distribution on the backlight with all three color LED turned on, where the frame indicate the active area of LCD panel. The uniformity is 81%.

3. Prototype and Measurement

Critical components in the system which request high precision fabrication are light guide plate with v-groove and lenticular array. Fig. 7 shows the measured surface profile of single v-groove, which features isosceles triangle with the width of 11.7 μm, and depth of 7 μm, and its angle is optimized for uniformity and diverging angle of emerging light from the backlight. Fig. 8 shows the measured surface profile of two lenslet of the lenticular array, which has a pitch of 105 μm to match the required pixel size of the display panel.

The full assembly of the prototype is shown in Fig. 9, with the marking of all the key components for pixelized illumination and polarization recycling. Fig. 10(a) and (b) show the microscopic view of the pixel structure from the backlight without and with WGP, which indicates that the polarization recycling mechanism does not deteriorate the light path for spatial color separation. When viewing the backlight through a polarizer with its transmission axis at two orthogonal directions as shown in Fig. 11, the apparent difference of brightness indicates that the emerging light from the light guide is highly polarized.

![Figure 7. Measured surface profile of v-groove](image)

![Figure 8. Measured surface profile of lenticular lenslet](image)

![Figure 9. Assembly of backlight prototype](image)

![Figure 10. Pixelized illumination](image)
4. Conclusion
The proposed architecture of backlight module is intended for improving the efficiency of LCD, and the evaluation on the prototype has shown the feasibility of combining pixelized illumination and polarization recycling scheme with wire grid polarizer so as to reduce the loss at color filter and down polarizer in traditional LCD. The light utilization efficiency of 20% has been achieved. The scaling up techniques is being investigated so that the architecture can be available for larger panel size.

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6. References