Novel diffraction grating light guide for LED backlight

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ABSTRACT

In conventional LED backlight as that used in mobile liquid crystal displays (LCDs), typically the structure consists of a light guide, a diffusing sheet, prism sheets and so on. In this work we would like to propose a novel light guide where we have applied a special diffraction grating technology which provides a high performance with a thinner backlight. The special designed diffraction gratings on the light guide redirects incident light by diffraction to the front direction without the utilization of prism sheets. For testing the performance we made a diffraction grating light guide suited for a 2.4 inch backlight with 4 LEDs in a trial. As a result, the backlight that consisted of a diffraction grating light guide, with either a single or none prism sheet achieved equivalent performance to conventional backlights.

Keywords: LCDs, LED backlight, light guide, diffraction grating, prism sheet

1. INTRODUCTION

The conventional LED backlights as that used in the mobile liquid crystal displays (LCDs) for high brightness and uniformity typically consists of a light guide, a diffusing sheet, prism sheets and so on. These backlights are sidelight types; input light comes from the side of the light guide and it is needs to be redirected to the front direction. The incident light from the side is guided inside the light guide by total reflection. As the light passes through the light guide, it is redirected by refraction or reflection at dots or prisms set on the light guide surface and it is emitted from the top surface of the light guide. But the emitted angle is quite large; the ordinary light guide that has dots or prisms don't redirect the transmitted light to the front direction itself. The emitted light from the ordinary light guide is redirected to the front direction by prism sheets. The prism sheets are indispensable for those backlights to redirect the emitting light in front.

On the other hand, the backlight for mobile phone is desired to be thin and light, therefore it is preferable to have good performance with a minimum of components. Besides, reduction of the optical components makes a big advantage to cut the cost down and simplify the manufacturing process for the backlight. Another demand for mobile phone backlight is power saving. For achieving it, the optical components must be optimized to be maximized light efficiency.

We propose a novel light guide with either a single or none prism sheet, which provides a high performance in a thinner backlight, by applying diffraction grating technology. The diffraction grating is suitable for sidelight type light guide because it is easy to redirect light to the front direction. The desired angular distribution of brightness is managed by controlling the emitted light to the desired direction, which is possible through a special designed diffraction grating pattern. This pattern was made possible by using Electron Beam (EB) technology. With this technique, the diffraction gratings found in tiny cells are drawn freely with the calculated parameters such as spatial frequency, azimuth angle, etc. We call this technique as "Crystagram" [1-4]. It is used widely for security purpose against counterfeiting.

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We applied this Crystagram technique to the light guide of the backlight. The special designed diffraction gratings on the light guide redirects incident light by diffraction to the front direction without the utilization of prism sheets. To show the actual performance, we built a backlight module with the diffraction grating light guide suited for a mobile phone in a trial.

2. OUTLINE OF NEW BACKLIGHT

2.1 Typical Backlight

The conventional LED backlight as that used in the mobile LCDs, typically consists of a light guide with diffusing dots or prisms, a diffusing sheet, a reflector sheet, and two prism sheets. Although the ordinary light guide that has dots or prisms is used to emit from the top surface of the light guide, it doesn't redirect the incident light from the side to the front direction itself. It is necessary to use two prism sheets that redirect the emitted light from the light guide to front direction. Moreover, additional diffusing sheets are required to smooth the distribution of the emitted light. The typical structure of conventional LED backlight is shown in Figure 1.

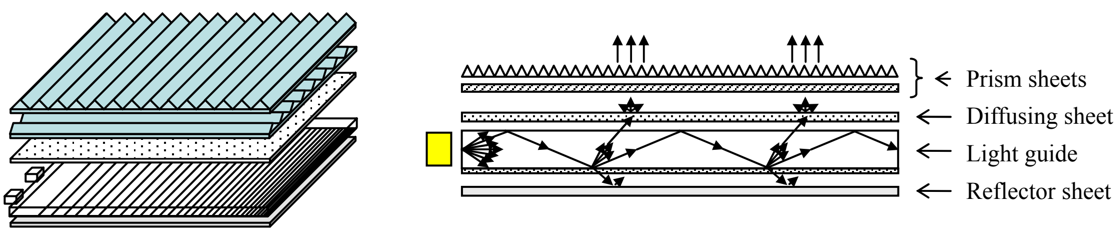


Figure 1 : The outline of conventional backlight using dots or prisms.

Because a lot of components besides backlight module, are used for LCDs. This makes assembling process complicated increasing the costs and making it thicker. Therefore, component reduction is demanded for thin backlight and cost reduction.

2.2 New Backlight using Diffraction

We aimed to redirect the incident light to front direction by light guide itself and eliminate the prism sheets by using diffraction grating in substitution for dots or prisms pattern on a conventional light guide.

The advantage of the diffraction grating is that the angle of the emitted light can be controlled. The angular distribution of the emitted light can be also designed. A typical light guide with a dots or prisms pattern can not redirect the incident light to the front direction without prism sheets. However, we designed and optimized a diffraction grating for a backlight system, which redirect incident light to the front direction with less components. The structure of the backlight using diffraction grating light guide is shown in Figure 2.

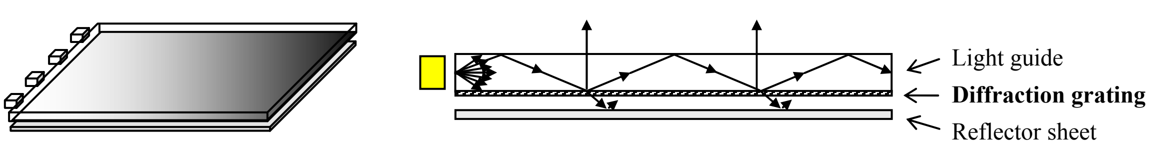


Figure 2 : The outline of our backlight using diffraction grating.

On the other hand, as it is well known, diffraction grating causes spectral dispersion and shows rainbow colors for white illumination. Therefore, it is needed to consider the structure to be able to have the emitted light from backlight shown white color for full color LCDs. For this, we designed the diffraction grating light guide to be not colored using an optimized diffraction grating pattern and a combined diffusing pattern within.

We designed the spatial frequency of the diffraction grating to redirect incident light to the front direction by light guide itself. Moreover, we use several numbers of spatial frequencies, which were selected theoretically for a designed angular distribution to ensure minimum color variation. In the case of light guide using diffraction grating with single spatial frequency, the angular distribution is narrow and the emitted light shows rainbow colors by the spectral dispersion. By using several numbers of spatial frequencies, diffraction angles for each spatial frequency are different, then the rainbow colors by the spectral dispersion are attenuated and the angular distribution is broadened.
The diffusing pattern is the preferred technique to optimize the angular distribution of the emitted light. In particular, a directional diffusing is better to be utilized in a diffraction grating light guide.
The whiteness is improved more when the diffusing pattern that is suited for the diffraction grating backlight is used.
In addition, high brightness uniformity is very important in backlight. High uniformity is acquired by optimizing the density distribution of the diffraction grating. Ordinarily, the density increased reciprocally to the distance of the light source. The density distribution in our light guide was decided from simulations on the basis of characteristics of diffraction grating.

We made the diffraction grating pattern by EB technology in a trial. In this method, as the diffraction grating is disposed in a cell unit, it is easy to combine many spatial frequencies and to change density distribution with cells locations.

3. DESIGN FOR DIFFRACTIVE LIGHT GUIDE

3.1 Diffraction Grating

(a) spatial frequency

The spatial frequencies of the diffraction grating on our backlight are calculated by

$$\lambda = d\,(\sin\theta_i \pm \sin\theta_d)$$
$$L = 1000/d$$

where λ is wavelength of diffracted light, d is grating pitch, θ_i is incident angle, θ_d is diffraction angle and L is spatial frequency of diffraction grating. For example, when it assumes that θ is 60 degree and λ is 550 nm, the necessary spatial frequency of diffraction grating is more than 2000 lines/mm to be able to diffract light to the front direction.
The effect of a single diffraction grating light guide within several sources is shown in Figure 3. It shows that light guided through the light guide is redirected to the front side.

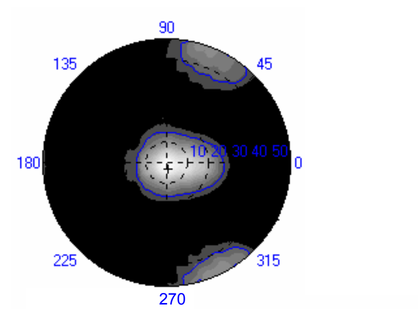


Figure 3 : The angular distribution of the light guide using a single diffraction grating.

Plural spatial frequencies are combined to optimize the angular distribution and to ensure whiteness of the emitted light. The effect rises when the number of spatial frequencies is increased.

(b) cell structure

We optimized the density distribution of diffraction grating cell to obtain brightness uniformity over the emitting area of the backlight.

To acquire uniformity, it is necessary that the density distribution of the arrangement of diffraction grating cells be optimized. For example if a diffraction grating occupies all of the emitting area, the brightness near light sources becomes too high, and is reduced significantly as far it is from the light sources. To achieve flatness in brightness distribution over the backlight, it is necessary that the density of diffraction grating becomes higher as far from the light sources. An example of cell density distribution in diffraction grating light guide is shown in Figure 4.

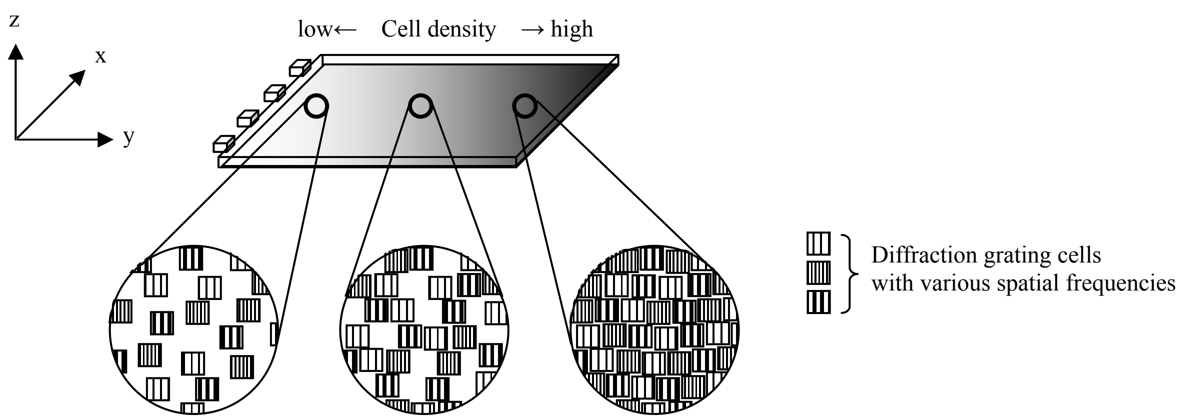


Figure 4 : Cell density distribution in diffraction grating light guide

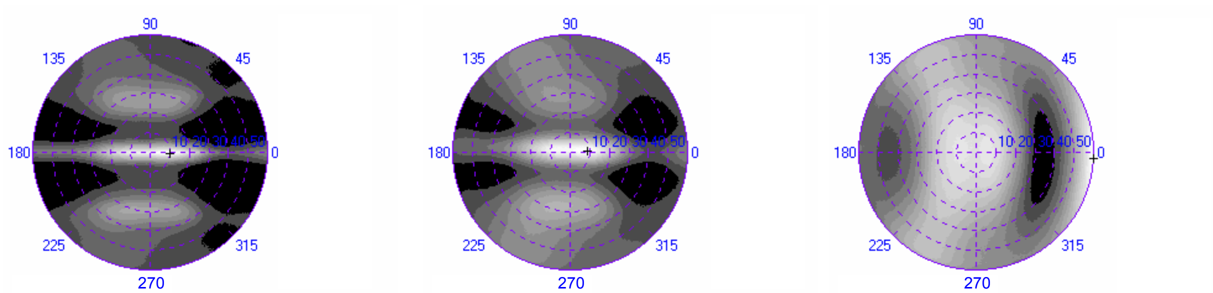
3.2 Diffusing Structure

Some diffusing structure is useful to get rid of rainbow colors. For our diffraction grating light guide, a directional diffusing pattern that extends the incident light to x direction is most suitable.

The effect of the directional diffusing pattern is shown in Figure 5. In Fig.5 (a), it is shown the result of diffraction grating only backlight; without any extra sheets. In (b), it is shown the result when an outside diffuser sheet is used. In (c), it is shown a result for diffraction grating backlight using an inside directional diffusing pattern.

In the case of (a), the brightness angular distribution is narrow and color change for angular shift is very large. In the case of (b), the distribution is broadened and the color change is smaller. In the case of (c), the distribution is dramatically broadened and the color change is sufficiently small. The reason why a good result is obtained in (c) is the directional diffusion pattern has a function to extend light in the x direction.

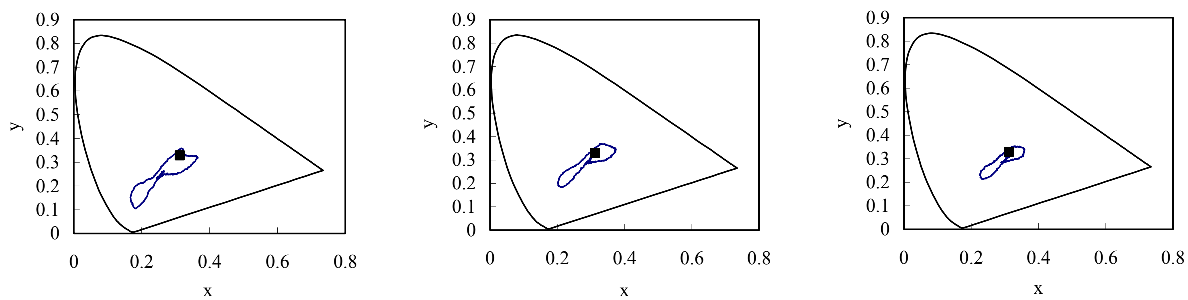
We added a directional diffuser effectively. In our diffraction grating light guide, we use areas without diffraction grating for the diffuser pattern (Fig. 6).



(a) Angular distribution for none extra sheets

(b) Angular distribution for normal diffuser

(c) Angular distribution for directional diffusing pattern



(a) Color change for ± 60 degree angular variation for none extra sheets

(b) Color change for ± 60 degree angular variation for normal diffuser

(c) Color change for ± 60 degree angular variation for directional diffusing pattern

Figure 5 : Angular distribution and color change for angular shift for various diffuser.

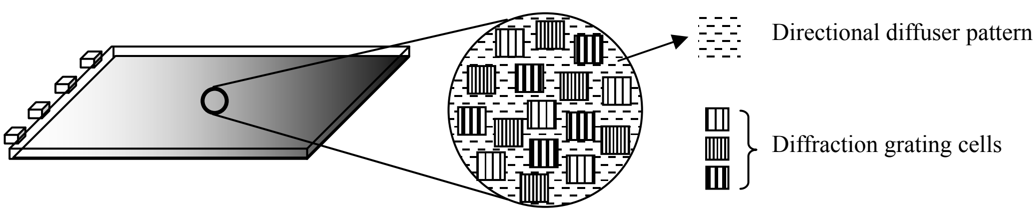


Figure 6 : Combination of diffraction grating and diffuser pattern.

4. EXPERIMENTAL RESULTS

Our diffraction grating light guide was made by injection mold.

Result for a 2.4 inch backlight with 4 LEDs in a trial is shown below. It is composed of a diffraction grating light guide, a reflector sheet, a diffusing sheet (Hz: 85.5%), and a prism sheet. In this trial, angular distribution and whiteness were good, on the other hand, brightness in front direction is reduced because the distribution is too wide. In order to restrict the angular distribution, a single prism sheet with the direction along the y direction was tried. The brightness achieved in the front direction was improved.

We show uniformity, brightness angular distribution and color at a representative point, and light efficiency.

Fig.7 shows the outward appearance of our backlight. It shows flat luminance without rainbow color.

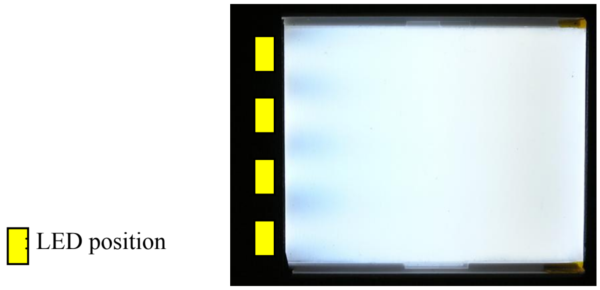


Figure 7 : Outward appearance of backlight unit in this trial.

Fig.8 shows brightness angular distribution of our backlight at a representative point. The brightness in front direction is about 2500cd/m^2. FWHM of emitting light is nearly 50 degrees in y direction and nearly 35 degree in x direction.
Fig.9 shows brightness angular distribution of a typical mobile phone. On comparing two results, the performance of our backlight meets the standard and our backlight has wider distribution.

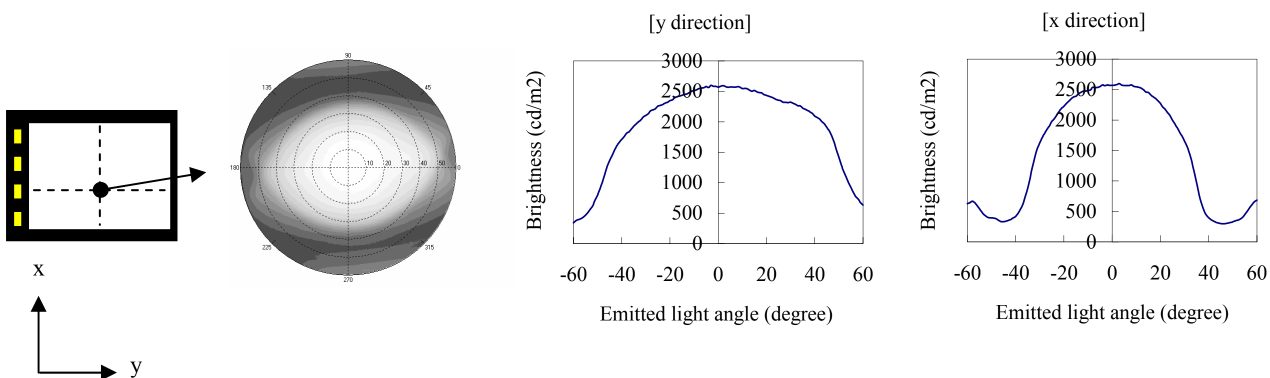


Figure 8 : Brightness angular distribution of our backlight.

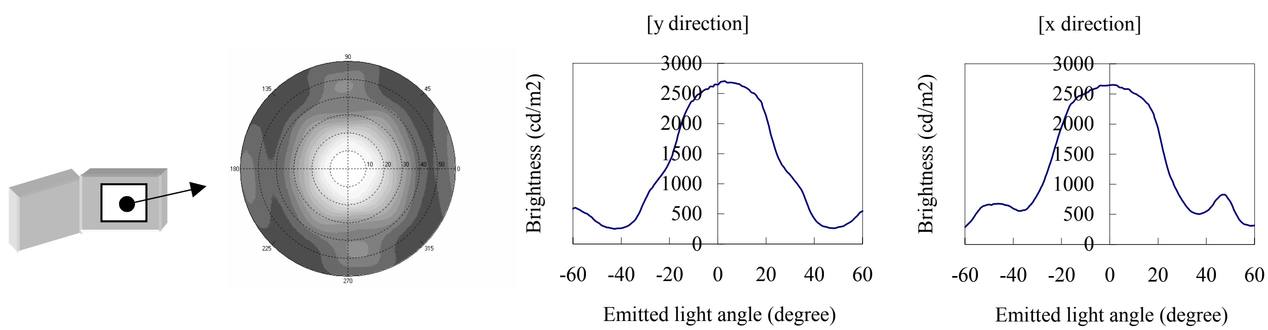


Figure 9 : Brightness angular distribution of typical mobile phone.

Fig.10 shows the color change for ± 60 degree angular variation of our backlight at a representative point. There are small changes by angler shifts, around standard white.
Then fig.11 shows color change for angular shift of typical mobile phone. Typical backlight has good whiteness because there is no factor for spectral dispersion. But, comparing two results, it may be said that there is no big difference although a distribution is wider on our backlight.

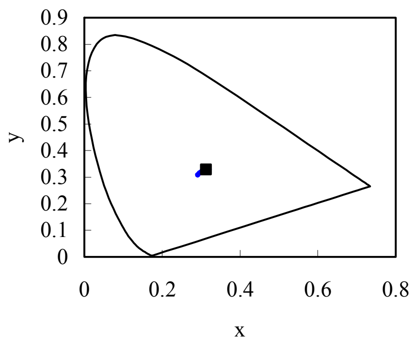


Figure 10 : Color change for ± 60 degree angular variation in our backlight

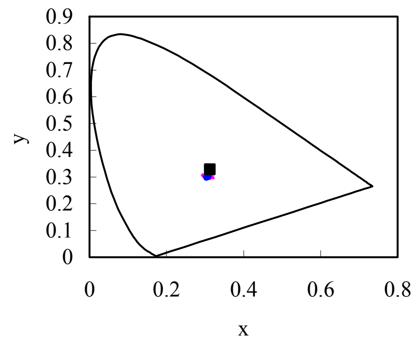


Figure 11 : Color change for ± 60 degree angular variation in typical mobile phone.

Fig.12 shows brightness distribution along the y direction of our backlight. It is sufficiently flat.

Fig.13 shows brightness distribution along the y direction of typical mobile phone. It is extremely flat. In our backlight, although brightness of the latter half fall slightly, it can be improved by optimizing density distribution of diffraction grating more.

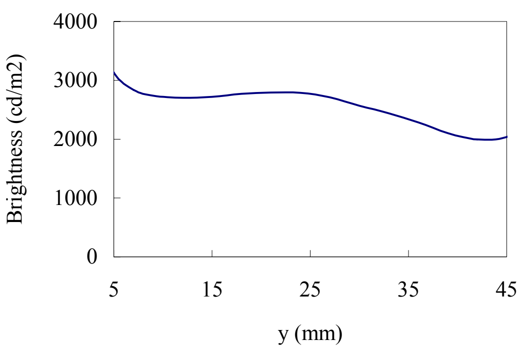


Figure 12 : Brightness distribution along the y direction of our backlight.

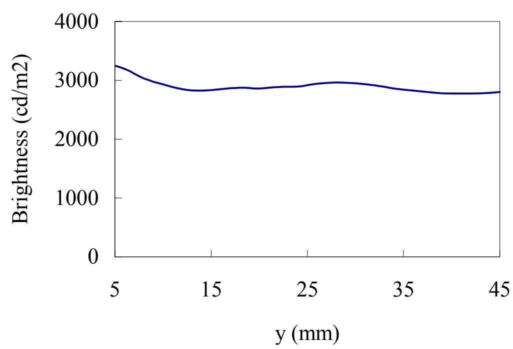


Figure 13 : Brightness distribution along the y direction of typical mobile phone.

Table.1 shows our trial result in comparison with the result for the general mobile phone. The brightness is almost equivalent with the mobile phone's. In the same way, it is achieved efficiency more than 30%. The efficiency can be risen more by improvement of backlight packaging accuracy.

	Toppan	Typical mobile phone
Normal brightness (cd/m2)	2787	2943
Efficiency (%)	33.1	39.2

Efficiency : OUTPUT luminance [lumen] / INPUT luminance [lumen] x 100

Table 1 : Comparison of our backlight and typical mobile phone.

5. CONCLUSION

A novel design for diffraction grating light guide was presented. We succeeded to redirect the incident light from the side to the front direction by light guide itself. It means to redirect the incident light by diffraction to the front direction without prism sheets.

We demonstrated a 2.4 inch backlight with 4 LEDs which consists of a new diffraction grating light guide, a reflector sheet, a diffusing sheet and a prism sheet. As a result, the backlight achieved equivalent performance to conventional backlights. We acquired an angular distribution and a uniformity of brightness that are almost desired, as a result of optimizing of the spatial frequency of diffraction grating, the diffusing pattern and the density distribution of diffraction grating cell. Moreover, we construct a white color backlight, canceling rainbow color by spectral dispersion that caused by diffraction.

We achieved above in a thinner backlight. However, for higher performance, it is better to improve further on brightness and uniformity. The diffraction grating backlight has the capability to be achieved a higher performance by the diffraction grating design. Not only light guide optimization but also total design for backlight components is necessary to satisfy optimum performance as a backlight.

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