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Pattern optimization of compound optical film for uniformity improvement in liquid-crystal displays

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ABSTRACT

The density dynamic adjustment algorithm (DDAA) is designed to efficiently promote the uniformity of the integrated backlight module (IBLM) by adjusting the microstructures' distribution on the compound optical film (COF), in which the COF is constructed in the SolidWorks and simulated in the TracePro. In order to demonstrate the universality of the proposed algorithm, the initial distribution is allocated by the Bezier curve instead of an empirical value. Simulation results maintains that the uniformity of the IBLM reaches over 90% only after four rounds. Moreover, the vertical and horizontal full width at half maximum of angular intensity are collimated to 24 deg and 14 deg, respectively. Compared with the current industry requirement, the IBLM has an 85% higher luminance uniformity of the emerging light, which demonstrate the feasibility and universality of the proposed algorithm.

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1. Introduction

Up to now, the liquid crystal display (LCD) still dominates the display industry domain with all-size products, which has advantages in terms of both cost and technology. As well known that the LCD is non-self-emitting, it needs a quasi-collimated backlight module (BLM) that provides a uniform and collimated surface planar light source, which is converted from a point- or line-light source. The backlight module can be categorized by the placement of the original light source, the one is direct-lit and the other is edge-lit [1–5].

With regard to the direct-lit backlight, the LED array light source is laid on the bottom surface of the BLM, and for uniformity improvement, there should have one diffusion sheet, two cross brightness enhancement films (BEF), and other films [6,7]. The BLM for the edge-lit backlight consists of the LED, LGP, reflective plate, two cross BEFs, diffusion sheet, in which the LED light source is placed close to the edge of the BLM. In order to obtain a uniform planar light source, the typical method is to regulate the distribution of the diffuse dots on the bottom surface of the LGP according to the emerging light quantity. As the light emerging from the LGP has a random spreading direction, the output light needs to be converged by the double crossed BEFs in the horizontal and vertical direction [8–12].

In order to furnish a uniform planar light source, some theoretical optical models of the BLM were presented, but there still had a serial of uncertain parameters, such as the optical material of the BLM, the characteristics of the adjusting light microstructure, and a lot of time to calculate the optical model for the BLM in advance. The literatures are as follows: Teng proposed a method for precisely simulating the optical behavior of an LGP with microstructures of rough texture and rugged edges [13], the model was complicated and there were lots of unknown parameters. Liu constructed precise optical modeling of blue LED by Monte Carlo ray-tracing [14], the model was intricate and it only described the LED model.

Other researchers also developed the distribution expressions for the microstructure, and the distribution formula depended on lots of parameters, such as the thickness, width and length of the LGP, the placement of the light source and etc... The literatures are as follows: Lee introduced a method of optimizing optical patterns in an LGP to promote illuminance and uniformity of the LCD [15], it needed two separate steps to realize the maximal luminance and uniformity. Li presented an algorithm of optimizing LGP with neural network and genetic algorithm [16], it required a complicated algorithm and the algorithm would take abound of time to reach the target for the uniformity. Fang researched the integrated optical design and optimization for LED BLM with prism patterns [17], but it still needed Taguchi method to improve the uniformity. Kim investigated an optimized pattern design for the thin LGP [18]. Although it adopted the pattern density function with a simple exponential function, the pattern density control

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coefficients were still uncertain and needed to be fixed. Wang analyzed optimized LGP optical brightness parameters [19], it integrated the back-propagation neural network and a revised genetic algorithm to identify the optimal experimental level combination of the optical brightness parameter's design, but Taguchi method is still needed.

Above all, the methods adopted a complicated algorithm and the optimization procedure would bring about heavy workload for designers. The optical model and distribution expressions mentioned above have not enough potential general-popularization and practicality.

The integrated backlight module (IBLM), proposed in Ref. [20], will be further studied to improve the uniformity in this paper. The uniformity for the literature was 85% and the initial value was decided by an empirical value, meantime, there still had hot spot area. Therefore, the uniformity and the algorithm need to be improved. The IBLM has no diffuse dots to adjust the light distribution, it only needs to adjust the area of the bottom of the compound optical film (COF). The double crossed BEFs can be removed from the IBLM. Therefore, the principle of acquiring the uniform planar light source is different from the typical method. In this paper, we further exploited the IBLM, which had been specifically discussed in preview research; the characteristic of the microstructure for pumping the light is studied. And we adopt dynamic adjustment algorithm (DDAA) to adjust the distribution of the microstructures.

2. The optimization principle

2.1. The principle of light adjustment for the IBLM

The IBLM consists of a reflective sheet, an LGP without diffuser dots and the COF, the structure of which is drawn in Fig. 1. The principle of light adjustment for the IBLM is obviously different from the conventional BLM. As the LGP itself has no diffuser dots on the bottom surface, the light is trapped in the LGP by the total internal reflection (TIR) surface before it encounters the interface surface between the COF and LGP. Therefore, the interface surface is the exclusive exit of the LGP, and the area of the interface surface can be set to regulate the amount of the emergent light. As shown in Fig. 1, the principle of the microstructures that can adjust the emergent light is that the area of the interface surface determines the amount of the light pumped. Therefore, the area ratio of the interface surface decides how much light can be extracted. The area ratio is defined as a parameter of the density as follows:

$$\mathrm{d} = \frac{\pi R^2}{A^2} \tag{1}$$

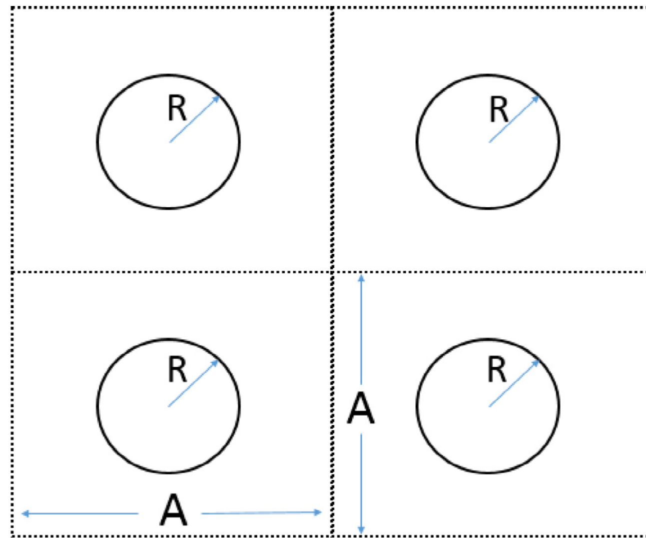

Fig. 2. The definition of the density for the area ratio of the interface surface.

where, d represents the density of the interface surface, A and R are the length of a side for the square cells and the radius of the interface surface, respectively. Fig. 2 is the sketch map for the definition of the density.

In this theory, the higher density the microstructure is set, the higher efficiency the BLM can achieve. However, the maximum value for the density conforms to the rule that two adjacent units cannot overlap each other, otherwise parts of the function for the microstructure will decrease, such as the collimated function. The maximum value can be calculated from geometric approach. Under the consideration of that the microstructure is specially designed and its shape should be kept, increasing the density means raising the number of the microstructures in the unit area.

2.2. The principle of the DDAA

The algorithm of adjusting the light is based on the principle of the geometrical optics. Once the dimension of the light source and IBLM is constant, the emergency light intensity should be proportional to the density of the microstructure at the corresponding position. In other words, this relationship can be expressed as follows.

$$\mathrm{L(i,j)} \propto \mathrm{d(i,j)} \tag{2}$$

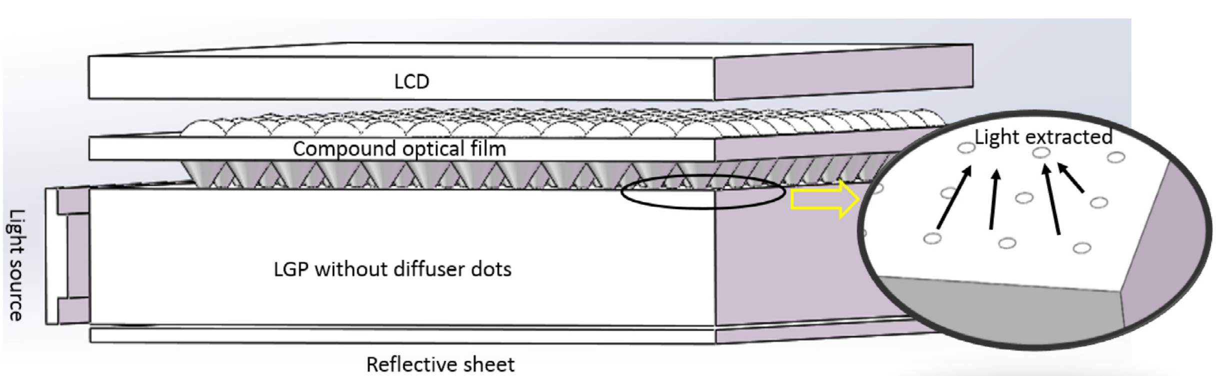

Fig. 1. The schematic diagram for the IBLM.

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