Brightness Enhancement Scheme for High-ppi VR Display

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Abstract

A high brightness backlight unit design scheme is proposed to meet the requirements for low power consumption and high pixel per inch in virtual reality products. And the backlight unit is successfully produced, whose brightness is increased by 24% compared with conventional virtual reality backlight unit, and the product performance, production stability, and reliability are also verified.

Author Keywords

VR display; backlight unit; brightness enhancement.

1. Introduction

The proposal of the metaverse concept has accelerated the development of virtual reality (VR) products [1-2]. In order to enhance the visual display effect and immersive experience of VR products, high pixel per inch (PPI) liquid crystal displays (LCD) is becoming increasingly crucial [3]. However, as PPI increases, the screen transmittance further decreases. To ensure display brightness, increasing the brightness of backlight unit (BLU) has become a top priority for high PPI products. In addition, as a near eye head mounted display device, to ensure user viewing comfort, the VR LED duty should be less than 20% to prevent dizziness caused by display ghosting. It means that for the same size and components to achieve the same BLU brightness, the current of LED for AR needs to exceed the level of conventional consumer electronics more than five times (as LED current increases, LED luminous efficiency decreases). Meanwhile, with the increase of LED current, the power consumption of BLU increases, which in turn leads to high temperature and reduced standby time of the VR machine. Therefore, in order to enhance user experience and meet their needs for high PPI, long battery life, and strong heat dissipation, it is imperative to improve the brightness of VR BLU and reduce module power consumption.

This study mainly starts from the design of Light guide plate (LGP) and conducts theoretical analysis on the brightness improvement of VR BLU. Taking the single light bar side-entry BLU as an example, using LightTools simulation, the parameter of LGP pattern is determined. Moreover, through the processes of dot colliding, electroforming, and injection molding, the processing of LGP pattern is achieved. In comparison with normal VR BLU, this product has been tested to increase brightness by up to 24%. Furthermore, it has passed the reliability verification, and there are no abnormal displays such as scratches and white spots on the product.

2. Principle

The side-entry VR BLU is comprised of LED light bars, optical films such as reflective sheets, LGP, diffusion sheets, and prism sheets, as well as structural components such as rubber frames and back plates. All these elements collaborate to transform the side-emitting point light source into a uniformly frontal-emitting planar light source. The LED light bar acts as the light source and supplies initial light for the BLU. The LGP, via its bottom patterns, disrupts total internal reflection and refracts light to above the diffusion sheet. The diffusion sheet homogenizes the light through internal diffusion particles. The prism sheet converges light and enhances the frontal brightness of the BLU. The reflective sheet reflects the light emitted by the LED onto the LGP to increase the utilization rate of light. Evidently, the light source LED light bar and the LGP that guides light to emit in the frontal direction are the key components for enhancing the brightness of the BLU. Hence, improving the luminous efficiency of LED [4] and optimizing the design of the LGP are the main research directions for boosting the brightness of the BLU. This paper focuses on commencing from the design of the LGP and maximizing the utilization rate of light transmission through the redistribution of brightness perspectives, thereby realizing the improvement of BLU brightness.

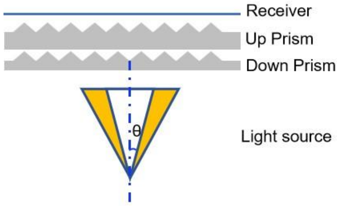

Figure 1. Schematic diagram of simulating the brightness of the upper prism surface at different emission angles (θ).

First, taking the upper and lower prisms as a whole, the light angle that can be maximally utilized by the prisms is determined by modeling in Lighttools. As shown in Figure 1, we take the upper and lower prisms as the light transmission medium, establish a surface light source under the lower prism, and simulate the light distribution after modulation by different LGP patterns by changing the light emission angle θ of the surface light source.Then, a detector is established above the upper prism to determine the effect of backlight brightness enhancement based on the distribution of viewing angle brightness at the center position of the detector.

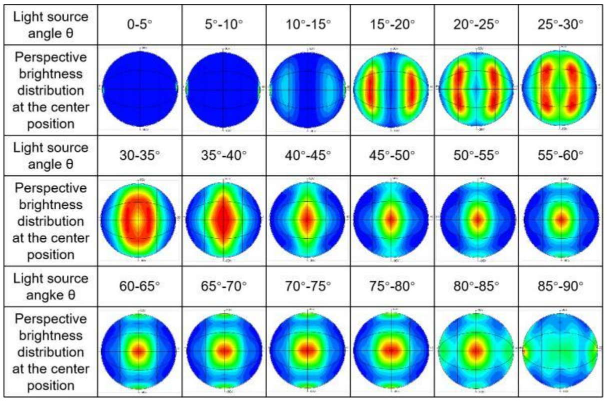

Figure 2. Simulation results of brightness distribution on the surface of the upper prism at different emission angles (θ).

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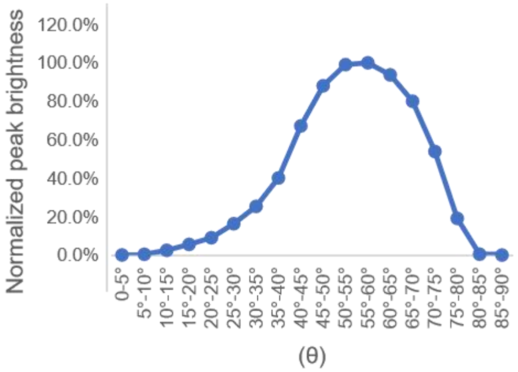

Figure 3. Normalized simulation results of peak brightness on the surface of the upper prism at different emission angles (θ).

Figure 2 shows the simulation results of the brightness distribution of the viewing angle of the light exiting from the surface of the upper prism at different θ angles. It can be seen that when θ = 50° ~ 80°, the brightness is mainly concentrated at the frontal viewing angle. Figure 3 shows the normalized simulation results of the peak brightness on the surface of the upper prism at different θ angles. When the light entering the lower prism is concentrated at 55° ~ 60°, the brightness is the highest, that is, the light utilization rate is the largest. It can be seen that by specifically designing the LGP and modulating the light emitted from the upper surface of the LGP to be within the range of 55° ~ 60° as much as possible, the brightness of the BLU can be enhanced.

3. Design Verification

Figure 4 shows the light path diagrams of LGP under different patterns, (a) hemispherical and (b) pyramidal. It can be seen that compared to the curved light-receiving surface of hemispherical patterns, the planar light-receiving surface of pyramidal patterns can export more light rays, which is more conducive to changing the angle of light transmission and achieve high efficiency brightness output.

Therefore, we establish a simulation model based on the VR BLU structure as shown in Figure 5(a), in which the materials and surface properties of each component are set according to the actual situation of a certain VR BLU product. The mass-produced hemispherical patterns are used as the control group to explore the effect of BLU brightness improvement by changing the pyramid patterns. As shown in Figure 5(b), there are 7 parameters for the four sided pyramid structure, namely A, B, α1, α2, β1, β2 and H.

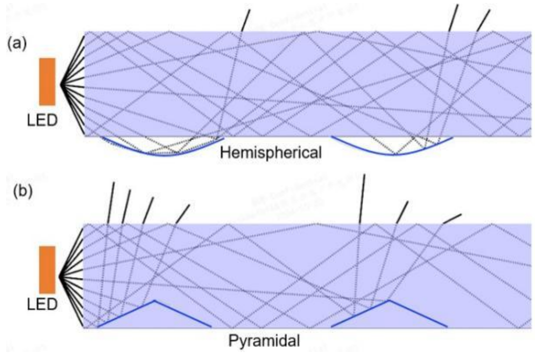

Figure 4. Light path diagrams of LGP under different patterns (a) hemispherical, (b) pyramidal.

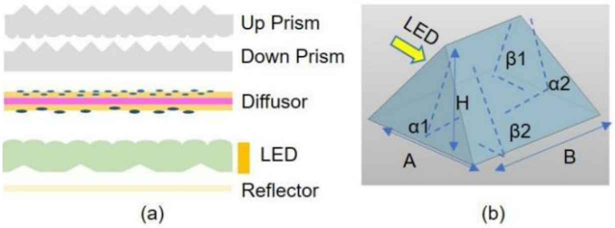

Figure 5. (a) Simulation structure diagram of BLU. (b) Diagram of four sided pyramid structure parameter.

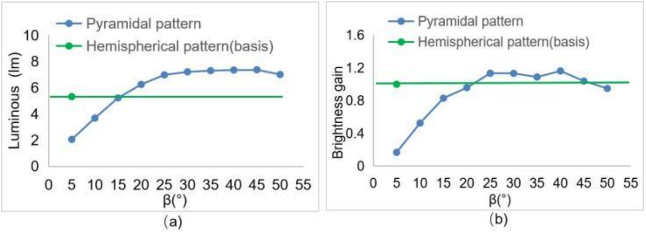

Figure 6. Simulation results of (a) luminous flux and (b) central brightness gain at different β.

As the incident angles β1and β2 are key parameters in modulating the angle of light emission and optimizing BLU performance. Therefore, we simulate the BLU luminous flux and center brightness gain under the condition of β angle ranging from 5° to 50° at intervals of 5°. As shown in Figure 6 (a), when β>25°, the light flux increases from 5 lm to 7 lm compared to the hemispherical pattern (green dotted line). As shown in Figure 6 (b) when β is in the range of 25° to 45°, the center brightness of BLU shows varying degrees of increases.

To determine the specific pattern of the pyramid structure, an univariate method is carried out for simulation. When β is in the range of 25° to 45°, the height H corresponding to the quadrangular pyramid pattern is between 7 μm and 15 μm. Considering the processing accuracy and avoiding the risk of product scratches, the pyramid height H should < 10 μm. Then based on a certain β (25° ≤ β ≤ 45 °) and α, the influence of base lengths A&B on the light enhancement efficiency is investigated. The simulation results show that when A & B ≥ 30 μm, the luminous flux tends to be stable at 7 lm. And when 25 μm ≤ A&B ≤ 60 μm, the gain fluctuates between 5% and 13%.

Finally, based on the determined A&B, H, and β, the influence of pyramid side angle α on BLU brightness was simulated at larger step sizes (10 ° intervals) and locally at 5 ° intervals (40 °~60 °). Following the same approach, BLU luminous flux and center brightness gain are used to determine the brightness enhancement effect. When α ≥ 40 °, there is no significant difference in BLU luminous flux. When 40 ° ≤ α ≤ 60 °, the brightness gain fluctuates between 17% and 25%. Therefore, the detailed configuration of the quadrangular pyramid can be determined based on the parameters corresponding to the maximum gain value.

After determining the size of the LGP pattern, its processing technology is subsequently evaluated. The process flow and the appearance of the LGP pattern after each process are shown in Figure 7. Taking into account processing accuracy, redesign efficiency, and processing costs, the collision point process (step1) is selected for mold processing, and the injection molding process (step4) is chosen for LGP production. There are two points that need to be specifically explained. Firstly, due to the presence of a 2 μm high crater around the pyramid after the collision point, as indicated by the blue circle in step 1 of Figure 7, a polishing process (step 2) is introduced to remove the crater. Then, different from the conventional raised hemispherical pattern, this design features a concave quadrangular pyramid structure. Thus, it is necessary to add an electroforming process (step 3) to convert the concave structure on the mold into a convex structure. Finally, concave patterns are produced through injection molding process, and the actual size is basically consistent with the design value. The forming condition of pyramid height H is used to evaluate the injection molding transfer rate, which can reach 95% (H4/H3) in the machining process of the LGP pattern. It should be noted that the processing of this pattern includes but is not limited to the above-mentioned process path. For example, step 1 can be replaced by photolithography, computer numerical control (CNC), or other processing technologies. And step 4 can be replaced by processes such as nanoimprint molding.

Based on the above process route, the LGP is produced successfully and it is used for the high brightness BLU product assembly, reliability verification and optical effect confirmation. The overall production yield of the high brightness BLU is over 85%， and the main source of defects is conventional defects such as white spots caused by foreign objects in the incoming film materials, which are not related to the design and process of the high brightness LGP. The product has passed 1000 hours of reliability testing and no abnormalities have been found. Table 1 shows the measurement results of optical performance for traditional BLU and high brightness BLU under the same power consumption. The center brightness of the high brightness BLU is 24% higher than the conventional BLU. The nine-point uniformity is 93%, which is 3% higher than the uniformity of conventional BLU.

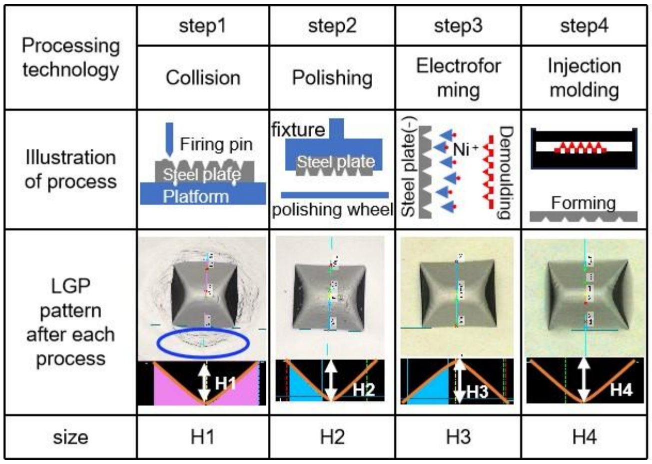

Figure 7. Process flow and the appearance of the LGP pattern after each process.

Table 1. Measurement results of optical performance for traditional BLU and high brightness BLU

	High brightness BLU	Conventional BLU
Power consumption	100%	100%
Brightness	124%	100%
Nine-point uniformity	93%	90%

4. Conclusion and discussion

In this paper, the light path of LGP is analyzed. Taking the side-entry single light bar as an example, the parameters of the LGP pattern for high-brightness output are simulated. At the same time, the feasibility of the scheme is verified through actual production, and the product brightness can be increased by up to 24%. In fact, we also use the design idea of this scheme to design the BLU with double light bars and produce samples through the photolithography process. This study is not limited to VR BLU with single or dual light bar. Following the design concept of this scheme, the parameters of the LGP pattern can be modified accordingly based on the position and quantity of the light bars. Thus, the scheme is of great significance for high PPI VR products to achieve high brightness and low power consumption and provide customers with a more excellent visual experience. Furthermore, based on the size, thickness, and material of the LGP, the design idea of this research is applicable to display screens in other different application scenarios, such as wearable, mobile, vehicle-mounted, TPC, NB, etc.

Although the demand for the metaverse market fluctuates, according to Verified Market Research predicts that the VR market will experience significant growth from 2024 to 2031, with an expected compound annual growth rate of 31.7%. Facing with the strong growth, We look forward to this research proposal contributing to the development of the metaverse.

5. References

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