ABSTRACT

A method of designing new light guide plate (LGP) of backlight system is presented in this paper using binary optical technique. Only one such new micro-optical LGP can integrate the function of multi-layer structures which include LGP, diffusion sheet and two prism sheets in the backlight system. The cell aperture’s structure is designed by using ZEMAX software, and the computer’s simulative result is given. It indicates that the output light uniformity of new LGP can reach 96.06%, axis direction center luminance is enhanced 1.52 times than the traditional approximately.

KEYWORDS: binary optics, backlight system, LGP, micro-optical arrays

1. INTRODUCTION

Flat plate display (FPD) is becoming the people’s concern focus increasingly because of its wider market prospect. Typically, as its principal representation, Liquid Crystal Display (LCD) is widely used in many fields such as Mobile telephone, TV, laptop PC, Global Position System (GPS), Personal Digital Assistant (PDA), VCD, DVD, etc. LCD backlight system is required higher and higher, whose uniformity and luminance of output light are very important technical parameters. In the past few years, the traditional ways at home and abroad is as follows: on the one hand, luminance is intensified by using two prism sheets to control the angle's distribution of output light; on the other hand, the output light is distributed equably by designing many types of patterns on the LGP’s bottom or adding diffusion sheet. However, this method has some problems in practice such as complicated setups, low light utilizing ratio and high cost, etc.

Binary optics technique is a new optical branch, which developed on the base of scalar diffractive theory, Computer-Generated Holography(CGH) and micro-fabricated technique. It is a rising synthetical subject and high technique. Binary optical elements have many special characteristics such as miniaturized, light weight, easy to copy on a large scale, low cost, multi-functional and integrated, able to design wavefront with any shapes. It is presented that a new LGP designed by binary optical and micro optical technique in this paper. Using only one such new micro-optical LGP, the performances of the multi-layer structures (LGP, diffusion sheet and two prism sheets) of backlight system is realized. Furthermore, it accords with the international prevalent designing tendency of integration and lightness.

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*This work is supported by the National Nature Science Foundation of China(No.60178023) and the Science & Technology Development Fund of Shenzhen (No.200311).
**Contact author, E-mail xuping@szu.edu.cn Tel.(0755)26557246
2. THEORY

With the method presented in this paper, the micro optical structures are etched on the light-output surface of the LGP. According to the scalar diffractive theory, the simple sketch maps are shown in Fig.1 and Fig.2. Let the transmissivity function of the micro optical integrated LGP is \( t(x_0, y_0) \). A light beam is transmitted into LGP’s bottom and reflective sheet where the light source is Lambert source \( u_0(x_0, y_0) \), while the beam at the light-output surface is defined as \( u'(x_0, y_0) \), and \( u(x, y) \) at the observing plane.

\[
\begin{align*}
\text{Lambert Source} & \quad \text{Binary Optical Structure} \\
\text{LGP} & \quad \text{Observing Plane}
\end{align*}
\]

Fig.1 Light path sketch map of back light system  
Fig.2 Binary optical array structure on the LGP’s surface

According to information optics, the transmissivity function of the integrated micro-optical LGP \( t(x_0, y_0) \) is:

\[
t(x_0, y_0) = \exp(j\phi) \cdot \text{rect}\left(\frac{x_0}{d}\right)\text{rect}\left(\frac{y_0}{d}\right) \ast \left\{ \frac{1}{d^2} \text{comb}\left(\frac{x_0}{d}\right)\text{comb}\left(\frac{y_0}{d}\right) \right\} \cdot \text{rect}\left(\frac{x_0}{D}\right)\text{rect}\left(\frac{y_0}{D}\right)
\]

(1)

Where \( \phi \) represents the original phase of the micro-optical structure, \( d \) is the space period of micro-structure, \( D \) is the size of whole aperture, and symbol \( \ast \) represents convolution operator.

After being transferred into the micro optical structure of the LGP, the optical field \( u'(x_0, y_0) \) at LGP’s surface can be given as:

\[
u'(x_0, y_0) = u_0(x_0, y_0) \cdot t(x_0, y_0)
\]

(2)

According to the diffractive theory, the \( u(x, y) \) is formed on the observing plane after \( u'(x_0, y_0) \) is transformed by the Fresnel diffraction, which can be given by:

\[
u(x, y) = \iint \left[ u'(x_0, y_0) \frac{\exp(jkz)}{j\lambda z} \exp\left\{ \frac{jk}{2z} \left[ (x-x_0)^2 + (y-y_0)^2 \right] \right\} \right] dx_0 dy_0
\]

\[
= \frac{\exp(jkz)}{j\lambda z} \cdot u'(x, y) * V(x, y)
\]

(3)

Where \( \Sigma \) represents the integral area of the LGP’s light output surface, the symbol \( \ast \) is convolution operator, and \( z \) is the distance between the LGP’s surface and the observing plane, and

\[
V(x, y) = \exp\left\{ \frac{jk}{2z} (x^2 + y^2) \right\}
\]

(4)
Ultimately, the distribution of the intensity on the LGP’s observing plane can be given by:

\[ I = |u(x, y)|^2 \]  

(5)

3. THE DESIGNING METHOD OF THE MICRO OPTICAL STRUCTURE

The LGP used in the mobile phone’s display is the object referred in this paper. Therefore, the parameters is designed as:

Aperture is 30\( \text{mm} \times 30\text{mm} \), Wavelength is 0.55 \( \mu \text{m} \), Material of LGP is Poly Methyl Meth Acrylate (PMMA), Refractive index of LGP is 1.49, Light source is Lambert source; Distance to the observing plane is 250\( \text{mm} \), Size of the observing plane is 60\( \text{mm} \times 60\text{mm} \).

According to the design requests of LGP in the backlight system, the followings should be met,

(1) Avoiding the image of net-dot structure at the LGP’s bottom to be formed in the observing plane.

(2) The light with larger deflection angles should be assembled to the axis center direction as much as it could in order to enhance center luminance along the axis.

(3) Improving the uniformity on the observing plane at the same time;

Therefore, the software ZEMAX is firstly used to obtain a conic structure by means of odd order aspherical constructing in this paper. Afterwards, the optimizing function of the ZEMAX is used, adding two optimizing parameters including the structure’s focal length \( F \) and the energy \( E \) which limited in the rectangle area. While 8 high order parameters of the odd order aspheric surface are used as the optimized variable, the initialize conic structure can be optimized. The geometrical structure designed by the z-axis is shown as:

\[
z = \frac{c r^2}{1 + \sqrt{1 - (1 + k)c^2 r^2}} + \beta_1 r^4 + \beta_3 r^6 + \beta_5 r^8,
\]

(6)

Where \( c \) is the curvature, \( r \) is radial coordinate by way of the geometrical length measure, \( k \) is conic coefficient.

The lengths of the semi-major axis and minor one can be transformed into the radius and conic parameter with several simple equations. Let the length of the semi-major axis \( a \) and the minor one \( b \), it exits:

\[
\frac{1}{c} = R = \pm \frac{b^2}{a}, \quad k = -e^2 = \left[ \frac{a^2 - b^2}{a^2} \right]
\]

(7)

\( \beta \) is the 8 high order parameters of the odd order aspheric surface. While two parameters with perfect value including the focal length \( F \) of the cell structure and the energy \( E \) that limited in the rectangle area of the observing plane are attained. In order to satisfy the design requests in the LGP of the backlight system aforementioned, a preferable values of \( \beta \) can be attained after several optimizations. The geometrical structure with the preferable value \( \beta \) is simulated as Figure 3.

Fig.3 The three-dimensional cell diagram map of the micro optical structure
4. COMPUTER SIMULATIONS AND DISCUSSION

4.1 Phase structure of the LGP surface

The cell structure of the surface phase designed by software ZEMAX is lessened proportionally. Therefore, based on the equation (6), the original phase function formed by the structure is given by:

$$\phi(r) = k(n-1)z$$  \hspace{1cm} (8)

Where $k$ is wave vector, $k=\frac{2\pi}{\lambda}$, $n$ is refractive index of material.

The original phase function is transformed by condensating and quantificating:

$$T_K(\phi) = \phi - \text{int} \left( \frac{\phi}{2\pi} \right) \cdot 2\pi$$ \hspace{1cm} (9)

$$T_B(\phi) = \text{int} \left( \frac{T_K(\phi) \cdot N}{2\pi} \right) \cdot \frac{2\pi}{N}$$ \hspace{1cm} (10)

Therefore, the original phase function becomes a binary discrete phase function of $N$ steps (in this paper $N$ is 8). Fig.4 shows the drawing of aperture cell-structure through 8-steps quantification.

Fig.4 8-steps quantificational map of cell’s phase

4.2 Uniformity of the intensity on the LGP’s observing plane

The simulative parameters as follows: micro-optical arrays is 16×16, sample points is 512×512, cell aperture is 50 μm×50 μm, wavelength is 0.55 μm, refractive index of material is 1.49, distance between the LGP’s surface and the observing plane is 250mm.

The uniformity of the intensity on the LGP’s observing plane is defined:

$$C = 1 - \sqrt{\frac{\sum_{i=1}^{N} (|g_i| - |G_i|)^2}{N}}$$ \hspace{1cm} (11)

Where $N$ is number of the sample point, $|g_i|$ is simulative output intensity, $|G_i|$ is the ideal output intensity.

According to the calculated results of the equation (11), the uniformity of the light field through the micro optical...
structure is to be 96.06% on the observing plane. Without the designed micro optical structure, the uniformity of observing plane is shown as Fig.5, in which the distribution of the intensity is highly asymmetry. Meanwhile, some relative high bright points exit. It is certainly not the hopeful result on the LGP's surface. Fig.6 gives the simulative results after the micro optical arrays are etched on the LGP’s surface. The uniformity on the observing plane is well improved, however, some bright break spots still exit. Compared with others, a few points have higher intensity. It’s believed that the brighter points will be eliminated by optimizing the micro optical structure for the better uniformity and luminance.

4.3 Luminance of LGP’s surface

Through the micro optical structure designed in this paper, the angle of the light beam that sends out from LGP’s surface can be assembled about 20° toward the axis direction center. According to the relationship between stereo angle and plane angle: $\omega = 4 \pi \sin^2(U/2)$, with the definition of the luminous intensity: $I_0 = \Phi / \omega$, under the same luminous flux, the luminous intensity at the center is 1.52 times stronger when passing the micro optical structure designed in this paper than that with no one. Fig.7 is the wavefront’s comparison between with the micro optical structures designed in this paper and without. Fig.8 is given the simulated comparison of the output light intensity whether there is micro optical structure on the LGP’s surface or not.

![Fig.5 Light intensity distribution at the observing plane without the micro optical structures](image1)

![Fig.6 Light intensity distribution at the observing plane with the micro optical structures](image2)

**Fig.7** a, Wavefront at the obversing plane without the micro optical structures  
  b, Wavefront at the obversing plane with the micro optical structures
4.4 Method of binary optical mask design

Based on the equations (9) and (10), after being transformed by condensating and quantificating, the original phase function of the design construction becomes a binary discrete phase function of N steps. Then numerical calculation is used to settle the following equation:

$$T_B(\phi) = 2\pi \frac{i}{N}, i = 0,1,2..., N - 1$$

(12)

Hence, the values of radius needed by binary mask could be attained. Let these values of radius array in a certain regulation, three groups of radius could be obtained.

5. DISCUSSION AND CONCLUSIONS

(1) The new micro optical LGP presented in this paper has the following performances:

   (A) Smart and condense structure: only one integrated micro optical LGP is used in this structure, effectively substituting the traditional multi-layer in the backlight system, which include LGP, diffusion sheet and two prism sheets.

   (B) Lightness and integration: owing to the applications of the micro optical technique and integrative design, the optical structure is condensed. Meanwhile, the thickness and the weight of the backlight system are reduced effectively.

   (C) Multi-function: using the binary optical technique with free design manner, we can design structures with any shapes of wavefront to meet the requirement of the high luminance and uniformity.

   (D) Low energy consumed and high efficiency: there is no dead area on the micro optical LGP surface, and the fill factor is 100%, hence, the utilizable efficiency is very high. According to diffractive efficiency equation of the binary optical structure with 8-step quantification: $\eta = |\text{sinc}(1/L)|^2$, the theoretical diffractive efficiency reaches to 95%.

   (E) Low cost: the micro optical LGP designed by the binary optical technique; hence, it can be produced in low cost and large scale.

(2) The output light uniformity and luminance are extremely important technique parameters in the backlight system. About uniformity, we use ideal Lambert source in the simulation, and the micro optical structure is quite perfect. Therefore, the theoretic value of the uniformity can reach to 96.06% on the observing plane. In the procession of the practical fabricating, considering the source error and the binary optical fabricated errors, the uniformity will be deceased on the observing plane, although as it is expected to reach 85%. About luminance, considering the factors, which included diffraction of the micro optical LGP in practice, the luminance can be enhanced to 1.30 times than the tradition does on the observing plane. In the future research, the technique parameters such as luminance and uniformity...
could be improved more, by considering the space period and arrangement of the binary optical-arrays structure on the LGP’s surface efficiently, taking the energy of the observing area into account and continuing optimizing the structure. It’s possible that such the new integrated optical LGP will replace the traditional multi-layer structure of backlight system in the future.

REFERENCES

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