

文章编号:1007-2780(2011)05-0598-06

Design and Optimization of Dot-Pattern for Large Scale LED Backlight Unit

HAO Dong-jing¹, QIAN Ke-yuan^{1*}, LUO Yi^{1,2}

(1. Semiconductor Lighting Lab, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China;
2. State Key Lab on Integrated Optoelectronics, Tsinghua University, Beijing 100084, China)

Abstract: Adopting LED as the light source, LCD TV has significant advantages over adopting Cold Cathode Fluorescent Lamp (CCFL). Light guide plate (LGP) with a two-dimensional array of dots scheme is the key to the design of the LED backlight unit (BLU). A LED BLU with 1.066 8 m in diagonal and 4 mm in thickness, using incidence structure with four-side light sources is proposed in this paper. Considering the complexity and time-consuming process of the large scale LGP dot-pattern design, the method of simplified model is introduced which is the simplification of the LGP and the LEDs. The optimization result between the simplified model and the actual model can be ignored. The LGP luminance uniformity reaches up to 90% and the extraction efficiency is around 50%. Adopting the same method to a BLU with 1.422 4 m in diagonal and the thickness of 3 mm, it also achieved a good result. The luminance uniformity reaches 85% and the extraction efficiency is around 50%.

Key words: large-scale LED backlight unit; light guide plate; dot-pattern; LED

CLC number: TN141. 9 **Document code:** A

大尺寸 LED 背光源网点的设计及优化

郝冬晶¹, 钱可元^{1*}, 罗毅^{1,2}

(1. 清华大学 深圳研究生院 半导体照明实验室, 广东 深圳 518055;
2. 清华大学 集成光电子国家重点实验室, 北京 100084)

摘 要: 基于白光 LED 侧入式背光结构, 设计了多光源四边入射、导光板厚度为 4 mm、对角线为 1.066 8 m 的液晶背光模组, 采用导光板底面印刷网点的方法导出光线。针对大尺寸导光板网点设计复杂、计算机辅助设计中光线模拟耗时的缺点, 采用简化的光源仿真模型, 减少了仿真计算时间, 网点在实际模型下依然有效; 同时采取了网点自动优化技术, 通过优化使导光板的效率和均匀度达到最理想的状态, 亮度均匀度达到了 90%, 光能利用效率在 50% 左右。采用相同方式设计了对角线为 1.422 4 m 的液晶背光模组, 亮度均匀度可达 90%, 光能利用率在 50% 左右, 总耗时 1 h, 较普通方法减少了优化时间。

关 键 词: 大尺寸; 背光源; 导光板; 网点; LED

中图分类号: TN141. 9 **文献标识码:** A **DOI:** 10.3788/YJYXS20112605.0598

收稿日期: 2011-02-25; 修订日期: 2011-05-15

基金项目: 广东省发展平板显示产业财政扶持基金(No. 20080902)

作者简介: 郝冬晶(1985—), 女, 吉林省吉林市人, 大学本科, 主要从事大尺寸 LED LGP 光学设计和优化工作。

* 通讯联系人, E-mail: qianky@sz. tsinghua. edu. cn

1 Introduction

Compared with the traditionally Cold Cathode Fluorescent Lamps (CCFL) as the LCD back-light source, LED has many unique merits, except the outstanding advantage in the field of energy conservation. LED is friendly to the environment with no toxic substance like mercury and it enriches the LCD TV's color display with a broader color gamut range. The lifetime of the LED is up to 100 000 h, and helps prolonging the lifetime of the LCD TV. The brightness adjustment range of LED is wide enough to realize all over light-shade shift control. By using LED as the light source, the BLU can be made thinner, so it can achieve the goal of both energy and space saving. According to the different locations of the LEDs in BLU, the unit has two kinds of structure: directlit and edge-lit. In contrast to the direct-lit which has LEDs below the LCD panel, the edge-lit which has LEDs at the sides of the LGP, is more energy-saving and can be made thinner in thickness, and it also received a warm welcome in the LCD TV market in recent years. Edge-lit BLU design concerns about two major issues: the extraction efficiency and the luminance uniformity. Trying to achieve higher luminance uniformity and lower LGP in thickness, the extraction efficiency declines. The extraction efficiency can be increased by varying dot-pattern in the LGP. Generally, the LGP dot-pattern design should bring the extraction efficiency and the thickness of LGP into consideration.

A simplified model is adopted in order to reduce the computational time for optimization and the model complexity. The dot size and the dot density were adjusted during the optimization process to achieve high extraction efficiency and make sure the dot-pattern is non-overlapping. After the optimization, replace the simplified source model with the actual SMD LED model to verify our assumption. For the 1. 066 8 m in

diagonal and the above size BLU, using four-side LED incident structure with the LGP 3 mm in thickness can achieve high luminance uniformity and extraction efficiency which satisfy the high luminance requirement of LCD TV. Compared to other methods, it can effectively reduce the optimizing time and the calculation complexity while achieving high extraction efficiency.

2 Simulations

First we proposed a LGP with the size of 930 mm×524 mm×3 mm and adopted the four-side LED incident structure, in regard to the high luminance demand.

The material of LGP is PMMA with refractive index of 1. 49. The LED simulation model has an emission angle of 90°, with a radiation power of 100 lm/W. In order to satisfy the demand of high luminance, the light source in the wide side is set to 450 lm (contains 45 LEDs, 0. 1 W each) and the long side is set to 900 lm. The total LED power is 54 W.

Because the number of LEDs on each side of the LGP is large and the distances between the LEDs are small, it is considered that the LEDs in the same side of the LGP can be seen as one large rectangle light source bar. Also, according to the symmetrical characteristic of LGP, the one fourth of it is chosen to represent the whole LGP in the simulation. The above is aimed at reducing the time of the optimization process and the computational complexity while achieving high extraction efficiency. Fig. 1 shows the schematic diagram of simplified BLU.

For there must be room for the necessary LED feedback circuits and other structural parts on the wide side of the LGP, the wide side light source is set half the length of that of the long side.

LGP's bottom surface is printed with a two-dimensional array of dots which varied in size and distribution. These dots usually made of high reflective index material, such as screen printing

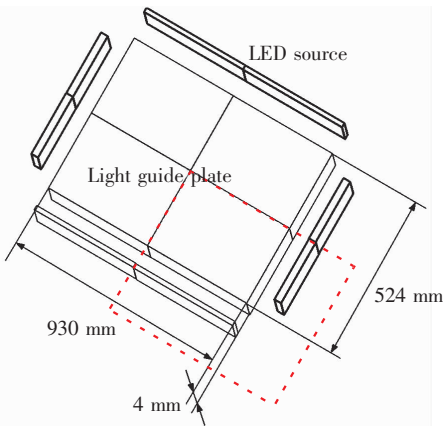


Fig. 1 Schematic diagram of simplified BLU

ink, and it scatters the rays hit on it and some of the scattering rays can get out of the LGP when the incidence angle is less than the angle of the total reflection. Fig. 2 shows the working principle of LGP with dots.

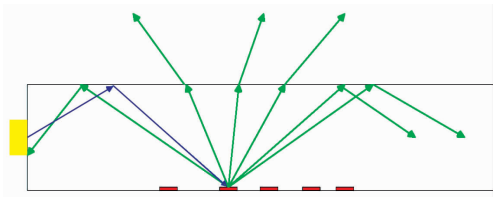


Fig. 2 Diffusion dots scatter the rays

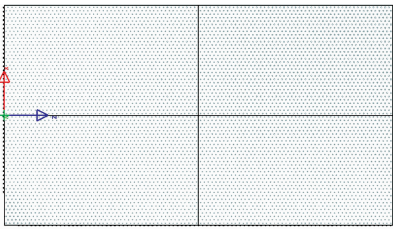


Fig. 3 1/4 LGP dot-pattern with light incident from the left edge and the bottom edge

The surface of the LGP and Diffuser is set as Fresnel loss optical surface. We simulate one fourth of the whole LGP, the right surface and the top surface of the LGP (as Fig. 3 shows) must be set as mirror surface with 100% reflectivity.

There are two phase in optimizing the LGP dots. First, set the dots distribution as radial polynomial and gain higher extraction efficiency and approximate uniformity. Then incorporate

the dot distribution to the backlight optimization tool, iterate it until a uniformity above 85% is achieved. The process of the simulation is shown in Fig. 4.

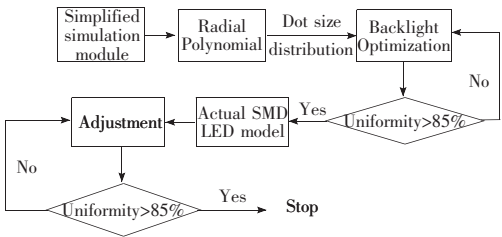


Fig. 4 Schematic diagram of the optimization flow

The dots are set as circles with 0.1 mm in diameter and radial polynomial distribution as shown in Fig. 5. Similar to the radial distribution which needs to set the distance in X and Y direction respectively, radial polynomial needs to adjust the coefficient of the formula below:

$$A + Bi + Ci^2 + Di^3 \tag{1}$$

where i is the ring number, counted from the center and extended to the positive direction.

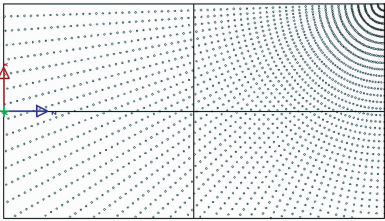


Fig. 5 Dot-pattern in radial polynomial distribution with light incident from the left edge and the bottom edge

Adjust the distance in X direction, Y direction and the coefficient B respectively, so as to get approximate illuminance uniformity and achieve the extraction efficiency more than 50% at the same time.

According to the 17-points uniformity measurement method, the minimum illuminance is 116 lx and the maximum is 180 lx(Fig. 6). Use the Equation 2 below, we can calculate the uniformity $U=64\%$.

$$U = \frac{P_{\min}}{P_{\max}} \times 100\% \tag{2}$$

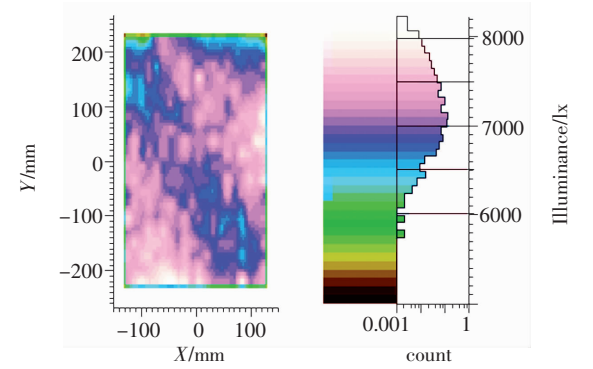


Fig. 6 Illuminance map (radial polynomial distribution is adopted)

Use the extraction efficiency Equation 3, the efficiency of the module is $\eta=64\%$.

$$\eta = \frac{lm_{out}}{lm_{in}} \times 100\%$$

(3)

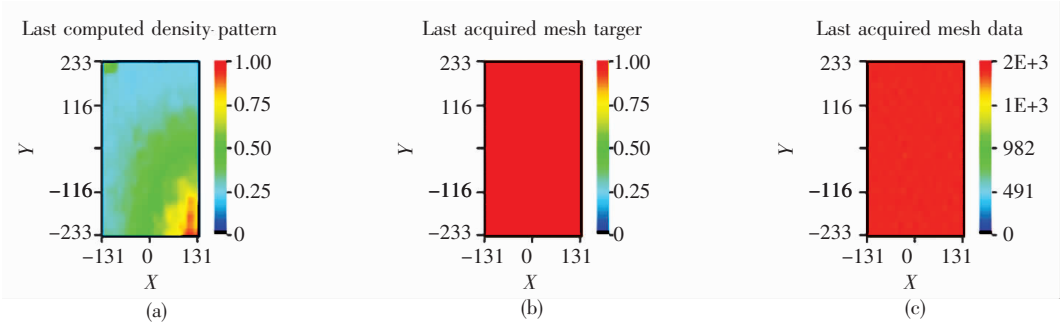


Fig. 7 Density map (a), target luminance map (b) and luminance result map (c).

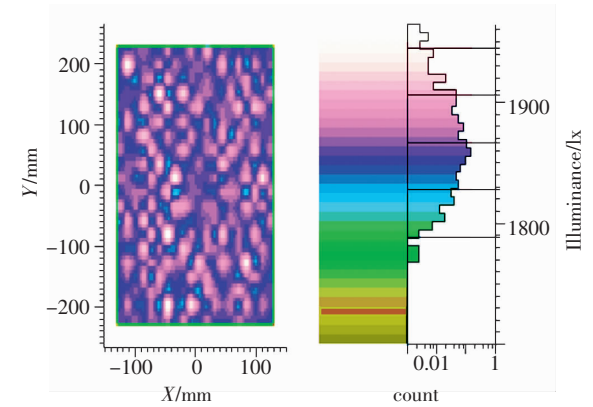


Fig. 8 Luminance result map

According to the 17-point uniformity measurement method, the maximum luminance is 1 964 cd/m², and the minimum is 1 770 cd/m² (Fig. 8). From the uniformity equation and the efficiency equation above, we can get $U = 90\%$ and $\eta=53\%$.

The dots distribution from the previous simulation will be incorporated into the backlight optimization tool of the optical simulation software. Considering the dot distance as constant, the dot size is changed to optimize.

Due to the actual process constraints and the precision limit, the dot diameters are set no less than 0.05 mm. Iterate it from the previous LGP dot-pattern and set a goal of 85% luminance uniformity. The purpose of choosing radial polynomial is that poor dot distribution will make the iteration results worse, and the extraction efficiency cannot be guaranteed. Fig. 7 shows the density map, target luminance map and luminance result map after the optimization.

The simplified model is replaced with the actual SMD LED and do the ray-tracing again.

According to the 17-point uniformity measurement method, the maximum luminance is 1 810 cd/m², and the minimum is 1 615 cd/m² (Fig. 9). From the uniformity equation and the

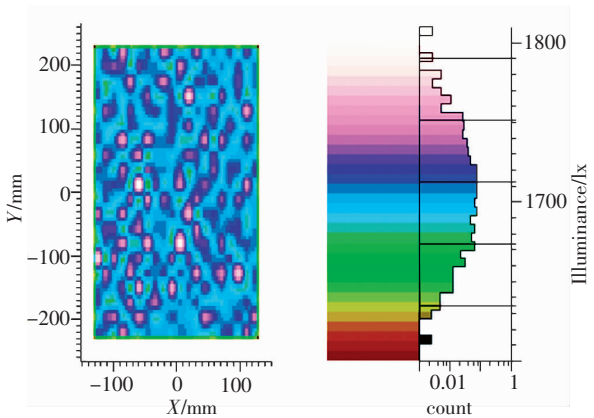


Fig. 9 Luminance map using the actual SMD LED as the light source

efficiency equation above, we can get $U=89\%$, and $\eta=48\%$.

Increasing the mesh numbers, it is found that there is no moiré strip between the LEDs. Compared with the simplified model the LGP luminance uniformity has no big difference and the efficiency is a bit lower. So we can conclude that the simplified model is effective in replacing the actual model in simulation.

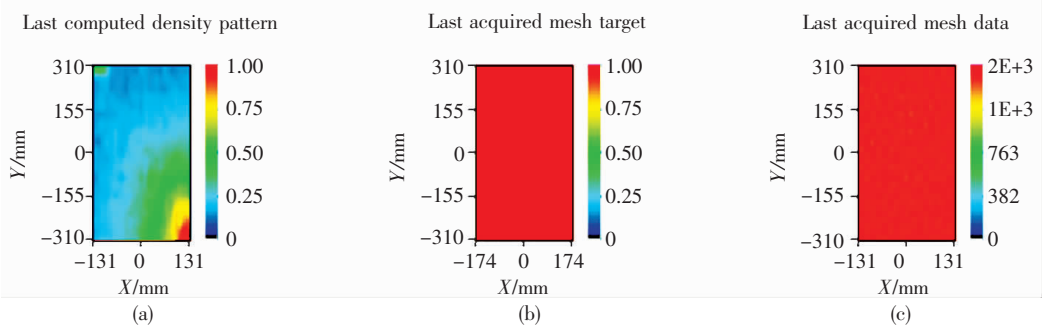


Fig. 10 1.422 4 m (56 in) LCD LGP density map (a), target luminance map (b), and luminance result map (c) after optimization.

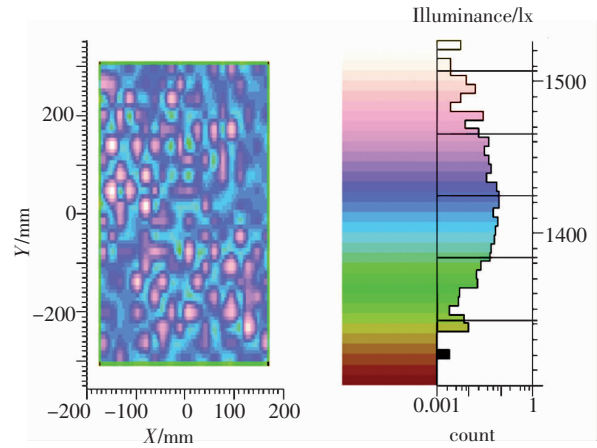


Fig. 11 Luminance result of simplified model

method, the maximum luminance is $1\,527\text{ cd/m}^2$, and the minimum is $1\,322\text{ cd/m}^2$ (Fig. 11). From the uniformity equation and the efficiency equation above, we can get $U=86.6\%$, and $\eta=53.4\%$. The simplified model is replaced with the actual SMD LED and begin ray-tracing.

According to the 17-point uniformity measurement method, the maximum luminance is $1\,551\text{ cd/m}^2$, and the minimum is $1\,325\text{ cd/m}^2$ (Fig. 12). From the uniformity equation and the

The same method is applied to a super large scale LGP with the size $1\,260\text{ mm}\times696\text{ mm}\times3\text{ mm}$. The light source in the wide side is set to 600 lm in power (equal to 60 LEDs, 0.1 W each) and the long side 1 200 lm. Fig. 10 shows the 1.422 4 m (56 in) LCD LGP density (a), target luminance (b), and luminance result (c) after optimization.

According to the 17-point uniformity measurement

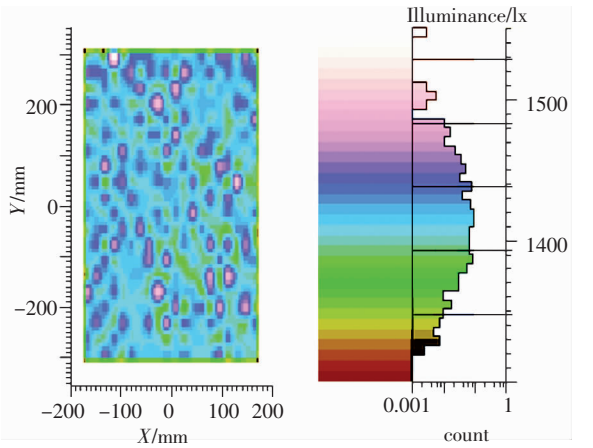


Fig. 12 Luminance map using the actual SMD LED as the light source

efficiency equation above, we can get $U=85.4\%$, and $\eta=53.4\%$.

The above data indicated that the LGP dot-pattern optimized using the simplified model is also suitable with the actual SMD LED model. The results of luminance uniformity and extraction efficiency have no big difference, but the simplified model can effectively reduce the optimizing time.

3 Conclusions

The 1.066 8 m (42 in) and 1.422 4 m (56 in) LCD BLU are proposed using a simplified model. The actual SMD LED model is applied to measuring difference which can be ignored in luminance uniformity and extraction efficiency. And we

also achieve the goal of a super large scale LGP with a luminance uniformity above 85%, extraction efficiency around 50% and thickness of 3 mm. The method we proposed can effectively reduce the time and complexity of BLU design and is more reliable in the factory manufacturing.

References:

[1] Miyamoto E, Maruyama S, Nagano A, *et al*. Novel diffraction grating light guide for LED backlight [J]. *SPIE*, 2007, 6488:64880H(1-8).

[2] Park S R, Kwon O J, Shin D, *et al*. Grating micro-dot patterned light guide plates for LED backlights [J]. *Opt. Exp.*, 2007, 15(6):2888-2899.

[3] Lee W Y, Lim T K, Lee Y W, *et al*. Fast ray-tracing methods for LCD backlight simulation using the characteristics of the pattern [J]. *Opt. Eng.*, 2005, 44(1): 014004(1-6).

[4] Funamoto A, Aoyama S. LED backlight system with double-prism pattern [J]. *J. Soc. Inf. Disp.*, 2006, 14(10-12):1045-1051.

[5] Feng D, Yan Y, Fan S. High quality light guide plates that can control the illumination angle based on micropism structures [J]. *Appl. Phys. Lett.*, 2004, 85(24):6016-6018.

[6] Idé T, Mizuta H, Numata H, *et al*. Dot pattern generation technique using molecular dynamics [J]. *J. Opt. Soc. Am.*, 2003, A20(1):248-255.



欢迎订阅《液晶与显示》

《液晶与显示》是中国最早创办的液晶学科专业期刊,也是中国液晶学科和显示技术领域中的惟一的综合性专业学术期刊。它由中国科学院长春光学精密机械与物理研究所、中国物理学会液晶分会和中国光学光电子行业协会液晶分会主办,科学出版社出版。

《液晶与显示》以创新性、综合性、实用性为办刊特色,内容丰富,涵盖面广,信息量大,可读性强,既是启迪科技人员开拓创新思路的参考期刊,又是从事液晶和显示技术研究与开发的广大科技人员、大专院校师生及相关领域的科技工作者进行学术交流的论坛,也是图书、情报等部门必不可少的信息来源。

《液晶与显示》为双月刊,国内定价 40.00 元,全年 240.00 元,国内外公开发行。国内邮发代号:12-203,国内读者可在当地邮局订阅;也可通过“全国非邮发报刊联合发行部”订阅(地址:天津市大寺泉集北里别墅 17 号,邮编 300385),本刊的代号为:5074。国外读者可通过中国国际图书贸易总公司订阅(地址:北京 399 信箱,邮编:100044),国外发行代号:4868BM。同时,《液晶与显示》编辑部将竭诚为广大读者服务,随时办理订阅。

地 址:长春市东南湖大路 3888 号 中国科学院长春光学精密机械与物理研究所	
《液晶与显示》编辑部	邮 编:130033
电 话:0431-86176059 0431-84613406	传 真:0431-84695881
E-mail: yjxs@ciomp. ac. cn; yjyxs@126. com	http://www. yjyxs. com