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侧入式导光板的激光微加工技术的验证研究

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摘　要：从设计、仿真与加工入手研究液晶背光模组中侧入式导光板的激光微加工技术．通过光学软件构建导光板的光学结构并采用蒙特卡洛光线追迹方法进行模拟仿真，结果表明具有渐变密度分布的微结构能够提供高均匀性的光输出．基于仿真结果，运用激光微加工技术进行验证设计．激光微加工获得的微结构在100倍光学显微镜放大测量下尺寸约为30.14 μm，接近于设计值30 μm，同时对单个微结构的3D表面形貌特征进行分析．十组采用激光微加工技术与丝网印刷技术加工的导光板分别安装至侧入式背光模组样机中进行对比．对比结果显示，激光微加工的导光板相比于传统的丝网印刷技术具有更好的光学均匀性和更低的色差，均匀性提高了6.2%，而色差下降了0.002 7．激光微加工技术快而简单，且整个加工过程是完全环保的，具备高性能、自动化生产和易于薄型化的优点．

关键词：激光加工；显示；导光板；背光；光学设计
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Demonstration of an Edge-lit Light-guide Plate Using Laser Micro-machining Technique

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Abstract: This paper presents the design, simulation and fabrication of edge-lit Light-Guide Plates (LGPs) using laser micro-machining technique for Liquid crystal display backlights. The optical structure of the LGP is established in an optical software, and simulated by tracing rays using Monte Carlo method. The designed microstructures with gradually changing desity are proved to offer output homogeneous illuminance. Based on the simulation results, Laser Micro-machining Technique (LMT) fabrication is performed for verification. The measured size of the fabricated microstructure is approximately 30.14 μm under 100× magnification, which is close to the prescribed size of 30 μm. The 3D surface morphology of the fabricated microstructure is also available. Ten groups of edge-lit LED display backlight prototypes equipped with the LGPs fabricated by LMT and Screen Printing Technique (SPT) are developed and analyzed. Comparison results show that LGPs fabricated by LMT can provide better optical uniformity (6.2% higher) and lower color difference (0.002 7 lower) than conventional method (SPT). Besides the advantages of faster and simpler, LMT is entirely environmentally-friendly during the machining process. With the characteristics of good performance, automatic production and thinning tendency, it is reasonably believed that LMT will have bright prospect in the near future, and may be a promising alternative method for SPT in display applications.

Key words: Laser processing; Display; Light-guide plate; Backlights; Optical design

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0 Introduction

Thin Film Transistor-Liquid Crystal Display (TFT-LCD) has dominated world market of high-quality display due to its high brightness, thin dimension and low-power consumption[1]. Undoubtedly, these display devices have greatly enriched people's daily life via making the information transfer more simple and convenient. However, miniaturization of these devices is the eternal direction of development, and, is still in urgent need. Many researchers have made liquid crystal displays thinner, brighter and more lightweight, as well as devoting much effort to improve the quality of backlight systems. As the most important subassembly, Light-Guide Plate (LGP) will determine to a large extent the performance and dimension of the backlight systems[2]. The light source of LGPs has been undergoing a rapid transition from fluorescent lamps to Light-Emitting Diodes (LED) to meet the requirements of high efficiency, compactness and environmental protection[3-4]. While introducing LEDs into display backlight systems, LGPs need to re-distribute the LED emitting light homogeneously over the whole upper face of the plate. If LEDs are edge-arranged, it is so-called "edge-lit backlight". Dot-pattern design and micro-structure integration of edge-lit LGP are two effective methods to maximize the uniformity of light, to make the backlight unit slim and to reorient the LEDs to a planar light source[5-9]. These implementations require both stable fabrication technology and accurate working repeatability.

The manufacturing technologies for making dot pattern include V-cutting, injection molding, hot embossing, screen-printing, etc., which have also their own advantages and disadvantages. Screen-Printing Technique (SPT) is one of the most widely applied processing operations in the manufacturing of edge-lit LGPs[10-11]. An important advantage is that SPT can be used to replicate stable and rapid output of complex geometries with a complete printing forme. Despite many advantages, SPT has some inherent problems, e. g., low degrees of automation and environmental pollution of printing wastes. As a promising alternative, Laser Micro-machining Technique (LMT) shows much promise as potential sources of choice in dot-pattern micromachining of LGPs[12]. It can rapidly produce high quality graphics with an electrostatic digital printing process[13]. The dot patterns can be directly engraved by a CO_2 laser, and the optical efficiency of backlighting is also improved[14]. The investigation has proved that laser processing technology is suitable for large-scaled application such as LCD TV backlighting. But for micro-scaled applications, the possibility, whether it can improve conventional method of Screen-Printing Technique (SPT), still needs validation.

In this paper, we focus on micro-structure fabrication of LGPs. A kind of edge-lit LGP using laser micro-machining technique is designed and demonstrated for LED backlights. The LGP is designed with non-periodically ring-shaped and single-sized microstructures, which could help to homogenize output light distribution. Simulation and fabrication are both discussed.

1 Optical design and simulation

Optical structure of a complete backlight system is shown in Fig. 1, which comprises a scattering film, an LGP and a reflective film. The red-color-denoted LEDs are considered as the light source of the LGP, which are arranged in certain side of the LGP. The LEDs with standard intensity distribution can be considered as Lambert radiators. Therefore, the smaller the distance between the LEDs and the LGP is, the more the rays will enter the LGP. This could, to some extent, improve the system efficiency. Polymethyl methacrylate (PMMA) is used as the material of polymer substrate of LGP, which has been proved to have good transparency and appropriate refractive index with easier fabrication process[15]. The PMMA medium substrate is covered with specially designed microstructures. These microstructures fabricated by LMT will provide different scattering properties in orthogonal directions, which can improve output uniformity. The emitting light from edge-arranged LEDs firstly enters the LGP, and then transmits from the source side to the other side according to the law of total internal reflection (here, critical angle is 42.2°). Once certain rays touch the surface of microstructures, they will change original direction and exit the PMMA medium. The light distribution will be further homogenized by the scattering film. The reflective film below the LGP will collect and reflect the light that exits the plate from the bottom direction. These rays that do not meet the total reflection law can be further re-used.

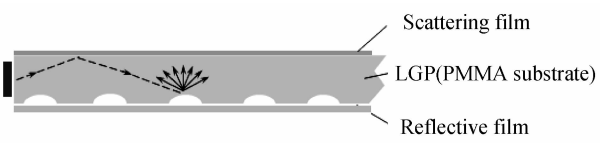
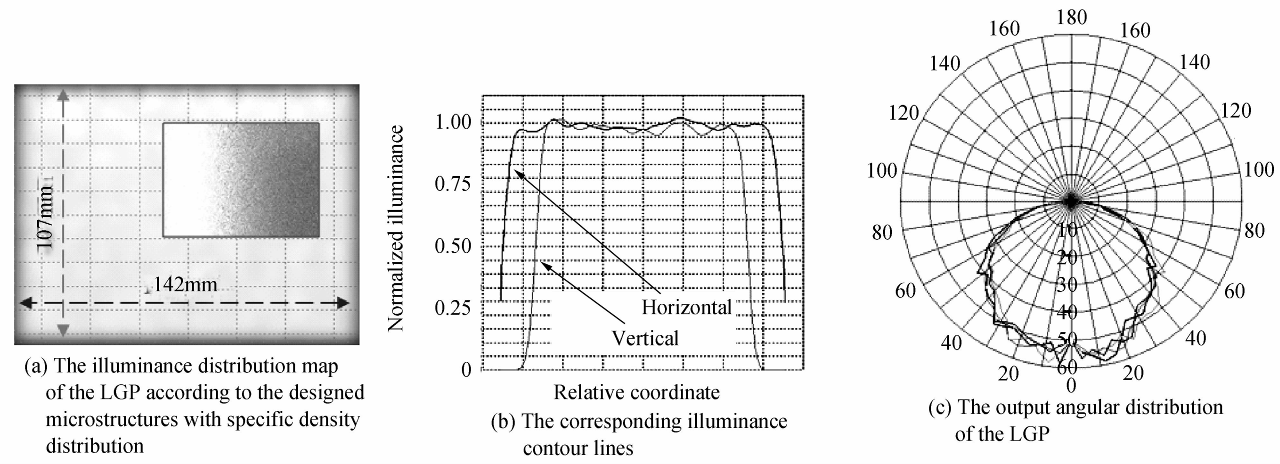


Fig. 1 The optical structure of the backlight systems

The optical structure of the designed LGP is established in an optical software, and simulated by tracing rays using Monte Carlo method. As shown in sub-graphic of Fig. 2 (a), the density of designed microstructures gradually changes from the source side to the other side far away from the source. Random microstructure arrangements have the advantage that they eliminate the moiré phenomenon[16]. The radius of each microstructure is identical, which should be easier to be fabricated by LMT. Finally, the output illuminance distribution within the prescribed illumination seems to be visually homogeneous. The tops of the corresponding contour lines are flat in Fig. 2 (b). It proves that high uniformity is achieved in simulation. The output angular distribution shown in Fig. 2(c) implies that the LPG may offer a wide visual perspective. Simulation results offer good performance of the LGP with such microstructure pattern.



(a) The illuminance distribution map of the LGP according to the designed microstructures with specific density distribution

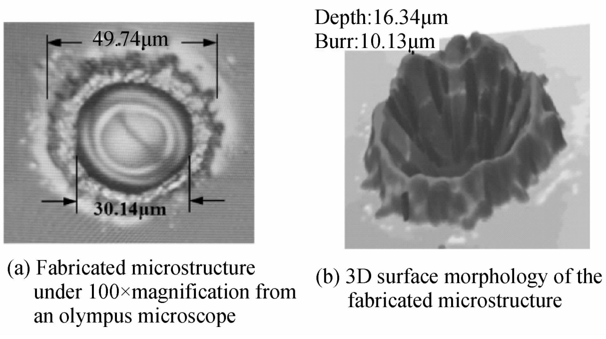
(b) The corresponding illuminance contour lines

(c) The output angular distribution of the LGP

Fig. 2 The simulation results of the designed LGP

2 Fabrication and experimental verification

The concave microstructures with non-periodical arrangement provide different scattering properties, which can be reasonably fabricated by LMT. Differed from the conventional SPT, LMT is a kind of processing method by reducing raw materials. Fabrication result observed by an Olympus microscope is shown in Fig. 3, in which a separate microstructure can be clearly observed. The prescribed size of the microstructures is 30 μm, and the corresponding measurement result is 30. 14 μm under 100 × magnification. The fabricated microstructure has an approximate circular boundary, which is consistent with the initial design. It can also be observed from Fig. 3 that irregular ringed mountains occurred around the boundary. Actually, these mountains are burrs after the substrate of raw materials is extruded. It can be seen in Fig. 3(b) that the 3d surface morphology of the fabricated microstructure resembles a craterlet. The actual diameter of the microstructure is extended to 49. 74 μm. The average burr height and the crater depth are 10. 13 μm and 16. 34 μm, respectively. As mentioned above, the radius of each microstructure is identical. The surface morphology of each fabricated microstructure is, therefore, approximately similar with each other. It is undesirable that some processing derivatives may induce excess light scattering and energy loss. Whether it can be accepted for actual application still needs to be verified by further experiments.

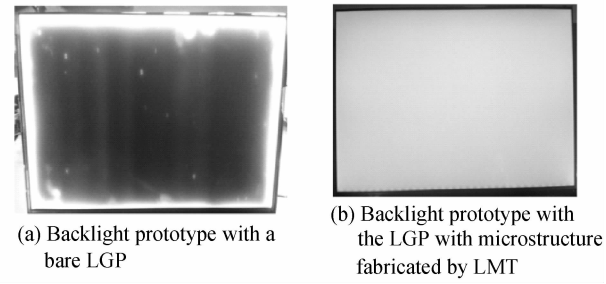


(a) Fabricated microstructure under 100×magnification from an olympus microscope

(b) 3D surface morphology of the fabricated microstructure

Fig. 3 Morphology of a fabricated microstructure

For experimental demonstration, an edge-lit LED display backlight prototype equipped with the fabricated LGP is developed and analyzed. The bare LGP before machining process is assembled into the backlight unit. In Fig. 4(a), most of the display zone is visually dark, but the boundary is bright. What is the cause of this phenomenon? Right, the reason is that light entering the LGP cannot scatter without microstructures, and they will continue to spread forward until reaching the LGP edges. Fig. 4(b) shows the illumination output of the backlight prototype. With the fabricated microstructures, a homogeneous illumination can be achieved.


(a) Backlight prototype with a bare LGP

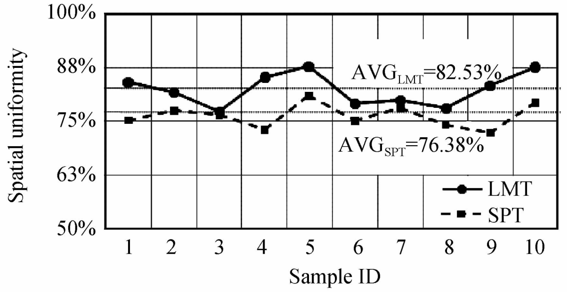
(b) Backlight prototype with the LGP with microstructure fabricated by LMT

Fig. 4 Comparison between backlight prototypes

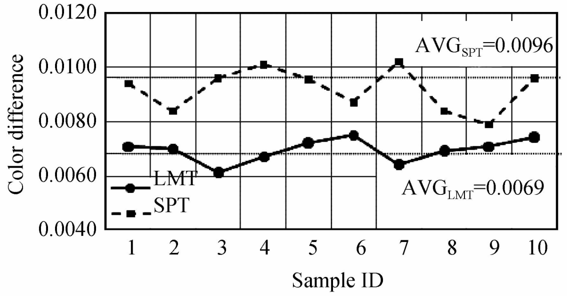
In order to quantitatively evaluate the output performance, the spatial uniformity and the color difference are both measured. The target region is divided into nine sub-regions with the same area. The spatial uniformity is defined as the minimal irradiance divided by the maximum one within the sub-regions. Assumed that the centre is considered as a reference region, whose color coordinates are (u_0', v_0'). The color differences between the reference and the surrounding regions could be calculated by

$$\Delta(u',v')_{(i)}=\sqrt{[u'_{(i)}-u'_0]^2+[v'_{(i)}-v'_0]^2} \qquad (1)$$

where $(u', v')_{(i)}$ are the color coordinates of the surrounding eight regions and the subscript i represent for the corresponding regions. The measured spatial uniformity and color difference are shown in Fig. 5.



(a) Spatial uniformity



(b) Color difference

Fig. 5 Comparison between ten groups of LGPs fabricated by LMT and SPT, respectively

Ten groups of LGPs, which are fabricated by LMT and SPT respectively, are analyzed and compared for verification and guidance. For comparison between the SPT and LMT LGPs, the diffuser and reflective film are the same in the both cases. The spatial uniformity of LGPs fabricated by LMT is changed from 77.48% to 87.94% , as shown in Fig. 5(a). The average uniformity is 82.53%, which is approximately 6.2% higher than that obtained from SPT. As drawn in Fig. 5(b), the color difference values of LGPs fabricated by LMT are fluctuated from 0.006 1 to 0.007 4. The overall fluctuation is larger than that by SPT. However, the average color difference values are 0.006 9 and 0.009 6 for LMT and SPT, respectively. Smaller color difference means that these LGPs will have better visual effect in actual applications. These experimental results demonstrate that LGPs fabricated by LMT can provide better optical uniformity and lower color difference than conventional method of SPT.

3 Conclusion

The increasing world-wide interest in laser micro-machining and the potential markets being investigated have encouraged further work on the laser applications. In this paper, a kind of edge-lit light-guide plate using laser micro-machining technique for LED backlights is demonstrated. Experimental results are in good agreement with the simulation results. Besides the advantages of faster and simpler, laser micro-machining technique is proved to offer better optical uniformity and lower color difference while compared to the conventional screen-printing technology. More importantly, it is entirely environmentally-friendly during the machining process. It is believed that LMT may be a promising alternative method for SPT in display applications.

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