Special Optics Element Design in Enhancing Illumination Effects

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Abstract - The special optics element based on linear Fresnel lens is applied to replace those with the traditional Fresnel lens formed with concentric circles. Such specially designed diffractive optical element is aimed to improve the problem of the traditional Fresnel lens, which causes the lights to centralize in various spot sizes, instead of evenly spreading on the working area. An ideal office environment requires the light to be shined evenly in a 300 mm by 300 mm reading desk. The ray-tracing software tool, TracePro, is used to simulate optical paths, and the efficiency analysis is also carried out. It is found that the radius of curvature of the diffractive optical element is a key factor in determining the ray distribution. The test results show that the optimum parameter for the radius of curvature is R= 480 mm, corresponding to optical efficiency enhanced by 2.5 times with the proposed diffractive optical element in comparison with traditional Fresnel lens. The experiments are made for a basis of the above conditions for the prototyped diffractive optical element, where the optical efficiency is theoretically and experimentally verified.

Keywords: Linear Fresnel Lens, Hot embossing, Nano-imprint

I. INTRODUCTION

With the maturity of hot embossing process, it has been applied for a variety of fields. Hot embossing process can allow fabricate larger contact area with the high aspect ratio of microstructures [1]. For larger hot embossing area, many elements can be combined to enhance the volume flow rate of plastic materials. Furthermore, hot embossing process also presents some disadvantages. For instance, the microstructures are hard to shape as well as the process needs high temperature, pressure and longer duration. The most important condition for successfully fabricating microstructures with high aspect ratio is the surface of a mold. If the surface has less roughness, the microstructures with dip angle can be easily shaped and released from a mold due to the affinity reduction between mold and plastics. If the microstructures do not apply on biomedical engineering, the releasing agent can be applied to easily release the mold. When PDMS mold [2] is used as one kind of mold for hot embossing process, the processing condition will need the higher temperature, pressure and longer durations than those made by Nickel. Although PDMS mold can successfully produce microstructures, it can be only duplicated about 20 times. Because PDMS mold is very soft, it needs to be frequently replaced by a new PDMS mold. Besides, a mold of micro-lens made by Focused Ion Beam (FIB) [3] technology is allowed to imprint on hot embossing process. The related studies also show that the temperature and pressure are two key factors, where nano-fabrication is an important part of nanotechnologies. Nano-imprint technology is the most essential technology among nano-fabrication technologies. The fabrication process is very simple to reach the resolution less than 100 nm. Presently, the academy puts more emphasis on nano-imprint technology and nano-photonics. Nano-imprint technology [4] is one kind of nontraditional lithography technology with low cost and high productivity. In 1995, Professor S. T. Chou in Princeton University developed nano-imprint lithography [5], which was an important innovation in the process. This technology can duplicate sub-microstructures and nanostructures on large area. The processing duration takes shortly, and the cost is lower enough in that less lithography processes are required. Therefore, this process is suitable for mass duplication. After nano-imprint technology is improved and novel material is discovered, this process can be used to replace traditional lithography and widely apply on many fields. In addition, nano-imprint technology provides high resolution, high speed, low cost and no diffraction limit. This process is very appropriate to fabricate nontraditional Fresnel structure here. In order to replace traditional desk lamps at office, we modify the nontraditional Fresnel structure as linear one.

The purpose of this linear Fresnel structure not only reduces the emission of carbon dioxide, but also saves power consumption at office. From the studies for investigating power consumption in business buildings, facilities like lighting and air-conditioners require the most energy. The specially designed with linear Fresnel lens, where a diffractive optical element is designed to collect light from ceiling lamps at office, is theoretically and experimentally demonstrated. The relative positions for office desk, lighting fixture and diffractive optical element are presented in Fig. 1-1. The specifications of lighting fixture are shown in Fig. 1-2.

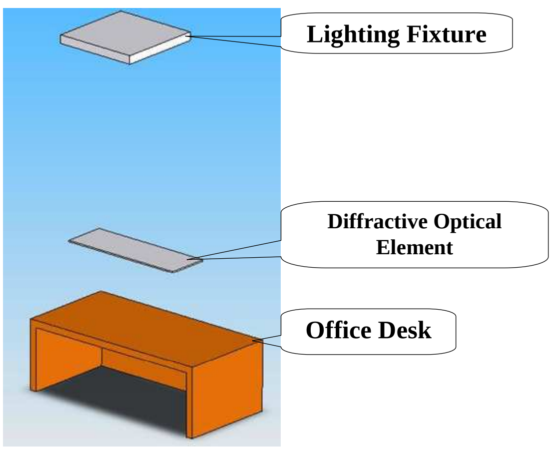


Fig. 1-1 The coordination among office desk, lighting fixture and optical elements

Fig. 1-2 Specifications of lighting fixture

II. METHOD

A Fresnel lens is one kind of diffractive optical elements for lighthouses originally developed by a French physicist, Augustin-Jean Fresnel. This design allows constructing lenses with large aperture and short focal length without voluminously using the materials for conventional lens. In comparison with conventional bulky lenses, the structure of Fresnel lens with a set of concentric annular sections can be much thinner, larger and flatter to project more oblique light from light source to longer distance. Using Fresnel lens for image projection will reduce image quality, whereas they are allowed to use only where image quality is not critical or easy to install. A new structure of Fresnel lens is proposed here in order to make the illumination distribution more averaged on working area than primitive Fresnel lens. The new structure of Fresnel lens is a set of linear sections. According to Snell's Law equations and thin lens equation, focal length f=2.58 mm can be determined. Then, the radius of curvature of diffractive optical element R=480 mm is obtained after the focal length f [6]. Finally, the thickness and profile of lens are obtained and shown in Fig. 2-1 and 2-2.

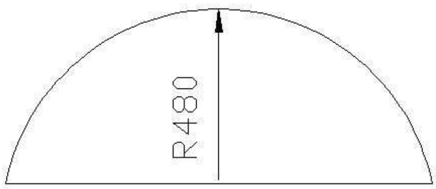


Fig. 2-1 The radius of curvature R=480 mm

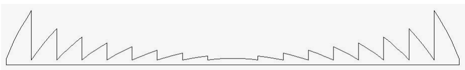


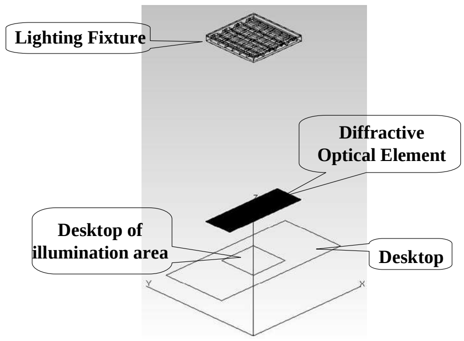
Fig. 2-2 Fresnel Lens (R=480 mm)

III. OPTIMIZATION AND SIMULATION RESULTS

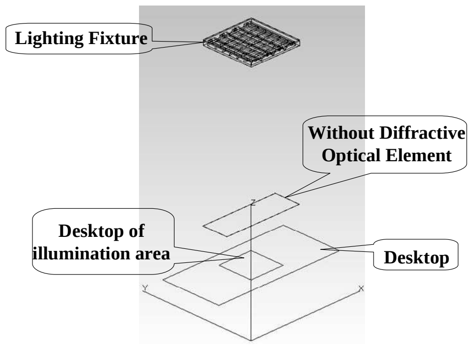
The environments and parameters for ray-tracing simulation with and without the diffractive optical element are shown in Fig. 3-1 and Table 3-1. Illumination of the desk without diffractive optical elements, simulated by TracePro, indicates 100% as shown in Fig. 3-2. Fresnel lens is transformed to V-cut structure with optimization. The results show that the basic angle of V-cut decreases from 64 to 9.7 degrees at the central portion and the pitch is 0.1 mm as shown in Fig. 3-3. Such structure can effectively eliminate the image of fluorescent tubes. The average illumination is 158% on projection area which is 300 mm x 300 mm as shown in Fig. 3-4. The simulation environments with and without the diffractive optical element are as shown in Fig. 3-5.

Table 3-1 Parameters for ray-tracing simulation

Parameters for ray-tracing simulation	
Light Source	
Lighting Fixture	**T-Bar**
Size	**600 mm x 600 mm**
Height	**3000 mm**
Structure of Diffractive Optical Element	
Material	**PMMA**
Size	**900 mm x 300 mm**
Desktop (Detector surface 1)	
Size	**1400 mm × 700 mm**
Height	**750 mm**
Desktop of Illumination Area (Detector surface 2)	
Size	**300 mm × 300 mm**
Height	**750 mm**

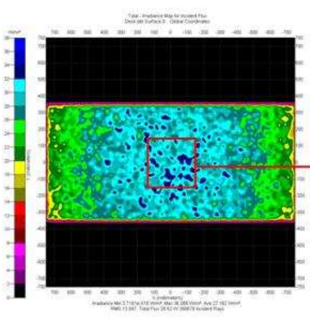


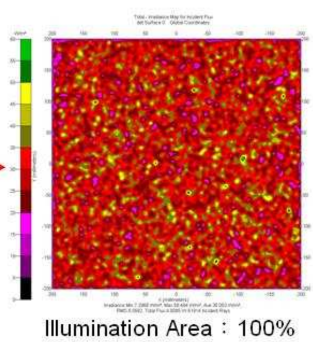
(a)



(b)

Fig. 3-1. The simulation environments (a) with and (b) without the diffractive optical element





(a) (b)

Fig. 3-2 Illumination distribution without the diffractive optical element (a) on the office desk and (b) on the working area

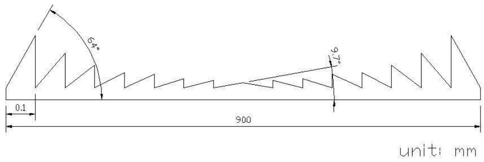


Fig. 3-3 Optimized V-cut structures

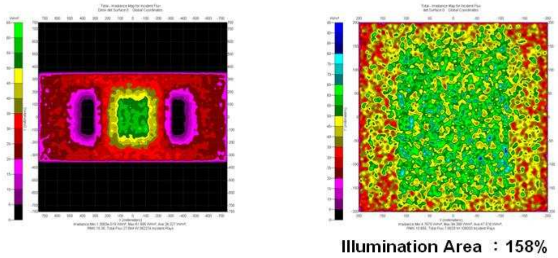
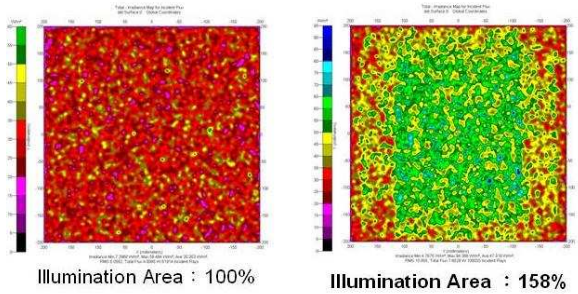


Fig. 3-4 Optimized V-cut structures of the nano-imprint process



(a) (b)

Fig. 3-5. The simulation results (a) without and (b) with the diffractive optical element

IV. EXPERIMENTS

The nano-imprint process is applied to fabricate the A4-sized samples with designed V-cut structures in this study. The nano-imprint equipment is shown in Fig. 4-1. The nickel mold for nano-imprint process is made by diamond cutting. The imprinting force, time and temperature are 7000 kgf, 600 seconds and 150 ℃ respectively. The fabricated samples by nano-imprint are shown in Fig. 4-2. The microstructures of nano-imprint sample are investigated by Confocal Microscopy and the results are shown in Fig. 4-3 and Table 4-1. It is found that the nano-imprint sample can achieve the high replication. The optical performances of fabricated samples are measured by Digital Illumination Meter (MLM-1010) under the environment same as the ray-tracing simulation. The illuminations measured without and with diffractive optical element indicate 218 lux and 526 lux, as shown in Fig. 4-4 and Fig. 4-5.

Fig. 4-1 Nano-imprint equipment

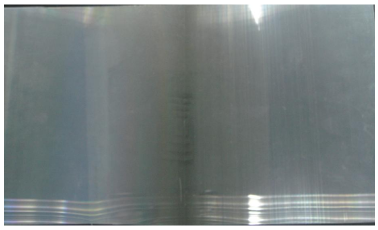


Fig. 4-2 Diffractive optical element fabricated by nano-imprint

Table 4-1 Results measured by Confocal Microscopy

Nanoimprint process						
Measured point	B1	B2	B3	B4	B5	B6
Height(um)	21.108	21.989	42.678	44.149	52.943	54.116

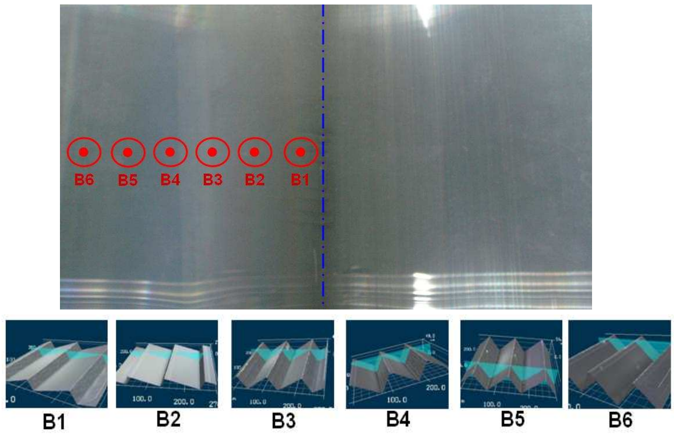


Fig. 4-3 Microstructure profiles of nano-imprint sample measured by Confocal Microscopy

Fig. 4-4 The illumination measured without diffractive optical element

Fig. 4-5 Illumination measured with diffractive optical element

V. DISSCUSIONS

The linear Fresnel lens is a combination of thousands of V-cut microstructures at different angles. The experimental results show that nano-imprint process is able to fabricate the designed linear Fresnel lens with high accuracy. It is considered that the desired microstructures on the rolling mold are hard to be machined in good shape accuracy by the diamond turning equipment used in this study. There are some limitations like shape of cutting tool, moving inaccuracy of tool position control, instability of turning machine and so on. The results of illumination experiment show the diffractive optical elements fabricated by nano-imprint significantly improve the illumination on the office desk. In addition, it agrees the results measured by Confocal Microscopy and indicates the shape accuracy of fabricated microstructures may greatly affect the optical performances.

Through the experiment, the illumination of projection area with diffractive optical elements is 2.5 times larger than the one without diffractive optical elements and 1.5 times larger than the ray-tracing simulation result. In ray-tracing simulation, the diffractive optical elements only receive the light from light source without the environmental light. Therefore, the illumination with diffractive optical elements in ray-tracing simulation is only 1.5 times larger than the one without diffractive optical elements. In real test, the diffractive optical elements not only receive the light from light source, but also collect the light from environment.

VI. CONCLUSIONS

The special diffractive optical elements not only effectively achieves the required illumination on office desk, but also has the potential to replace traditional desk lamp. Such microstructures of linear Fresnel lens have been successfully fabricated by nano-imprint process with diamond cutting mold. The ray-tracing simulation results show that the optimum parameter for the radius of curvature is R=480 mm, and the optical efficiency was raised 2.5 times by such diffractive optical element. The experiments are made on the above design, and the results show the optical efficiency can be enhanced about 2.5 times. The proposed structures have been demonstrated, and the results also present the possibility to reduce the power consumption and accomplish the energy-saving objective.

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