Microlens Array Diffuser with Randomly Distributed Structure Parameters

Tianyi Guo\textsuperscript{1,2}, Chao Yu\textsuperscript{1,2}, Haifeng Li\textsuperscript{*}, Chen Su\textsuperscript{1,2}, Yinxu Bian\textsuperscript{1,2} and Xu Liu\textsuperscript{1,2}

\textsuperscript{1}College of Optical Science and Engineering, Zhejiang University, Hangzhou, 310027, China
\textsuperscript{2}State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou, 310027, China

lihaifeng@zju.edu.cn

Abstract. With regard to optical diffusers, the configuration parameters is determined according to the need of application including beam shape, homogeneity, diffusing angle, transmittance etc. Differentiating with conventional optical diffuser design methods such as diffractive optical element (DOE) methods, we proposed a method to design microlens array (MLA) diffuser configured with random-distributed microlens parameter for generation of a large diffusing angle and uniform intensity distribution. And we discussed the relation between the beam homogeneity and random distribution type of structure parameters. Furthermore, in this article, the author validated that it was possible to splice duplicated small-scale unit into a large-scale diffuser screen with maintaining its scattering properties.

1. Introduction
Optical diffusers have attracted the attention from worldwide researchers for its application in the respects of display, beam-shaping and directional illumination, for example, the diffuser with large diffusing angle and uniform intensity distribution is widely used to achieve horizontal-parallax-only 3D display. Based on reflection or diffraction theory, optical diffusers redistribute incident light into target area, which is characterized by the parameters such as diffusing angle and projection distance. A lot of work have been done in diffractive optical element (DOE) diffuser. Parikka\textsuperscript{[1]} and Mendez\textsuperscript{[2]} have applied the DOE (diffractive optical elements) method to theoretically design optical diffusers. However, dealing with the introduced sampling interval properly and meeting strict processing precision makes fabrication of the diffuser more difficult. Frank C. Wippermann has proposed a novel setup that consists of a chirped microlens arrays (MLAs), which homogenizes the far-field intensity distribution, using reflective principle. Notwithstanding simple set-ups, the mapped structure of two-microlens arrays demands higher alignment precision\textsuperscript{[3]}. Traditional scattering material, such as holographic diffuser and frosted glass, distributes beam into room because its homogenization capability is statistically related to the random distribution of micro-unit centres\textsuperscript{[4]}. Meanwhile, the shape and emergent angle of diffusing beam depends on micro-unit’s surface profile and aperture type. Thus, the single MLA diffuser whose micro-unit centres satisfies the random distribution has been proposed\textsuperscript{[5]}. However, its diffusing angle is small with expensive fabrication cost.

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In this paper, we established one kind of microlens arrays model using optical simulation software LightTools and VBA macro language. Then, the structure parameters of microlens array model was distributed randomly. Due to random relation between parameters of microlens, beam through the diffuser will be deflected randomly in direction and quantity. Consequently, large-angle and uniform distribution of incident energy is constituted by randomly deflected beam in target area. Moreover, the relation was discussed that microlens deflection direction is mainly determined by the off-aperture extent of microlens centre. Also, it was discussed that which type random distribution results in uniform profile in target area. Finally, we focused on the possibility to splice duplicated small-scale diffuser units into a large-scale diffuser screen with maintaining its scattering properties.

2. Design principle

For the microlens array, with random distribution of its micro-unit scattering centres, it could make some contribution to a large angular uniform intensity distribution, as shown in Fig.1. For the reason that regarding emergent beam profile of every unit as Gaussian distribution in this scheme, the centre axis of emergent beam is exactly perpendicular to the target plane. Moreover, it’s inevitable that beam energy is accumulated in the centre of the target plane to form a Gaussian-like energy distribution. Researchers made efforts on aspheric surface design of micro-units to improve non-uniform distribution. But the fabrication cost is expensive with little diffusing angle below ± 5°.

Fig.1. (a) Ideal MLA diffuser configuration. (b) The angular distribution of one kind of MLA diffuser.

Fig.1(a) shows the far-field configuration of an ideal top-hat MLA diffuser, and Fig.1(b) is the angular distribution of one kind of MLA diffuser[6]. Assuming that the beam transmitting microlens corresponds
to Gaussian distribution, thereby the emergent light intensity of MLA should be the intensity integration of all the Gaussian beams as indicated by Eq. (1),

$$I_x = \sum_{p=1}^{m} I_p = \sum_{p=1}^{m} A_p^2$$

Where $m$ is amount of micro-units in MLA diffuser. The letter $p$ represents the index of micro-units from 1 to $m$. And $I_x$ is the intensity distribution in target plane, while $I_p$ is the intensity distribution of micro-units with index $p$. And $A_p$ is the amplitude of micro-units emergent wave surface with index $p$.

![Fig. 2. Ideal microlens incident ray-path](image)

With regard to an ideal lens model, as shown in Fig.2, optical ray path can be described using geometrical optics. For micro-units on the diffuser, their surface profile correspond to the specific part of an ideal lens surface which is symmetrical or asymmetrical (for example, as gray-shadow part shows). When the surface profile is asymmetrical, the micro-unit achieves outgoing beam with deflection. The first deflection angle $\tan \theta$ can be expressed as,

$$\tan \theta = \frac{dx}{L} = \frac{dx}{F - \sqrt{R^2 - dx^2}}$$

Where $F$ and $R$ indicates the focal length and the curvature radius of the microlens respectively. The distance $dx$ is measured by length from the incident position of beam centre to the ideal lens optical axis, $L$ is the axial distance from the position of incident beam centre to the lens focus point. Similarly, the twice deflection angle can be expressed as,

$$\tan \theta = \frac{1}{l'} \times \left[ dx - \tan \theta \cdot \left[T - (F - L)\right] \right]$$

Where $l'$ represents the back focal length of microlen, and $T$ is the maximum thickness of the lens. It is found that the emergent beam deflection direction is determined by the off-aperture direction of microlens centre. Obviously, the deflection direction is opposite to the off-aperture direction of microlens centre. Following, deflection degree can be calculated by the extent of microlens off-aperture extent $dx$.

The microlens array diffuser with randomly distributed structure parameters is proposed to achieve homogeneity illumination. The random distribution of microlens structural parameters within a specific range causes beam deflection is randomly distributed in target area. The specific range of structural parameters is calculated by Eq. (2) (3) (4), including the radius of curvature, the micro-unit aperture, thickness, etc. The micro-units beam deflection of the proposed MLA diffuser is different in direction and quantity as the Fig. 3. Setting arbitrary 3*3 microlens as one group, the centre unit of each group (Blue part) will be surrounded by eight nearby units (Yellow part). Due to their different radii, resulting in partly surface overlapping of the centre unit, its beam deflection occurs varying in direction and
degrees. Except micro-units in the edge of the diffuser, each unit conducts independently random deflection, which constitutes the uniform distribution of energy in target scattering zone.

In the Fig.3, it shows several situations that the emergent beam from centre unit of each group deflects in target area, (a) shows upwards beam-shaping comparing with (b) shows downwards beam-shaping. Moreover (c) and (d) shows different deflection characteristics of the micro-unit with randomly distributed structural parameters.

![Fig. 3. Various beam deflection of center micro-unit (Blue part) surrounded by eight nearby micro-units (Yellow part) (a) Beam deflection upward. (b) Beam deflection downward. (c) Beam deflection towards right. (d) Beam deflection towards left.](image)

### 3. Experiment

In the experiment, one model of standard microlens array was built by the optical simulation software LightTools. It concluded 30*30 microlenses and the device size was 0.9mm*0.9mm. The unit size and microlens thickness was 30μm*30μm and 15μm respectively. Then, by using VBA macro language, we resetted the structure parameters like radius randomly distributed in the range from 25μm to 50μm. Actual micro-units structure characteristics was related with designed scattering beam shape. Simulation results about output beam of various designed MLA diffuser with randomly distributed structure parameters was obtained by LightTools, shown in Figure 4. The intensity profile in Y-axis of scattering beam shape is shown in below, and the diffusing angle in X-axis is ± 17°.
In order to verify the replicability of designed MLA diffuser, we confirmed the possibility that splicing duplicated small-scale diffuser units into a large-scale diffuser screen with maintaining its scattering properties. In this experiment, two MLA diffuser units A and B were connected together, with parallel light incident in the centre of Unit A and another one incident at the junction section of A and B. For the reason that the structure parameters accorded with random distribution, it made no difference to change the micro-units index of designed MLA diffuser. As the theory, the simulation results were shown in Figure 5. The intensity outline of the conjunction units is the same with the single one.

![Image](a) ![Image](d)

**Fig. 4.** The energy intensity profile of simulation result in Y-axis (Left), and the intensity distribution of diffusing shape (Right) from 200mm. (a) Rectangular-shape. (b) Slender rectangular-shape.

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![Image](a) ![Image](d)

**Fig. 5.** Verification the scalability and replicability of designed MLA diffuser by the setup (Bottom) and the intensity (Top).

4. **Conclusions**

In this paper, based on the beam deflection characteristics of micro-units, the emergent beam deflection of designed MLA diffuser is randomly distributed in direction and quantity, which realizes a large-angle uniform distribution of the device scattering capability. Theoretically, the quantitative relation of beam deflection characteristics is discussed among the off-aperture extent of microlens centre, deflection degree and deflection direction. And we propose a design method of MLA diffuser with randomly distributed structure parameters. In addition, optical simulation software LightTools with Visual Basic Application macro language programming is used to model and simulate scattering effect of designed diffuser. Compared to general MLA diffusers, the designed diffuser expands diffusing angle to ± 17°.
in X-axis. In particular, it’s possible to make larger diffuser device using the proposed design method by conjunction the duplicated diffusing units. In fabrication, the designed diffuser could be fabricated by lithography-melting process with high precision.

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Acknowledgments
This work is supported by National Basic Research Program of China (973 Program) (No. 2013CB328802), National High Technology Research and Development Program of China (863 Program) (No.2012AA011902) and National Natural Science Foundation of China (Grant No. 61177015).