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Microlens Array Homogenizer for Laser Illuminated Projector

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Abstract. Laser light source is a potential illumination light source for non-emissive display applications, especially for liquid crystal projection displays, due to its requirement of low etendue source and highly polarized light. In order to make a conversion from a circular Gaussian beam profile to a rectangular uniform distribution, a microlens array has been proposed as a homogenizer. The analytical and experimental results show that the microlens array with a pitch of 100um under laser beam illumination works as a diffractive element, and a promising uniformity can be obtained with a stack of two microlens array.

Introduction

The traditional light source for projection displays are high intensity discharge (HID) lamps, whose spectrum contains fixed ratio of red, green and blue content, which consequently results in low color efficiency or low color saturation. It is also difficult to modulate light source in time frame, due to its mechanism of emission. Recently, light emitting diodes (LED) is becoming a potential light source for projector applications. However, the problem with LEDs is low light collection efficiency, mainly because the total lumen per unit area and per unit solid angle of LED is relatively low compared to the HID lamps. The other choice of solid state illumination for projectors is diode laser. The advantage of laser source for projector application is low diverging angle, which means low source etendue and high light collection efficiency on the microdisplays [1]. For liquid crystal projectors, polarized light of laser source will significantly reduce the complication of optical design, and the low diverging angle of laser source will also give a relatively higher contrast compared to the case of using light source lambertian. However, a laser beam normally has a circular or elliptical cross section with a size of about 2mm in diameter. In order to expand and reshape the beam as well as redistribute the energy to make a uniform illumination on the microdisplay, a complicated and bulky illumination optics might be required [2], or the surface relief of the homogenizer and beam shaper becomes very complicated and difficult to fabricate [3]. In this paper, a microlens array, which traditionally is used for splitting laser beam energy into an array of bright spots has been proposed as a compact solution to make laser beam energy uniformly shine on the microdisplay for projector applications.

Microlens array homogenizer

A microlens array (MLA) in most cases is a two dimensional array of repeated optical structure [4,5,6]. Its optical behavior depends on its pitch size and the characteristics of the illumination light source. It would be more like a diffractive element when the pitch size of the array becomes smaller and the coherency of the illumination light source becomes stronger. In that case, the far field pattern of laser beam passing through a MLA is normally an array of bright spots, and in several applications, the surface profile of the MLA is designed so that every spot can have the same energy, which also implies that an MLA has the function of evenly distributing the laser source energy, and hence a potential solution for obtaining a uniform illumination from laser source. Although the far field pattern is an array of bright spots, the near field pattern has the energy distribution much more widely spread, and hence more suitable for projector illumination. The proposed MLA is composed of a square lenslet array with a pitch of 100um, a thickness of 6um and radius of curvature of 418um. The surface profile of the lenslet has been probed with a profiler and is shown in Fig. 1 .The material is UV resin cured on PET substrate with a thickness of 110um.

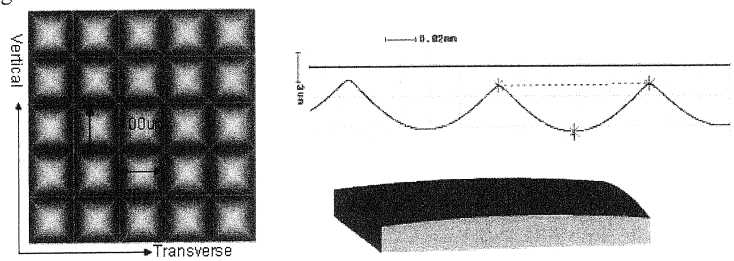


Fig. 1 The feature of MLA

With a He-Ne laser shining on the microlens array as shown in Fig. 2, a varying optical field pattern can be observed at different distance from the MLA. This pattern has also been verified with scalar diffraction theory. Fig. 3 shows the propagation of light from a point P within an aperture plane to a point Q.

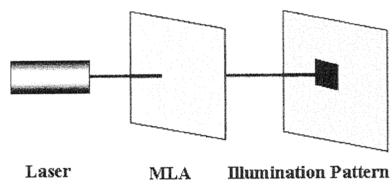


Fig. 2 The configuration for single MLA

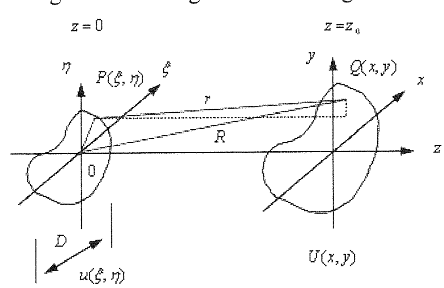


Fig. 3 The propagation of light from an aperture to plane

The field distribution at the observation plane (x-y plane) can be calculated using the Helmholtz Kirchhoff integral. The far field and near field transform are described mathematically by Eq. (1) and Eq. (2) respectively.

$$U(x,y)=\frac{\exp(ikz)}{z}\iint_{\Sigma}u(\xi,\eta)\exp\left[-i(\frac{x\xi+y\eta}{z})d\xi d\eta\right] \tag{1}$$

$$U(x,y)=\frac{\exp(ikz)}{z}\iint_{\Sigma}u(\xi,\eta)\exp\left[ik(\frac{\xi^2+\eta^2}{2z})\right]\exp\left[-i(\frac{x\xi+y\eta}{z})d\xi d\eta\right] \tag{2}$$

Where $u(\xi,\eta)$ is the optical distribution at the exit of diffractive element and $U(x,y)$ the optical distribution at the observation plane.

The simulated and measured far field pattern at 2m away from the MLA is shown in Fig. 4. The near field diffraction pattern simulated and measured at 0mm, 50mm, and 100mm are shown in Fig. 5.

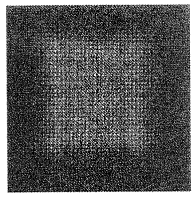
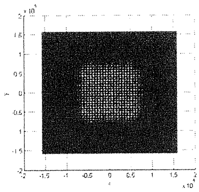
Distance	Illumination area	Experiment	Simulation
200mm	445mm × 445mm (square)		

Fig. 4 Far field diffraction pattern of microlens array

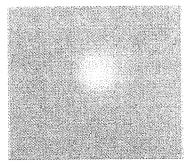
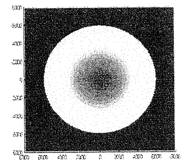
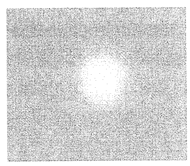
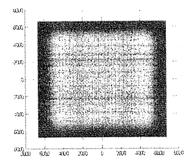
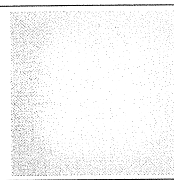
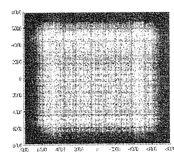
Distance	Illumination area	Experiment	Simulation
0mm	1mm (circle)		
50mm	11mm × 11mm (square)		
100mm	21mm × 21mm (square)		

Fig. 5 Near field diffraction pattern of microlens array

The result shows that the scalar diffraction theory predicts the behavior of the MLA quite well, which implies the MLA actually functions as a diffractive element. In addition, at the distance close to and far from the MLA, the optical field distribution, including the shape and the uniformity, does not match well with a microdisplay, which is normally a rectangular shape with a diagonal of 0.5 to 1.1 inches. In the former case, the shape is still circular and the size is too small, while in the latter case, the shape and size are sufficiently close, but the energy concentrates at a few spots. However, in between these two extremes as the case of 50mm away from the MLA in Fig. 5, the irradiance distribution becomes more suitable for illuminating a microdisplay, as the energy is more evenly spread and the pattern shape has been transformed into a square, which can be controlled by the shape of the lenslet. The dark spot remains to be eliminated for the MLA to be useful as a homogenizer. It has been found difficult to find a distance where the pattern is uniformly spread over a square shape by using a single MLA. With a square illumination pattern of 0.5 " in diagonal as the target, the field pattern at 85mm from the single MLA is shown in Fig. 6, which clearly illustrates the problem associated with single MLA.

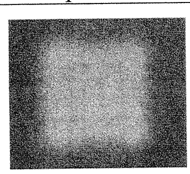
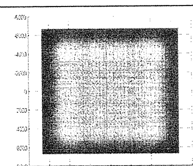
Distance	Illumination area	Experiment	Simulation
85mm	0.5" (diagonal)		

Fig. 6 Field pattern of single MLA at 85mm distance

Stacked Microlens Array

In order to avoid making complicated surface profile or even irregular pitch of the lenslet, a stack of two MLA has been proposed for eliminating the dark area in the diffractive field pattern. With this configuration, the only parameter to be manipulated is the lateral shift between two lenslet arrays. For simulation on the field pattern, it is reasonable to assume that the phase delay from two MLA can be directly added together if the thickness of the MLA is sufficiently thin. The configuration of double MLA is shown in Fig. 7.

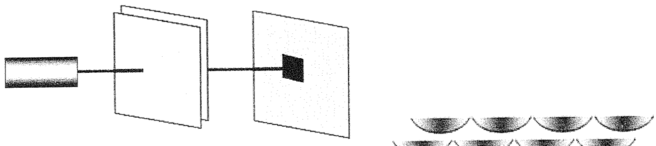


Fig. 7 A stack of MLA

Taking a 0.5" diagonal illumination pattern as the target, the distance where a suitable size of field pattern can be generated becomes 56mm, regardless of the lateral shift of the two MLA. The simulated and measured field pattern at 56mm from the double MLA in Fig. 8 show two different patterns are generated with different lateral shift between the two MLAs. It has also shown that the lateral shift of the two MLAs affects the uniformity significantly. Fig. 8(b) shows the best uniformity achievable with a lateral shift of 44um in diagonal direction, which is nearly a flat top distribution over 0.5" area and also indicates the feasibility of using double MLA for laser illumination in projector application. The physical distance of the illumination light path from the MLA homogenizer to the microdisplay will then be only 56mm. The overall transmittance of the stacked MLA has been measured to be 81%.

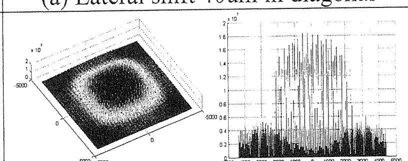
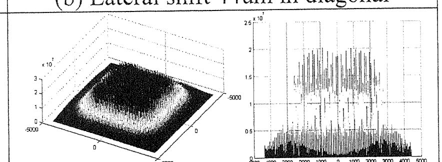
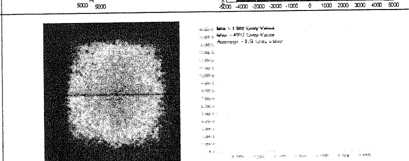
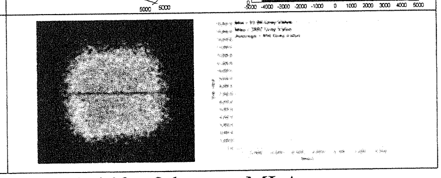
	(a) Lateral shift 40um in diagonal	(b) Lateral shift 44um in diagonal
Simulation		
Experiment		

Fig. 8 Two different patterns with different lateral shift of the two MLAs

Laser illuminated projector engine with MLA

A laser illuminated projector engine has been constructed using the proposed stacked MLA with a proper lateral shift, as shown in Fig. 9, where the optical paths of RGB channel are different, but it has little influence on the illumination pattern as the divergence of the laser beam is negligible at such a short distance. Their light paths are combined with dichroic plates before illuminating on the MLA. Fig. 10 shows the prototype of the laser illuminated projector engine with red diode laser, green second harmonic generation laser and blue pumped solid state laser. Blue and green laser beam have been attenuated with neutral density filter before combining with red laser beam for the white light with the desired color temperature. The result has shown that there is no significant dispersion at the edge of the illumination pattern after passing through the double MLA. The total feature size of the projector engine is 150×50mm. With the progress on blue diode laser, this architecture will be a potential solution for compact projector [7].

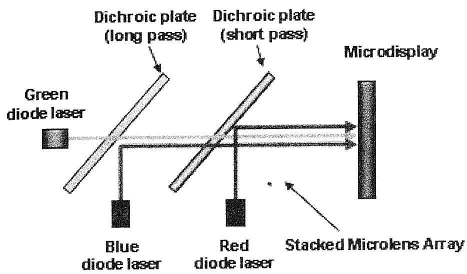


Fig. 9 Laser illuminated projector engine

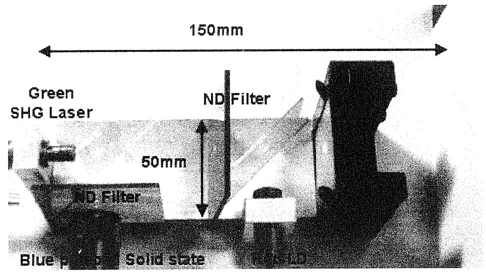


Fig. 10 Prototype of laser illuminated projector engine

Conclusion

The proposed double microlens array has been shown as a viable compact solution to provide a uniform illumination from a laser light source, which will be a potential alternative as a light source for future light valve projection displays. The light source features low etendue and polarized light, which is significant for simplifying optical design and improving optical performance of projectors. The compact architecture of the projector engine based on MLA and diode laser makes it especially suitable for mini-projector.

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