Projection of arbitrary far-field patterns using tailored microlens apertures

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Designs of maskless multi-aperture pattern projectors are presented. The entrance lenslets are arbitrarily shaped corresponding to the pattern to be projected and arranged into space-filling arrays. Any residual regions which cannot be shut-off are patterned with diffusor structures to scatter away incoming light. We present realized maskless projectors together with preliminary characterization results.

1 Introduction

Usually, the pattern projected by multi-aperture micro-optical projector is shaped by an absorbing slide mask array buried in a tandem microlens array (MLA). The transmission of such MLA is limited by the fill-factor of the mask array which in turn depends on the geometry of the pattern [1]. Additionally, such projectors are realized as a polymer-on-glass (POG) element by alignment of 3 micro-optical layers in a mask aligner [2].

To increase the transmission of the MLA, we propose eliminating the mask layer and shape the pattern by tailoring the apertures of the entrance lenslets corresponding to the desired pattern geometry and arrange them into a space-filling array. Any residual regions which could not be covered by the lenslet apertures can be structured with refractive diffusor structures to scatter away incident light under large angles.

With this approach we also reduce the MLA to a double-sided aligned element which allows us to replicate such components using alternate large-scale technologies like injection molding, bringing down manufacturing costs.

2 Design principle

For the maskless arrayed projectors, the projection lenslets image the apertures of the condenser lenslets towards the far-field. Hence the aperture of the condenser lenslets correspond to the shape of the projected pattern. Additionally, the fill-factor of the entrance or condenser side must be high to avoid any ‘dead-zones’ since we don’t use masks to block light.

Certain patterns are inherently space-filling as shown in Fig. 1 (left), therefore lenslets of such shapes can be easily arranged into a full fill-factor array. On the other hand, some geometries cannot be tessellated easily as shown in Fig. 1 (right), however one can decompose such geometries into some simple primitives which can be arranged into space-filling arrays. The individual far-fields generated by the individual primitives must be rearranged to get the intended far-field pattern. This optical ‘jigsawing’ is done by using decentered lens segments preferably of the projection lenslets.

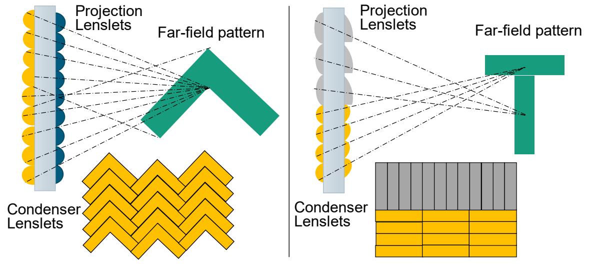

Fig. 1 *Exemplary strategies for maskless MLA depending upon the projected far-field. When pattern is inherently space filling (left) & when pattern can be decomposed by space filling elementary shapes (right).*

Finally, some patterns cannot be achieved with 100% space filling at all. E.g., tessellation of distortion/keystone corrected regular shaped lenslets leading to inevitable dead zones. In such cases the areas are populated by diffusor structures which scatter away incident light at large angles so that, at the screen the unwanted light appears dim and smeared out. The diffusor structures should be randomized between each channel to avoid imaging of the structures as hot spots. The transition from the diffusive to transmissive region of the lens array should be gradual to avoid sudden height jumps.

3 Design examples

We present two examples of maskless projectors with space filling and non-space filling cases. We design a projected automotive blinker which projects a sequence of 3 chevrons on the road surface as schematically shown in Fig. 2 (left). The condenser lenslets MLA are similar in shape to the projected chevron and are arranged in a space filling way shown in Fig. 2 (right). The three chevrons are projected by utilizing intentional crosstalk by decentered LEDs with a common collimation optics.

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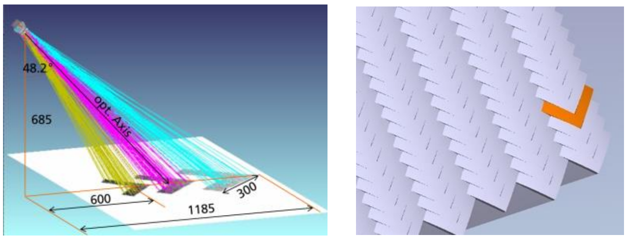

Fig. 2 *Projection geometry of projected blinker (left). Shape of condenser lenslet and arrangement in a space-filling array (right).*

For the second example a vehicle interior 'forget-me-not' light integrated in the roof console projects keystone corrected rectangular shapes on the driver and passenger seats as well as on the mid-console as shown in Fig. 3. Due to keystone correction the condenser lenslets are distorted and the array is not space-filling. The residual regions between the lenslets are populated by diffusor structures.

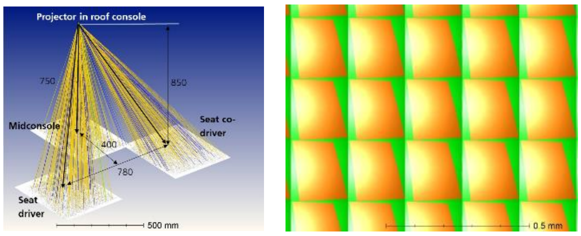

Fig. 3 *Projection geometry of 'forget-me-not' light (left). Shape of irregular shaped condenser lenslet for the passenger seat and diffusors structured between the condenser lenslets of the array, shown in green (right)*

4 Realization and Characterization

The mastering of the lenslets is done by grayscale lithography [3] and replicated as double-sided polymer-on-glass elements. Tooling for injection molding of MLA is derived from the grayscale masters.

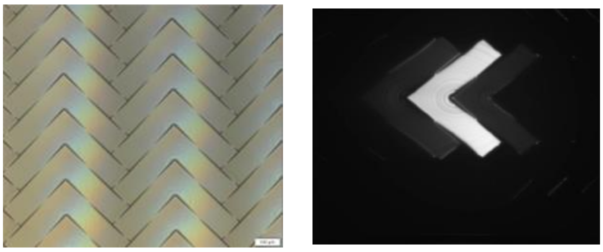

Fig. 4 *Microscope image of realized condenser array for blinker application (left). Single projected chevron illuminated using provisional light source (right).*

An array of chevron-shaped condenser lenslets for the blinker is shown in Fig. 4 (left). By illuminating the MLA with a provisional source, a bright projected chevron with some faint ghost images is recorded. Stray light like circular ripples which are artefacts from the direct-writing method as well as hotspots due to sag-height jumps on the condenser side can also be seen in Fig. 4(right).

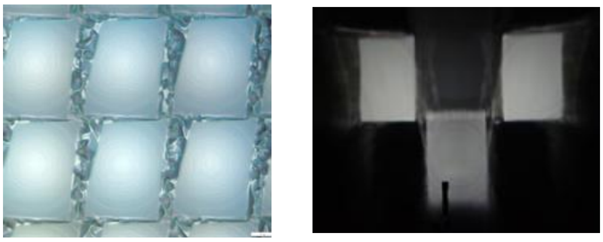

Fig. 5 *Microscopic image of the condenser lenslets for the driver seat showing the transmissive aperture and diffusor structures (left). Light distribution from the projector on a screen (right)*

Condenser array with transmissive and diffusive regions for the interior illumination MLA is realized as shown in Fig. 5. Projected distribution shows slight residual barrel distortion since lenslet contours are straight and not curved. Residual stray light, scattered by diffusor structures, has illuminance of ~4x-5x lower than the useful light.

5 Conclusions and Outlook

Maskless array projectors with arbitrary apertures have been realized using grayscale lithography. They offer higher transmission at the cost of edge sharpness and contrast. Due to a maskless design, such MLAs can be produced by injection molding with relatively similar quality.

However, maskless methods entail more effort in terms of design simulation and mastering. Due to irregular lenslets, and decentered lens segments, it is more sensitive to stray light due to abrupt height jumps and flanks, therefore stray light suppression is more critical. Further work is to realistically model the effects of replication on lenslet contours and edges to identify possible straylight mechanisms and take remedial measures either in the design of the micro-optics, or illumination optics or in the housing design.

Acknowledgements

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References

[1] M. Sieler et al., "Ultraslim fixed pattern projectors with inherent homogenization of illumination", Applied optics, vol. 51, pp. 64-74, 2012.

[2] P. Dannberg et al., "Wafer-Level Hybrid Integration of Complex Micro-Optical Modules", Micromachines vol. 5(2), pp. 325-340, 2014.

[3] H.-Ch. Eckstein et al., "Direct write grayscale lithography for arbitrary shaped micro-optical surfaces", 20th MOC, Fukuoka 2015.

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