Design and realization of micro-optic lightfield displays

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Lightfield displays based on principles of integral photography are designed and realized. Microlens arrays together with an object mask array encoded with lightfield information allows various artistic motifs to be displayed with a 3D effect.

1 Introduction

Early in the 20th century, the French engineer Eugène Estanave experimented with integral photography [1] using an array of lenslets to capture the lightfield of a subject and display a 3D image, but it was limited by the available technology in that era.

Present day multi-aperture projection devices consisting of double sided microlens array along with buried aperture arrays are used to project homogenously illuminated patterns on various tilted and free-form surfaces [2]. The optical scheme of such arrayed projectors is analog to the precursor lightfield apparatus and hence one can use such a combination of MLAs and an array of tailored apertures to project images in front or behind the display towards a viewer. The visual impression of an observer is that one sees objects floating in space which is illustrated in Fig. 1.

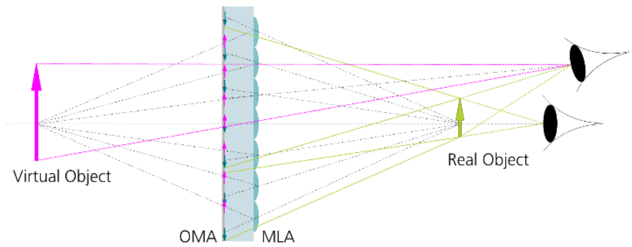

Fig. 1 *Working principle of the lightfield display. As the viewer moves their gaze, the objects seem to float about following the gaze or in the opposite direction.*

2 Design

In the framework of an interdisciplinary project, Berlin based artist duo Dachroth + Jeschonnek conceptualized the motifs as shown in Fig. 2 for displaying with the lightfield device.

We intend to design two distinct displays – one with a high resolution and a medium viewing angle of ±20° referred to as 'hi-res' and one with lower resolution and larger viewing angle of ±40° referred to as 'wide-angle'.

To remain within the technological window of reflow mastering, we restrict the design of the lenslets to plano-convex conic aspheres with circular apertures [3]. High refractive index polymer (n =1.7) is chosen as lenslet material.

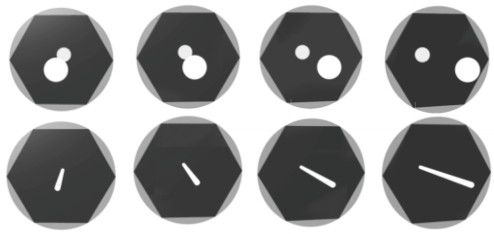

Fig. 2 *Visual impression of the motifs - double sphere (top) and piercing stick (bottom) to be displayed by the lightfield device. Source: Dachroth + Jeschonnek.*

2.1 Optics design

The hi-res MLA consists of 300 µm diameter channels with a pitch of 350 µm arranged in a hexagonal array. The radius of curvature (ROC) of a single channel is optimized for the FOV of ±20° for the smallest spot size at the mask plane. To improve resolution, intentional vignetting is realized using mid-substrate apertures. 86 resolvable pixels could be displayed from a single channel with an 80 % light fall-off at the edges of the MLA.

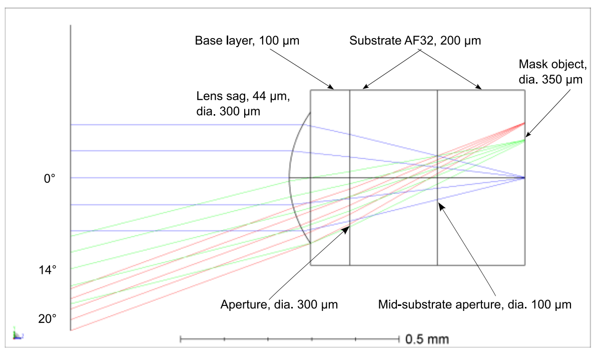

Fig. 3 *Layout of single channel of the regular MLA with ray traced backwards from 20° field towards mask plane.*

For the wide-angle MLA we employ a chirped lens array with channels diameters of 300 – 340 µm. The channels have radially varying chief ray angles to address the large FOV. The ROC of the on-axis and outer channels are individually corrected. The number of resolvable pixels varies from 84 pixels on-axis

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to 48 pixels at the rim. Channel are arranged in a hexagonal arrangement and the pitch is increased to 500 µm to address the enlarged FOV.

2.2 Mask Design

The mask structures are generated by backward ray tracing from the subject contour through the optic channel towards the mask plane using the ray-tracer program like Zemax. This task is automated using a suitable programming language like Python [4]. However, this method is tedious for the display MLA where there are ca. 260,000 channels.

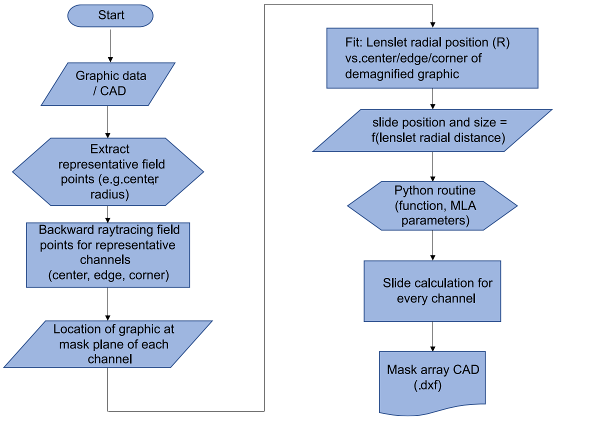

***Fig. 4** Flow-diagram for analytical mask generation.*

A simpler method for generation of the mask structures is devised where the distortion, demagnification and location of the mask structures are mapped as a function of the channel location. This method is described as a flow-diagram in Fig. 4.

3 Realization

The lightfield devices are realized using wafer level optics. Circular lenslets are mastered using reflow technology. MLAs are replicated on 8” Borofloat glass wafers. Interstitial gaps between lenslets are masked by buried circular apertures of same as that of the lenslets. Circular apertures (dia. 100 µm) are replicated on a separate glass wafer and in black matrix resist. Masters of the mask structures are written by electron beam lithography and are replicated by wet etching into a separate chromium coated wafer. Finally, all three wafers are precisely aligned and stacked together for the lightfield device. The final device is ca. 2.5 mm thick.

4 Characterization

The lightfield display wafers are illuminated by natural light and a camera is used to capture the displayed motifs under different viewing angles as shown in Fig. 5.

Laboratory measurements are carried out using luminance camera to measure the geometry of the motifs. The measured geometries are slightly larger than the intended geometries due to blurring from residual aberrations of the MLA.

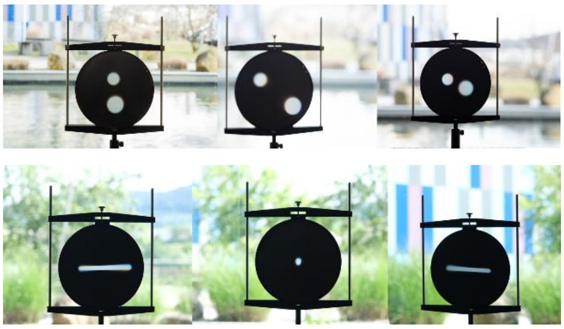

***Fig. 5** Lightfield device displaying the double-sphere (top) and piercing stick (bottom) motif under various viewing angles.*

5 Conclusions and outlook

Lightfield displays with medium to large viewing angles (±20°...±40°) realized using microlens arrays to display static 2D motifs with a 3D appearance. The motifs appear to float in space in front or behind the display. One can illuminate the display using extended Lambertian sources.

Presence of an absorbing mask, depending on the fill factor of the mask structures limits the transmission of the system. If the motifs involve complicated contours, analytical methods of mask generation would not be suitable and conventional mask generation would be time intensive. Stacking of 3 wafers, makes alignment of such devices challenging.

Possible applications of such lightfield devices would be to display ‘floating-in-space’ buttons for touchless interfaces or providing 3D appearance to rear light clusters for automobiles, logos and icons for branding.

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