Design of irregular MLA for the switchable adaptive headlight high beam

D. Stefanidi*, P. Schreiber**, R. Leitel**, R. Brüning**, A. Tünnermann**

***Fraunhofer Institute for Applied Optics and Precision Engineering*

**Institute for Applied Physics, Friedrich-Schiller-University*
Albert-Einstein-Straße 15, 07745 Jena, Germany, dmitrii.stefanidi@iof.fraunhofer.de

We present a maskless irregular microlens array for a segmented high beam with a feature of dynamic switching of its vertical segments for the adaptation during driving, using a concept of intentional “cross-talk” between the array channels.

1 Introduction

Today a “slit-like” appearance of car headlamps with very small vertical size is getting more attractive to the customer. This causes a significant drop in the light transmission, which may be a critical disadvantage for future electric cars, where electrical efficiency of each unit is crucial.

Beam shaping with microlens array (MLA) is an effective way for system miniaturization, whilst keeping its high transmission. Multichannel structure ensures more design flexibility, while intentional irregularities of the lenslets' shape provide a possibility of achieving a desired arbitrary symmetric or asymmetric light beam profile without absorbing masks, hence saving a lot of system transmission in a compact size. A dynamic beam in the far-field is achievable with intentional cross-talk in the array channels. The MLAs are mastered by grayscale lithography [1]. The masters are replicated as double-side aligned polymer-on-glass elements by UV-molding.

2 Irregular Fly's Eye Condenser (iFEC)

An adaptive high beam has a continuous intensity profile in the vertical and horizontal direction with a hot-spot in the center, as well as individually controlled vertical segments, entitled for the adaptation.

An iFEC is a high-efficient solution for achieving an arbitrary vertical intensity profile with no absorbing masks [2]. For the target vertical intensity distribution of the single segment of the beam we build a 1x7 vertical “Elementary Cell” (EC) with the following irregularities of the lenslets (Fig. 1):

- different pitch and the aperture position of the entrance lenslets with fixed vertex position;
- different vertex position of the exit lenslets of constant pitch.

The number of steps in the intensity profile corresponds to the number of channels in the EC [3]. For the smoother vertical profile, the exit lenslets are slightly defocused in the vertical plane ($f_V^1 < f_V^2$), while still being perfectly focused in the horizontal plane ($f_H^1 = f_H^2$) for the sharp edges of the segment.

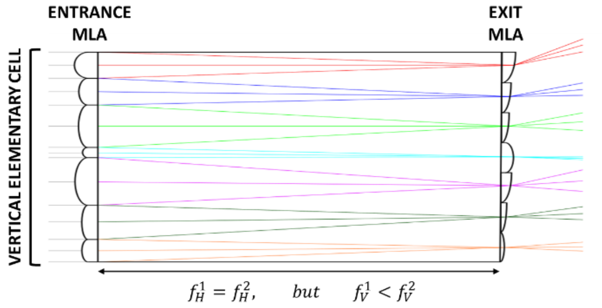

Fig. 1 *1x7 elementary cell of the iFEC (side view)*

The key-feature of the EC is lack of height jumps between the entrance lenslets. This helps to avoid localized stray-light, which is very harmful at the entrance array – being projected by the exit array towards infinity, it generates unwanted cross-talk of high orders and leads to parasitic images around the useful beam.

Once the target intensity profile is achieved in the vertical direction, the EC is replicated over the whole area of the MLA, which ensures a completely jumpless profile of the entrance lenslets in both directions (Fig. 2). The residual height jumps between exit lenslets in the EC are much less critical since they only generate overall lack of contrast of the beam in the vertical plane. Due to the identical replication of the EC, there are no height jumps between the exit lenslets in the horizontal plane as well, which ensures a high contrast of the segments w.r.t. dark area during adaptation of the beam.

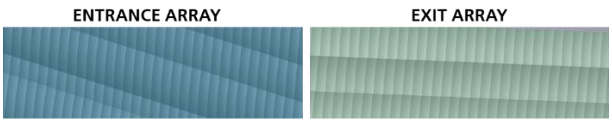

Fig. 2 *Models of the entrance and exit array*

3 Intentional cross-talk

To achieve the desired horizontal extent of the beam, as well as its segmentation for the adaptive function, an intentional cross-talk is implemented in the system. The approach is to use a one-dimensional LED array, where individual LEDs are positioned in a horizontal line and collimated equally, but

DGaO Proceedings 2022 – *http://www.dgao-proceedings.de* – ISSN: 1614-8436 – urn:nbn:de:0287-2022-A014-8

submitted: 24.07.2022 published: 05.09.2022

with a constant angular pitch of their chief rays, corresponding to the target pitch of the segments in the resulting beam. Thus, each collimated LED is assigned to its particular cross-talk order (Fig. 3).

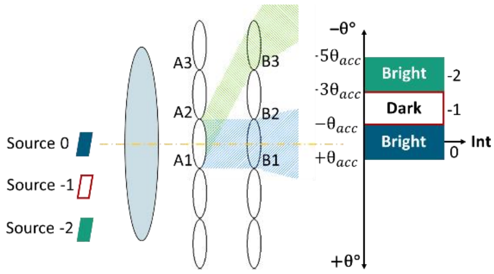

***Fig. 3** Cross-talk at the microlens array (top-view)*

The residual divergence of each individual collimated light beam should be slightly smaller than the horizontal NA of the lenslets in the array, which corresponds to the horizontal width of the individual segment. With a precise control of the LEDs' lateral pitch, we can achieve a full direction of the light from one channel to another (e.g., from lenslet A1 to lenslet B3 → an order of cross-talk # "-2"). As a result, we get seamlessly adjacent beam segments, which can be controlled individually.

4 High beam system design

An optical system consists of 3-lens collimator and an MLA designed in accordance to §2. The system dimensions are 95 x 120 x **20** mm^3 (L x W x **H**), which corresponds to the current design trends of very thin headlamps.

An array of 19 LED sources is used for achieving 19 individual segments. A vertically irregular MLA provides a target vertical profile of the beam (Fig. 4). Resulting angular vertical extent of the beam, as well as its profile correspond to the typical automotive high beam.

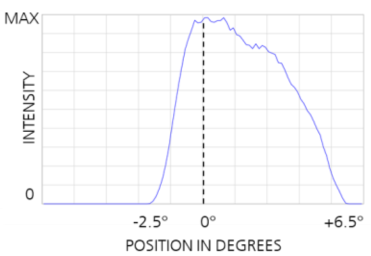

***Fig. 4** Vertical intensity profile of the beam*

To achieve the target intensity distribution in the horizontal plane, LEDs are gradually dimmed starting from #±2. The three central LEDs are responsible for the hot-spot region. The achieved peak intensity is 74 kcd (Fig. 5). This value is mostly limited by the large mismatch of the Etendue of the collimator and Etendue of the light source in the vertical plane, which leads to significant transmission drop (~48% losses) at the collimation optics.

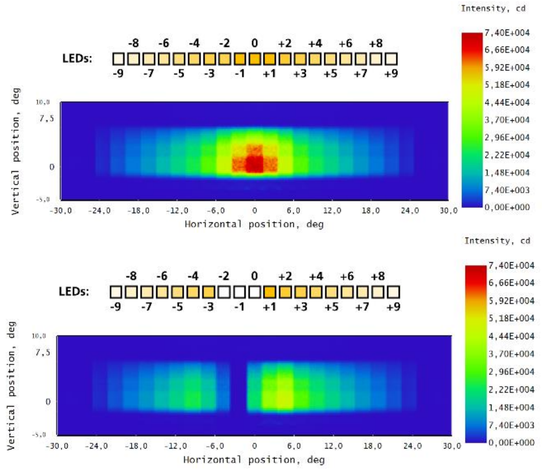

***Fig. 5** Full beam (top) and its adaptation (bottom)*

Transmission at the MLA is about 100 % since no absorbing elements are applied in it. The intensity ratio of the dark area of the switched-off segment to the peak intensity is about 1/370, which corresponds to ECE regulations. Due to a very low NA of the microlenses in the horizontal plane (0.02), the 2.4° full width of the single segment is achieved, as for typical adaptive driving beam. Smaller segment would require even smaller NA and additional effort for the system correction due to the diffraction caused by such small NA.

Conclusion and outlook

We presented a design of the maskless iFEC for an adaptive automotive high beam. The overall efficiency of the system is only limited by the collimator's Etendue. For a higher peak intensity, one should use either better collimation optics, or brighter LEDs. The further work for the presented system is its manufacturing and characterization of the MLA.

Acknowledgment

The authors like to thank all involved colleagues and Fraunhofer society for funding this work in the project "PREPARE Smart Headlight".

References

[1] R. Leitel, et. al. – "Evaluation of lenslet fabrication technologies for micro-optical array projectors," Proc. SPIE 10692, Optical Fabrication, Testing, and Metrology VI (15 June 2018).

[2] C. Li, P. Schreiber, et. al. – "Etendue conserving light shaping using microlens arrays with irregular lenslets," Proc. SPIE 10693, Illumination Optics V, 1069304 (28 May 2018).

[3] P. Schreiber, L. M. Wilhelm, "Light shaping with micro-optical irregular fly's eye condensers," Proc. SPIE 12078, International Optical Design Conference 2021.

submitted: 24.07.2022 published: 05.09.2022