

# Diffractive optical elements for beam shaping of spatially incoherent light



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## Abstract

Diffractive optical elements (DOEs) for beam shaping of spatially incoherent light into an output spot with arbitrary intensity profile, particularly into a tightly focused output spot are demonstrated. Several different design examples are shown. The ratio of the maximum sidelobe intensity to the maximum intensity in the signal window ranges from 5.0% to ~50%. Experimental results are in close agreement with numerical predictions.

## Introduction

Recently high-performance, high-resolution (1200 dots per inch, 20 $\mu$ m-sized), broad-area (0.1-1.0mm<sup>2</sup>) and matrix-addressable  $\mu$ -LED arrays have been reported by a number of groups [1,2]. These micro-LED arrays are anticipated to offer potential applications including micro displays, exposure tools for mask-free photolithography and high-density data storage. In these applications, small and bright illuminating spots are desired because they provide higher resolution. However, as spatially incoherent light sources, their image spot size at the conjugate plane is limited by geometrical optics, i.e.  $size_{image} = size_{object} \times z_{out} / z_{in}$ , where  $z_{in}$  and  $z_{out}$  are the object distance and image distance respectively. Is it possible to focus the LEDs light to an image spot whose central lobe is smaller than the geometrical-optics limit while surrounded by sidelobes with acceptably lower intensity? Further to our demonstrating that using DOEs to generate output spots with arbitrary intensity profiles, allowing some sidelobes, for spatially incoherent light [3], we design DOEs for tightly focussed spots whose central lobe is smaller than the geometrical-optical limit.

## Design methods

Figure 1 shows the configuration used for beam shaping of spatially incoherent light. Iterative Fourier transform algorithms (IFTAs), simulated annealing (SA), direct binary search (DBS) and genetic algorithm etc. can be used for the design and Table 1 compares their performance.

Fig. 1 Configuration used for beam shaping

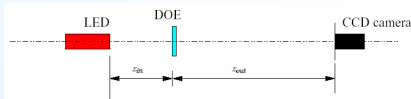


Table 1 comparison of different algorithms

	IFTA	SA / DBS
Sidelobes	Low (<4%)	High (5%~60%)
Diffraction efficiency	High (>96%)	Low (40~50%)
Size of output image	Almost impossible to obtain an image spot smaller than the geometrical-optics limit	Can obtain an image spot smaller than the geometrical-optics limit subject to high sidelobes

## Arbitrary and tightly focused spot beam shaping

Reference 3 has described arbitrary beam shaping in detail. Figure 2 shows simulated (solid and dashed curves) and experimental (dotted curve) intensity profiles generated by designed and fabricated DOE. The curve "Simulated 1" is the intensity profiles when no fabrication errors exist, i.e. the feature size is 2 $\mu$ m and no vertical etching depth errors. "Simulated 2" is the situation when the feature size is 11.7 $\mu$ m and the etching depth error is -20%. The feature size for the measured curve is 4.5 $\mu$ m.

For tightly focused spot beam shaping, Table 2 shows 6 design problems and their performance obtained by DBS, where  $G$  is the ratio of the central lobe size of the output spots to the geometrical-optics limit, and  $S$  is the maximum sidelobe intensity compared with maximum intensity in the signal window. We can see that more pixel number or larger central lobe size can result in lower sidelobes. We can also see that  $S$  ranges from 48.9% to 58.6%. Using SA can slightly decrease the sidelobes, usually by 3.0 - 5.0%. Figure 3 shows the results of design problem (4).

## Conclusions

By using IFTAs, it is almost impossible to obtain an image spot smaller than the geometrical-optics limit. For DBS, the sidelobe of a tightly focussed spot whose central lobe is 0.3 and 0.8 times the geometrical-optics limit is 54.0 and 48.9% respectively. Using SA can result in slightly better performance indicated by lower sidelobes.

Fig. 2 Measured and simulated arbitrary beam shaping

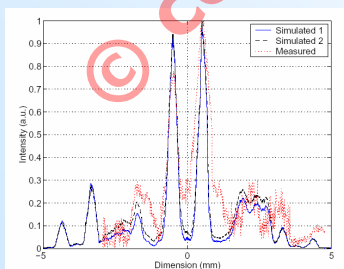


Fig. 3 Simulated performance of problem (4) in Table 2

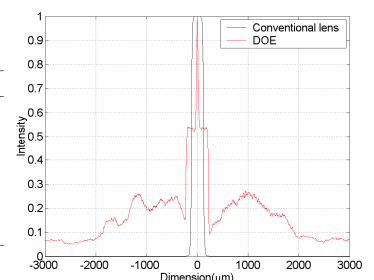


Table 2 Tightly focused spot beam shaping problems

No	$z_{in}$	$z_{out}$	$W_{DOE}$	pixel number	$G$	Iteration number	$S$
(1)	300	70	24	512	0.3	20	58.6%
(2)	300	70	24	1024	0.3	37	57.4%
(3)	300	70	24	2048	0.3	15	53.3%
(4)	300	70	24	4096	0.3	10	54.0%
(5)	300	70	24	4096	0.8	6	50.2%
(6)	300	70	24	8192	0.8	9	48.9%

## References

- [1] C. W. Jeon, E. Gu and M. D. Dawson, "Mask-free photolithographic exposure using a matrix-addressable micropixelated AlInGaN ultraviolet light-emitting diode," *Appl. Phys. Lett.*, 86, Art. No. 221105 (2005).
- [2] C. Griffin, E. Gu, H. W. Choi, et al., "Beam divergence measurement of InGaN/GaN micro-array light-emitting diodes using confocal microscopy," *Appl. Phys. Lett.*, 86, Art. No. 041111 (2005).
- [3] J. S. Liu, A. J. Caley and M. R. Taghizadeh, et al., "Diffractive optical elements for beam shaping of monochromatic spatially incoherent light," Oral presentation, EOS Annual Meeting, Paris, 2006; *Appl. Opt.*, in press.