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Beam shaping in deep UV: comparison of methods

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1 Introduction

Beam shaping is one of the most important applications of diffractive optics, and as such has been widely studied by numerous authors in the context of quite different underlying tasks[1]. Fundamentally, there are two ways to perform beam shaping. The first approach is to re-map the incidence beam into the desired shape using classical map-transform techniques based on geometrical optics or by iterative design approaches based on physical optics. This approach leads to exact realization of the desired shape, but the resulting elements are highly space-variant, sensitive to misalignment and changes in the incidence beam.

An alternative approach is to use a periodic element that diffracts the incidence beam into the desired angular distribution. The element may be either an array of re-mapping type sub-elements, where each cell can realize the desired distribution individually and the periodicity is just used to minimize space-variant properties[2], or a grating type element where the pattern is constructed from overlapping diffraction orders[1, 3]. The obvious benefit is that the element is space-invariant, but as a down-side strong speckle-like fluctuations are present in the intensity distribution under coherent illumination. Under incoherent illumination the speckle-like fluctuations tend to be smoothed out and do not typically present a problem.

In this paper we consider far field beam shaping in the deep UV region with a virtually incoherent beam for applications requiring space-invariant elements. Our aim is to compare the two different types of such elements, and in essence benchmark their performance in term of efficiency and signal quality and suitability for fabrication by multi-mask photolithography in terms of tolerances to typical fabrication errors such as mask misalignments and etch-errors.

2 Comparison of perfect elements

To gain an understanding on the differences between elements of the two different types, several designs were compared. We considered both binary and 8-level elements, and realized symmetric and asymmetric shapes both on- and off-axis. Our simulations, based on the thin-element approximation, indicate that some key differences do exist. First, elements constructed from arrays of re-mapping type sub-elements show generally higher efficiency than grating type elements. The difference, which can be attributed to different use of amplitude freedom, varies from shape to shape but is typically in the region of few percents. Second, signal quality in terms of uniformity of the pattern is typically better with grating type elements. Re-mapping type elements do offer good uniformity over most regions of the desired shape, but suffer from sharp oscillations at the edges. These oscillations are not smoothed out by source incoherence and are enhanced when the shape has sharp corners or small details. In figure 1(a) the encircled energy of a hexagonal far field shape created by the different approaches is plotted. The difference in efficiency can be clearly seen. The curves also indicate that there is a clear difference in the amount and the distribution of the noise-like energy outside the shape, with grating-type elements exhibiting stronger and more wide-spread noise pattern. It should be noted that strategies exist to control the noise distribution of grating-type elements, but typically at cost of efficiency.

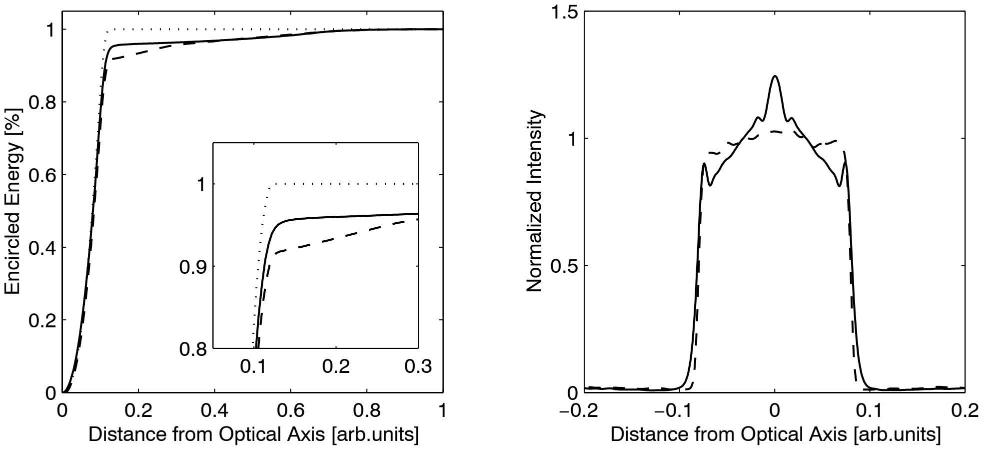

Figure 1: (a) The encircled energy of a hexagonal far field shape created by re-mapping type (solid line) and grating-type (dashed line) elements. Ideal energy distribution is indicated by the dotted line. (b) Cross section of a hexagonal shape assuming single mask misalignment parallel to the cross section during fabrication. Line types as in (a).

3 Comparison of fabrication tolerances

To compare the fabrication tolerances of the different approaches, we simulated typical fabrication errors such as mask misalignments and etch depth errors and evaluated their effects on the properties of the shape. Our study indicates that the only significant difference between the approaches is the way mask misalignment influences the uniformity of the shape. We found that re-mapping type elements tend to exhibit systematic and symmetric uniformity errors, while with grating-type elements mask misalignment appears more as random noise. This can be explained by considering the properties of the different structures. Because re-mapping type elements typically have a space-variant average effective feature size, e.g. the local period in a Fresnel Zone Plate, the relative magnitude of the mask misalignment and consequently the magnitude of the error in the mapping changes over the element leading to an systematic overall error that reflects the change in the structure. Grating-type elements usually have nearly constant average effective feature size and quite random local structure, and the mask misalignment errors therefore appear as random noise. This fundamental difference is illustrated in Fig. 1(b). We see how the intensity distribution with re-mapping type element has assumed a roof-like shape, while the energy is redistributed randomly with grating-type element. It should be noted that it is relatively straightforward to device strategies to compensate for random uniformity errors, while systematic errors present a much greater challenge.

4 Acknowledgements

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