Optimizing Photon Sieves to Approach Fresnel Diffraction Limit via Pixel-based Inverse Lithography

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Abstract

This paper presents a novel, rigorous method to construct photonic sieves whose imaging resolution approaches the Fresnel diffraction limit. Photon sieves (PS), which use sub-wavelength holes instead of Fresnel Zone Plate (FZP) as diffractive elements, offer many advantages as alternative lenses, such as low fabrication cost, potentially higher contrast, narrower main lobe and smaller side lobes [1]. It is particularly attractive in space-based telescope, EUV and X-ray imaging, maskless lithography, etc. [2]. When used in imaging, the ideal focused beam should be as narrow as possible. That is, the Point Spread Function (PSF) on the focal plane should approximate a δ-function. For this sake, we explored optimal design of PS using a non-iterative, forward Optical Proximity Correction (OPC) technique.

Consider the configuration shown in Figure 1, a coherent light normally incident upon the diffraction plane, focused by the PS to the focal plane. The PS is decomposed into many pixels, each corresponding to a sub-wavelength hole and may be transparent or opaque (transmission 1 or 0). The PSF on the focal plane produced by each pixel is calculated by Fresnel diffraction integral. Thus the PSF of this PS is the sum of the PSF due to those transparent pixels. The objective is to minimize the mean square error between the PSF and δ-function, by tuning the transmission coefficients of all pixels. This can be treated as a typical pixel-based forward OPC problem in which the desired pattern is a δ-function. Although general inverse lithography algorithms may be employed [3], we exploited the fact that the desired pattern is δ-function. First, assume no constraint on the transmission and obtain analytical solution. Then the transmissions of 1 or 0 are randomly assigned to each pixel, with the probability density function approximating the analytical solution.

As an example, a PS and a FZP of the same NA are compared in Figure 2, λ 400 nm, focal length 50 μm, NA 0.45. Figure 2 (c) shows that the optimized PS achieves 408 nm FWHM and much smaller sidelobes (except for the 1st sidelobe), whereas the FZP has FWHM of 447 nm. The optimization technique will be applied to PS at λ 13~400 nm, NA 0.6~0.9. Their use in EUV/X-ray imaging and DUV maskless lithography will be evaluated

according to their resolution, contrast and depth-of-focus (DOF). The same technique can be used to construct PS to generate arbitrary complex wavefront.

Key Words: Photon sieve, imaging, point spread function, Fresnel diffraction, inverse lithography

References

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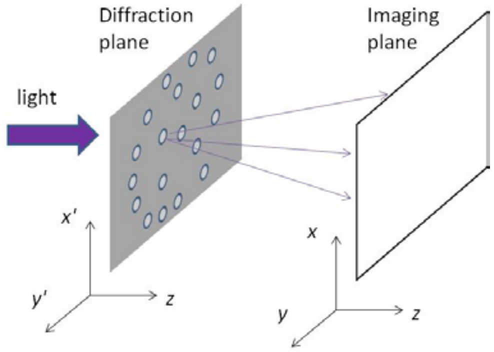

Figure 1 A photon sieve, consisting of transparent holes in the diffraction plane, focuses the incident light. The focused image is the superposition of the diffraction patterns due to all the holes.

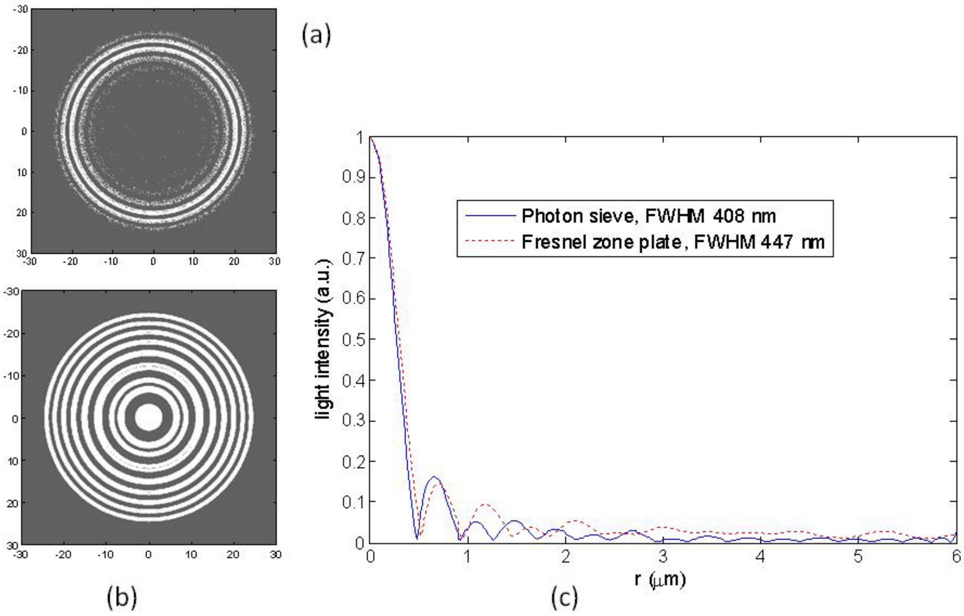

Figure 2 Comparison of (a) optimized PS and (b) Fresnel zone plate, (c) compares their light intensity distributions along the lateral direction on the focal plane.