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Fabrication of spiral-phase diffractive elements using scanning electron-beam lithography

Hsin-Yu Tsai[1], Henry I. Smith[1,2,3] and Rajesh Menon[2, 3, *]

[1] Department of Electrical Engineering & Computer Science
[2]Research Laboratory of Electronics,
Massachusetts Institute of Technology, Cambridge, MA
[3]LumArray Inc, 15 Ward St. Somerville, MA

Abstract

Focused beams of light with central nulls are essential for a variety of applications including particle manipulation [1], fluorescence microscopy [2], and deep sub-wavelength lithography [3, 4]. In all these applications, the intensity of the focused light at the central null should be minimized at high focusing efficiency. Imposing an on-axis phase singularity on a uniform plane wave will generate a beam with a central null. This is achieved with either a spiral phase plate (SPP) [5] or a spiral zone plate (SZP) [6], the phase distribution of which are illustrated in Fig. 1.

In the past, SPPs in quartz were fabricated using scanning-electron-beam lithography (SEBL) [5]. The spiral phase variation was discretized into 8 phase steps. This discretization introduces background noise into the focused beam, causing the intensity of the central null to be non-zero. Furthermore, since this technique requires several multi-level alignment steps, it is difficult to scale up to a larger number of phase steps. In this paper, we investigate an alternative approach using grayscale SEBL to fabricate the SPP. PMMA is spun on top of a transparent substrate to a thickness that corresponds to a 2π phase shift. One of the patterning strategies we investigated divided the aperture of the SPP into over 70 slices; each slice being exposed at a different dose. Subsequently, a low-contrast developer (MIBK:IPA in the ratio 1:1) was used to partially develop the PMMA. Figure 3 (a) shows the Linnik interferogram of the resulting SPP. The phase singularity at the center is clearly visible as a fork in the line fringes. Figure 3(b) is the scanning-electron micrograph of the same SPP. This patterning strategy, although simple, suffers from misalignment errors between the slices as evident in the micrograph. In this paper, we present other patterning strategies to overcome these limitations and improve the quality of the fabricated SPP. We will also report on the fabrication of binary SZPs. We characterize the optical performance of the fabricated elements via photoresist exposures following the methodology of ref [7], and compare to theory.

References:

[1] V. Garcés-Chávez, *et al, Phys. Rev. A,*66, p. 063402 (2002).
[2] G. Donnert, *et al, PNAS*, 103, p. 1140 (2006).
[3] R. Menon, *et al, J. Opt. Soc. Am. A*, 23, p. 2290 (2006).
[4] R. Menon, *et al, Phys. Rev. Lett.* (in press).
[5] T. Watanabe, *et al., Rev. of Sci. Instr.,* 75 (12) p. 5131 (2004).
[6] Huguenin, *et al., J. Opt. Sco. Am .A*, 20(10), p.1883 (2003).
[7] R. Menon, *et al, J. Opt. Soc. Am. A.,* 23, p. 567 (2006).

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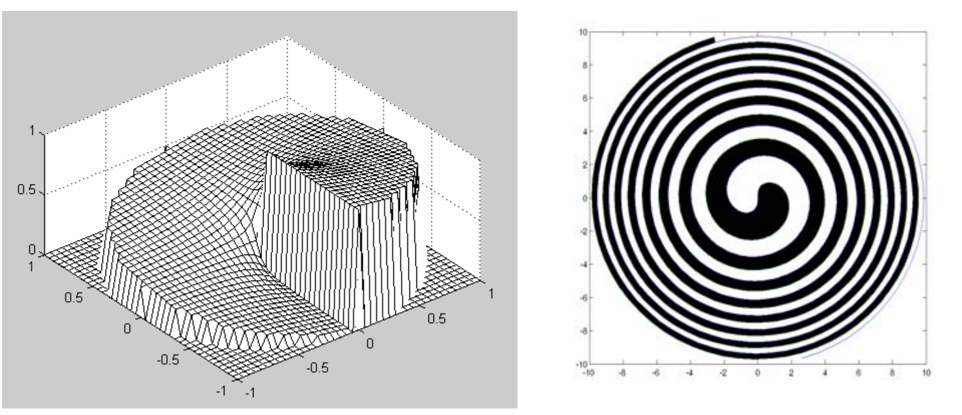
[*] Email: rmenon@nano.mit.edu



(a) (b)

Figure 1: *The phase distribution of (a) the spiral phase plate, and (b) the binary spiral zone plate (black represents a π phase shift).*

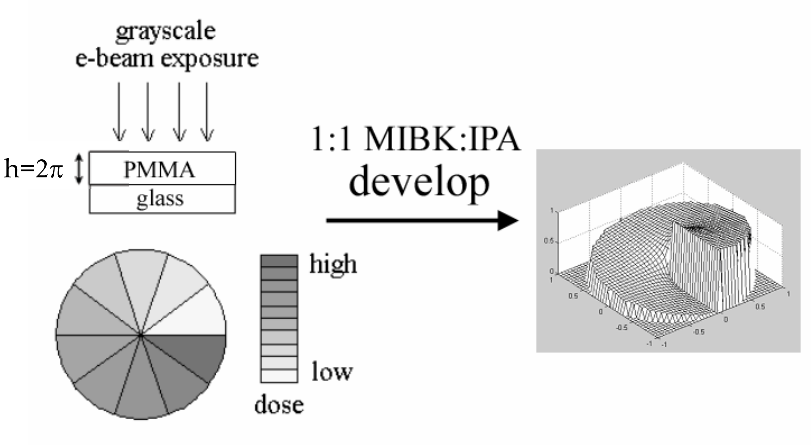
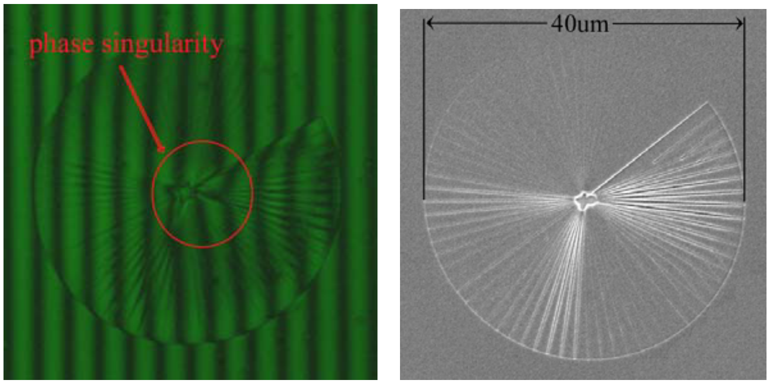


Figure 2: *Schematic of fabrication process. PMMA is spun on top of a glass substrate to a thickness corresponding to a 2π phase shift. The electron beam dose is varied in slices along the azimuthal direction as shown. The exposed PMMA is developed in a solution of MIBK and IPA in the ratio 1:1. Partial development of the PMMA results in a spiral height (phase) variation.*



(a) (b)

Figure 3: *(a) A LINNIK interferogram of a fabricated SPP, revealing the height profile of the spiral in PMMA. (b) Scanning-electron micrograph of the SPP. The radial bright*

lines indicate misalignment between the slices described in Fig.2. Improved writing strategy will be presented that will address this problem.