Pattern-integrated interference lithography: vector modeling of the single-exposure recording of integrated photonic-crystal structures

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With lossless control of the propagation of light at nanometer size scales, photonic-crystal (PC) technology has potentially many significant applications [1]. Among PC fabrication techniques, multi-beam interference lithography is a promising approach to produce rapidly large areas of two- and three-dimensional PC structures with submicron periodicity and a full range of group lattices [2]. However, with this method, an additional time-consuming trim-step is typically required to integrate functional elements, such as waveguides or resonators, in the PC. To address this shortcoming, we recently proposed pattern-integrated interference lithography (PIIL) [3-5]. With PIIL, custom-modified interference patterns, resulting from the optical interference of photo-mask projections, are recorded in a photo-sensitive material in a single-exposure step. An example optical configuration implementing PIIL is illustrated in Fig. 1. PIIL represents a rapid, cost-effective, and wafer-scale fabrication technique for dense integrated PC devices and circuits.

In the present work, we introduce a new PIIL vector modeling that accounts for a thin-mask, off-axis illumination, aperture limitation, and high numerical-aperture. Due to the diffraction limit and imaging aberrations, the interference motifs surrounding the integrated defects may be malformed as illustrated by the example 90deg bend of Fig. 2. However, we show that these distortions are minimized by optimizing the size and shape of the photo-mask pattern. Also, the response of a positive photoresist during exposure is simulated as shown in Fig. 3. Standing waves, off-axis propagation of light, and absorption change during exposure are considered [6,7]. The present vector modeling is proposed to determine aerial images and the final pattern in photoresist after exposure.

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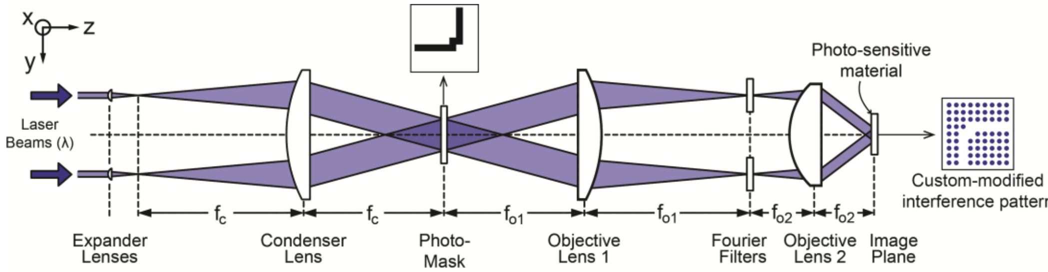

Figure 1: Single-exposure recording of a custom modified interference pattern. A photo-mask contains the pattern to be integrated within the PC. The lenses are arranged in a 6*f* configuration, producing collimated projections of the mask at the image plane. A photo-sensitive material is employed to record the custom-modified interference pattern.

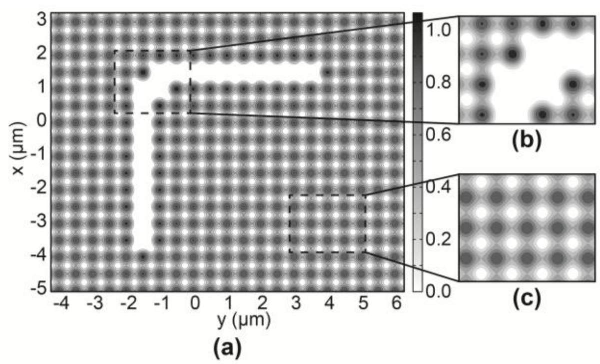

Figure 2: Normalized pattern-integrated interference aerial image. (a) An example 90deg bend is integrated within a square-lattice PC structure. (b) In the vicinity of the waveguide, the interference motifs are distorted. (c) Away from the functional element, the interference pattern remains unperturbed.

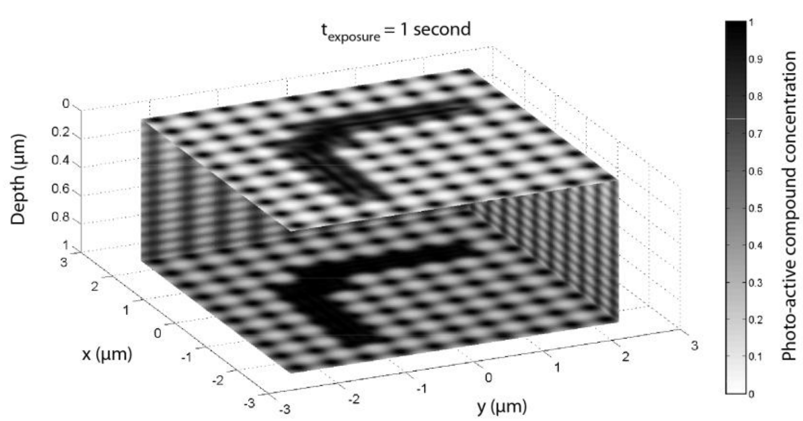

Figure 3. Photo-active compound (PAC) concentration at depths of 0 and 1μm within a 1μm-thick film of positive photoresist. The image plane corresponds to the bottom of the photoresist film, where the mask pattern is correctly imaged. Standing waves and inhomogeneous PAC concentration along the z-axis are visible. The exposure-time is 1s.