3D Super-Resolution Using a Phase Mask Fabricated via Grey-Level Lithography

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Abstract:

Three dimensional (3D) super-resolution can be achieved in microscopy instruments by means of phase masks that shape the point spread function [1]. Grey level lithography is an attractive procedure for the generation of these phase masks. The photolithographic phase masks (PPM) encode the light emitted from a specimen via a topographical index of refraction variation consisting of a series of phase-singularities [2]. In our case, the mask produces a double helix point-spread function (DH-PSF), which allows for the estimation of the object position throughout the depth of focus of a typical system [3]. The goal of this project was to develop processes to fabricate and characterize PPMs. We manipulated the grey-scale lithography capabilities of a maskless lithography system by priming the photoresist with multiple exposures prior to the final exposure pattern. This procedure allowed us to produce the desired topography expressed by the photoresist after exposure and development (with feature sizes on the order of 10^{-6}m). Upon testing these phase masks in an optical system, we were able to observe the desired DH-PSF. Currently, experiments are being done to translate the fabricated topography of the photoresist into quartz through reactive ion etching.

Introduction:

Implementing phase masks that shape the PSF of an imaging system using a spatial light modulator (SLM) to produce 3D super-resolution is impractical for widespread use in the scientific world. Current high-end SLMs operate in reflective mode so systems are bulky in addition to being expensive. Also, an SLM is only capable of processing polarized light, which means 50% of the light emitted by a specimen is lost before any imaging can be done. Utilizing a PPM that is inherently transparent and isotropic would allow for all light to be imaged and analyzed and would also allow for a more practical, affordable microscopy set-up to produce 3D super-resolution.

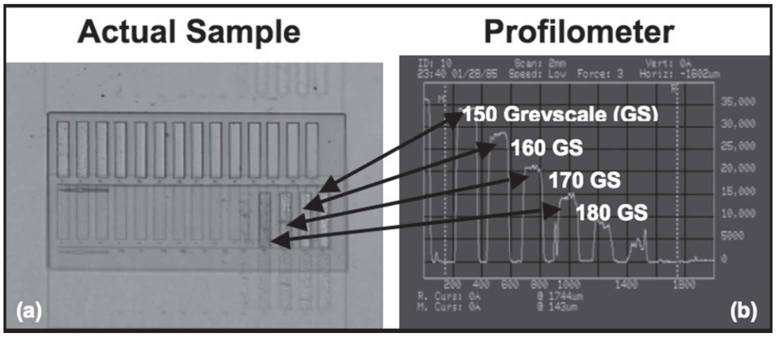

Figure 1: The optical image of the photoresist's topographical surface after exposure to a mask consisting of varying greyscale values; (a) displays the linear correlation to the photoresist's height, and (b) after varying exposure doses via different greysale values.

Experimental Procedure:

Materials. A microscope slide was used as the substrate upon which we spun a negligible amount of hexamethyldisilazane (HMDS) as an adhesion layer before spinning 3.5 μm of positive AZ-4210 photoresist.

Calibration. A phase mask requires a linear slope in the exposure and development rate of the photoresist. The experiment used positive photoresist AZ-4210, but further experimentation showed that other resists may improve the quality of the devices. To utilize the greyscale lithography abilities of the SF-100 Xpress maskless lithography instrument, we first developed a procedure to calibrate the photoresist with the instrument, which had to be done on a daily basis. The greyscale values interpreted by the instrument were correlated to a linear exposure rate, as seen in Figure 1.

AZ-4210 has a linear exposure rate and produces linearly sloped topographical features in the photoresist after exposure, but the slope of these features was far too steep for

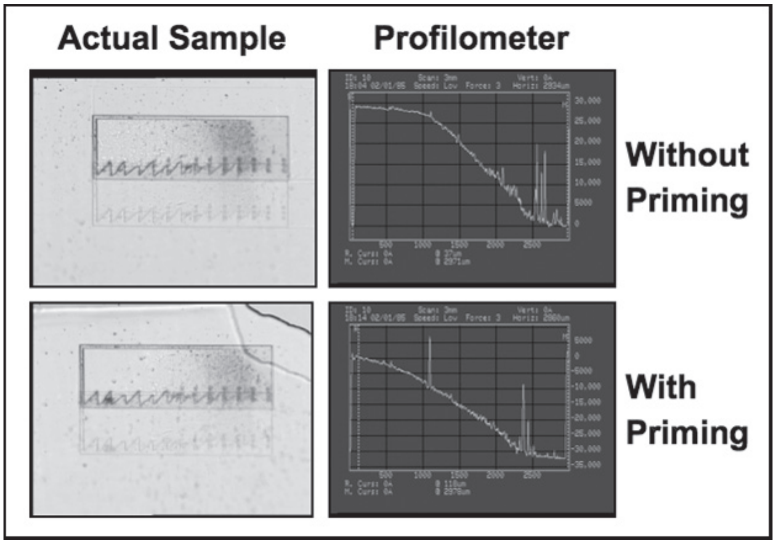

Figure 2: The slope of the photoresist topography in the calibration sample with priming (bottom row) is significantly less steep than that of the sample without priming (top row), which is desired.

the sensitive topography of the PPM. To reduce the slope, a series of pre-exposures to the photoresist were conducted as a method of priming the photoresist for the final image. Priming the area of exposure first, yielded a lower slope in the linear topography of the PPM, as seen in Figure 2.

Fabrication. Using bitmap files created in MatLab for the desired phase mask in the desired range of greyscale values, we primed our substrate and then used the SF-100 to project our image onto our substrate for varying amounts of exposure times (usually ranging between 1-2 seconds). The PPMs were developed in AZ-400 from 90 to 120 seconds.

Characterization. The physical, topographical characteristics of each PPM was determined using a differential interference contrast microscope, which allowed for the viewing of defects that could potentially disrupt the functionality of the PPM, as shown in Figure 3. To determine the functionality of each PPM, a microscopy system was used with a region where the PPM was placed and then imaged through a camera onto a computer.

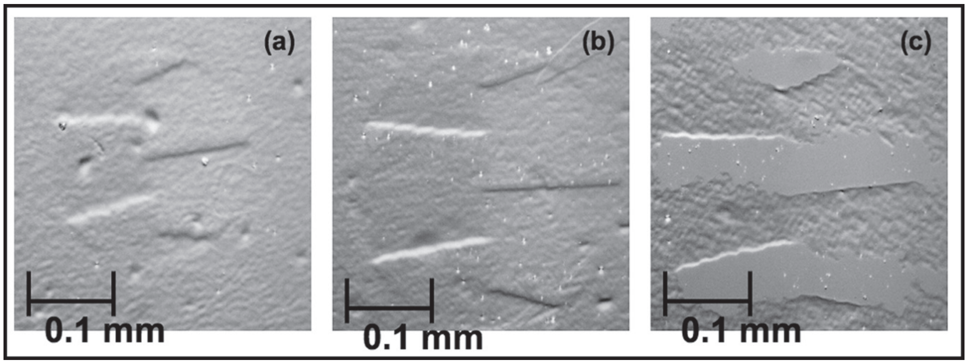

Figure 3: Images produced from DIC displaying varying qualities of fabricated PPMs. Image (a) depicts defect in the mask produced either by air or dust, rendering it useless. Image (b) depicts a PPM with little to no irregularities and should, thus, function properly. Image (c) depicts an underexposure as seen by the residual, non-sloping regions in the PPM.

Results and Conclusion:

Using a simple microscopy system, we demonstrated, successfully, the fabrication of PPMs. Two types of PPMs were implemented, which correlated to varying amounts of lobe rotation observed throughout the object's PSF.

These PPMs are now ready to be implemented into further microscopy experiments to progress towards more accessible 3D super-resolution.

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