Analog Lithography with Phase Masks in Projection Exposure Tools

E. G. Johnson, P. Srinivasan, M. Poutous, Z. Roth
Center for Optoelectronics and Optical Communications, Charlotte, NC 28223
egjohnso@uncc.edu

Micro-optics requires the use of 3D micro-structures, which is in direct contrast to most photolithographic processes that are largely based on a binary exposure. Therefore, the need exists to minimize the number of required steps to create a complex topography. In recent work[1], we demonstrated a method to create analog structures in resist using a single step lithographic process. This process exploits the properties of a projection printing tool to filter out the higher orders of the diffraction and image the low orders onto the wafer plane. This imaging technique enables one to create rather complex structures at the wafer plane. Fig. 1 (a) illustrates the phase mask used for creating the vortex structure in the photoresist highlighted in Fig. 1 (b). This resist pattern can then be transfer etched into a substrate of choice. Other structures can easily be fabricated with this approach and additional exposures can be added to create even more complex resist profiles based solely on the exposure process.

Another example of how once can exploit this process for more complex shapes is the fabrication of spatially varying structures. In this case, one needs to change the fill fraction of a binary structure in a prescribed fashion. Often this is done in creating the binary photomask used in the printing, but once this is done the gradient is fixed and coupled to the binary design. An alternate approach to this can be realized through a combination of binary and analog exposures[2]. In this case a standard binary pattern is exposed in the resist followed by the exposure of an analog intensity created with a phase mask. Once this is done, it is easy to realize rather complex space varying structures across an area in the wafer plane as highlighted in Fig. 2 (a) and (b). This structures exhibit very smooth gradients across the surface and can then be transfer etched into the substrate, depending on the desired functionality of the device.

In this paper, we present the process for creating 3D micro and nano-structures using the analog lithography process presented herein. This process is then extended to include results for fabricating structures that have fine gradients in their duty cycle and topography. Results will be presented for both thin and thick resists and specific examples of resulting devices will be discussed with perspectives on future applications.

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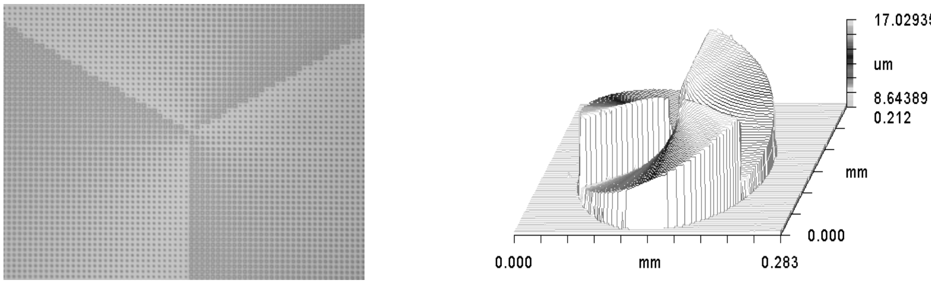
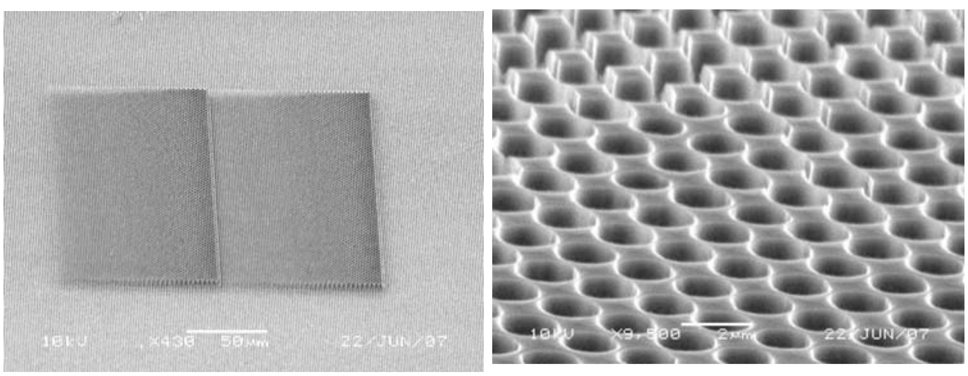
[1] Jinwon Sung, Heidi Hockel, Jeremiah D. Brown, and Eric G. Johnson, "Development of a two-dimensional phase grating mask for fabrication of an analog-resist profile," Applied Optics, Vol. 45, No. 1, pp. 33-43, Jan. 2006.

[2] Pradeep Srinivasan, Zachary A. Roth, Menelaos K. Poutous, and Eric G. Johnson, "Novel method for the fabrication of spatially variant structures," J. Micro/Nanolith. MEMS MOEMS Vol. 8, 013010, Feb. 12, 2009.



(a) (b)

Figure 1: (a): Phase mask: The micrograph shows an image of the phase mask fabricated in PMMA on a glass reticle for use in a G-Line GCA Stepper. (b) Resist Pattern: Resulting resist profile from (a) using SPR 220 resist.



(a) (b)

Figure 2: (a) Space variant Prisms: The SEM Image shows a prism function that was created with the exposure of an analog Intensity prism array with a binary hexagonal pattern. The fill fraction of the hexagonal array changes with the local exposure gradient found in the prism function and (b) *expanded view* of the resulting pattern.