Optical microlithography on oblique surfaces via a novel diffractive phase mask

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3D microstructures and microstructures on oblique surfaces can enable unique functionalities in photonics, electronics and MEMS, and provide a wide array of interesting applications in metamaterials, microfluidics, aberration-correction optics and biomedicine. However, in general, conventional optical projection lithography (OPL) is limited to pattern 2D structures on single planar surface. Here, we propose a novel approach employing computer-generated diffractive optics to project complex 3D light fields into space. Such a technique can enable patterning of 3D structures or planar microstructures on oblique surfaces by a single exposure and hence, circumvent constraints in traditional methods.

A basic setup of our approach is illustrated in Fig. 1(a). A pixelated diffractive phase mask, which is comprised of square pixels of 3um size and of multiple height levels varying from 0 to 430nm (see the AFM measurement of a small area in Fig. 1(b)), is designed in Fresnel domain using an extension of the direct-binary-search (DBS) algorithm,[1] and fabricated by grayscale lithography.[2] Preliminary results by both simulation and experiment are illustrated in Fig. 1(a), in which four letters of 'UTAH' are projected on spatially separated planes with an average optical efficiency of over 65%. Exposures on Shipley 1813 photoresist demonstrate the validity of our method. Improvements to the background noise and the cross-talk between adjacent planes will be addressed in the conference presentation.

In addition, we would further exploit the advantage of the presented technique in patterning on oblique surfaces, such as neural electrode arrays[3] (Fig.2(a)). The goal is to pattern multiple metal ring electrodes along each needle so that real-time 3D neural monitoring and stimulating in vivo is desirable (Figs.2(b) and (c)). A preliminary result of exposure on Shipley 1813 photoresist coated on silicon surface perpendicular to the illumination plane (X-Y) is summarized in Fig.2(d) – (f). For simplicity, the diffractive phase mask was chosen to be the same with the one used in Fig.1. It demonstrates that we could manipulate light in 3D space and eventually pattern on extremely oblique surfaces (nearly 90° in this case). We will present the patterning results on the array in the conference.

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[1] G. Kim, J. A. Dominguez-Caballero, and R. Menon, *Design and analysis of multi-wavelength diffractive optics,* Opt. Express 20, 2814-2823 (2012).

[2] K. Tostu, K. Fujishiro, S. Tanaka, and M Esashi, *Fabrication of three-dimensional microstructure using maskless gray-scale lithography,* Sens. Actuators. A 130, 387-392 (2006).

[3] E. M. Maynard, C. T. Nordhausen, and R. A. Norman, *The Utah Intracortical Electrode Array: a recording structure for potential brain-computer interfaces,* Electroen. Clin. Neuro. 102, 228 (1997).

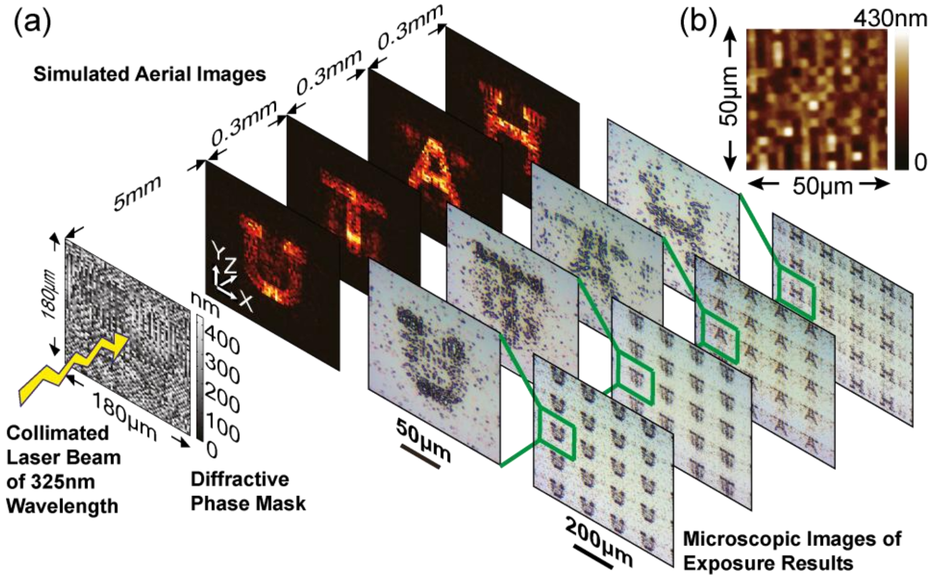

Figure 1:(a) Illustration for 3D microlithography by computer-generated diffractive phase mask with pixel size of 3um, and preliminary results on exposing four letters of 'UTAH' on Shipley 1813 photoresist on separate planes; (b) An AFM measurement of a small region of the phase mask.

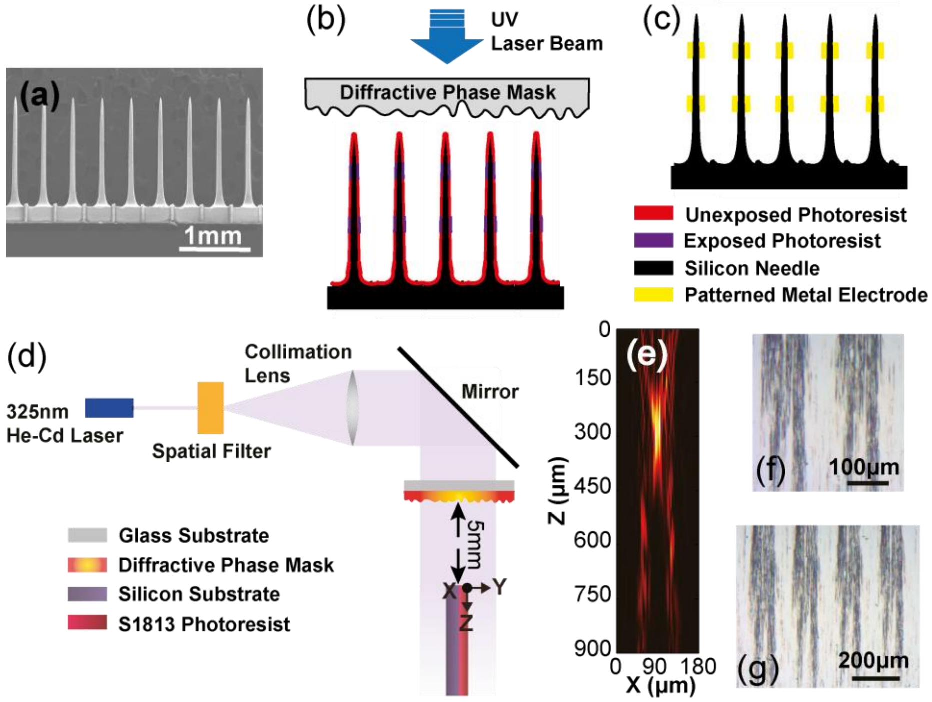

Figure 2:(a) An SEM image of the Utah Electrode Array (UEA); (b) Exposure setup for patterning on electrode array; (c) Cross-sectional illustration of the electrode array with patterned metal electrodes; (d) Illustration of the optical setup for exposure on extremely oblique surface; (e) Simulated light field in X-Z plane for exposure in (d); (f)-(g) Microscopic images of the exposure results on extremely oblique plane (~90^o) parallel to the direction of light propagation (Z).