Single-Step Interferometric Patterning of High-Aspect-Ratio Three-Dimensional Nanostructures

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Standing wave phenomena have long been regarded as deterrent in lithography processes. The standing wave is created when the incoming irradiation source interferes with the reflectance off from a substrate, forming a vertical standing wave registered as a sinusoidal pattern along the sidewall of photoresist (PR) structures. The amplitude of the sinusoidal scalloping pattern is typically comparable to the wavelength of the optical source so that it seriously deforms the vertical geometry of the PR patterns and limits the minimum feature size that can be defined in nano-lithography. To overcome this issue and retain well-defined perpendicular PR structures, an anti-reflective coating (ARC) is typically employed as an intermediate layer, which makes the lithography process complicated and inefficient. The use of a single PR layer as thin as a quarter wavelength can circumvent the sinusoidal scalloping pattern along the sidewall. However, such thin PR layer limits the fabrication processes such as using the PR layer as etch mask [1]. In this study, we report how to manipulate and utilize the standing wave phenomena to produce high-aspect-ratio three-dimensional (3D) PR nanostructures, especially in maskless interference lithography with no use of ARC layers.

Relying on the interference of two or more coherent beams with an angular separation, interference lithography registers on a PR layer two standing waves, a horizontal and a vertical. In this study, a Lloyd-mirror configuration [2] was used as the interferometer to engineer high-aspect ratio 3D nanostructures. A HeCd 325 nm in wavelength laser was used as a light source. Negative PR (NR7 series, Futurrex) was mostly tested due to high sensitivity at the operating wavelength. Nanostructures up to 1 μm tall and with the aspect ratio of 1:8 were realized (Figure 1). Control of lithographic process (e.g. exposure dosage) further enabled to realize 3D features (e.g. interconnected pore network, opposed to disconnected single pore array) (Figure 2). High-aspect-ratio 3D pillar patterns were also achieved with the negative PR by controlling lithographic conditions. Such well-regulated thick PR mask layer further allowed us to transfer the patterns onto underlying substrates to define (e.g. etch) high-aspect-ratio 3D nanostructures with a wide range of substrate materials. The single-step interferometric nano-patterning of high-aspect-ratio 3D PR nanostructures with good uniformity and control will enhance nanofabrication capability significantly, such as in the design and performance of various optical and micro-fluidic applications and systems.

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[1] C.-H Choi and C.-J, Kim, Nanotechnology **17,** 5326 (2006).
[2] I.Wathuthanthri, W.Mao, C-H.Choi, Opt. Lett. “in review”.

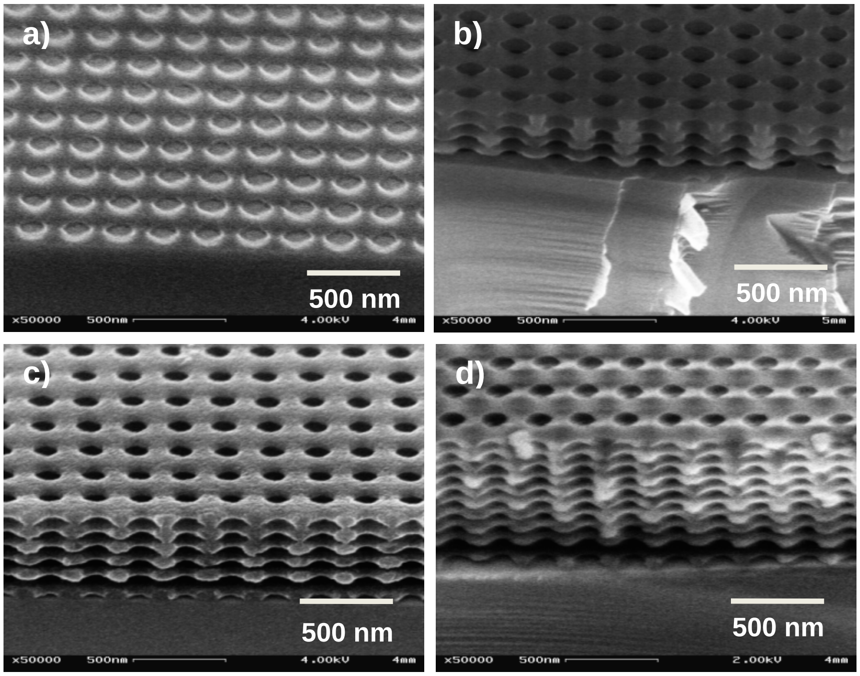

Figure 1: Scanning electron microscope (SEM) images of varying aspect ratios (ARs) of PR nanopore patterns with a constant periodicity of 250 nm. a) AR=1:1. b) AR=1:3. c) AR=1:5. d) AR=1:8.

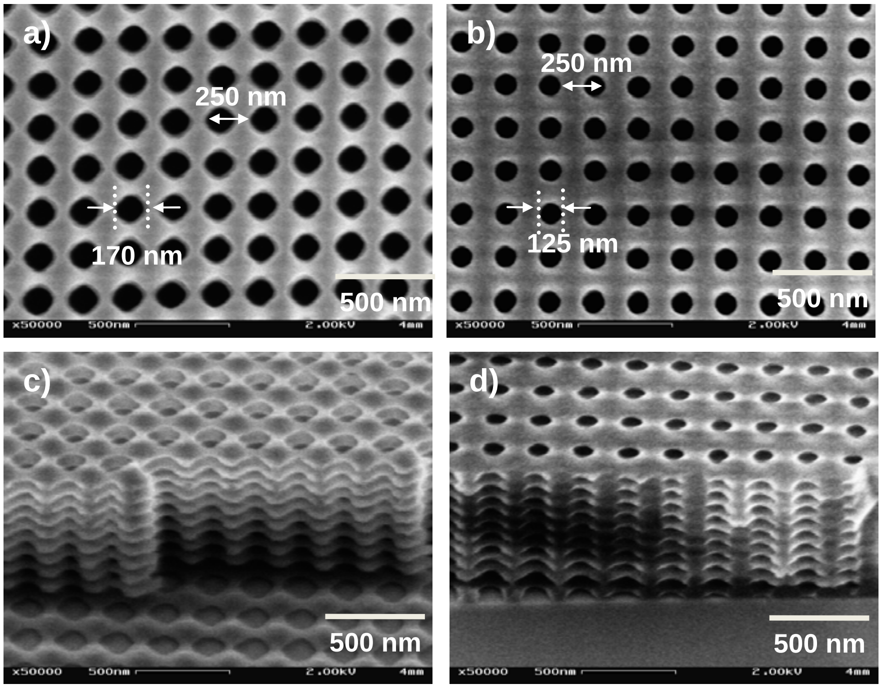

Figure 2: SEM images (a and b: top views, c and d: cross-sectional views) of varying pore sizes with a constant periodicity of 250 nm. The pore size was regulated by controlling exposure dosage. The large (170 nm) pores (a and c) are interconnected laterally due to the sizable scalloping effects along the sidewalls.