Ultra-high aspect ratio silicon dry-etch process

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We present a breakthrough multistage dry-etch process to create 100 nm half-pitch gratings in silicon with depths up to 5.5 microns. Interference lithography was used to pattern gratings in an optically-matched stack of materials to form a 400 nm thick silicon oxide hard mask. The oxide was then used to mask the subsequent silicon deep reactive-ion etch (DRIE).

In the past, two techniques have been used to create extreme-aspect-ratio silicon gratings: an oxygen-rich Bosch process,[1] and an anisotropic wet etch using <110> wafers.[2] The former was limited to aspect ratios of 15-20 and had problems with micromasking due to sputtering and redeposition of the metal mask, while the latter resulted in high aspect ratios up to 150, but relatively low open area due to buried {111} planes orthogonal to the grating sidewalls. Our new process solves many of the problems of both approaches, enabling highly efficient x-ray diffraction gratings and ultraviolet filters.

Since the new process uses silicon oxide as a mask and DRIE for etching, it has no problems with micromasking or crystal orientation. Careful balancing of etch parameters on a variety of tools allows us to control the duty cycle and aspect ratio of the gratings, etch speed and selectivity, and the profile of grating lines. We have achieved a 200 nm-pitch grating with 50% duty cycle and 5.5 micron etch depth (see Fig. 1) over a surface greater than a two centimeter square. The undercut of the silicon oxide mask was minimal, and scalloping was less than 5nm (see Fig. 2).

The uniformity of interference lithography and the control allowed by advanced dry etch tools result in a very repeatable process that creates templates that can be further tailored for a variety of applications. For x-ray diffraction gratings, <110> silicon is used and the gratings are carefully aligned to the {111} planes, and subsequent to the dry etch the grating can be smoothed and narrowed by a short potassium hydroxide (KOH) etch.[2] For ultraviolet filters, the opposite effect is desired; the grating lines are widened via atomic layer deposition of dielectric and/or metallic layers tailored for the greatest absorption.[1]

In this paper we describe our grating patterning, pattern transfer, and deep etch processes, and present progress towards combining this technique with coarse lithography steps designed to form an integrated mechanical support structure to produce free-standing transmission gratings.

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[1] Mukherjee et al., *J. Vac. Sci. Technol. B,* **25**(6)*,* 2645 (2007); *Nanotechnology,* **20**, 325301 (2009).

[2] Ahn et al., *J. Vac. Sci. Technol. B*, **25**(6), 2593 (2007); *J. Vac. Sci. Technol. B,* **26**(6), 2179 (2008).

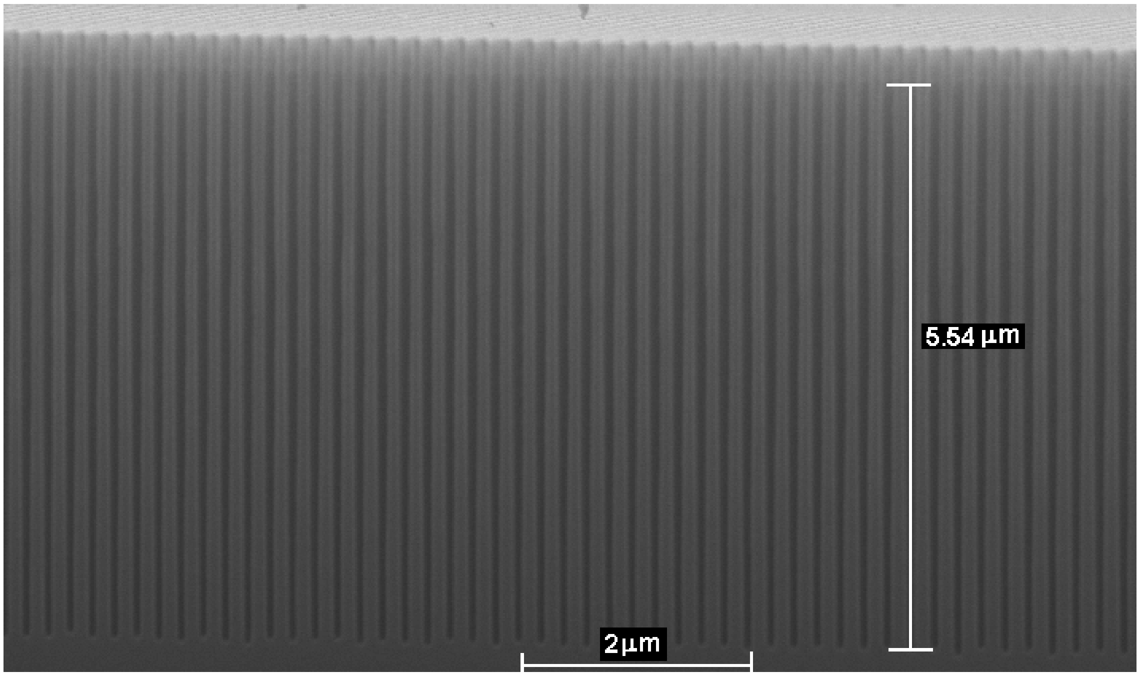

Figure 1. Post-etch micrograph of a 200 nm-period silicon grating, with remaining silicon oxide mask material on top. The aspect ratio is approximately 55.

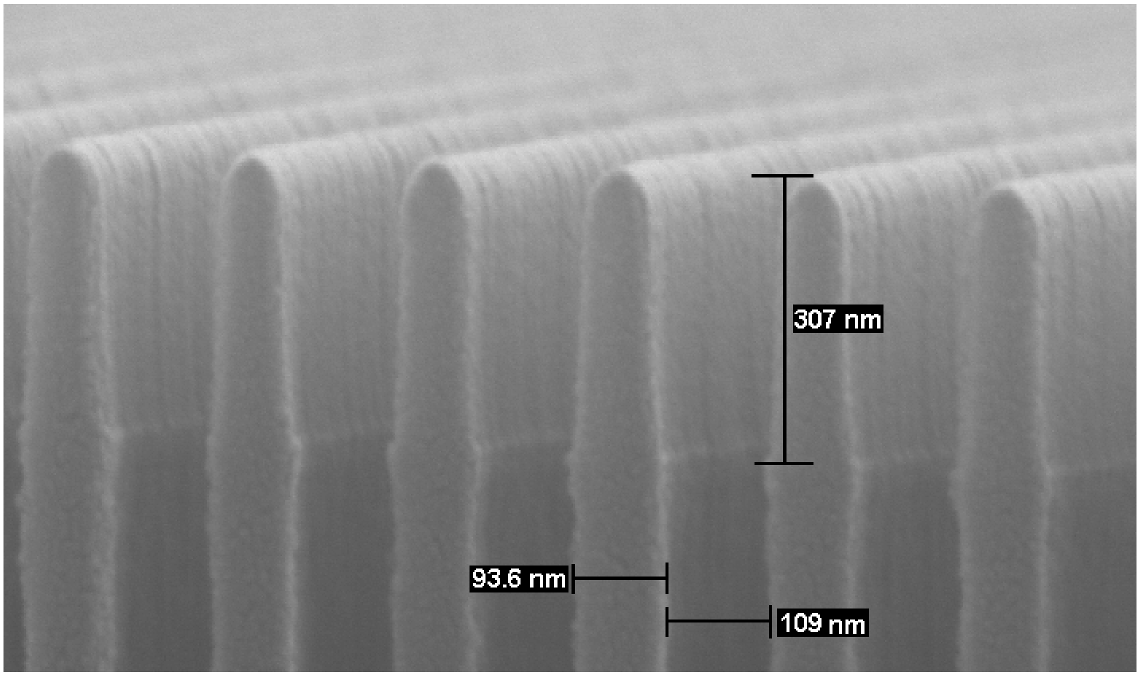

Figure 2. Magnified view of Fig. 1 showing detail near the oxide caps. Note minimal scalloping and undercut even at the most critical top portion of the grating lines. The remaining 300 nm of mask material indicates that the etch could have been continued, resulting in even deeper lines.