Fabrication Process for 200 nm-Pitch Polished Freestanding Ultra-High Aspect Ratio Gratings

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A fully integrated fabrication process has been developed to fabricate freestanding, ultra-high aspect ratio silicon gratings with KOH-polished sidewalls. The gratings are being developed for wavelength-dispersive, soft x-ray spectroscopy on future space telescopes. For this application, the grating needs to have a large open-area fraction, and smooth sidewalls (roughness < 1 nm) to maximize efficiency. The prototype gratings fabricated with the process presented here have been tested on a synchrotron beamline, and demonstrated an absolute efficiency greater than 30% for 2 nm-wavelength x-rays[1]. This efficiency is greater than twice the efficiency of previously fabricated gratings.

The fabrication process utilizes silicon-on-insulator (SOI) wafers where the grating and a cross support are etched in the device layer, and an additional structural support is etched in the handle layer. The device layer and handle layer are both etched via deep reactive-ion etching (DRIE) using a Bosch process. The buried SiO_2 layer stops both etches, and is removed at the end of the process to create a freestanding structure. The gratings have a pitch of 200 nm, a depth of 4 μm, and the bars are polished via KOH. The polishing process both reduces roughness and reduces the grating-bar thickness to approximately 50 nm. The finished gratings span an area of approximately 10 by 30 mm, supported by 1 mm-wide hexagons in the handle layer.

Past work has demonstrated key steps such as ultra-high aspect ratio DRIE[2], integration of two DRIE steps to make freestanding, unpolished gratings[3], and polishing gratings in bulk silicon[4]. Significant advancements have been made to enable an integrated process with polished grating bars, and minimal damage to both the grating membranes and individual grating bars. An improved DRIE step was developed to control the bar width, which lead to a reentrant profile (see Fig 1). This profile was necessary to yield straighter grating bars after KOH polishing as the KOH etches the tops of the bars quicker than the bottoms. To protect the polished grating bars during the handle layer etch, photoresist is diffused into the channels and spun and baked. The past process of directly spinning photoresist damaged grating bars thinner than approximately 100 nm. A vapor HF etch step was also developed to remove the buried SiO_2 without damaging the membranes or grating bars. See Figs 2, 3 and 4 for images of freestanding gratings.

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[1] R. K. Heilmann et al., "High-efficiency blazed transmission gratings for high-resolution soft x-ray spectroscopy," *Optics for EUV, X-Ray, and Gamma-Ray Astronomy VII, Proc. SPIE*, 9603, 960314 (2015).

[2] P. Mukherjee et al., "Plasmaetch fabrication of 60:1 aspect ratio silicon nanogratings with 200 nm pitch," *J. Vac. Sci. Technol. B*, vol. 28(6), C6P70 (2010).

[3] Bruccoleri et al., "Fabrication of nanoscale, high throughput, high aspect ratio freestanding gratings," *J. Vac. Sci. Technol. B*, vol. 30(6), 06FF03 (2012).

[4] Bruccoleri et al., "Potassium hydroxide polishing of nanoscale deep reactive-ion etched ultra-high aspect ratio gratings," *J. Vac. Sci. Technol. B*, vol. 31(6), 06FF02 (2013).

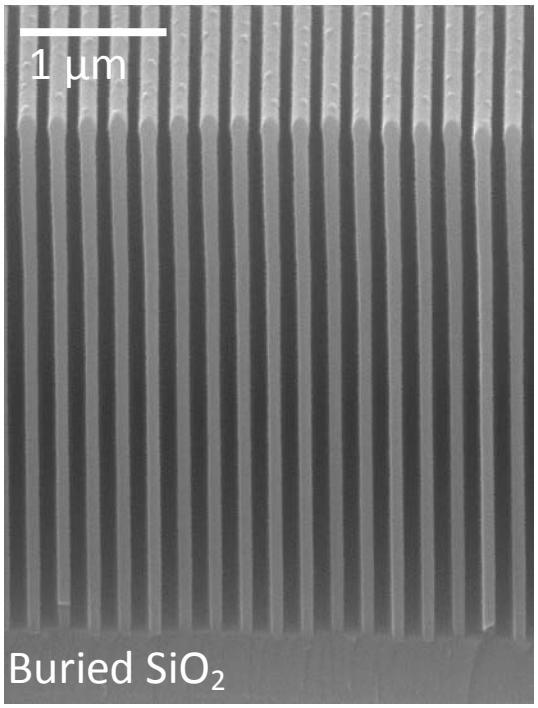

Figure 1.

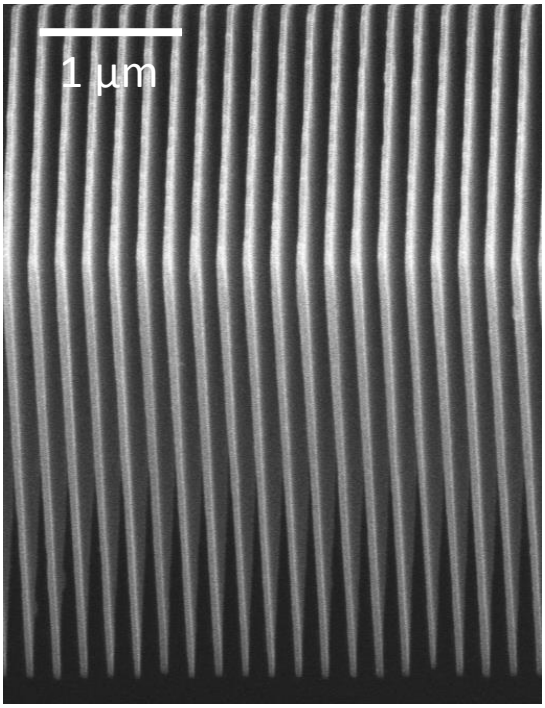

Figure 2.

Figure 1: Scanning electron micrograph of a cleaved 200 nm-pitch grating after DRIE without KOH polishing. Observe the grating bars get gradually thinner with depth.

Figure 2: Scanning electron micrograph of a cleaved 200 nm-pitch, KOH polished, freestanding grating. Observe thin grating bars.

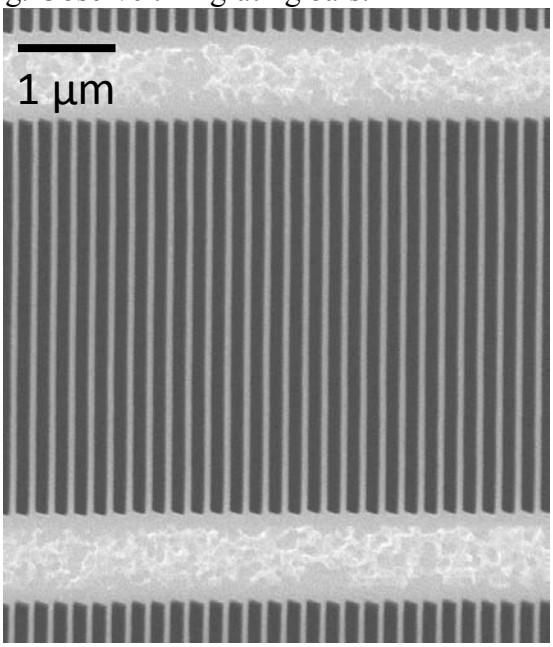

Figure 3.

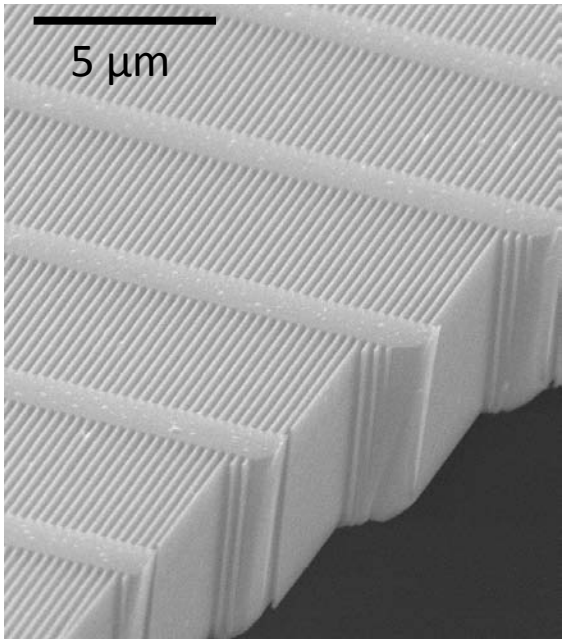

Figure 4.

Figure 3: Scanning electron micrograph looking from the top of a cleaved 200 nm-pitch, KOH polished, freestanding grating. Observe straight, undamaged grating lines.

Figure4: Scanning electron micrograph of a cleaved 200 nm-pitch, KOH polished, freestanding grating. Observe undamaged sidewalls.