# Fabrication of Nano-scale, High Throughput, High Aspect Ratio Freestanding Gratings

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We have developed a breakthrough fabrication process for ultra-high aspect ratio freestanding gratings. The pitch of the gratings is 200 nm, and the depth is 4 μm (which exceeds the state-of-the-art in aspect ratio by over a factor of two for freestanding nano-scale gratings) with open areas on the order of 50%, and several square centimeters in area.[1] They have a broad array of applications in ultraviolet filtration, nanophotonics, biofiltration and x-ray spectroscopy.[2] Furthermore they will be the prototype of a breakthrough critical-angle transmission grating for astronomical x-ray spectroscopy. This paper discusses the fabrication steps in detail, and analyzes alternative fabrication processes.

The gratings are fabricated as a monolithic structure in silicon via two lithographic and pattern transfer processes, integrated together on a silicon-on-insulator wafer. The grating is patterned via interference lithography on a tri-layer stack, and transferred into a hard mask of thermal $SiO_2$. A 5 μm–pitch, <25 % duty cycle, cross support grating is patterned perpendicular to the 200 nm-pitch grating in 700 nm of photoresist to create a 2-dimensional mask.[3] This mask is used to etch the grating into the 4 μm thick device layer via a Bosch deep reactive-ion etch (DRIE) until it stops cleanly on the buried $SiO_2$. (See Fig 1.) The grating channels are then filled without voids by spinning photoresist on them, which wicks into the channels. (See Fig 2.)

Prior to patterning the grating, a large (31x31 mm$^2$) 1 mm-pitch honeycomb support structure is patterned in PECVD $SiO_2$ on the back side of the SOI wafer. After the grating is filled, it is bonded in a vacuum via crystal bond to a carrier wafer, and the honeycomb pattern is etched via DRIE through the handle layer until it stops cleanly on the buried $SiO_2$. The buried $SiO_2$ is etched away via a HF wet etch, and the SOI wafer is separated from the carrier in DI water at 80 C. The resist filling is cleaned from the channels via a piranha clean, and finally the grating is critical-point dried and cleaned in an isotropic $O_2$ plasma to create a freestanding structure. See Figures 3 & 4 for images of the grating film, support structure and a cleaved edge of the grating.

The freestanding grating can now be structurally analyzed and tested for launch and deployment in space.

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[1]Mukherjee et al., *J. Vac. Sci. Technol. B* **25**, 2645 (2007), DOI:10.1116/1.2804612
[2]R. K. Heilmann et al., *Opt. Express* **16**, 8658 (2008)..
[3]Mukherjee et al., *J. Vac. Sci. Technol. B* **28**, C6P70 (2010), DOI:10.1116/1.3507427

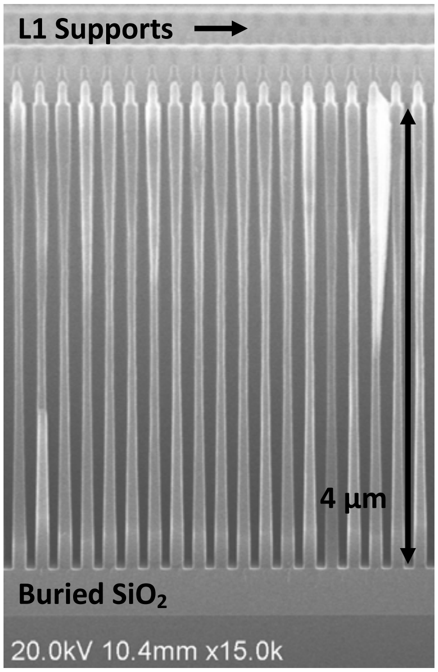


*Figure 1:* Front side DRIE with a clean stop on buried $SiO_2$

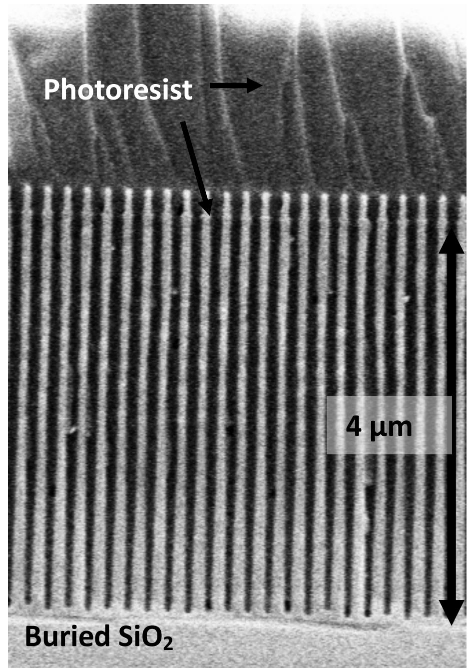


*Figure 2:* Photoresist filled grating

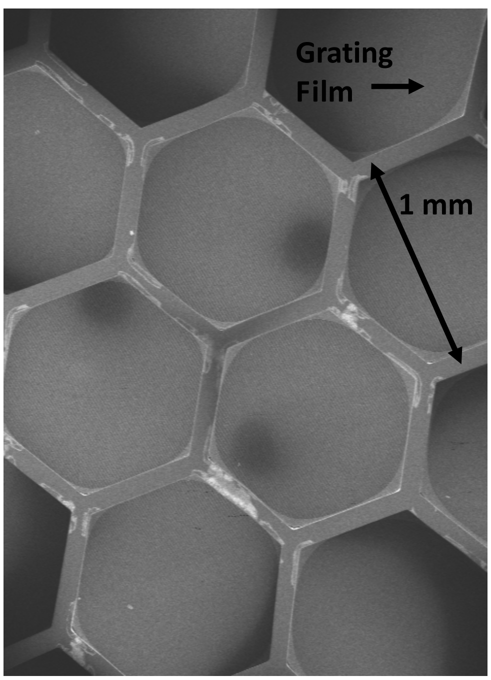


*Figure 3:* Bottom view of freestanding grating film with hexagon support structure

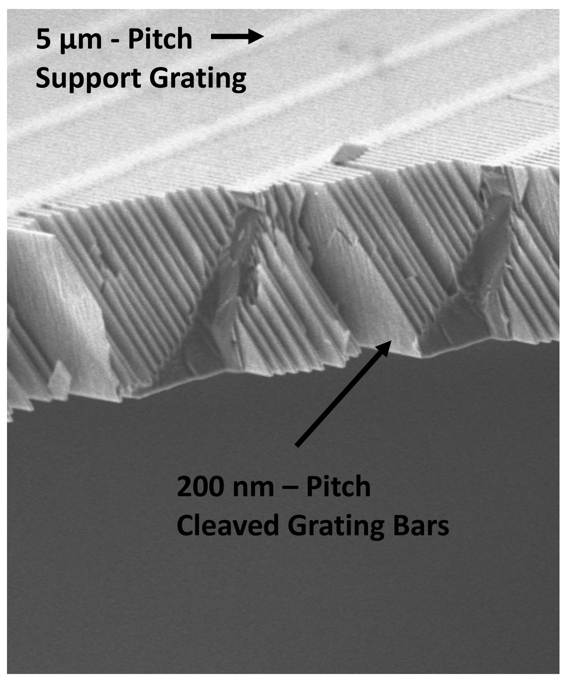


*Figure 4:* Cleaved cross section of freestanding grating film