Fabrication of Ultra-High Aspect Ratio Freestanding Gratings on Silicon-on-Insulator Wafers

Minseung Ahn*, Ralf K. Heilmann and Mark L. Schattenburg
Space Nanotechnology Laboratory, Massachusetts Institute of Technology,
Cambridge, MA 02139, USA

We present a silicon-on-insulator (SOI) process for the fabrication of ultra-high aspect ratio (AR) freestanding gratings for high efficiency x-ray and extreme ultraviolet (EUV) spectroscopy. This new design will lead to blazed transmission gratings via total external reflection on the sidewalls for x-rays incident at graze angles below the critical angle Θ_c (~1-2°), as shown in Fig. 1. We call this new configuration the critical-angle transmission (CAT) grating. It combines, for the first time in the EUV-to-x-ray band, the alignment and figure insensitivity of transmission gratings with high broadband diffraction efficiency, which traditionally has been the domain of blazed reflection gratings.

The required straight and ultra-high AR freestanding structure is achieved by anisotropic etching of <110> SOI wafers in potassium hydroxide (KOH) solution. Figure 2 shows the fabrication process in detail. To overcome the structural weakness, chromium is patterned as a reactive-ion etch (RIE) mask to form a support mesh with a period of 40 μm. The submicron fine grating with period of 574 nm is written by scanning-beam interference lithography (SBIL) based on interference of phase-locked scanning beams.[1] The freestanding structure is accomplished by etching the handle layer and device layer in tetramethylammonium hydroxide (TMAH) and KOH solution, respectively, followed by hydrofluoric acid (HF) etching of the buried oxide. To prevent collapse of the high AR structure caused by water surface tension during drying, we use a critical point dryer after dehydration of the sample in pure ethanol.

We achieved freestanding transmission gratings with aspect ratio of 150 on the 8 μm thick device layer of an SOI wafer, as shown in Fig. 3. The sidewall slope is 0.15°. The root mean square (RMS) roughness of atomically-smooth <111> sidewalls is less than 0.2 nm in a scanned area of around 65 nm^2, as directly measured by atomic force microscope (AFM). In addition, we attained a duty cycle (b/p) of 9.3% by over-etching in KOH. Small duty cycle (less than ~20%) is desirable for high diffraction efficiency.

References:

1. P. Konkola, C. Chen, R.K. Heilmann, C. Joo, J. Montoya, C.-H. Chang and M.L. Schattenburg, J. Vac. Sci. Technol. B **21**, 3097 (2003)

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* E-mail: msahn@mit.edu

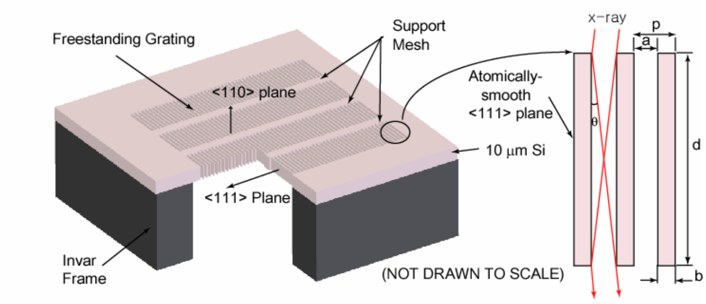

FIG. 1. Concept design of CAT gratings. X-rays incident from the top reflect at the sidewalls and constructively interfere with one another downstream of the grating. Diffraction is enhanced for wavelengths and diffraction orders simultaneously satisfying the grating equation and the reflection condition while the other orders are suppressed.

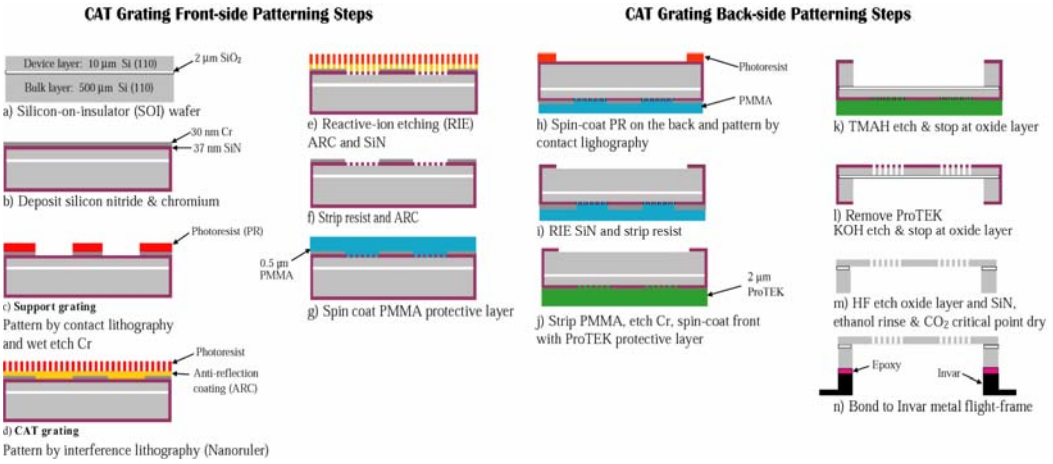

FIG. 2. SOI process for the fabrication of CAT gratings.

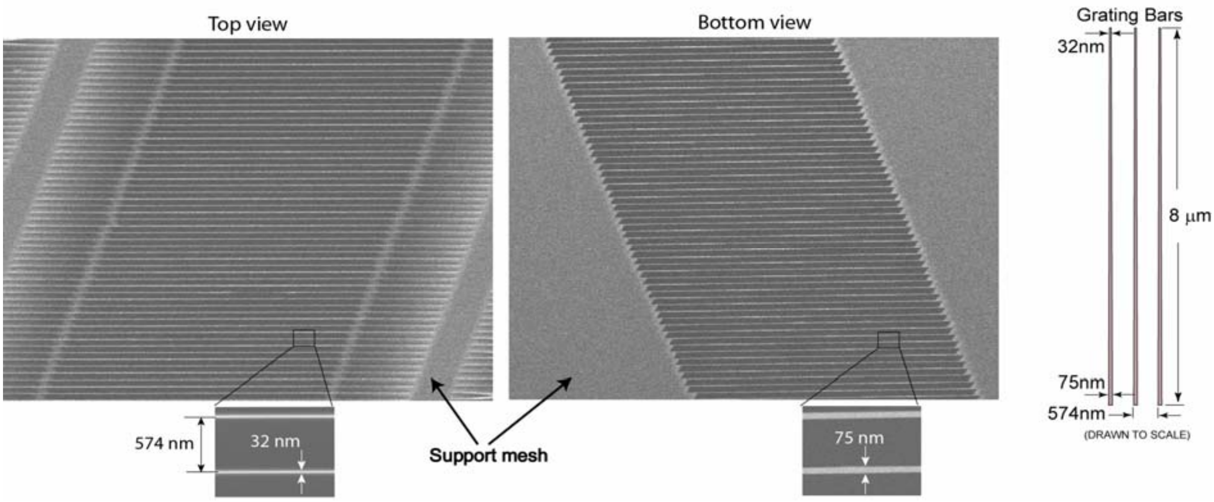

FIG. 3 Electron micrographs of the CAT grating. The width of grating bars is thinning from 75 nm at the bottom to 32 nm at the top. Aspect ratio=150, sidewall slope=0.15°, and duty cycle=0.093.