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Sandia National Laboratories

High aspect ratio silicon template fabrication for 100 keV X-ray phase contrast imaging

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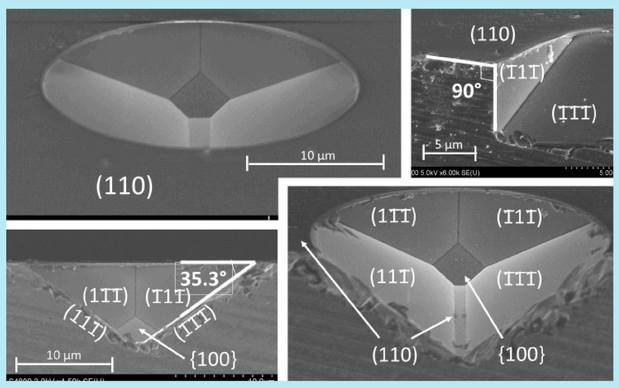
Overview

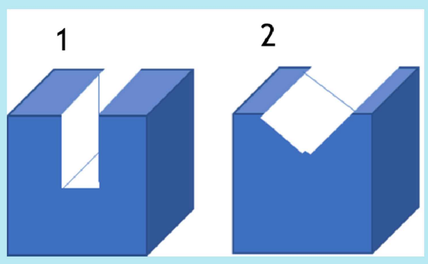
Lab based x-ray phase contrast imaging (XPCI) systems depend on high aspect ratio, micro-fabricated gratings. Sandia has developed alternative fabrication methods for high aspect ratio gratings using an anisotropic KOH etch in (110) silicon wafers and deep reactive ion etching.

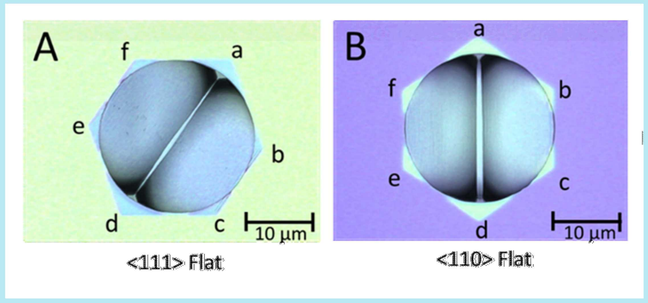
KOH anisotropic etching



Using a silicon nitride hard mask circular features are KOH etched into (110) silicon wafer. Self terminating hexahedron cavity bound by 6 {111} crystalline planes, revealing crystal orientation.

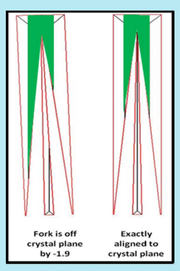
Hexahedron cavities etched in Si to determine crystal orientation



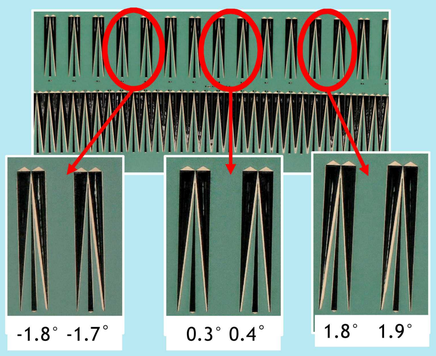


1. Trench profile parallel to {111} planes ab, cd, de and fa in images A & B
2. Trench profile parallel to (111) planes bc and ef in images A & B

Determining crystallographic alignment



M. Vangbo et. al. J. Micromech. Microeng. 6 (1996) 279-284



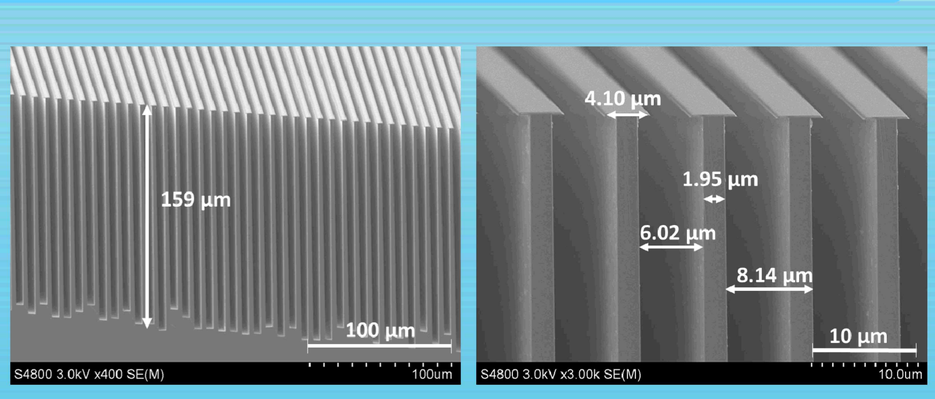
Combed for features pre etched into <110> wafer to define accurate theta adjustment from -3° to +3°

Alignment marks for contact lithography with rotational array of 0.1° from -3° to +3°

A. Alignment with no theta rotation.

B. Alignment to a 1.6° rotational adjustment in the counter clockwise direction.

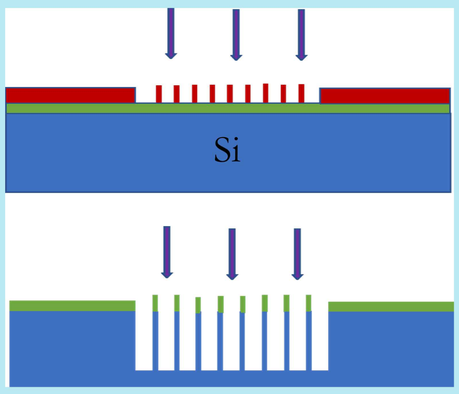
80:1 aspect ratio achieved with KOH

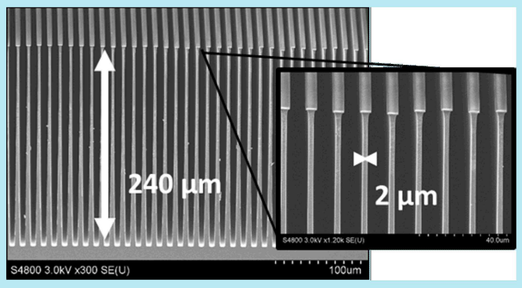


159 µm tall rigid Si grating template to be filled with electroplated gold

Deep reactive ion etch

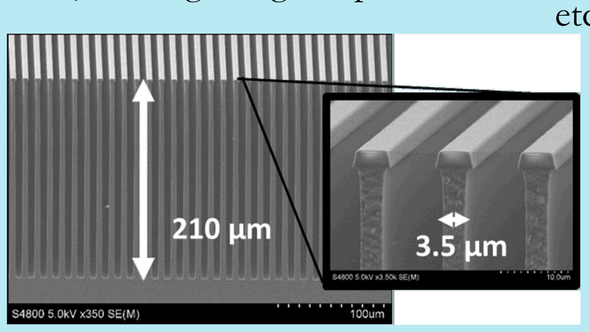
- Photlithographically patterned and etched SiO_2 Hard mask 4 µm thick
- Bosch etch using alternate gasses of SF_6 (etch) and C_4F_8 (polymer sidewall passivation)



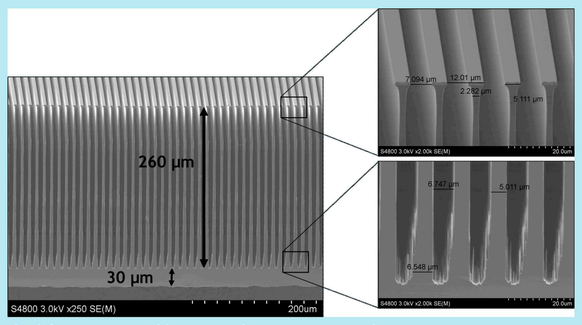


240 µm tall grating template

By manipulating the etch time to dep times we can improve sidewall profiles. Bosh etching has it's limitations and starts loosing uniformity the deeper the etch

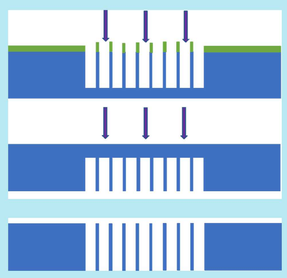


210 µm tall grating template

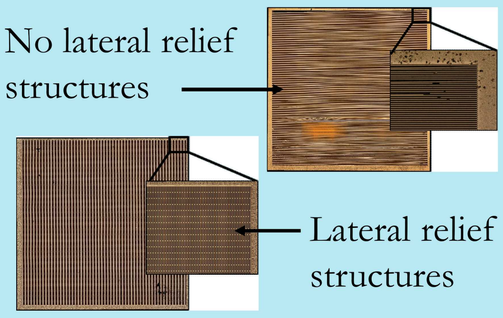


260 µm tall grating template

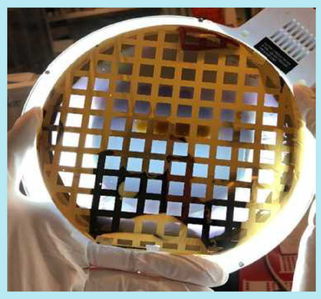
Through etched Si template

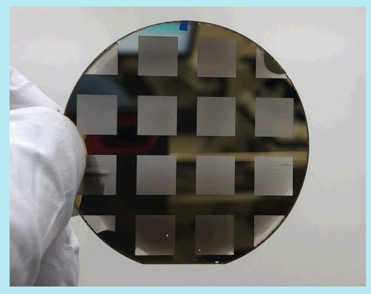


Using Bosch etch, we are able to create a through wafer etched grating template. By etching a 240 tall grating in the front side turning the wafer over and bulk etching the Si down to the gratings on the other side resulting in a completely through etched suspended grating



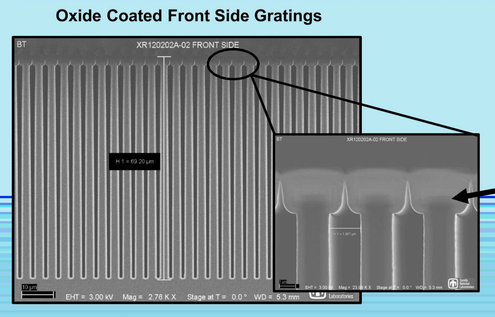
Lateral relief needed to maintain geometry and prevent broken Si



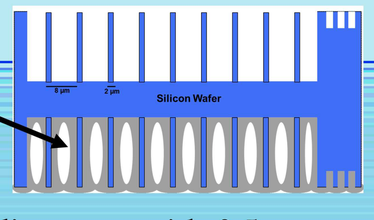


Right: Six inch Si wafer Left: 2 inch Si wafer. Both have been through etched with a 12 µm pitch diffraction grating pattern

Front to backside alignment



SiO_2 plugged grating to protect while processing the other side. It is later removed.



Front to backside alignment with 0.5 µm accuracy. The first Bosch etched grating is plugged with SiO2 to protect the grating while the other side is patterned and etched. The rigid Si template is then precision electrocoated with gold. See Hollowell.

References:
Patrick S. Finnegan*, Andrew E. Hollowell, Christian L. Arrington, Amber L. Dagel, High aspect ratio anisotropic silicon etching for x-ray phase contrast imaging grating fabrication, Materials Science in Semiconductor Processing, 92 (2019) 80-85

M. Vangbo, Y. Backlund, Precise mask alignment to the crystallographic orientation of silicon wafers using wet anisotropic etching, J. Micromech. Microeng. 6 (1996) 279–284

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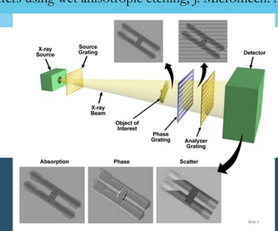

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