PAUL SCHERRER INSTITUT

BEAMeeting Stuttgart 2024

Grayscale lithography in HSQ and the application of dose gradient shapes

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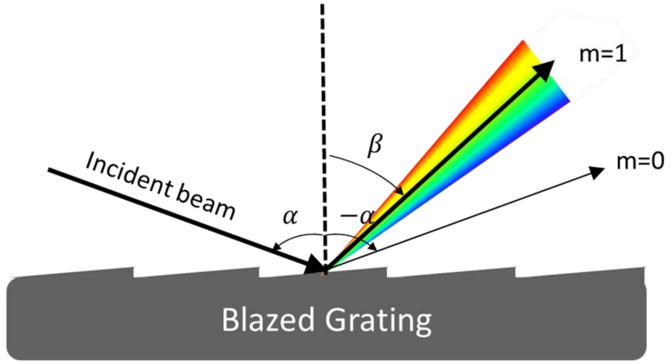
Blazed X-ray Diffraction Gratings

For application at Synchrotrons and XFELs in the soft and tender x-ray range (E ≈ 40 … 4000 eV)

- Monochromators
- Analyzers for inelastic scattering (RIXS)
- Self-seeding & pulse compression

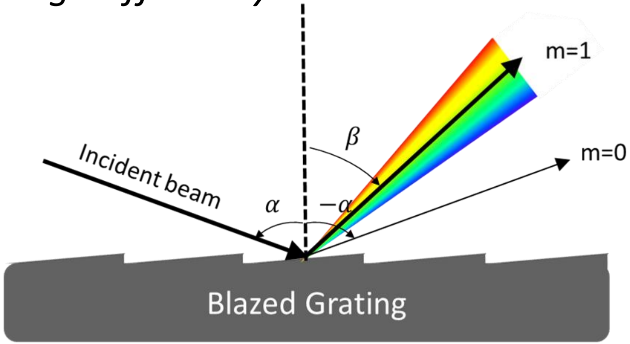


Blazed profile
Pitch: few microns down to 100 nm
Flat or curved substrates
Up to 140 mm length

$$m\lambda = k_0(\sin\alpha + \sin\beta)$$

Current fabrication methods

- *Ruling*
  - *Blazed gratings*
  - *High efficiency*



Sensitive to vibrations

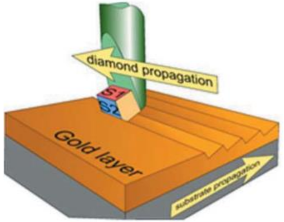
Quality of line patterns

Longer time for higher line density

Suppliers of high-quality gratings are very few

Availability of high quality gratings a key bottle-neck

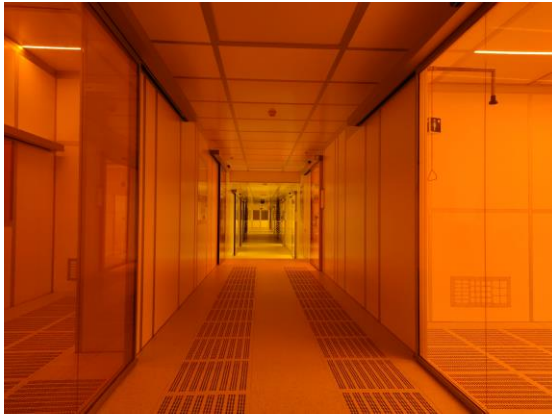
Bigger problem in view of next generation light sources



Mechanical ruling of a blazed grating (F. Siewert et al., J. Synchrotron Rad. (2018). 25, 91)

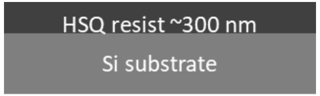
Electron Beam Lithography - Gratings

High resolution in placement (< 1 nm)
Sufficient throughput (~1 cm^2/hr)
Flat or curved substrates
Blazed or laminar structures
Length: up 140 mm
Pitch: few microns, down to few 100 nm



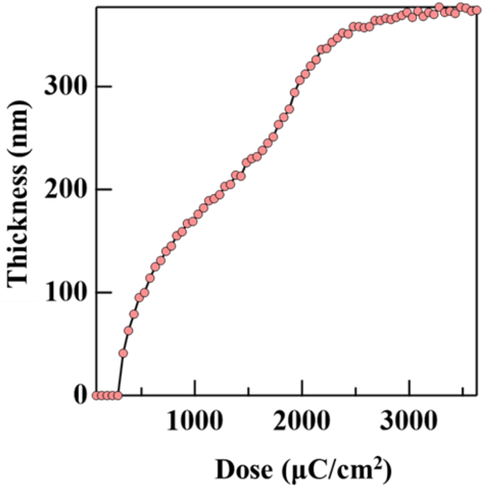
Several gratings with different pitch or blaze angle on the same substrate
Enhanced flexibility => more advanced optical designs such as curved lines

Grayscale Electron-Beam Lithography

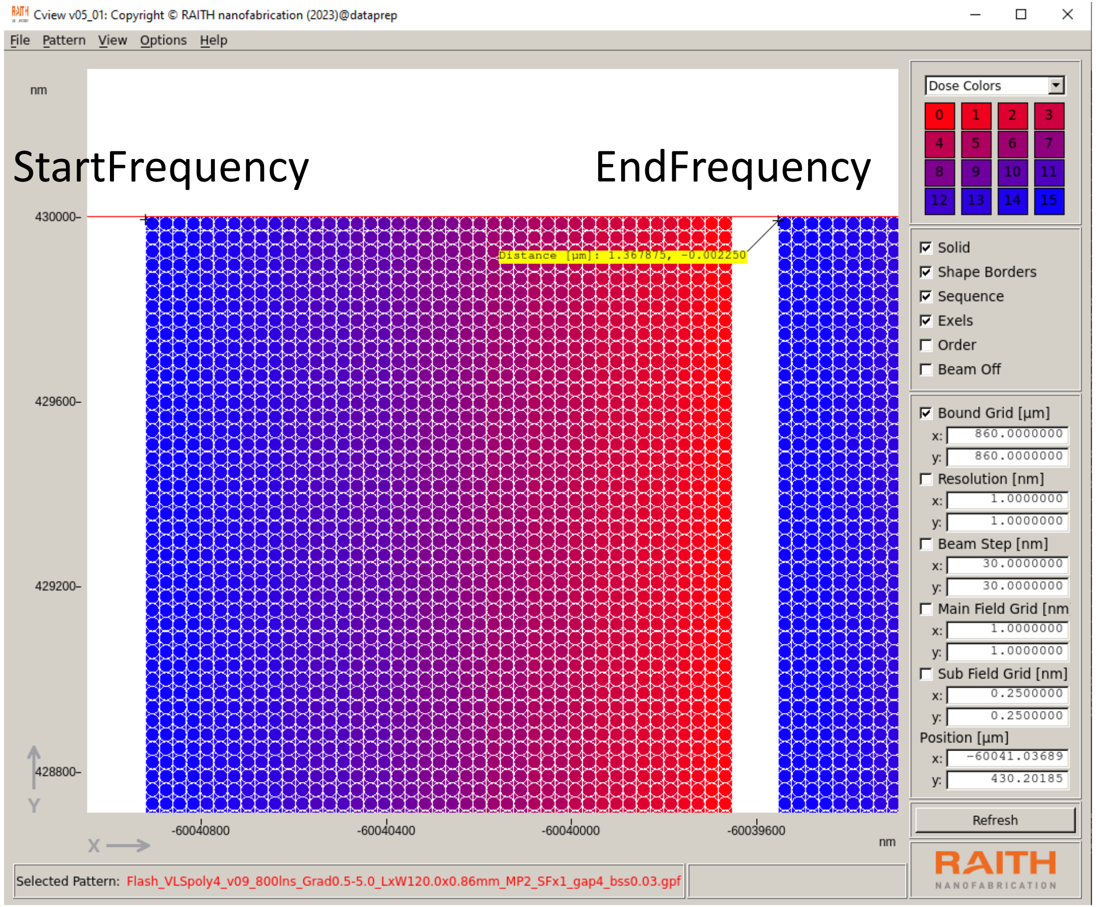


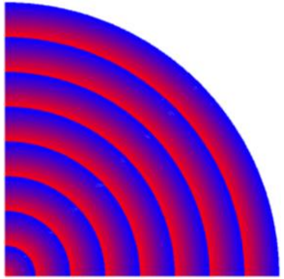
resist spinning

- Spin coating HSQ as resist (300 nm)
- Gray scale exposure
  – Dose gradient shapes (new development for EBPG)
- Convert resist structures into blazed grating lines
  – Mask oxidation (patent pending)



Dose gradient shape





Partial circle

Grayscale EBL and Thermal Oxidation of Silicon

Spin coating

– HSQ as resist, Thickness ~300 nm

Grey tone exposure

– Exposed area is converted to SiO_x

Development

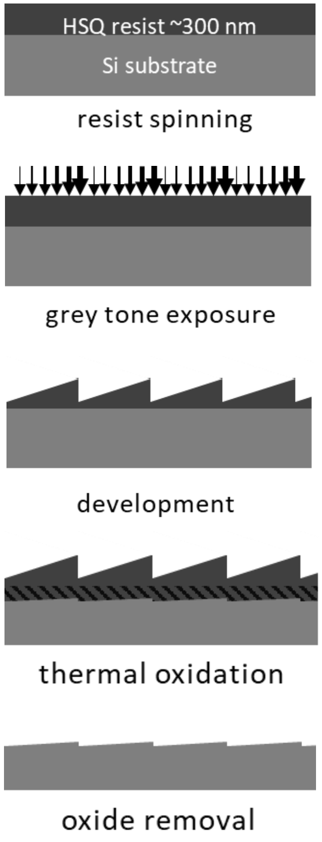
– NaOH based developer

Thermal oxidation

– Dry oxidation, Different SiO_x thickness => different oxidation speed

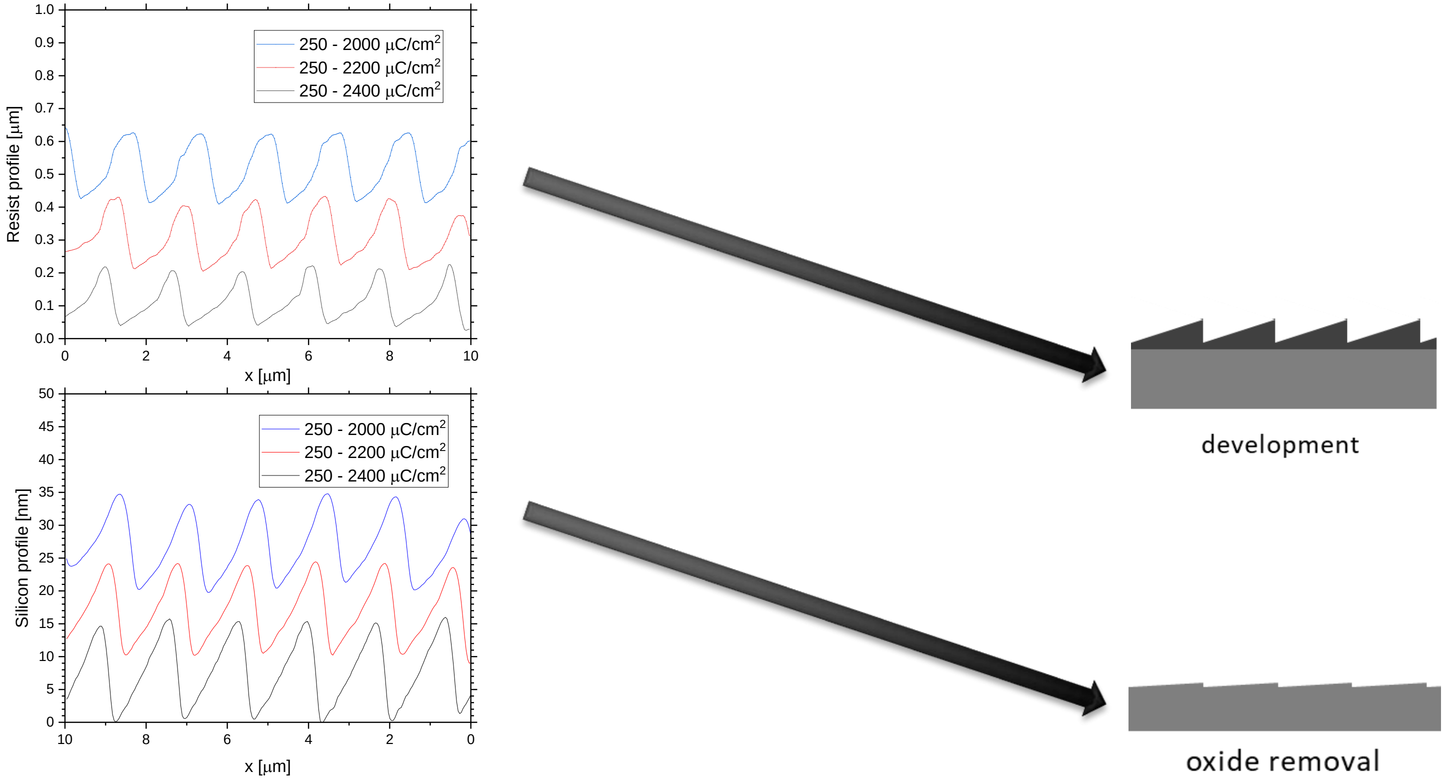
Oxide removal

– Wet chemical oxide removal with HF => reduces the roughness



Patent pending: V.A. Guzenko, C. David: *Fabrication of blazed diffractive optics by through-mask oxidation,* 2019P20969WO

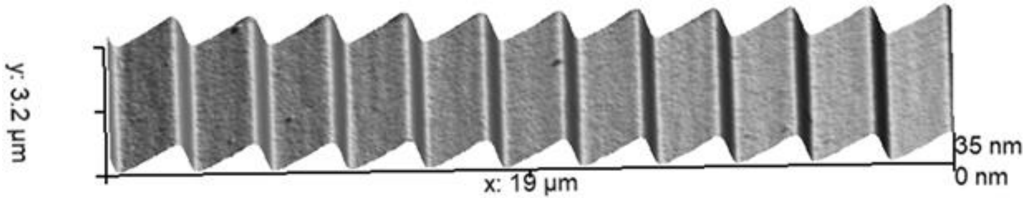
Grayscale EBL and Thermal Oxidation of Silicon



Patent pending: V.A. Guzenko, C. David: *Fabrication of blazed diffractive optics by through-mask oxidation,* 2019P20969WO

Fabrication results

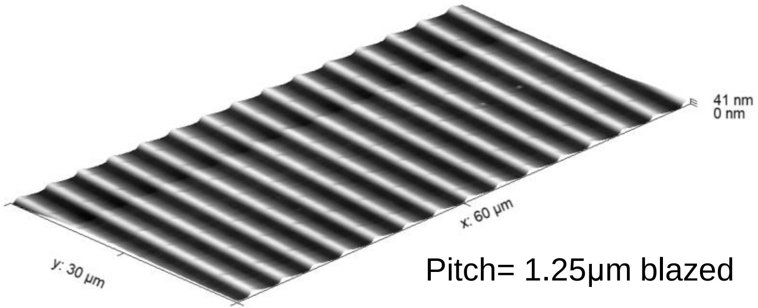
600l/mm (P1.666 µm)
Blazed angle = 1.61°
Step height = 31 nm
Anti-blazed angle = 4.88°
0.2 nm RMS roughness
Dose: 275-2750 µC/cm2
Beam step size 20 nm



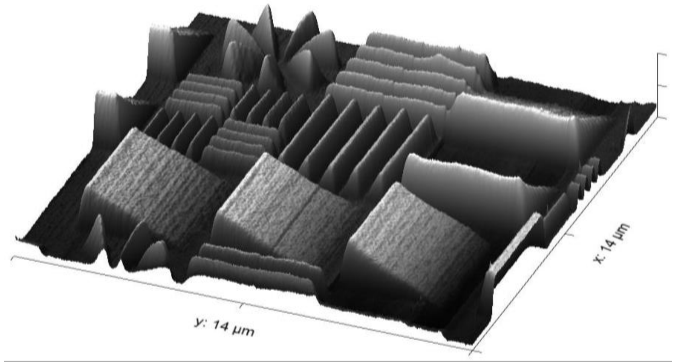
Pitch= 1.666µm blazed

AFM image of blazed EBL test structures

250 l/mm – 2000 l/mm, 0.35 nm RMS roughness



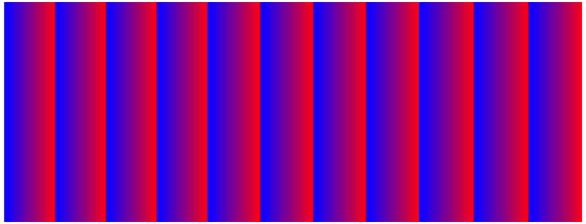
Pitch= 1.25µm blazed



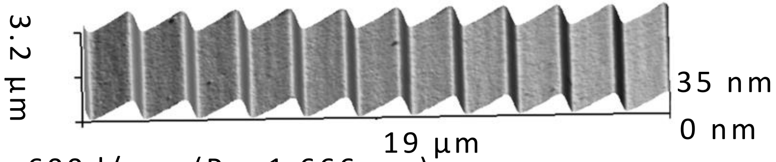
In summary

- From design
- To Grating
- To cool images (testing)

EBL design

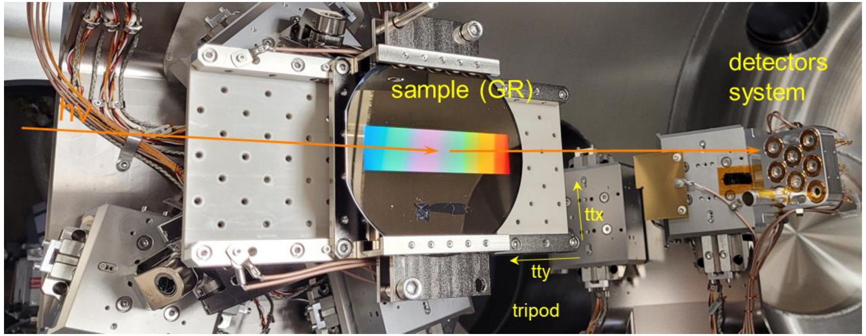


AFM profile of test grating

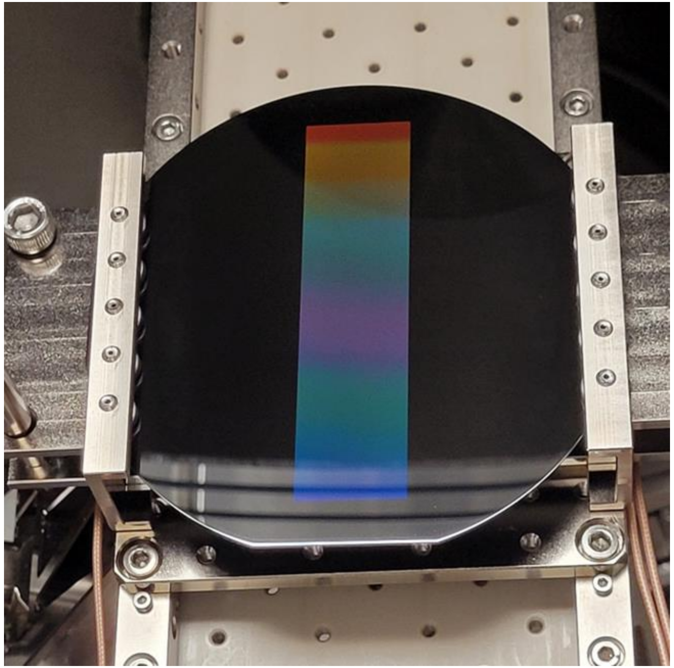


600 l/mm (P = 1.666 µm)
Step height 31 nm
0.2 nm RMS roughness
Dose: 275-2750 µC/cm^2
Beam step size 20 nm
Current 150 nA

At Wavelength Metrology @ BESSY II Optics Beamline on gold coated grating



Gold coated test grating in the reflectometer



Future steps

- Finalizing the lithography process
  - Full size gratings
  - Curved substrates
  - VLS gratings

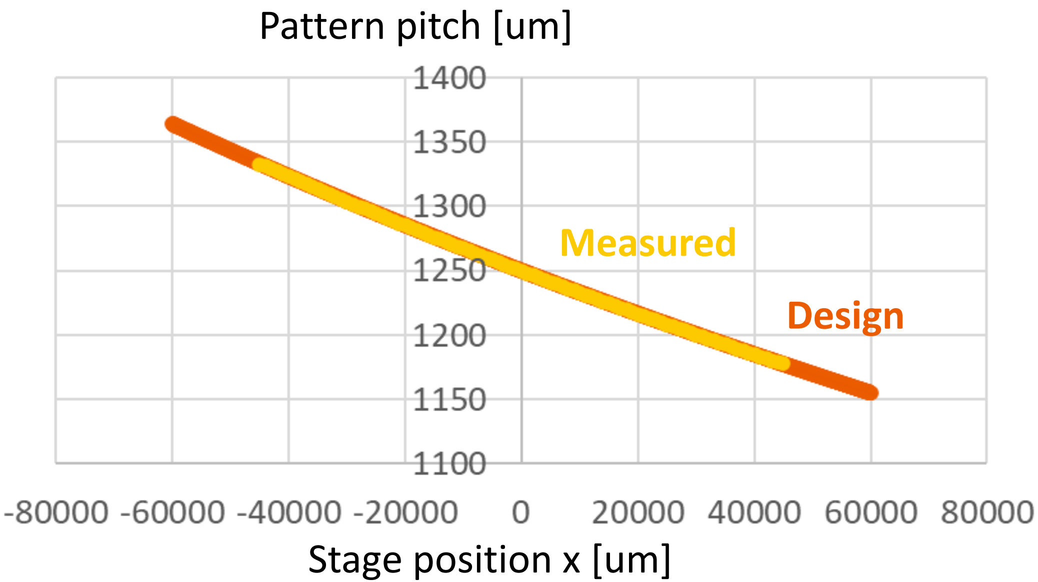
Sneak peak – VLS gratings

Variable line spacing

- Line density = $a_0 + a_1x + a_2x^2 + a_3x^3$

Stage position x	-60000	um
Calculate line density	742.4984	lines/mm
Patternpitch	1346.804249	nm
Rounded pattern pitch	1347	nm
Scaling of MF in X	-14532	[ppm]
Scaled pitch corrected	-0.19574604	nm
Final pitch	1346.804254	nm
Final line density	742.4983973	lines/mm

Initial results



Residual in pattern pitch
< 1 Angstrom

Acknowledgements

X-ray Nano-optics group :

Nazanin Samadi

Christian David

Vitaliy Guzenko

Colleagues at HZB:

Analía Fernández Herrero

Andrey Sokolov

Frank Siewert

Colleagues at Raith:

Bas Ketelaars, Christiaan Zonnevylle, and the entire team

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No. 101004728

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Thank you!

Thank you for your attention!

Question?