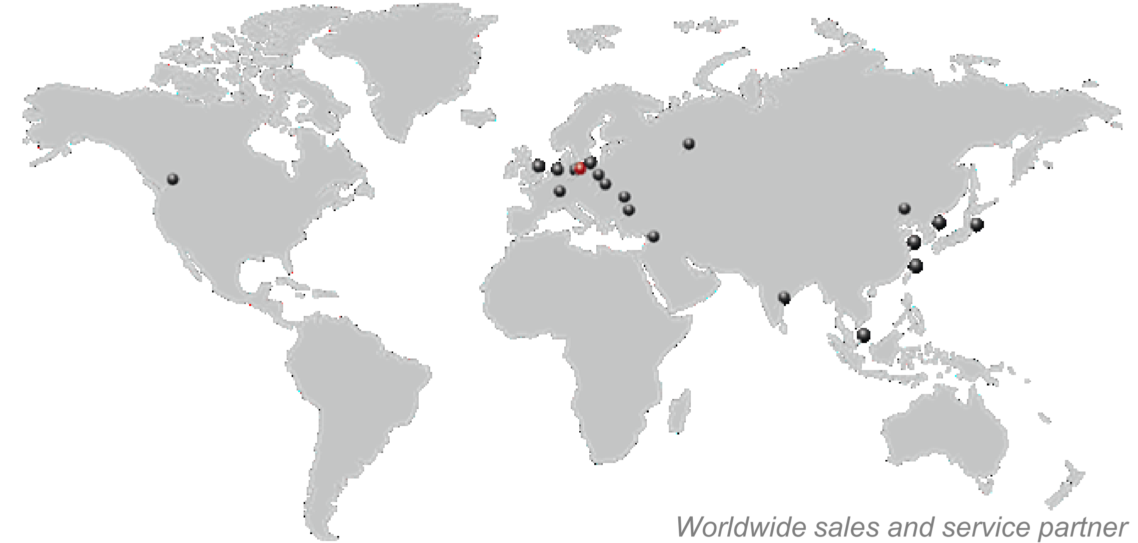
Flexible Approach for the Production of Slanted Surface Relief Gratings by Ion Beam Trimming

XXVIII. Erfahrungsaustausch
“Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen”
Mühlleithen

16st March 2023

scia Systems at a Glance

- Design and manufacturing of vacuum processing equipment for optics and MEMS/sensor industry
- Privately owned company
- Founded 2013
- Located in Chemnitz (200 km south of Berlin)
- Over 180 employees, more than half with university degree in physics, chemistry and engineering
- ~ 70 Mio. EUR annual revenue
- Sales and service partners in 17 countries



Worldwide sales and service partner

New company facility, built in 2021

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Glasses for Augmented Reality

Augmented Reality (AR) / Mixed Reality (MR) devices project additional information in the field of view of the human eye

- Image projection in front of the eye's pupil → eye-box
- Image generation by display at the edge near the frame arm
- Eye-glass act as optical waveguide
- As uniform illumination of the eye-box as possible

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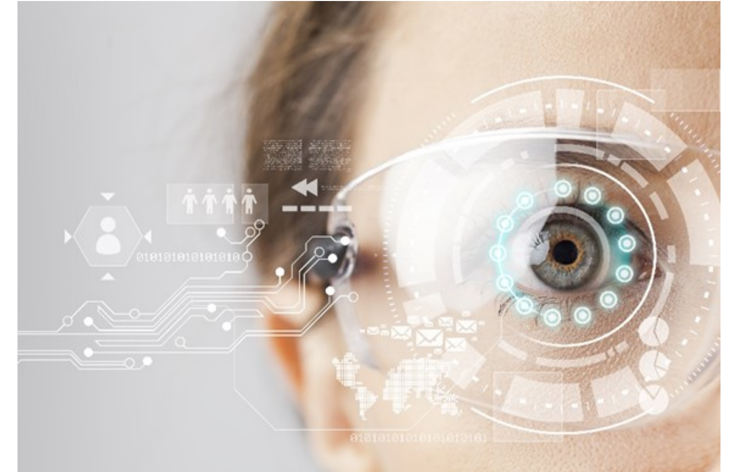

Possible lens for augmented reality

Optics processing for Augmented Reality

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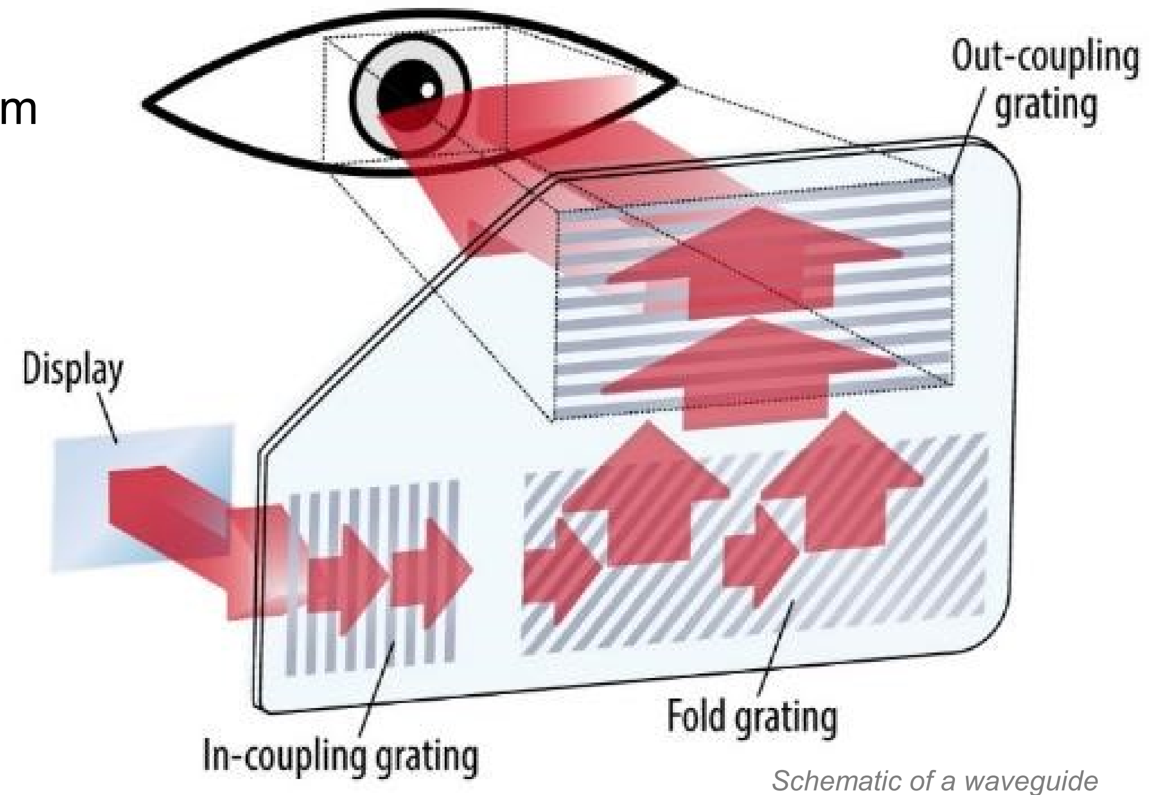


Schematic of a waveguide

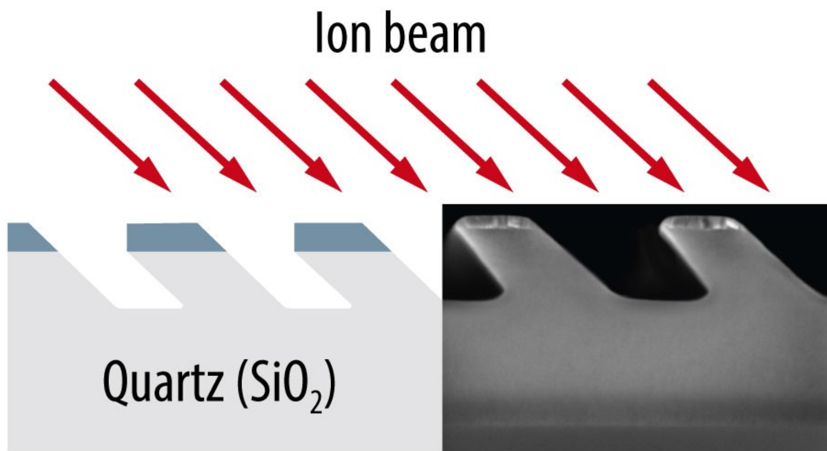
Sub-wavelength Surface Relief Gratings (SRG) as optical couplers

- Slanted SRG's in various orientations for directionality of light coupling

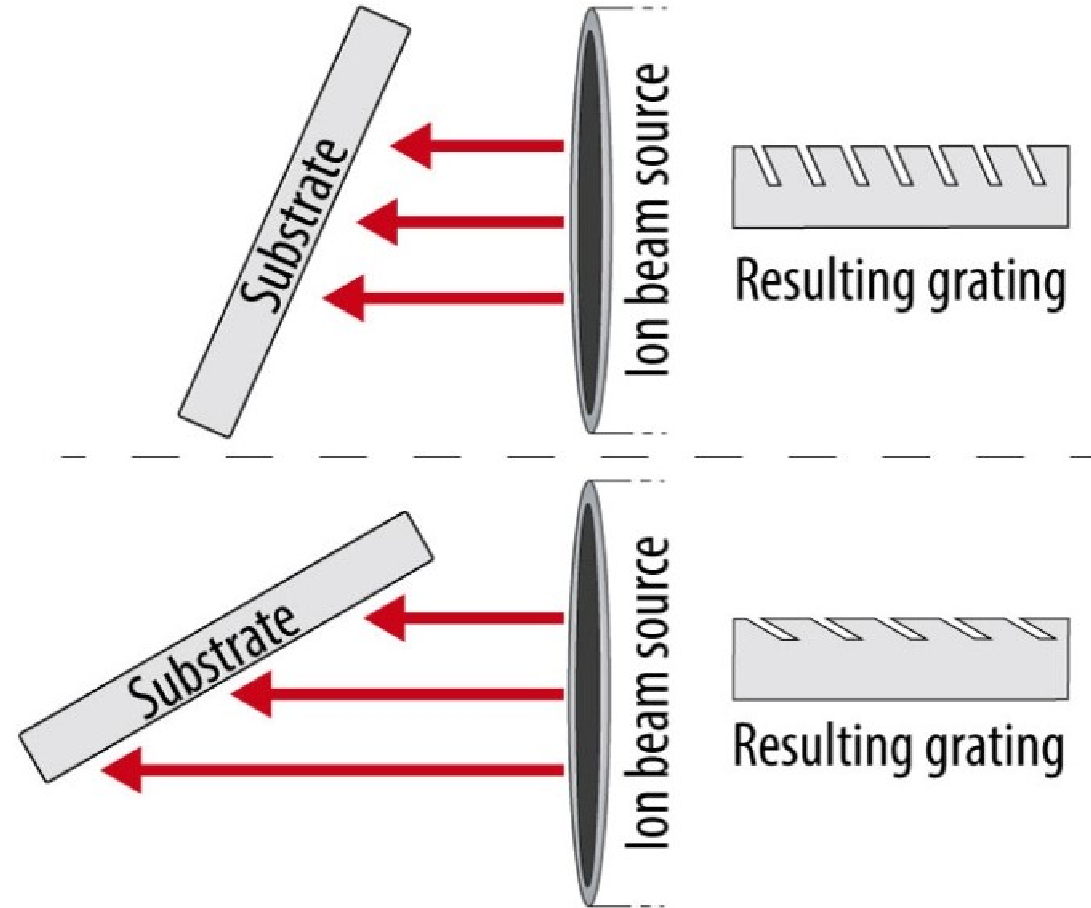
Structuring of SRG

- Reactive Ion Beam Etching (RIBE) for optical material (e. g. SiO_2, Si_3N_4)
- Suitable mask required, typical metal mask (e. g. Cr)
- Angle control by chuck tilt angle
- Manufacturing with
  - Direct Etching
  - Nanoimprint Lithography

Fabrication of a master structure



Etching of SRG with RIBE



Principle of tilted etching

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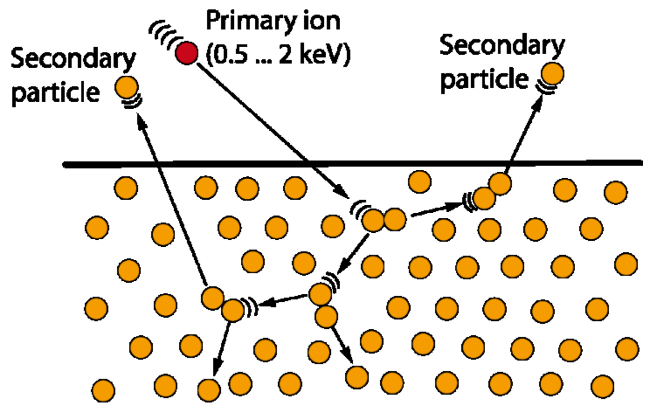
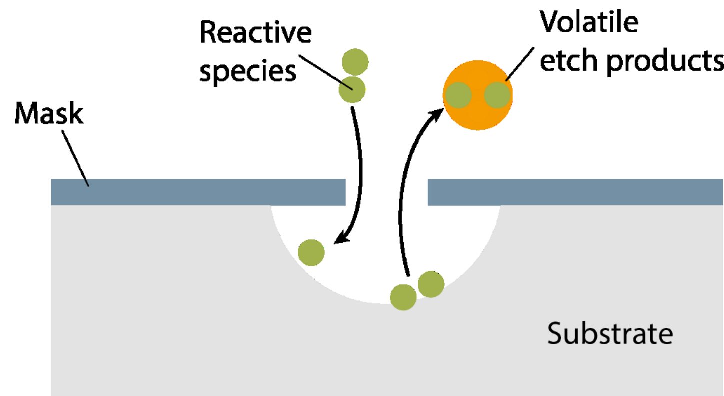
Ion Beam Etching Principles

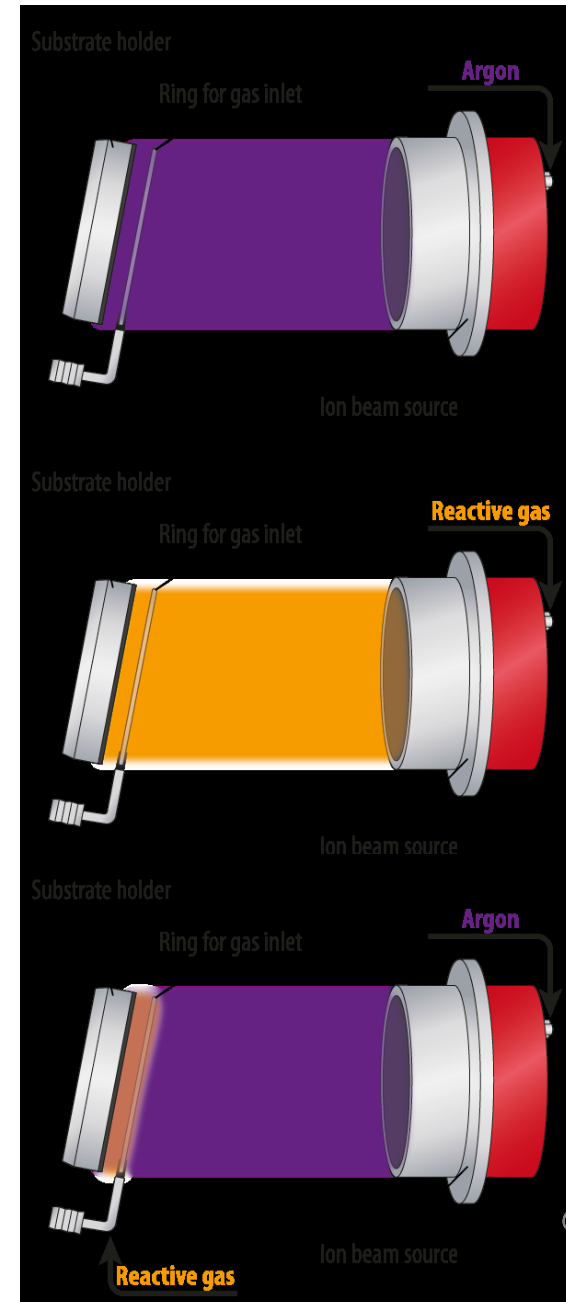
- Atoms of target material can be ejected by bombardment of high-energy ions
- Momentum exchange between incident ions and atoms of the target material in collision cascades
- Additional chemical etching with reactive gases (RIBE, CAIBE)
  → enhanced rate, control of selectivity



Principle of ion beam etching



Principle of chemical dry etching



Ion Beam Etching (IBE)

Reactive Ion Beam Etching (RIBE)

Chemically Assisted Ion Beam Etching (CAIBE)

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RIBE-Systems and Process

- Coupling performance depends strongly on front and back slant angle and the shape of the gratings and the trenches
- Control of selectivity and trench shape by variation of
  - Gas mixture (Ar, N_2, O_2, H_2, N_2O, CHF_3, SF_6, CF_4, Cl_2)
  - Ion energy and ion current density
- Requirements for the trench bottom shape

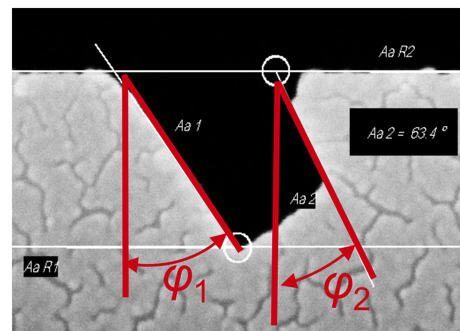
scia Mill 200

200 mm wafer

350 mm IBS

One slant Angle @whole wafer

Angle	φ_1	φ_2	φ_{mean}
30°	28°	21°	25°
35°	37°	24°	31°
40°	42°	30°	36°

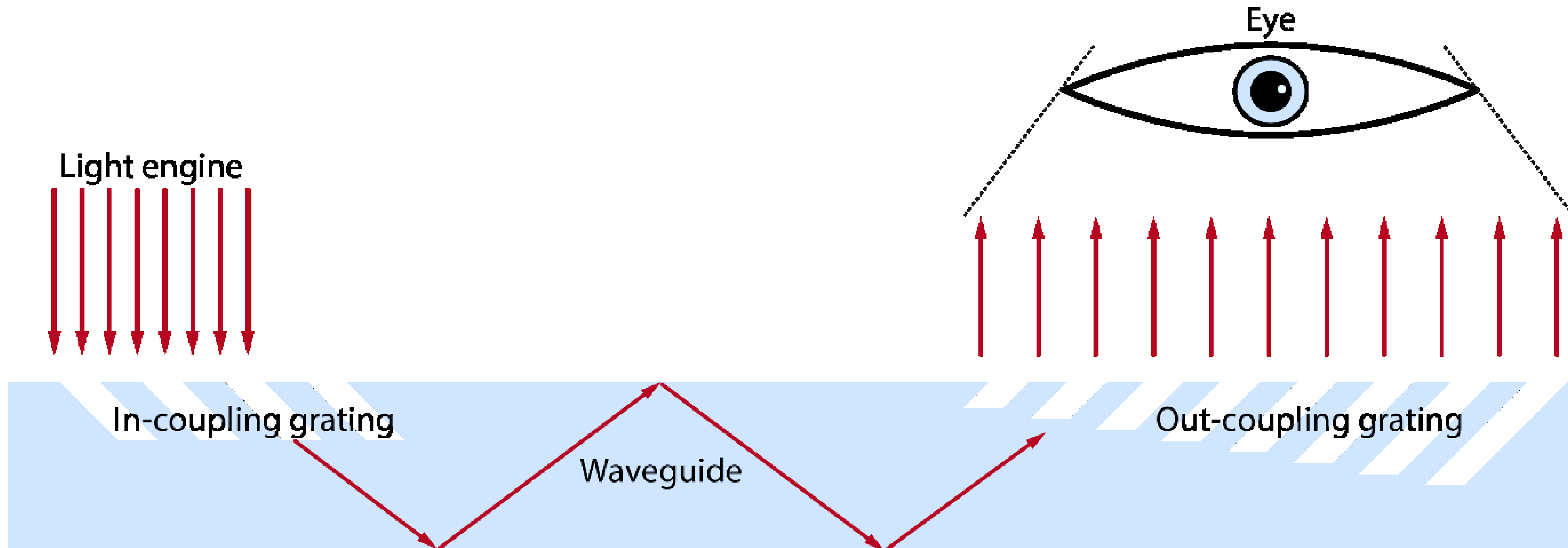


Angle control by chuck tilt angle

Control of parallelism with different etching conditions for SiO_2

Variable Gratings on Wafer-Sized Substrates

- Uniform illumination of the eye-box as an important requirement for high-end devices
- Varying Angle Surface Relief Gratings (VASRG)
  - Opens further more options for the optical design



Schematic illustration of a waveguide with in- and out-coupling grating

Reactive Ion Beam Trimming - RIBT

- Localized etching by focused broad ion beam
- Material specific gas composition
- Stepwise Wafer tilting during processing for slant angle control
- Removal controlled by local dwell time of ion beam at certain wafer positions
- Dwell time adjustment handled by pre-calculated velocity map in raster scan pattern

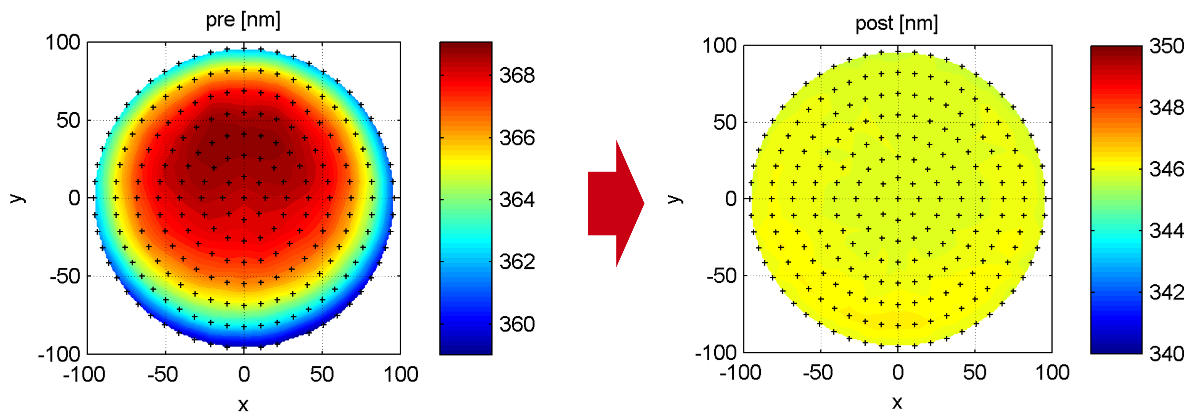
scia Trim 200

200 mm wafer

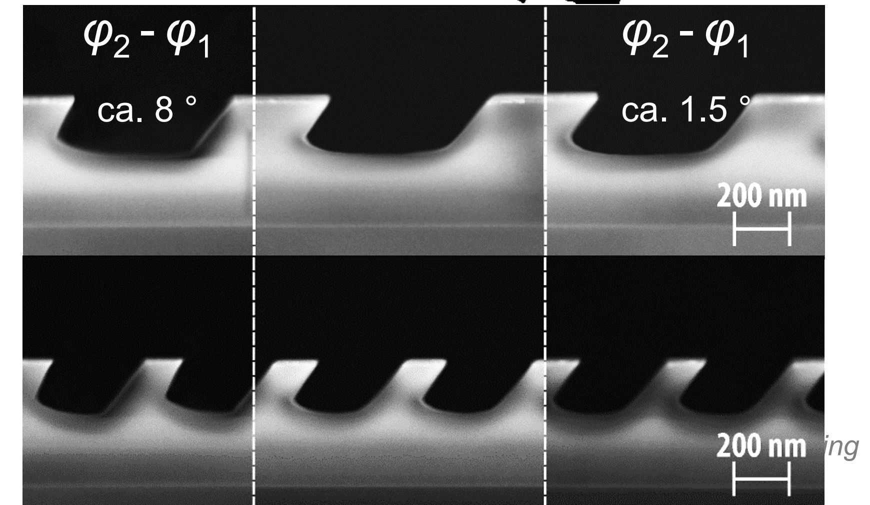
37 mm IBS focused

arbitrary pattern distribution

scia Trim 200



Thickness data before (left) and after (right) ion beam trimming



Control of parallelism with different etching conditions for SiO_2

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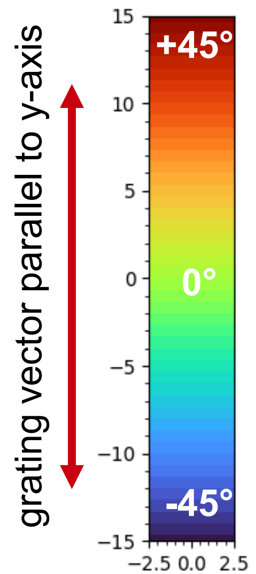
Trimming with Varying Angle of Incidence and Depth

- Varying angle of incidence by tilting the substrate

desired design
(slant angle, grating height)



Trimming with Varying Angle of Incidence

- Varying angle of incidence by tilting the substrate
- Aiming for a specific removal across sample area

desired design
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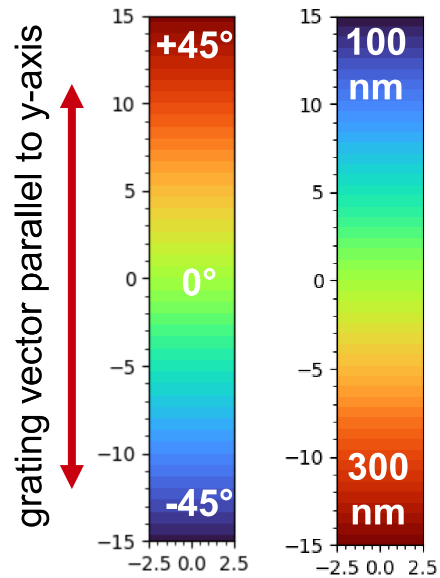

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- Varying angle of incidence by tilting the substrate
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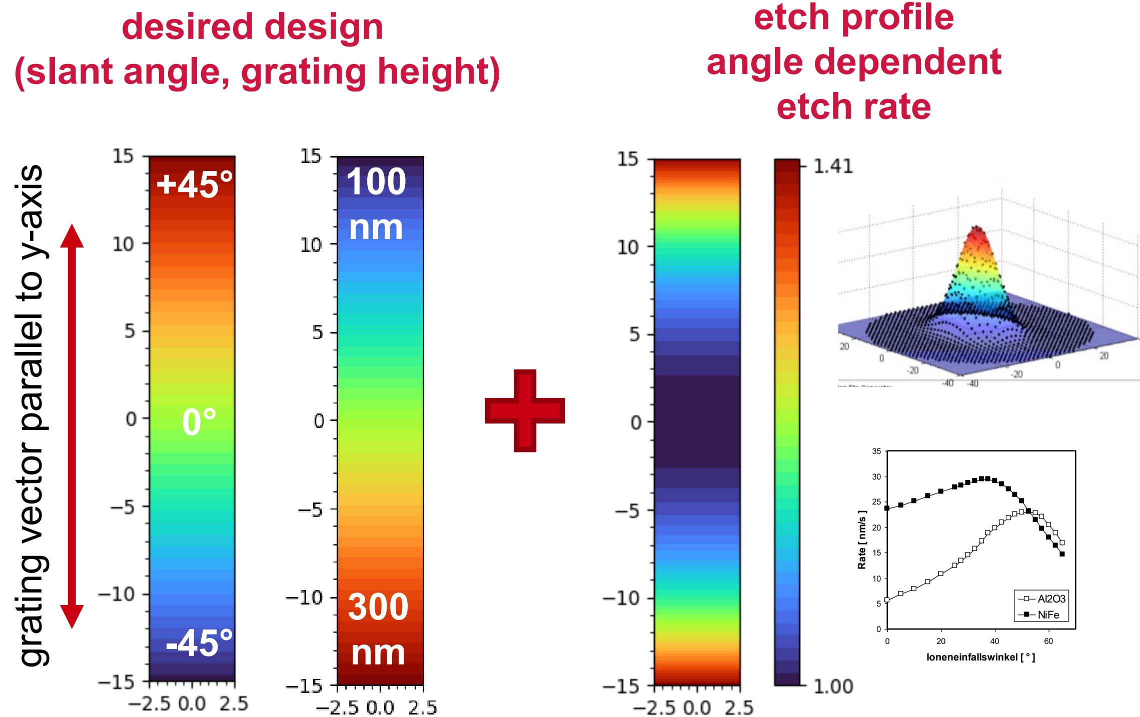
- AOI-dependent etch rate to be considered



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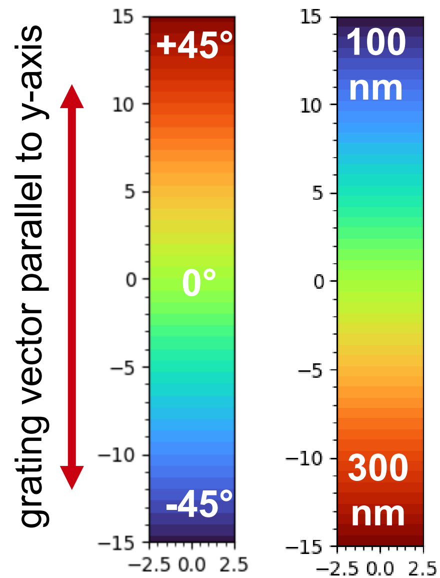
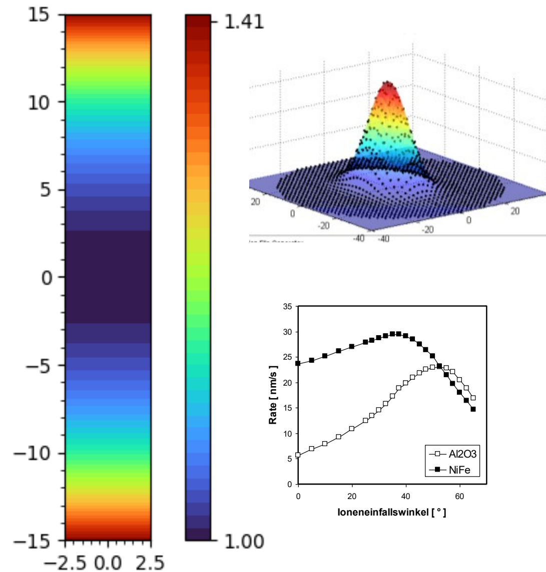
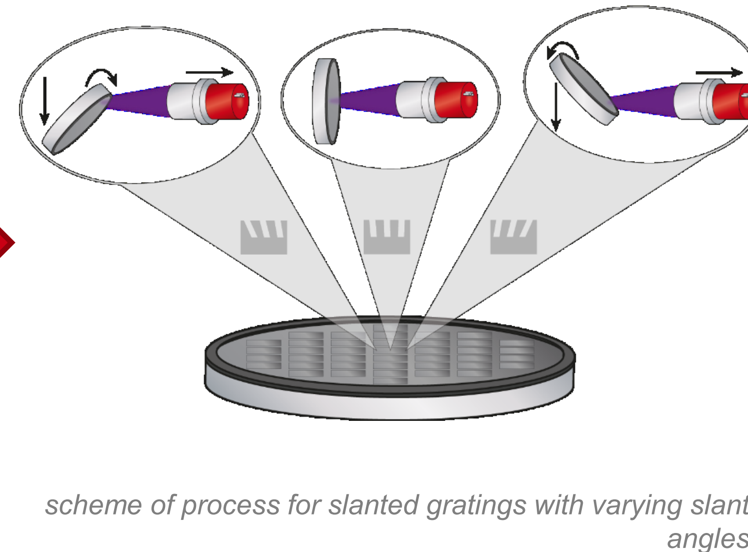


etch profile
angle dependent
etch rate



calculation of dwell time and
generation of axis control data



scheme of process for slanted gratings with varying slant angles

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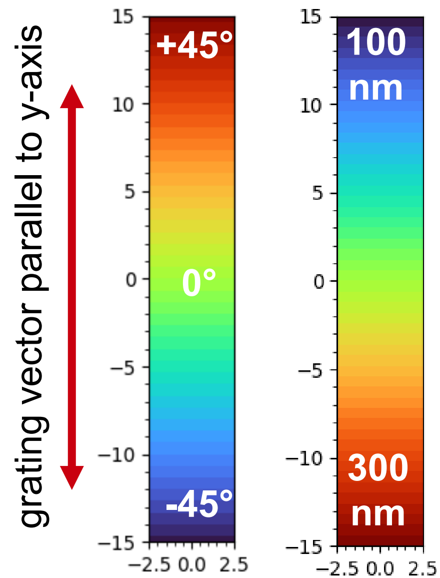
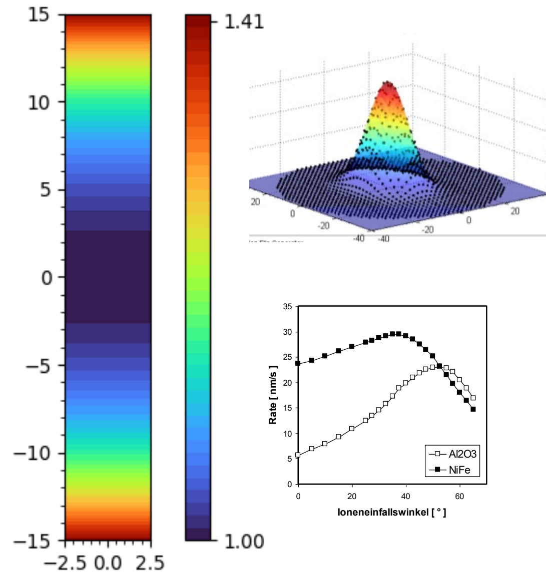
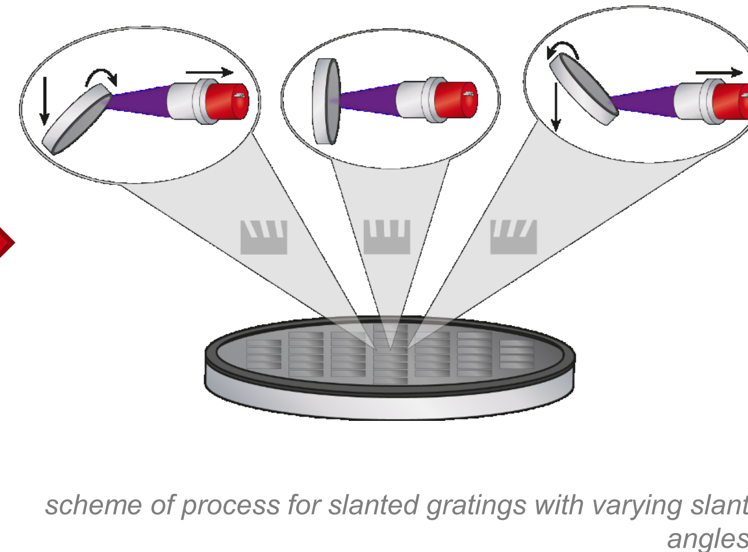


etch profile angle dependent etch rate

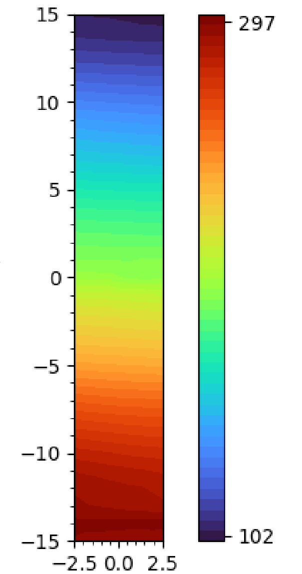


calculation of dwell time and generation of axis control data



scheme of process for slanted gratings with varying slant angles

etch result



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Trimming of VASRG – First Achievments

Si_3N_4
Pitch: 800 nm
Linewidth: 400 nm

400 nm
400 nm
400 nm

Angle / °
80
60
40
20
0
-20
-40
-60
-80
0
5
10
15
20
25
30
Position on sample / mm

Angle of incidence
φ_1
φ_2

0 mm
30 mm

φ_1
φ_2
Cr
Si

scheme of the sample after process with definition of the angles α and β

Trimming of VASRG – First Achievments

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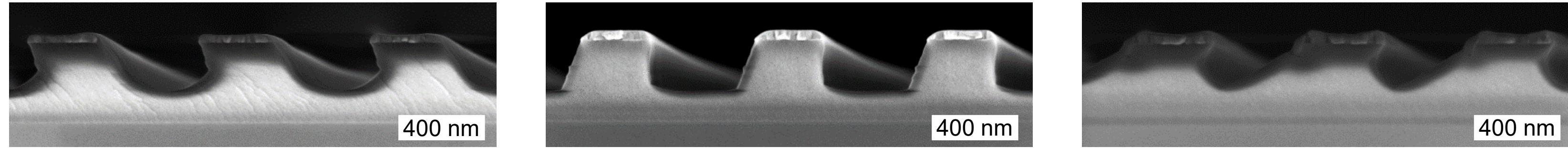
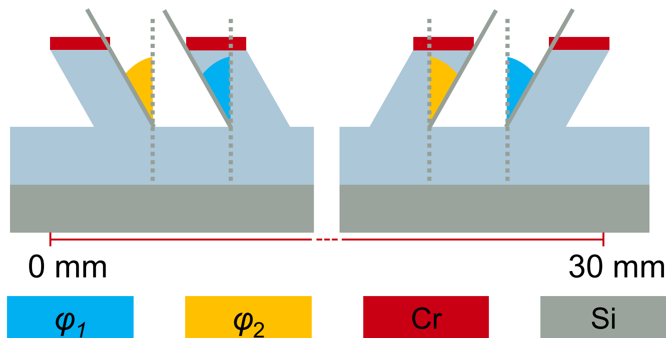
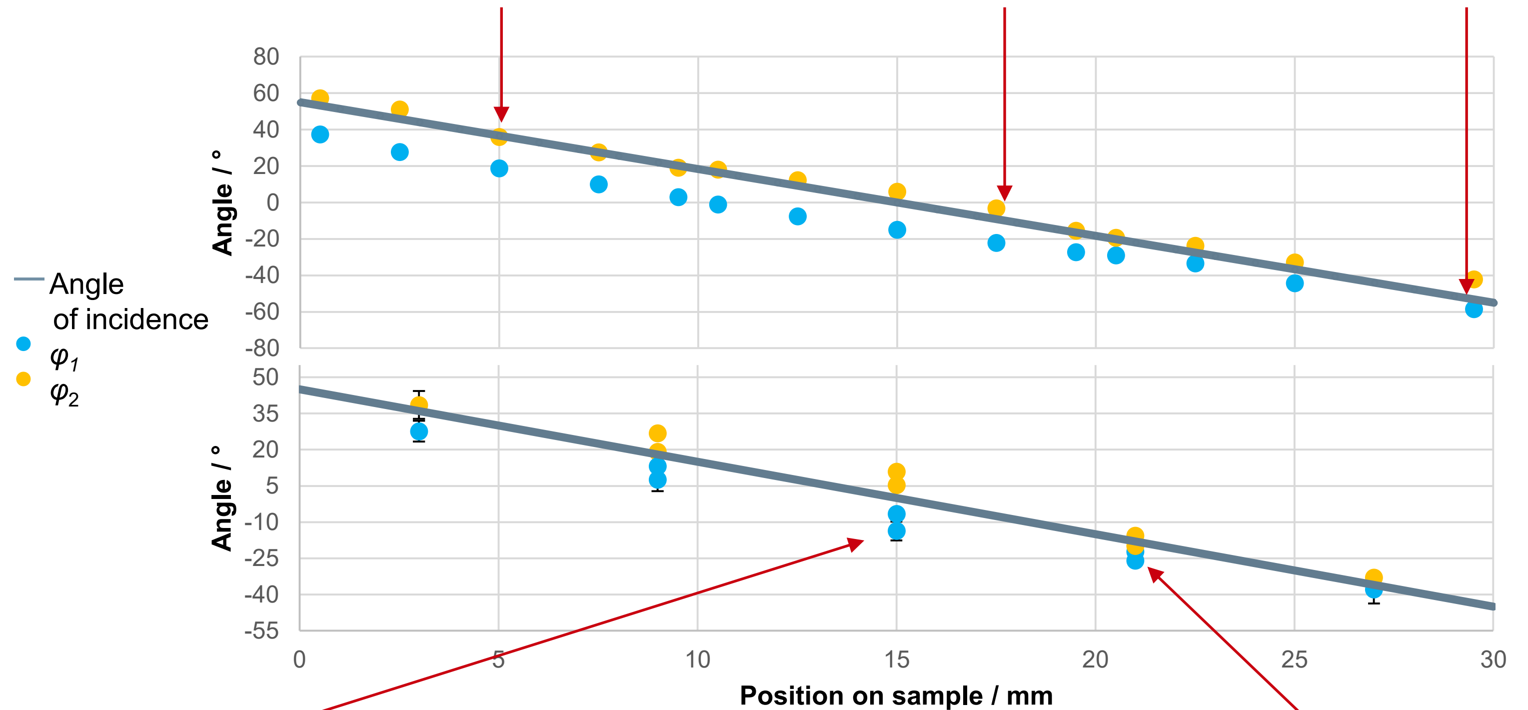
Linewidth: 400 nm





scheme of the sample after process with definition of the angles α and β



SiO_2

Pitch: 800/400 nm
Linewidth: 400/150 nm

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Variable Gratings on BIGGER area

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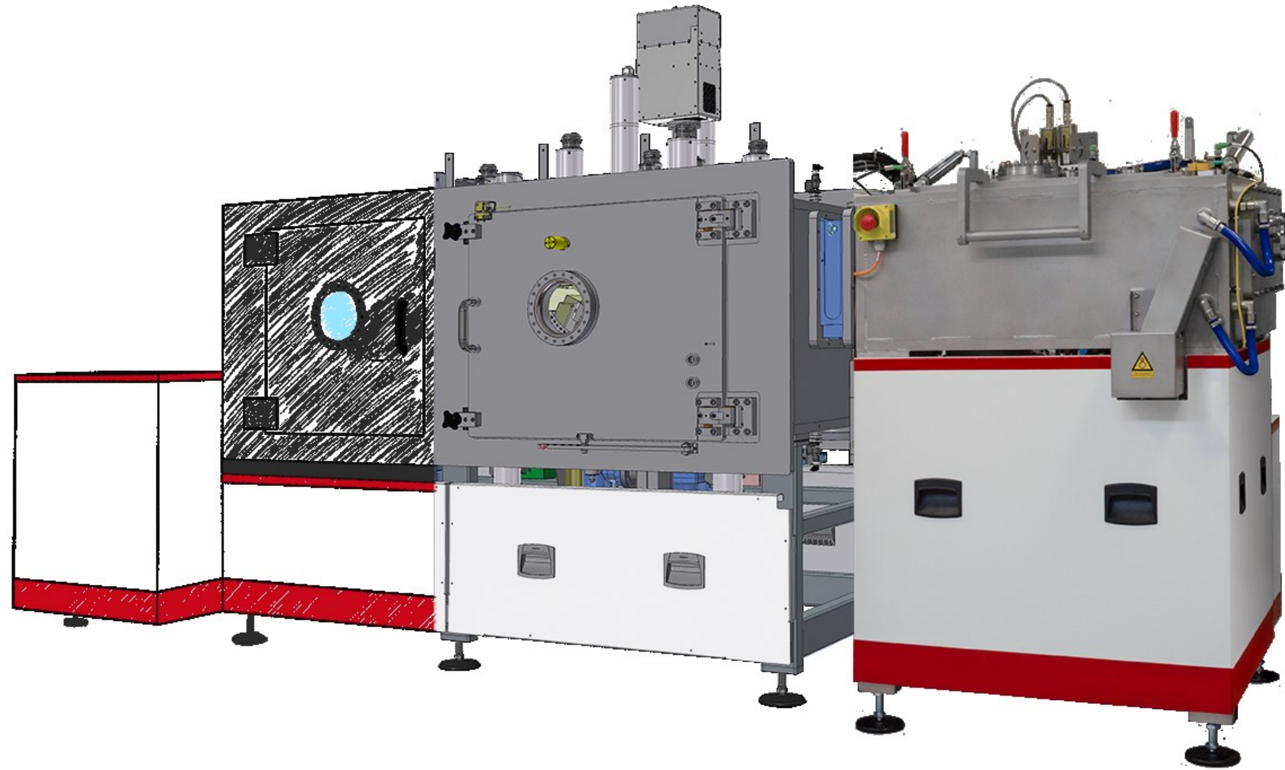
To be continued

New concepts are coming alive



… to bring optical gratings to the next level!

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Summary

- RIBE established in industrial applications for SRG etching
- RIBT proved to be a versatile process for manufacturing of VASRG - industrialisation in ramp
- Uniform gratings on different sample geometries and sizes possible
- Variable structuring on 200 mm wafers demonstrated
- Scaling concepts in development

Thank you!

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