PTB
Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Development and Characterisation of Scatterometry Reference Standards

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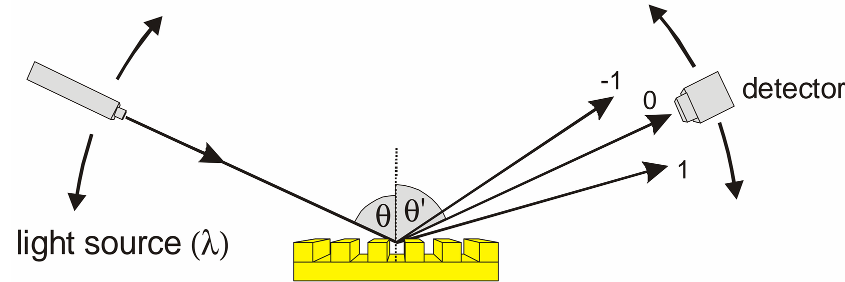
1) HZB Helmholtz Zentrum Berlin
2) JCMwave

Introduction



- Scatterometry (also: Optical Critical Dimension OCD), including reflectometry, ellipsometry,... is an important metrology method widely used for process development & control in nanolithography
- Very high sensitivity with respect to variations of many important structure parameters
- Shows usually an excellent linearity to CD-SEM measurements
- However, often some significant measurement offsets with respect to CD-SEM measurements are observed, which are usually accounted for by introducing some dubious 'bias values'
- Accurate and absolute scatterometry measurements are quite challenging due to the relative complex data analysis
- Currently there is a lack of reliable scatterometry reference standard samples traceable to the SI unit *Meter*

Objective

Aim:

- Realisation of scatterometry reference standards: U(CD) ≈ 1 nm
- To improve significantly the tool matching between different types of scatterometers and also with microscopy tools (SEM, AFM,...).

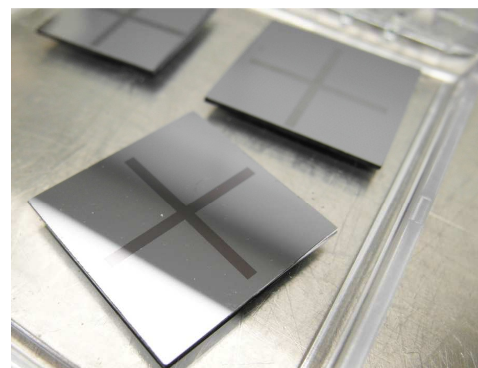
Requirements:

- Design (sample size, materials, structuring) has to take into account the requirements of different types of scatterometers, SEMs and AFMs
- Set of targets representative for current and future lithography technologies
- Good knowledge of optical parameters of the materials and of structure geometry details
- Stable over time
- Suitable for state of the art metrology tools (for industrial applications)
- Two different materials: silicon, dielectric (resist mimicking) material

Developed reference standards

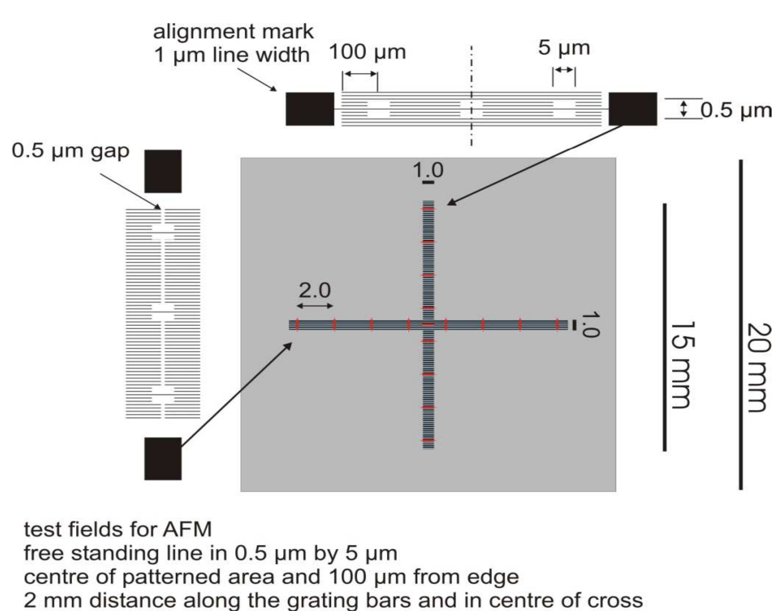
Aimed specifications:

- Material: silicon wafer with Si or Si_3N_4 structures
- Manufactured by e-beam lithography by HZB
- Size: sample (20 mm)^2, targets 1 mm^2 & (1x15) mm^2
- Line gratings: periods (50-250) nm,
- Linewidths (25-132) nm
- Structure height (40-90) nm, edge angles ≈ 90°
- Line edge roughness <≈ 1 nm (rms), low corner rounding

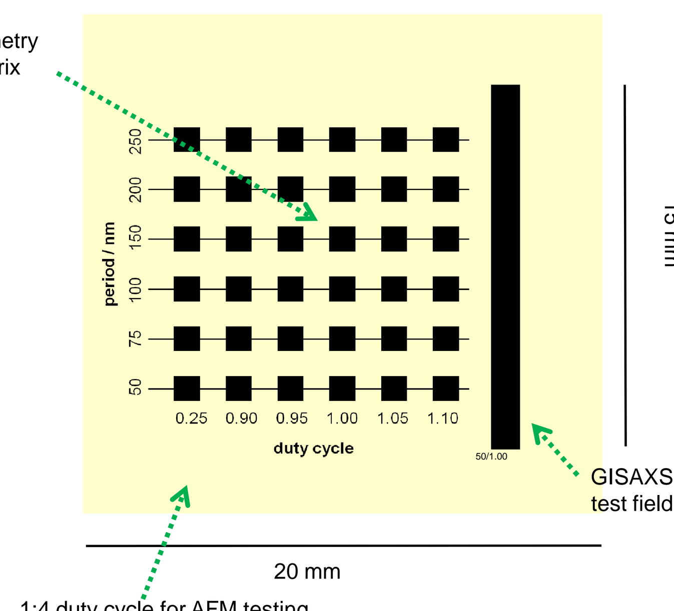


Si based grating samples

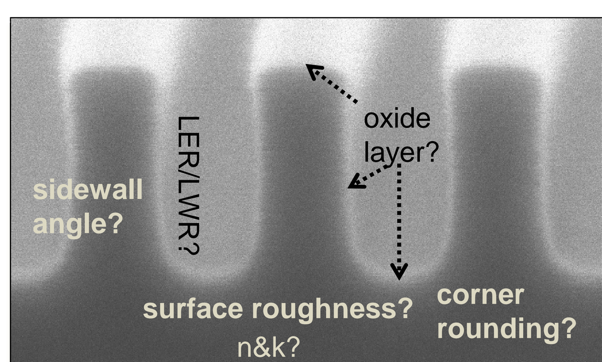
Design: for sample development and testing phase



Draft of final design



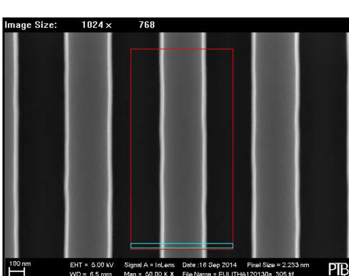
Characterisation

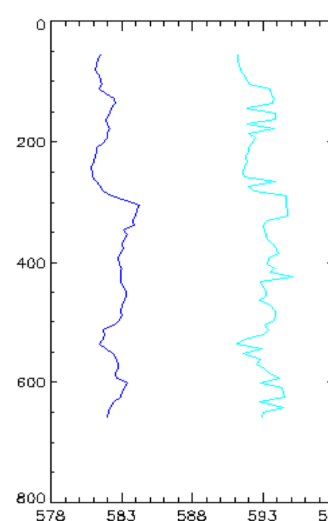


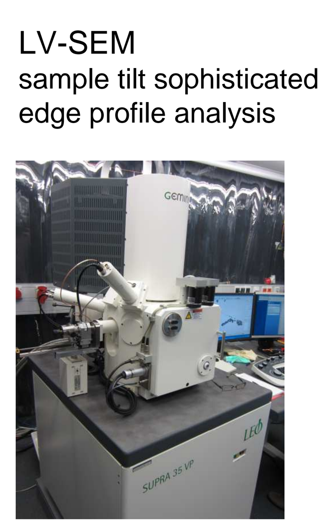
Spectroscopic Mueller polarimeter
Sentech SE 850 DUV

<u>Optical / X-ray reflectometry and spectroscopic ellipsometry:</u> Characterisation of layers and opt. material parameters
<u>Cross section SEM:</u> Verification of structure geometry

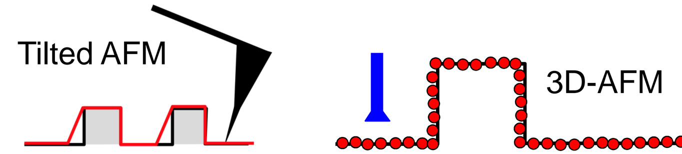
<u>Top-down SEM, tilted & 3D/CD-AFM and GISAXS:</u>
Line Edge/Width roughness determination

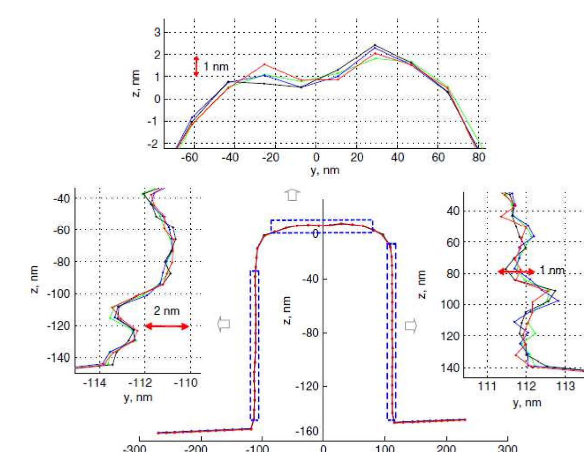






LV-SEM
sample tilt sophisticated edge profile analysis





SEM image and analysis of edge positions applying PTB's BDF-edge detection algorithm (left), top (blue) and bottom (cyan) edge position versus scanning position

Measurement repeatability of 3D/CD-AFM

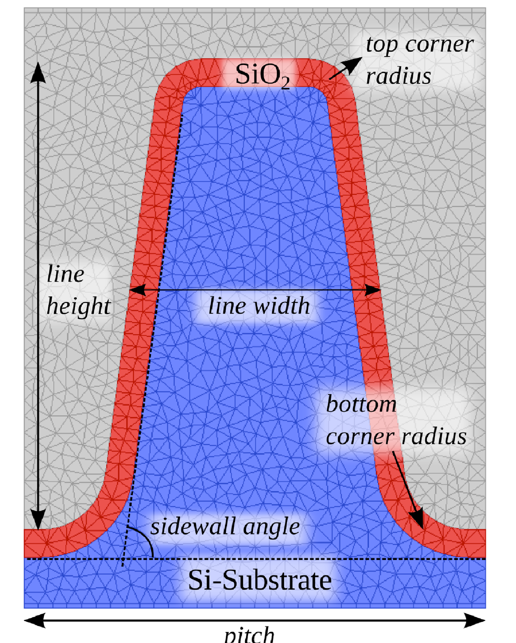
Structure model

<u>Rigorous modelling</u> for all 'optical' methods from NIR to X-ray

- Spectr. Ellipsometry / Mueller
- DUV Scatterometry
- EUV SAS
- GISAXS

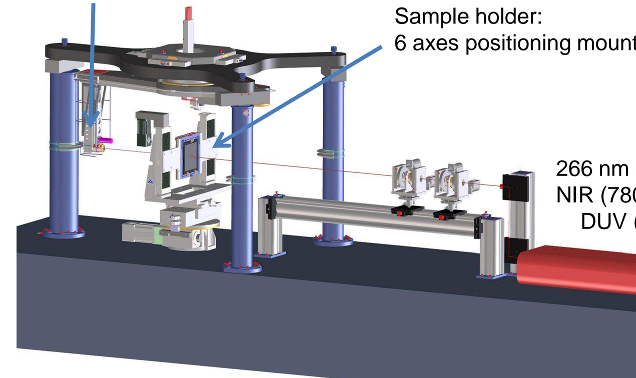
<u>Maxwell solver **JCMwave**:</u>
FEM allows to model arbitrary structures

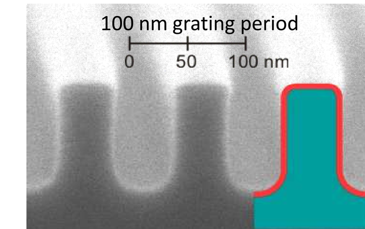
<u>Optimisation:</u>
global: *Particle Swarm* or *Differential Evolution*
local: gradient based

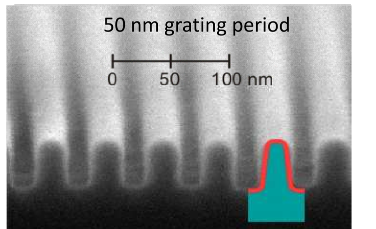


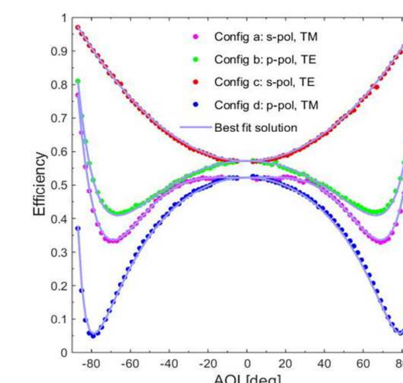
Calibration

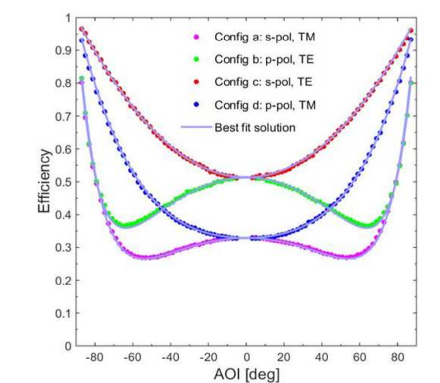
DUV goniometric scatterometer

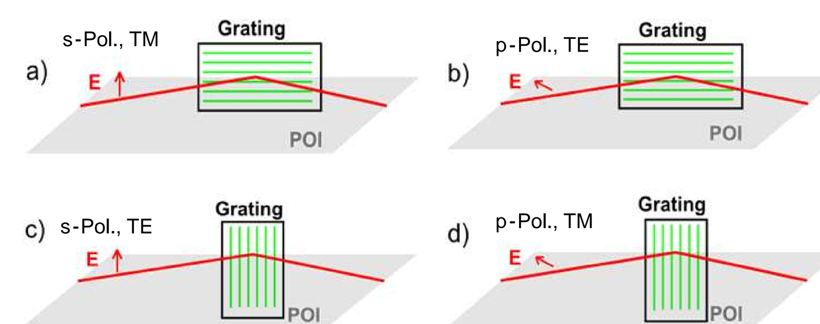






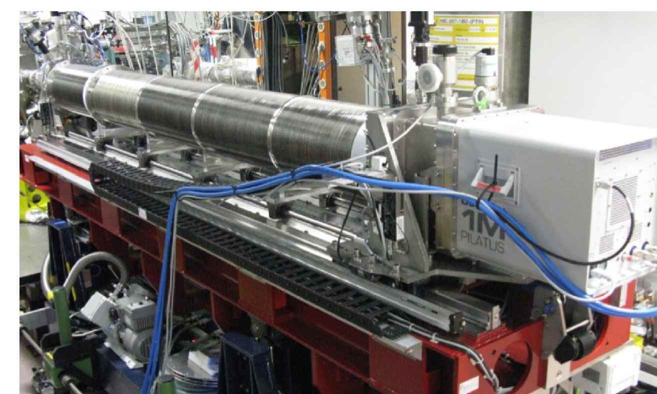




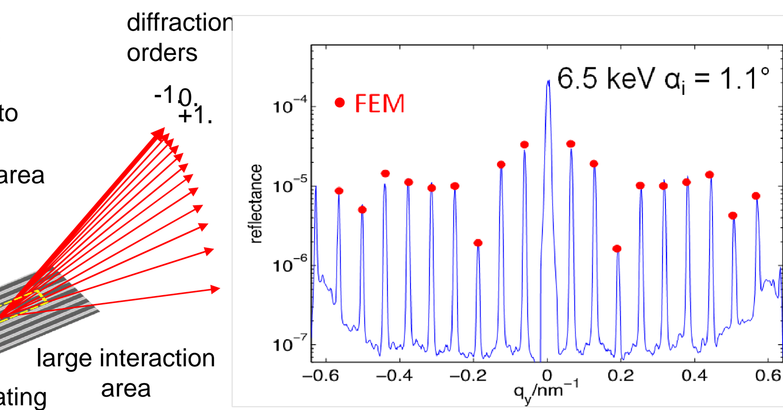


Left: four measurement configurations (polarization state and sample orientation) for sub-wavelength grating characterisation. Right: measured (dotted curves) and the fitted (line curves) reflectance of two samples with 100nm (left side) and 50 nm grating period (right side) versus angle of incidence (AOI) for these four configurations

Grazing Incidence Small Angle X-ray Scattering GISAXS: (1.7-10) keV



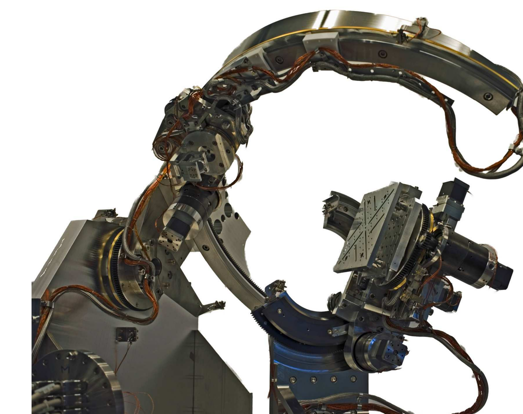
Scheme of GISAXS (EUV-SAS similar)
- Grating lines parallel to incoming beam
- Illuminated < grating area
- Circular shape: Ewald sphere section

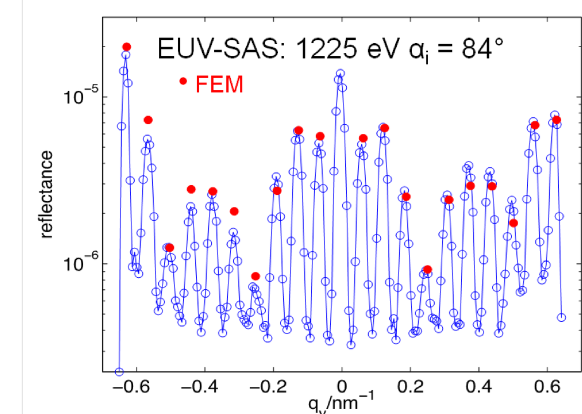


Soft X-ray reflectometry SX700 EUV-SAS: (50–1700) eV , (0.7-25) nm

X-ray-scattering (GISAXS & EUV-SAS) is sensitive to:

- Structure geometry (CD, SWA,..)
- LER/LWR, Surface and interlayer roughness
- Superstructures (e. g. stitching errors)





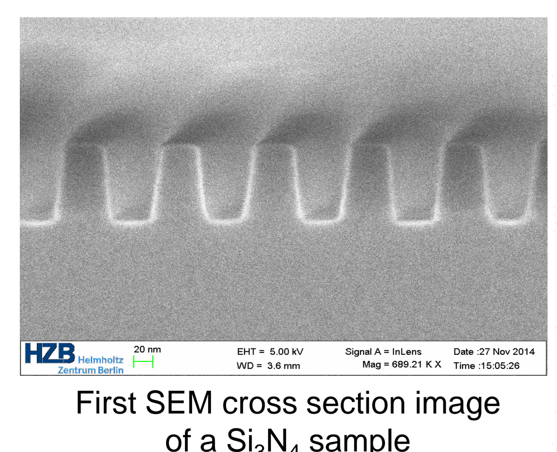
Additional calibrations:
- Spectroscopic ellipsometry / Mueller polarimetry
- Scanning electron microscopy (CD-SEM)
- Atomic force microscopy (CD-AFM)

First calibration results

	CD / nm	Height /nm	Side Wall angle/°	Corner Radius		Oxide Height /nm
				Top /nm	Bottom/nm	
GISAXS (6.5 keV)	25.1	48.2	87.7	4.2	13.8	-
DUV-Scatt. (266 nm)	24.8	51.7	84.4	4.5	9.5	5.0
EUV-SAS (~ 1.3 keV)	23.3	48.9	88.6	6.4	11.6	4.7
GISAXS (6.5 keV)	55.0	102.1	82.9	5.7	14.0	-
DUV-Scatt. (266 nm)	53.4	101.2	90.0	8.0	20.5	5.3
EUV-SAS (~ 1.3 keV), (84°, 86°)	53.6 55.5	100.8 101.4	87.6 88.2	2.9 6.0	15.8 15.9	8.7 9.3

Discussion and Outlook

- Process and design for high quality scatterometry standards developed
- Characterisation confirms good quality for edge roughness and angles
- Calibration of first Si-samples currently performed with reasonable agreement. For final calibration combined data analysis including AFM, SEM and ellipsometry data will be applied
- First Si_3N_4 samples have been manufactured and are currently characterised
- Calibration service will be offered in the future



First SEM cross section image of a Si_3N_4 sample

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