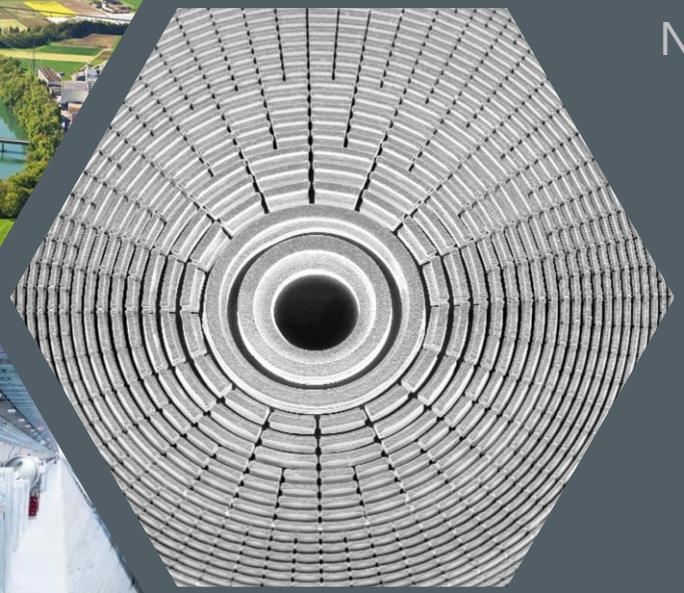
PAUL SCHERRER INSTITUT

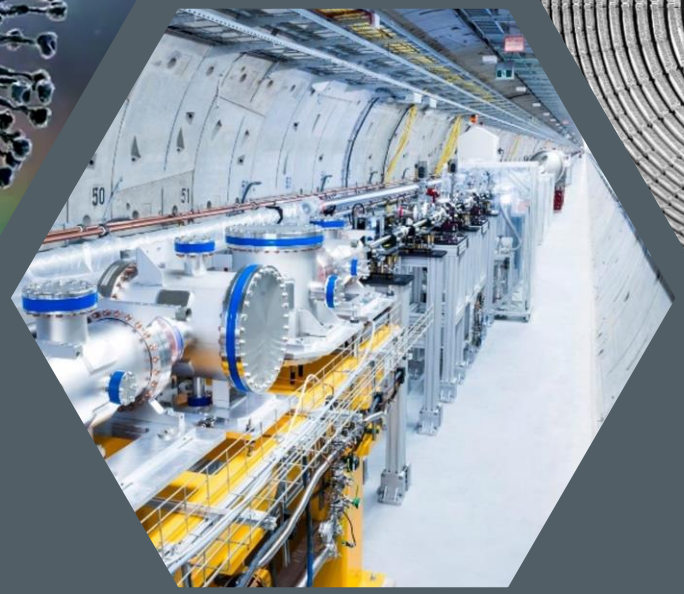
PSI

SPINOFF

XRnanotech

Diffractive optics with Swiss precision





Nanostructured diffractive optics for high-energy laser applications

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30.03.2021

RhySearch
Das Forschungs- und Innovationszentrum Rheintal

SWISS PHOTONICS

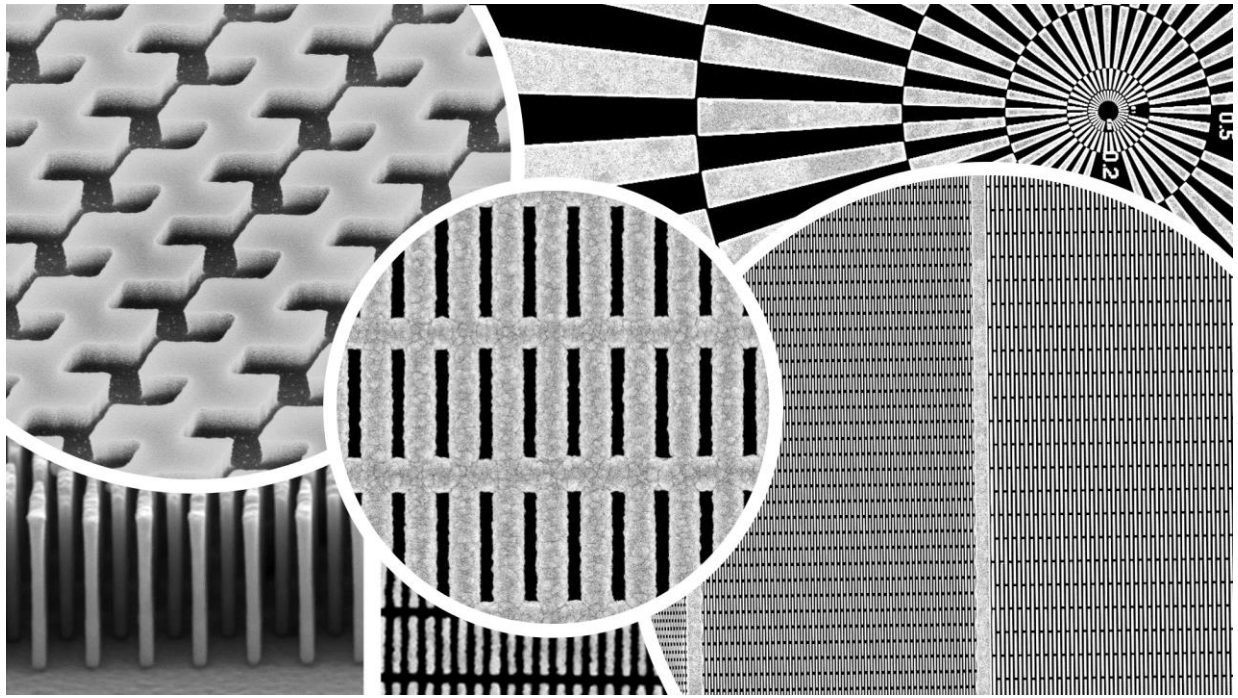
A Spin-off from the Paul Scherrer Institut (PSI)

Company
Purpose

XRnanotech

Diffractive optics with Swiss precision

"We enable high-tech customers all over the world to gain unprecedented insights by offering breakthrough innovations for X-ray optics based on our competence in nanofabrication and design."



Intro

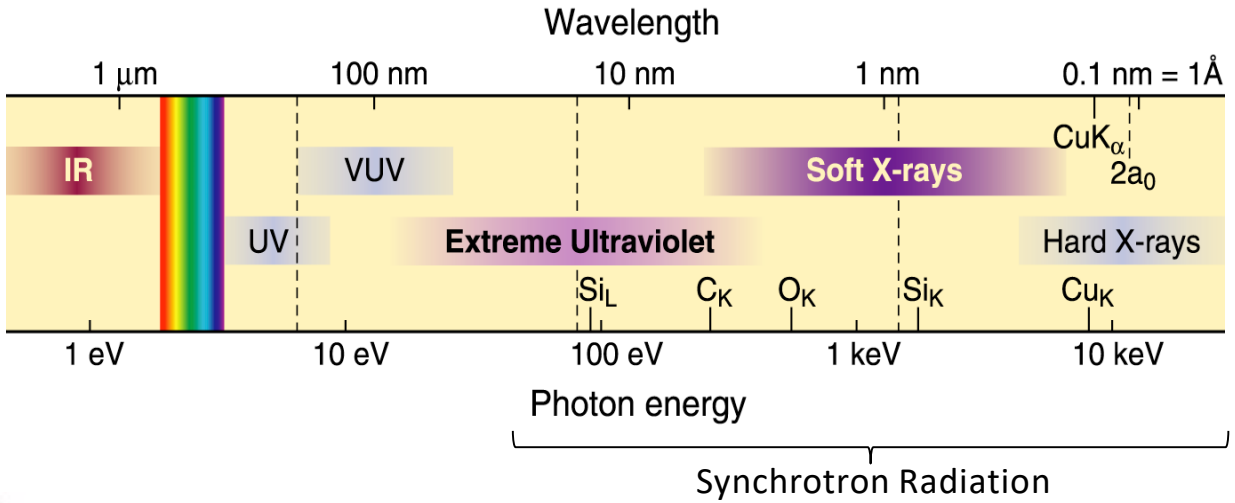
Diffractive optical elements with feature sizes down to the single digit nano-meter range have strong advantages for X-ray applications.

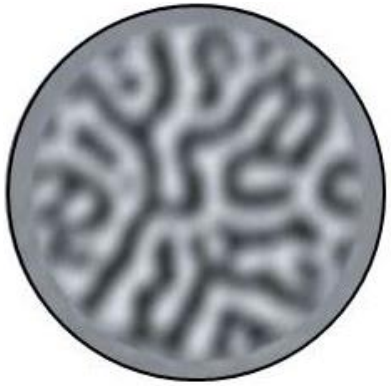
Diffractive optical elements (DOEs) with feature sizes down to the micro- and nanometer range are key components for systems and devices that require small dimensions, compactness and light weight.

Such optical elements consist of a complex pattern of micro- and **nano-scale structures**. They can modulate and transform light in a predetermined way and offer **unique optical functionalities**.

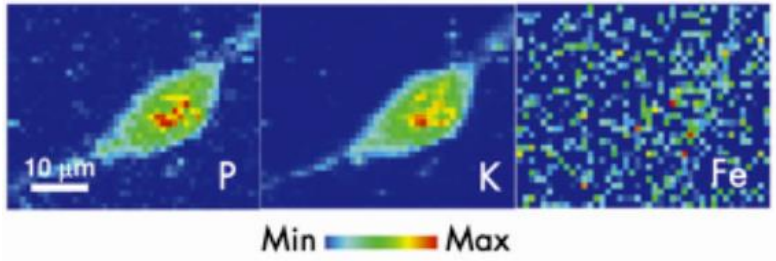
At **XRnanotech**, we offer expertise in the fabrication of DOEs and related micro- and nano-scale optical components. Our portfolio of elements allowing applications in the fields of imaging, spectroscopy, scattering etc.

X-rays span a wide spectrum and enable unique insights.

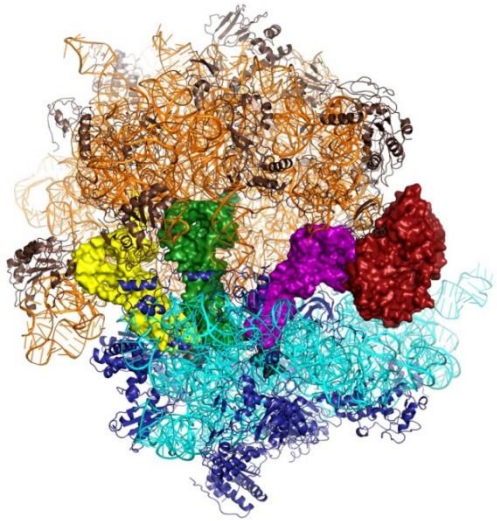




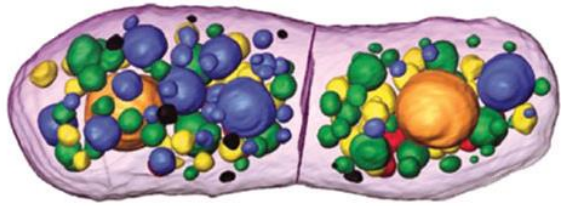
Holographic reconstruction of magnetic domains with 50 nm resolution (S. Eisebitt, Berlin)



X-ray fluorescence mapping (M. Cotte, ESRF, Grenoble)



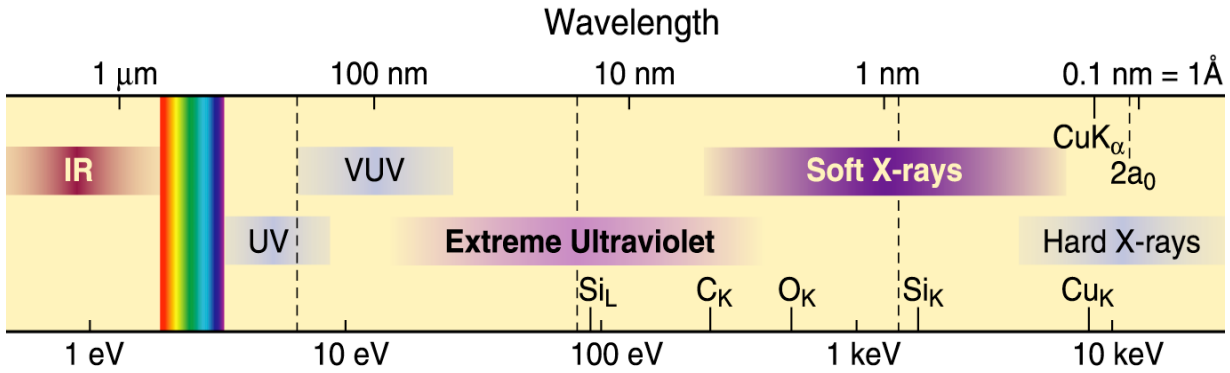
Structure of the ribosome solved by protein crystallography (M. Schmeing, Cambridge)



Tomographic rendering of a biological cell (C. Larabell, ALS, Berkeley)

X-rays

Enable high spatial, spectral, and temporal resolution

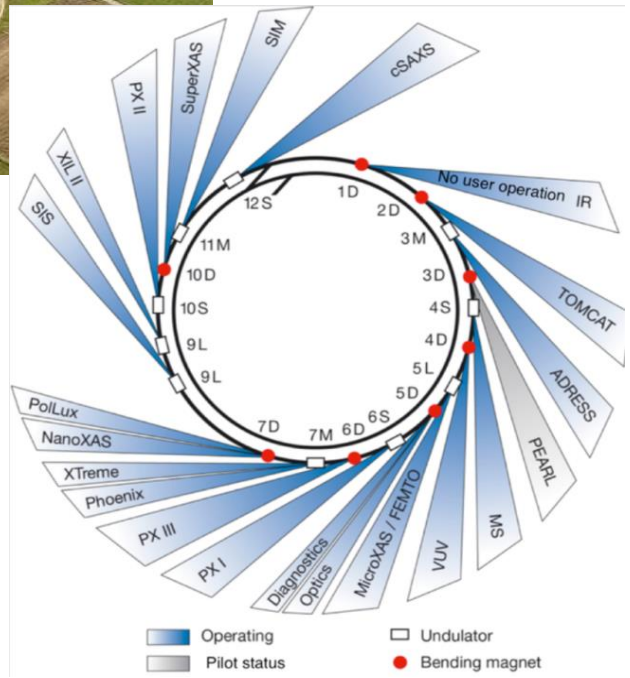


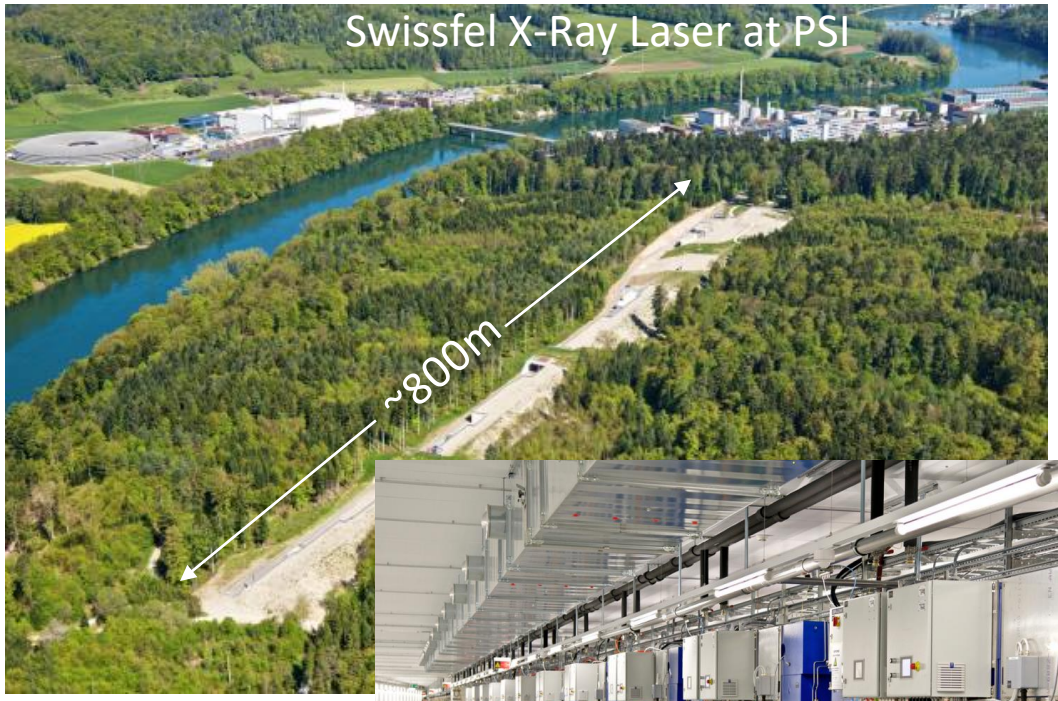
nature

Stopping the pandemic could rely on breakneck efforts to visualize SARS-CoV-2 proteins and use them to design drugs and vaccines.

Synchrotrons and X-ray Free Electron Lasers unlock an unprecedented brilliance.


Swiss Light Source at PSI






SwissFEL Aramis undulator

“Standard” glass lenses cannot be used for X-ray applications.

X-ray refractive index:

$$n = 1 - \delta + i\beta$$

with δ close to 0 and $\delta>0$

X-ray lenses:

- Weak refracting power: $f = R/2\delta$
- Lossy, especially for soft x-rays
- Resolution limited by shape errors
- Convex for focusing

X-ray optics

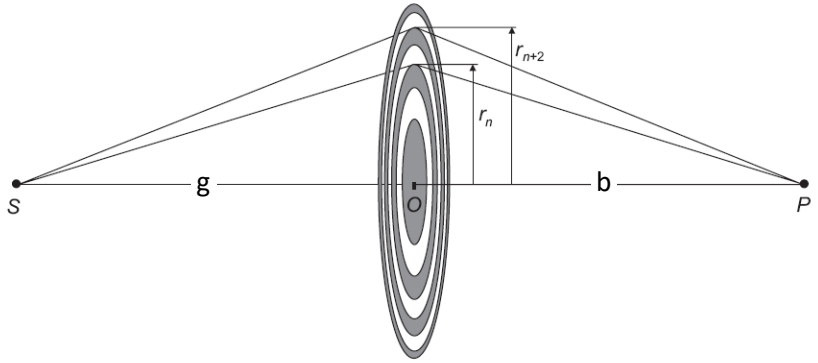
Diffractive optical elements with feature sizes down to the single digit nano-meter range have an outstanding resolution.

Spatial resolution depends on numerical aperture

=> depends on diffraction angle

=> depends on wavelength and outer zone width dr

Spatial resolution ≈ dr

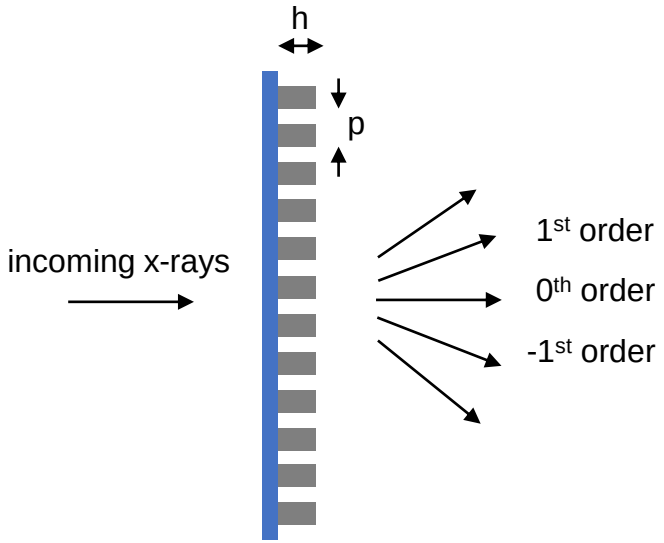


Several diffraction orders exist

=> **efficiency**
depends on phase shift

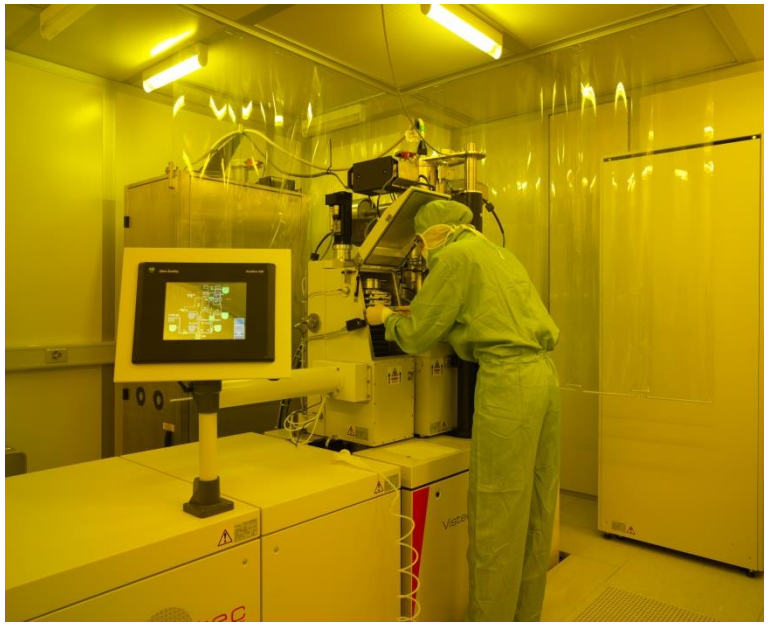
=> high structures are needed

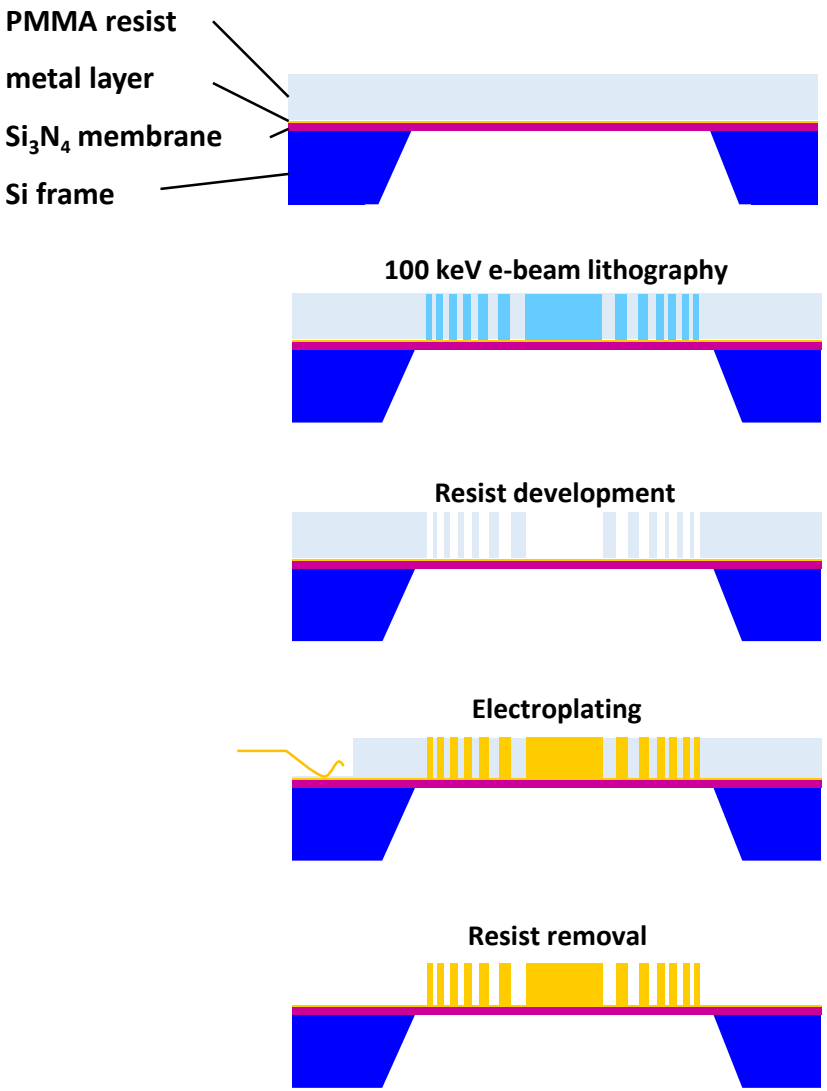
=> maximum for π phase shift and zero absorption: **40.4%**

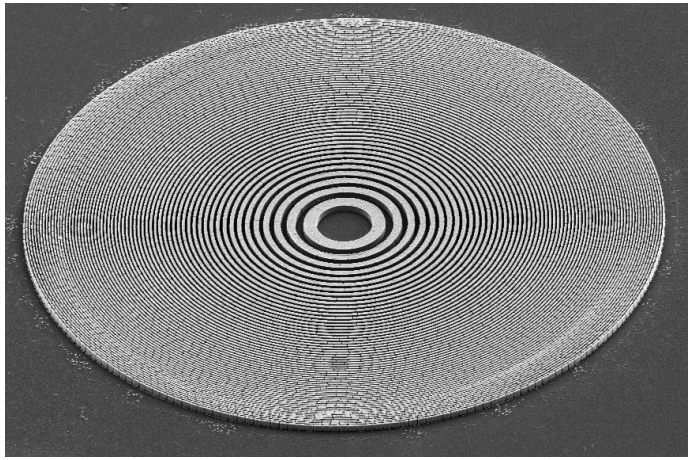


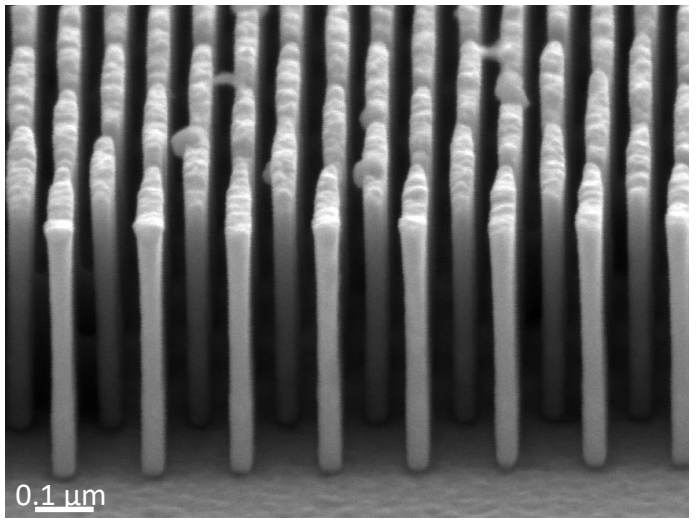
Electron beam nanolithography allows to fabricate high aspect-ratio nanostructures.

Electron beam nano-lithography









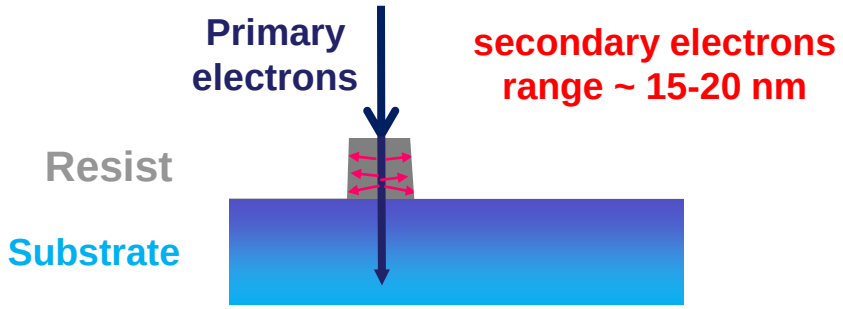
50 nm Au zone plate structures, 500 nm high

S. Gorelick, et al., *Nanotechnology* **21** (2010) 295303

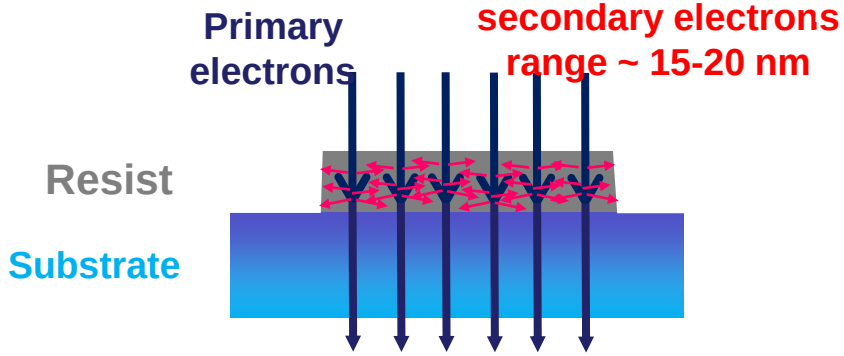
Problem

Secondary electrons in electron-beam exposures limit the smallest possible structure sizes.

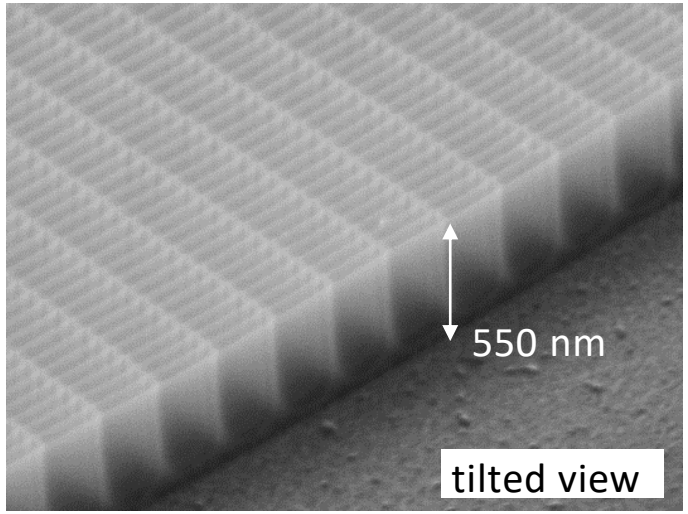
Isolated line exposure

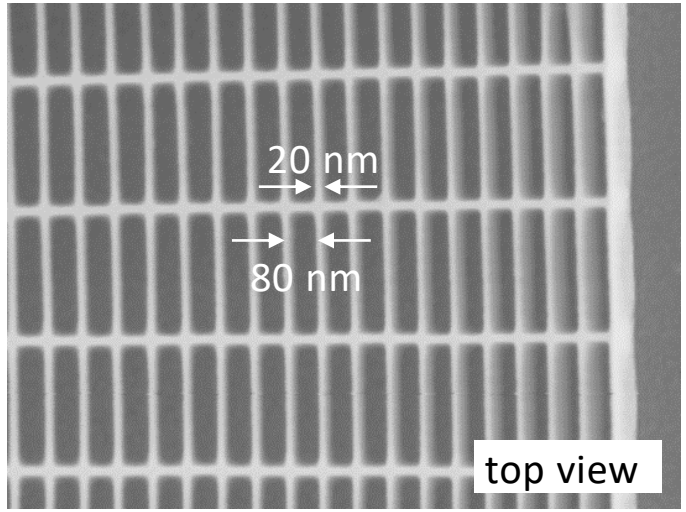


Dense line exposure



Fundamental limitation of e-beam lithography

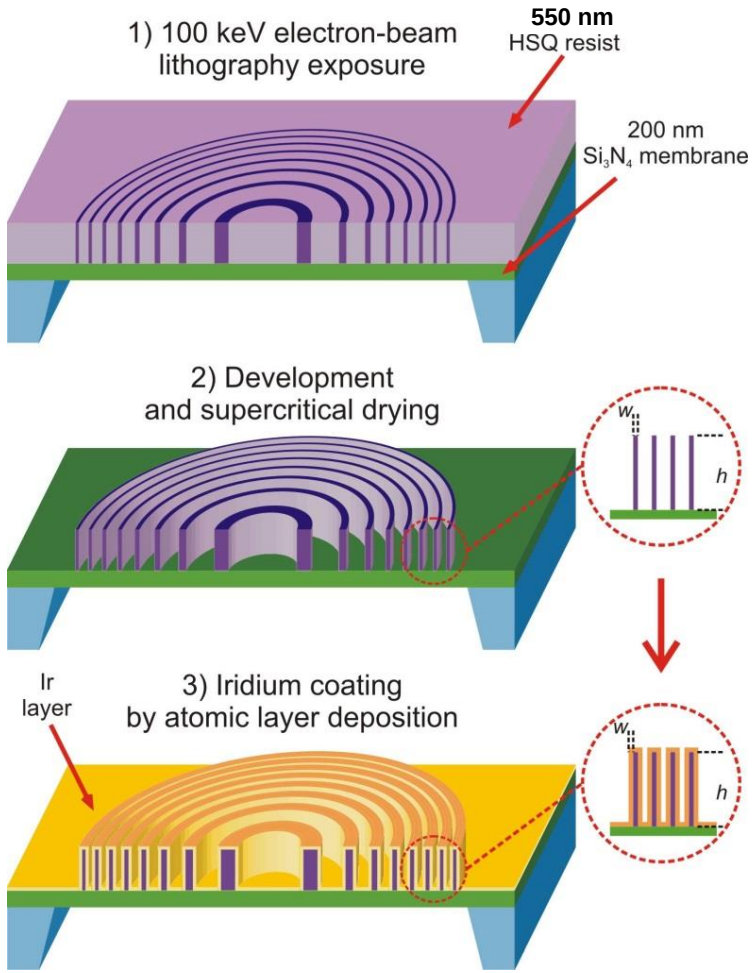


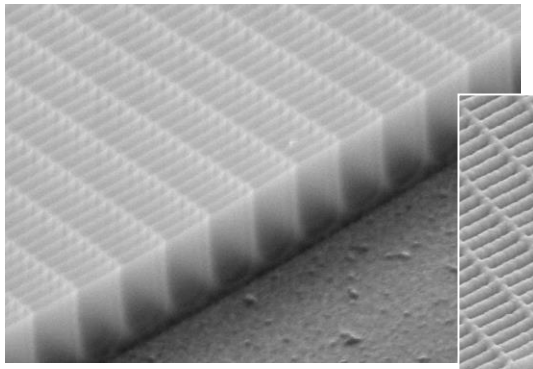


SEM image of HSQ resist lines,
20 nm wide, 80 nm pitch, 550 nm high

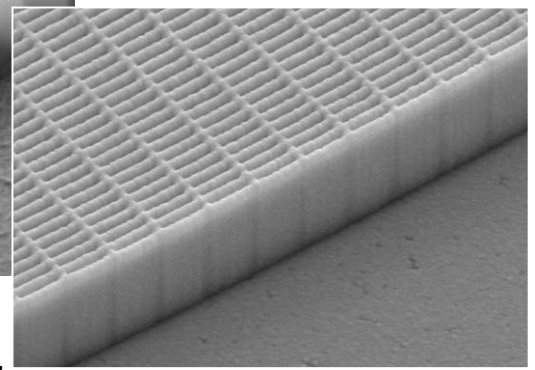
Solution

By coating a sparse template, this problem can be solved and the ultimate resolution can be unlocked.

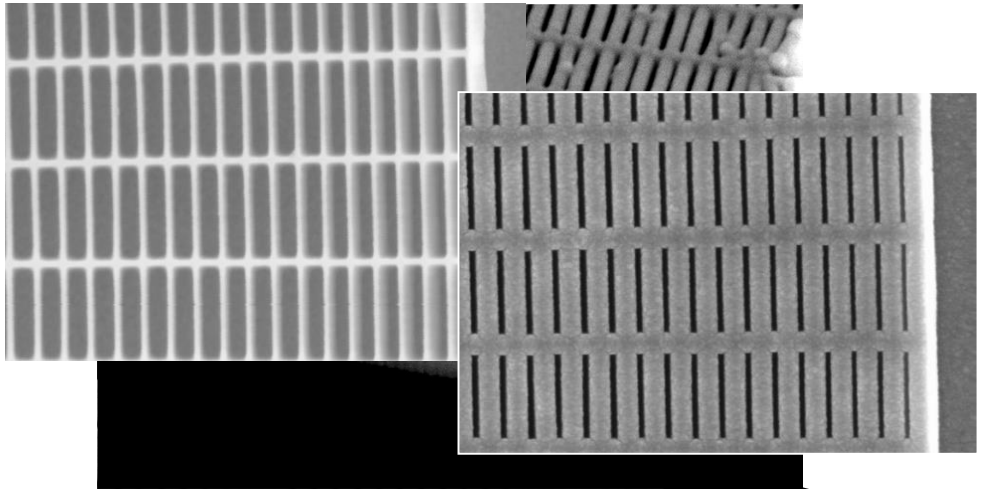




HSQ resist structures, 550 nm high, 20 nm wide, 80 nm period



After ALD coating with Iridium

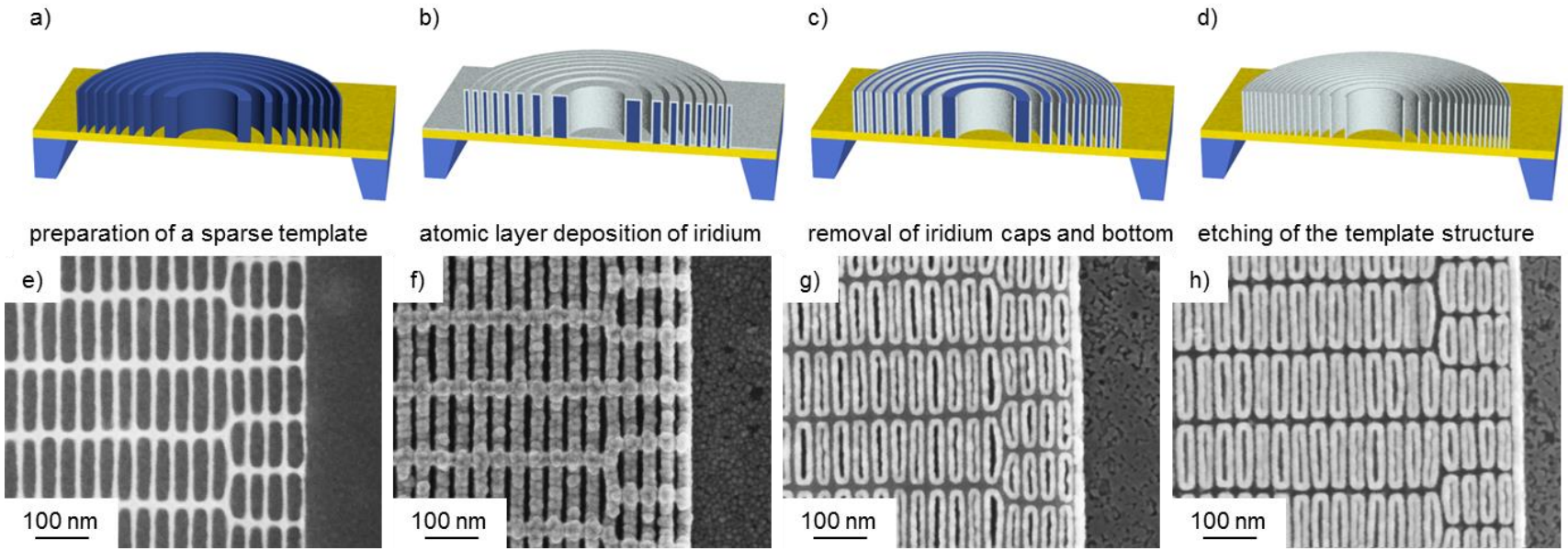


FIB cross-section of 20 nm wide, 550 nm high Iridium zone plate with 50 nm period

K. Jefimovs et al. *Phys. Rev. Lett.* **99** (2007) 264801; J. Vila-Comamala et al., *Ultramicroscopy* **109** (2009) p. 1360
J. Vila-Comamala et al., *Nanotechnology* **21** (2010) 285305; J. Vila-Comamala et al., *Optics Express* **19** (2011) 175

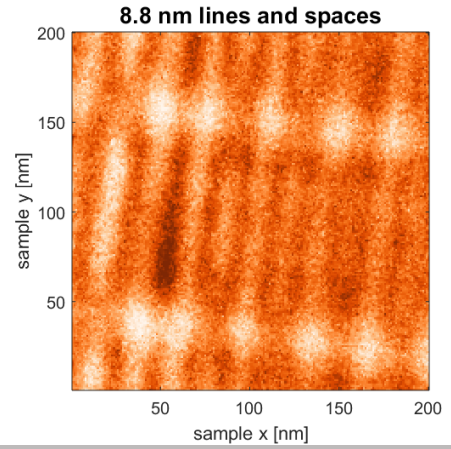
Application

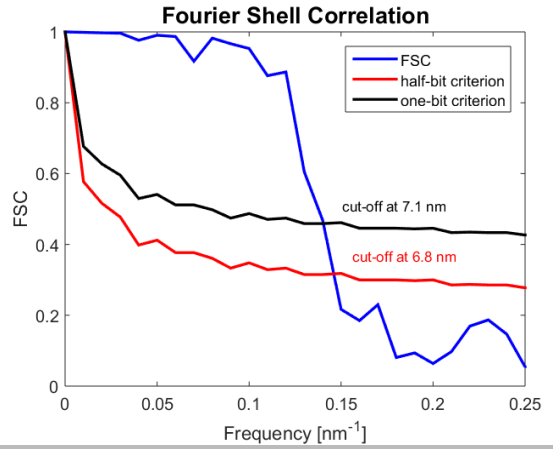
World-record in direct X-ray imaging



SEM images of line doubled soft x-ray Iridium zone plate with 8.8 nm outermost zone width

- SLS-Pollux at E = 700 eV
- Ir zone plate, 8.8 nm zone width, 70 nm zone height, 100 µm diameter, 500 µm focal length
- 8.8 nm lines/spaces resolved
- Fourier shell correlation gives ~ 7 nm



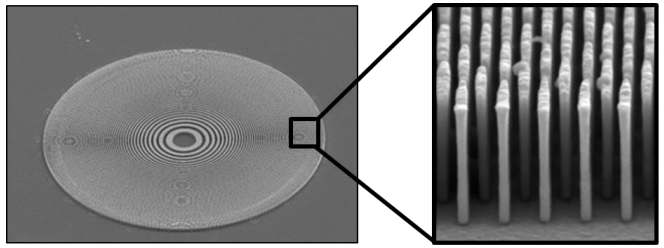


B. Rösner, et al., *Microelectron. Eng.* **191** (2018) p. 91–96

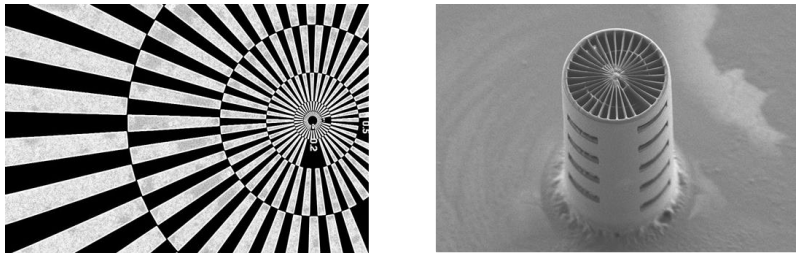
Products

XRnanotech offers various products based on nano-lithography.

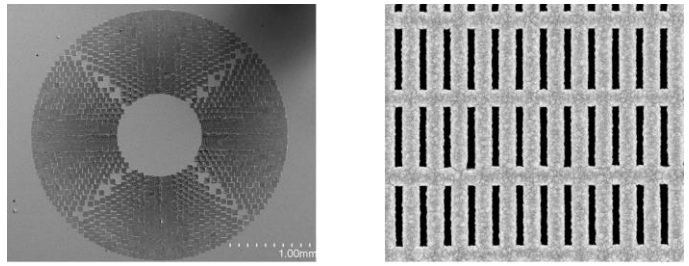
Fresnel lenses



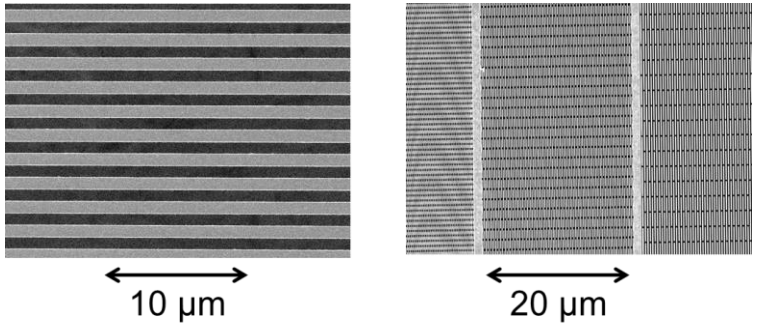
2D and 3D resolution test targets



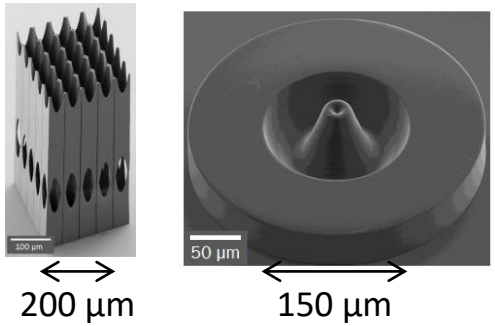
Beam-shapers



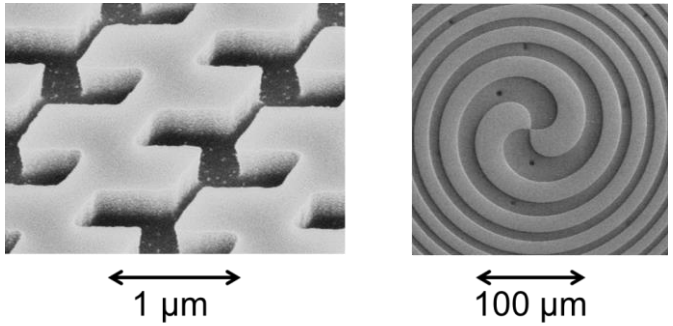
Gratings and beam splitters



3D nanostructures



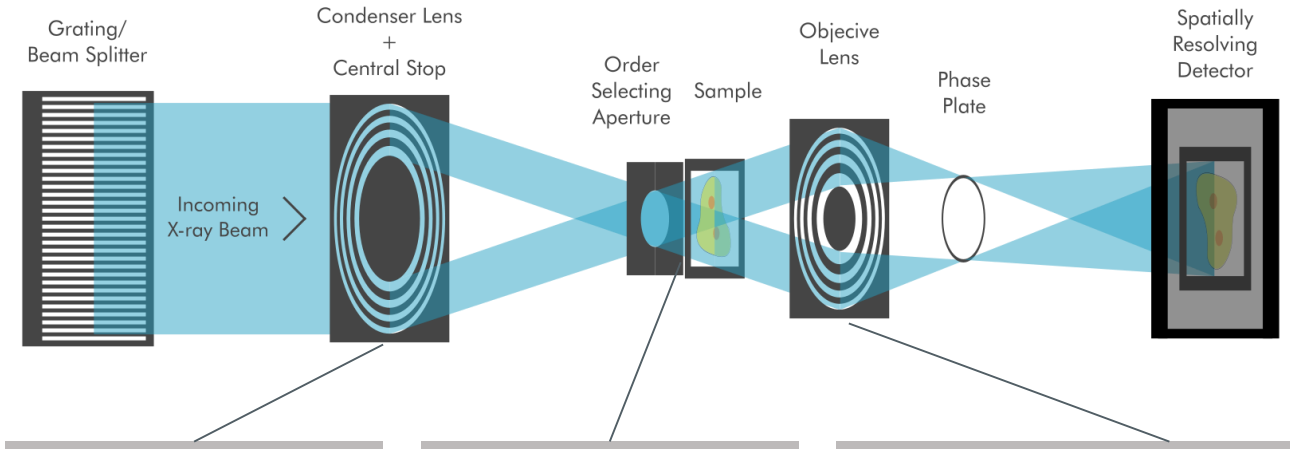
Custom design optics for advanced applications



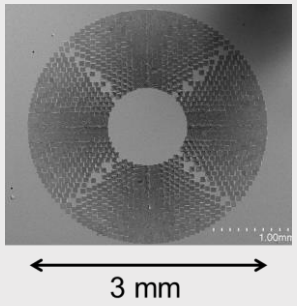
Applications

Our products enable applications in imaging, spectroscopy, scattering and beyond.

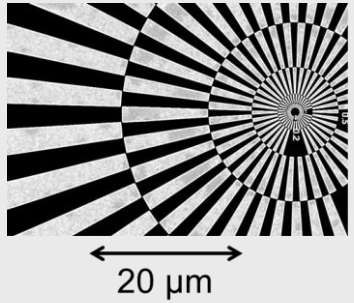
Imaging Optics



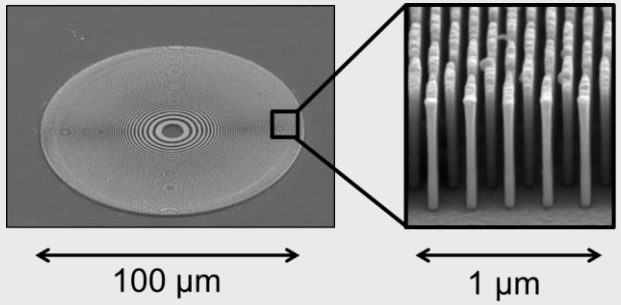
Condenser



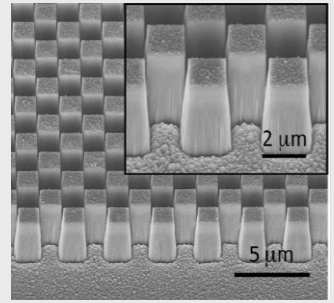
Test Sample

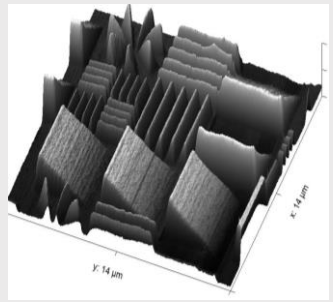


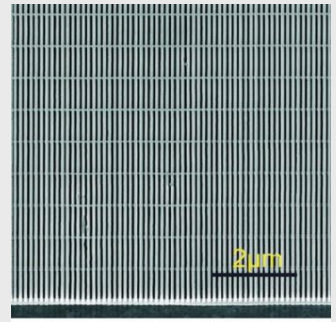
Objective Lens



Diffractive Optical Elements







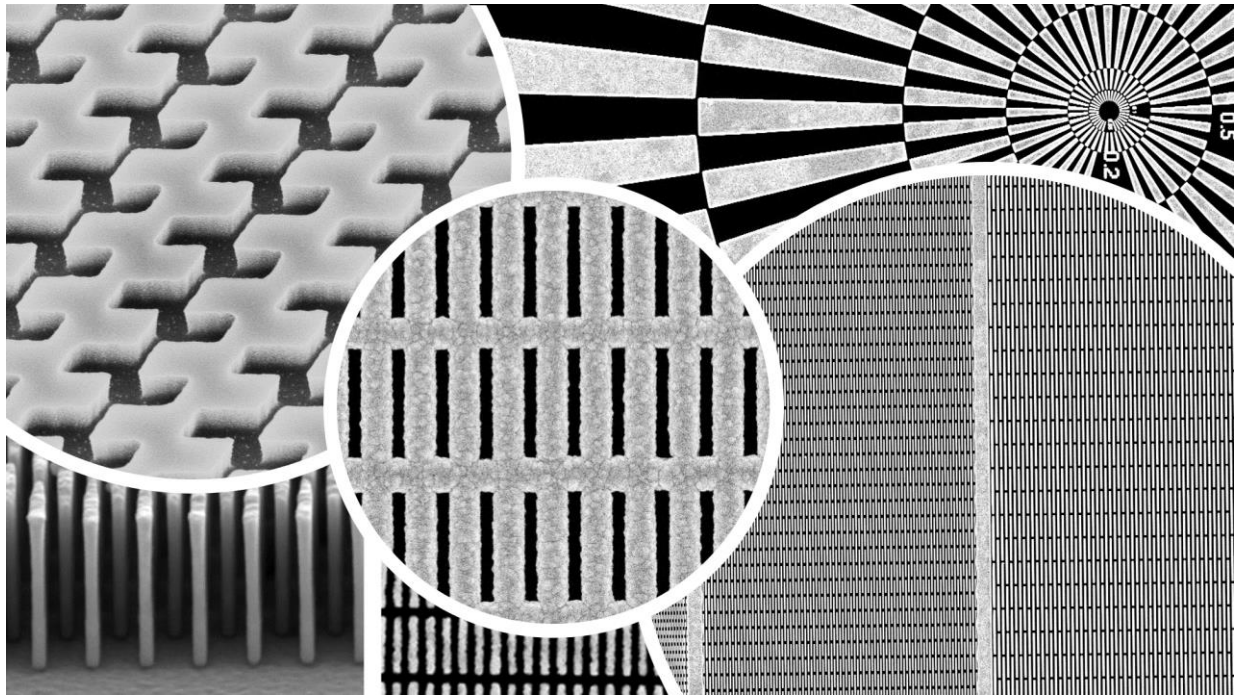
Next-Generation Nanostructured Diffractive Optics

Conclusion

A unique coating technology allows overcoming limitations of diffractive X-ray optics.

Diffractive X-ray optics are useful devices for high-resolution research

- Compact and easy to use
- Complex optical functionalities can be implemented
- Unique coating technology overcomes limitations of e-beam lithography
- Provide spatial resolutions below 10 nm level



Thanks

Thank you for your attention.