Extreme Ultraviolet Radiation: A Versatile Tool For Nanometrology

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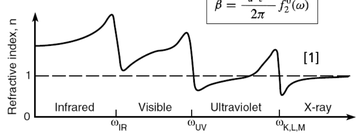
Abstract

Extreme ultraviolet and soft x-ray radiation (XUV, 1-50 nm, or EUV, at around 13.5 nm) enables a variety of new optical, analytical and imaging procedures. The distinct features of XUV light such as the short wavelength allow resolutions in the range of a few nanometers in printing or imaging. Its strong interaction with matter permits high elemental contrast and photochemical sensitivity. Taking into account the recent progress in the development of sources and optics, XUV applications in the semiconductor industry, thin-film technology, life- and material sciences are envisioned. Examples are the determination of element composition, layer thickness and surface roughness from grazing incidence reflectivity or defect characterization from scattered light measurements using EUV dark field microscopy. Relevant applications are, e.g., mapping of mask blanks for EUV lithography, which requires the ability to scan large surfaces for the presence of small printable defects as rapid as possible or the examination of ultra-thin gate oxides or interlayers.

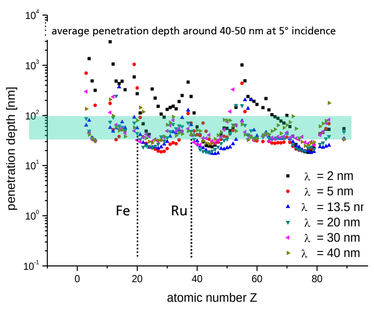
$n(\omega) = 1 - \delta + i\beta$

$\delta = \frac{n_a r_e \lambda^2}{2\pi} f_1^0(\omega)$

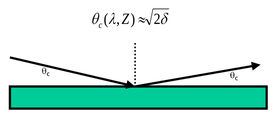
$\beta = \frac{n_a r_e \lambda^2}{2\pi} f_2^0(\omega)$

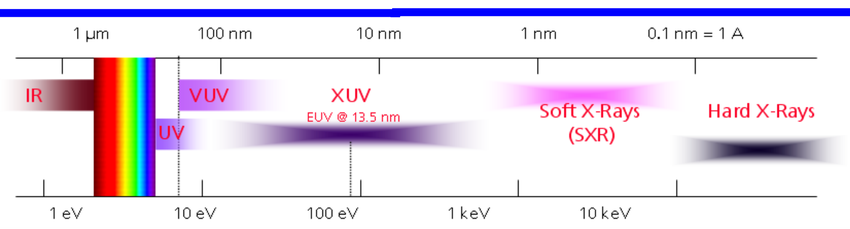


[1] D. Attwood, Soft X-Rays and Extreme Ultraviolet Radiation, Cambridge University Press, (1999)



- refractive index close to unity
- all materials highly absorptive
- low penetration depths into matter
- surfaces are strongly reflective for XUV under grazing incidence
- HV conditions necessary
- much higher grazing angles than for X-rays

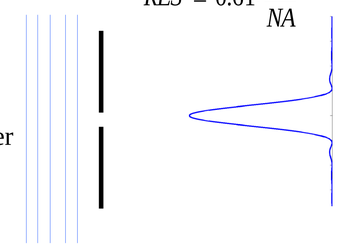


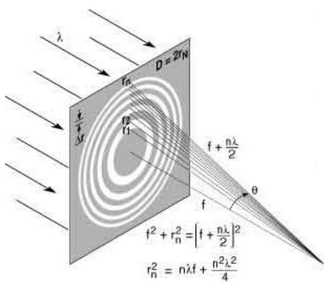


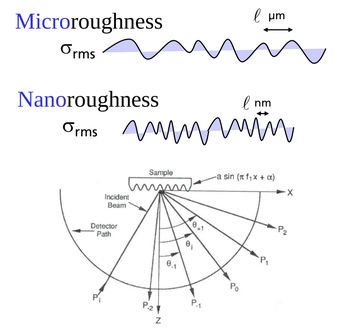
short wavelength	⟷	**good lateral resolution**	⟷	**microscopy, structuring**
strong interaction with matter	⟷	**short $L_{penetration}$**	⟷	**surface analysis, reflectometry**
ionizing radiation	⟷	**photochemical properties**	⟷	**lithography, spectroscopy**

- high lateral resolutions due to the short wavelength
- only diffractive or reflective optics can be used, e.g. multilayer mirrors, zone plates
- sensitivity to high frequency surface roughness

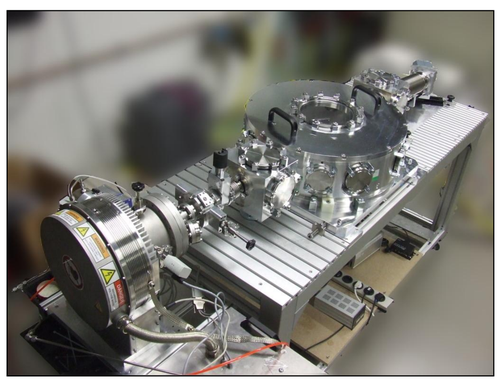
$RES = 0.61 \cdot \frac{\lambda}{NA}$



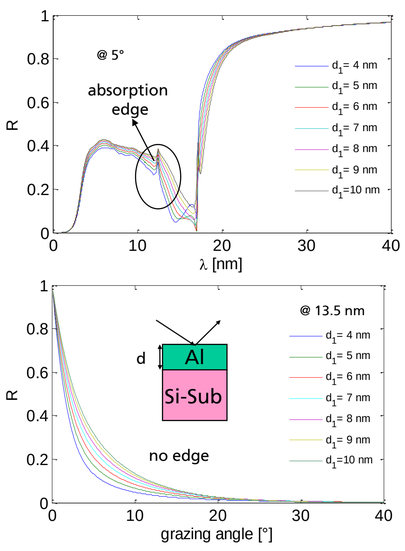


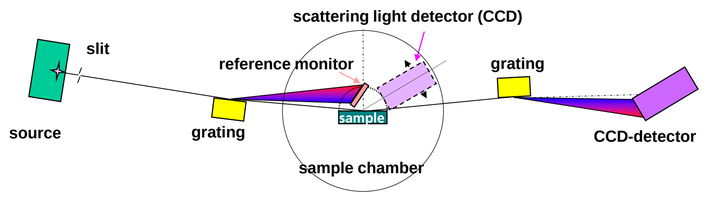


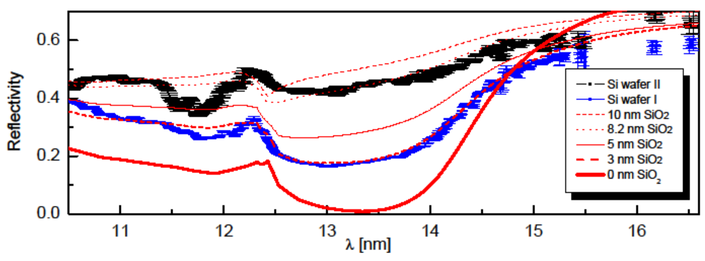
Reflectometry

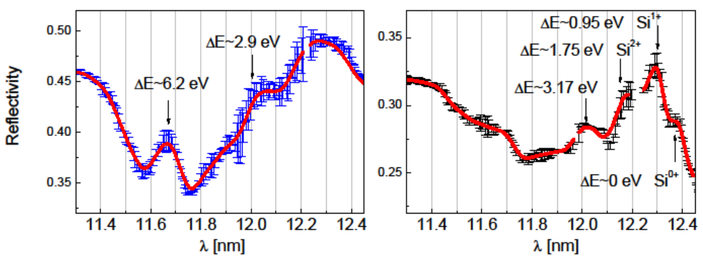


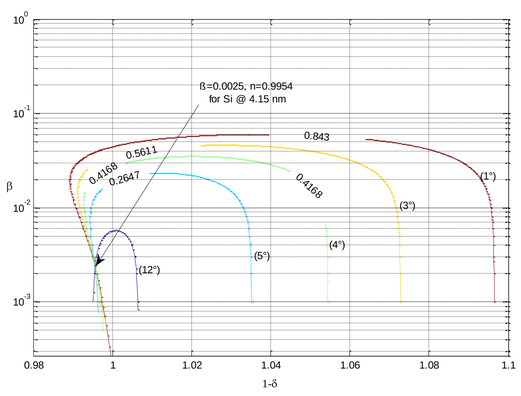
- reflectivity of a surface is measured as a function of wavelength at different fixed angles

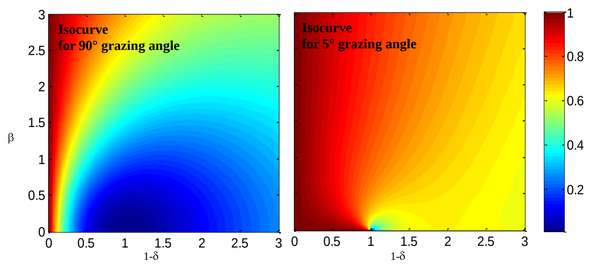








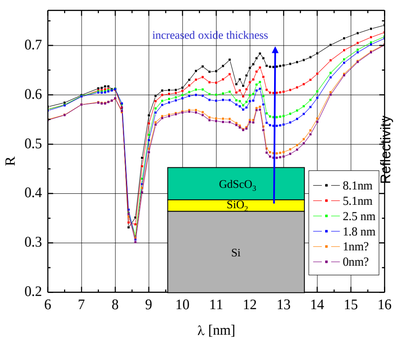


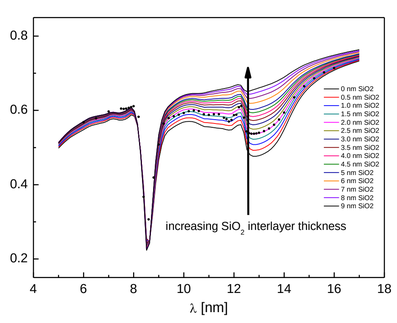


- surfaces are highly reflective for XUV under grazing incidence
- high surface sensitivity, thickness/roughness strong material dependence
- absorption edges of materials accessible, determination of n = 1–δ+*i*β
- Xe spectrum accesses Si fine structure at L-edge (12.4 nm)
- measuring times ~ms
- spectral analysis algorithms developed

- concept of isoreflectance curves allows determination δ and ß via measuring at several fixed angles

Extended applications





- analysis of ultra-thin interlayers, e.g. Si oxide interlayers
- Probing of unoccupied molecular orbitals
- „fingerprint“ method
- NEXAFS spectra obtainable in transmission and reflection

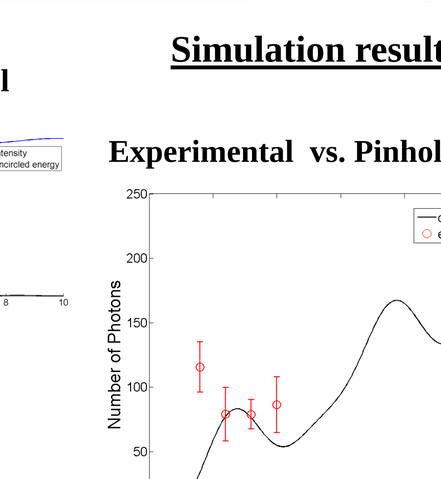
Microscopy

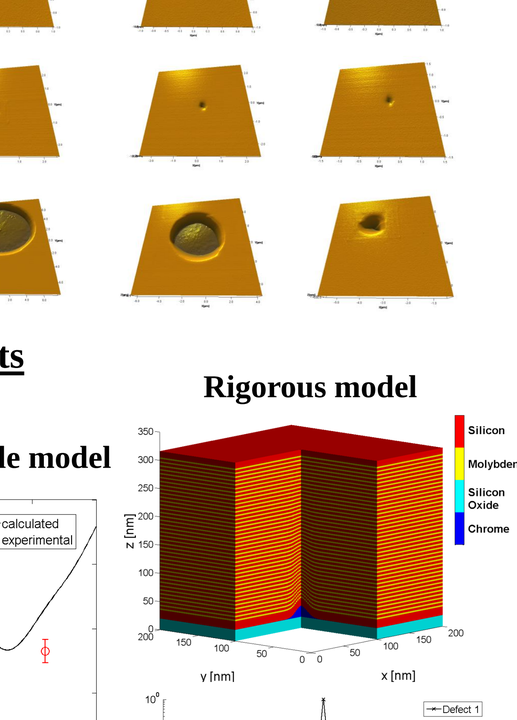
- at-wavelength metrology is mandatory for inspection of all printable defects on a mask
- compact EUV microscopes are usable for detection of all kind of defects in bright and dark field operation

DPP-Source:
- E_p=5 mJ / 2π sr into 2% b.w.
- frequency: 50 Hz

Objective:
- magnification: 21
- FOV: 650 µm

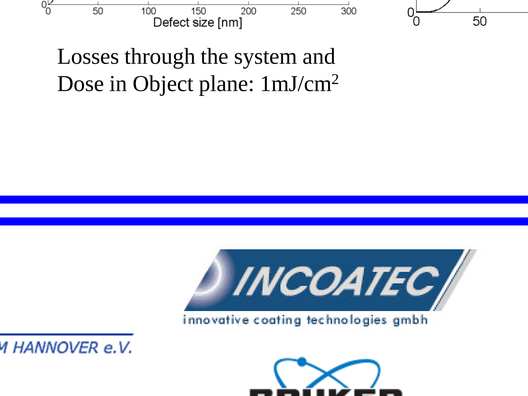
CCD:
- pixel size: 13 µm
- area: 1024^2 pixel
- 1.1 fps



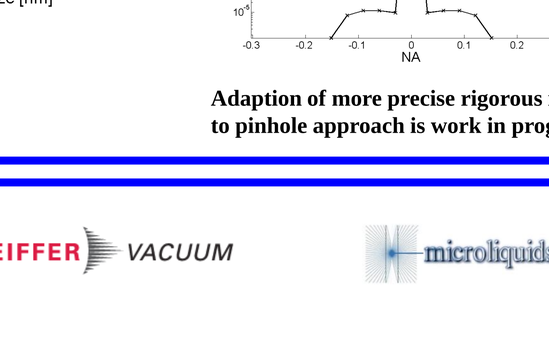


Experimental results

Pit structures on a multilayer



AFM analyis of the pits



Simulation results

Pinhole model

Losses through the system and Dose in Object plane: 1mJ/cm²

Experimental vs. Pinhole model

Rigorous model

Adaption of more precise rigorous model to pinhole approach is work in progress

Funding and project partners

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