Methoden moderner Röntgenphysik II: Streuung und Abbildung

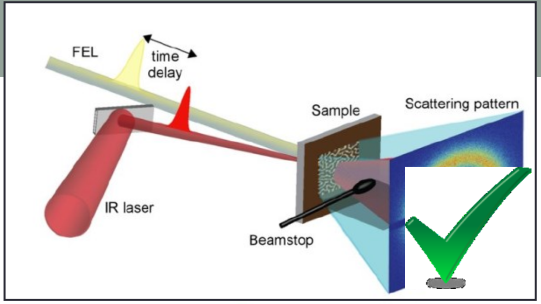
Lecture 20	Vorlesung zum Haupt- oder Masterstudiengang Physik, SoSe 2018 G. Grübel, A. Philippi-Kobs, O. Seeck, T. Schneider, L. Frenzel, M. Martins, W. Wurth		
Location	Lecture hall AP, Physics, Jungiusstraße		
Date	Tuesday	13:00 - 14:30	(starting 3.4.)
	Thursday	8:30 - 10:00	(until 12.7.)

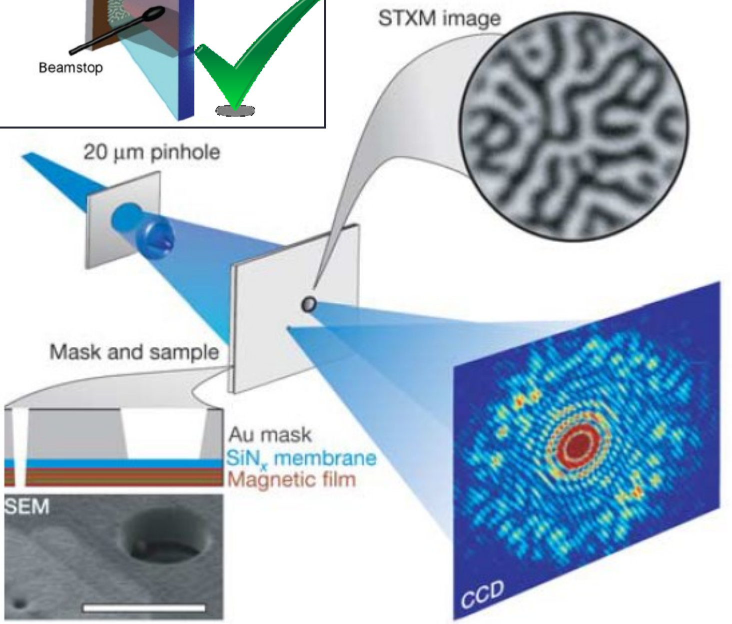
Outline

Part II/3:

Studies on Magnetic Nanostructures

by André Philippi-Kobs (AP)





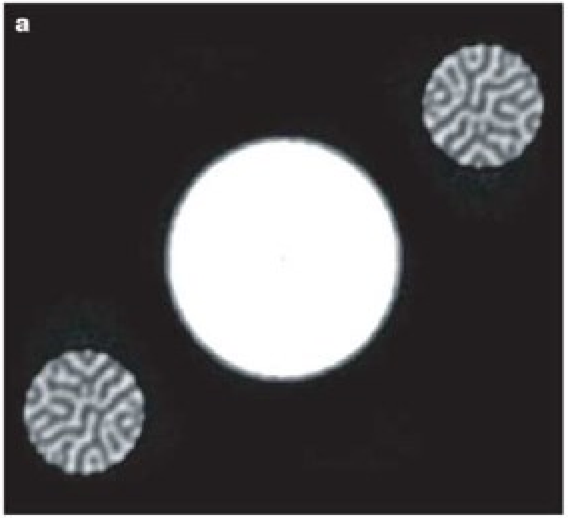
[26.6.] Imaging of Magnetic Domains

- **Fourier Transform Holography (FTH)**
- Scanning Transmission X-ray Microscopy (STXM)
- Coherent Diffraction Imaging (CDI)

Lensless imaging of magnetic nanostructures by X-ray spectro-holography

S. Eisebitt[1], J. Lüning[2], W. F. Schlotter[2,3], M. Lörgen[1], O. Hellwig[1,4], W. Eberhardt[1] & J. Stöhr[2]

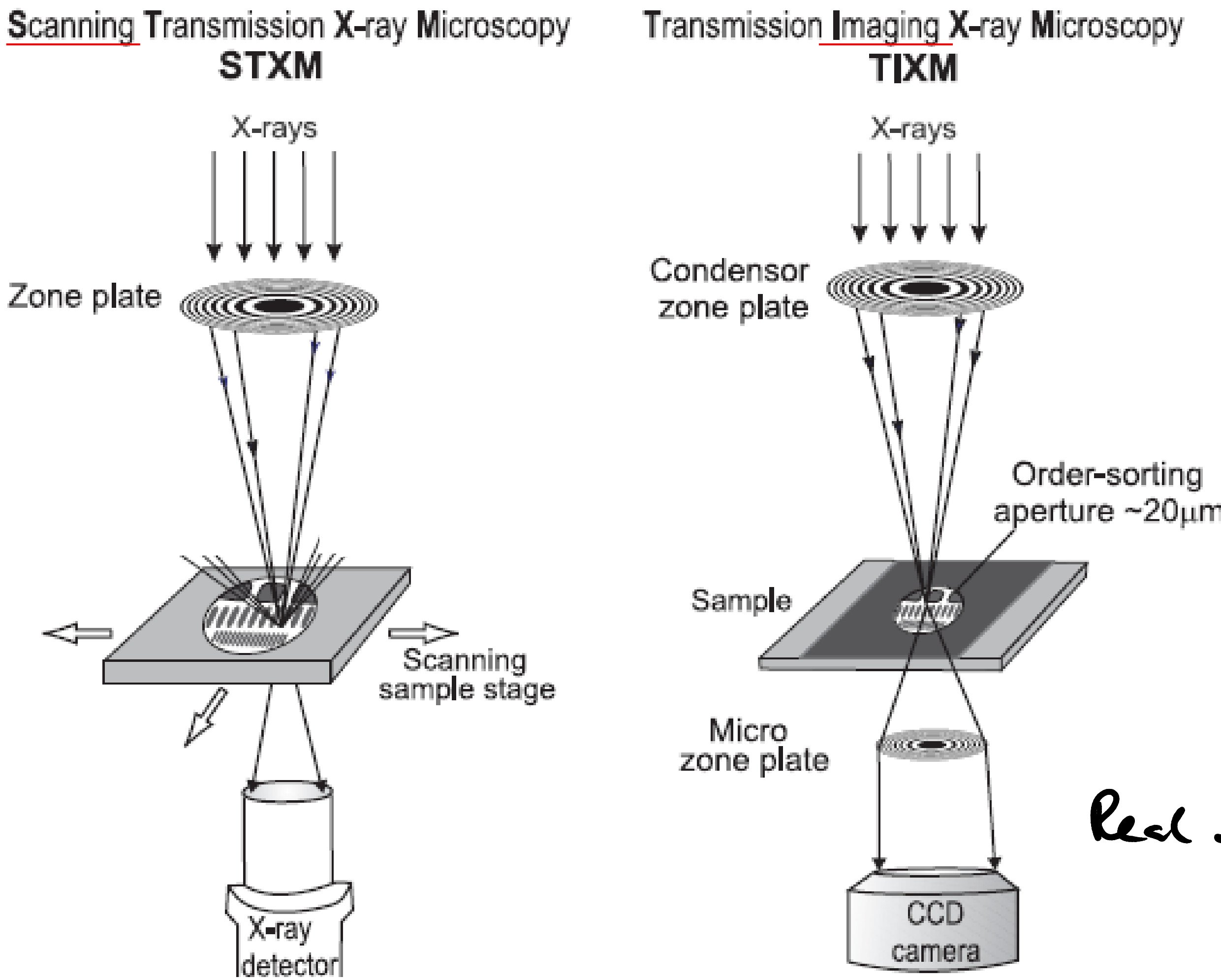
NATURE | VOL 432 | 16 DECEMBER 2004 |



FTH

Imaging of magnetic domain patterns with X-rays

> X-ray lenses based methods

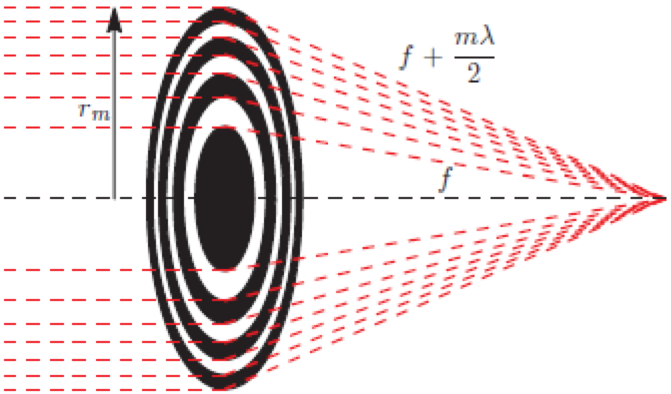


Real space image!

Imaging of magnetic domain patterns with X-rays

> X-ray lenses based method

Fresnel Zone plates:



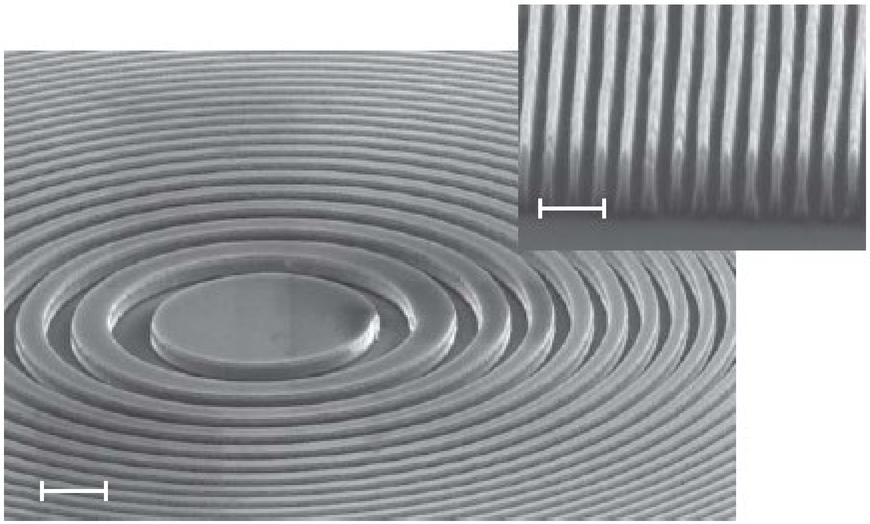
Condition for constructive interference at focus f:

$$r_m = \sqrt{m\lambda f + \frac{m^2\lambda^2}{4}} \approx \sqrt{m\lambda f}$$

Resolution Δx determined by width of outermost zone Δr_m:

$$\Delta x = 1.22\, \Delta r_m$$

$$\Delta r_m \gtrsim 10\,\text{nm nowadays}$$



disadvantages:
- High absorption
- Hard to fabricate

Imaging of magnetic domain patterns with X-rays

> X-ray lenses based method

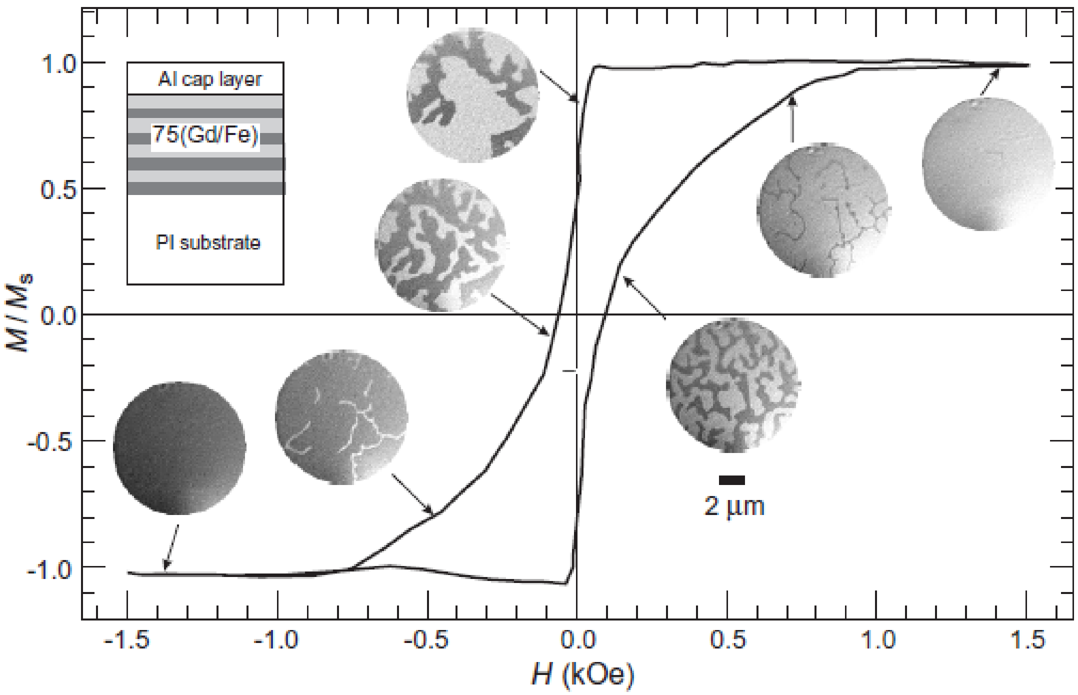


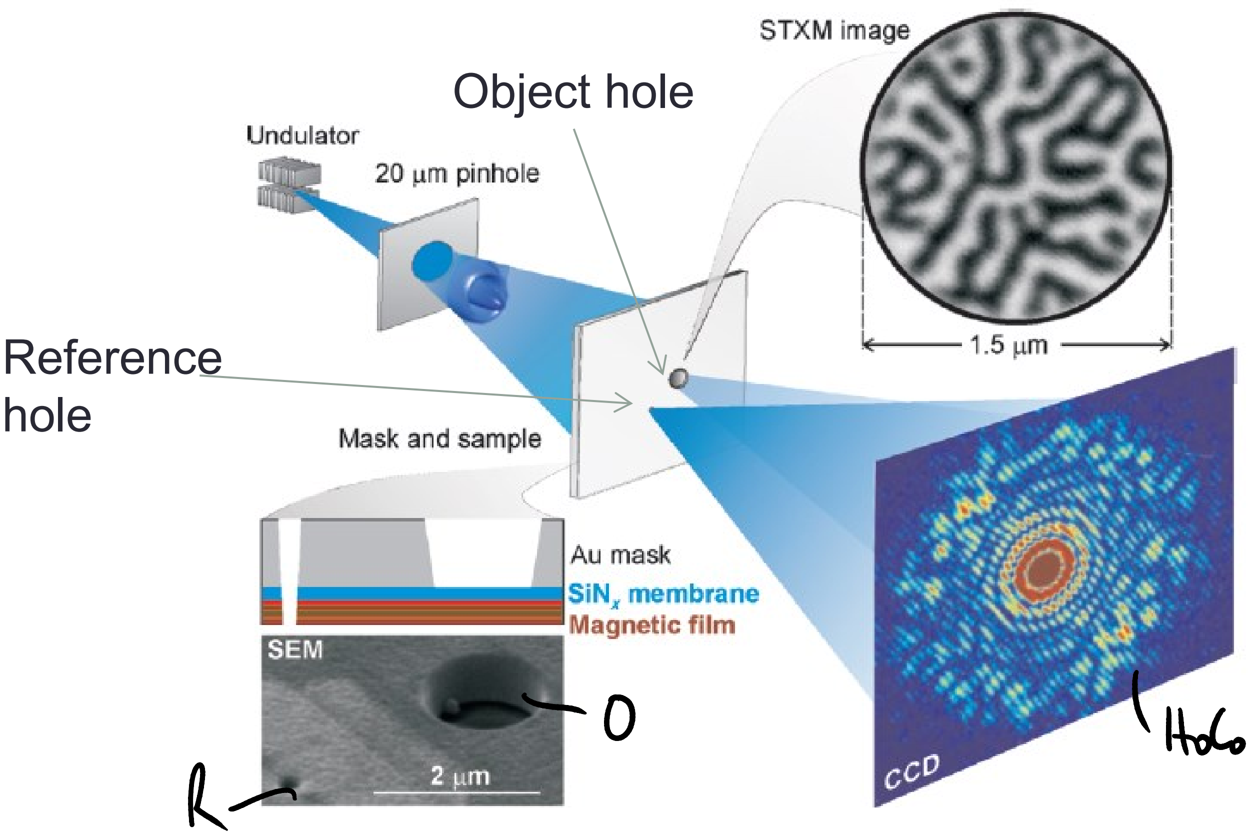
Fig. 10.22. TIXM images recorded at the FeL_3-edge as a function of applied field for a 75 × [Fe(4.1 Å)/Gd(4.5 Å)] multilayer deposited on polyimide and capped for protection with an Al layer [463, 482]

- Element-sensitivity
- Integration of gray values for each field value
  ➔ hysteresis

Imaging of magnetic domain patterns with X-rays

> Lensless Imaging – Fourier transform Holography

	Schlüsselelement-Herstellung		Bild-Rekonstruktion	
TXM	Zonenplatte	XXXXX	-direkt-	X
FTH	Optikmaske	XX	Einfache Fourier-Transformation	XX

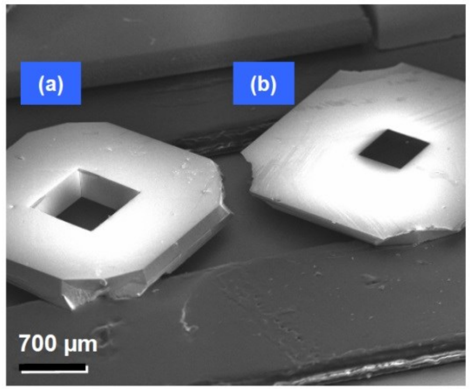


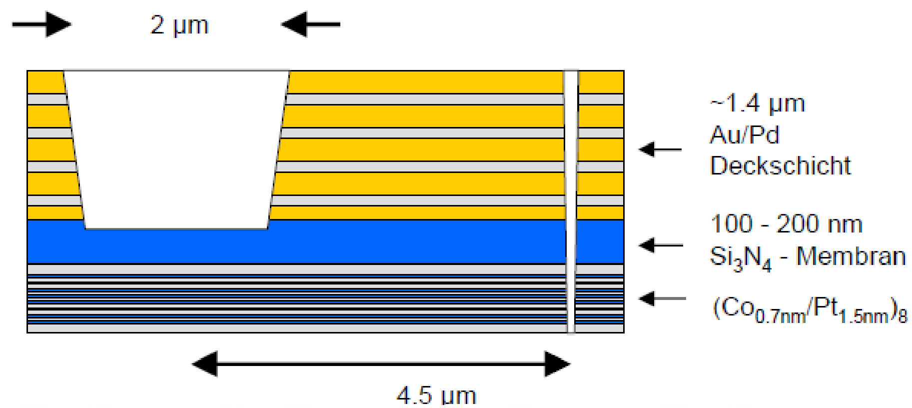
transverse coherence length > distance $\overline{OR}$.

Imaging of magnetic domain patterns with X-rays

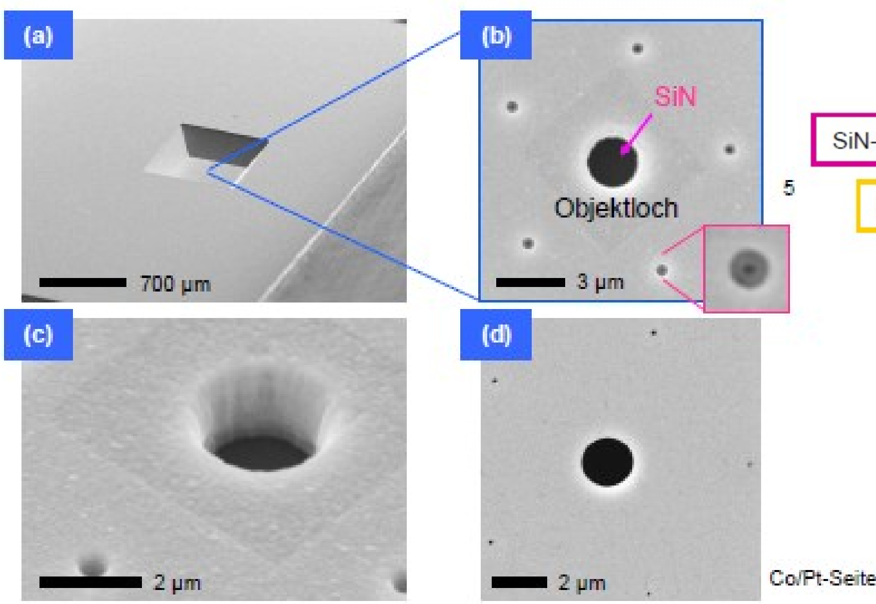
> Lensless Imaging – Fourier transform Holography

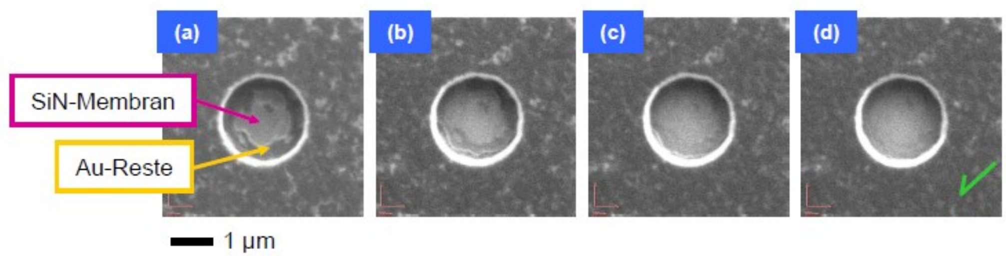
Mask and sample:

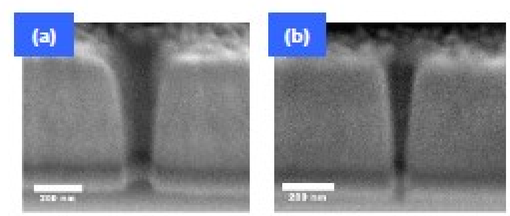




Preparation
by focused ion beam
technique







Imaging of magnetic domain patterns with X-rays

> Lensless Imaging – Fourier transform Holography (FTH)

$$\tilde{f}_j(\vec{Q}) = FT(f_j(\vec{r}))$$

Principle:

- Intensity on detector: $I(\vec{Q}) = \Big|\underbrace{\sum_j f_j(Q)\, e^{i\vec{Q}\cdot\vec{r}_j}}_{\tilde{f}_j(\vec{Q})}\Big|^2$

- Scattering factor for circularly polarized light and **M||L**$_{ph}$:

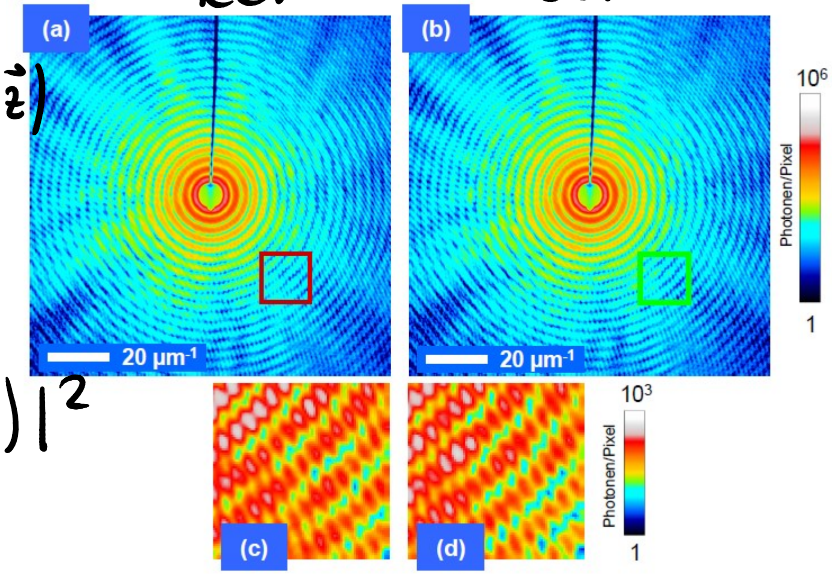
$$f = \hat{\varepsilon}\cdot\hat{\varepsilon}' F_c - i(\hat{\varepsilon}\times\hat{\varepsilon}')\cdot\hat{m} F^m$$

$$= f^c(\vec{Q}) \pm f^m_R(\vec{Q}) \quad \left(\begin{smallmatrix}+\text{RCP}\\ -\text{LCP}\end{smallmatrix} \text{ for } \hat{m} \parallel \hat{z}\right)$$

$$f^c(\vec{Q}) = f^c_0(\vec{Q}) + f^c_R(\vec{Q})$$

- "Hologram" (= $I(\mathbf{Q})$) with RCP and LCP

$$I(\vec{Q}) = |\tilde{f}^c_0(\vec{Q}) + \tilde{f}^c_R(\vec{Q}) \pm \tilde{f}^m_R(\vec{Q})|^2$$



phase change due to $\pm f^m_0(\vec{Q})$

Imaging of magnetic domain patterns with X-rays

> Lensless Imaging – Fourier transform Holography (FTH)

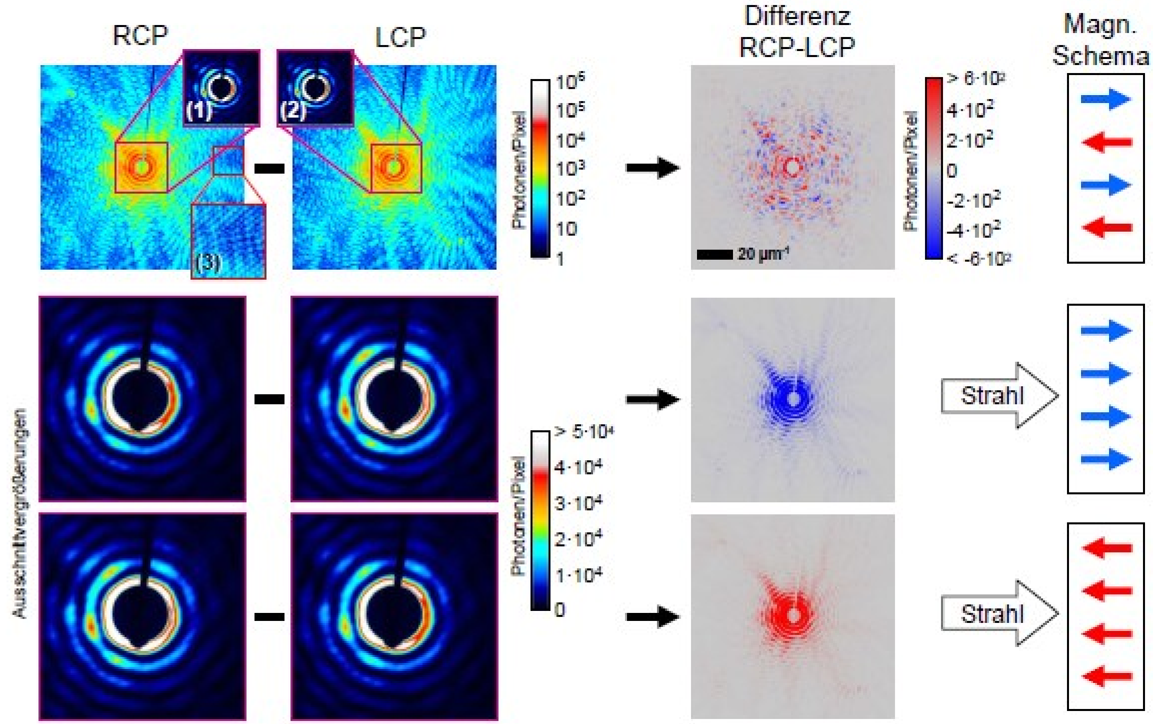
Principle:

- Difference hologram: $\Delta I(\vec{Q})$

$$= I^{+}(\vec{Q}) - I^{-}(\vec{Q})$$

$$= \tilde{f}_0^{m*} \cdot \tilde{f}_0^{c} + \tilde{f}_0^{m} \cdot \tilde{f}_0^{c*}$$

$$+ \tilde{f}_0^{m*} \tilde{f}_R^{c} + \tilde{f}_0^{m} \cdot \tilde{f}_R^{c*}$$



Imaging of magnetic domain patterns with X-rays

> Lensless Imaging – Fourier transform Holography (FTH)

Principle: Note: $FT^{-1}(\tilde{f}(\vec{Q})) = FT^{-1}FT(f(\vec{r})) = f(\vec{r})$

- Reconstruction = Fourier transformation: (inverse)

$$FT^{-1}(\Delta I(\vec{Q}))$$

$$= FT^{-1}(\tilde{f}_0^{\sim *}\cdot\tilde{f}_0^{c}) + FT(\tilde{f}_0^{\sim}\cdot\tilde{f}_0^{c*})$$

Autocorr.

(1) (2)

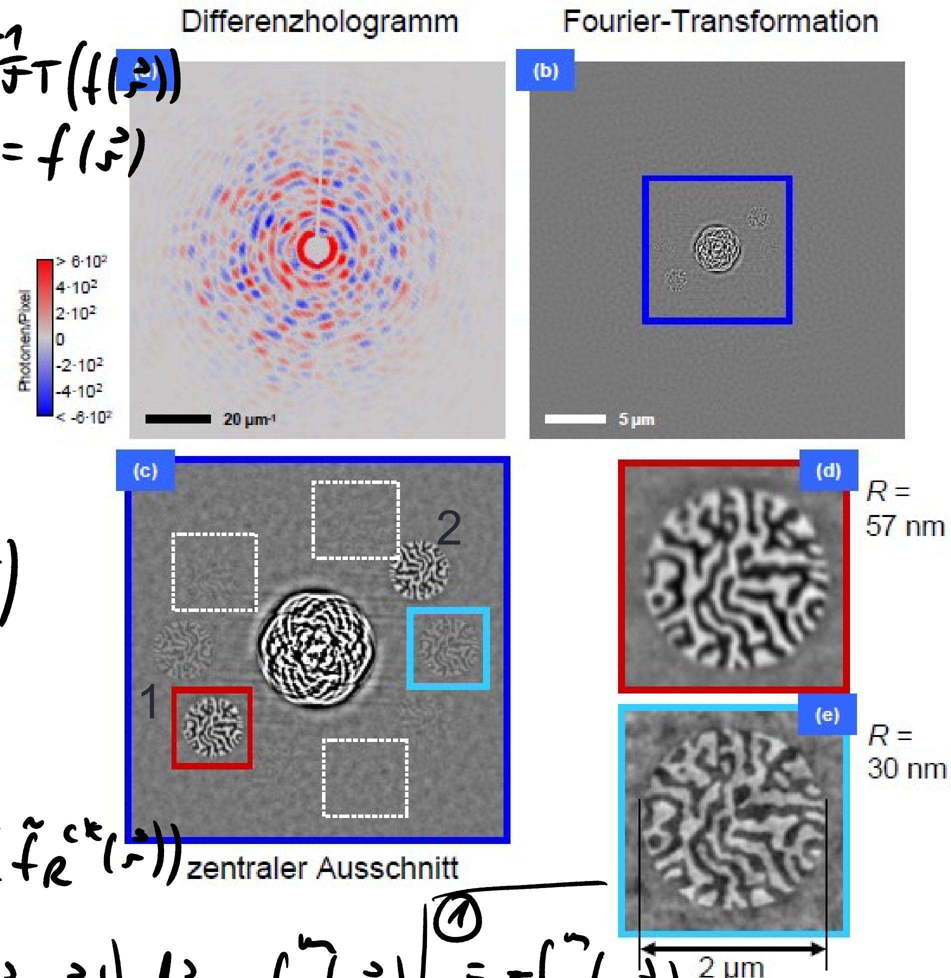
$$+ FT^{-1}(\tilde{f}_0^{\sim *}\cdot\tilde{f}_R^{c}) + FT(\tilde{f}_0^{\sim}\cdot\tilde{f}_R^{c*})$$

Reconstruction

(2) $= FT^{-1}(\tilde{f}_0^{\sim}) \otimes FT^{-1}(\tilde{f}_R^{c*})$

$= FT^{-1}FT(f_0^{\sim}(\vec{r})) \otimes FT^{-1}FT(\tilde{f}_R^{c*}(\vec{r}))$

$= f_0^{\sim}(\vec{r}) \otimes f_R^{c*}(\vec{r}) = \int_{-\infty}^{\infty} f_0(\vec{r}')\,\delta(\vec{r}-\vec{r}')\,d\vec{r}' = f_0(\vec{r})$ | (1) $= -f_0^{\sim}(-\vec{r})$

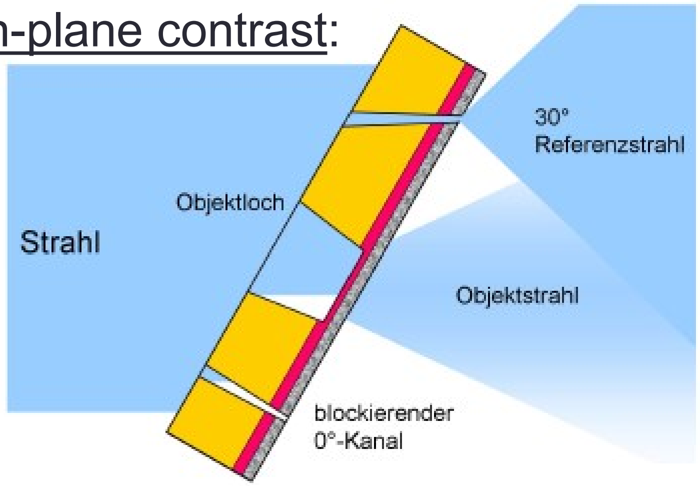


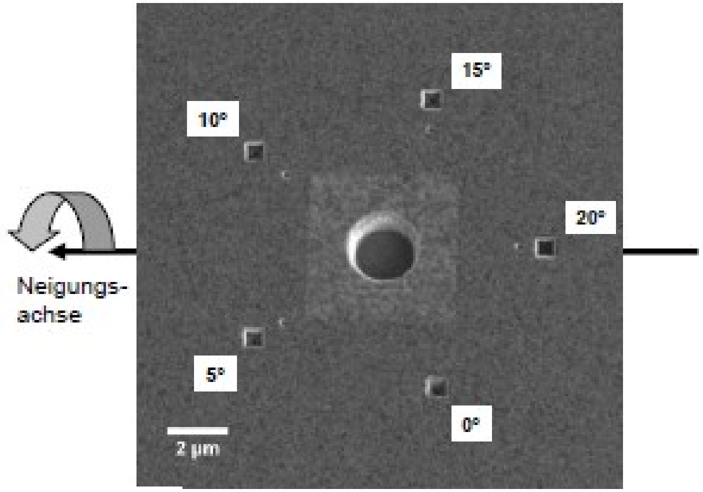
DESY

Imaging of magnetic domain patterns with X-rays

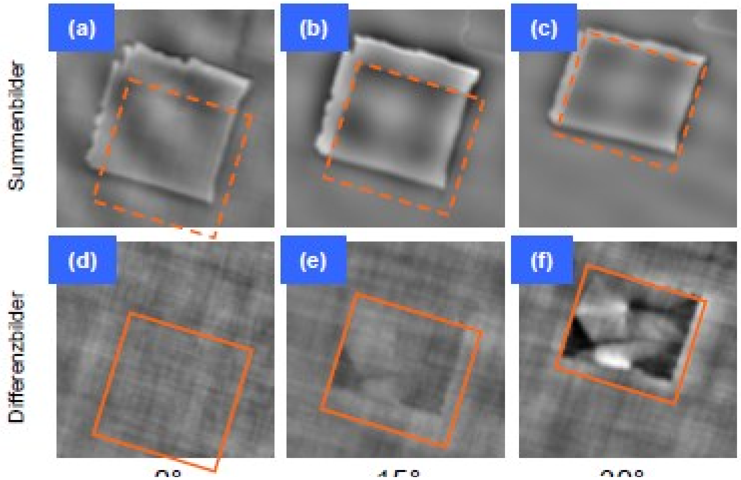
> Lensless Imaging – Fourier transform Holography (FTH)

In-plane contrast:





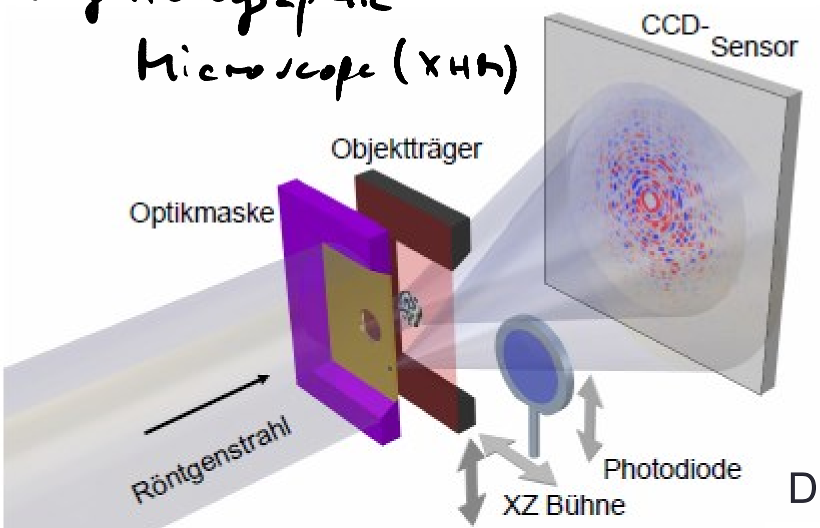
In-plane magnetized
20 nm thick Co film

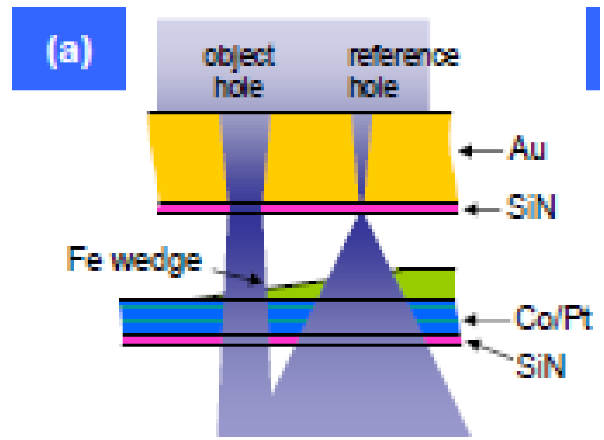


Imaging of magnetic domain patterns with X-rays

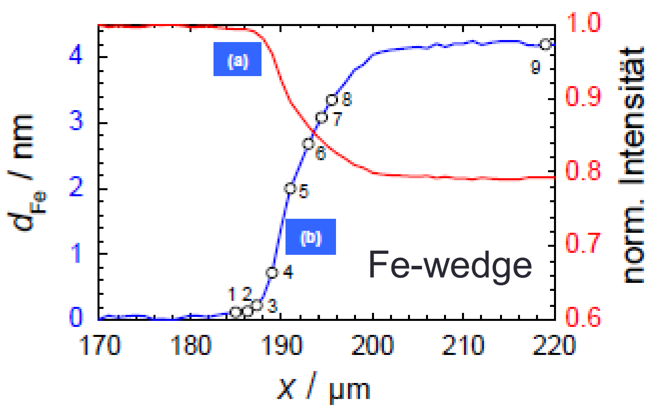
> Lensless Imaging – Fourier transform Holography (FTH)

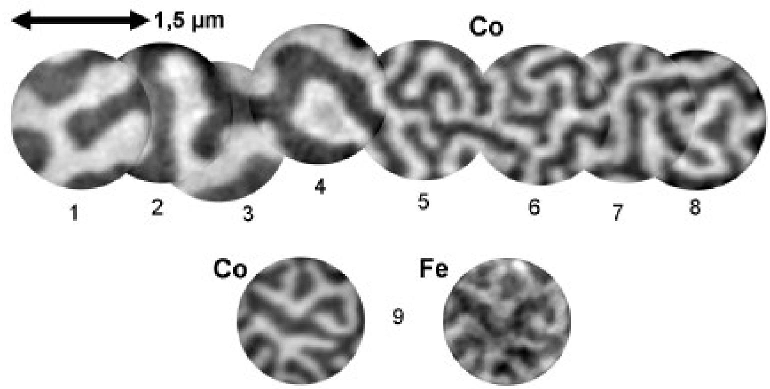
X-ray Holographic Microscope (XHM)





D. Stickler et al., Appl. Phys. Lett. **96**, 042501 (2010)





Element-selectivity

Imaging of magnetic domain patterns with X-rays

> Lensless Imaging – Coherent Diffraction Imaging (CDI)

	Schlüsselelement-Herstellung		Bild-Rekonstruktion	
TXM	Zonenplatte	XXXXX	-direkt-	X
FTH	Optikmaske	XX	Einfache Fourier-Transformation	XX
CDI	-direkt-	X	Phasen-Rückgewinnung	XXXXX