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EUV Litho, Inc.

EUV Litho Workshop 2017

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SCDI for EUV photomask metrology

RESCAN - Reflective EUV Mask Scanning Lensless Imaging Tool

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Outline

Our Goal

- RESCAN project overview

Background

- 2-step method for defect inspection
- short introduction to Ptychography & scattering contrast microscopy
- experimental setup

Results

- reconstructed sample mask

Future

- outlook & conclusions

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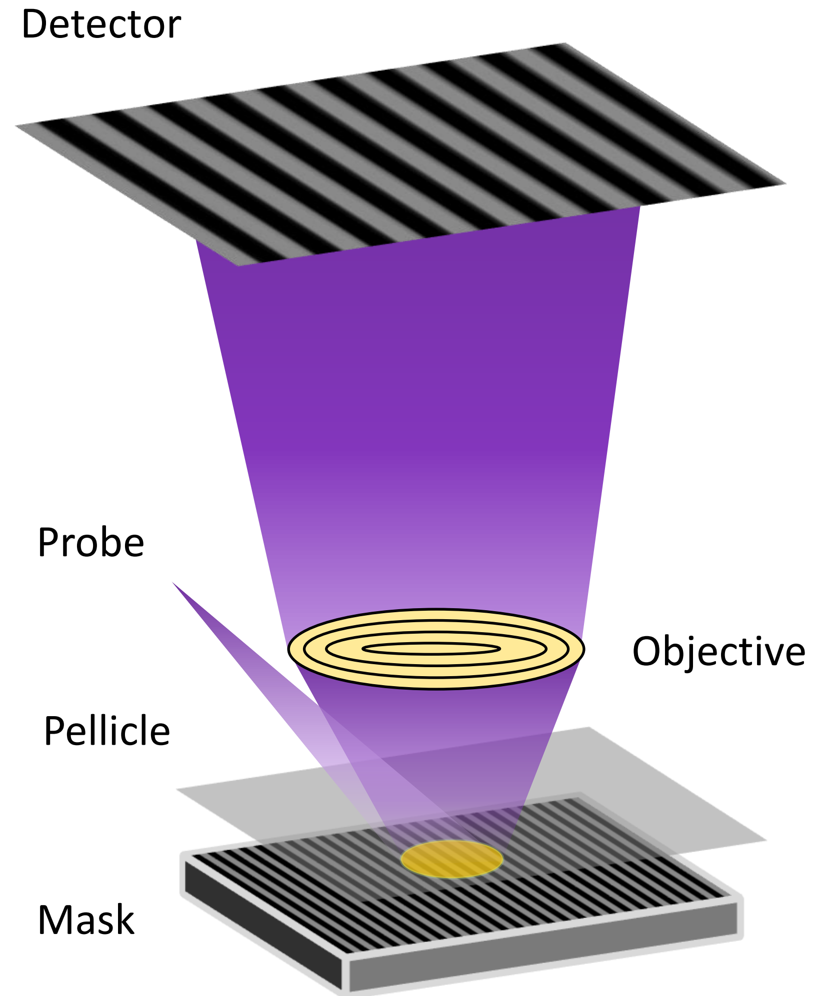
RESCAN: Project Overview

- **Goal**
  - develop scanning coherent lens-less imaging methods
    - algorithms and instrumentation
    - provide EUV metrology in reflection mode
  - provide method for actinic pattern inspection of EUV reticles
  - reach a resolution of 38 nm with high throughput and sensitivity
- **Research Plan**
  - implement mask defect inspection (at 6˚ incidence angle) at the Swiss Light Source (SLS)
  - maximize performance in terms of resolution and throughput
  - develop stand-alone prototype for mask defect inspection

Mask Inspection in Real Space

- output is easy to interpret
- resolution is limited by optics
- limited depth of focus
- needs expensive optics



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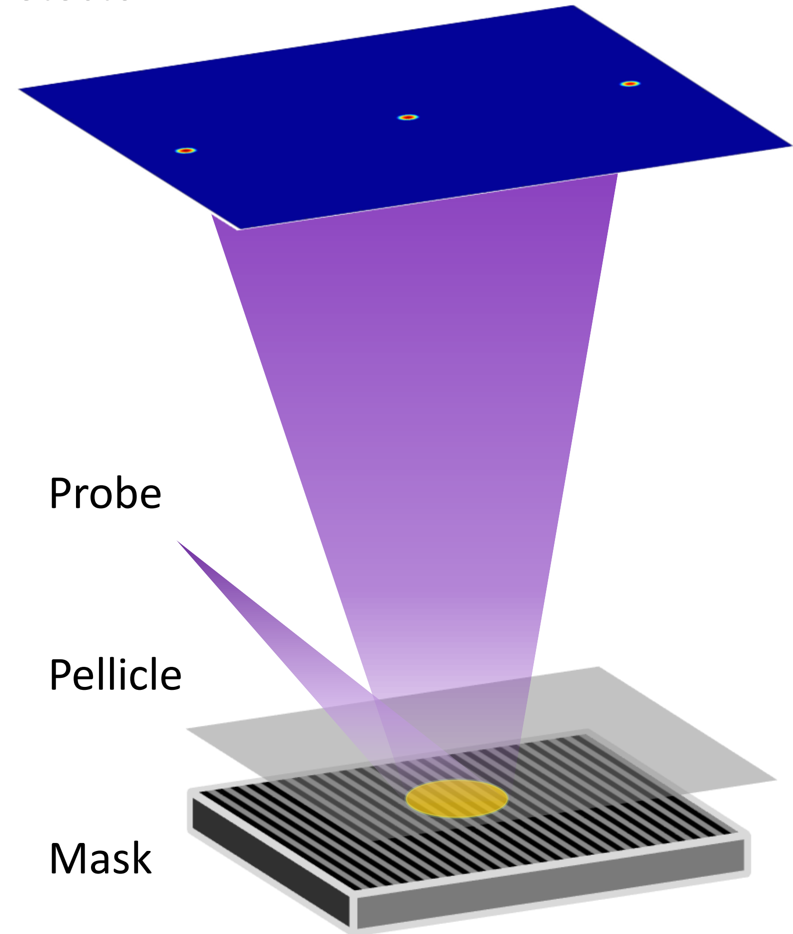
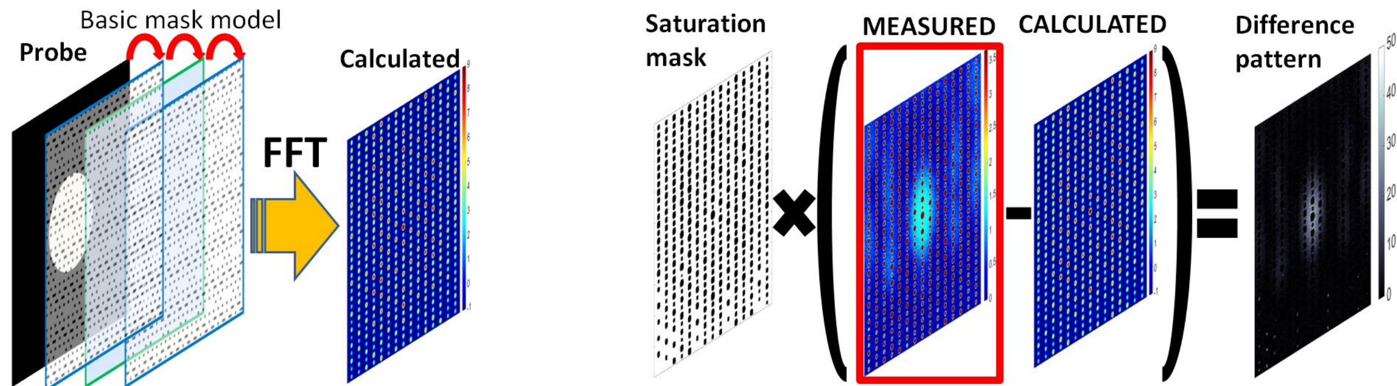
Mask Inspection in Fourier Space

- resolution is defined by detector size
- large depth of focus
- output is hard to interpret and needs complex algorithms
- easy setup due to absence of objective lens

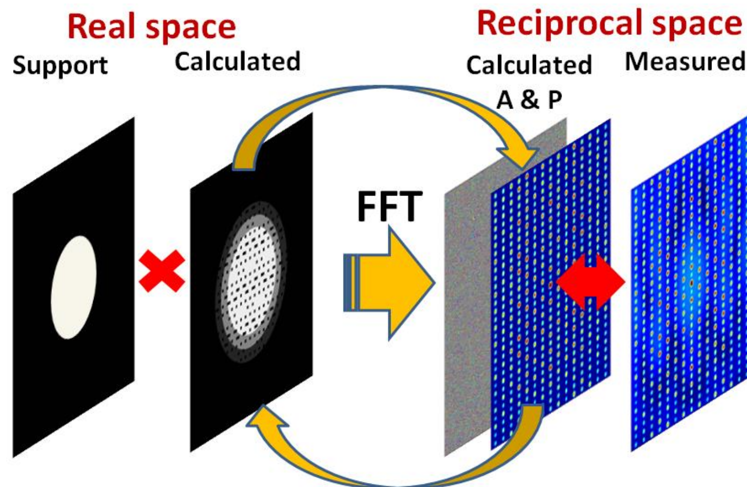


RESCAN: a 2-Step Approach

- **Idea**
  - combine real space and Fourier space inspection into a 2-step method
    i. rough inspection with Scanning Scattering Contrast Microscopy to locate defects



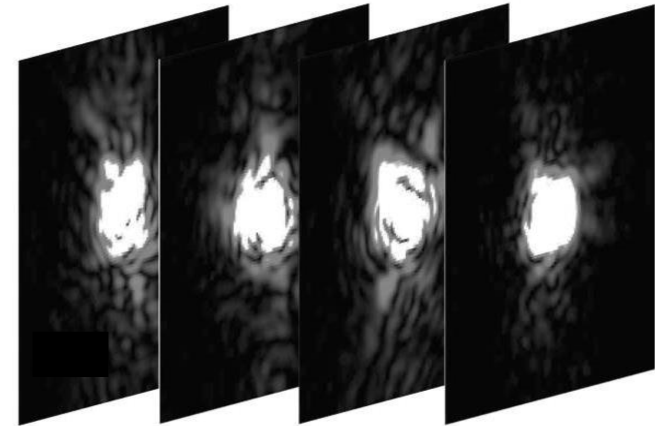
    ii. fine inspection using phase retrieval algorithm in areas with defects

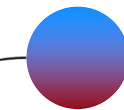


Scanning Coherent Diffractive Imaging

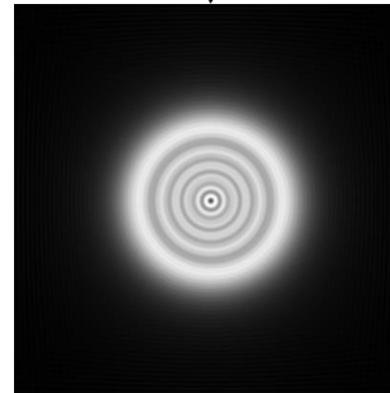
Ptychography

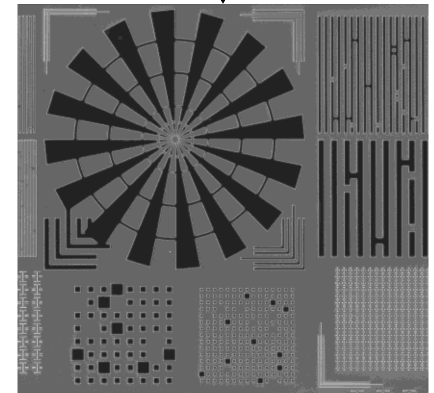
- no image formation optics
- resolution is not limited by optics
- large depth of focus
- scan across specimen to get multiple diffraction patterns with redundant data
- simultaneously recover incident illumination (Probe) and sample structure (Object)
- solve the phase problem



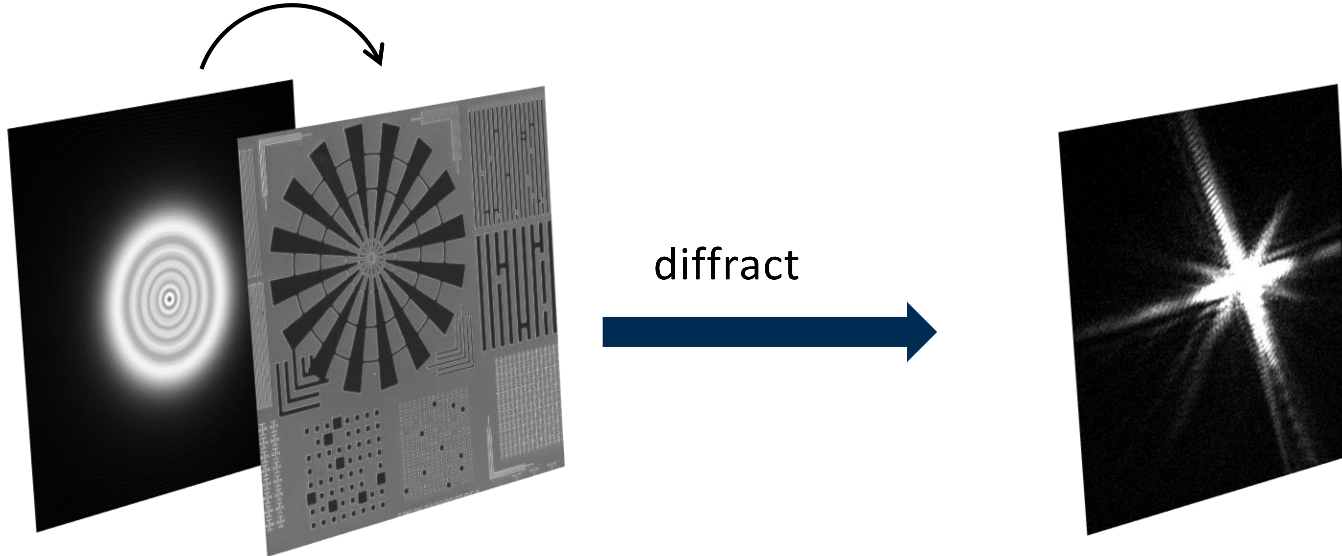


magic





Ptychography and the Difference Map



$$\psi_j(\mathbf{r}) = P(\mathbf{r} - \mathbf{r}_j)O(\mathbf{r})$$

constraints:

i. reconstructed magnitude must match measured magnitude

ii. data in overlapping areas must match

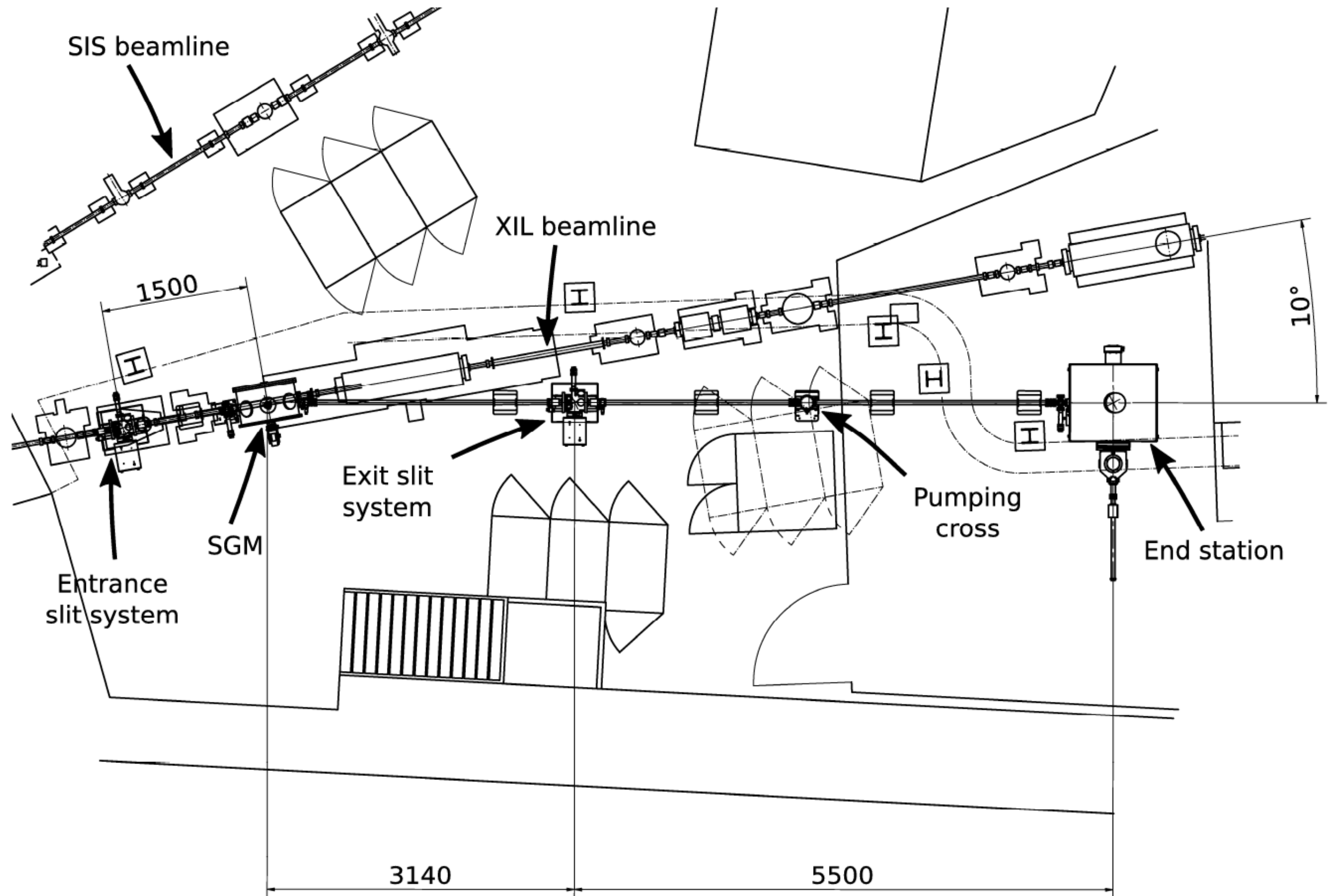
iteration:

$$\hat{O}(\mathbf{r}) = \frac{\sum_j \hat{P}^*(\mathbf{r} - \mathbf{r}_j)\psi_j(\mathbf{r})}{\sum_j |\hat{P}(\mathbf{r} - \mathbf{r}_j)|^2}$$

$$\hat{P}(\mathbf{r}) = \frac{\sum_j \hat{O}^*(\mathbf{r} + \mathbf{r}_j)\psi_j(\mathbf{r} + \mathbf{r}_j)}{\sum_j |\hat{O}(\mathbf{r} + \mathbf{r}_j)|^2}.$$

Source: P. Thibault, M. Dierolf, A. Menzel et al., Science **321**, 379 (2008)

RESCAN – Experimental Setup



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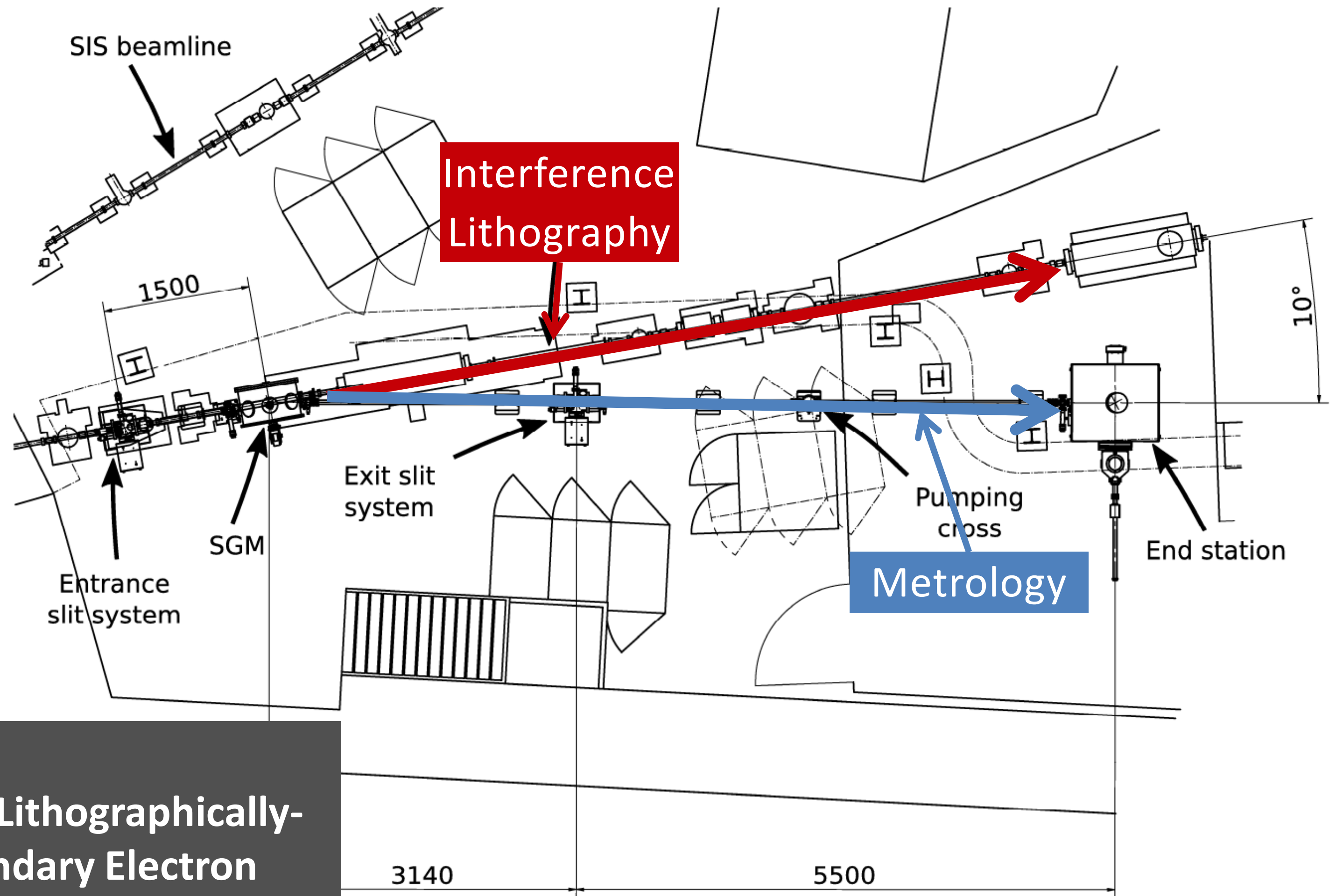
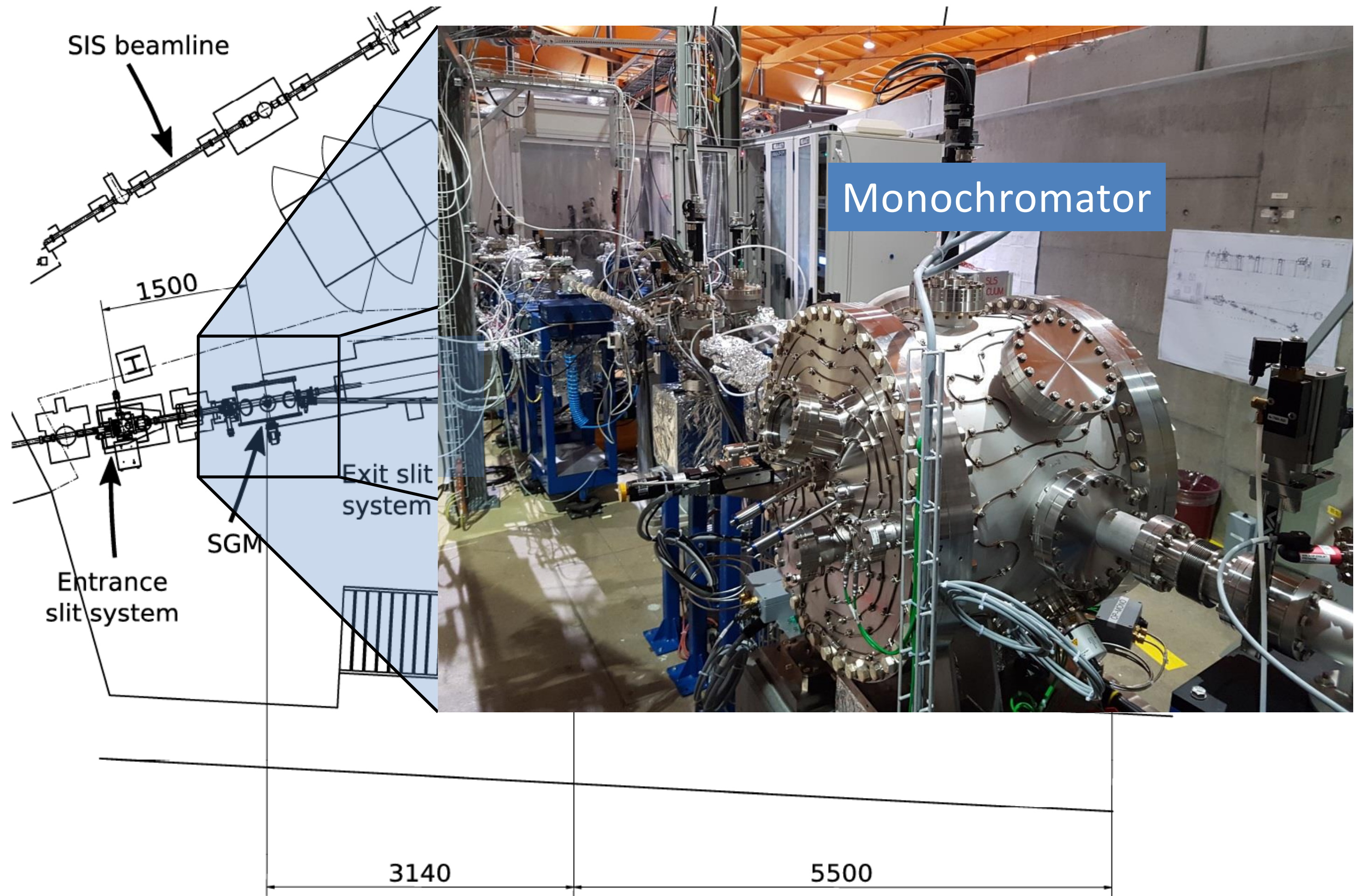
RESCAN – Experimental Setup



See also:
Estimation of Lithographically-relevant Secondary Electron Blur (P51)
Roberto Fallica

RESCAN – Experimental Setup



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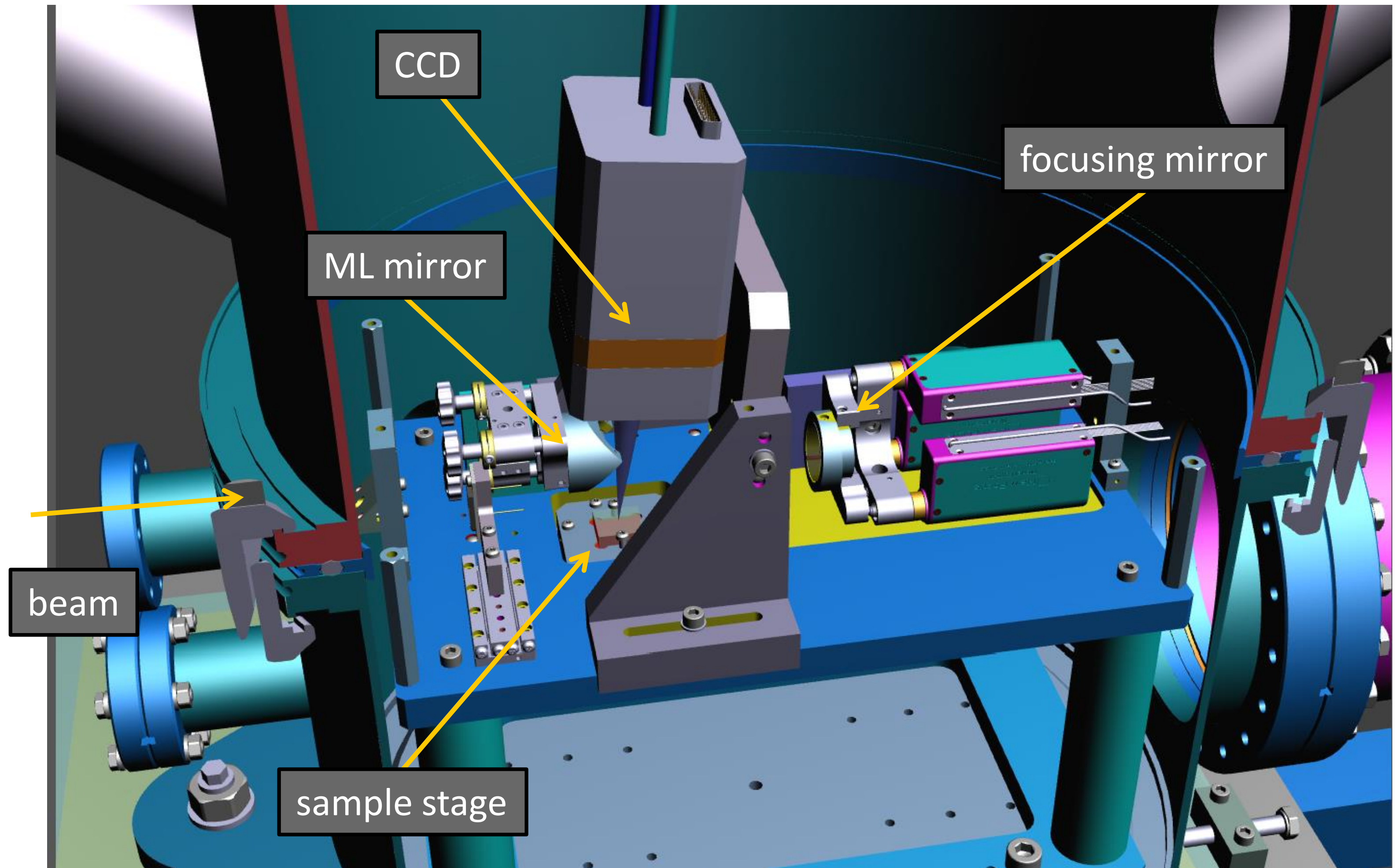
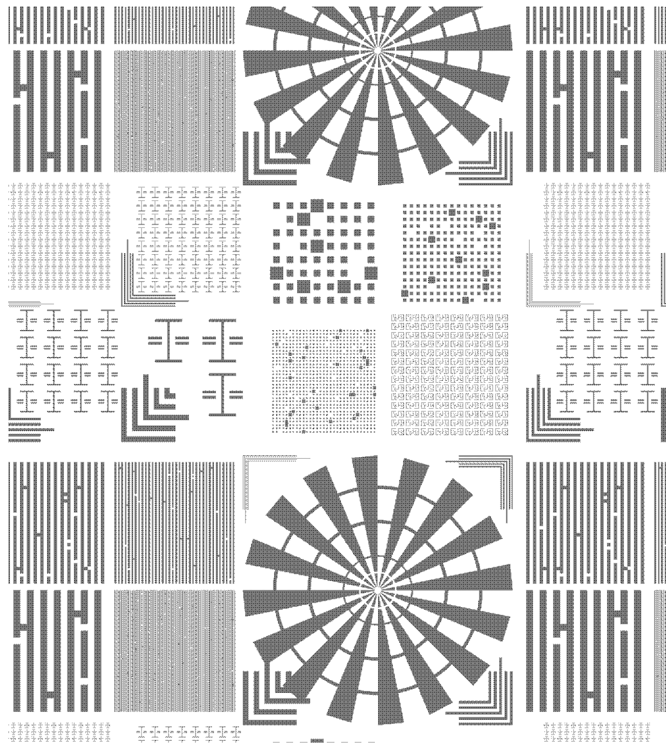
RESCAN – Experimental Setup



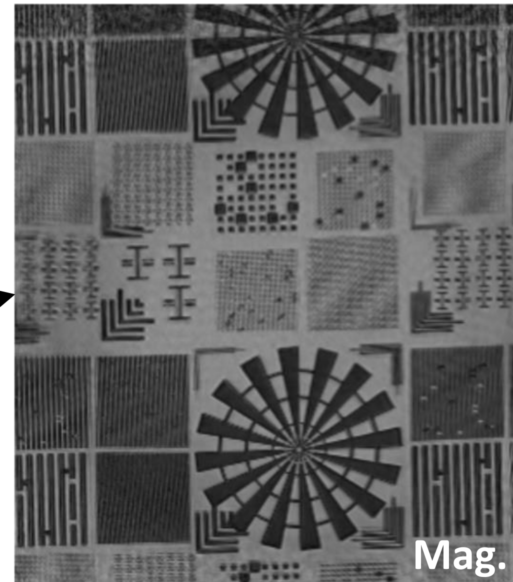
SCDI Reconstructed Image

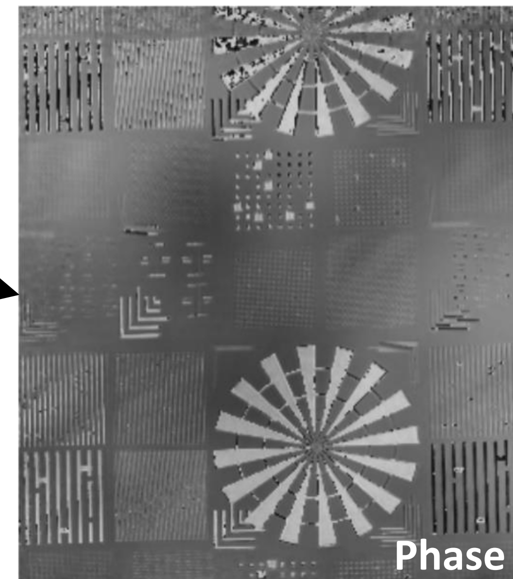
mask pattern



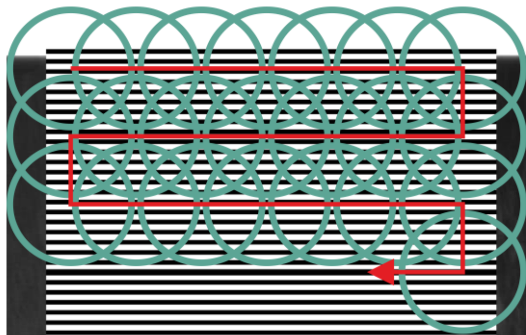
10 µm

Reconstructed Sample

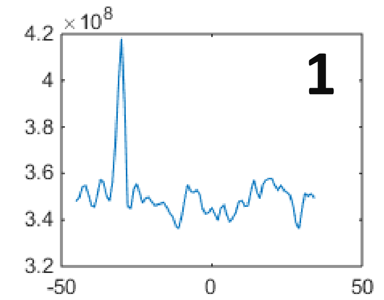


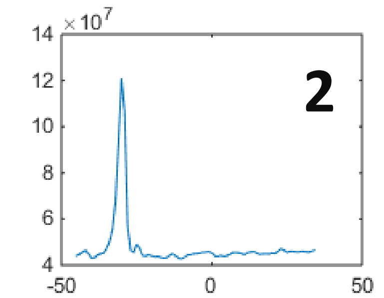


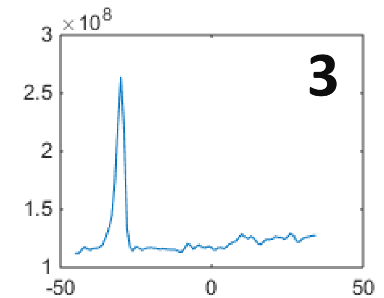
Detecting a 10 nm CD Error

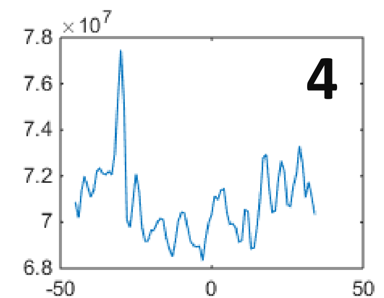


1 2 3 4



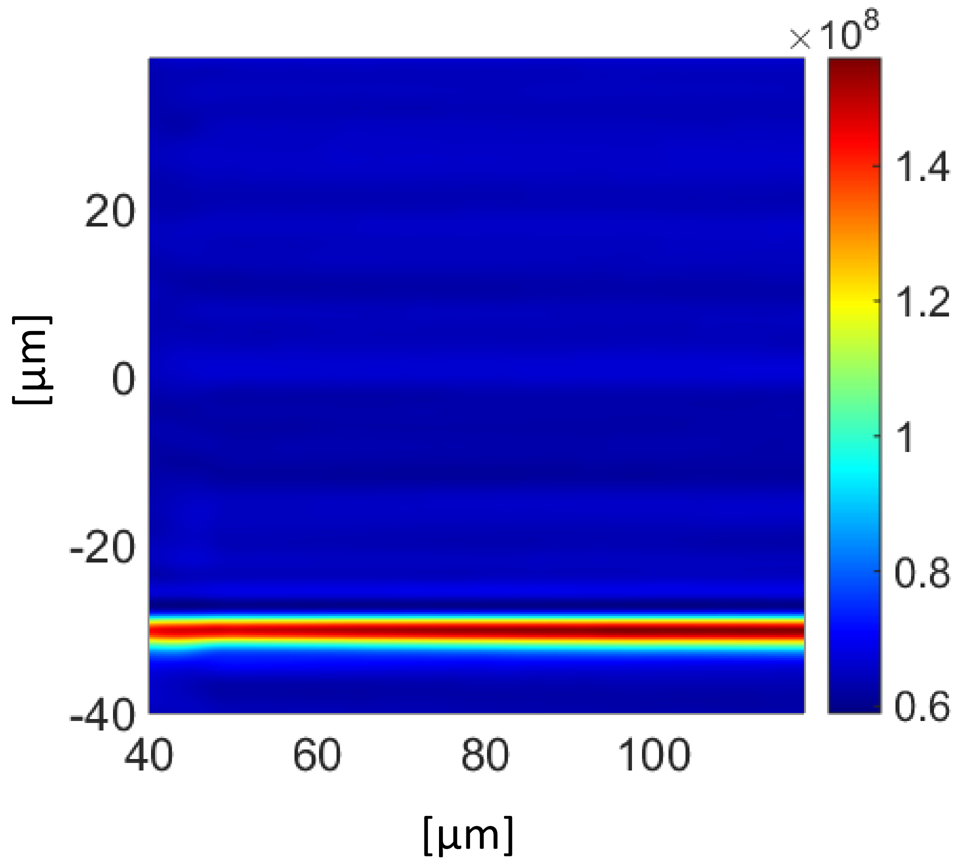






[µm]

Detecting a 10 nm CD Error



- 10 nm CD error in 100 nm hp grating can be detected
- location accuracy defined by spot size and scan step width
- subsequently, fine inspection would be done using SCDI

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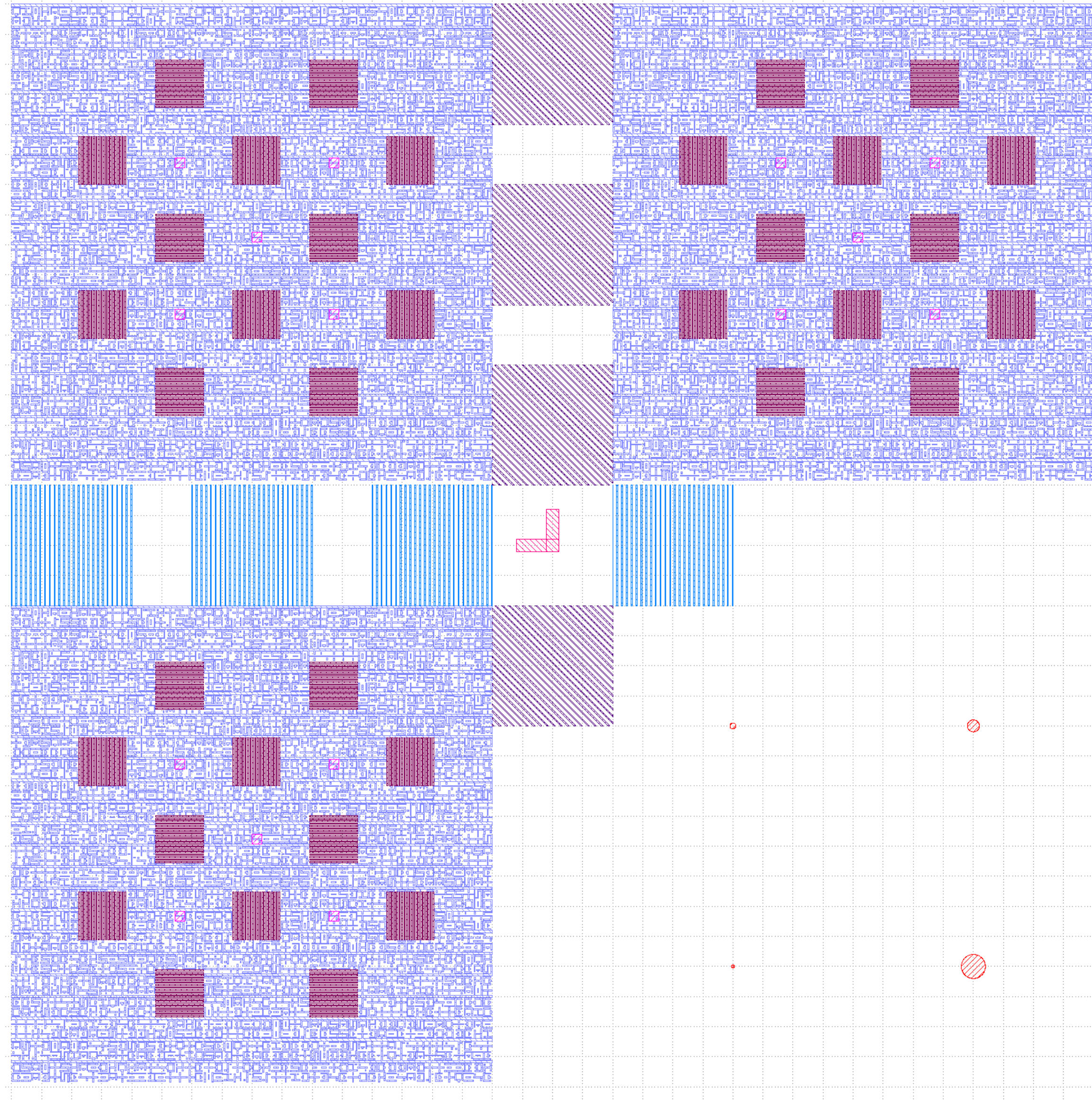
Defect Inspection with Non-Periodic Masks



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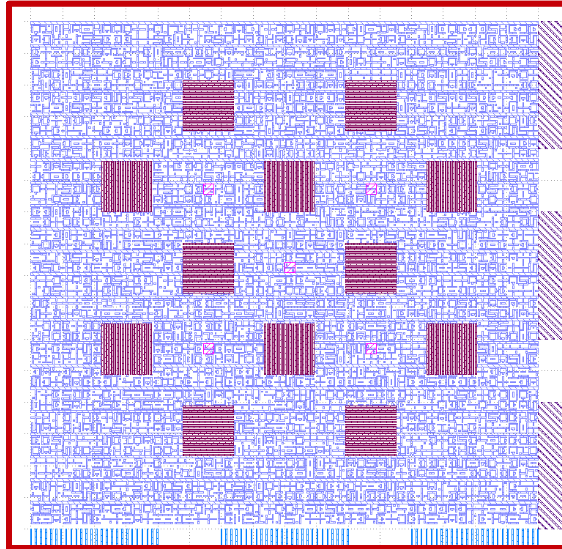
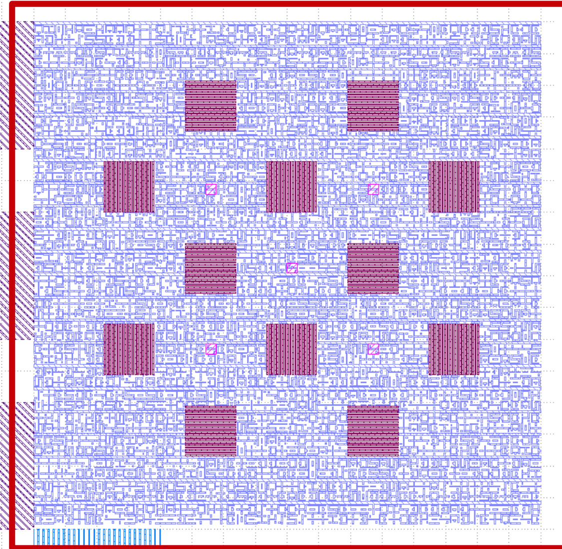
Defect Inspection with Non-Periodic Masks

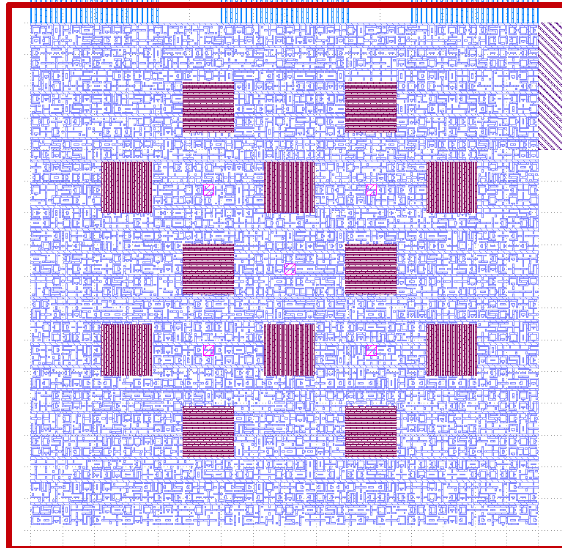
Reference



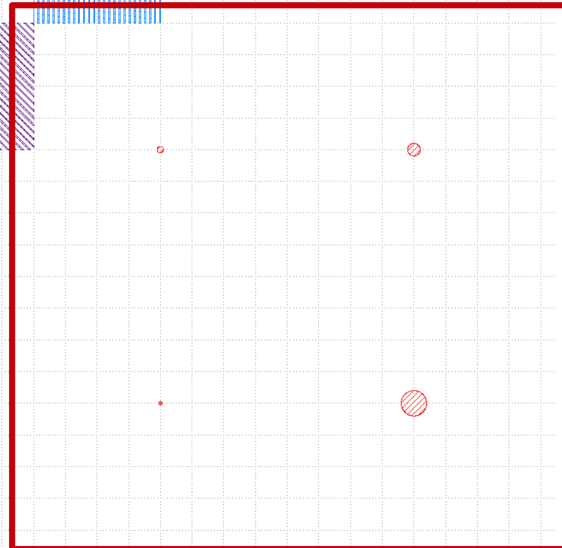
Extrusion



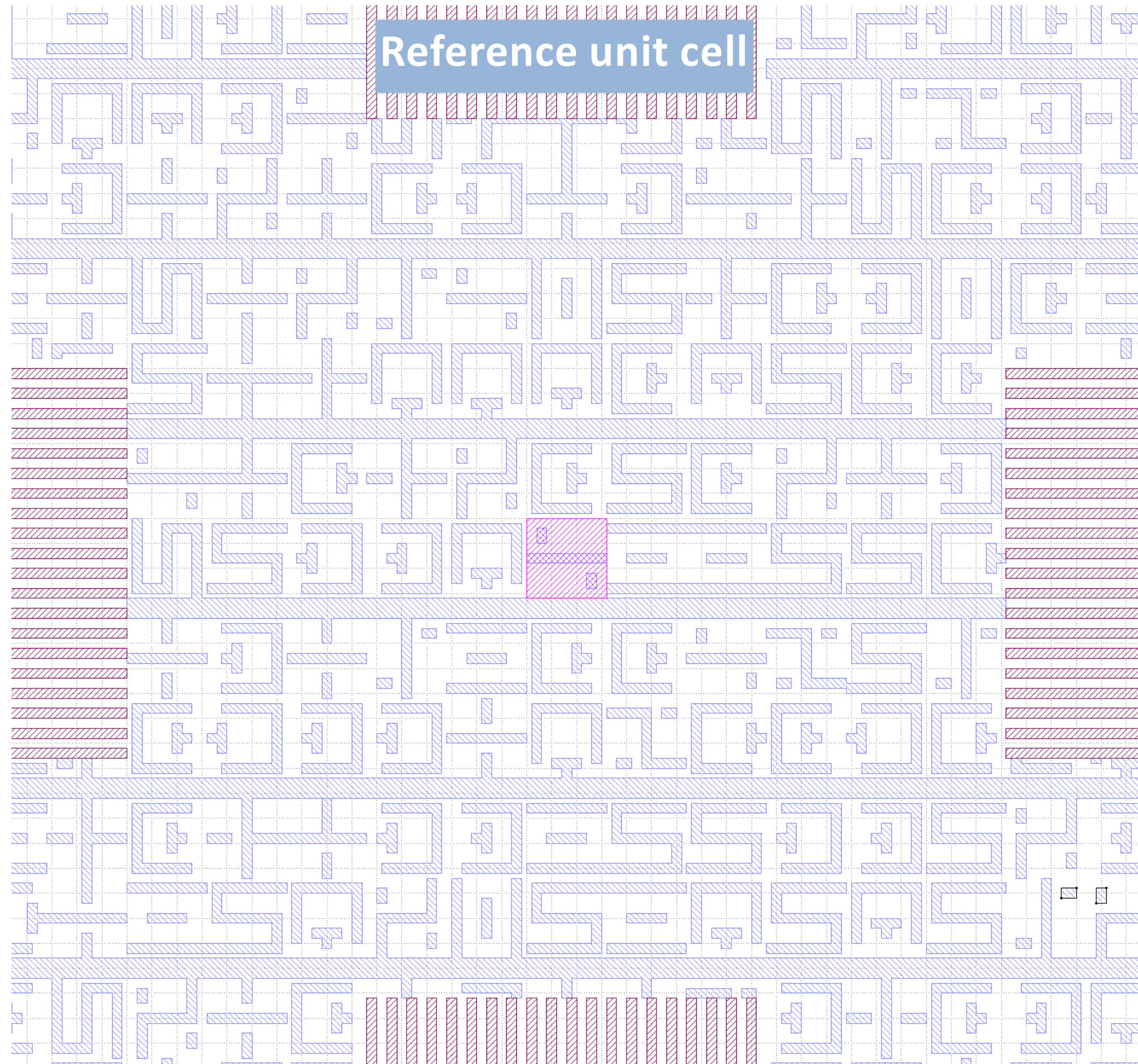
Gap



Calibration



Defect Inspection with Non-Periodic Masks



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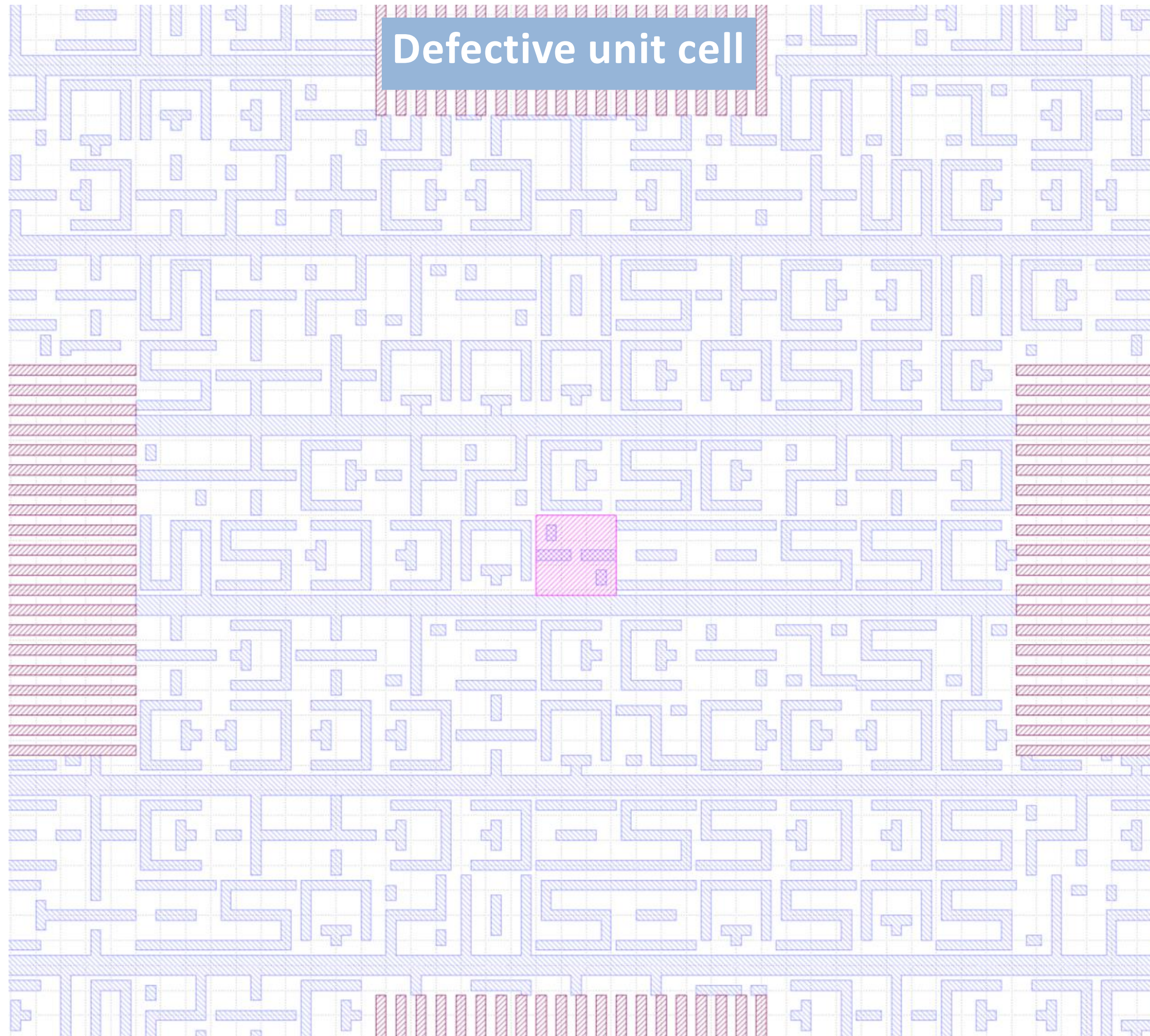
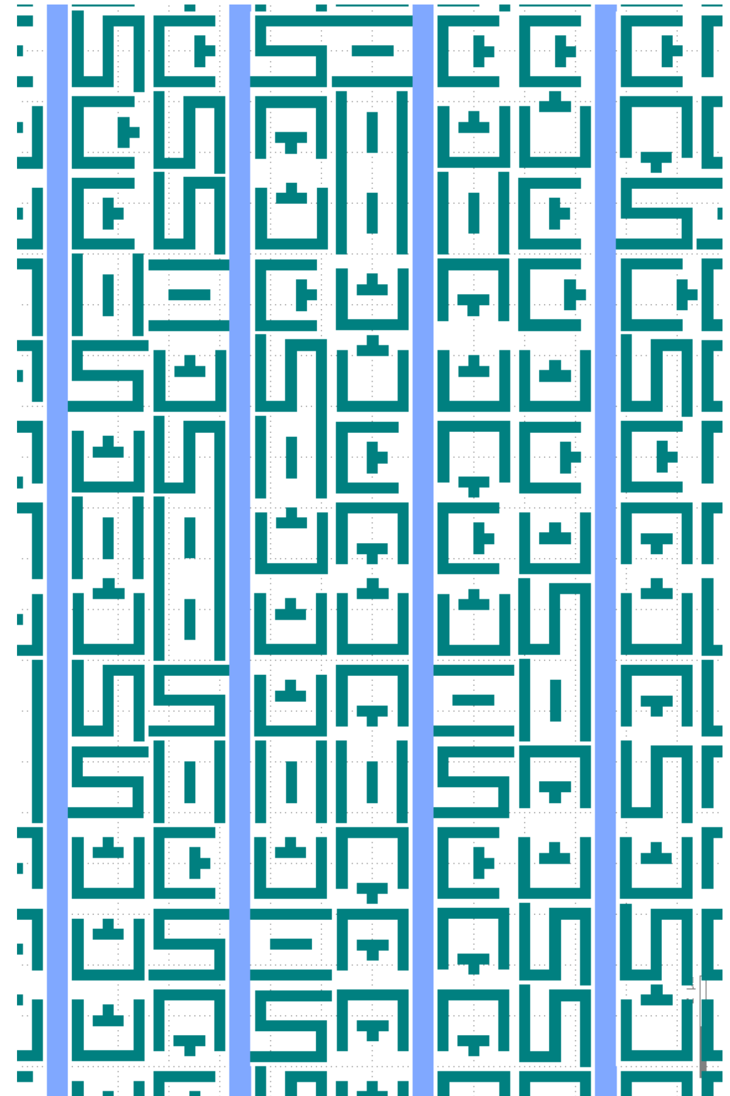
Defect Inspection with Non-Periodic Masks



Defect Inspection with Non-Periodic Masks

- **sample**
  - HSQ on multilayer
- **method & challenges**
  - die-to-die inspection, reference pattern and several defects
  - SSCM is more challenging due to background (LER, noise), need higher contrast
  - alignment is important
  - SCDI remains the same



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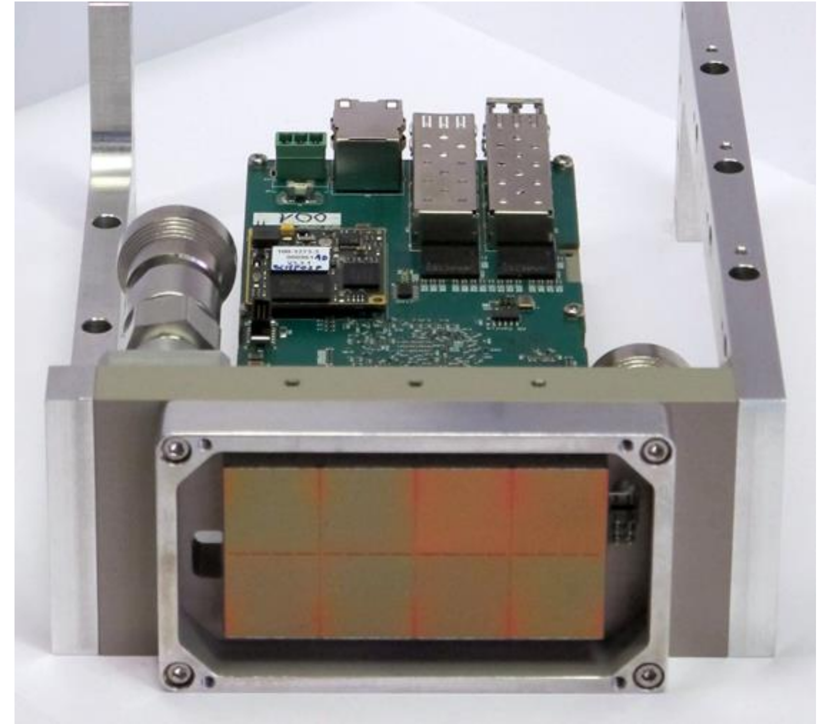
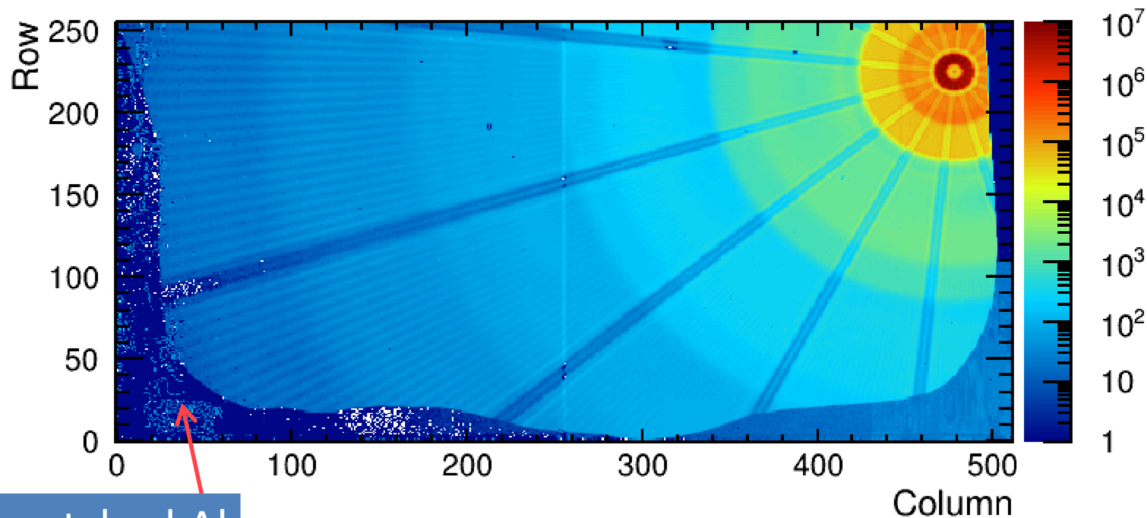
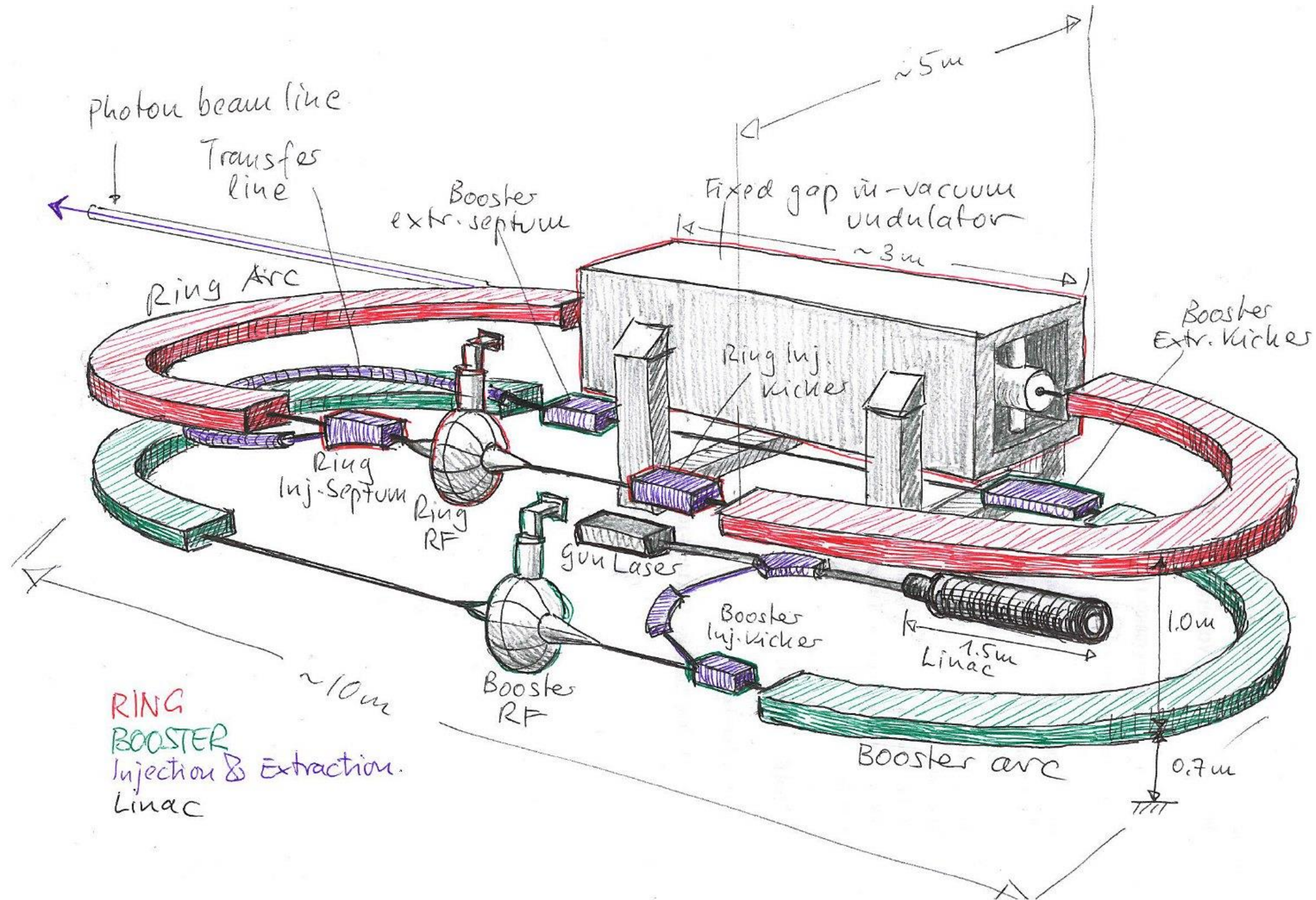
Fast Detector

- Hybrid CMOS detector: Jungfrau
  - 2 kHz acquisition rate
  - 10^6 photons/pixel dynamic range
  - 60% quantum efficiency
  - 75 µm pixel size
  - 50 e^- rms noise





Compact Source For Actinic Mask Inspection



Thank you all for listening

special thanks to the members of our group at PSI

we acknowledge financial support from NUFLARE