At-wavelength EUV mask inspection and imaging

Anton Barty
Lawrence Livermore National Laboratory

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Statement of the problem

The supply of defect-free masks remains the number one mask concern for the commercialisation of EUVL

Accurate, validated defect inspection metrology is essential to understanding defects and benchmarking industry tools and progress

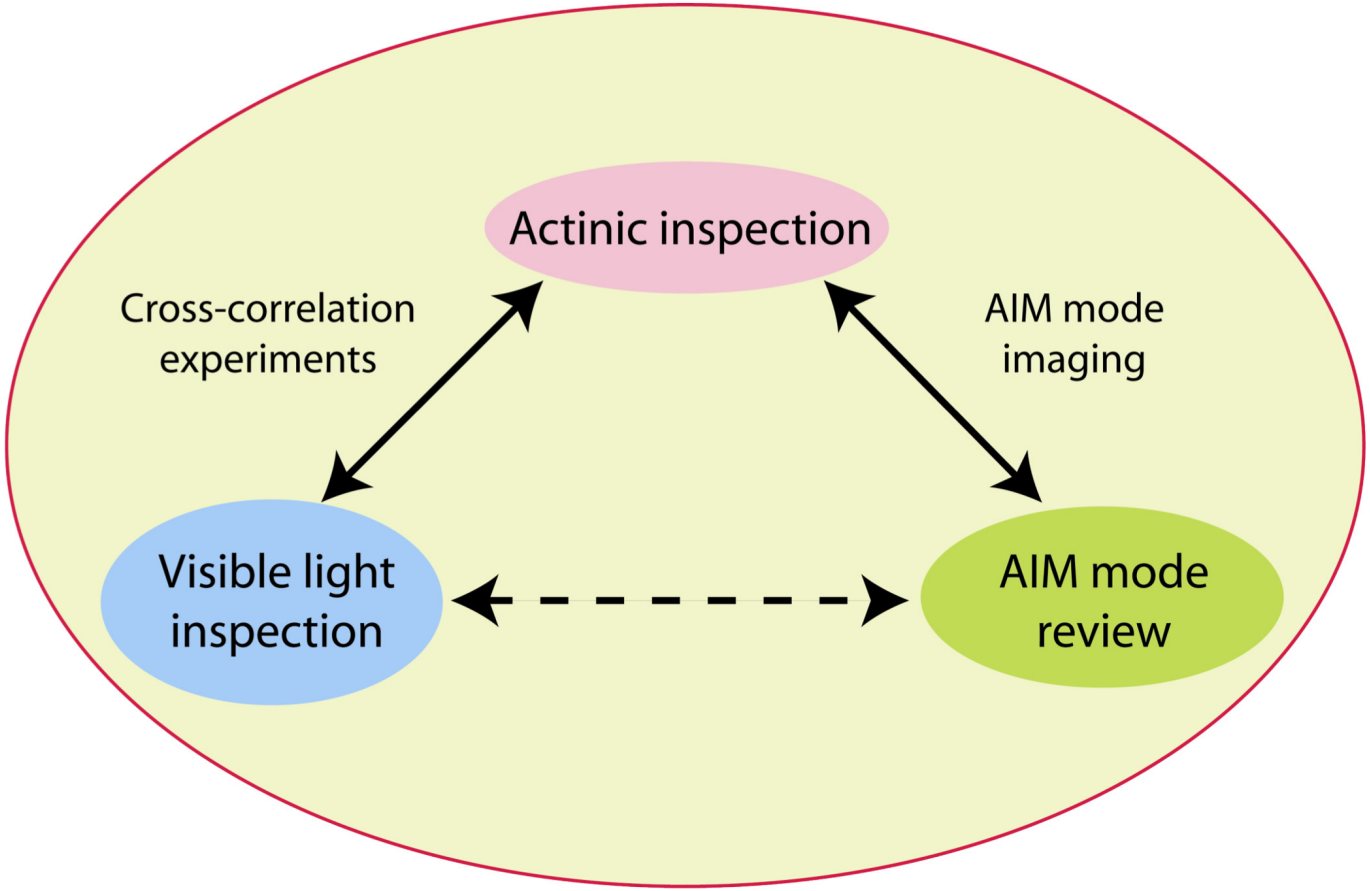
At-wavelength inspection of masks at the ALS using 13.5nm light is being used to validate the efficacy of laser-based mask inspection

- **High-speed at-wavelength inspection to locate defects on production mask blanks**
- **Defect review using an at-wavelength aerial image microscope**
- **Integrated modeling of actinic inspection, non-actinic inspection and defect printability side by side with MET printing capability**

This project supports the Sematech EUV mask blank pilot line project at Albany, NY

- **Funded under Sematech project Lith-343**

Goal is to validate the methodology and assumptions behind laser-based EUV mask inspection



Correlate results of actinic inspection with visible light scattering tools:

- Top-level strategy is to measure the same samples in both inspection tools
- Check whether the same defects are reliably captured by both systems
- AIM mode review determines whether the differences are significant

Cross-correlation experiments must be able to detect any false negatives in non-actinic inspection tools

		Printable defect	
		Defect	**No defect**
Non-actinic inspection result	**Defect**	Inspection is correct (desired result)	False positive (mask is actually OK)
	No defect	False Negative (defect exists but is not found)	Inspection is correct (desired result)

EUV mask inspection system requirements:

- Need a fast EUV mask scanner
  - A large area of low-defect mask must be scanned to find defects, gather sufficient statistics and ensure there are no false negatives
- Need an EUV microscope to image the mask
  - A defect review tool (AIM microscope) is essential to determine printability and discriminate false positives

High-speed scanning mode is used to locate defects

Scanning mode parameters

Optics:
20x Schwarzschild illuminates mask

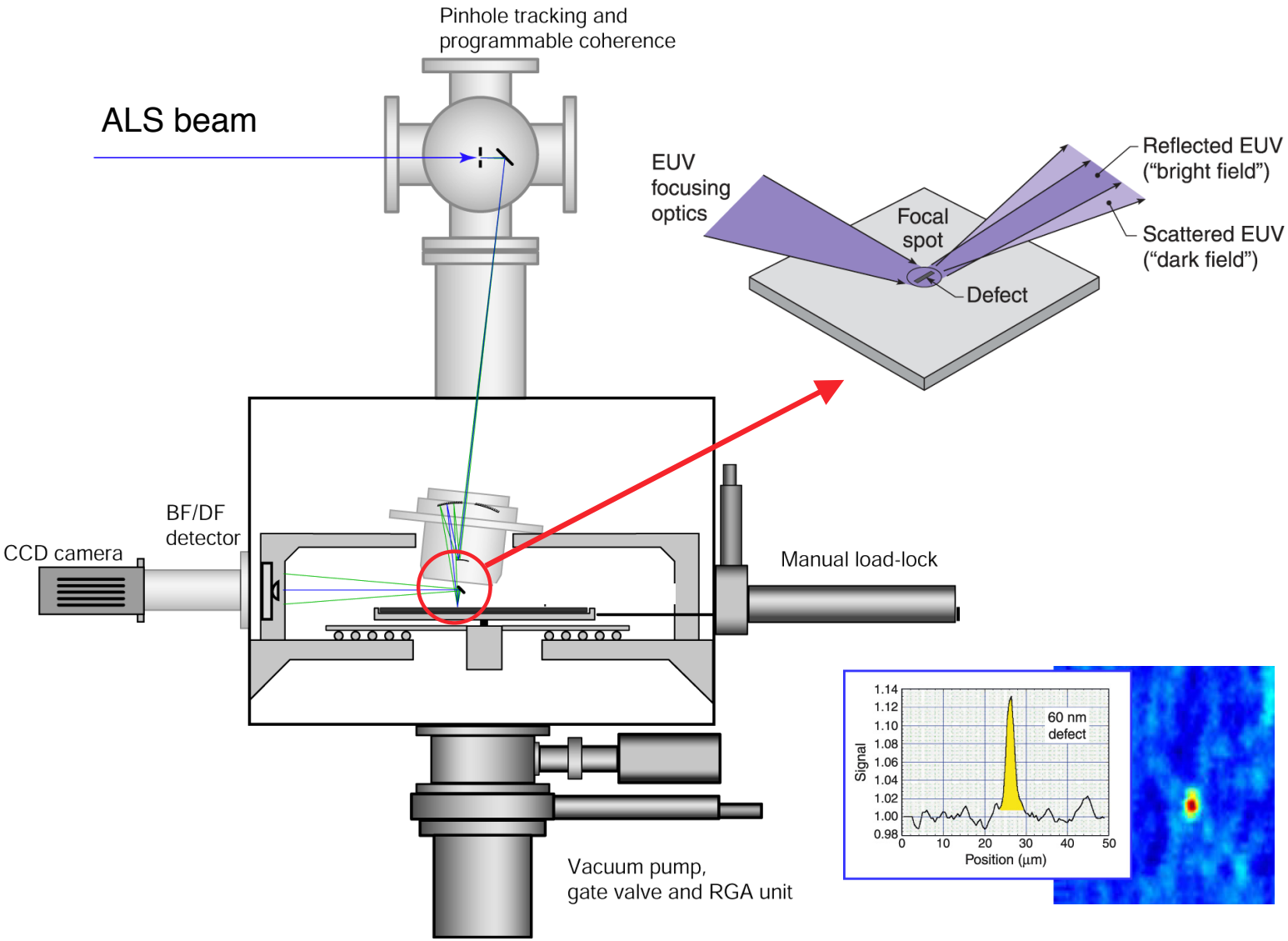
Scanned spot size:
1μm dia.

Scan speed:
2cm²/hr

Scanning sensitivity:
50nm PSL

Defect location:
10μm or better over 6”x6” mask

Added defects:
< 1 per cm²



Aerial imaging mode is used for defect review

Imaging mode parameters

Optics:
- Zone plate images mask at >500x mag.

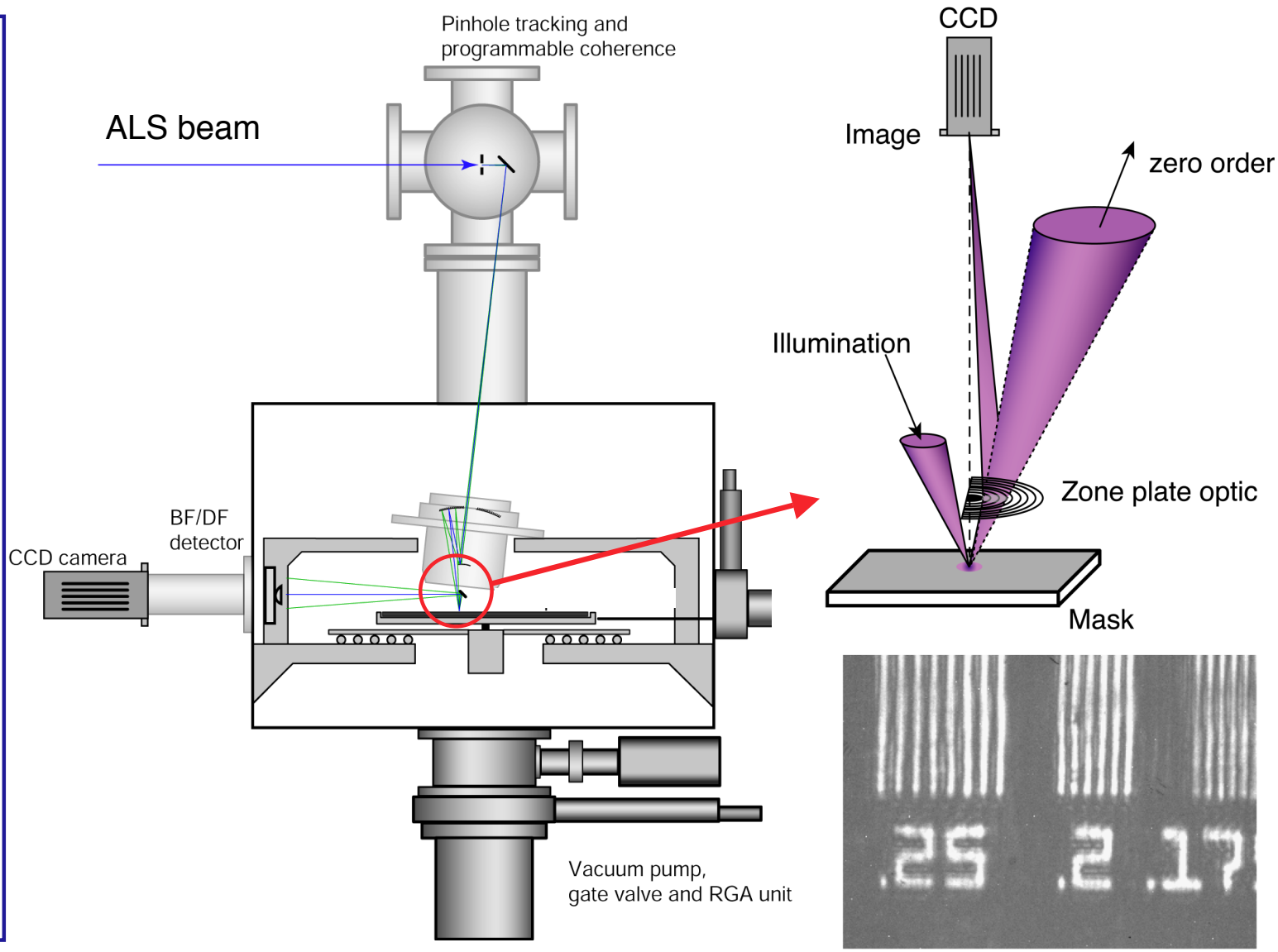
NA to mask:
- Emulates 0.25NA EUVL stepper

Field of view:
- 5μm square
- 1024x1024 pixels

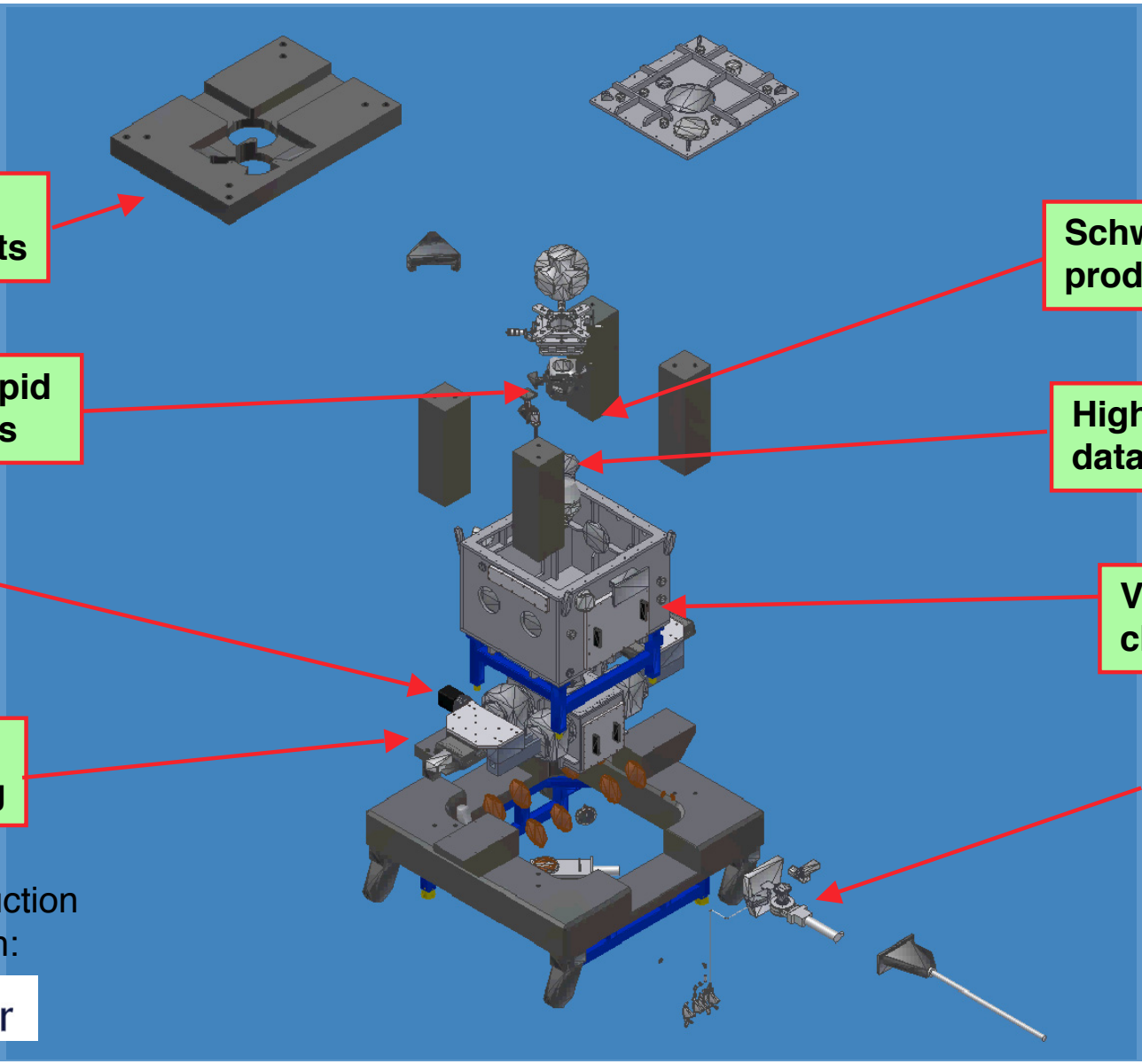
Exposure time:
- 15sec - 1min

Defect location:
- 10μm or better over 6”x6” mask

Time to change to imaging mode:
- <30 min



Key elements of end-station design

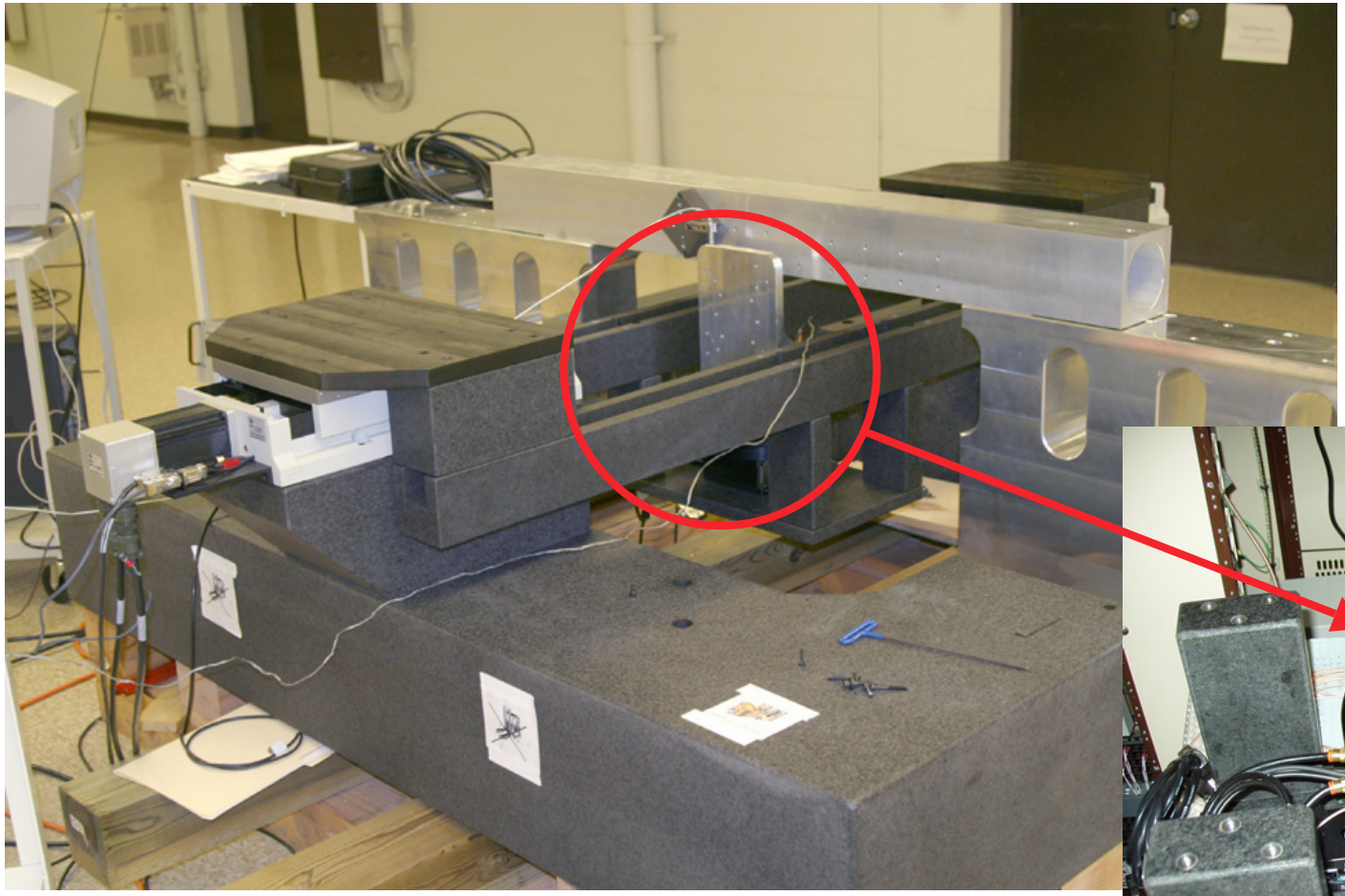


Design and construction in collaboration with:

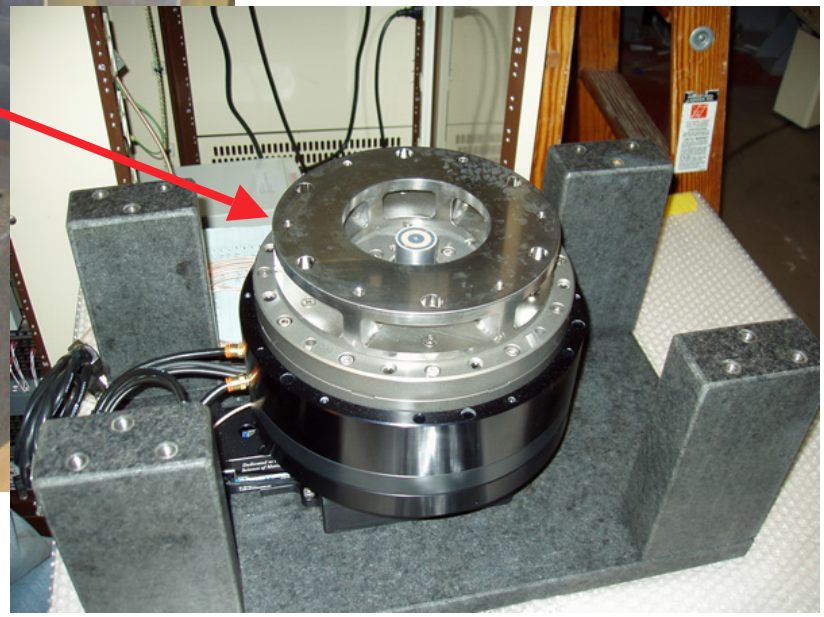
Rohwedder

Continuous rotation and linear scan under stationary spot

Granite frame and scanning stages



Rotary stage assembly



Construction at the ALS

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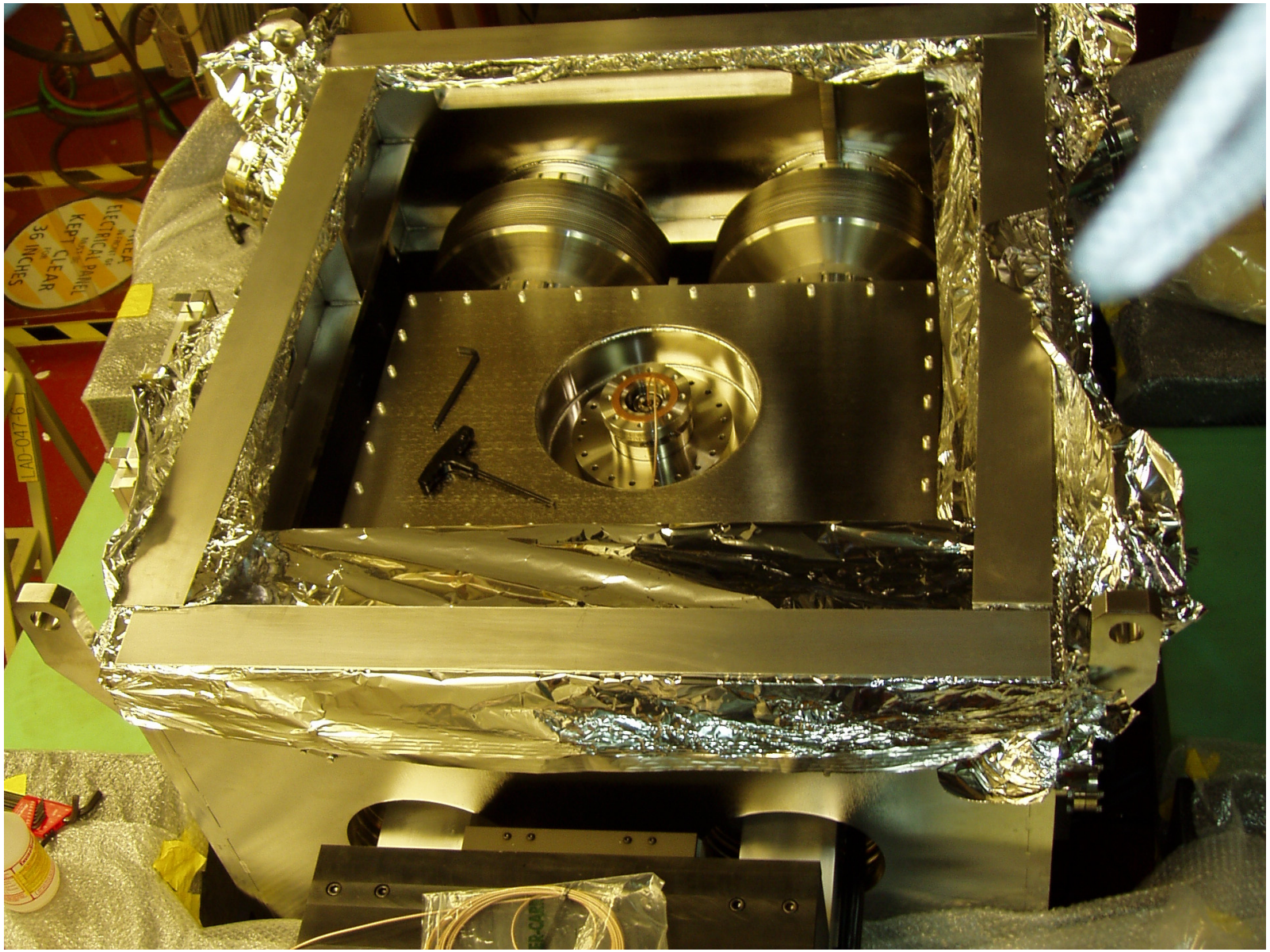

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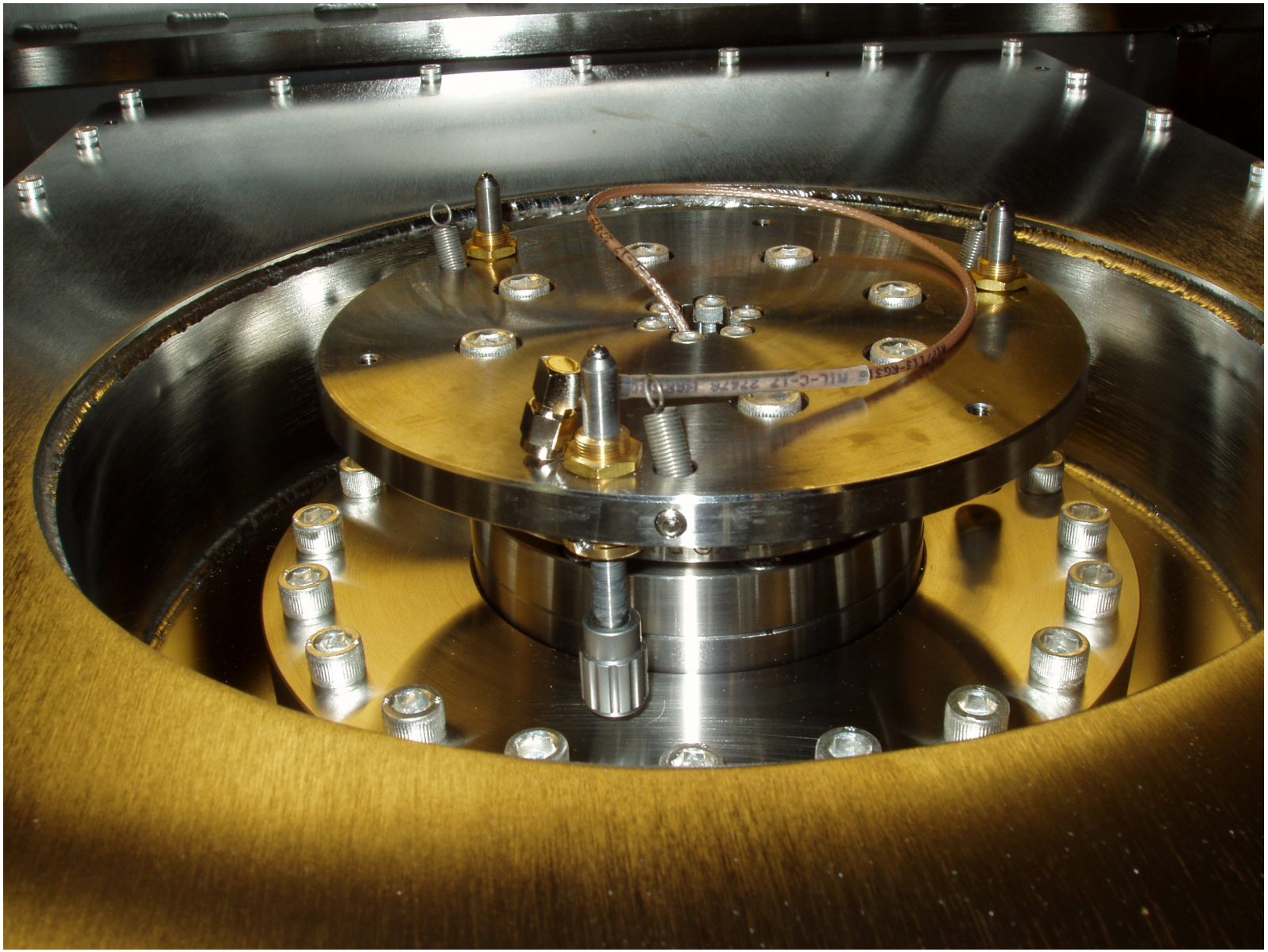

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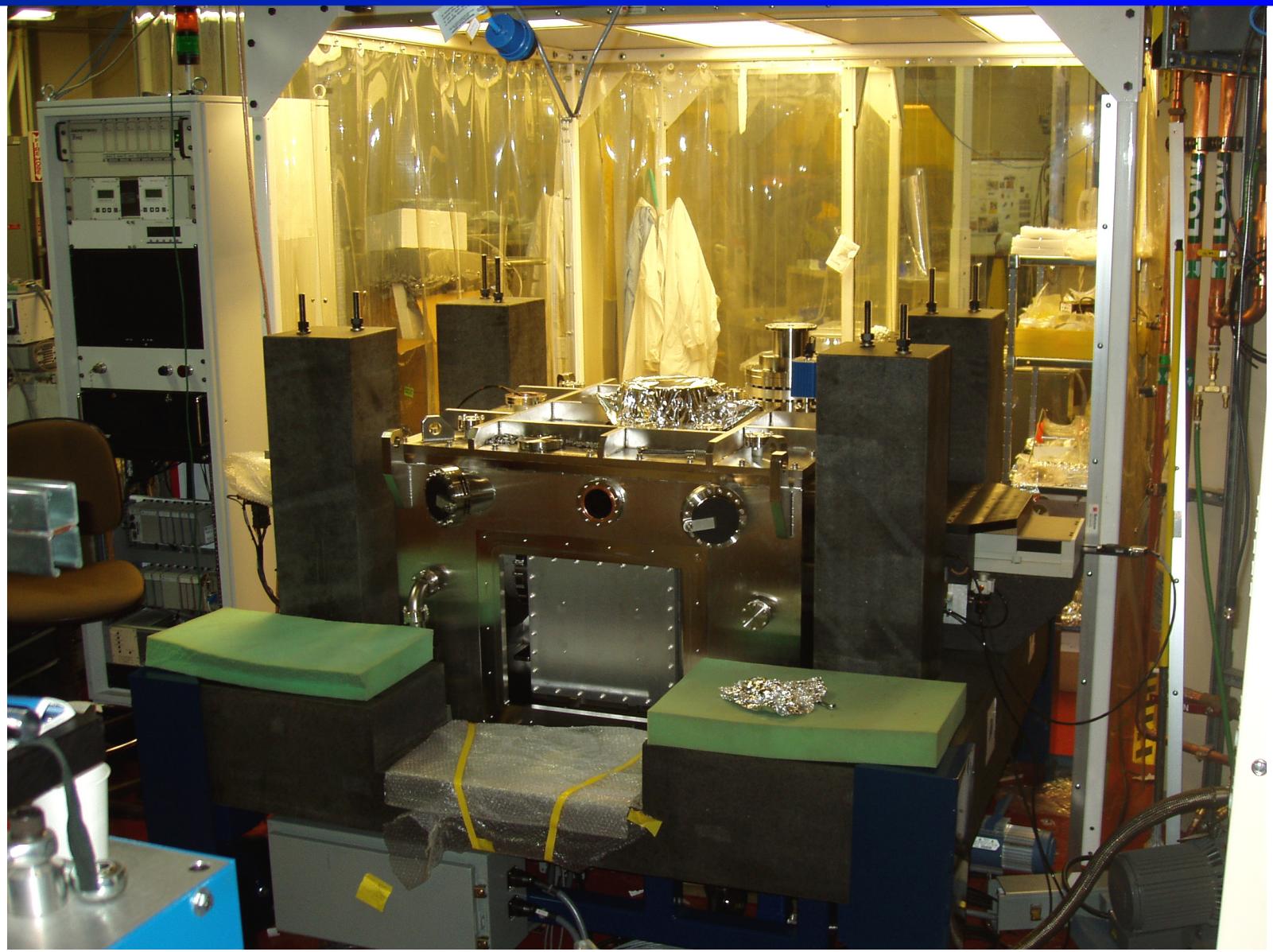
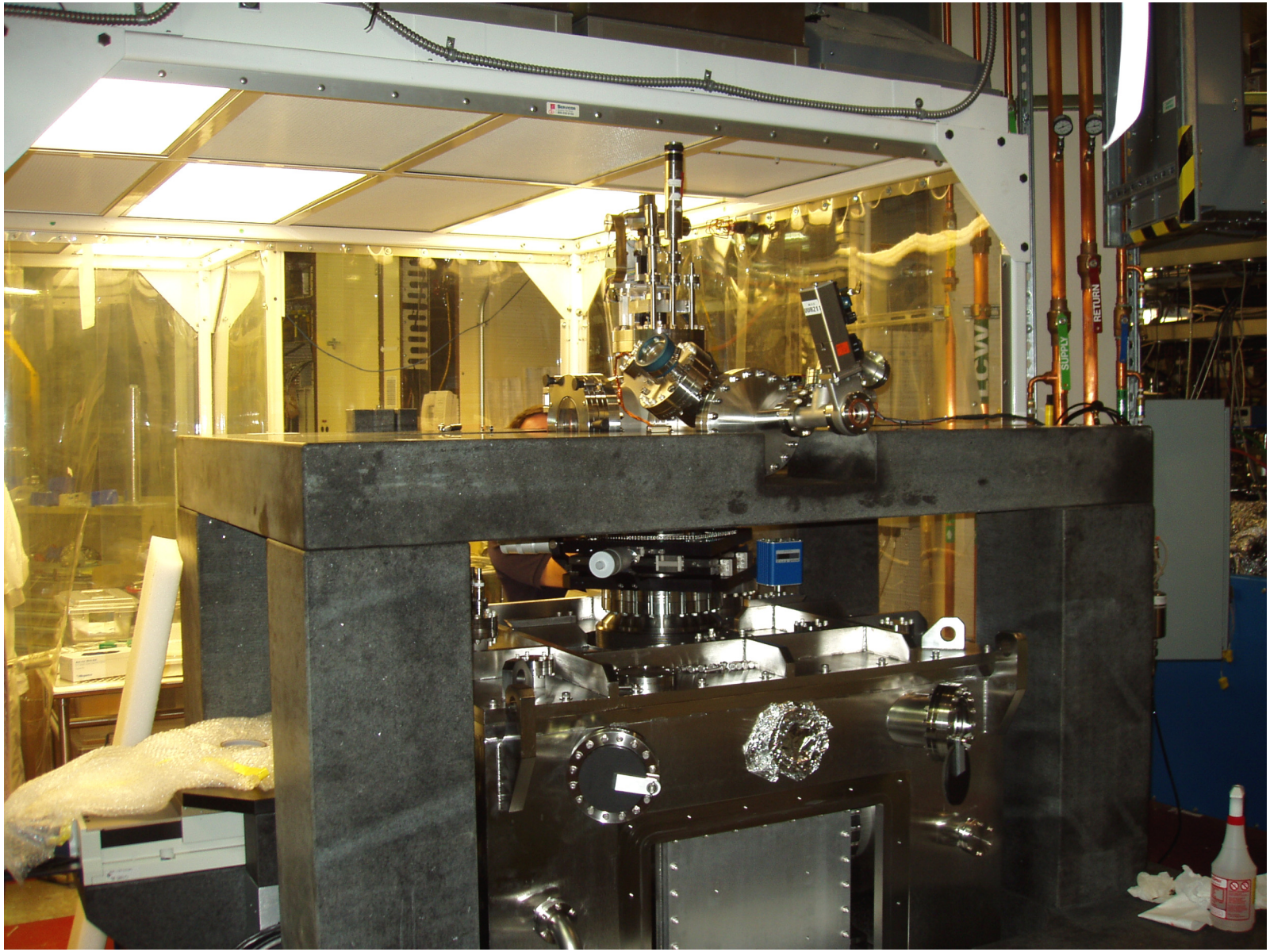
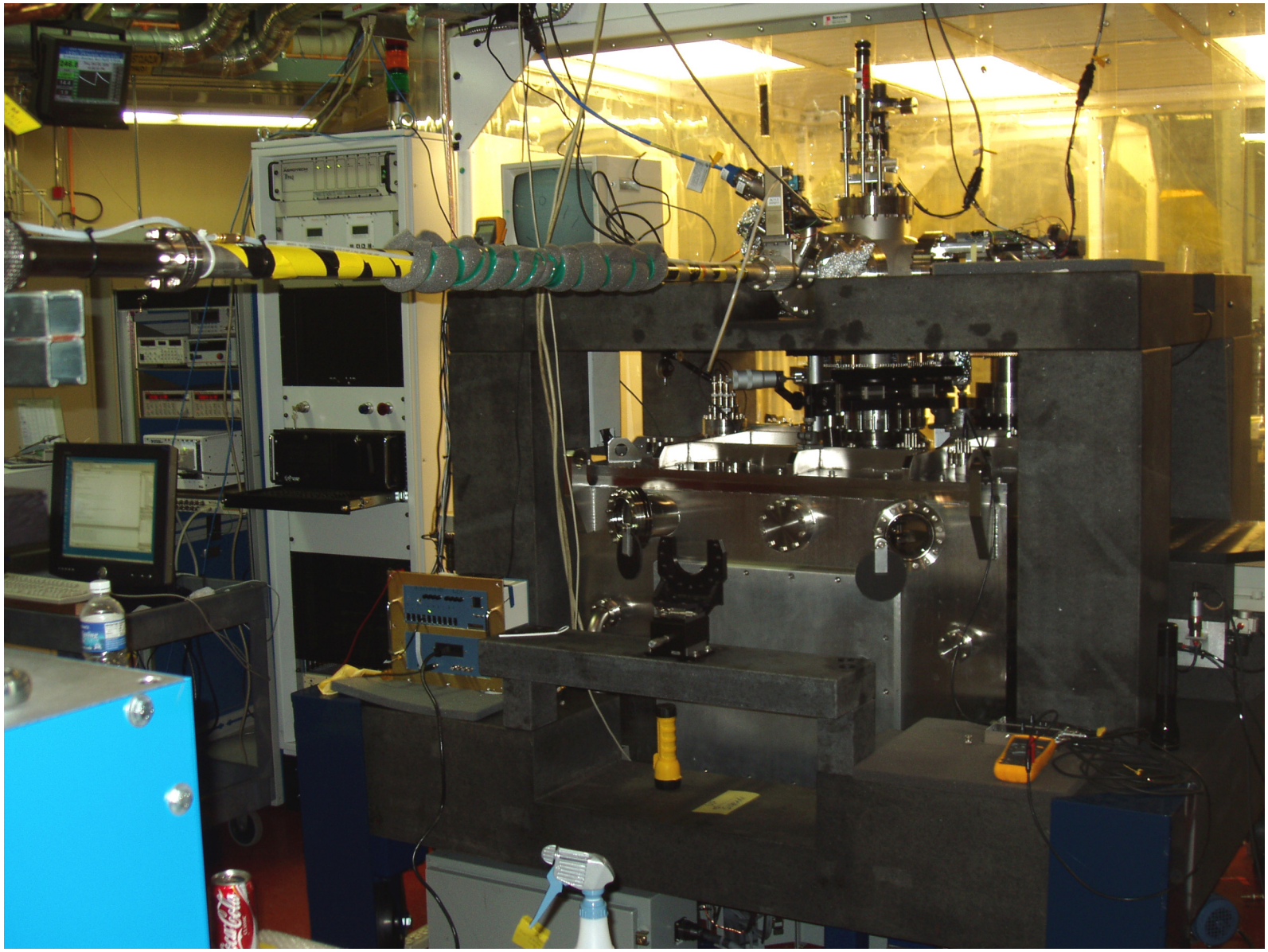


Construction at the ALS



Completed end-station at the ALS



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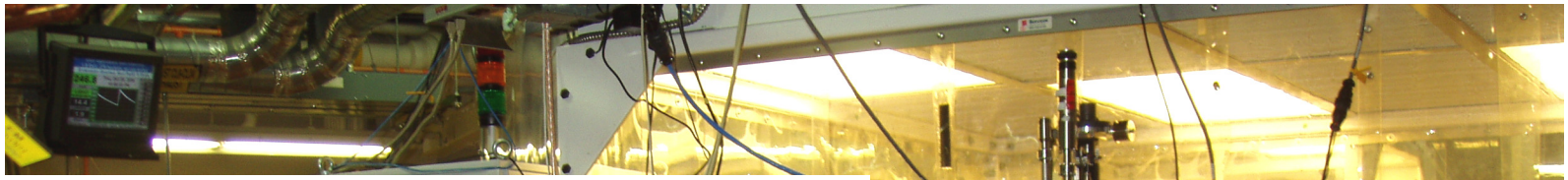
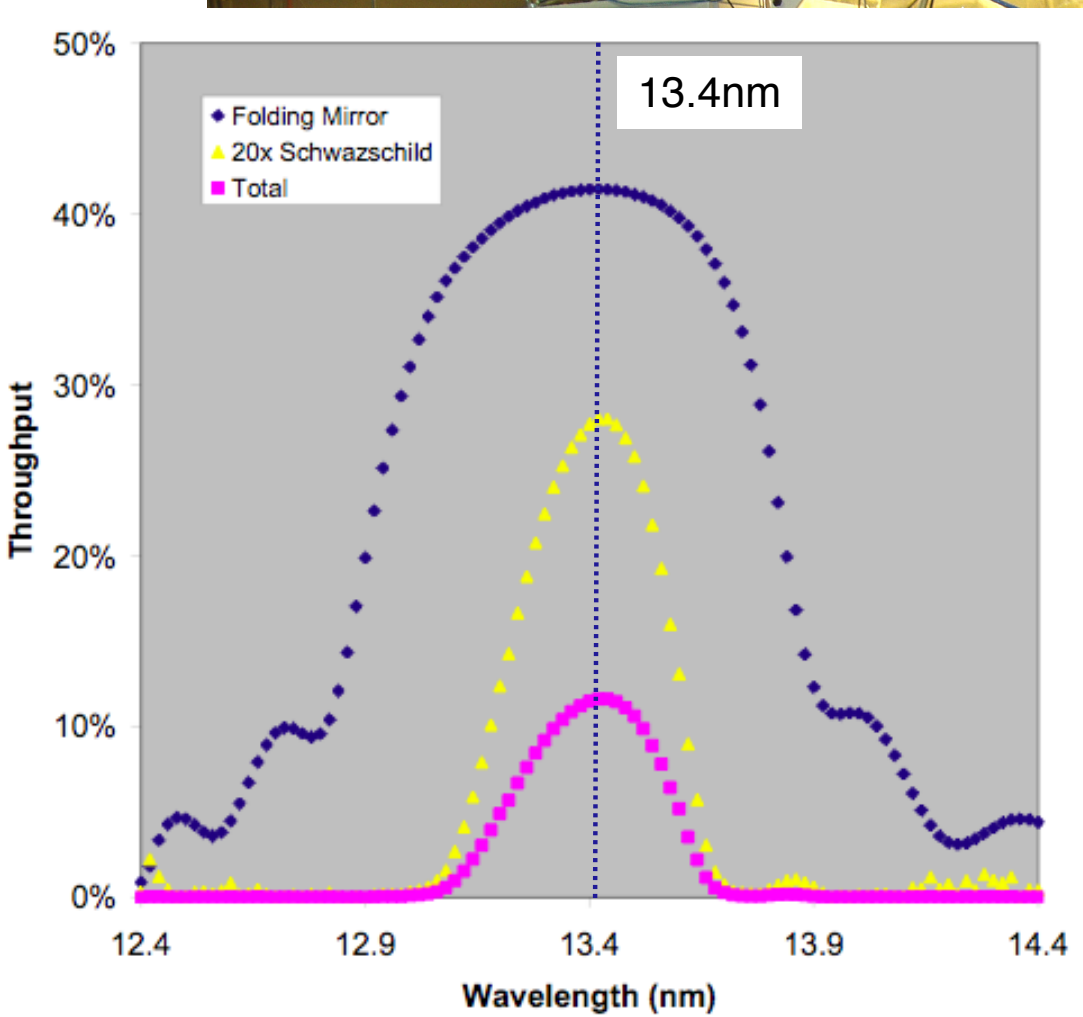
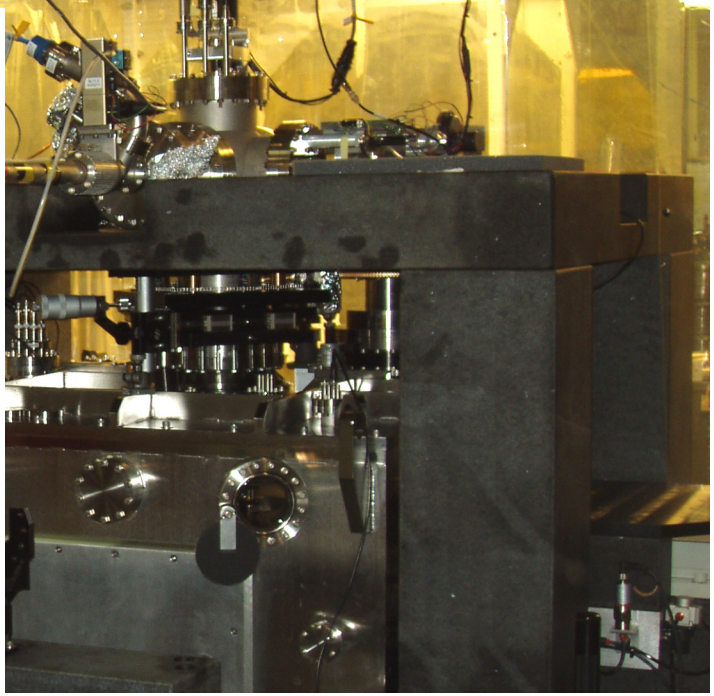


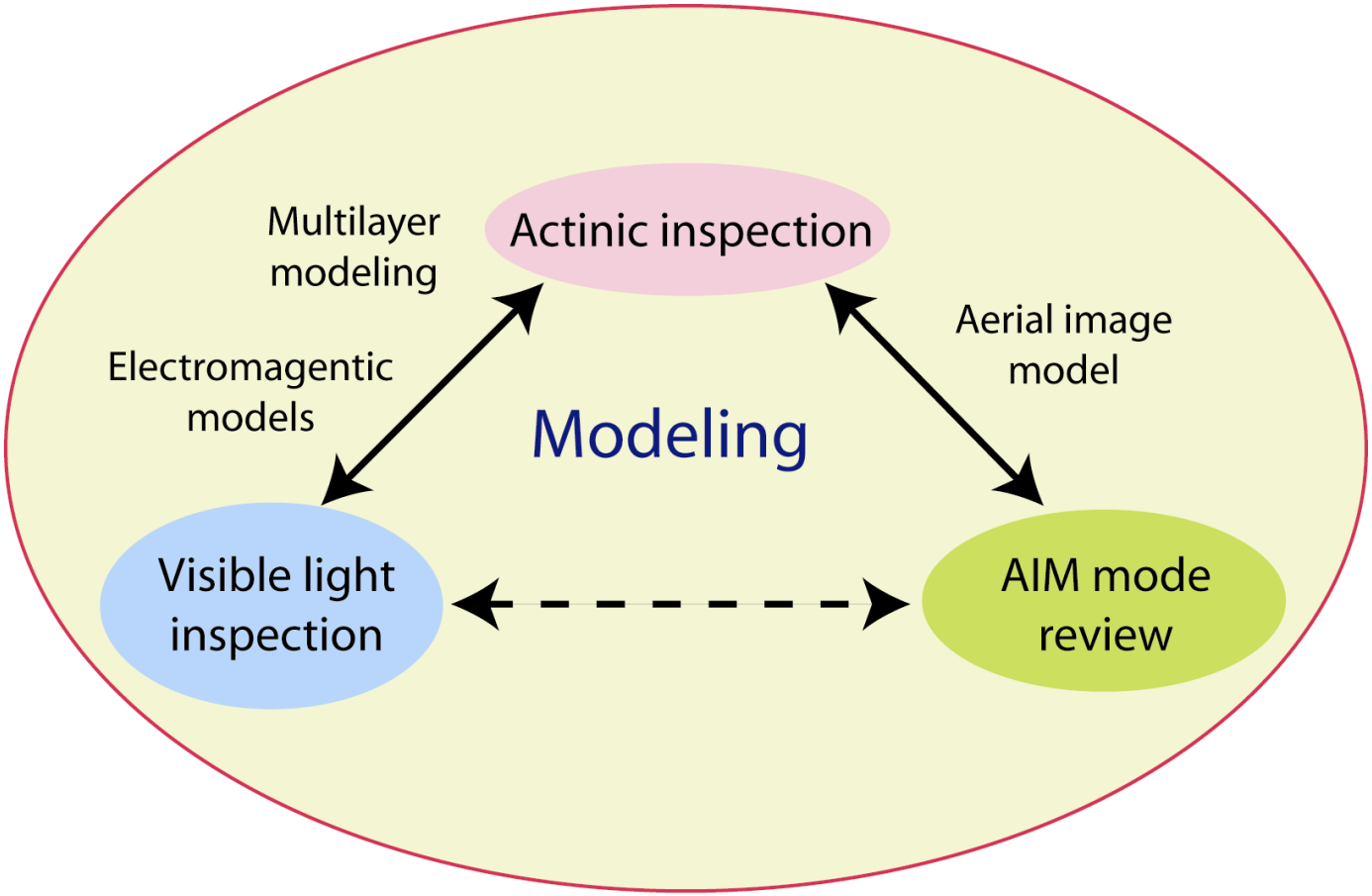




1.3μW at 13.4nm in a 1μm spot at the mask

Peak throughput: 13.4nm
Angle of incidence at the mask: 6°

Experimental plan incorporates cross-correlation experiments using both programmed and native defects



Multilayer and system modeling facilitates advanced learning on defect inspection and printability.

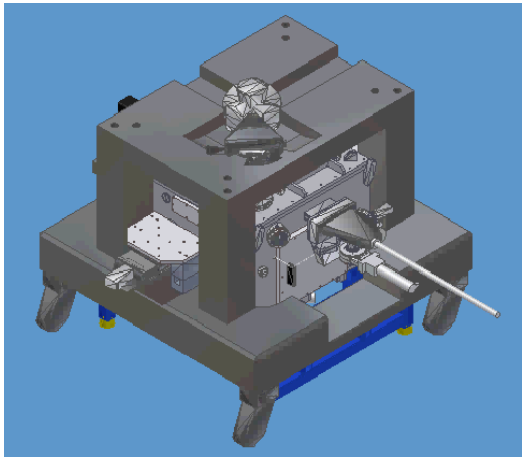
Comparison of predicted and measured inspection signal and aerial images closes the loop on inspection learning:

- Does theory match experiment??

Modeling lays the scientific groundwork to address differences between actinic and non-actinic inspection

2. Actinic Inspection

- Predict performance of actinic inspection system
- Validate EUV scattering models
- Characterise system performance



1. Non-actinic inspection

- Analyse optical performance of commercial, non-actinic EUV mask inspection systems
- In particular, confocal microscope based systems
- Validate calculations using Lasertec M1350
- Predict performance of next-generation tools (eg: the Lasertec M266)

3. EUV printability

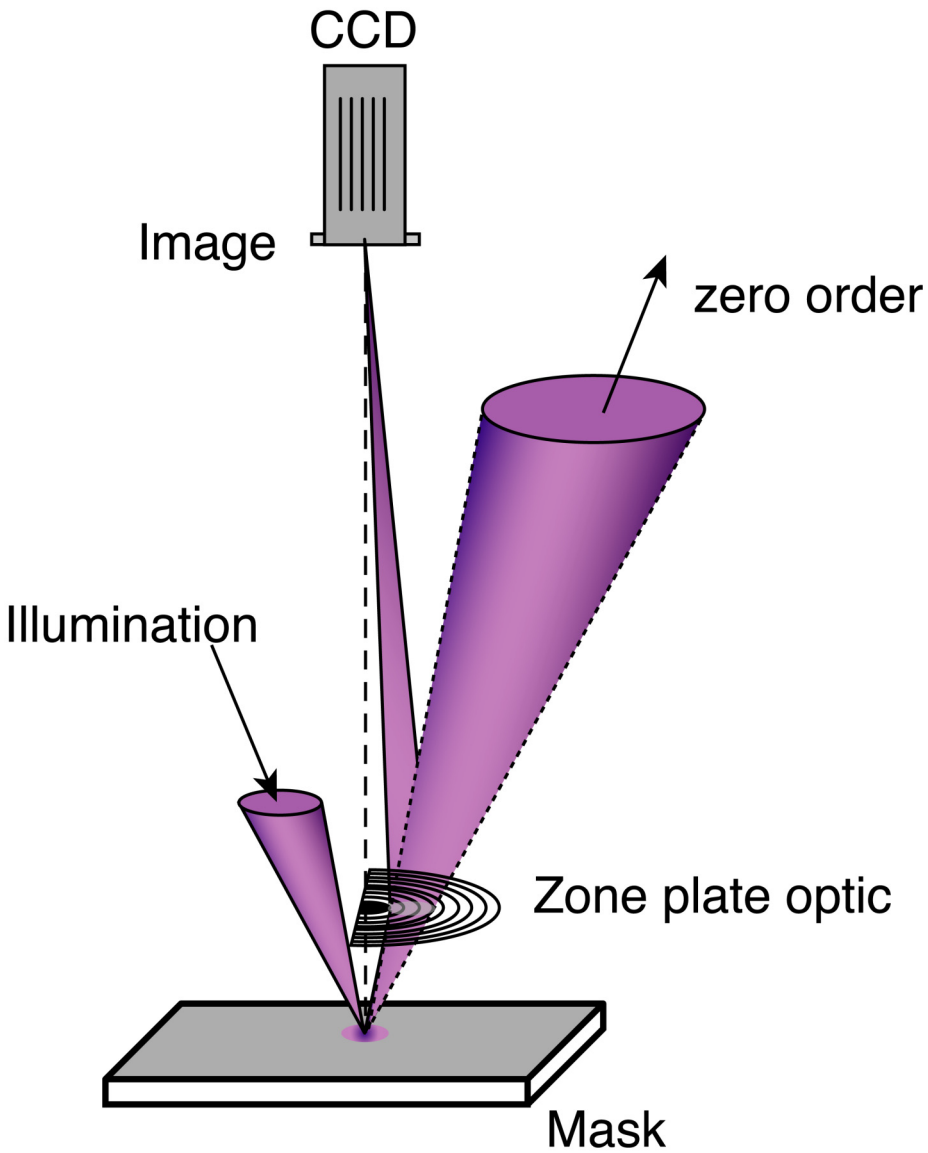
- Are all detected defects printable?
- Are any printable defects not detected?

Initial performance in imaging mode

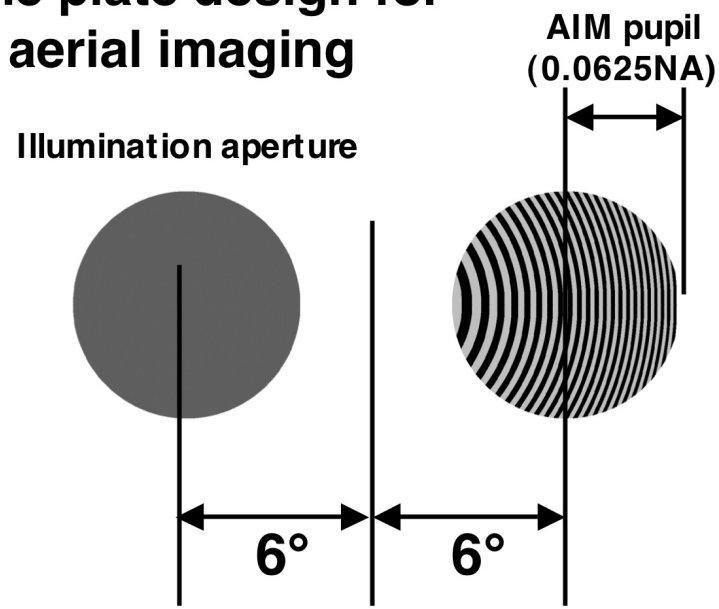
Imaging sub-system consists of a zone plate microscope imaging onto a CCD camera

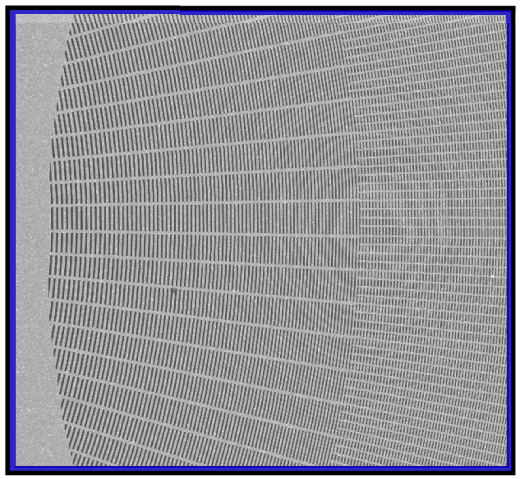
- **Designed to match the numerical aperture and angle of incidence of a 0.25NA stepper system (AIM mode)**
- **Digital capture of the aerial image enables printability assessment**
- **Coordinate location cross-correlated with high-speed scanning mode**
- **System design is not restricted to AIM mode imaging:**
  High resolution imaging possible using a zone plate design with a larger input aperture than used for AIM mode imaging

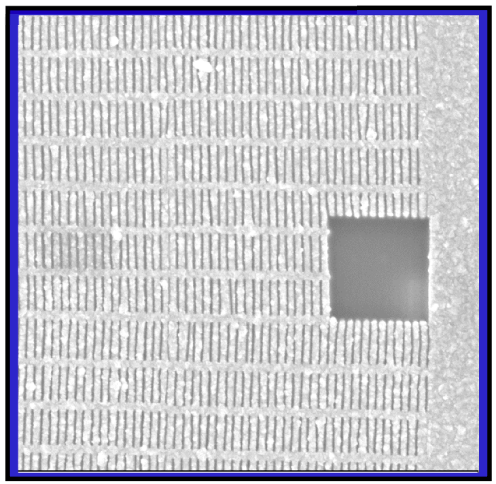
Off-axis zone plate design to be used for AIM mode imaging



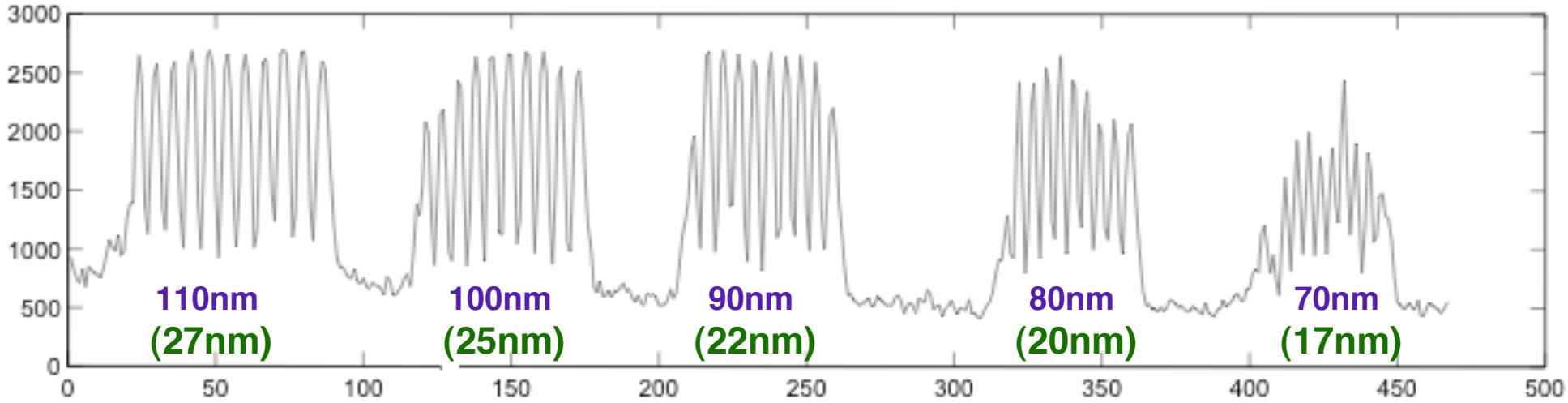
Zone plate design for aerial imaging

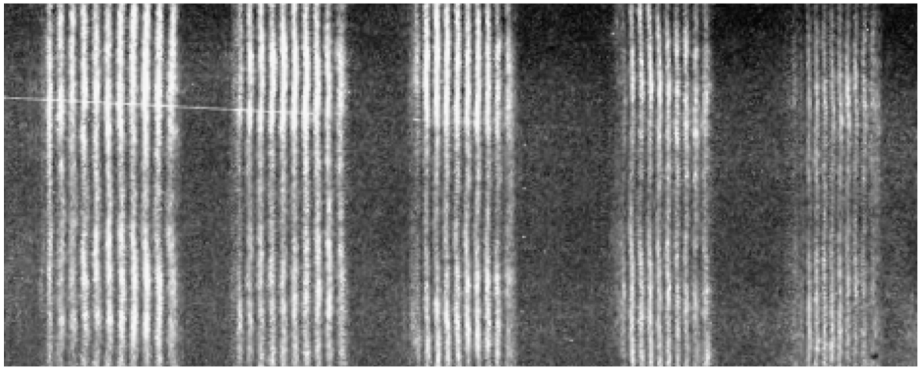






80nm resolution at the mask (20nm at the wafer) demonstrated using free-standing zone plate design





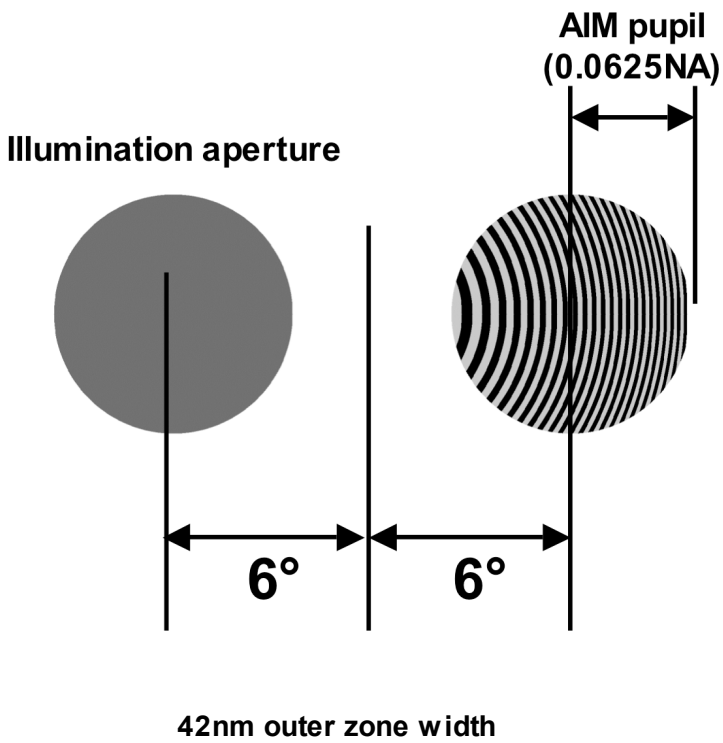
Coherent resolution cutoff at 107nm

Coherence and vibration artifacts are present in these images
(σ<0.1 here vs σ=0.6-0.8 in final system)

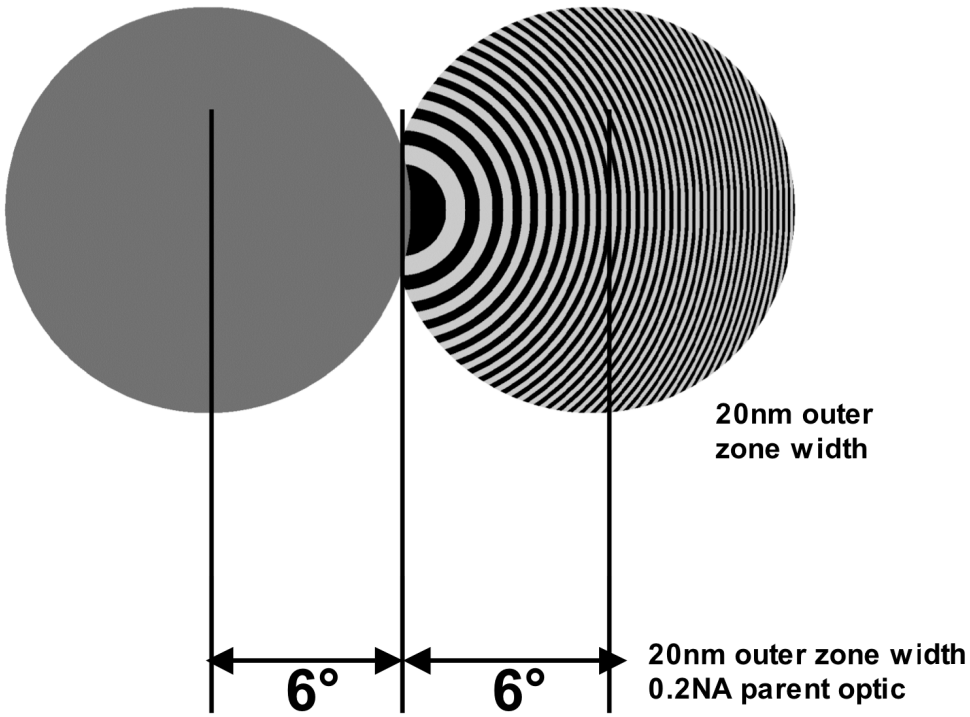
110nm, 100nm, 90nm, 80nm, 70nm at mask
27nm, 25nm, 22nm, 20nm, 17nm at wafer

High-resolution imaging is possible by changing zone plates

Zone plate for AIM imaging



Zone plate for high resolution imaging



Expect 20nm resolution on mask = 5nm on wafer

Conclusion and status

Accurate, validated defect inspection metrology is essential to understanding defects and benchmarking industry tools and progress

A new at-wavelength mask inspection end station is installed at the ALS and is being used to validate the efficacy of laser-based mask inspection

- **High-speed at-wavelength inspection to locate defects on production mask blanks and record defect coordinates**
- **Defect review using an at-wavelength aerial image microscope (also useful for pattern inspection in synergy with with MET printing)**
- **Integrated modeling of actinic inspection, non-actinic inspection and defect printability is being used to understand EUV defects**

This project supports the SEMATECH EUV mask blank pilot line project at Albany, NY and is funded under SEMATECH project Lith-343

Key technical personnel

SEMATECH

Obert Wood

LLNL

Anton Barty
Rick Levesque
Jay Ayers
Shannon Ward

LBNL

Yanwei Liu
Eric Gullikson
Paul Barale
Seno Rekawa
Ron Tackaberry
…and the CXRO team
Alex Liddle

Rohwedder Inc.

David Thompson
Jeff Budd
Jeff Rosino