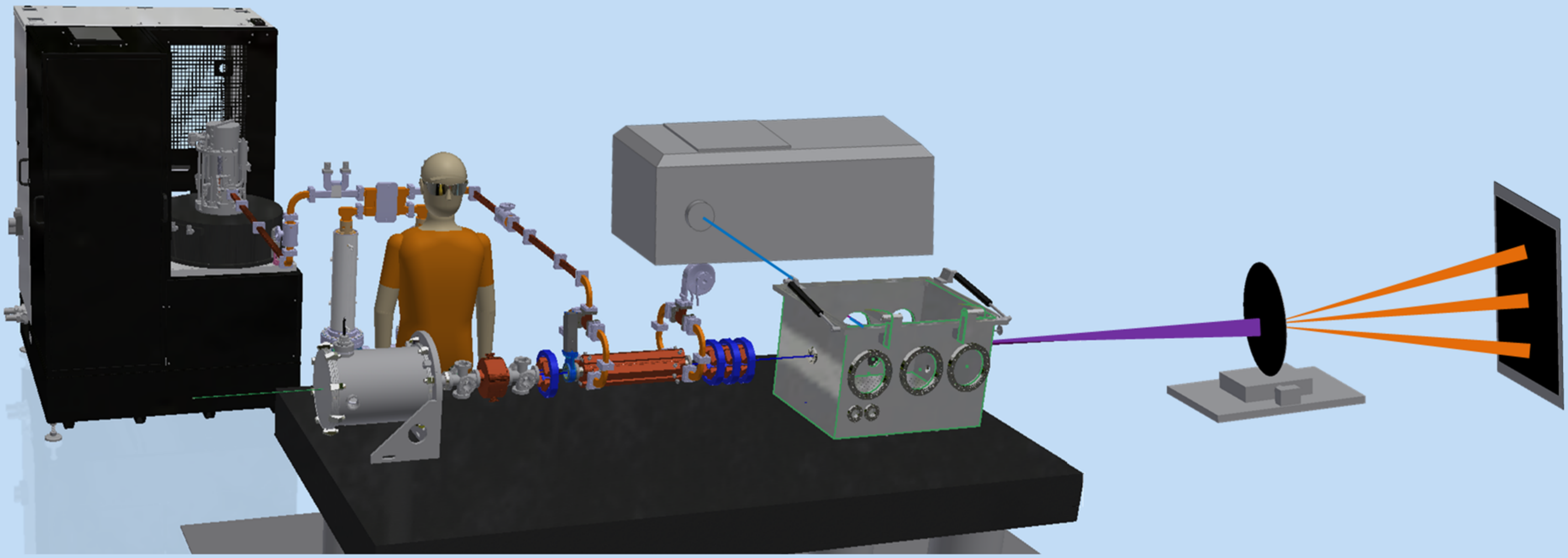
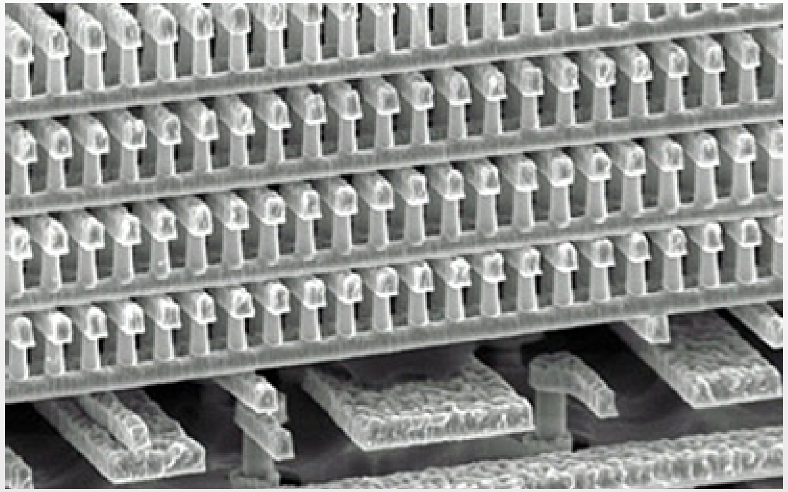
ICS bright X-ray system



The challenge
Measuring is knowing

How to measure and qualify the dimensions of these semiconductor devices?



The finest details will have dimensions of 1 to 2 nm in the future.

To optimize semicon equipment + material process parameters, sub-nm resolution metrology is required.

Metrology solutions

- CD-SEM — Critical Dimension Scanning Electron Beam Microscope
- OCD — Optical Critical Dimension scatterometry
- CD-AFM — Critical Dimension Atomic Force Microscopy
- CD-SAXS — Critical Dimension Small Angle X-ray Scatterometry
- TEM — Transmission Electron Microscopy

CD Metrology Overview

HITACHI
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Metrology method	Pros	Cons
CD-SEM (image-based) (In-line use)	➢ Measure any complex arbitrary feature ➢ Direct measurement from image (no modeling) ➢ Automated, stable, precise	➢ Mid throughput for large area coverage ➢ Difficult to measure pattern height
Optical Scatterometry (OCD) (model-based) (in-line use)	➢ High throughput (for global monitoring) ➢ High sensitivity, CD/ 3D profile measurement ➢ Automated, stable, precise	➢ Average measurement only (unavailable for complex pattern) ➢ Long time for modeling (recipe setup) (reference needs)
CD-AFM (image-based)	➢ Measure 3D profile of arbitrary feature	➢ Measurable pattern is limited ➢ Low throughput
X-ray Scatterometry (CD-SAXS) (model-based) (off-line)	➢ CD/ 2D X-section profile measurement	➢ Need large test pad ➢ Average measurement only (unavailable for complex pattern) ➢ Low throughput
Cross section TEM/ STEM (image-based) (off-line)	➢ Atomic resolution, CD/ 3D profile measurement	➢ Destructive ➢ Low throughput

CDSAXS is the only non-destructive metrology for deep 2D x-section profile measurements

Unavoidable property of CDSAXS metrology

If throughput can be sufficiently increased, CDSAXS is a valuable metrology solution

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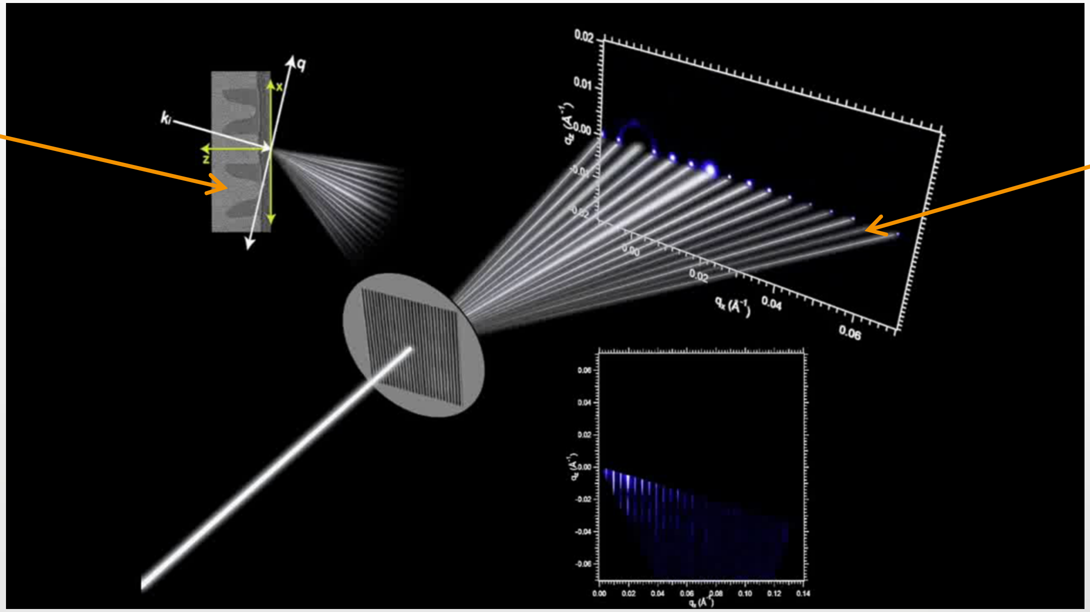
Metrology solution: CDSAXS

The measured intensities of the diffracted orders are used to reconstruct an average 2D profile

Reconstructed 2D profile

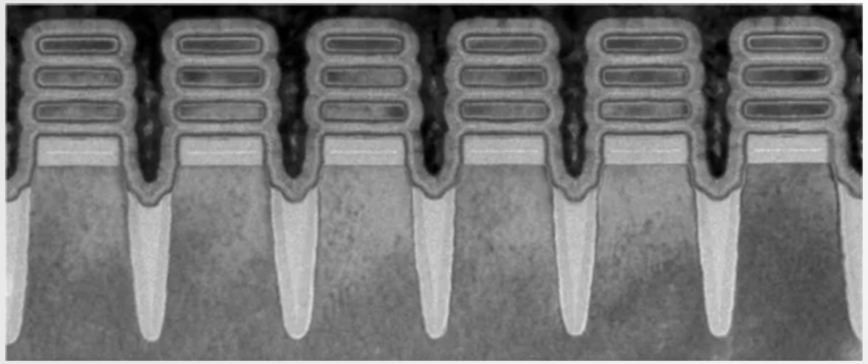


Diffracted orders

Ref.: X-ray scattering critical dimension metrology using a compact x-ray source for next generation semiconductor devices, Joseph Kline, J. Micro/Nanlith. MEMS MOEMS 16(1), 2017

Destructive TEM versus non-destructive CDSAXS measurements

TEM picture of nanosheet transistors



Two-nanometer technology as seen using transmission electron microscopy. Two nanometers is smaller than the width of a single strand of human DNA. [Image: courtesy of IBM]

Destructive measurement (wafer can not be used anymore)

Reconstructed 2D profile using CDSAXS ??

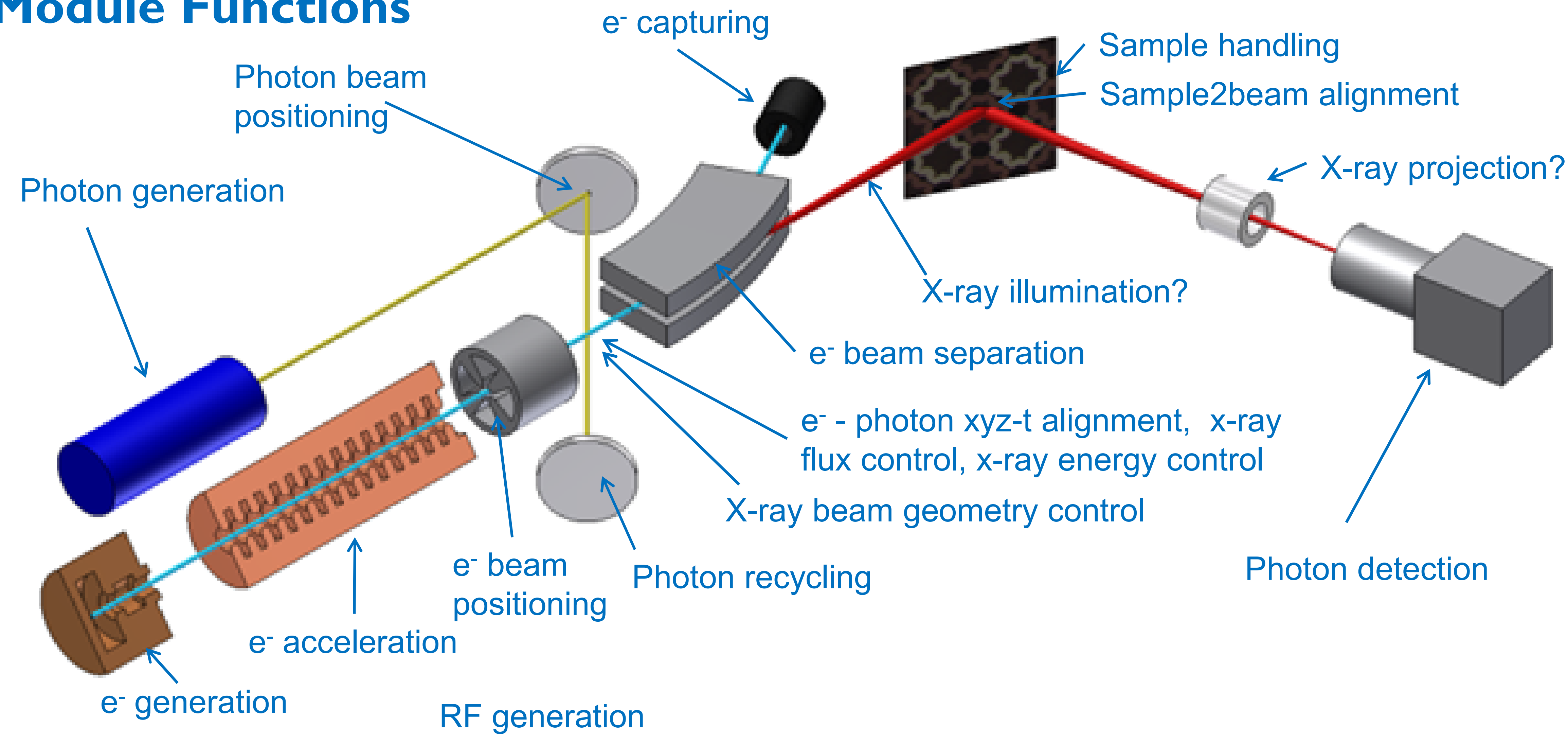
Extracted information (?):

- Height
- Distances
- Slopes
- ?

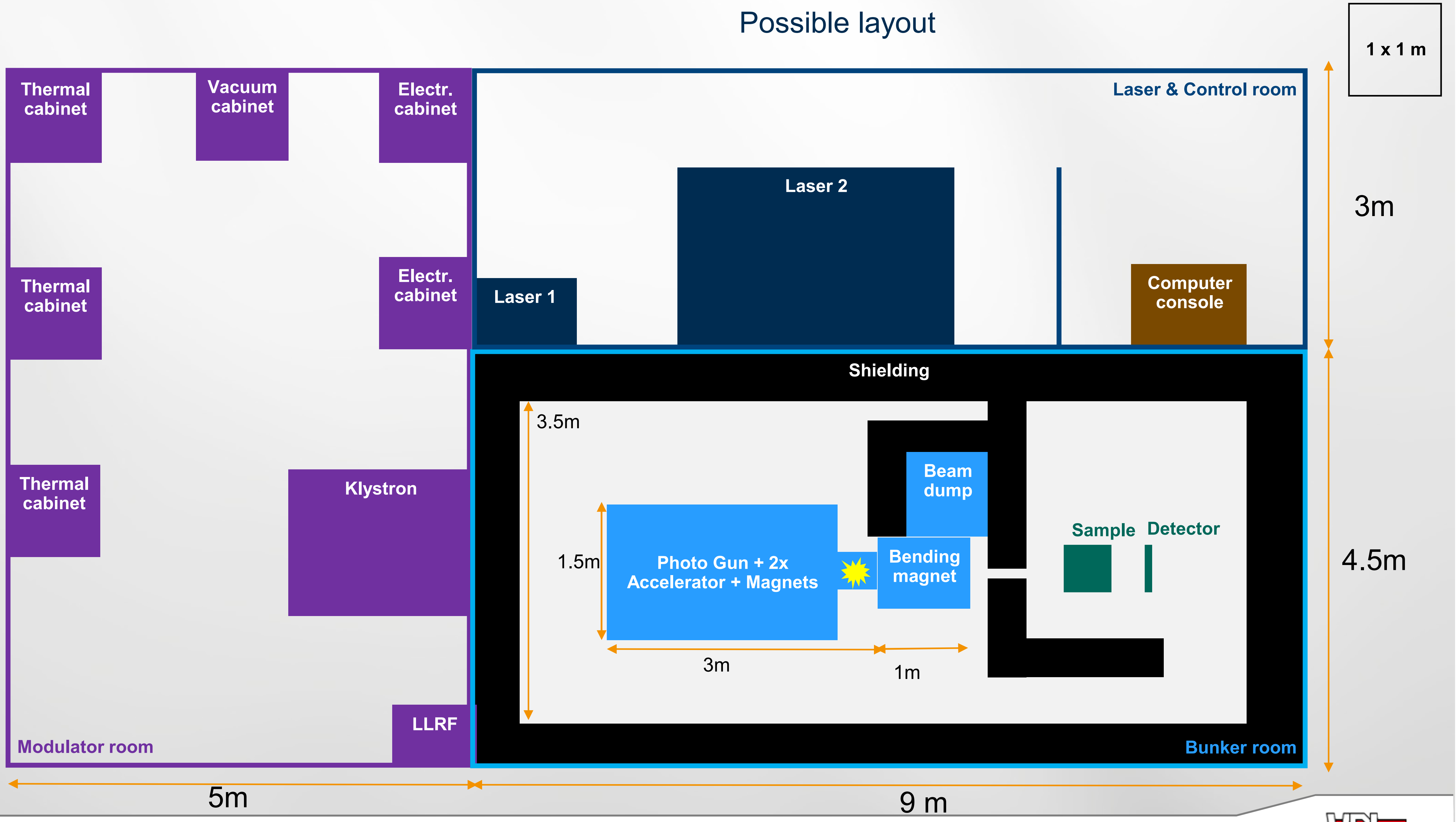
It is not clear yet what useful information can be extracted with the CDSAXS measurements

If sufficiently fast, measurements could also be done after successive process steps instead of measuring the complete profile at once

Module Functions

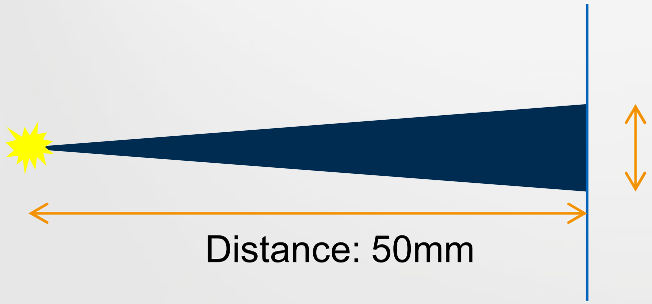


Possible layout

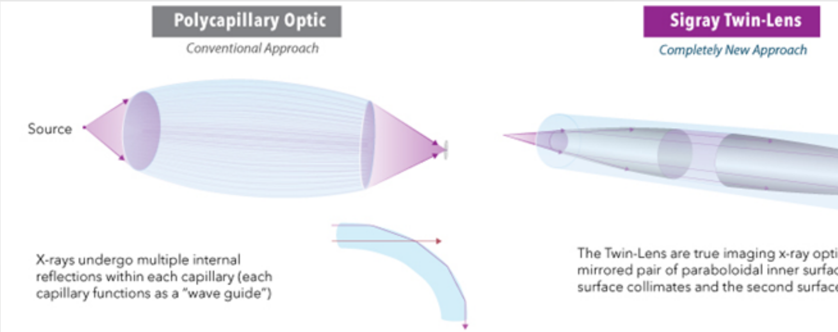


X-ray optics
Distances

With 1 mrad beam divergence and 50µm spotsize, source-wafer distance needs to be 50 mm, this is too small



Distance needs to be >100mm. What mirrors are needed? How much light will be lost?



Solution?

Performance

	Unit	Value	Remark
X-ray energy	keV	20	
X-ray energy spread, FWHM	%	1	
Beam divergence	mrad	1	
Spot size at wafer	µm	100	50 µm may a better target
Photon flux	#/s	10^8	Request is 10^{9-10}, but 10^8 seems feasible

It seems unlikely that changing the energy to probe the wafer at different depths avoids wafer rotation.

Measurement time versus flux

- From the article of Joe Kline, NIST, relation flux – measurement time:

Exposure time (s)	High-*k*-coated fin (ph/s)	Si fin (ph/s)	Resist (ph/s)
1	10^9	10^{10}	10^{12}
10	10^8	10^9	10^{11}
100	10^7	10^8	10^{10}

Concluding remarks

- Flux might be the bottleneck
  - If the flux can be made high enough, the ICS system is a feasible solution for wafer inspection

- IMEC, Leuven, is a candidate to be the first ‘customer’
  - IMEC is a leading semicon research facility that serves many semicon industries
  - First impression: with the expected price between 6 and 10 M€, business case looks good