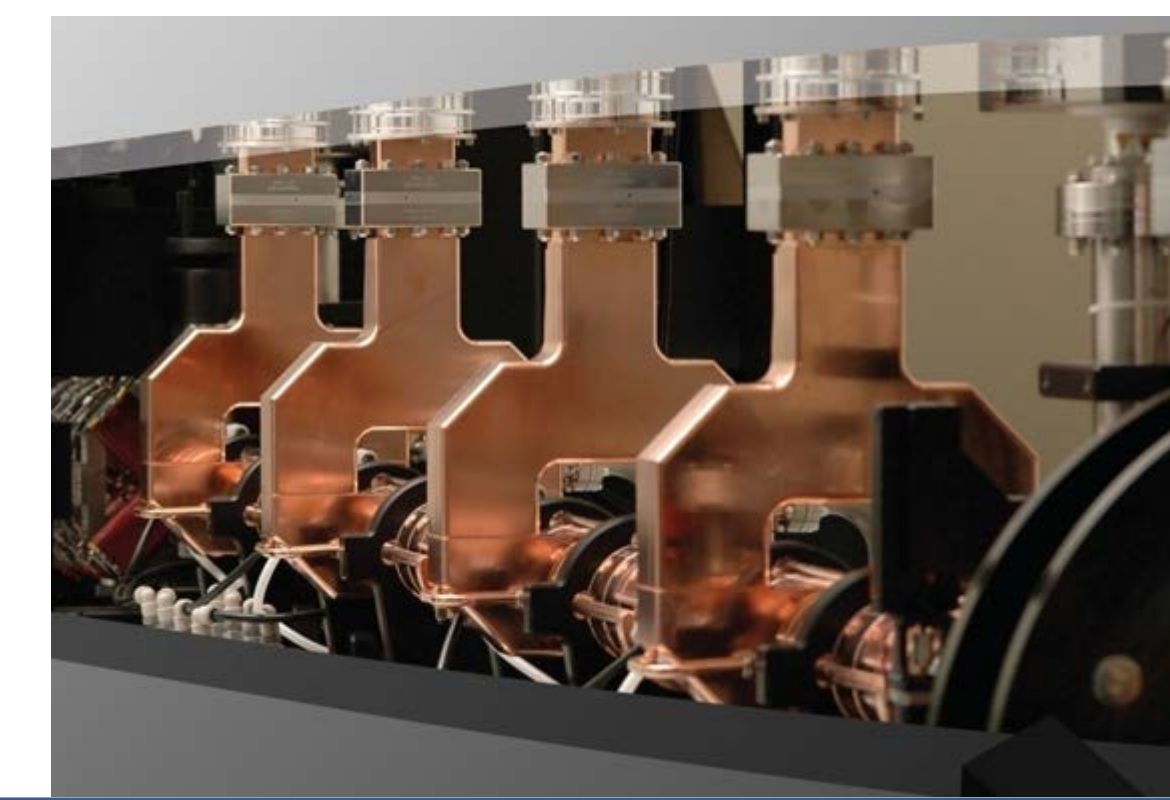


High Throughput X-ray CD Metrology

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INTRODUCTION

- Conventional CD metrology techniques face challenges to pace with 3D device architectures, increasingly smaller feature size and design tolerances, and new materials
- Limitations in existing tools drive the need for development of new techniques that can offer a path to process control in high volume manufacturing (HVM)
- Hard x-rays, as a replacement for optical scatterometry, can penetrate materials to create scattering profiles that are highly sensitive to patterned structure dimensions
- Unlike optical scatterometry, x-ray scattering methods become easier as feature sizes shrink

CONCEPT

- Two conventional x-ray scatterometry methods have been evaluated for CD metrology
 - CD Small Angle X-ray Scattering (CD-SAXS) developed at NIST (Wen-li Wu) used in transmission mode
 - Grazing Incidence Small Angle X-ray Scattering (GI-SAXS), a conventional technique used in reflection mode
- CD-SAXS requires high energy x-rays (≥ 15 keV) and x-ray brightness that is currently 3 to 4 orders of magnitude higher than current conventional lab sources in order to be useful in HVM
- GI-SAXS is performed at lower x-ray energies (~ 8 keV) and produces more scattering signal than CD-SAXS, but suffers from large spot sizes, is dominated by surface features and requires more complicated analysis to extract structure information
- This poster presents a complementary, reflection based x-ray method called **Grazing Incidence In-plane Diffraction (GIID)**. This method employs a *focused* x-ray beam in which the sample itself produces interference effects that are highly dependent on the periodic structure of the patterned objects

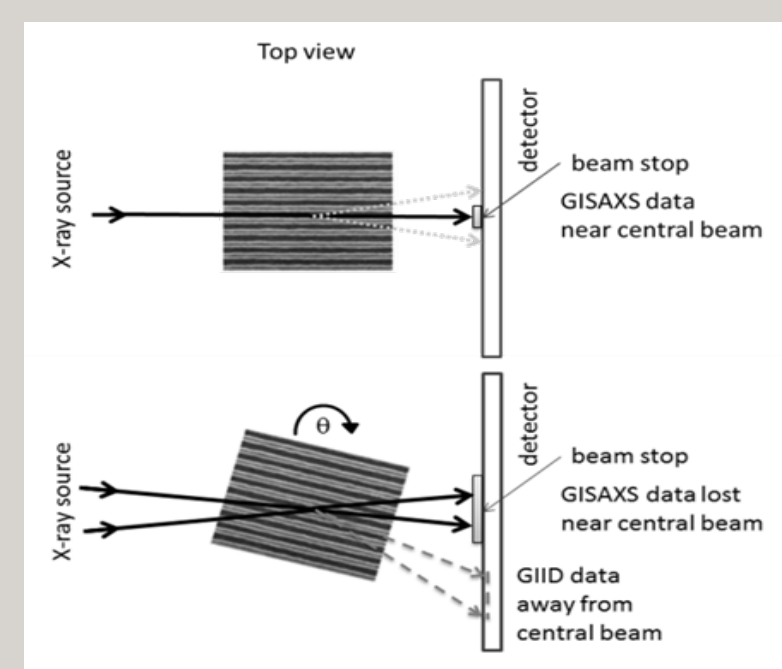
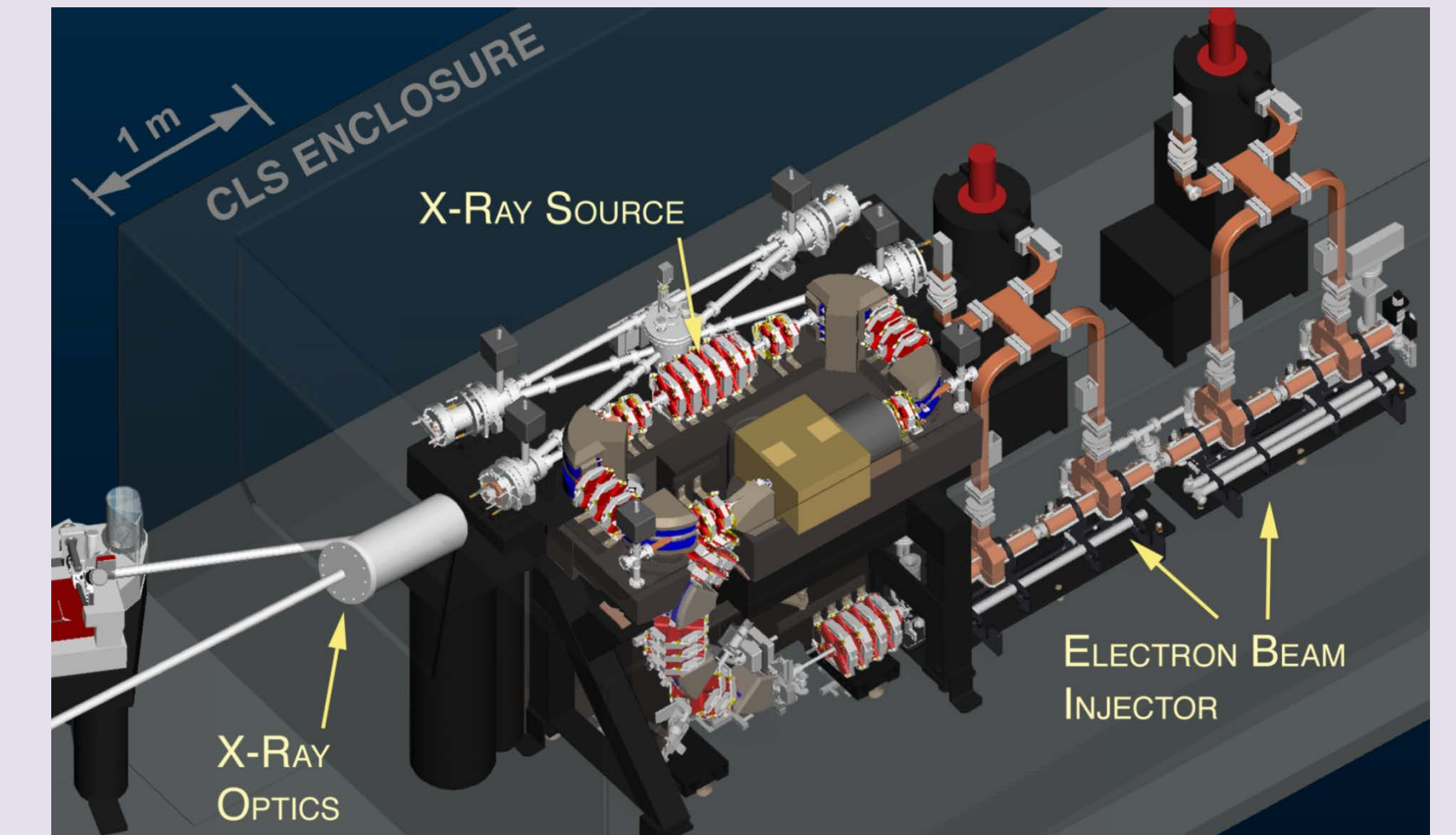
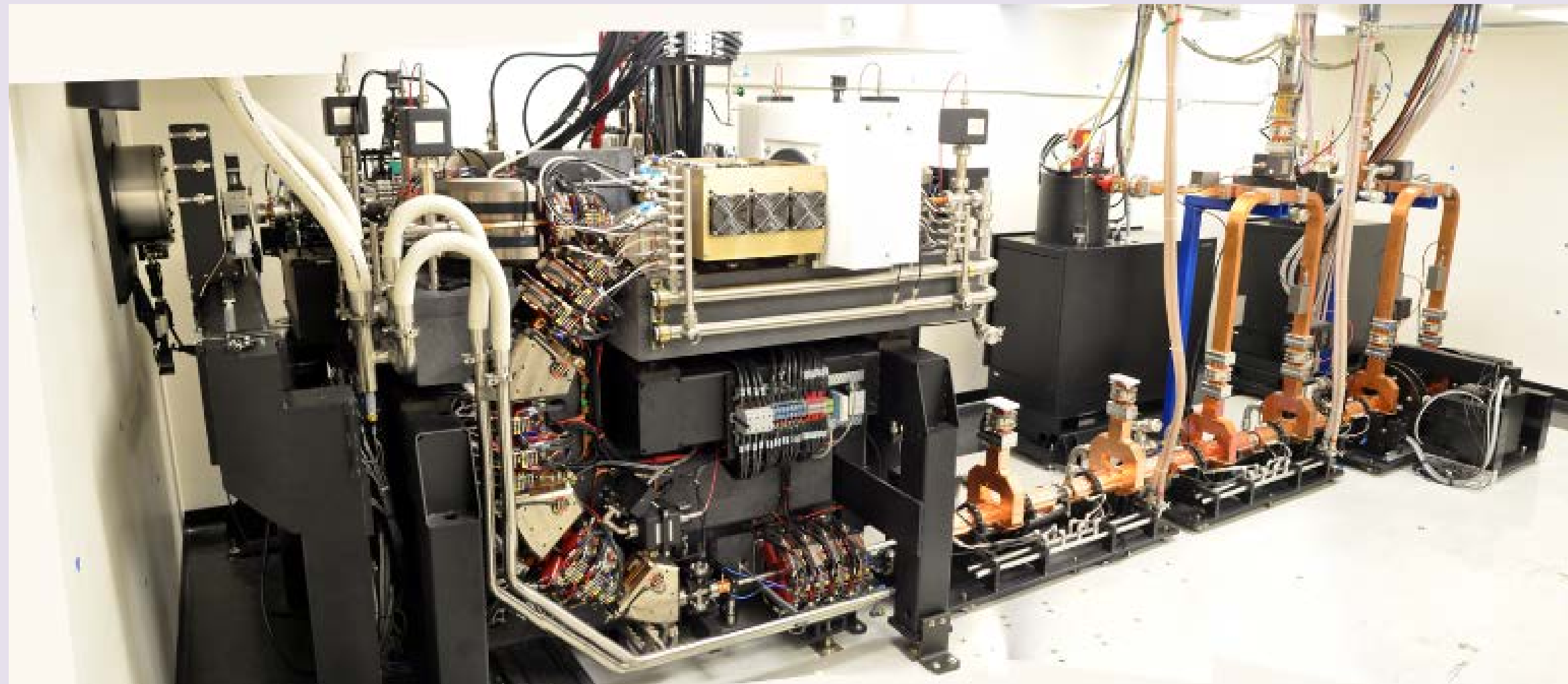


Figure 1: Top view comparison of GI-SAXS and GIID. At top, GI-SAXS requires a collimated beam and fine alignment of features along the beam direction. A beam stop is used to prevent the detector from saturating in order to measure scattering. At bottom, rotating the sample in-plane creates conditions for **interference effects from multiple scattering sites** in the patterned sample.

- Unlike typical diffraction methods, the sample itself modulates the intensity profile by relying on a superposition of optical path phase effects, which for a monochromatic beam is geometrical
- By using higher energy x-rays (≥ 15 keV) in a specific reflection orientation, enhanced in-plane signals resulting from the interference of multiple interfaces can dramatically increase the cross-section of scattering
- The in-plane scattered signal contains information about the absolute linewidth and spacing, and in multiple pattern deposition applications, variations such as pitch walk and roughness
- Combined with a higher brightness x-ray source such as the Lyncean Compact Light Source, GIID has 10,000x higher throughput than CD-SAXS, providing a path towards a HVM process control tool

ENABLING TECHNOLOGY: LYNCEAN COMPACT LIGHT SOURCE



- The Lyncean Compact Light Source (CLS) is the first and only technology in the world that can fit in a laboratory and produce near monochromatic, tunable x-ray that approach the quality of x-ray beams produced at a synchrotron
- The CLS is a new X-ray source based on inverse Compton scattering in a mini-synchrotron
- A high-gain, optical enhancement cavity is employed to collide high-power laser pulses with an electron beam pulse circulating in the storage ring
- The combination of high optical power and high repetition rate produces high x-ray flux from a device that is 200x smaller than a synchrotron
- The first Lyncean CLS, installed in early 2015 at the Technical University of Munich is enabling Prof. Franz Pfeiffer's Bio-Medical physics group to conduct research and generate publications in grating based phase contrast imaging and other clinically motivated medical applications

FIRST RESULTS

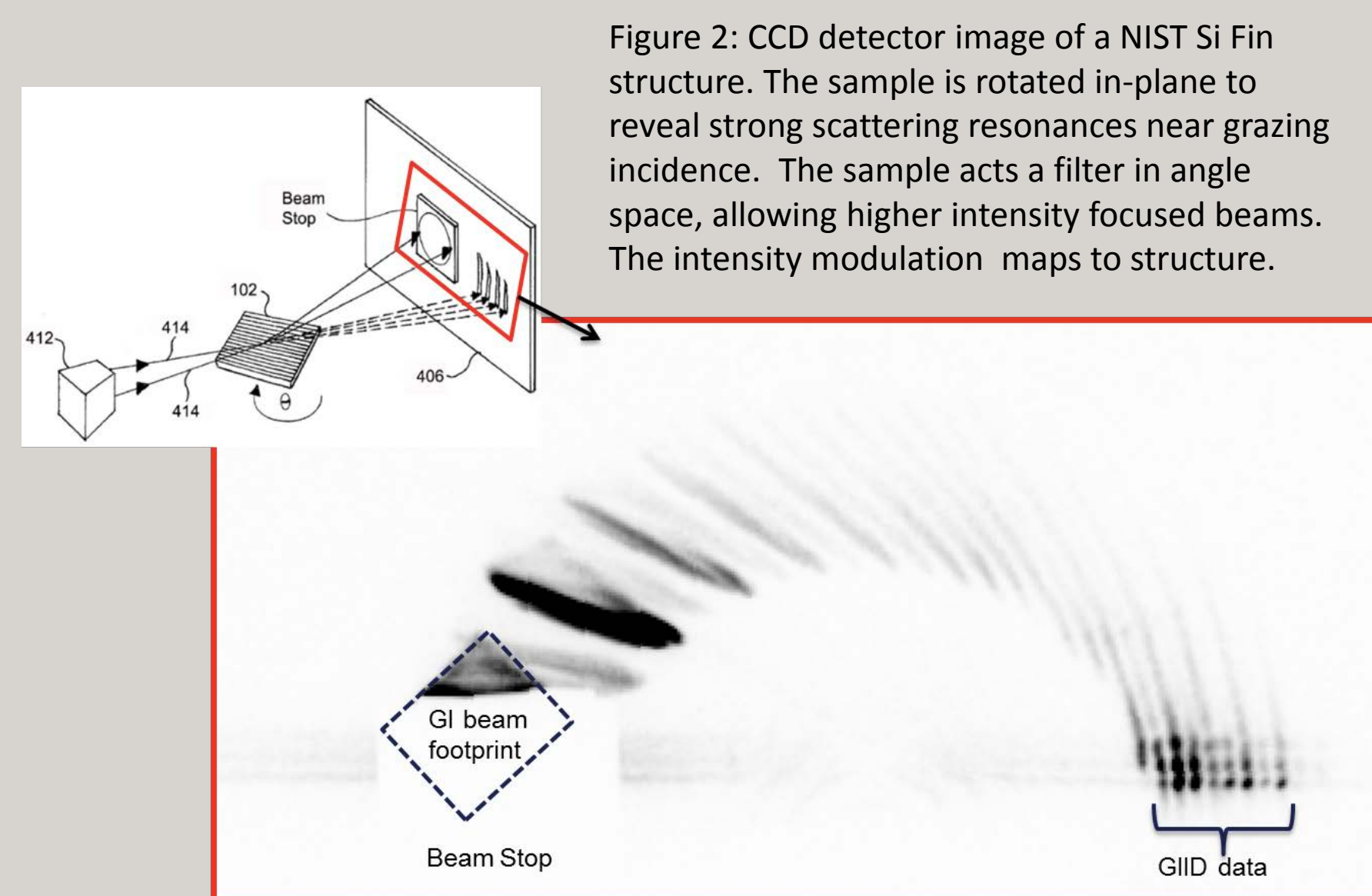


Figure 2: CCD detector image of a NIST Si Fin structure. The sample is rotated in-plane to reveal strong scattering resonances near grazing incidence. The sample acts a filter in angle space, allowing higher intensity focused beams. The intensity modulation maps to structure.

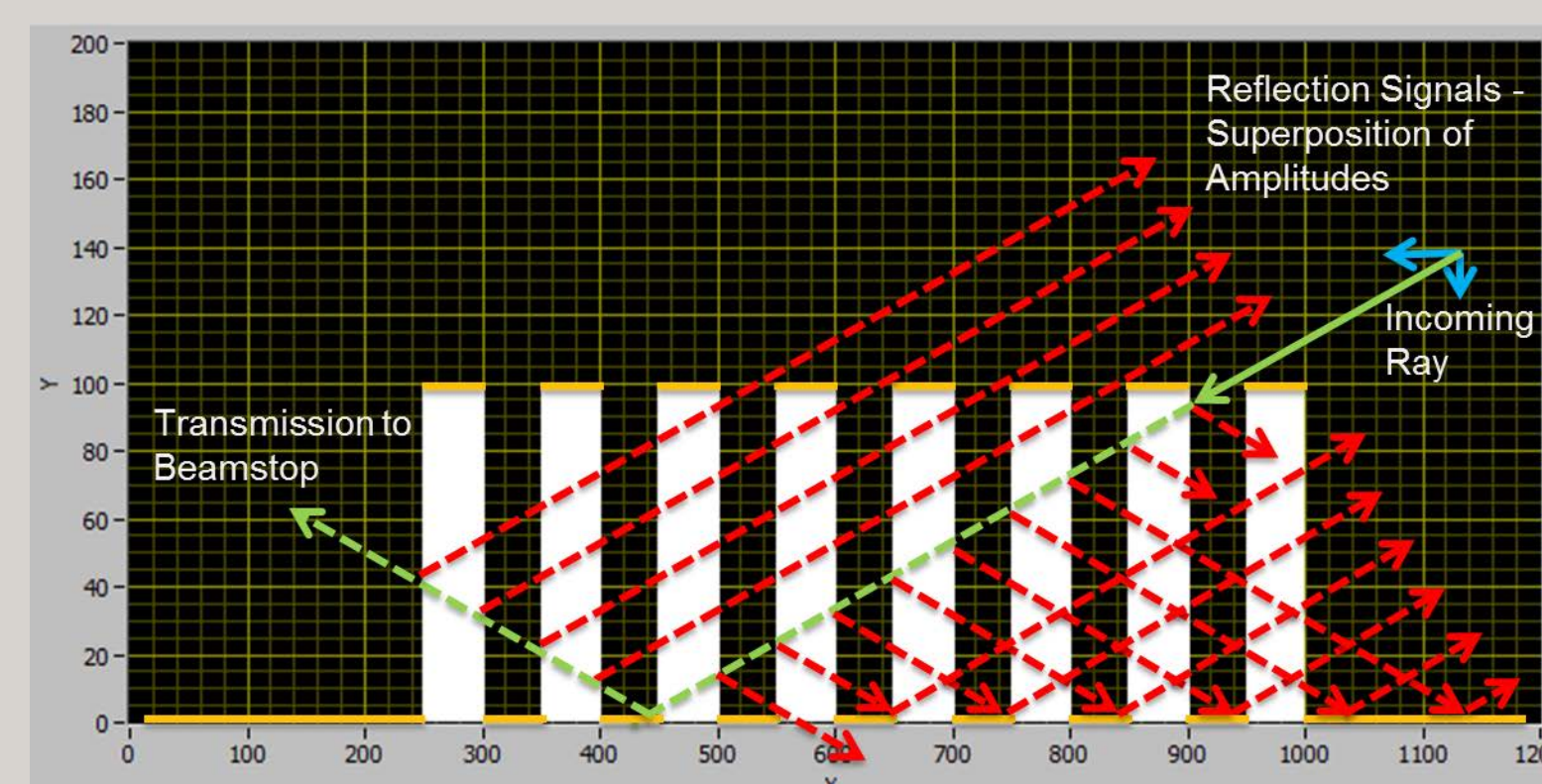


Figure 3: Each interface has a Fresnel reflection with a corresponding r , t amplitude. Some paths reflect off bottom substrate while others enter the substrate. Trajectories shown are "specular" but each has its own amplitude. Total paths include phase information (phasors).

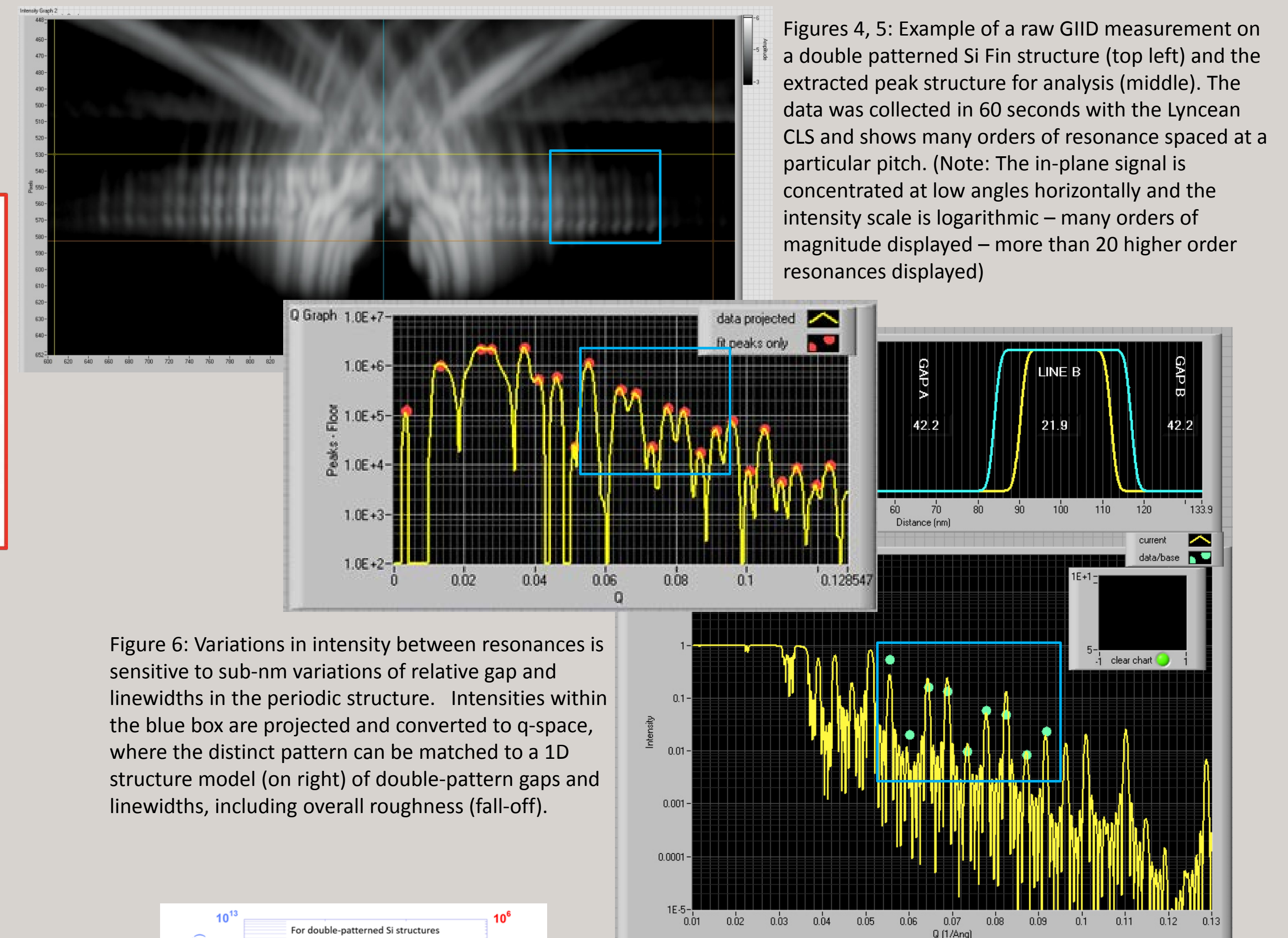


Figure 4, 5: Example of a raw GIID measurement on a double patterned Si Fin structure (top left) and the extracted peak structure for analysis (middle). The data was collected in 60 seconds with the Lyncean CLS and shows many orders of resonance spaced at a particular pitch. (Note: The in-plane signal is concentrated at low angles horizontally and the intensity scale is logarithmic – more than 20 higher order resonances displayed)

Figure 6: Variations in intensity between resonances is sensitive to sub-nm variations of relative gap and linewidths in the periodic structure. Intensities within the blue box are projected and converted to q-space, where the distinct pattern can be matched to a 1D structure model (on right) of double-pattern gaps and linewidths, including overall roughness (fall-off).

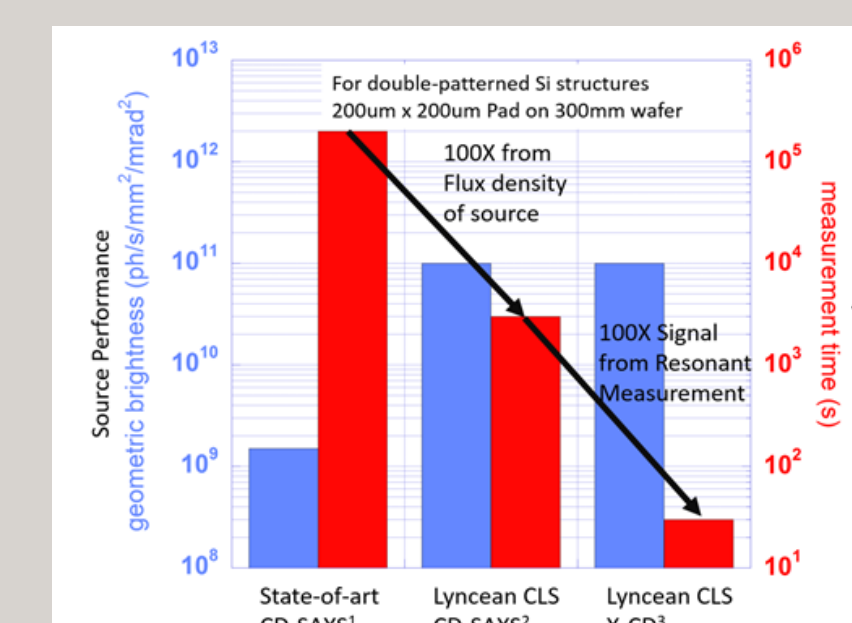


Figure 7: Comparison of raw source performance (left axis) and CD measurement time (right axis) for a 200 μm x 200 μm pad on a 300 mm wafer. The combination of CLS and GIID is 10,000x faster than CD-SAXS with a conventional lab source.