National Synchrotron Light Source II

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Light sources for microelectronics

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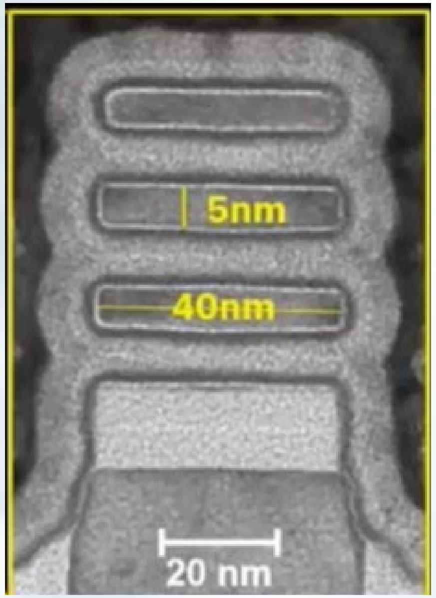
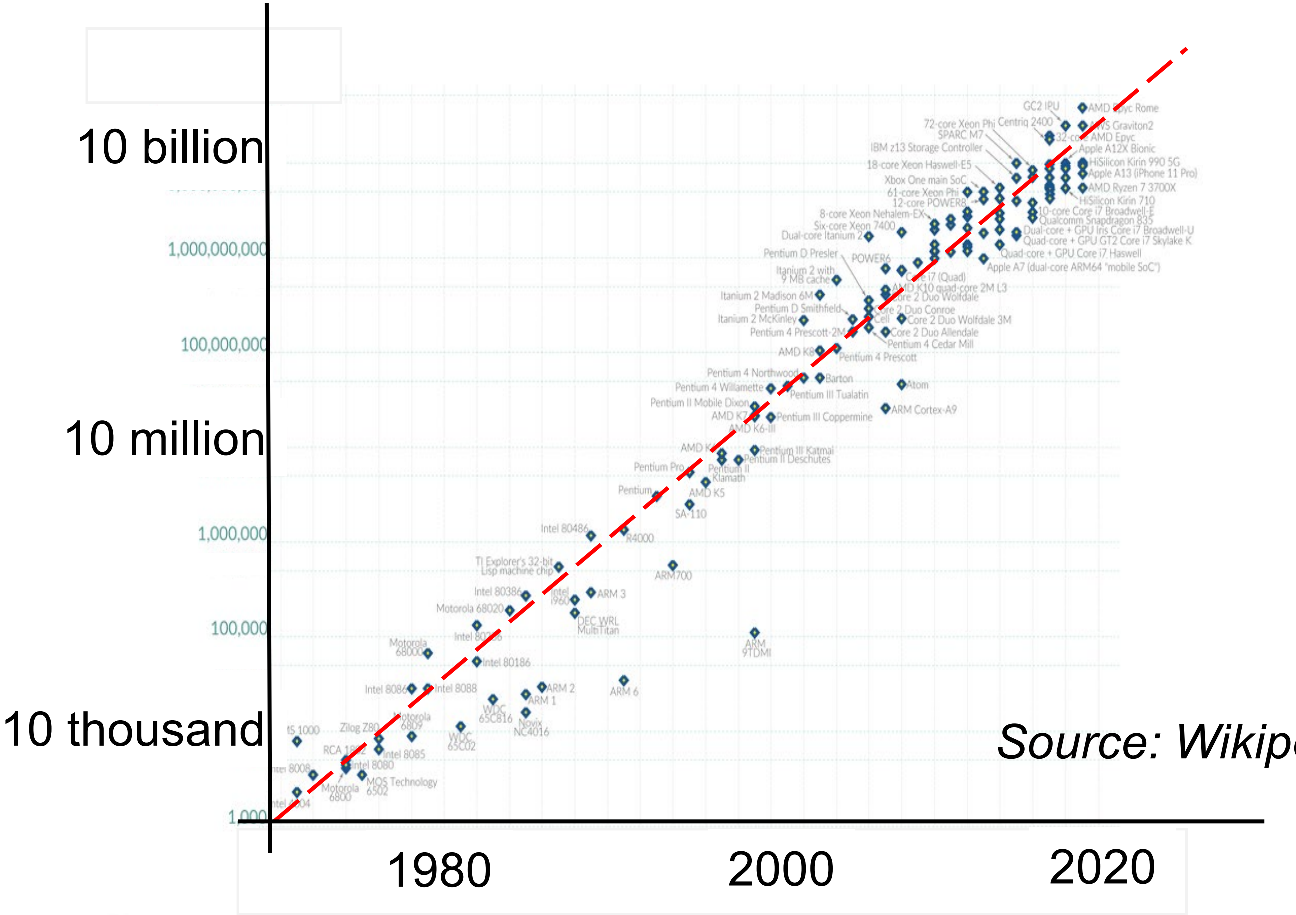
BESAC April 25th 2023



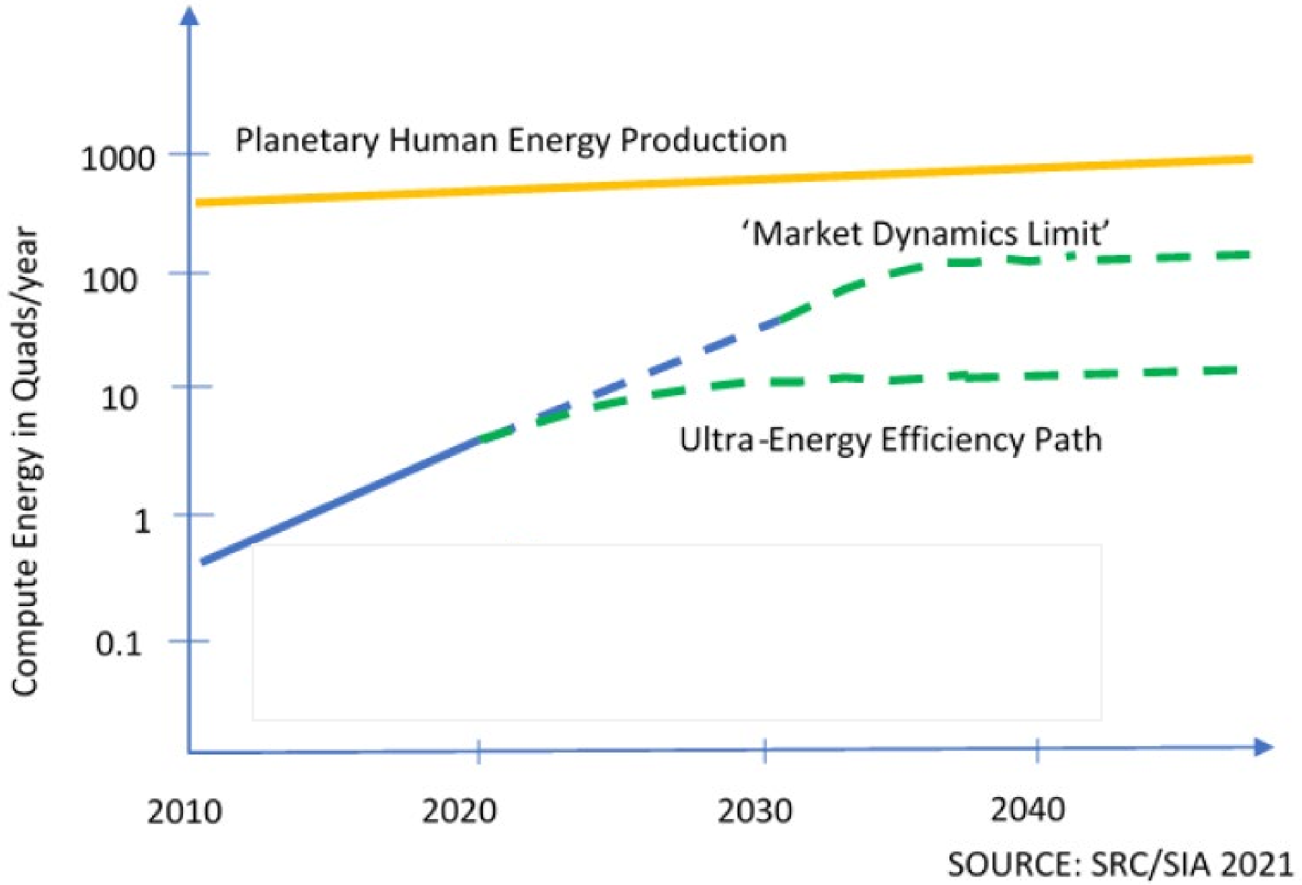
Two big drivers:1) Continue to increase functionality per chip



Source: Wikipedia

Moore’s law has driven unprecedented growth in the power and ubiquity of microelectronics making them essential to everyday life, and to national security

2) Energy efficiency

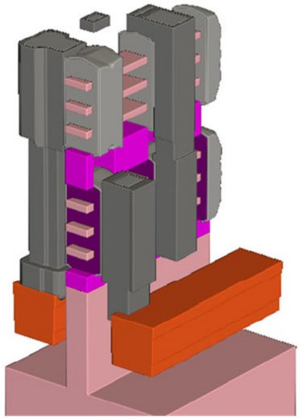


If current trends were to continue, microchips would use a significant fraction of the world's energy production by 2035

Future of Computing*

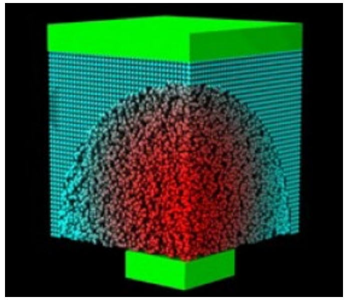
To solve these problems, industry is taking three approaches:

1) Dense 3D integration through materials breakthroughs and device architecture innovations



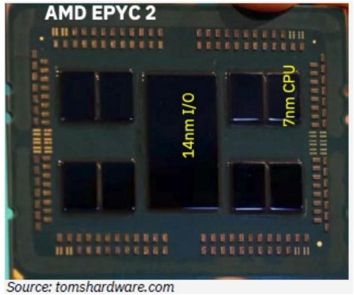
3D architectures

2) Analog AI cores using non-volatile memory for energy efficient neural networks



Phase change memory

3) Chiplet technology to enable high-bandwidth interoperability of disparate components to increase compute density and improve yield



Source: tomshardware.com

Chiplet block from AMD

*courtesy of V. Narayanan (IBM)

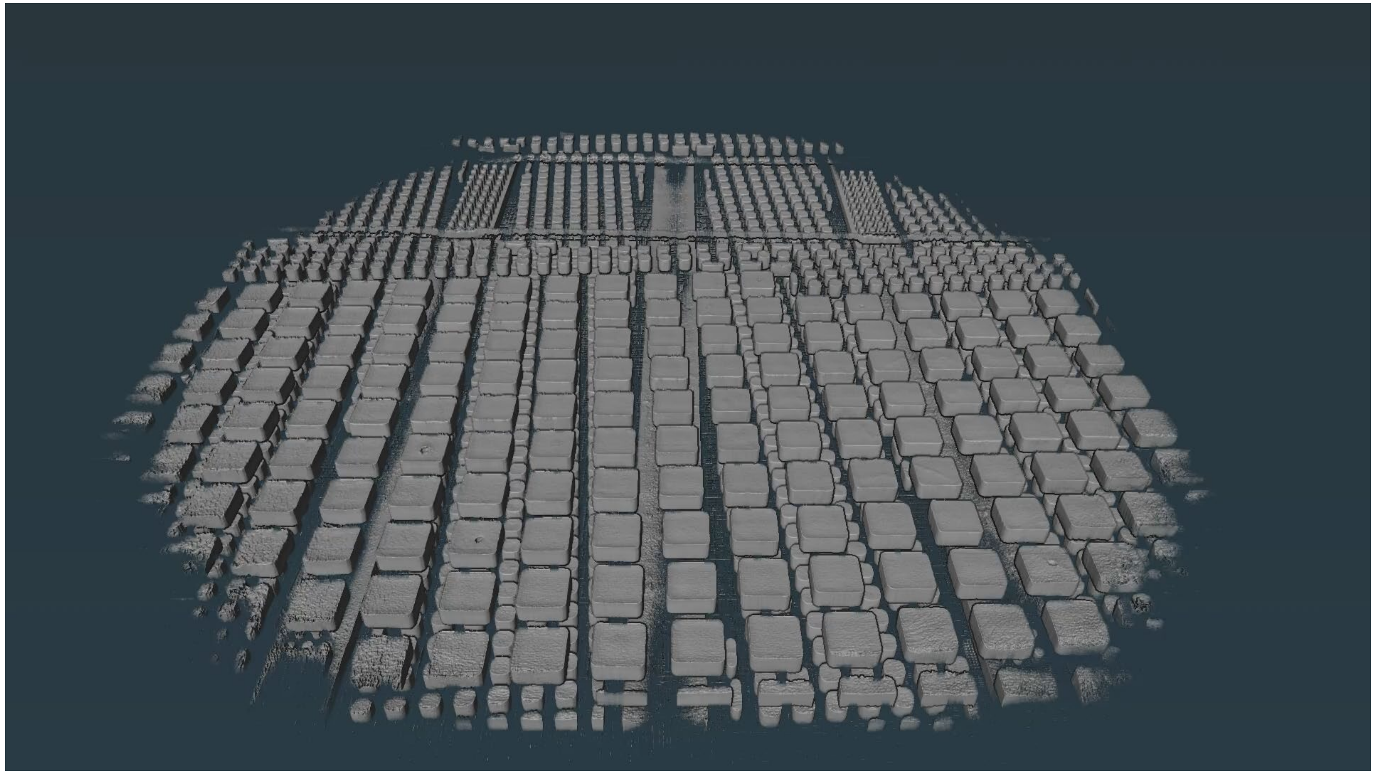
How can the light sources help?

1. Characterization of important properties of fabricated devices

2. Understanding and improving fabrication processes and characterizing failure mechanisms

3. Synthesizing and characterizing potential new materials/processes for next generation microelectronics

3D Imaging of Microelectronics

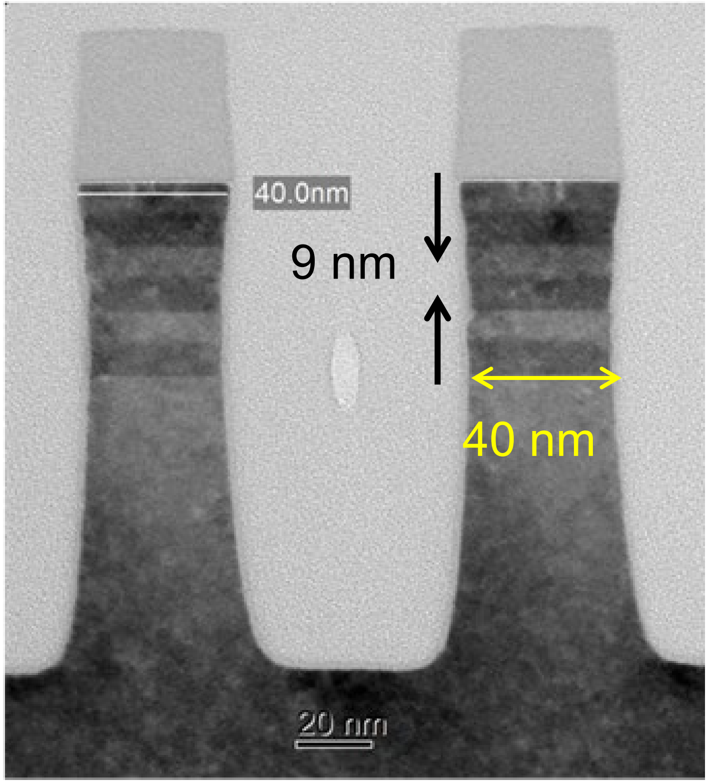


Fly-through of reconstructed volume from ptychography-laminography data collected from a 16 nm FinFET IC

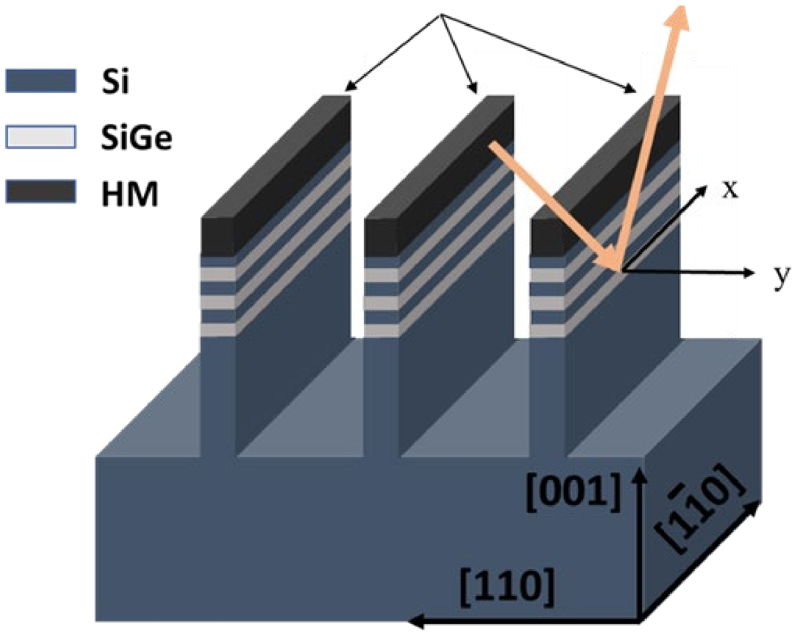
Lensless 3D imaging of integrated circuits with hard X-rays

Data taken at the APS

Strain mapping at 10nm



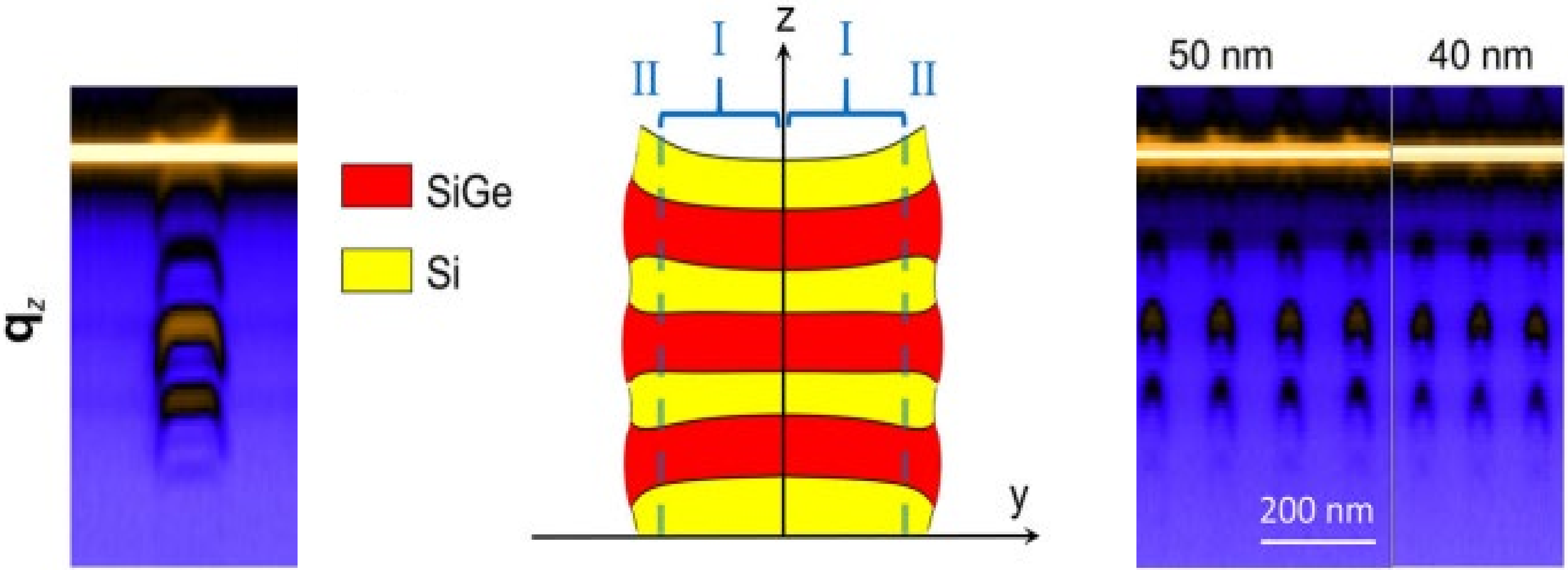
IBM-NSLS-II collaboration



Data taken at NSLS-II

Murray et. al., Commun. Eng. 1 (2022)

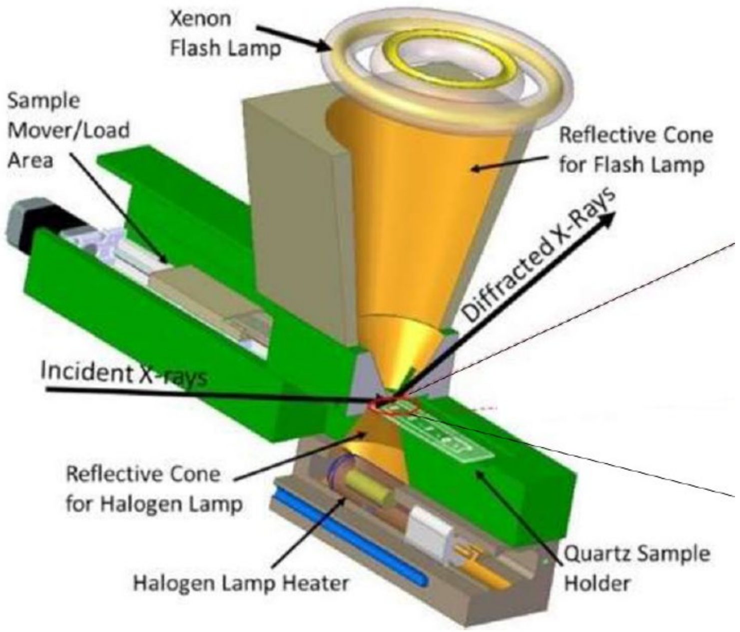
Spatially-resolved Diffraction Pattern

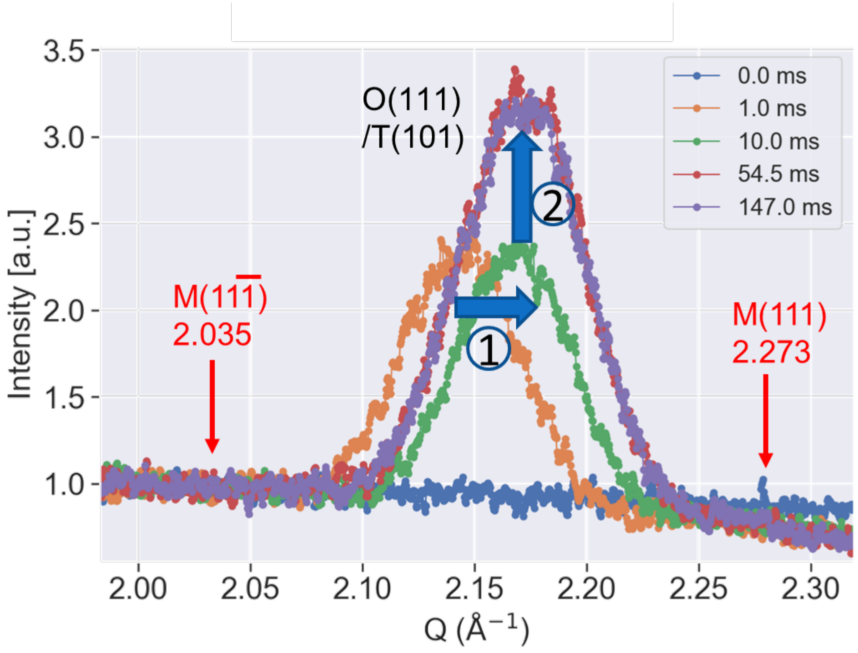


Murray et. al., Commun. Eng. 1 (2022)

Characterizing materials processing

Ex: Characterizing the process dependence on the formation of ferroelectric phase of Hafnium Zirconium Oxide (HZO) during rapid thermal processing



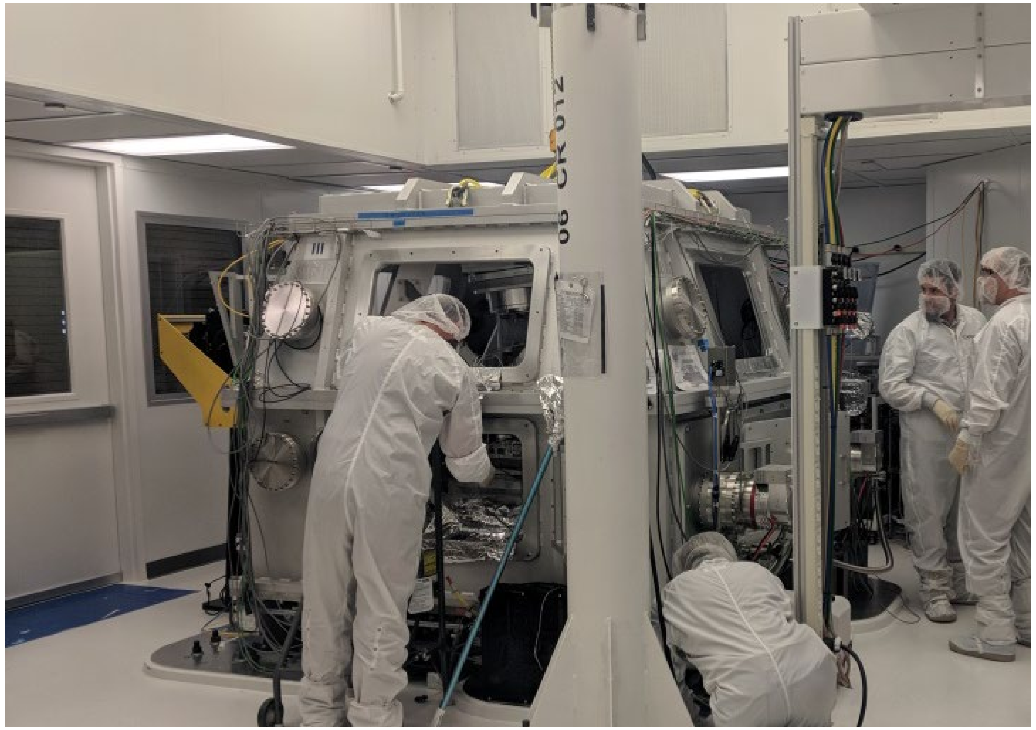


Data taken at SSRL

Phase transformation kinetics of HZO as a function of input power density to directly observe desired phase stabilization

Materials processing – photo resists

LBNL EUV program, 1997-present



CXRO

EUREKA

intel SAMSUNG

APPLIED MATERIALS ZEISS Lam RESEARCH

euvtech KLA ASML FST

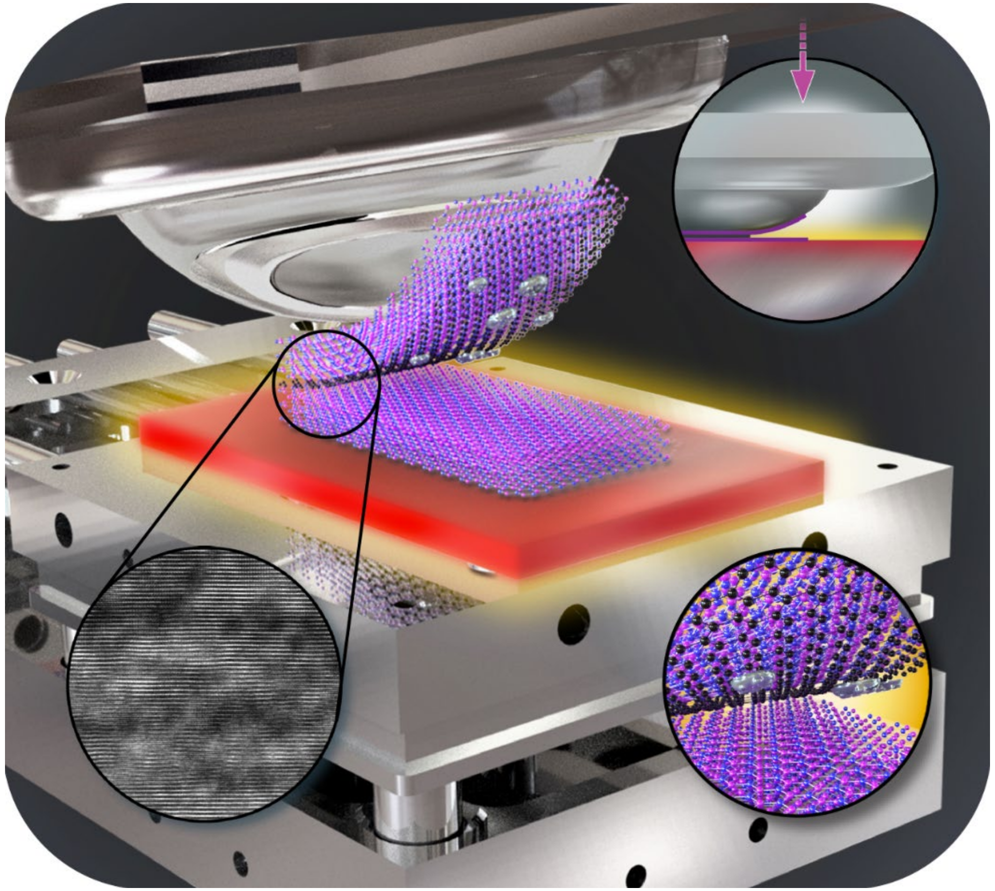
DUPONT inpria JSR tok

- World's only high Numerical Aperture (NA) EUV research facility (relevant to 1-nm node)
  - – High NA project started in 2011 with SEMATECH
- Enable materials research for the next generation of EUV

Synthesis of next generation materials

User facilities also have unique tools to synthesize, and characterize next-generation materials and processes for micro-electronics.

Example: The “Qpress” at CFN, BNL provides robotic assembly of 2D heterostructures, which can then be characterized at NSLS-II.



Conclusion

- Light sources – and nanocenters - can provide unique capabilities to understand and improve all steps in the microelectronics life cycle from materials synthesis and processing to device characterization
- Existing work has had, and continues to have, impact on the development of microelectronics
- Going forward, capability set should be expanded to include operando imaging/characterization
- Success requires dedicated instrumentation and, crucially, expertise at the interface between synchrotron science and the microelectronics industry