Optics for APS Operations and MBA Upgrade

X-ray Science Division

L. Assoufid, R. Conley, X. Huang, C. Jacobsen, S. Gleber, E. Kasman, A. Macrander, X. Shi, D. Shu, R. Reininger, S. Vogt, M. Wojcik

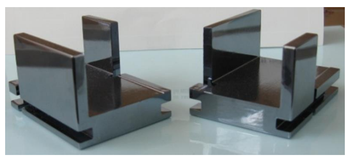
Optics Group, Argonne National Laboratory

The APS relies on high quality x-ray optics to deliver the x-ray beam to the sample under study, and in many cases to collect the relevant signal from the experiment (such as with crystal analyzers). As one of the world's largest hard x-ray synchrotron radiation facilities, the APS has invested early in optics fabrication and characterization infrastructure. This supports the APS scientific mission by developing and providing state-of-the-art optics and related services efficiently and at low cost. Over the years, the Optics Group at the APS has developed expertise and know-how in key optics areas including crystals, mirrors, multilayers, as well as ex-situ and at-wavelength characterization. As noted in "X-ray Optics for BES Light Source Facilities" (a 2013 workshop report), "with ever more powerful X-ray sources on the horizon, a new generation of x-ray optics must be developed that will allow us to fully utilize these beams of unprecedented brightness." As the APS is embarking on the MBA upgrade, the APS Optics group has a set of strategies to develop optics that meet future needs. This includes:

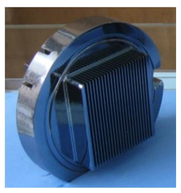
- Improve crystal optics fabrication techniques
- Further develop advanced thin film optics capabilities
- Advance simulation tools for optics' design and beamline optimization
- Push focusing optics' performance to nano-scale resolution
- Enhance ex-situ and beamline optics evaluation tools and techniques
- Continue working with external vendors and institutions to supplement in-house capabilities (e.g., diamond crystals, CRLs, etc.)

Crystal Optics Fabrication

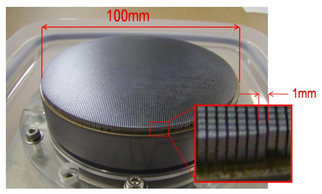
The optics group has considerable capabilities and expertise in:
- Design one-of-a-kind crystal components
- Design complex crystal optics systems
- In-house crystal machining and processing
- Crystal precision dicing
- Orientation to <0.1° accuracy
- In-house development of complete crystal optics system



Channel-cut crystal monochromators



High heat load Si monochro-mator



Diced spherical analyzer

M. Wieczorek cutting a Si crystal boule with a diamond wire saw

Future efforts will include:
- Further develop techniques to fabricate strain-free and defect-free crystals for high and ultra-high resolution, and high efficiency
- Improve crystal boule cutting and orienting to 0.01° accuracy
- Work towards standardization of crystal monochromators and analyzers across APS
- Improve crystal monochromators for high-heat-load, e.g. diamond
- Improve fabrication efficiency
- Develop coherence preserving crystal optics, advanced RIXS optics, and next –generation crystal optics

Crystal polishing for high resolution and coherence preservation

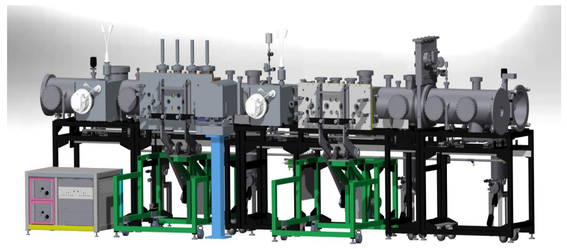
Current polishing capabilities includes:
- Strain-free crystal polishing of Si, Ge, Sapphire, Quartz, etc.
- Super-smooth (RMS roughness ≤3 Å)
- Pitch polishing

Future efforts will include:
- Expand strain-free crystal polishing to new materials and to channel-cuts
- Ultra-smooth (RMS roughness ≤1 Å)
- Improve pitch polishing process to <nm figure error
- Continue working with external vendors to supplement in-house capabilities

Elina Kasman cutting grooves into newly configured pitch polishing table on Strasbaugh Continuous Polisher.

Advanced Thin Film Optics

New "Modular Deposition System" has been conceptually designed to replace the outdated deposition system. The new system incorporates the state-of-art features and capabilities, including ion milling for in-situ optics preparation and figuring, and advanced metrology tools for in-situ characterization.



3-D drawing for the APS next generation deposition system

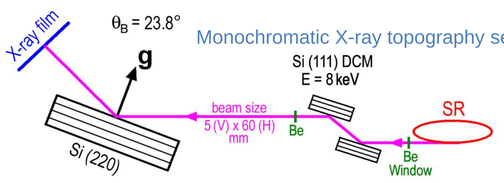
This new system will allow us to develop novel thin film optics to explore new science frontiers and meet the many of "Grand Challenges" highlighted in the 2013 DOE x-ray optics report.

Fixed Geometry K-B Mirror Systems

The Optics group delivered the first complete K-B mirror system for micron focusing to 8-BM beamline. The mirrors were fabricated using profile coating. With the future deposition system, we expect to further improve accuracy with the goal to deliver K-B mirror assemblies for 50 nm focusing.

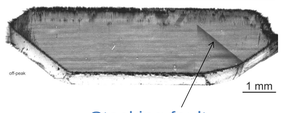
New Optics Testing Capabilities

1-BM Beamline for Optics and Detector Testing



Monochromatic X-ray topography set-up

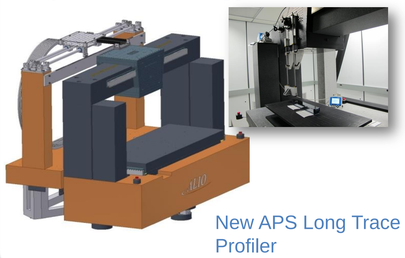
Optics Testing Capabilities:
- Monochromatic topography
- White beam topography
- Talbot grating interferometry
- K-B mirrors testing
- Zone plate and MLL testing



Stacking fault

Topographs of type IIa diamond for FEL

Optical Metrology



New APS Long Trace Profiler

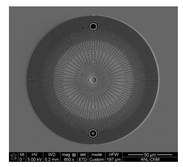
Current capabilities:
- New LTP with NOM configuration achieved 50 nrad precision
- Stitching microscope interferometer with 3 nm resolution

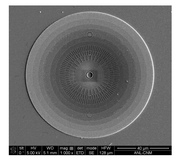
Future efforts:
- Push LTP accuracy to <50 nrad precision
- Upgrade stitching interferometry to <nm resolution

Zone Plates for Efficient Focusing of Hard X-rays to <20 nm

Fresnel zone plates (FZPs) remain the optics of choice for most x-ray microscopes. For hard x-rays, main challenges remain fabrication of FZPs with large aspect ratios as required to achieve both high resolution and high efficiencies. New fabrication methods that draw upon Argonne's strengths in nanolithography (at the Center for Nanoscale Materials) and atomic layer deposition (at the Energy Sciences Division) as well as new developments of ways to stack multiple zone plates offer the promise of delivering sub-20 nm focusing optics with high efficiency. A program to realize such optics is now underway as part of APS MBA Upgrade.

Zone Plate fabrication

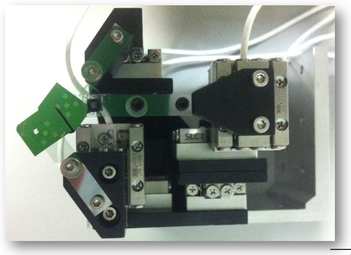




Examples of current achievements:
(Left) zone plates with 80 nm zone width and 800 nm structure height (Development toward sub-30 nm zone plates); and (Right) zone doubling zone plates with 20 nm zone width and 400 structure height (Development toward 10 nm zone plates)

Zone Plate stacking

The APS is in the process of developing a mounting system for stacking up to 6 zone plates. Alignment of 3 ZPs, two 800 nm thick and 1000 nm thick, stacked in the intermediate field has been achieved.



Zone plate stacking apparatus Z2-34 [Patent application in progress for ANL-IN-13-092]
Shows mounted chips with zone plates for intermediate field stacking.

Results for alignment: measured (M) and theoretical (T) efficiencies [1]

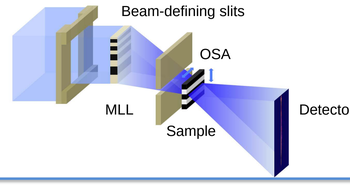
	total height	10 keV (T)	10 keV (M)	11.8 keV (T)	11.8 keV (M)
optimum FZP height		1.99 μm		2.55 μm	
USZP	0.8 μm	12.1%	9.3%	8.01%	6.9%
CZP	0.8 μm	12.1%	10.6%	8.01%	7.7%
DSZP	0.9 μm	14.6%	13.8%	9.87%	9.6%
USZP & CZP	1.6 μm	29.9%	17.4%	23.9%	14.3%
CZP & DSZP	1.7 μm	31.2%	20.2%	25.8%	19.4%
DSZP & CZP & DSZP	2.5 μm	28.1%	18.5%	33.8%	23.6%

Further work is needed to achieve optimum results.

Focusing with Multilayer Laue Lenses (MLLs)

MLLs offer a path to efficient focusing of hard X-rays to <10 nm. The next generation modular deposition system currently under development at the APS will have capabilities for exploration into entirely new regimes of aperture size and materials for MLL fabrication to complement the efforts at BNL.

Example of multilayer Laue microscope [2]



Simulation & Modeling

- **Goal:** Develop advanced simulation tools for optics' design and beamline optimization in support of optics development and beamlines
- **See Poster by Xianbo Shi et.al.**

References

1S.-C. Gleber, M. Wojcik, J. Liu, C. Roehrig, M. Cummings, J. Vila-Comamala, K. Li, B. Lai, D. Shu, S.Vogt. In prep
2X. Huang, H. Yan, E. Nazaretski, R. Conley, et al., SCIENTIFIC REPORTS | 3 : 3562 | DOI: 10.1038/srep0356

The Advanced Photon Source is funded by the U.S. Department of Energy Office of Science