Optics Group Strategy Document

Introduction

Achieving the mission of the APS requires high-quality x-ray optics (such as monochromators, mirrors, and focusing optics) to deliver x-ray beams to the samples and, in many cases (such as crystal analyzers), to collect the relevant signal from the experiments. Both the APS-U feature beamlines and the existing APS beamlines will require a new generation of x-ray optics that will take advantage of the 100-fold increase in brightness, smaller source size, and increased coherence enabled by APS-U. This document describes the strategy of the APS Optics Group (OPT) to deliver state-of-the-art optics and integrated solutions, in synergy with the other X-ray Science Technologies (XST) groups, to further the missions of the X-ray Science Division (XSD) and the APS.

Mission

The core mission of OPT is to develop and deliver innovative x-ray optics and optical systems and provide related services to further the APS mission of enabling cutting-edge scientific research. In support of this mission, OPT

- Designs, fabricates, and characterizes x-ray optical elements, such as crystal monochromators and analyzers, single- and multi-layer optics, and nano-focusing optics;
- Operates and develops optics fabrication and characterization laboratories and instruments, including the crystal optics fabrication laboratory, the deposition laboratory, the optical metrology laboratory, and the 1-BM Optics Testing Beamline; and
- Conducts R&D to develop future-generation optical components, such as wavefront-preserving optics and wavefront sensors and characterization tools, as well as beamline optics simulation, diagnostics, and optimization tools.

XSD/XST/OPT Organization

Established in the mid-1990s after the commissioning of the APS, OPT has evolved to comprise the following main activities: 1) crystal optics and multilayer optics development and fabrication, 2) zone plate development and fabrication, 3) beamline optics simulation, characterization, and optimization, 4) optical metrology, and 5) operation of the 1-BM Optics Testing Beamline.

Vision

The OPT's vision for the next 5 years and beyond is to be the world-leading expert and knowledge base on wavefront-preserving and nano-focusing x-ray optics R&D, with world-class capabilities, and to continue enabling research in a broad range of high-impact science and technology programs.

Strategy

The OPT performs R&D, design, fabrication, and delivery of cutting-edge optics and related services that are targeted to further the missions of XSD and the APS, and to support the APS-U. These activities are conducted in synergy with other XST support groups and in line with XST and XSD priorities. The OPT strategy is to strengthen its capabilities through developing the following two key areas:

- **High-performance nano-focusing optics** for current and future APS needs

- **Wavefront-preserving optics and optical systems**, including advanced crystal optics, mirrors, multilayers, and adaptive optics

In developing these capabilities, the OPT group members will 1) develop novel optics tools and techniques (including design, fabrication, and optical and at-wavelength characterizations), wavefront sensors, and relevant simulation codes; 2) perform R&D and design, fabricate, and test optics either independently or in collaboration with beamline scientists or others as appropriate; and 3) collaborate with the XST staff and APS beamline scientists and resident users to ensure successful beamline optics implementation and integration.

Five-year Strategy/Goals

The five-year strategy in the above areas is as follows:
- Develop wavefront-preserving crystal monochromators, multilayers, and mirror optics, including related modeling/simulation and characterization tools; and
- Develop high-resolution focusing optics with the goal of 5 nm for the future APS Ptychoprobe.

Goals and Action Plan for FY 2022

Nano-focusing Optics
- Continue R&D of nano-focusing optics for sub-10-nm spot size focusing needed for APS-U beamlines. Demonstrate fabrication technology for sub-10-nm focusing optics.
- Continue R&D and fabrication of zone plates for APS beamlines, including fabricating 10- to 14-nm zone plates, optics for new applications, and improvements to currently deployed zone plates.

Wavefront-preserving Optics and *in situ* Wavefront Sensors

- Continue R&D on advanced wavefront sensing techniques.
- Continue studies of wavefront-preserving high-heat-load mirrors, adaptive mirrors, monochromator crystals, and phase correctors.

Optics Characterization and Beamline Diagnostics
- Continue at-wavelength metrology characterization of X-ray optics (lenses, mirrors, crystals, windows) for APS and APS-U, focusing on the quality acceptance testing of procured refractive lenses.
- Begin developing beamline diagnostic tools (including coded-mask-based wavefront sensors and machine-learning-based beamline control) for APS-U beamlines.

Crystal Optics
- Continue to fabricate and develop crystal optics for APS-U and APS beamlines in collaboration with APS-U staff and APS beamline scientists.
- Continue to develop tools and refine strategies and plans to test and install APS-U crystal monochromators and analyzers in collaboration with APS-U staff, APS beamline scientists, and relevant XST support staff.
- Continue to develop the tool (the C-CHIRP) and procedures to polish channel-cut Si and Ge crystals.

Thin-film and Multilayer Optics

- Continue fabrication of high-quality coatings and multilayer optics as needed for APS-U and APS beamlines in collaboration with beamline staff and scientists.
- Continue to develop thin-film and multilayer optics techniques, including material system validation and associated testing to meet the new characteristics of APS-U beamlines.
- Build and commission a new high-resolution X-ray reflectometer.

Beamline Optics Simulation and Optimization

- Continue to provide simulation support as part of the optics procurement process for APS-U feature beamlines and the beamlines selected for enhancements.
- Continue to develop and maintain beamline optics design and simulation software.

Optics Metrology

- Continue to improve the metrology laboratory instruments and procedures to stay at the forefront and meet the demands of the APS-U beamline mirror measurements.
- Upgrade and commission the metrology laboratory HVAC system to improve temperature stability and cleanliness, essential to performing accurate measurements and reducing particle contamination of X-ray mirrors.
- Begin measuring APS-U mirrors for quality control and refine and update the APS-U mirror metrology plan as needed, in collaboration with APS-U staff, resident users and relevant XST staff.

Beamline Operations and Development

- Continue to support 1-BM optics testing activities.
- Develop a strategy and plan to upgrade 1-BM for post-APS-U operations.
- Enhance the topography and rocking-curve imaging capabilities to support APS-U and APS missions, and meet increasing user demands for characterization of wide-bandgap semiconductors including SiC, GaN, Ga_2O_3, and others.

Optics for Future Light Sources

- Continue to develop wavefront-preserving crystal optics (silicon, diamond, etc.), including wavefront-preserving cryo-cooled optics for extreme power loads and advanced imaging optics.
- Continue to develop optical concepts for cavity-based X-ray free electron laser oscillators (CB-XFELOs), output-coupling optics for CB-XFELOs, and wavefront-preserving optical components for CB-XFELOs. Design, build, and test a pilot CBXFEL cavity via a DOE-funded CB-XFELO collaboration between Argonne and SLAC.
- Continue to develop deformable-mirror-based zoom optics, including *in situ* surface metrology and wavefront sensing with integrated intelligent feedback control.
- Continue to develop new concepts for high-resolution high-throughput ix-ray spectrometers (spectrographs, x-ray echo).
- Build a prototype single-shot, high-speed wavefront sensor and test DOE prototype cryo-mirror project in collaboration with SLAC, BNL, and ALS.

Staffing

- Fill in the Group's vacant positions to support optics fabrication and testing efforts.

Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis

Strengths	Weaknesses
• Fast response to beamline optics needs and support requests. • Cost-effective and quick delivery of one-of-a-kind optical elements to APS beamlines and users. • Strong and versatile team with a wide range of expertise (unmatched in the U.S.) in optics fabrication, characterization, and theory. • Access to wide-ranging capabilities within the ANL complex, e.g., CNM. • Established collaborations with APS beamline scientists to advance optics development.	• Obsolete equipment for crystal optics fabrication and characterization limits performance and reduces productivity. • Dispersed and disjointed crystal fabrication labs hamper efficiency and impede workflow. • Lack of Central Shops equipment and expertise for advanced crystal machining results in lower productivity and efficiency and increased cost. • Reliance on matrix support system for critical activities leads to lack of project ownership, lack of continuity, and decreased success rate.
Opportunities	**Threats**
• Develop new-generation x-ray optics and related expertise and tools. • Strengthen synergies with other XST groups and with beamline scientists in developing and implementing complex optical systems. • Increase scientific and publication output. • Become a world leader in nano-focusing and wavefront-preserving x-ray optics. • Develop strong collaborations within DOE light sources and with industry to help meet APS optics needs.	• Potential for shrinking budgets could impede progress and diminish quality of scientific output. • Reduced investments in staff could compromise readiness for next shift in x-ray optics technology and will minimize the ability to meet key optics goals for APS-U Feature beamlines and APS beamline enhancements. • Moving to a “cost recovery” operating model will significantly diminish much-needed R&D. • Lack of reliable source of large-size, defect-free crystal materials, including diamond, quartz, sapphire, and SiC, could impede progress.