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, the Optics group:

- Designs, fabricates, and characterizes x-ray optical elements, such as crystal monochromators and analyzers, single- and multi-layer optics, and nanofocusing 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 nanofocusing 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 activities 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, and adaptive optics

In developing these capabilities, the OPT group members will: 1) develop novel optics tools and techniques **(**including design, fabrication, 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 and mirror optics, including related modeling/simulation, and characterization tools.
- Develop high-resolution focusing optics with the stretch goal of 5 nm for the future APS Ptychoprobe.

Goals and Action Plan for FY 2021

Focusing Optics
- Continue R&D of nanofocusing optics for sub-10 nm spot size focusing needed for APS-U beamlines.
- Continue R&D and fabrication of zone plates for APS beamlines, including the push to 10 nm optics, novel application optics, and improvements to currently deployed zone plates.

Multilayer Optics
- Continue to supply high-quality multilayers requested by several beamlines.
- Install components for in-situ metrology of flats in the Modular Deposition System (FY2020).
- Secure funding, order components, and begin assembly for a new high-resolution x-ray diffraction instrument.

Wavefront-preserving Optics and *in situ* Wavefront Sensors

- Continue R&D on advanced wavefront sensors.
- Continue studies of the ultimate performance of diamond (and other) crystals in Bragg diffraction, with a focus on wavefront preservation.

Crystal Optics

- Continue to supply crystal monochromators and analyzers to APS-U feature beamlines and APS operations. Finalize the plan to characterize and test APS-U crystal monochromators.

- As funding becomes available, upgrade the crystal optics fabrication equipment, including a) the C-CHiRP-400 automated channel-cut polishing machine with monolithic control system and b) the Laue camera for high-resolution orienting of crystals (0.05°-0.02° as

required by APS-U).

- Continue to support APS-U documentation efforts, specifically for drawings of multilayers, mirrors and crystal optics components using the ISO 10110 optics drawing standard.
- Develop capabilities for laser cutting and laser ablation of diamond crystals in collaboration with USA vendors.

Beamline Optics Simulation and Optimization

- Finalize the optics specifications for all feature beamlines and for the beamlines selected for enhancements.
- Continue to develop and maintain beamline optics design and simulation software.

Optics Metrology

- Finalize the metrology plan for APS-U mirrors. Continue to improve the APS slope measuring system and begin measuring the first APS-U mirrors.
- Install and commission the APS Verifire HD Fizeau interferometer for 2-D metrology of APS-U mirrors.

Beamline Operations and Optics Testing

- 1-BM beamline: Develop a strategy and plan to upgrade 1-BM for post APS-U operations. Continue to support 1-BM beamline users in optics testing and topography of crystals. Develop and enhance 1-BM characterization tools and performance to support the APS-U. Implement tools to support automation for remote/mail-in operations.
- IDEA beamline: Begin testing optics for APS-U and APS beamline enhancements. Test and validate 1-D mirror-based zoom optics with a fully automated and intelligent closed loop feedback system.

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-XFELO, and wavefront-preserving optical components for CB-XFELOs. Design, build, and test a pilot CBXFEL cavity via a joint CB-XFELO DOE-funded project between Argonne and SLAC.
- Continue to develop deformable-mirror-based zoom optics, including *in situ* surface metrology and wavefront sensing with integrated intelligent feed-back control.
- Build a protype single-shot, high-speed wavefront sensor and finalize the test plan for the DOE light source cryo-mirror project.

Staffing

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

Strengths Weaknesses, Opportunities, and Threats (SWOT) Analysis. (Needs participation from all)

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. • 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 nanofocusing and wavefront-preserving x-ray optics.	• 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.