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) support 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 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, mirrors, multilayers, and other specialized optics;
- Operates and develops instruments and tools, including the 1-BM Optics Testing Beamline, for design, fabrication, and characterization of optics; and
- Conducts R&D to develop future-generation optical components.

XSD/XST/OPT Organization
Established in the mid-1990s after the commissioning of the APS, OPT has evolved to comprise the following main sections: 1) Crystal Optics, 2) Mirrors and Multilayer Optics and Metrology, 3) Beamline 1-BM for Optics and Detector Testing, and 4) Beamline Optics Simulation.

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 overall strategy is to focus its activities on the following key areas:
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- **High-performance focusing optics** for current and future APS needs;
- **Wavefront-preserving optics**, including novel crystal optics, mirrors, and adaptive optics; and

In developing these capabilities, the OPT group members will: 1) develop **novel optics tools and techniques**, including design, fabrication, optical and at-wavelength characterization, and simulation; 2) perform **R&D**, 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 three areas is as follows:

**Focusing optics**

- Fabricate zone plate with 5-nm focus: multi-step fabrication for sub-10-nm features; higher-order focusing with compensated zone plate designs. Example of relevant beamlines and desired spot sizes or resolution: PtychoProbe (5 nm), Bionanoprobe at 2-ID (10 nm), 2-ID microprobe, 26-ID Nanoprobe (<20 nm), and 32-ID TXM (<20 nm resolution imaging), PRISMA.
- Fabricate graded multilayer focusing mirrors. Example of a relevant beamline: 11-ID.
- Acquire Multilayer Laue lens (MLL) from NSLS-II as part of the strategic APS/NSLS-II optics collaboration. Example of a relevant beamline and desired spot size: PtychoProbe (5 nm).

**Wavefront-preserving optics**

- Crystal optics:
  - Achieve strain-free polishing to <0.2 nm rms, and precision orienting to <0.02°.
  - Develop crystal optics with <10-meV resolution using quartz, diamond, and other less-common materials. Example of relevant beamlines: 27-ID and 30-ID.
  - Perform R&D and implementation of diamond crystal beam-splitters, monochromators, lenses, and other diamond optical elements. Example of a relevant beamline: CHEX.
- “Wavefront-preserving mirrors” project [DOE/BES/SUF ADR grant. PIs: D. Cocco (SLAC), L. Assoufid (APS), K. Goldberg (ALS), M. Idir (NSLS-II)]:
  - Complete R&D on non-invasive hard x-ray wavefront sensors as part of this project. Example of a relevant beamline: ATOMIC.
- Adaptive optics with beam wavefront sensing and correction, e.g., mirror-based zoom optics. Example of a relevant beamline and desired spot size: ATOMIC (50 nm to 1.5 µm).
- High-performance reflective multilayers:
- Integrate new diagnostic instrumentation into the Modular Deposition System (MDS) to enable fabrication of high-performance multilayer optics.
- Develop large bandpass (>2%) for increased flux and tunability range.
- Develop narrow bandpass (<0.5%) using special material combinations.

Examples of relevant beamlines: ATOMIC, CSSI, InSitu Nanoprobe, XPCS, 20-ID, and PRISMA.

Optics Tools and Techniques
- Beamline optics simulation and optimization:
  - Continue to develop and maintain the HYBRID code for general-purpose beamline simulation.
  - Develop Mutual Optical Intensity (MOI) propagation code to provide complete coherence information where applicable.
  - Integrate optics simulation code developed at the APS into other widely used, publicly available software packages.
  - Support the APS-U via optics simulation and optimization of all Feature beamlines and selected beamlines for enhancement.
  - Develop software for fast back-propagation and adaptive control for in-line optical surface modification.
- Optics testing:
  - Further develop tools and instruments for testing wavefront-preserving optics at 1-BM.
  - Continue to develop optical metrology tools and methods for wavefront-preserving mirrors

Goals and Action Plan for FY 2017

Focusing Optics
- Continue fabrication of profile-coated KB optics using existing material systems. Explore new materials for longer mirror lifetimes.
- Start zone plate fabrication development for 10- to 14-nm spot-size focusing and zone plates for high-efficiency focusing using blazed structures.
- Conduct R&D and testing of prototype diamond refractive lenses

Thin-film Optics
- Complete commissioning process for the MDS for multilayer deposition, and produce the high-quality multilayers that several beamlines have requested for FY 2017 delivery.
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- Test components and instrumentation for *in situ* metrology.

**Wavefront-preserving Mirrors and *in situ* Wavefront Sensors**
- Begin R&D on non-invasive wavefront sensors.
- Develop software package for 2-D single-shot grating interferometer.
- Build and test a prototype single-crystal diamond beam splitter setup for wavefront sensing.

**Crystal Optics (including high-energy x-ray crystal optics, etc.)**
- Complete and commission the prototype of the automated channel-cut polishing machine.
- Begin the development of the 0.02°-precision crystal-orienting technique on the Topo Unit.
- Develop procedure for fabricating quartz-based crystal monochromators and analyzers for resonant inelastic x-ray scattering (RIXS).
- Begin exploring the development of high-efficiency Pendellosung-fringe-free thin Laue monochromators.

**Beamline Optics Simulation and Optimization**
- Complete the preliminary design of all APS-U Feature beamlines.
- Complete the integration of the HYBRID code with the OASYS-ShadowOui interface.
- Develop the 1-D MOI code to simulate non-ideal optics.
- Develop the data analysis software for optics characterization (coherence measurement and wavefront sensing).

**Optics Metrology**
- Upgrade the Long Trace profiler.
- Commission a new roughness and microstitching microscope.

**Imaging Optics and Imaging Spectrometers**
- Perform conceptual development and R&D on sub-meV resolution high-throughput x-ray monochromators, imaging spectrographs, and echo-type spectrometers utilizing combined focusing and crystal optics for high-brilliance APS-U and x-ray free electron lasers.

**1-BM Beamline**
- Commission rapid wavefront characterization technique.
- Commission rapid ptychography for focusing optics measurements.
- Fabricate and commission additional conditioning crystals for the rocking curve topography set-up to allow study of more sample crystals.
## Strengths Weaknesses, Opportunities, and Threats (SWOT) Analysis.

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