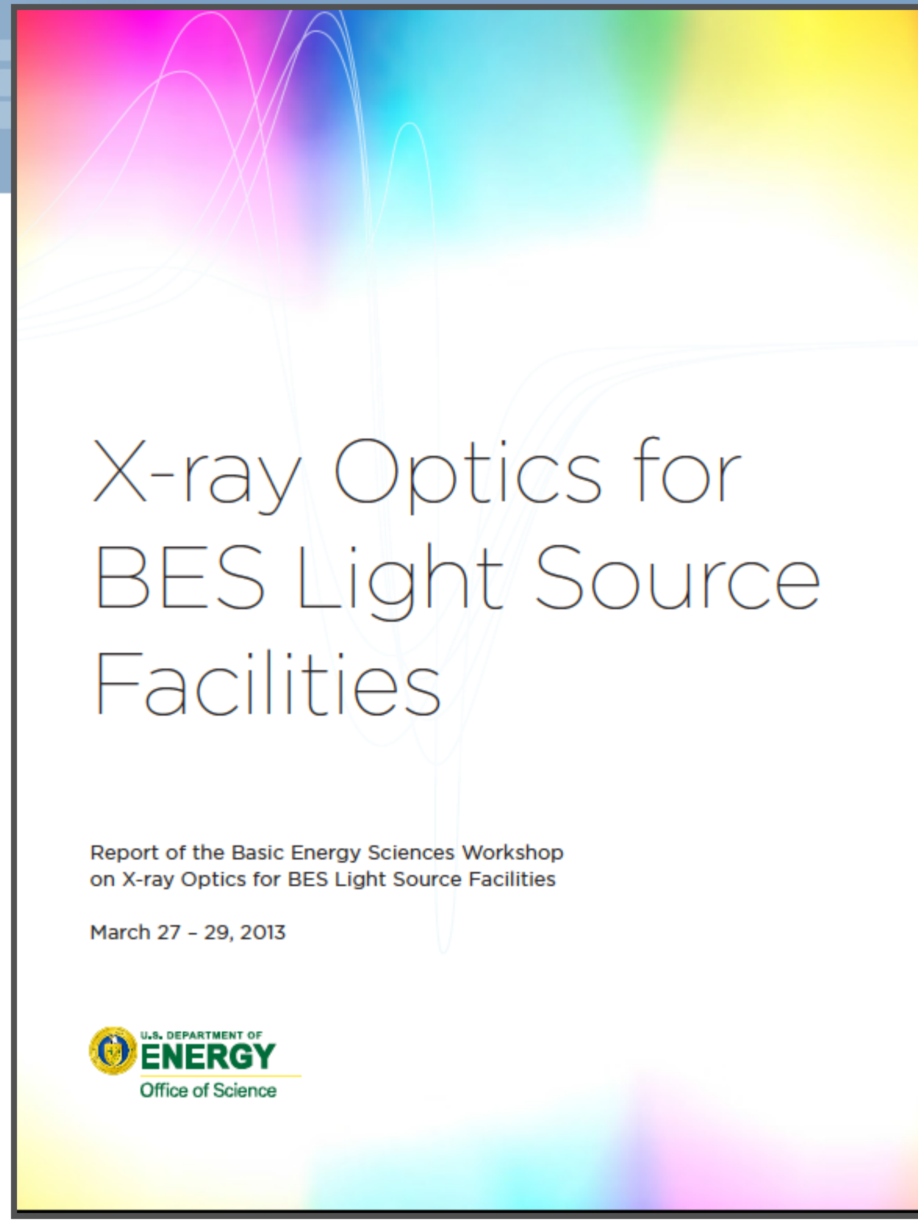
BES X-ray Optics Workshop

Dennis Mills

APS

Monthly Operations Meeting

April 16, 2014



X-ray Optics for BES Light Source Facilities

Report of the Basic Energy Sciences Workshop on X-ray Optics for BES Light Source Facilities

March 27 – 29, 2013

U.S. DEPARTMENT OF ENERGY

Office of Science

Motivation

The increasing brightness of X-ray sources will enable a new generation of measurements that could have revolutionary impact across a broad area of science.

However, in almost all the forefront areas of X-ray science today, the main limitation is our ability to focus, monochromate, and manipulate X-rays at the level required for these advanced measurements.

To address these issues, BES sponsored a workshop, X-ray Optics for BES Light Source Facilities, which was held March 27–29, 2013, near Washington, D.C. The charge given to the co-chairs of this workshop is given on the next slide.

Report of the Basic Energy Sciences Workshop on X-ray Optics for BES Light Source Facilities

Potomac, MD / March 27-29, 2013

CO-CHAIRS

Dennis Mills
Argonne National Laboratory

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http://science.energy.gov/bes/news-and-resources/reports/

Charge to Organizers of the X-ray Optics Workshop

- The goals of this workshop are to:
  - Evaluate the present state of the air in X-ray optics
  - Identify the gaps in current X-ray capabilities and what developments should have high priority to support current and future photon-based science
  - Identify the engineering, science, and technology challenges
  - Identify methods of interaction and collaboration among the facilities so that resources are most effectively focused onto key problems
  - Generate a report of the workshop activities, including a prioritized list of research directions to address the key challenges

- To cover as much as of the field as possible, we broke it down into 9 technical areas and 2 other topics we thought important to discuss:

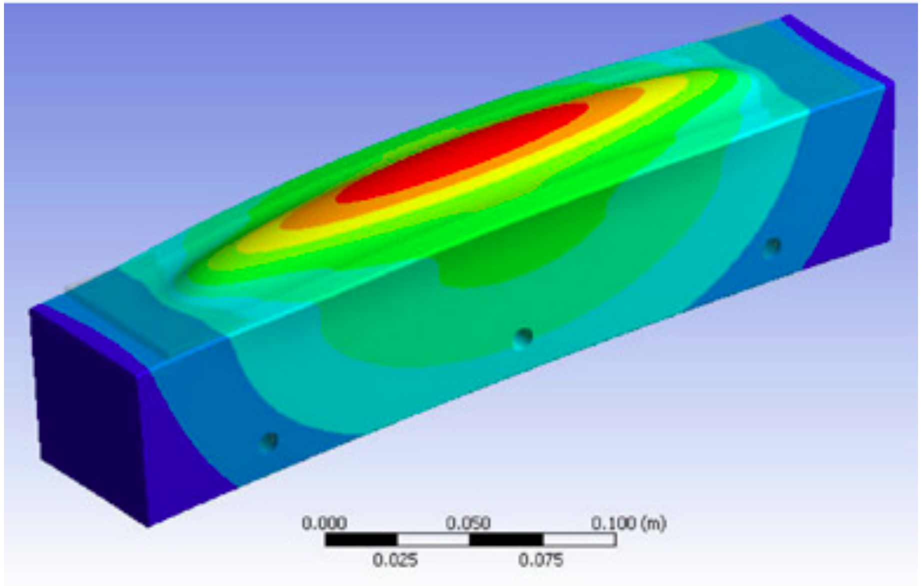
Gratings	Simulations and Modeling	Adaptive Optics
Mirrors	Crystal Optics	Nanodiffractive Optics
Metrology	Thin Film Optics	Refractive Optics

Industry   Models for Inter-laboratory Coordination

Workshop Participation

- The workshop was attended by X-ray optics experts from the DOE light sources, from ORNL, LLNL, from academia, from the NIST, and from the NASA as well as by representatives from the optics-manufacturing industry, BL scientists, and by senior managers from the DOE/BES. Also in attendance were senior optics and instrumentation experts from Europe and Japan to provide an international perspective.

- Participation from APS staff and CAT members included:
  - Lahsen Assoufid
  - Peter Eng
  - Ray Conley
  - Ali Khounsary
  - Alec Sandy
  - Tom Toellner
  - Stefan Vogt
  - DM



Crystal Optics [T.S. Toellner (ANL) & P. Siddons (BNL)]

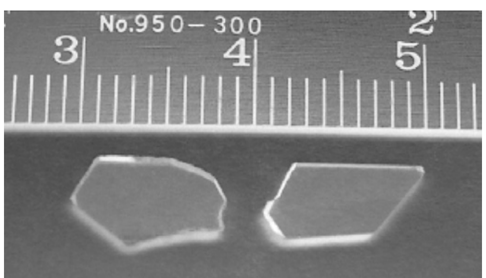
Benefits: Seeding and beamsplitting optics for X-ray FELs will allow these sources to provide higher-quality beams and multiplexing capabilities to increase much-needed capacity. Currently, hard X-ray RIXS is severely limited by the unavailability of energy analyzers that perform well at specific X-ray energies. To expand the technique's repertoire, suitable analyzers that operate at a variety of specific X-ray energies and have good energy resolution with high efficiency must be developed.

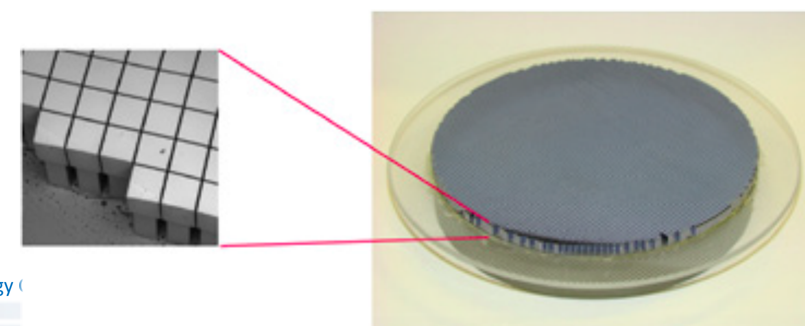
Recommendations:

1. Develop alternative crystalline materials (other than silicon) for X-ray optics.

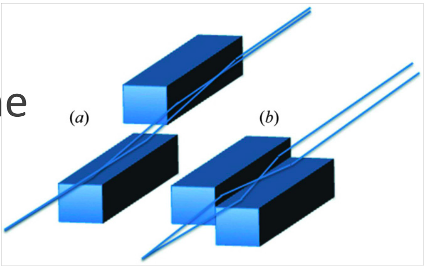
2. Improve the fabrication process of X-ray energy analyzers.

3. Explore the limit of high-average and peak X-ray incident power on crystal optics and the crystal-optics requirements for preservation of X-ray beam coherence.

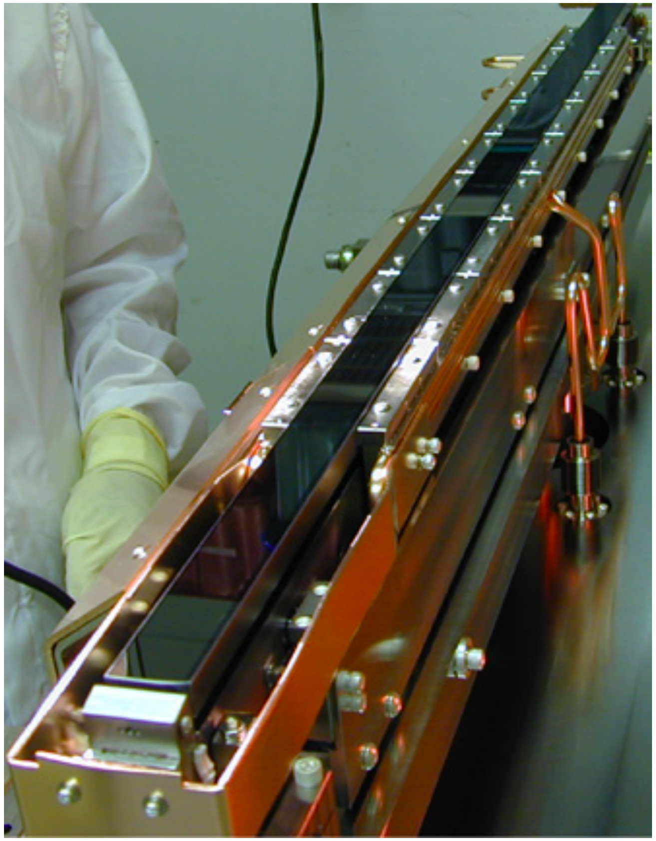




X-ray Mirrors [L. Assoufid (ANL) & T. Rabedeau (SLAC)]



Benefits: Mirrors are critical components of almost every beamline. Optics presently cannot be manufactured to the precision required for the brightest sources today and are far from what will be needed for next-generation light sources. Mirror perfection is limited by manufacturing precision, mechanical mounting, and thermal management.

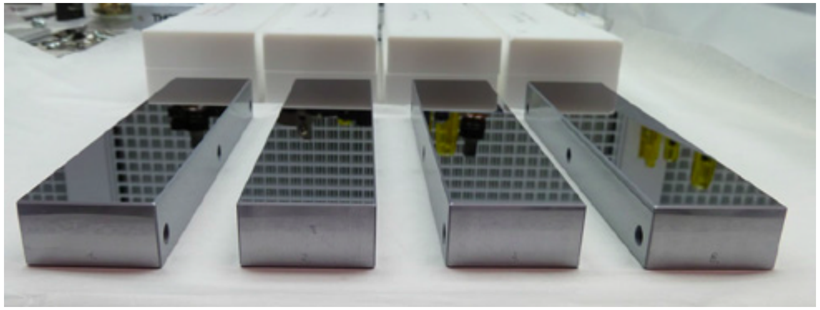


Recommendations:

1. Improve fabrication process-compatible metrology.
2. Reduce the thermal deformation of mirrors by applying LN2 cooling technology to mirror optics.
3. Expand research into the damage mechanisms, damage onset thresholds, and damage-mitigation strategies for both mirror coatings and substrates.
4. Explore the requirement for diffraction-limited grazing incidence mirror performance to avoid aperture edge effects.

Optical and X-ray Metrology

M. Idir (BNL) & V. Yashchuk (LBNL)



Benefits: Advanced metrology tolls at the manufacturing site can drive improvements in mirror quality. At-wavelength metrology tools can greatly assist in the diagnostics and control of the optical-system alignment and performance under operational conditions, improving beamline performance and throughput.

Recommendations:

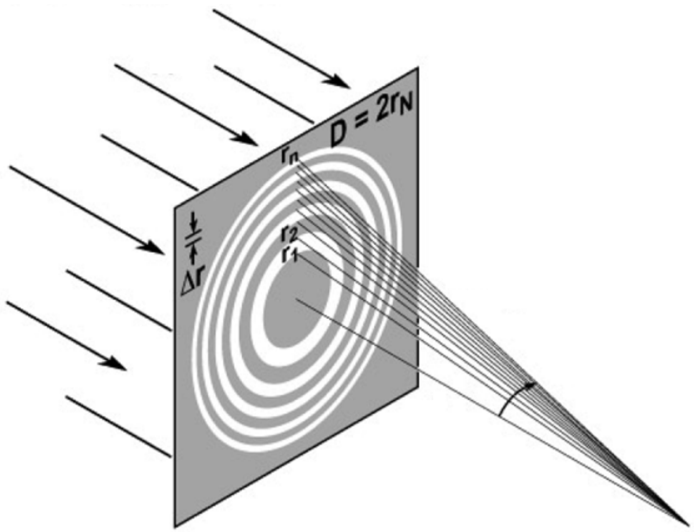
1. Work with industry to develop advanced metrology tools that can be used as part of the manufacturing process.

2. Develop and implement at-wavelength X-ray metrology that can be used routinely in beamlines in a minimally invasive manner.

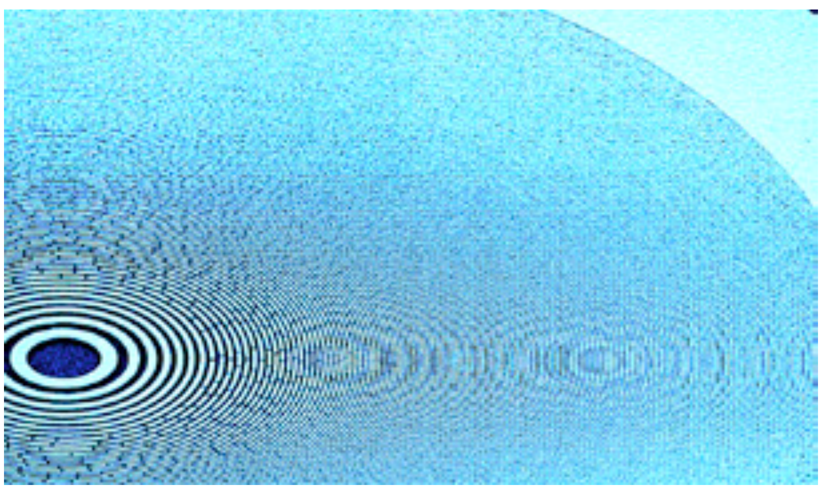
3. Develop and support R&D X-ray beamlines for X-ray metrology of optical elements as part of the development of new optics and detectors.

4. Upgrade and maintain existing optical-metrology facilities at light sources to provide measurement capabilities commensurate with the high brightness of sources.

Nanodiffractive Optics [P. Naulleau (LBNL) & S. Vogt (ANL)]



Benefits: Spatial resolution in x-ray microscopes is limited by the properties of nanodiffractive optics, such as zone plates. Advances would enable better resolution, particularly at hard X-ray energies, together with higher efficiency. This is particularly important in many areas of energy sciences, where small features must be chemically identified, such as in hierarchically ordered synthetic materials used in energy storage, conversion, and catalysis.

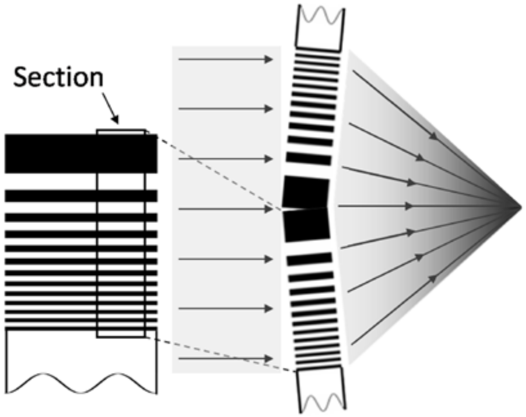


Recommendations:

1. Resolution of zone plates should be improved.
2. Improve the efficiency of zone plates.
3. Increase the size of zone plates.

Thin Films [R. Conley (ANL/BNL) & R. Soufli (LLNL)]

Benefits: Spatial resolution of grazing-incidence nanofocusing optics and MML optics could drive toward the nm regime, opening up many new applications such as in the exploration of hierarchically mesoscale ordered materials.



Recommendations:

1. Investigation of the physics of thin-film growth and atomistic modeling is necessary to advance performance of thin-film optics such as ultrashort-period multilayers, and MLLs.

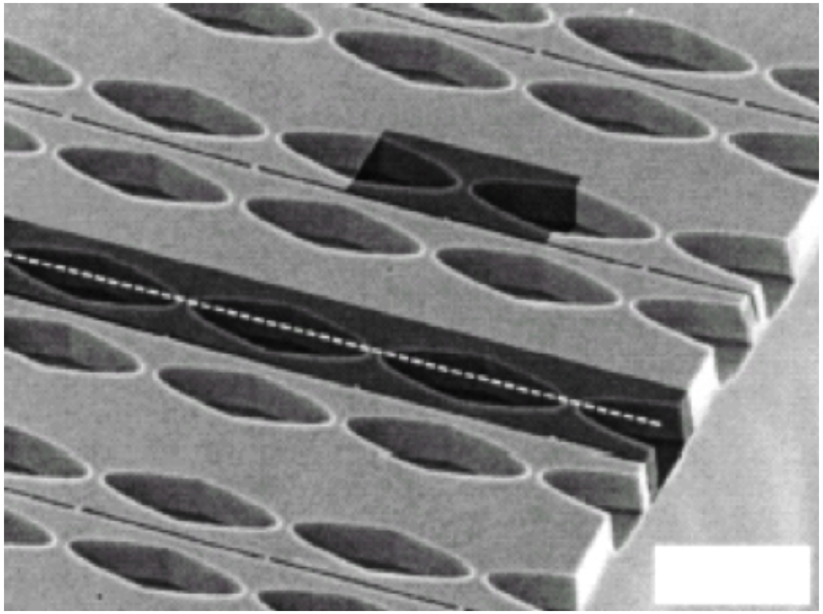
2. R&D is needed on damage origins, mitigation, recovery, and lifetime enhancement of coatings used in extreme environments.

3. Investigation of methods for 3-D multilayer deposition on highly profiled surfaces will enable the use of new optical geometries and allow for higher efficiency and mirror figure correction.

4. Multilayer Laue lens research, including stress reduction, larger thicknesses, manual thinning, focused ion-beam milling, and mounting, needs augmentation. The results of this effort will be applicable toward other thick or diffractive multilayer optics.

Refractive Optics [K. Evans-Lutterodt (BNL) & A. Sandy (ANL)]

Benefits: Coherence-preserving CLRs for focusing in one or two dimensions can lead to significant improvements in experiments where the coherent flux is critical, such as XPCS. CRLs are also particularly advantageous for techniques using very-high X-ray energies where other types of optics do not perform well. At very-high X-ray energies, refractive optics provide an optimum solution for transport and nanofocusing.



Recommendations:

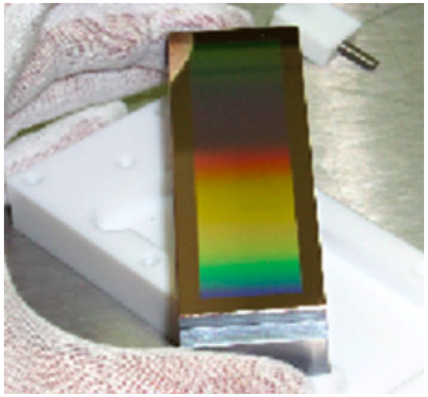
1. Develop the full potential of silicon refractive optics by improving the quality of deep silicon etching, resulting in larger optical apertures, better transmission, and reduced aberrations.

2. Develop improved fabrication technologies that can more precisely shape diamond.

3. Consolidate the requirements of DOE labs for refractive lenses, and explore and encourage commercial development of single-crystal and vapor-deposited Be lenses.

High-resolution Gratings [D. Cocco (SLAC) & T. Warwick (LBNL)]

Benefits: Gratings are critical for all soft x-ray measurements. At the frontier of X-ray condensed-matter physics, RIXS is used to elucidate the electronic structure of correlated electronic systems. We have the potential to advance from the 150 meV resolution of today to sub-10 meV resolution and beyond using advanced grating technology.



Recommendations:

1. Work with industry to develop domestic manufacturing capability for varied line-space blazed gratings. This includes gratings up to 600 mm long and with line densities from 100 lines/mm to 6,000 lines/mm.

2. Work with industry to investigate and exploit new high-precision patterning techniques for arbitrary grating patterns written at high speed.

3. Develop multilayer gratings on shallow-blazed substrates.

4. Explore innovative grating configurations for particular applications, such as transmission gratings for use in medium-resolution spectrometers.

Adaptive Optics [N. Kelez (SLAC) & L. Poyneer (LLNL)]

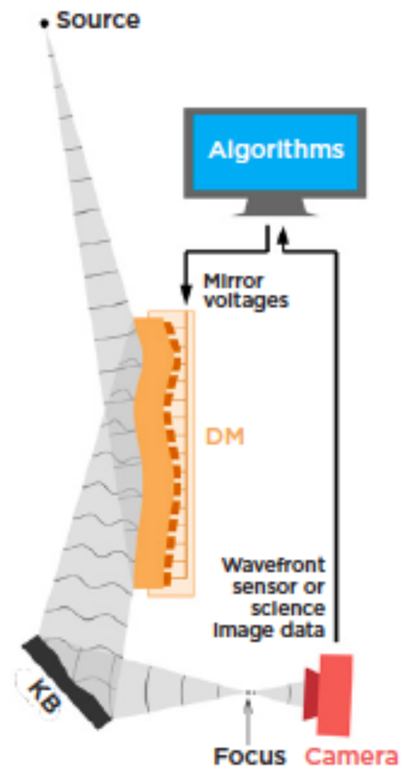
Benefits: Adaptive Optics (AO) in astronomy has had a revolutionary impact. When applied to x-ray light sources, these techniques will help scientists utilize the ultimate capabilities that modern sources can provide in terms of brightness, wavefront quality, and coherence. AO provides correction of wavefront errors, as well as on-demand beam shaping customized to each science target, and real-time correction of optics under dynamic environmental conditions.

Recommendations:
1. An R&D program should be developed in support and actuation technologies for deformable mirrors.

2. Algorithms and control software should be developed.

3. Ready access is needed to test facilities for long-term technology development.

4. Collaboration should be enhanced.



Simulation & Modeling [O. Chubar (BNL) & J. Krzywinski (SLAC)]

Benefits: Integrated and more sophisticated design tools will allow us to design higher-performance optical systems with high confidence. Beamline optical systems can cost $10 million to $20 million; tools that can aid in their design and accurately predict beamline performance are absolutely essential for taking the next steps forward.

Recommendations:

1. Establish a framework for start-to-end simulations and inter-operation of different computers for use with current and future generations of X-ray light sources.

2. Develop accurate physical-optics-based methods for detailed description of radiation propagation through different types of X-ray optical elements and samples, and implement these methods in a reliable software.

3. Improve overall efficiency and reliability of partially coherent emission and wavefront-propagation simulation methods and software tools for different types of sources.

4. Develop libraries of functions for solving inverse problems in some experimental techniques, using the mathematical apparatus of physical optics.

5. Software development efforts should be carried out across the whole community but tightly coordinated within an overall framework with defined leadership roles.

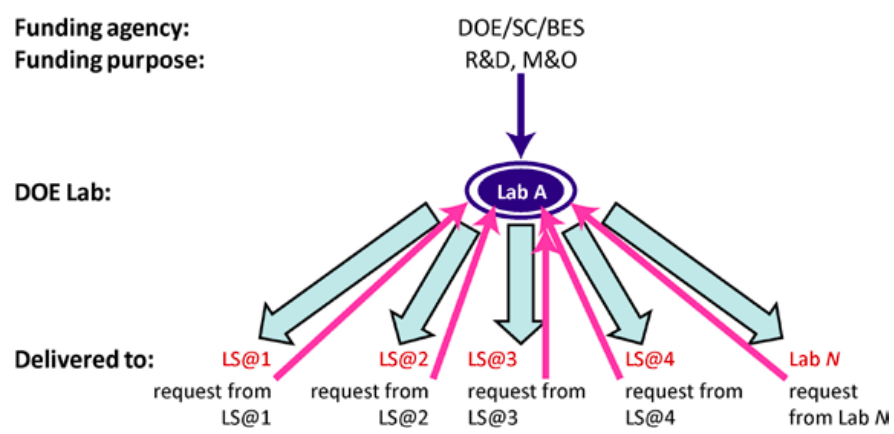
Optics Facility Cooperation [M. Pivovarof (LLNL) & J. Arthur (SLAC)]

Benefits: Optimal organization and collaborations would provide a number of functional models tailored to the services or research needed across the DOE X-ray facility complex. Organizational models should be developed, from the specialized center providing expertise and optics to the whole community, to a delocalized effort across all the labs, with a coordination center. Benefits will be increased efficiency and optimal use of limited resources.

Recommendations:

1. With input from facility managers and DOE Basic Energy Sciences (BES) staff, organize consortia in the various areas of optics and have them submit white papers to BES describing how best to move forward on improved X-ray optics.

2. Initiate a single program to serve as a pathfinder and prototype for cross-laboratory collaborations.



National Capability model. The dark-blue arrow shows flow of funding from BES to the national center, which can be located at any DOE laboratory for general support of its capabilities. The light-blue block arrows show flow of the optics capability to various light sources, and the pink arrows indicate the tasking requests generated by each light source.

Industry [K.A. Goldberg (LBNL) & A. Khounsary (ANL)]

Benefits: We have unique challenges that can only be overcome by a new collaborative interaction with industry. The development of a vibrant industry around X-ray optics will be a necessary and key component if the US is to lead in X-ray science using ultrabright sources.

Recommendations:

1. Collectively define the needs of the X-ray optics community for industry.
2. Enhance collaboration in key areas.
3. Reduce contractual barriers where possible.
4. Incentivize interactions with industry.
5. Strategize closely with industry partners.

Focus Areas for R&D

Principal research directions (PRDs)

1. Development of advanced grating lithography and manufacturing for high-energy resolution techniques.
2. Development of higher-precision mirrors for brightness preservation through the use of advanced metrology during manufacturing and improved mounting/cooling.
3. Development of higher-accuracy optical metrology that can be used in a manufacturing setting as well as at-wavelength metrology for testing at beamlines.
4. Development of an integrated optical modeling and design framework that is designed and maintained specifically for X-ray optics.
5. Development of nanolithographic techniques for improved spatial resolution and efficiency of zone plates.
6. Development of large, perfect crystals of materials other than SI for beam-splitters, seeding monos, and high resolution analyzers.
7. Development of improved thin-film deposition methods for fabrication of MMLs and high spectral-resolution multilayer gratings.
8. Development of supports, actuator technologies, algorithms, and controls to provide fully integrated and robust adaptive X-ray optics systems.
9. Development of fabrication processes for refractive lenses in materials other than silicon.

Summary

The Report also addressed two important nontechnical areas:

- our relationship with industry
- organization of optics within the light source facilities

Optimization of activities within these two areas could have an important effect on the effectiveness and efficiency of our overall endeavor. These are crosscutting managerial issues that we identified as areas that needed further in-depth study.

"This workshop served as an ideal venue to bring together optics experts from national laboratories, universities, and industry to talk with one another, share ideas, and debate the virtues and potential problems of coordinating R&D activities. We suggest this be a first step in formalizing discussions and cooperation among the laboratories to address the challenges in creating the X-ray optics needed to harness the full potential of current and future BES X-ray user facilities."