APS ERL Optics Workshop Report

Date of Workshop: April 23, 2007

Organizing Committee: D. H. Bilderback, A. Macrander (Chair), J. Maser, D. M. Mills, Q. Shen, G. B. Stephenson

Contents:

1) Executive summary

A one day workshop to address the status, scientific agenda, and development needs for x-ray optics at an ERL upgrade of the APS was held on April 23, 2007 at the APS. Since there had been a workshop the summer before at Cornell devoted to x-ray optics for an ERL, this workshop was organized to complement and update the one held at Cornell. The date of the workshop was partly chosen to accommodate two international speakers, Dr. K. Nugent and Dr. T. Ishikawa, who could not attend the earlier workshop. The APS ERL is expected to upgrade the APS storage ring performance to have approximately two orders of magnitude more coherent photons than the APS today. There was consensus among the attendees concerning optics development needs. These are: a) improved surface preparation for crystal optics and improved theoretical understanding of the reasons that they produce speckle patterns; b) improved metrology to reach a root-mean-square value well below 0.2 microrad precision for slope errors, and a program to perform at-wavelength metrology with a synchrotron beam; c) re-examination of current solutions to prevent distortion in optics due to heat loads from the beam, and consideration of the possibility that optics deformation may be prevented by a clever design of the ERL or of the undulators; d) optimization of a few key conceptual ERL beamlines to set optics requirements; e) measurement of the coherence fraction at various points along a few APS beamlines to assess their utility in an ERL mode. A prioritized list of action items was developed as a result of correspondence within the committee subsequent to the workshop.

2) Summaries of Presentations

E. Gluskin

ERL upgrade options for the APS at 7 GeV were presented beginning with a synopsis of smaller brightness limits inherent in a linac compared to a ring. Efim quoted M. Tigner that "Energy recovery addresses the only real advantage of rings: higher current." The three modes envisioned for the APS ERL, similar to ones at Cornell, were presented, namely, i) high flux, ii) high coherence, and iii) ultrashort pulses. Additionally, a storage ring mode in the existing APS will also be possible. In high coherence mode, the emittances predicted at new beamlines are 7 pm (picometer-radians) in both lateral dimensions. A roughly 100 times larger fraction of the number of x-ray photons will be coherent for an ERL than for the APS. An advantageous helical undulator design was presented, as well as a crossed undulator that can produce a very high degree of polarization. No loss in flux relative to the present APS is necessitated, contingent on the development of a successful electron emission source.

D. Bilderback

CESR upgrade plans for an ERL at Cornell University and its progress were first presented. The Phase IA project has been operating since 2005 and will continue through 2009. Photocathode development and injection to 15 Mev is the near term objective. A high voltage DC gun, based on photoinjection from a GaAs cathode illuminated by a frequency doubled (green light) Nd:YAG laser system, is under development and testing. An injector front end design was shown and tests of the next-in-line cryomodule are planned for June 2007. A proposal for Phase II to achieve 5 GeV operation at 100 mA is scheduled to be delivered by late 2008. The balance of the talk was devoted to outlining optics issues. Monochromators are well known to suffer distortions under severe heat loads and slope errors of such distortions should be 0.3 microrad (rms) or less to preserve the beam brightness with a 10 pm emittance. Isotopically pure Si has a thermal conductivity 6 times higher at 20 K , and the availability of such Si should be explored. Monochromator surfaces will need new levels of smoothness to avoid introducing speckle contrast. Mirror slope errors less than 0.1 microrad will be needed with 0.02 nm roughness. These are roughly an order of magnitude lower than is readily available today. Work on improving mirror surface perfection and the metrology of those surfaces should be undertaken seriously to have useful mirrors by the time that ERLs produce their first beams. A roadmap to guide optics development efforts is needed. This could build on previous roadmap discussions at a recent SPIE meeting and at a recent international SRI meeting.

K. Nugent

After a review of the basics of phase retrieval (via repeated Fourier transformation between an intensity constraint to match the diffraction pattern and a support constraint applied at the scattering sample), examples of successful coherent diffractive imaging were presented. The relative merits of short or long coherence lengths relative to the sample size and different degrees of wave front curvature were explored. A unique solution, an improved support constraint, and faster convergence result with a curved illuminating wave front. The best inversion results were obtained when there was both high coherence and high curvature. For coherent diffractive imaging one needs not only very good knowledge of the incident wave field, but also a very stable sample and beam (~3 nm). The support constraint can be set by the illumination. To achieve a suitable incident wave field, one needs very high quality optics, especially for resolutions approaching 1 nm. The resolution is, however, not limited by the optics. The central stop inherent with Fresnel zone plates is problematic since one needs to have a uniform illumination. From this point of view, focusing mirrors are advantageous.

T. Ishikawa

After a review of SASE for XFELs, the status of plans and preparations for the Japanese XFEL to be built on the SPring-8 site were presented. In vacuum undulators and a high field gradient linac design lead to a compact FEL design operating at 8 GeV to be completed by 2010. Lasing at 49 nm wavelength was achieved in June 2006. A UV laser may be used to do beam seeding to pre-bunch the electron beam. A SPring-8 upgrade planned for 2009-2010 will use the linac of the XFEL to inject into the storage ring for a 10 pm emittance at 200 mA and at 4 - 6 GeV. K-B mirror optics developed at Osaka University were reviewed. They were made by Elastic Emission Machining (EEM), and were evaluated by micro-stitching interferometry that incorporates a relative angle determination to allow subapertures to be stitched together for an assessment of an entire mirror. Results showing 0.087 nm (rms) over 100 mm with a peak-to-valley variation of 0.769 nm were presented. Only three atomic layers were found to be in the surface in an AFM study. A molecular orbital calculation confirmed an atomistic model for the EEM process. A 2-D focus of 30 nm by 25 nm was reported. X-ray fluorescence element mapping images of biological cells were shown as obtained with these mirrors with 15 keV radiation. A new knife edge design prepared by lithography was presented. The knife edge was made of Pt and was a bridge-like structure with a width of 2.5 microns. Phase retrieval techniques have been used to obtain surface profiles in at-wavelength metrology of K-B mirrors. Differential deposition of Pt was used to improve the surface figure of polished elliptical mirrors.

S. Shastri

Optics for short pulses from an ERL as well as from an XFEL were presented. For a few ps to 100 fs pulse widths, most conventional synchrotron optics will preserve the durations. Significant pulse stretching due to spectral narrowing (dynamical diffraction broadening) occurs for high-energy-resolution monochromators and longitudinal shear broadening occurs for crystal reflections that are not symmetric-Bragg cases (but rather, Laue or asymmetric-Bragg) due to path length differences. Monochromators with meV bandwidths usually employ highly asymmetric reflections and can, therefore, exhibit both types of pulse lengthening effects. Dynamical diffraction broadening cannot yield a product of [energy resolution] times [pulse width] less than ~ 2 eV fs. The longitudinal shearing phenomenon can often dominate. For a single Laue reflection (Si220, 8 keV, 50 microns thick) the shear broadening can be as large as 600 fs (ten times the dynamical diffraction broadening) and for a 4-reflection monochromator of meV energy resolution that broadening can increase to 1 ns. However, broadening effects can sometimes be compensated. For example, a nondispersive (+,-) double-Laue geometry compensates both dynamical diffraction and longitudinal shear broadening, which would be relevant for double-Laue monochromators used at high-energies (50-100 keV). Pulse compression techniques were also reviewed. Angular-chirped beams produced by RF deflection of the electron beam can be slitted or diffracted from an asymmetric set of crystal planes to reduce the ERL pulse width from a few picoseconds to 220 fs. Pulse compression can also be obtained by using an energy chirped beam to illuminate a double-Laue-multilayer arrangement. Energy bandwidth increase associated with diffraction by a strained crystal does not correspond to a reduced temporal broadening. However, by having a properly matched coherent energy-chirp in the incident x-ray pulse (conceivable with seeded XFELs), the strain effect can be compensated, achieving compression to transform-limited pulses. Results for SASE-XFEL-produced pulses at 8 keV after diffraction from Si(111) and Si(444) crystal systems were also presented, showing shot-to-shot integrated intensity fluctuations, as well and modification of the spiky intra-pulse structure.

T. Toellner

Monochromator arrangements employed at the APS for Nuclear Resonant Scattering (NRS) and for Inelastic X-ray Scattering were reviewed. Weak links and asymmetric reflection designs have been used extensively to achieve energy resolutions down to 0.55 meV. The agreement between calculated and measured resolutions is very good, but measured efficiencies are less than 50% of the calculated values. Cryogenic cooling is generally useful to stabilize the monochromators. An extremely asymmetric double bounce arrangement has been used to obtain 0.14 meV bandpass at 23.9 keV. A 6-bounce optical arrangement was predicted to permit perfect compensation of pulse width broadening due to optical path length differences (i.e., shear broadening). The design is similar to one already built and used to obtain 1.15 meV energy resolution. A table of ERL operating modes and the resulting properties at sector 3 of the APS for a 4.8 m undulator having a 27 mm period was presented. NRS is possible with 150 ns between x-ray pulses . Only spacings much shorter (0.77 ns -3.1 ns) or much longer (1000 ns) are presently envisioned for the ERL at the APS.

L. Assoufid

The present state-of-the-art for mirrors and for metrology of mirrors was reviewed. To date, the best long mirrors (>0.5 m) have slope errors only slightly larger than 0.5 microrad and roughnesses slightly larger than 0.1 nm (all values quoted are root-mean-square). For shorter mirrors (< 0.3 m) best values to date reduce to 0.5 microrad and 0.05 nm. Data going back to 1993 compiled recently for all three third generation synchrotron sources, shows that both average slope error and roughness have steadily declined at average rates of 0.36 microrad and 0.03 nm per year. In the coming years, improvements in metrology will be needed to realize the projected lower values for both slope error and roughness. A review of metrology instruments and capabilities at the APS and worldwide was presented. The metrology laboratory at the APS has an LTP, a Fizeau interferometer, a phase-shifting interferometer, and an atomic force microscope. Both the LTP and Fizeau interferometer measure slope and have been used to confirm slope measurement accuracy. Noise levels for slope measurements are 0.3 microrad and systematic errors in accuracy are roughly 0.5 microrad. There are reports from BESSY in Germany quoting an order of magnitude lower slope measurements. For roughness measurements, the phase-shifting interferometer is repeatable, in normal use, to 0.03 nm and is accurate to ~ 0.05 nm. This roughness measurement precision is believed to be the state-of-the-art worldwide. Stitching of subaperture data is used extensively at the APS, especially for strongly curved surfaces such as nanofocusing K-B mirrors. Stitching methods have been implemented worldwide and are anticipated to play a crucial role for improving both precision and accuracy in the future. Round-robin comparisons with several synchrotron based metrology laboratories worldwide have been conducted and results have been reported in the literature. Round robin comparisons are also seen as being quite important for future progress. From a metrology perspective, 0.01 microrad slope precision should be set as a goal for the metrology of ERL optics. Improvements in polishing methods will be essential since power-spectral-density data regularly reveal features due to tool marks. Development of a standard beamline “coherence meter” was urged which could perhaps be based on the Talbot effect as implemented with a double grating interferometer. Lastly, off-line metrology methods will always have a limited value since they do not employ x-ray wavelengths. An at-wavelength metrology program implemented at a beamline is seen as being very important to establish the future validity of off-line measurements as the state-of-the-art of optics fabrication and metrology continues to improve to the point where excellent ERL optics can be available.

A. Khounsary

Undulators for the ERL are about twice as long as current APS undulators, and the peak heat flux could approach 400 W/mm^2, compared with about 200 W/mm^2 today. Predicting the performance of cryo-cooled monochromators, for example, under this higher heat load is not trivial because of strong non-linearities and variability in the thermal properties of silicon and cooling rates at cryogenic temperatures. As such, the present APS designs cannot be linearly scaled up. Thus, to deliver the expected coherent beam generated by the ERL, development work both on surface quality and on cooling is necessary. In addition to thermal management, beam stability and optics mounting must also be improved. Presently at the APS, the overall slope error encompassing the combined effects of surface quality, thermal deformation, and mounting strains is typically 1 to 2 μr rms. This has to be improved by a factor of 10. This is not trivial, and all avenues to tackle this issue must be explored. In this context, it remains true that the best optics is none at all, and that the best approach to handling heat or vibration is not to have them in the first place. These dictate an integrated approach to ERL system design where the optics, source (undulator), and the machine are optimized together rather than separately. For example, undulator designs that result in a substantial reduction in the beam peak heat flux or provide a beneficial spatial power distribution–even at the expense of a modest brilliance loss–should seriously be considered. Various machine designs, for example, that affect some focusing of the x-ray beam through electron optics are worth considering. Focusing on optics, it can be stated that a good optic is one that, from the point of view of an observer, does not significantly enlarge or distort the ERL source. For the APS ERL, the X-ray beam size is almost entirely determined by the size of the electron beams, which for the high coherence mode is 14 μm x 6 μm (h x v). Viewed at a mirror located a typical 30 m from the source, the 6-μm vertical beam size projects a modest 0.2 μr angle. Therefore, the overall mirror slope error must be kept substantially below 0.2 μr, and this places very severe demands on both the fabrication and metrology for ERL mirrors, on the order 0.1 μr slope error or below. ERL mirrors will be typically smaller and the best available presently have 0.25 μr rms slope error and 0.04 nm rms roughness. However, these two specifications are not generally met simultaneously on the same optic by the same vendor. Progress in vendor polishing and metrology capabilities is essential and must be supported. In thermal management of monochromators for the ERL, it may be appropriate to pursue isotopically pure Si or diamond because these result in significantly increased thermal conductivity. For cooled mirrors, conductive substrates such as CVD SiC or CVD diamond overcoated and polished could be promising. Metrology improvements will also be needed, where the best metrology may prove to be with an x-ray beam. X-ray windows should be avoided, if possible, and new possible windows should be explored. Polishing single crystal Be is now being studied, but the possibility if using polished diamond windows should not be ignored.

C. Schroer

An update on the state-of-the-art in nanofocusing with compound refractive lenses was presented. To date the best reported focus is 55 nm (h) by 47 nm (v). The optimum material is diamond since it has the highest density to atomic number ratio. Limited refractive power per unit length limits the achievable Numerical Aperture (NA). Adiabatic focusing lenses (AFLs), whereby downstream lenslets are weakly and sequentially changed to accommodate a focusing beam, are calculated to be able to reach down to a 4.7 nm focus with diamond. For parameters applicable to the Cornell ERL, this lens is projected to reach a photon density of 10^9 to 10^{10} photons/nm^2/sec. AFLs made of Si are calculated to reach to 15.3 nm focus. Kinoform lens designs address the problem that the NA is limited by absorption. They are predicted to lower the achievable focus to 2.2 nm. New calculations for stacked kinoform lenses, for possibly better efficiency, were presented. Owing to reflection from the borders between segments, stacking was found to worsen the efficiency relative to a single thin lens.

J. Maser

Diffractive optics with high numerical aperture were discussed. It was pointed out that if the smaller inherent source size at an ERL is used to relax source demagnification requirements, x-ray microscope and x-ray nanoprobe working distances can be increased. Working distances can be made even larger if beam lines are made very long, but then one must have a lens which is proportionally larger. A direct consequence of the higher brilliance of an ERL is more flux delivered into a focused spot. Also, a more symmetric source implies fewer manipulations to correct for astigmatism. An overview of the high-resolution microprobe at sector 26 was presented. A “Moore’s Law” like behavior for the smallest worldwide achieved x-ray focus size over time was discussed. The present smallest are15 - 20 nm focuses for both soft and hard x rays. An inherent disadvantage of diffractive optics is that they are chromatic with the focal length proportional to the photon energy. The present state of development of Multilayer Laue Lenses (MLL) was presented. New calculations based on a Takagi-Taupin description were offered. Wedged ideal structures with flat interfaces and with curved interfaces were found to produce focuses well below 1 nm. A fundamental diffraction limit above the standardly invoked Rayleigh criterion was not found in these calculations. Physically measured focuses of 17 nm to 18 nm were reported for both 19.5 keV and 29.25 keV x-rays as measured at the APS. An overview of a new nano-positioning stage currently being commissioned at sector 26 was presented. Plans for two-dimensional focusing via crossed MLLs were presented. MLL performance at the Cornell and APS ERLs was contrasted. Performances were predicted to be comparable with slightly better performance at Cornell. In both cases an MLL with a very large number of layers will be needed. The monochromaticity requirements in these cases for focuses near 1 nm will also be higher than is available with standard monochromators.

C. Kewish

The status of Kirkpatrick-Baez mirror nano-focusing developments worldwide and at the APS was reviewed. A wave optical simulation with a point source was presented. The method was based on an exit pupil function approach wherein the Fresnel-Kirchoff integral is solved to transport wavefronts. The Fresnel reflectivity for an incident electric wave field (a complex number) was computed to include the phase shift incurred upon total external reflection from the mirror surface. The pupil function approach is amenable to simulations of both true diffuse scattering and of the mutual coherence function. Simulation results for a differentially polished mirror starting from microstitched metrology data were presented. The mirror was predicted to focus 15 keV radiation to 41 nm. Only spatial wavelengths longer than 0.1 mm were found to broaden the focus. A more direct method of simulation was also reported and, although there were small differences, overall corroboration of the results obtained by the pupil function method was obtained. Isophase maps a few millimeters from the focus were shown to be consistent with phase retrieval requirements for coherent diffractive imaging according to a published criterion.

3) Summary of Workshop Discussions

1) The surface perfection of monochromators , especially at low incidence angles, that is required to prevent phase contrast effects cannot presently be specified. The effects of small slope errors, residual roughness, and residual strain in the present generation of monochromators is generally sufficient to introduce phase contrast in imaging done at the APS, and these effects will be magnified on ERL beamlines due to the higher fraction of coherent photons. There is presently no developed theory of dynamical diffraction from crystals that has adequate predicting power.

2) The state-of-the-art for slope error measurements with long trace profilers (LTPs) is roughly 0.5 microradian, but ERL source sizes will lead to slope error requirements for mirrors of 0.2 microradian. Metrology advances will be needed. Complementary tools to corroborate new precision levels have been essential and other metrology instruments that measure slope errors will also be needed. One of these methods could be *in-situ* beamline measurements. A suggestion was made that the 1-km beamline at SPring 8 could serve this need.

3) Maximum heat loads in the high flux mode will be about twice as large as the current maximum on APS undulator beamlines. The present APS heat load solutions may be inadequate. Either R&D to explore new solutions, or a clear effort to keep heat loads on optics low enough by design of the accelerator or of the undulator, should be undertaken.

4) A “roadmap” for optics development should be developed in collaboration with Cornell. This assumes that general solutions to optics problems that will profit both the APS and Cornell can be found.

5) A small number of “key beamlines” that concentrate on likely important scientific agendas should be considered. The coherence requirements at the sample should be traced back through each optical element, ending at the beta functions for the accelerator. A beamline for intensity fluctuation spectroscopy was mentioned in this regard. Others might be coherent diffractive imaging and phase contrast imaging (including time resolved imaging). The optics requirements for these beamlines could then be specified more clearly. How effectively present APS beamlines would operate with an ERL source, instead of with stored beam, would also become apparent. Also the consequences of asymmetry between vertical and horizontal x-ray beam parameters would become more apparent.

6) A program to measure the mutual coherence function after each optical element on a few APS beamlines should be undertaken. There has been no systematic study undertaken at the APS. In conjunction with this effort a “coherence meter” should be developed.

7) Beam stability needs to be clearly specified since the effects of imperfect optics will be similar.

4) <u>Action Items</u>

In order of priority

1) Develop an R&D plan to achieve polishing of Si crystals to reach slope errors for monochromator surfaces below 1.0 microrad rms and height errors below 0.1 nm rms while preserving the required energy resolution of 1 meV.

2) Demonstrate 1 nm focusing with a multilayer Laue lens

3) Develop a metrology roadmap to reach a precision of 0.01 microrad rms for slope errors.

4) Demonstrate 25 nm focusing with K-B mirrors.

5) Develop a "coherence meter" useful at the APS to monitor coherence at various points along a beamline.

6) Pursue the procurement of isotopically pure silicon of low resisitivity.

5) Working Groups

1) Dr. T. Ishikawa offered that an agenda for optics testing at the 1-km beamline at SPring 8 be developed. Optics intended for use at the APS ERL could be tested there is the coming years. He agreed to pursue that option in connection with SPring 8 plans.

2) Dr. K. Nugent offered to collaborate on the development of phase retrieval techniques and algorithms as applied to optics fabricated for use at the APS presently and for the APS ERL.

3) Dr. D. Bilderback stressed that both the APS and Cornell ERLs may tax optics with a higher heat load than has been the case at the APS. Options and plans to mitigate heat load related deformation will be considered.

Appendix 1: Relationship to prior Cornell ERL Workshop #6

The present workshop followed a previous workshop on the same topic that took place 10 months earlier at Cornell University. A major emphasis of the Cornell workshop was nanofocusing, and the present workshop was also constructed to update the state-of-art for nanofocusing developments. The organizers and agenda for the Cornell Workshop are listed below.

Organizers: Don Bilderback (Cornell High Energy Synchrotron Source), Gene Ice (Oak Ridge National Laboratory), Kenneth Evans-Lutterodt (National Synchrotron Light Source, Brookhaven National Laboratory), Friso van der Veen (Swiss Light Source), & Wenbing Yun (Xradia)

Friday, June 23rd - Saturday, June 24th, 2006

Name	**Abstract**
Don Bilderback Cornell University	ERL Overview and Charge to Workshop
Wenbing Yun Xradia	The Limits of Hard X-Ray Zone Plates and Science Opportunities with nm Diameter X-Rays
Gene Ice Oak Ridge National Laboratory	KB Mirrors and Nanobeam Material Science
Friso van der Veen Swiss Light Source	Local Ordering of Fluids and Other Nanobeam Applications & Waveguides
Andrei Sirenko New Jersey Institute of Technology	Nanobeams for Nanoelectronic Devices - the Importance of ERL for Characterization of the Optoelectronic and Device Structures
Oliver Hignette European Synchrotron Radiation Facility	A Roadmap Towards Nanometre Size Hard X-Ray Focusing with Reflective Optics
Anatoly Snigirev European Synchrotron Radiation Facility	Pathways for X-Ray Nanometer Focusing and What are the Scientific Opportunities
Al Macrander Advanced Photon Source, Argonne National Laborato	Multilayer-Laue-Lens Optics for nm X-Ray Beams
Christian Schroer Technische Universität Dresden	Adiabatic Refractive Lenses for Making nm Beamsizes
Christian Fuhse Universität Göttingen	Nm Science Enabled by Waveguides
Kenneth Evans-Lutterodt National Synchrotron Light Source, Brookhaven National Laboratory	Can Kinoform Hard X-Ray Optics Produce sub-10 nm Beams?
David Muller Cornell University	Imaging at the Nanoscale - Complementarities Between Electron and X-Ray Beams
Kazuto Yamauchi Osaka University	Diffraction-limited X-Ray Nanobeam with KB Mirrors
Harald Reichert Max-Planck Institute for Metals Research	Nanobeams at High Photon Energy
Chris Jacobsen Stony Brook University	X-Ray Focusing: How Small a Spot Can We Make and use in X-Ray Experiments?

Appendix 2. **Charge to committee:**

The ERL proposed for the APS Upgrade would provide ultra-fast, ultra-short, coherent, and ultra-high brilliance hard x-ray beams. Optics to handle these beams for a wide variety of scientific investigations will be very challenging. This is a charge to organize and convene a full-day workshop in April 2007 on behalf of the X-ray Science Division at the APS to determine our fundamental needs and opportunities for x-ray optics development in view of a future hard-x-ray ERL at the APS.

Specifically, the workshop report should address the following questions:

1. What is the current status of applicable x-ray optics technology? What scientific opportunities can be addressed by these?
2. How would optimal x-ray optics deliver the scientific promise of an ERL? What are the parameters of the requirements? Can these requirements be prioritized?
3. What is the best way to satisfy the demand for optimal optics for a future ERL? What is the optimum path for optics development efforts within XSD to achieve these objectives?

Appendix 3 : Agenda

Workshop on APS upgrade/ERL Optics
Date: Monday , April 23, 2007

committee
A. Macrander ANL/APS/XSD - chair
Q. Shen ANL/APS/XSD
D. Bilderback Cornell/CHESS
J. Maser ANL/APS/XSD &CNM
B. Stephenson ANL/ MSD&CNM
D. Mills ANL/APS

	APS Auditorium		session chair
8:00	Breakfast buffet/coffee		
8:30	Welcome	D. Mills	
8:35	Charge to committee & to workshop speakers	G.Long	Long
8:40	Workshop overview and workshop report	A. Macrander	
9:00	X-ray Sources at the APS ERL	E. Gluskin	
9:30	Hard X-ray Optics Considerations for X-rays Beams Produced by an Energy Recovery Linac Source of X-rays	D. Bilderback	
10:00	Break		
10:15	Coherence Optics and Coherent Imaging	K. Nugent	Macrander
10:45	Optics for Coherent X-rays for SPring-8 and XFEL's	T. Ishikawa	
11:15	X-Ray Optics Considerations for Short Pulses	S.Shastri	
11:45	Lunch		
13:00	High Resolution Monochromators	T. Toellner	Shen
13:30	X-ray Optics Metrology at the State of the Art	L. Assoufid	
14:00	Optical Requirements For Preservation of The ERL Beam Quality	A. Khounsary	
14:30	Break		
14:45	Nanofocusing Hard X-rays with Refractive Lenses	C. Schroer	Stephenson
15:15	Nanofocusing with Multilayer Laue Lenses: Status and Prospects	J. Maser	
15:45	Wave-optical simulations of Hard X-ray Nanofocusing by K-B Mirrors	C. Kewish	
16:15	Summary and discussion for workshop report	A. Macrander	
18:00	End of workshop		