NSLS-II Beamline Development Proposal

Type I [X] Type II [ ]

OFT: NSLS-II beamline for at-wavelength metrology, in-situ surface figuring, crystal optics, radiometry, detectors and instrumentation development

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This proposal will develop a unique facility for **at-wavelength metrology, in situ surface figuring, crystal optics, radiometry, detectors and instrumentation testing. This capability is essential to realize the potential of ultra-high brilliance sources like the NSLS-II and will foster the development** of the next generation of advanced synchrotron instrumentation and science. The key points of the proposal are:

- **At-wavelength** (x-ray) metrology is **superior** to visible light optical metrology in terms of sensitivity, accuracy and simplicity. The stability of the NSLS-II source will exceed 100nrad, and in-vacuum operation will not only eliminate problems associated with air turbulence, but also provide a better control over the optical surface (reactivity, composition and topology). Vibration and temperature controls at modern SR centers are only rivaled by state-of-the-art e-beam microscopy facilities. Finally, the geometry can be chosen to match the orientation, clamping design, and static stress of the final sample/mirror configuration.
- Aspheric surface figuring techniques require **deterministic** profiling of the optics. It also requires **local** polishing (or deposition) with sub-nm precision and a small footprint of the polishing tool (a fraction of a millimeter). Our survey suggests that two novel profiling techniques, **ion-beam figuring** and differential deposition, can be performed **in situ** and are compatible with **simultaneous** x-ray metrology. This capability will revolutionize mirror fabrication, as polishing and coating have previously been done (i) in a different apparatus (ii) for different geometries and (iii) at a different time.
- Hard x-ray high-resolution optical schemes rely on crystal perfection as well as the precise arrangement of x-ray optics. **A spatially resolved technique** to measure crystal quality and stability (thermal and mechanical) is essential.
- Advanced SR instrumentation requires significant R&D efforts. A state-of-the-art test bench is needed to build advanced prototype instrumentation and to perform precise calibration before these systems can be deployed at specific beamlines.
- At-wavelength metrology will also advance **radiometry** and assist in **detector** development and **calibration**.

We advocate that the construction of an **at-wavelength metrology beamline with a dedicated ion-figuring station** at NSLS-II could **make coherence preserving x-ray optics** a reality. It would also provide a sustainable supply of state-of-the-art x-ray mirror for the nation and restore the U.S. position in atomistic surface fabrication with a minimal investment. It is natural to extend such a facility to crystal optics testing, and a second hutch would provide sufficient flexibility for prototype instrument development.

Construction of the **optical fabrication and testing (OFT)** beamline will also be **beneficial for the rapid-access user-research program**. The OFT beamline will be optimized for (i) reflectivity and scattering measurements, (ii) diffraction, topography and diffraction enhanced imaging, and (iii) imaging which requires coherence, such as coherent diffractive imaging, differential phase imaging and x-ray interferometry.

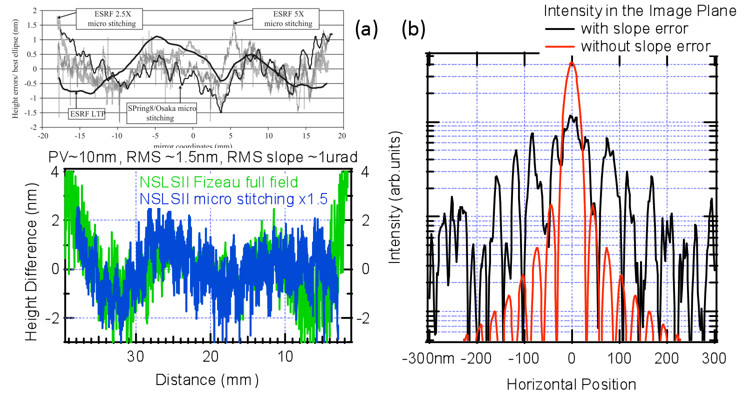

Fig.1. (a) The result of optical testing of the plane elliptical mirror fabricated by Tinsley and its expected performance (b) for the NSLSII source (25keV).

A. User Community and Demands

X-ray optics play an essential role in enabling new scientific research at synchrotron facilities worldwide, but the requirements imposed on x-ray optics by the next generation of ultra-bright sources are beyond our current measurement and manufacturing capabilities. This concern has been raised at recent x-ray metrology workshops and meetings (see Appendix) which emphasize the substantial investments required in precision fabrication, polishing and metrology. To overcome "conventional technique" limits, SR centers abroad have established their own programs to develop x-ray mirrors adequate for the 21st century. Of particular note is the Japanese "Atomistic Fabrication Technology" program, led by Osaka University, that has demonstrated technological breakthroughs and sub-10nm focusing of hard x-rays[1]. The NSLSII must also establish a strategy toward "state of the art" SR optics, particular x-ray mirrors. Accumulated experience suggests that it is now possible to **combine the ultimate precision of at-wavelength metrology with *in situ* fabrication of SR reflective optics to achieve nm-level precision and make final mirror figuring directly at SR facilities.**

The visible light metrology performed on a state-of-the-art elliptical mirror fabricated by Tinsley (Fig.1a) illustrates the typical discrepancy and noise level achieved. Although there are strong correlations between different techniques and apparatus, it is a challenge to improve their performance by the factor of 5 needed, particularly over a 250mm long optical surface with a sag of ~100microns[2]. Optical systems can measure at near their diffraction-limited performance, if the wavefront in the exit pupil departs from the reference sphere by less than a quarter of a wavelength[3], or, if random phase errors are assumed for a 20% intensity loss criteria (Strehl), root mean square (RMS) departure does not exceed $\lambda/14$. Taking into account that the height bump h on a mirror's surface contributes to a $2\times2\pi/\lambda\times h\times \mathrm{Sin}(\Theta)$ phase shift (where Θ is the grazing incidence angle), such criteria limits the surface figure error to 0.5nm RMS for 25keV x-rays. Table 1 lists requirements typical of soft and hard x-ray mirrors. A more detailed analysis would account for the distribution of figure errors over the relevant range of spatial frequencies and compute their contribution to the wavefront distortion for particular experiments[4]. Such calculations will be an integrated part of the current proposal.

Table 1. Targeted Mirror Requirements.

	soft x-ray mirrors 0.2-2.5keV	hard x-ray mirrors (4-20keV)
Setting for test	~1keV, Si at ~1.5deg (1.2keV), projected to reach 50nm	6.5keV, Si at ~4mrad, projected to reach 45nm for Si or 20nm with Pt (18keV)
Typical mirror/ pupil size	up to 280/8.5mm	up to 250/1mm
Figure Accuracy: PV/RMS/ slope error	PV: 5nm/RMS:1.5nm/ 35nrad RMS	PV: 2.5nm/ RMS:0.7nm/ 20nrad RMS
Roughness (RMS)	<0.3nm	<0.2nm

[1] H. Mimura, et al., Breaking the 10nm barrier in hard-x-ray focusing, Nature Phys. (2009),DOI: 10.1038/NPHYS1457
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Fig.1b shows the result of a SRW simulation[5] and indicates that current polishing accuracy is not sufficient to reach near diffraction limited performance. Clearly, innovation is required to meet the stringent specifications required to fabricate coherence preserving x-ray mirrors.

B. Proposal Team Expertise and Experience

The proposal team includes the lead optical metrology scientists from DOE SR labs: Valeriy Y. Yashchuk (ALS), Lahsen Assoufid (APS), Konstantine Kaznatcheev (NSLSII) and Peter Z. Takacs (BNL). The interest (and needs) of the proposal also extends beyond US SR facilities. Mikhail V. Gubarev (NASA) represents the interests of the x-ray astronomy and space exploration community. Kenneth A. Goldberg (CXRO) plays an important role in active partnership to develop Extreme Ultraviolet Lithography and would provide a bridge to the U.S. semiconductor industry. Michael Pivovaroff (LLNL) is group leader for the team that designed and fabricated the x-ray mirror systems for LCLS, the x-ray FEL at SLAC. This group also makes x-ray optics for the National Ignition Facility at LLNL and is beginning an effort in x-ray adaptive optics. Gene E. Ice (ORNL) brings expertise to neutron optics. Yuri Shvyd'ko is an expert in high resolution hard x-ray optics. He is also a leading figure for the "X-Ray Free-Electron Laser Oscillator" proposal, a key components of the APS upgrade. Oleg Tchoubar developed first principle wave propagation analysis software, which will be essential for an interpretation of x-ray interferometric images. The strength of academic excellence will be complemented by the practical knowledge and technological development of U.S. optics fabrication companies. Integrated Optical System- Tinsley (Anthony Hull) just completed the optics for the James Webb space telescope[6] and Optimax System (Jessica DeGroote Nelson) represents the interests of the large Rochester (NY) cluster focused not only on optical manufacturing but also on the development of state-of-the-art equipment for optical fabrication.

C. Science Case

The following section includes a short description of mirror polishing technology with an emphasis on ion beam figuring. It also describes the fundamentals of x-ray metrology, interferometry and the beamline requirements. It is followed by a description of x-ray topography, as applied for crystal optics testing. A pre-conceptual description of the dedicated OFT beamline is given in section D. Because of the space constraints, the prospects of instrumentation and detector development are discussed briefly. However, the ongoing programs at other SR centers provided compelling justification for these capabilities (see Appendix). We also omit a discussion of SR as a radiometric standard, used to measure the quantum efficiency, uniformity, linearity and time response of detectors or as a bench-mark for characterization of other VUV and x-ray sources. These aspects of the SR metrology are well reviewed[7], used at almost every SR facility and certainly will become a part of the OFT beamline. Instead, we focus attention on novel aspects of the OFT and the way they should enable state-of-the-art x-ray optics and instrumentation.

Mirror fabrication: Due to the achromatic nature of total external reflection and wide energy tunability, x-ray mirrors cover the soft and hard x-ray range. The critical angle for total reflection scales as $1.6\times10^{-2}\lambda\rho^{1/2}$ (where ρ [g/cm3] is the density of the mirror material and λ [nm] is the x-ray wavelength)[8], so the optimized geometry

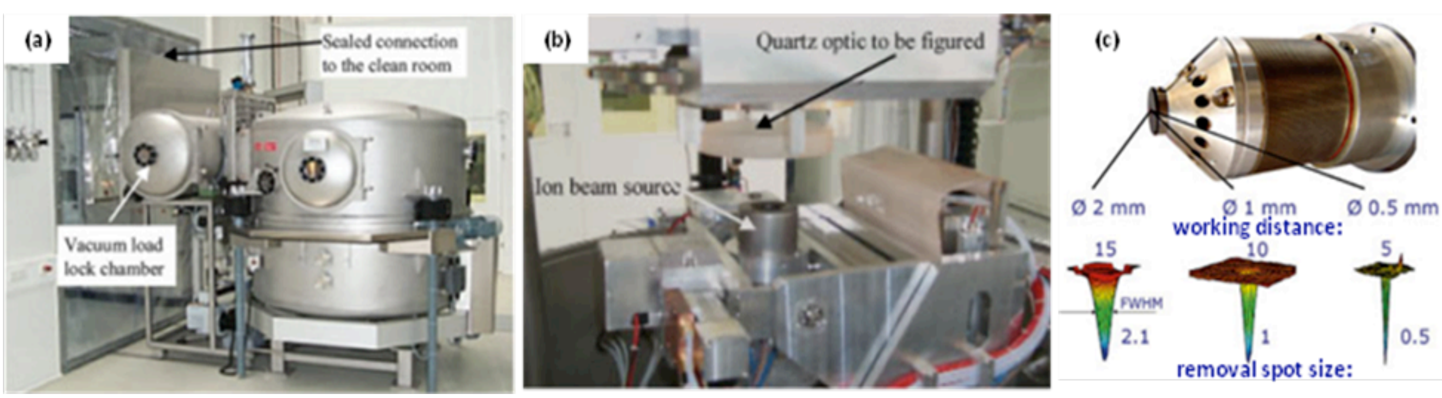

Fig.2. (a) Overall picture of IBF plant, (b) internal component and (c) multi-aperture Ar^+ ion source and its characteristics.

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6 J.P. Gardner, et al., The James Webb space telescope, Space Science Reviews (2006) 123: 485–606
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will differ for specific applications. We identify two regimes: soft and hard x-rays (Table 1) that cover mirrors of different shapes used for collimation (spheres or toroids), high energy suppression (flats) or extreme focusing (ellipses). We will focus on Si substrates, as using a thin coating of a high density material like Os, Pt, Ru or Au to extend the mirror performance to 20keV. Thin film thickness can be controlled to sub-nm precision by visible light ellipsometry. Si has excellent thermo-mechanical characteristics[9], radiation hardness and the ability to be polished to an ultra-precise surface finish[10]. In addition, single crystal ingots one meter long and several inches in diameter are commercially available, with stringent specifications for crystal imperfection dictated by the even more demanding requirements of the semiconducting industry. Using modern CNC machines and well-established Si cutting, grinding and lapping processes results in blank fabrication with surface departure below 10µm. Techniques for stress relief are also developed[11]. Using conventional polishing techniques, many optical companies can make aspherical mirrors with figure errors of 10µrad/100nm and surface finish below 1nm RMS. The manufacturing process would start with such mirrors, with only the final stages of precise figuring and metrology performed at the NSLSII.

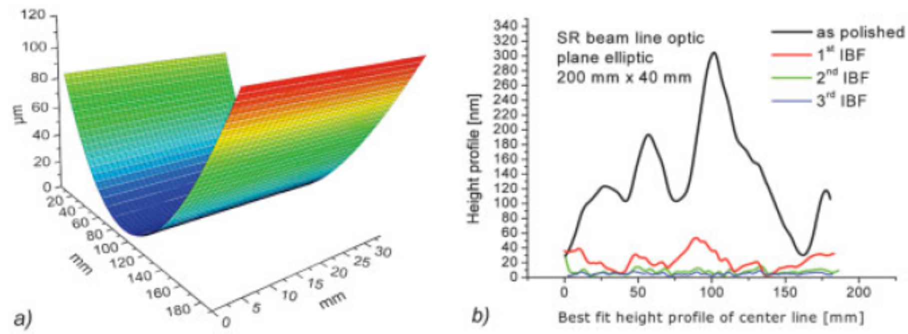

Fig.3. Interferometric stitched profile of SR Si mirror (a) and (b) residual (best fit ellipse subtracted) profile along central line at different stage of Ar^+ ion beam figuring. After three iterations a slope error of 0.6urad (RMS) has been achieved.

Several new polishing techniques have emerged to satisfy the requirements for being (i) deterministic, (ii) local, (iii) "gentle", (iv) chemically inert, all necessary to shape the mirror surface to the atomistic level. Computer-controlled plasma chemical vaporization machining (PCVM)[12] and elastic emission machining (EEM)[13] were developed within the framework of the Center for Atomistic Fabrication Technology and enable the figuring of mirror surfaces to a peak-to-valley (PV) accuracy better that 1nm and a lateral resolution close to 0.1mm[14]. Magneto-rheological polishing (MRF), by introducing ferromagnetic particles in the polishing jet, can precisely shape surfaces without immediate contact with a polishing tool[15]. Flexible and fast, MRF machines have demonstrated the ability to produce highly-curved freeform optical surfaces with accuracies better than 30nm PV. Although state-of-the-art mirrors can be produced with the above techniques, the presence of polishing fluids and geometrical constraints limit our ability to incorporate *in-situ* metrology and require a separate metrology station[16]. Sequential metrology creates the serious problems of cross correlation between the calibrations of two instruments. For highly-curved surfaces, lateral mirror angles and positions must be controlled to better than 0.2mrad (sagittal) and 10µm with environment < 0.1^oC and with drifts < $0.05^oC/h$. Additional time is needed for parts to settle and stress to be relieved. This all leads to substantial engineering challenges, slows the polishing- measurement process and requires large capital investments. Fortunately, this is

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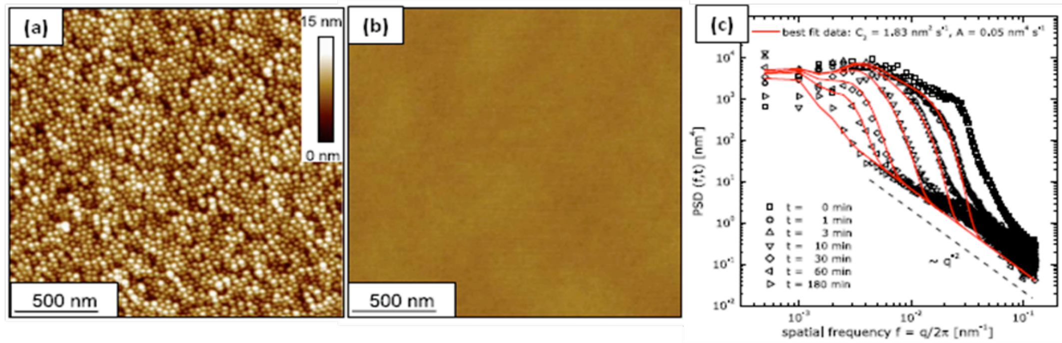

Fig.4. AFM images before (a: s(rms)~2.2nm) and after (b: s~0.2nm) Ar^{+} ion beam figuring and PSD (c) variation during the progressive smoothing of a Si surface.

not the only approach available. Spatially-controlled thin-film deposition and ion-beam figuring (IBF) are both compatible with in-situ metrology and create the possibility of at-wavelength metrology[17].

Differential deposition[18] has been used at the APS and results in a mirror quality similar to Fig.1. Although its use will be considered[19], its effectiveness may be limited, because: (i) deposition of the "foreign layer" is regulated by complex thin film growth mechanisms, with differences in the mechanical and crystallographic structure creating stress[20] and/or even delamination of thick films, (ii) correction by thin film can result in interference effects and phase shifts that vary spatially and with x-ray energy, and (iii) an ion (charge) beam is easier to shape, control and raster, compared to atomistic sputtering. Furthermore, commercial IBF system that can accommodate mirrors up to 700mm long are available and used for the final polishing to reach state-of-the-art specifications not achievable by conventional full lap and small abrasive polishing process (Zeiss[21], Nikon). Fig.2 shows the IBF plant produced by NTG (Germany)[22]. Large vacuum vessels house mirror-alignment stages, and a RF-type ion source (Ar^{+}) is mounted on a multi-axis precision manipulator. Several ion-beam-shaping diaphragms permit a broad adjustment range of the active spot (from 20 to sub mm size) with a working distance of 50 to 5mm. Removal rate can reach nm/sec, where local removal depth is controlled by gate voltage, dwell time and scan trajectory. One passage of ion beam figuring over the mirror's full aperture is reasonable (hours): several iterations might be needed to reduce figure errors from 100nm to a nm level (Fig.3). During operation, the typical vacuum increases to~ 10^{-6}torr which poses no problem for x-ray metrology. Ion-beam-induced erosion can also be used to relieve and modify the surface to bring it to atomistic smoothness. Fig.4 shows the result of AFM measurements of a Si mirror surface during ion beam polishing[23]. Clearly IBF not only avoids characteristic tooling marks, but also reduces the imprint of preexisting marks.

At-wavelength metrology: Emerging techniques with ultra-high accuracy wavefront feedback make it possible to perform the fine alignment and qualification of x-ray optics *in situ* using x-ray light (*at-wavelength*) as the final quantitative measure of focusing quality. The preferred approach is to perform a series of different tests with increasing accuracy and sensitivity, to bring an optical system from its initial alignment state (with µm-scale figure errors) toward diffraction-limited performance, where λ/50 to λ/100 accuracy is theoretically possible. Several methods, which have been successfully employed, are shown schematically in Fig. 5. These methods coexist as they share similar hardware requirements. The key components are an object-plane spatial filter to define a coherent cylindrical or spherical illuminating wavefront, high-resolution focal-plane stages holding nanofabricated elements, and a downstream CCD detector. In the following we refer to their successful SR implementation and focus on specific beamline requirements to enable them.

The Foucault test[24] (insertion of a knife edge in the beam with downstream recording of the resulting shadow) and the Hartman test (where a grid of pinholes is inserted after the beam waist and their projection

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[24] D. Malacara, Optical shop testing, Wiley & Sons, Inc., 2007

recorded on a CCD) do not rely on transverse source coherence. Figure sensitivity as high as >λ/100 has been demonstrated[25], but both methods relays on absorption-pinhole-mask fabrication and generally 2D focusing is needed. The requirements on the CCD are modest, a pixel pitch of 12μm is sufficient.

A second class of emerging methods uses the measured near- or far-field diffraction patterns to reconstruct a wavefront numerically[26]. Its canonical implementation for a divergent beam is shown in Fig.5d. Spatial resolution better than 4nm has been reported with good reconstruction of the main peak but poor restoration of error sensitive side bands (see Fig.1b). There have also been successful examples of useing a uniformly redundant array to simultaneously reconstruct the complex coherence factor [27].

For hard x-rays the design of a proper nano-object and high-resolution detector are the main concerns. A recent paper describes an innovative design for a test object (a few micron Si bridge would provide a π-shift for hard x-rays, but would need to be polished to sub-nm RMS), that extends the diffracted wave to an extreme inward direction (known as Sommerfeld's solution). A sensitive, high-dynamic range detector (such as an APD) is used to measure the fringe structure and thus permit reconstruction of the near-focus intensity profile in greater detail[28]. The transverse coherence needed for coherent diffractive imaging (CDI) should be twice the lateral extension of the wavefront to be reconstructed[29], but an even higher degree of coherence would be needed to resolve the side lobes (Fig.5c). This requires a flexible beamline design which can vary the transverse coherence from a fraction of a mirror pupil size to several times the pupil size. CDI also requires temporal coherence, so the energy width ΔE/E should not exceed 2δx (ultimate spatial resolution required)/W (wavefield size) or should be better than 10^{-2} to reconstruct mirror figure errors of 1/mm lateral scale. If a plane coherent wave experiences phase distortion, the set of interference fringes appears at a distance and multiple images measured at different planes can be used to reconstruct the initial phase distortion. This effect, known as the self-amplified Talbot effect, has been successfully used to deterministically retrieve surface errors[30]. For mirror surfaces with a characteristic roughness spatial wavelength τ inclined at angle Θ, the fringe visibility

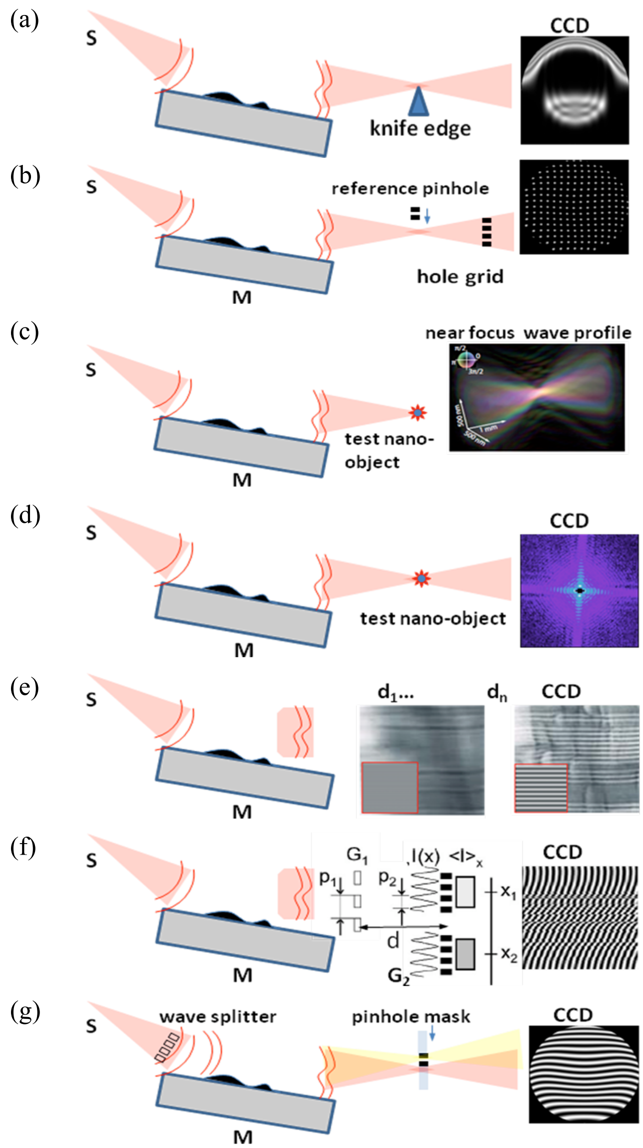

Fig.5. Cartoon representation of the different at-wavelength testing schemes: (a) the Foucault and (b) the Hartmann tests are widely used for incoherent light. Other tests relay on x-ray light coherence to measure (c) near focus fine structure, (d) far- field coherent diffraction image (speckles) of known test object or (e) intermediate field figure errors induced fringes (similar to in-line holography). The sensitivity of at wavelength test can be further enhanced by introducing special wavefront splitting optics to construct of (f) the Talbot or (g) the point shearing x-ray interferometers.

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reaches a maximum at a distance L, so $\tau=(2\lambda L)^{1/2}/\mathrm{Sin}(\Theta)$. The fringes period is $\tau\times\mathrm{Sin}(\Theta)/2$. A very fine resolution detector is needed to resolve such fringes. These structures and parasitic scattering from upstream beamline components limit the accuracy of the mirror slope measurements to 1μrad.

A third class of techniques consists of phase-shifting x-ray interferometers. Currently, interest is focused on common path optical schemes (rather that beam-splitting such as the original Bonse- Hart design) that relax temporal coherence requirements and are less prone to drift and vibrations. A phase grating placed in the vicinity of the test mirror splits the wavefront into plus/minus first orders and results in intensity modulations (fringes) at a distance $d=np_1^2/(8\lambda)$, where n=1,3,5.. is the interference order, and p_1 is the period of phase (π) grating (see Fig.5f). As in the case of a self-amplified Talbot interferometer (Fig.5e), the interference fringes have a period of ~ $p_1/2$ or in the micron range, which is beyond the resolution of most detectors. The second amplitude grating matching the period of the fringes (p_2~ $p_1/2$) and inclined at a small angle α would result in a Moire pattern, but with the period $p_2/\{2\sin(\alpha)\}$, or large enough for modern high resolution detection. The phase errors associated with test mirrors would be also amplified and seen as a distortion (wiggling) of the Moire fringes. The lateral shift between two gratings (x_1,x_2.. of Fig.5f) results in the shift of fringes, and algorithms developed for visible light phase shifting interferometery can be used to derive the wavefront. The measurable quantity is the phase gradient, which would be equivalent to the mirror slope error, and sensitivity below 100nrad has been demonstrated[31]. It has also been shown that the visibility of the fringes derived from measurements over an extended range of grating separation (d, or different order n) directly quantifies the complex coherence factor[32] and so provides information on test mirror quality at higher spatial frequencies. The requirement for beamline monochromaticity is minimal, as fringes retain visibility over a large energy range, so even a 10% energy window would be sufficient to 5th-order Talbot distance. Unfortunately, extension to the soft x-ray regime is limited by the ability to fabricate good phase gratings. Fig.5g shows an alternative approach. Rather than use a second grating, a pinhole is used to construct a point diffractometer[33]. The spherical wave produced by a pinhole interferes with the "object" wave coming unobstructed through an adjacent aperture. The close separation of the pinhole and aperture ensures moderate fringe spacing at the detector plane, but further optimization is needed to avoid scattered-light pollution. Two reconstruction algorithms have been developed: phase shifting (by lateral movement of the grating) and Fourier transformation of interference patterns[34]. Further analysis is needed for a one dimensional focusing optic (such as single test mirror). The $\lambda/300$ accuracy is achieved[35], but as in the case of Tablot-type interferometer, the quality of "special optics" drives the sensitivity and the accuracy of the technique, so cooperation with a nanofabrication facility (such as CFN (BNL) or CXRO (LBL)) would be important. For instance, the optimum pinhole size should be close to 20nm, but the mask opacity requirements necessitate the use of Au (or Ni, if a lower energy would be chosen) films at least 250nm thick, making pinhole fabrication a significant challenge. Furthermore, the alignment of the interferometer requires accurate and stable positioning (estimated to be better than 10nm laterally and 100nm longitudinally).

Scattering and reflectometry: Most mirrors used in SR beam lines will have a reflecting coating applied to the surface. These coatings run the gamut from simple single-layer noble metals through complex graded-layer multilayer coatings. Preliminary studies show that at a shallow angle the top surface chemistry and morphology (which might not coincide with bulk parameters) strongly affects film reflectivity. Effective performance of these coatings require not only a complete knowledge of the properties of the coating materials, but also knowledge of thickness variations and even interface composition. These properties can be measured at wavelength in real time[36]. Diffuse scattering is another important parameter, as even a very small roughness creates an extended halo of scattering in the x-ray regime. This is especially important for x-ray

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monochromators (gratings and crystals), as extended tails affect bandpass and contaminate the monochromatic line. We would like to incorporate a variable angle reflectometer in the main mirror-fabrication station similar to the ALS 6.3.2 design. An in-vacuum CCD mounted on a rotational arm and a tilt adjustment stage for the main mirror holder would complete the 2-axis vertically-disperse reflectometer. A monocromaticity of the beam better than 10^{-2} should be sufficient even for multilayer structures tests. Soft x-ray gratings efficiency can also be measured, although low transverse coherence is important to avoid ripples caused by speckles.

Crystal optics: The development of at wavelength metrology will be also essential for pushing high-energy-resolution optics with resolving power of 10^6-10^8 for both soft and hard x-rays. One promising method to achieve this goal for hard x-ray is to use extreme asymmetric back-reflection Bragg optics. Fig.6 shows recent results focused on the fabrication and testing of synthetic diamond, which is essential for realization of an x-ray free-electron laser oscillator[37]. Colored dots represent the results of high-resolution x-ray diffractometry, a technique used to measure crystalline quality via the rocking curve parameters. It achieves high angular or equivalently reciprocal space resolution, but integrates in real space over the illuminated area of the sample. The limited spatial resolution of this technique results in poor correlation of the measured crystalline quality with the origin of microscopic imperfections. X-ray diffraction topography (Fig.6 gray image) permits direct defect visualization and analysis[38]. Localized crystal defects, such as inclusions, dislocations, stacking faults and grain boundaries are clearly resolved, but their appearance and sensitivity (or contrast mechanism) depends on the measurement geometry (Bragg vs. Laue), x-ray divergence and monochromaticity. The technique is less sensitive to long-range variation of crystalline quality (such as strain fields), but recent results, which rely on x-ray coherence and a combination of x-ray tomography with phase imaging and spatially-resolved diffractometry, suggest that strain fields as small as 10^{-7} can be measured. Their contributions, distinguished from changes in local crystalline plane orientation[39] and even topographical defects (such as scratches on the crystal surface) can be visualized[40]. The three techniques described above (x-ray topography, phase imaging and spatially-resolved diffractometry) use similar experimental set-ups and can be combined. Such a facility will not only provide a basis for high-resolution spectrometer testing, but will be essential for characterization of other hard x-ray optical components, such as beam splitters, phase plates[41], or bent crystals. It can be also used to run a vibrant user-driven program, as the demand and interest in x-ray topography is extended well beyond research in crystal growth and characterization.

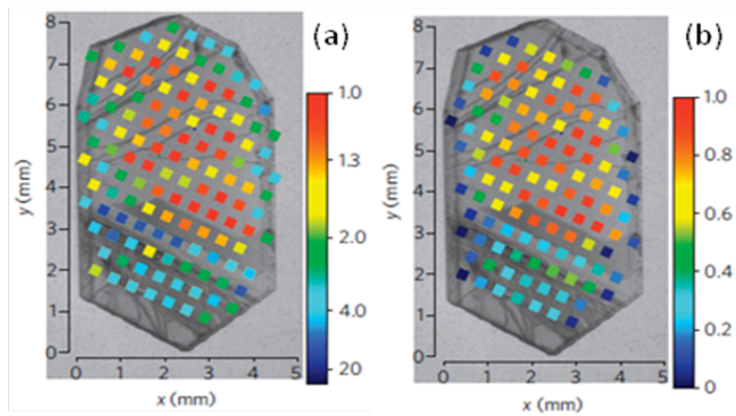
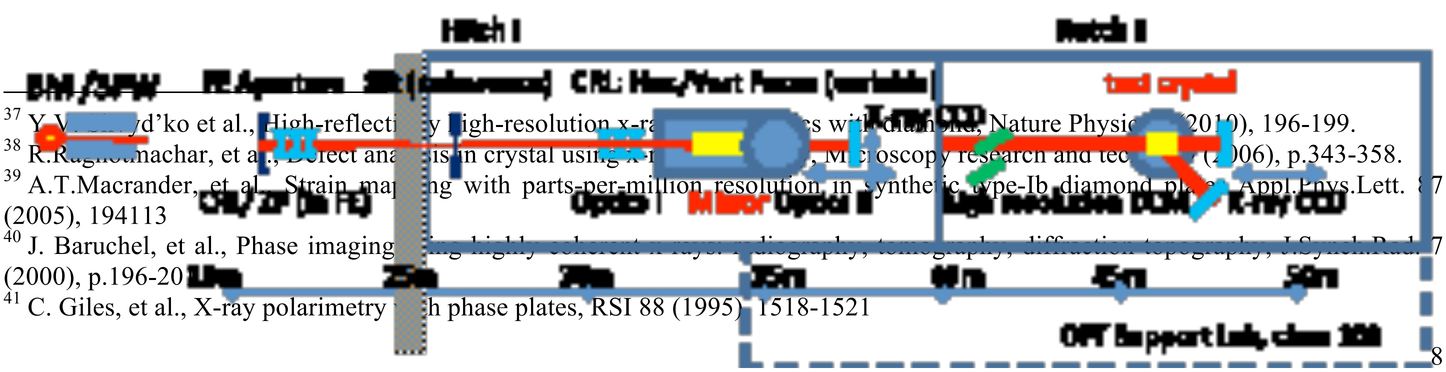


Fig.6. Color maps for the relative spectral width, $\Delta E / \Delta E_{min}$ (a), and the relative peak reflectivity for the (995) Bragg reflection, R/R_{max} (b), at different points on the diamond crystal, measured with a 23.765 keV X-ray photon beam overlaid on white-beam x-ray transmission topogram.

D. Beamline Concept & Feasibility

Our baseline concept, sketched in Fig.7, has the following properties:

- *Broad spectral coverage.* The design allows testing of optics across soft and hard x-ray bands. It optimized for two energies (~0.6keV and 6keV) to facilitate Si mirror fabrications.



[37] Y.V.[illegible]d'ko et al., High-reflecti[illegible]y high-resolution x-ra[illegible]s with diamond, Nature Physic[illegible] (2010), 196-199.
[38] R.R[illegible]machar, et a[illegible], [illegible] ana[illegible]is in crystal using x-r[illegible], Microscopy research and tec[illegible] (2006), p.343-358.
[39] A.T.Macrander, et al., Strain mapping with parts-per-million resolution in synthetic type-Ib diamond plates, Appl.Phys.Lett. 87 (2005), 194113
[40] J. Baruchel, et al., Phase imaging [illegible] highly coherent x-rays: radiography, tomography, diffraction topography, J.Synch.Rad. 7 (2000), p.196-20[illegible]
[41] C. Giles, et al., X-ray polarimetry [illegible]h phase plates, RSI 88 (1995), 1518-1521

Fig.7. Cartoon representation of the OFT beamline main components and 3PW/BM spectral performance

- *Two hutches and adjacent clean room class-1000 facility.* The upstream hutch will host *ion figuring* and equipment needed for *at-wavelength metrology*. The upstream optics can be removed to provide a clear passage to the downstream hutch that will be used for crystal testing and instrumentation development.
- *Moderate temporal and (adjustable) transverse coherence,* achieved with coherence preserving optics.
- *Simplicity and versatility.* The virtual source distance can be matched to the requirements of the optics under test by adjusting refocusing lens parameters.
- *Ion figuring capabilities*, provided by IBF machine with a fixed mirror and a 4 degrees of freedom movable ion source.
- *At-wavelength metrology:* several complimentary approaches to span variation in geometry and energy.
- *Advanced detectors:* a high resolution CCD (~2μm PSF) as the primary detector, and a back illuminated x-ray CCD for reflectivity measurements. Precise scanner (<10nm) will be a part of IBF.

The spectral performance of an NSLSII 3PW/BM source is shown on Fig.8b. With a proper choice of extraction angle it is possible to combine the lower-energy peak originating from bend magnet radiation with the high-energy lobe produced by the side pole of the 3PW. An appropriate 2D x-ray lens (compound refractive lens (CRL) for hard x-rays, and Fourier zone plate (FZP) for soft x-rays) inserted into the beam is used to focus the light onto an entrance slit. To reduce the total length of the beamline and increase the angular acceptance the focusing lens is located behind the rachet wall (at approximately 21m from the source), with the entrance slit just after the ratchet wall. A pair of CRLs with R_{apex}~0.13mm or a ZP with outermost zone ~800nm (assuming 10mm diameter) is adequate. Electron beam source (RMS) of ~40μm (h)*3μm (v) corresponds to the coherent length of 15μm (h)*190μm (v) for E~6keV at the location of the lens; transverse coherence can be further increased by closing the slit[42]. Because of refractive/zone plate lens chromaticity, these devices also serve as a rough energy filter. A model analysis suggests that the monochromaticity of the light can reach 10^{-2} (or 70 eV for hard x-ray, as shown on Fig.8d). Lens(es) after the exit slit (at ~31 m) will be used to adjust the virtual source distance as required for mirror fabrication. Although each geometry requires a particular lens, we expect to use a set of lenses and use them in a "transfocator" fashion. The long focal distance of the lens relaxes the technological challenges, and we expect practical devices to preserve the wavefront[43]. As some at-wavelength metrology schemes need 2D focusing even for single mirror measurements, a provision for independent horizontal and vertical focusing will be included. The flux at the mirror position (Fig.8d) for hard x-ray tests will reach 10^9ph/s/mm^2, comparable to the 10^{11}ph/s/mm^2 flux reported for the 1km long Spring8 ID beamline[44] and will permit real time at-wavelength metrology.

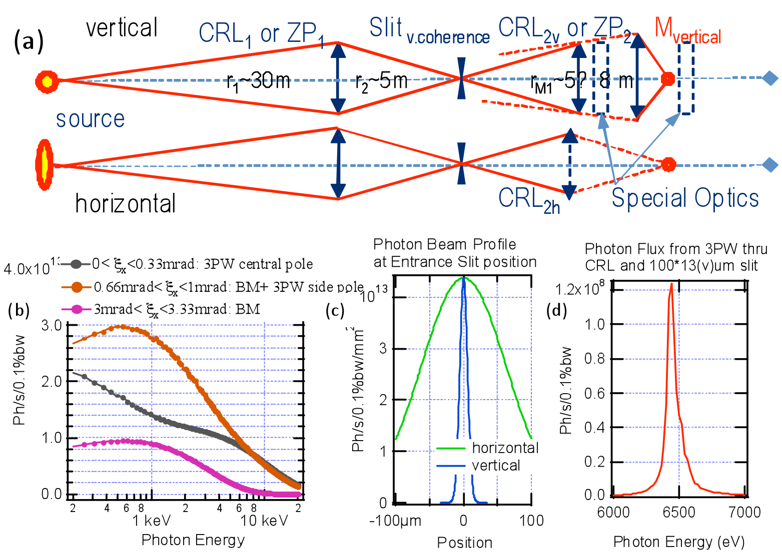


Fig.8. Optical scheme and basic characteristics of OFT beamline.

Hutch I: IBF and at-wavelength metrology: To reach 25nm performance, x-ray mirrors must be accurately positioned with respect to the beam and must remain stable. Model analysis suggests 10 μm position accuracy and 100μrad rotational accuracies are needed. Mirror support should be decoupled from the vacuum vessel and a large granite table provide the vibration suppression and stability required. During ion-milling, the mirror remains stationary, and the ion source position will be controlled by a robotic arm within the vacuum vessel. The ion source will move to follow the polishing profile. The same vacuum vessel will hold the ion-s

[42] It is comparable to ESRF ID19 beamline coherence length of ~100 μm (at 20keV)

[43] B. Lengeler, et al., Imaging by parabolic refractive lenses in the hard X-ray range, J. Synchrotron Rad. (1999). 6, 1153-1167

[44] K. Tamasaku, et al., SPring-8 RIKEN beamline III for coherent x-ray optics, NIM A 467-468 (2001), p.686-689

beam diagnostic. The accuracy of the ion beam head travel (~tens of microns) is moderate. Four degrees of freedom (two translations and two head rotations) should be sufficient, since the mirror slope errors are orders of magnitude less sensitive in the sagittal direction. Further optimization of the system schematics will be sought in conjunction with ion source design. A preferable approach will be to capitalize on the proponent group (Tinsley) experience in design and operation of ion beam figuring, but a full commercial solution for an ion beam plant is also an option[45]. A space upstream of the mirror tank is reserved for special optics. Downstream of the mirror system (on the same granite block) a precise scanner will be needed to implement the at-wavelength metrology schemes described above. A CCD-based imaging system with spatial resolution approaching ~ one micron and a large field of view will be placed downstream. Linearity, dynamic range, sensitivity and frame speed need further discussion, but a similar system has been developed by different SR labs and is used for differential phase and coherent diffraction imaging. Another in-vacuum CCD mounted on a rotational arm would be used for 2-axis vertically dispersive reflectometry. A commercial back illuminated CCD (with ~15μm pixel size) will be adequate.

Hutch II: crystal optics and instrumentation development: As it would be possible to remove all upstream components, hutch II will be compatible with white beam experiments. An x-ray transparent window (Be) and differential pumping section ensure vacuum separation from the upstream IBF components. A large optical table provides a stable and flexible platform for ancillary systems, such as beam-defining apertures, shutters, ion chambers, photodiodes or other opto-mechanical components. Rather than purchasing a commercial DCM, a set of precise weak-link angular stages (similar to those developed at the APS[46]) will provide a basic modular block to be organized in a user-specific configuration. A bent mirror system can be installed to provide user specified illumination or rastering of the beam if desired. The upstream IBF optics can be used if higher collimation is needed. A second high-resolution CCD camera optimized for high x-rays will be the primary detector. Other detectors, *e.g.* energy-dispersive or fast cameras will be available through the NSLS-II detector pool. An integrated motor and detector control system is of the great importance. It would not only secure a remote operation, but provides easy configurable access to video servers, analog and digital I/O, counters, frequency generators, or external timing signals if ultra fast time-resolved measurements are demanded.

Mobile metrology equipment for beamline commissioning and troubleshooting: Some of the metrology equipment described above is compact and can be used as a stand-alone mobile test station to facilitate other beamline commissioning. In fact, some of them are already developed and used at different SR facilities for measurements of: power load induced mirror deformation[47], EPU emission and polarization properties[48], and mutual coherence[49]. The development of such tools and their characterization is an important part of the current proposal.

[45] NTG Offer V14362: Ion Beam Figuring plant (IBF 300) for BNL

[46] D. Shu, et al., Novel miniature multi-axis driving structure for artificial channel-cut crystals, AIP Proceedings 521 (2000) 219

[47] Qian, et al., In-situ surface profiler for high heat load mirror measurement, Opt. Eng. 34(1995), p.396-402.

[48] K. Desjardins, et al., The DiagOn: an undulator diagnostic for SOLEIL low energy beamlines, 2008 IEEE Nuclear Science Symposium Conference Record, N30-424, pp. 2571-2574

[49] A. Snigirev, et al., x-ray nanointerferometer based on Si refractive bilenses, PRL 103 (2009), 064801.

Appendix A. Beam lines for metrology, optics and instrumentation development.
Beam lines for metrology and optics development exist at other **synchrotron facilities**, both in the US and abroad. Beam line 6.3.2 at the **ALS** is dedicated to EUV optics testing, calibration, and standards development. This is a bending magnet beam line with an energy range of 25−1300 eV run by Eric Gullikson. It has played a major role in characterizing the materials properties of thin films used in multilayer reflective optics. It has enabled development of novel grating designs to enhance reflectivity in the soft x-ray region and played a major role in the development of optics for the EUV Lithography program. **APS** has an ongoing proposal for a bending beamline (6-BM) upgrade with a focus on extensive optics and detector characterization and testing. In the short term, this beamline is expected to play a major role in R&D activities in support of the APS upgrade. Beamline also has an extensive general user agenda and may serve a wider optics and detector community. **ESRF** has a dedicated X-ray Optics Group that encompasses several areas essential to synchrotron beam line operation. These areas are in crystal preparation, mirror metrology, IBF, KB mirror bender assembly and development, and multilayer coating applications. Off-line metrology and optical testing is closely integrated with the at-wavelength testing done at beam line BM05, one of the first built at ESRF. This is a hard x-ray line with monochromators that provide photons in the 6−100keV range[50]. **SPring8** has several beam lines for machine diagnostics that are also used for optics development. The most well-known of these is BL29XUL, the 1 km long undulator beam line used for coherent x-ray optics development and for investigation x-ray coherence phenomena. A cooled Si(111) monochromator provides photons over a 4.4−37.8 keV range. Pioneering work was done on this beam line to demonstrate the usefulness of phase retrieval methods for measuring the quality of coherent x-ray wavefronts, enabling the evaluation of mirror surface roughness and figure errors that affect the quality of the focal spots available at this beamline. **Diamond** has a dedicated bend magnet beamline. The beamline is used for the characterization of optics, detectors and other instrumentation, and for the development of novel techniques[51]. **Soleil** has operational bending magnet beamline with two branches dedicated to soft and hard x-rays and covering the 50 eV to 40 keV energy range[52]. Constructed in collaboration with the Bureau National de Métrologie it is expected to become the national primary VUV to x-ray radiometric standard and carry an extensive program focused on optical elements and materials characterization. **Swiss Light Source** just completed the construction of the beamline for the photon energy range from 5.5 to 22.5keV based on a cryogenically cooled Si(111) channel cut monochromator as a general purpose beamline for quick access to the synchrotron beam for optics and instrumentation R&D, at-wavelength metrology and detector developments. In addition it provides a user-friendly and robust generic instrument that can be used for feasibility tests, training and student practicals.

Other major facilities exist at various institutions around the world for specialized at-wavelength testing of optics. Most relevant to the SR x-ray range is the 500m long **X-ray Calibration Facility (XRCF) at NASA Marshall Space Flight Center** with a 23m long by 7.3m diameter vacuum test chamber used to calibrate large space telescopes, such as the *Chandra X-ray Observatory*. A similar facility (PANTER) exists at the Max-Planck-Institute in Munich, Germany, with a shorter source distance of 130m. Both of these facilities require a large staff to operate, with correspondingly large operating costs. The PTB maintains a suite of beam lines at BESSY II for radiometric calibration of detectors and characterization of optical components, but the energy range is limited to 1.8keV. A similar facility at NIST, SURF III, performs calibrations in the UV and VUV range up to 1.2keV. The Physikalisch-Technische Bundesanstalt (**PTB**), Germany's national metrology institute, is using synchrotron radiation for metrology and related applications for research and industry. The new 600 MeV electron storage ring, named 'Metrology Light source' (MLS) dedicated to metrology and technological development in the UV and VUV spectral range started its operation in 2008. At its beamlines, the MLS offers capabilities for precise measurements and calibrations in the spectral range from the far infrared/THz to the extreme ultraviolet (EUV), thus complementing the activities of PTB at BESSY II, which cover the short-wavelength spectral ranges from the EUV to the X-ray range.

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[50] E.Ziegler,et al., The ESRF BM5 metrology beamline: instrumentation and performance upgrade, AIP Conference Proceedings 705 (2004), p.436

[51] S. Alcock, et al., Optical metrology laboratory for Diamond, http://www.diamond.ac.uk/Beamlines/Beamlineplan/B16/index.htm

[52] M.Idir,et al., Metrology and tests beamline at SOLEIL, AIP Conference Proceedings 879 (2007), p.619.

Appendix B Recent workshops (last five years) or meeting organized by the proponent group.

- Oct. 2004 – "Advanced Optical Systems and Metrology for High Power and Coherent Beam Lines" at Brookhaven National Lab
- May 2006 - "The 3rd International Workshop on Metrology for X-ray Optics" at Daegu, South Korea
- Oct. 2007 – "Advanced X-ray Optics Metrology for Nano-focusing and Coherence Preservation" at Lawrence Berkeley Lab
- Sept. 2009 – "International Workshop on X-ray Mirror Design, Fabrication, and Metrology" at Osaka University
- March 2010 - First Meeting on Development of a New Optical Surface Slope Measuring System (OSMS-I) at Lawrence Berkeley Lab
- May 2010 - Second Meeting on Development of a New Optical Surface Slope Measuring System (OSMS-I) at Argonne National Lab

Other conferences and meetings (where members of the proposal team gave talks or chair sections)**:**

SPIE Optical Metrology 2005 | 2007 | 2009 and SPIE Optifab 2005 | 2007 | 2009 each had sections dedicated to SR metrology, mirror fabrication or precise optical metrology related to SR instrumentation. An upcoming SPIE conference (August 2010, San Diego) is dedicated to "Advances in Metrology for X-Ray and EUV Optics".

The synchrotron radiation instrumentation (SRI) international (every second year) and pan-American (in between) have dedicated SR optical design sections. Coming Sixteenth Pan-American Synchrotron Radiation Instrumentation (SRI) Conference (to be held at Argonne) will have a satellite workshop "Coherence Preserving Optics for High Brightness Light Sources".

The Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI) conference is now a stand alone meeting, which historically covers SR optics, for instance, past MEDSI (2008, hosted by Canadian Light Source, Saskatoon) had a day-long section on "Challenges in Beamline Optics". An upcoming MEDSI (Diamond Light Source, Oxford) will have a two day section dedicated to "Developments in Beamline Optics and End Stations".

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Education/Training:

Institution	Degree	Year	Field of Study
Russian Research center "Kurchatov Institute"	PhD	1995	Physics& Material Science
Moscow Physics Engineering Institute	M.S	1988	Physics& Engineering

Research and Professional Experience:

NSLS II	2008-present	Visiting Scientist & Consultant
Canadian Light Source	2001-2007	Staff Scientist
NCSU (at ALS LBNL)	2000-2001	Research Assistant
SUNY SB (at NSLS BNL)	1998-1999	Research Assistant
RRC "Kurchatov Institute"	1988-1998	Engineer, Scientist, vice-Director of the Kurchatov SR Source

Honors, Awards:
Mombukagakusho Fellowship, (Photon Factory, KEK, Japan), 1996-1997
Basic Science Research Award, Ministry of the Atomic Energy (Russia), 1991

Professional Activities:
Review panelist: NSLS Imaging and Microfocusing, 2008-present.
Consultant: Canadian Light Source, 2008-present.

Selected Publications:
L. Tortora, H.-S. Park,b, S.-W. Kang, V. Savaryn, S.-Ho Hong, K. Kaznatcheev, D. Finotello, S. Sprunt, S. Kumara, Oleg D. Lavrentovich, *Self-assembly, condensation, and order in aqueous lyotropic chromonic liquid crystals crowded with additives*, accepted by Soft Matter

Lam, K.P.; A.P. Hitchcock, M. Obst, J.R. Lawrence., G.D.W. Swerhone, G.G. Leppard, T. Tyliszczak, C. Karunakaran, J. Wang, K. Kaznatcheev, D. Bazylinski, U. Lins, *Characterizing magnetism of individual magnetosomes by X-ray magnetic circular dichroism in a scanning transmission X-ray microscope*, Chemical Geology, Vol. 270 (2010), pp. 110-116.

Obst. M., J.J. Dynes, J.R. Lawrence, G.D.W. Swerhone, K. Benzerara, C. Karunakaran, K. Kaznatcheev, T. Tyliszczak, A.P. Hitchcock, *Precipitation of amorphous CaCO3 (aragonite-like) by cyanobacteria: A STXM study of the influence of EPS on the nucleation process*, Geo. Cosmo. Acta, Vol. 73, pp. 4180-4198

Weigand, M.; B. Van Waeyenberge, A. Vansteenkiste, M. Curcic, V. Sackmann, H. Stoll, T. Tyliszczak, K. Kaznatcheev, D. Bertwistle, G. Woldersdorf, C.H. Back, G. Schutz *Vortex Core Switching by Coherent Excitation with Single In-Plane Magnetic Field Pulses* PRL, Vol. 102 (2009), pp. 177201, 1-4

K. V. Kaznacheev and T. Hegmann, *Molecular ordering in a biaxial smectic-A phase studied by scanning transmission X-ray microscopy (STXM)* Phys. Chem. Chem. Phys. Vol. **9**, (2007), p.1705-1712 selected for the front page cover.

K.V. Kaznatcheev, P. Dudin, O.D. Lavrentovich, A.P. Hitchcock, *An X-ray Microscopy Study of Chromonic Liquid Crystal Texture* Phys. Rev. E. Vol. **76**, (2007) p.061703 (1-14)

K.V. Kaznatcheev, C. Karunakaran, U.D. Lanke, S.G. Urquhart, M. Obst, A.P. Hitchcock *Soft X-ray Spectromicroscopy Beamline at the CLS: Commissioning Results* NIM A, Vol. **582**, (2007) pp. 96-99.

K.V. Kaznatcheev, C. Karunakaran, F. He, M. Sigrist, T. Summers, M. Obst, A.P. Hitchcock *CLS ID-10 Chicane Configuration: From "Simple Sharing" to Extended Performance with High-Speed Polarization Switching* NIM A, Vol. **582**, (2007) pp. 103-106.

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Education/Training:

Institution	Degree.	Year	Field of Study:
University Paris-7, Paris, France	Ph.D. (with highest honors)	1991	Physics
University Paris-7, Paris	M.S.	1987	Physics

Research and Professional Experience:

Period	Organization	Position
10/2009-Present	Argonne Nat. Lab., APS, X-ray Science Division	Physicist/Section Leader for Mirrors, Multilayers and Metrology Section of ODG
1996-09/2009	Argonne Nat. Lab., APS, X-ray Science Division	Physicist, Principal Investigator for the x-ray optics metrology program
1993-1996	Argonne Nat. Lab., APS, X-ray Science Division	Assistant Physicist, Optics Group

Honors, Awards:

- Pacesetter Award *"For excellence in achievement and performance which truly surpasses normal job expectations,"* Argonne National Laboratory, February 16, 2008.
- Pacesetter Award, shared with Dr. Chian Liu for "*Developing masked differential deposition of Kirkpatrick-Baez-type elliptical mirrors by means of thin-film sputter deposition,"* Argonne National Laboratory, November 2002.
- Graduate research scholarship from the Ministry of Research and Technology of France, 1987-90; College education scholarship from the Ministry of Education of France, 1983-85.

Professional Activities:

- Chair, SPIE conference in "Advances in Metrology for X-ray and EUV Optics-III," SPIE Optics & Photonics International Symposium, San Diego, CA, August 1-5, 2010
- Program Co-Chair for the 2009 Optical Society "Frontiers in Optics" meeting, held in San Jose, CA, October 11-15, 2009

Selected Publications:

1. **L. Assoufid**, et al. "A Microstitching Interferometer for Evaluating the Surface Profile of Precisely Figured Hard X-ray K-B Mirrors," SPIE Proc. (2007) 6704.
2. C. Liu, **L. Assoufid**, R. Conley, A. T. Macrander, G. E. Ice, and J. Z. Tischler, "Profile coating and their application for KB mirrors," Opt. Eng. 42, (2003) 3622.
3. C.M. Kewish, **L. Assoufid**, A.T. Macrander, and J. Qian, "Wave-optical simulation of hard X-ray nanofocusing by precisely figured elliptical mirrors," Applied Optics, (2007). 46(11):2010-2021.

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Physicist, scientific software developer, Ph.D.

Work experience

Since Jan. 2009: X-ray Source Scientist, Experimental Facilities Division, National Synchrotron Light Source-II, Brookhaven National Laboratory, USA.
Parametric optimization of insertion devices for the NSLS-II project beamlines; calculation of emission characteristics (spectral-angular and intensity distributions, brightness, flux, power density distributions / heat load on optical elements) for all NSLS-II radiation sources; knowledge transfer on properties of different kinds of synchrotron radiation to beamline scientists. Development of general physical optics based simulation methods for partially-coherent synchrotron radiation wavefront propagation; implementation of these methods in the SRW computer code and application of this code for performance evaluation and optimization of NSLS-II synchrotron radiation beamlines: X-ray Nanoprobe, Inelastic X-ray Scattering, Soft- and Hard X-ray Coherent and other beamlines. Support and further development of Radia magnetostatics code - the main tool for magnetic design of insertion devices for NSLS-II.

2002 - 2009: "Physicien du rayonnement" (<synchrotron> radiation physicist), Division of Accelerators and Sources, Group of Magnets and Insertion devices, Synchrotron SOLEIL, France.
Design and optimization of insertion devices for Synchrotron SOLEIL (responsible for first SOLEIL APPLE-II type undulators); calculation of synchrotron emission and wavefront propagation through optical beamlines; participation in optimization of infra-red and some X-ray beamlines; physical optics simulations and extraction scheme optimization for femtosecond slicing project; automation of magnetic measurements of insertion devices; undulator commissioning; electron beam optical diagnostics. Development of genetic algorithm based computer code for sorting and shimming of insertion device magnets; support and further development of SRW and Radia codes. Transfer of knowledge on magnetostatics and SR calculation to SOLEIL scientists and engineers.

2000 - 2002: Software engineer / developer of scientific software, ESRF, Grenoble, France.
Support and extension of SRW and Radia computer codes; analysis and development of the ESRF Scientific MIS project. Synchrotron emission calculations; participation in optimization and construction of the infrared beamline based on Edge Radiation.

1996 - 2000: Scientific collaborator, group of Insertion Devices, European Synchrotron Radiation Facility, Grenoble, France.
Development of “Radia” – a 3D magnetostatics computer code optimized for insertion devices, and a code for high-accuracy computation of synchrotron emission and wavefront propagation – “Synchrotron Radiation Workshop” (SRW). These codes are currently used in large number of laboratories dealing with synchrotron radiation worldwide. Web: http://www.esrf.eu/Accelerators/Groups/InsertionDevices/Software.

1992 - 1996: Scientific collaborator, Kurchatov Synchrotron Radiation Source, RRC Kurchatov Institute, Moscow. Development of accurate calculation methods for synchrotron radiation generated by relativistic electrons in magnetic fields of arbitrary configuration, in near-field observation region; theoretical and experimental studies of "Edge Radiation" - a special kind of synchrotron radiation with properties similar to the Transition Radiation. Development of Synchrotron Radiation interference-based methods of electron beam diagnostics. Participation in design and optimization of insertion devices for synchrotron radiation sources.

1991 - 1992: Professor assistant, Department of Nuclear Physics, Moscow Engineering Physics Institute, Russia.

Degree

Dec. 1995: Candidate of Physical and Mathematical Sciences (= Ph.D), held in Moscow Engineering Physics Institute. Thesis: “Computation methods for synchrotron radiation; applications to electron beam diagnostics”.

Education

1992 - 1995: Post-graduate courses in Moscow Engineering Physics Institute, Russia. Qualified as researcher.

1983 - 1991: Moscow Engineering Physics Institute (Technical University), USSR. Diploma with honors. Qualified as engineer-physicist specialized in nuclear physics.

RECENT PUBLICATIONS

O.Chubar, Y.S.Chu, K.Kaznatcheev, H.Yan, "Performance Optimization for Hard X-ray Microscopy Beamlines Guided by Partially-Coherent Wavefront Propagation Calculations" - to appear in proceedings of SRI-2009 Conference (Melbourne, September 27 - October 2, 2009), oral presentation.

O.Chubar, J.Bengtsson, A.Broadbent, Y.Q.Cai, Q.Shen, T.Tanabe, "Parametric Optimization of Undulators for NSLS-II Project Beamlines" - to appear in proceedings of SRI-2009 Conference (Melbourne, September 27 - October 2, 2009), oral presentation.

G. Lambert, T. Hara, D. Garzella, T. Tanikawa, M. Labat, B. Carre, H. Kitamura, T. Shintake, M. Bougeard, S. Inoue, Y. Tanaka, P. Salieres, H. Merdji, O. Chubar, O. Gobert, K. Tahara & M.-E. Couprie, “Injection of harmonics generated in gas in a free-electron laser providing intense and coherent extreme-ultraviolet light”, Nature Physics 4 (2008), pp.296-300.

M. Bowler, J. Bahrdt and O. Chubar, “Wavefront Propagation” in “Modern Developments in X-Ray and Neutron Optics”, Springer Series in Optical Sciences, Springer Berlin / Heidelberg, vol.137 (2008), pp.69-90.

O.Chubar, M.-E.Couprie, M.Labat, G.Lambert, F. Polack, O.Tcherbakoff, “Time-dependent FEL wavefront propagation calculations: Fourier optics approach” (oral presentation at "FEL Frontiers 2007" Workshop), Nucl. Instr. and Meth., 2008, vol.A593, pp.30-34.

A.Giuliani, F.Jamme, V. Rouam, F.Wien, J.-L.Giorgetta, B.Lagarde, O.Chubar, S.Bac, I.Yao, S.Rey, C.Herbeaux, J.-L.Marlats, D.Zerbib, F.Polack, M.Refregiers, "DISCO: a low-energy multipurpose beamline at synchrotron SOLEIL", Journal of Synchrotron Radiation, 2009, vol.16, pp.835-841.

<u>Jessica DeGroote Nelson, Ph. D.</u>

Select Work History

Optimax Systems Inc., Ontario, NY — 2007 – Present
Scientist

The Institute of Optics, University of Rochester — 2002 – 2007
Graduate Student – Ph. D. Advisor: Dr. Stephen D. Jacobs
Thesis title: Surface Interactions Between Nanodiamonds and Glass in Magnetorheological Finishing (MRF)

Center for Optics Manufacturing, University of Rochester — 2000 – 2002
Engineer and Student Lab Technician

Education

Ph. D. Optics, May 2007, University of Rochester, Rochester, NY
M.S. Optics, March 2004, University of Rochester, Rochester, NY
B.S. Optics, May 2002, University of Rochester, Rochester, NY

Select Publications

<u>J. DeGroote Nelson</u>, R. N. Youngworth, D. Aikens, "The cost of tolerancing" SPIE Proceedings, Optical System Alignment, Tolerancing and Verification III (2009).

D. Aikens, <u>J. E. DeGroote</u>, R. N. Youngworth, "Specification and Control of Mid-Spatial Frequency Wavefront Errors in Optical Systems," in *OSA Optical Fabrication and Testing Topical Meeting*, OTuA1 (2008).

<u>J. E. DeGroote</u>, A. E. Marino, J. P. Wilson, A. L. Bishop, J. C. Lambropoulos and S. D. Jacobs, "Removal rate model for magnetorheological finishing (MRF) of glass," *Applied Optics*, **46** (32) 7927-7941 (2007).

<u>J. E. DeGroote</u>, A. E. Marino, K. E. Spencer, S. D. Jacobs, "Power Spectral Density plots inside MRF spots made with a polishing abrasive-free MR fluid" *Optifab*, SPIE, 134 – 138 (2005).

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Education/Training:

Institution	Degree	Year	Field of Study
University of California, Berkeley	PhD	1997	Physics
University of California, Berkeley	MA	1994	Physics
University of California, Berkeley	A.B.	1992	Physics & Applied Mathematics

Research and Professional Experience:

Period	Organization	Position
April 2010–	Center for X-Ray Optics	Deputy Director
Dec 1997–	Center for X-Ray Optics	Staff Physicist

Honors, Awards:

Outstanding Performance Awards, LBNL, 1999, 2000, 2002, 2010
SPOT Recognition Award, 2008
R&D 100 Award, 2003
Advanced Light Source Halbach Price for Instrumentation, 1998
Outstanding Graduate Student Instructor Award, 1993
University of California Berkeley Physics Department Citation, 1992

Professional Activities:

Advanced Light Source Users Executive Committee, 2007–2010, Chairman 2009
Electron Ion Photon Beam and Nanotechnology conference (EIPBN), EUV Program Committee and Section Head, 2001–present
Member SPIE, OSA

Selected Publications:

K. A. Goldberg, "EUV Optical Testing," in *EUV Lithography*, Vivek Bakshi (ed.), (SPIE Press, 2008), 205–225.

K. A. Goldberg, *P. Naulleau, S. Rekawa, P. Denham, et al.*, "Ultra-high-accuracy optical testing: creating diffraction-limited short-wavelength optical systems," Proc. SPIE **5900**, 114–23 (2005).

K. Goldberg, P. Naulleau, J. Bokor and H. Chapman, "Testing EUV Optics with Visible-Light and EUV Interferometry," J. Vac. Sci. Technol. B, **20** (6), 2834–39 (2002).

K. A. Goldberg and J. Bokor, "Fourier-transform method of phase-shift determination," Applied Optics **40** (17), 2886–94 (2001).

P. P. Naulleau, K. A. Goldberg, *et al.* "Extreme ultraviolet carrier-frequency shearing Interferometry of a lithographic four-mirror optical system," J. Vac. Sci. Technol. B, **18** (6), 2939–43 (2000).

K. A. Goldberg, "Testing extreme ultraviolet optical systems at-wavelength with sub-angstrom accuracy," in *Fabrication and Testing of Aspheres*, J. S. Taylor, M. Piscotty, and A. Lindquist, (eds.) (Optical Society of America, Washington, D.C., 1999).

H. Medecki, E. Tejnil, K. A. Goldberg, and J. Bokor, "A Phase-Shifting Point Diffraction Interferometer," Optics Letters **21** (19), 1526–8 (1996).

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Astrophysicist

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PROFESSIONAL PREPARATION

M.S., Physics Engineering, Moscow Physics Engineering Institute, 1988
M.S., Physics, University at Albany (SUNY), 1995
Ph.D., Physics, University at Albany (SUNY), 1998

APPOINTMENTS

2007 – present	Marshall Space Flight Center, Huntsville, AL
2002 - 2007	Sr. Scientist, Universities Space Research Association, Huntsville, AL
2000 – 2002	Sr. Engineer, Raytheon ITSS, Marshall Space Flight Center, Huntsville, AL
1998 – 2000	Postdoctoral Associate, Marshall Space Flight Center, Huntsville, AL
1994 -1998	Research Assistant, Center for X-ray Optic, University at Albany (SUNY), Albany, NY
1987 – 1994	Engineer-Researcher, Scientific Researcher, Laboratory for Electro-magnetic Interactions, Russian National Scientific Center "Kurchatov Institute", Moscow, Russia

AWARDS

- National Research Council Postdoctoral Research Award, 1998 – 2000
- MSFC NASA Director's Commendation, 2000

SELECTED PUBLICATIONS

1. M.V. Gubarev, K. Kilaru, B.D. Ramsey "An investigation of differential deposition for figure corrections in full-shell grazing-incidence X-ray optics" - Nuclear Instruments and Methods in Physics Research A 616 (2010) 273–276
2. S. Romaine, J. Boike, R. Bruni, D. Engelhaupt, P. Gorenstein, M. Gubarev, B. Ramsey, **"**Mandrel replication for hard x-ray optics using titanium nitride**",** Proceedings of the SPIE, Volume 7437, pp. 74370Y-74370Y-8 (2009)
3. G.S.Khan, M.Gubarev, W.Arnold and B.D.Ramsey "Development of a computer-controlled polishing process for x-ray optics" - SPIE 7437 (2009)
4. M. V. Gubarev, B. D. Ramsey, D. E. Engelhaupt, J.M. Burgess, D.F.R. Mildner, "An Evaluation of Grazing-Incidence Optics for Neutron Imaging" –Nuclear Instr. And Meth. B, 265 (2007) 626-630.
5. M. Gubarev, B. Ramsey, D. Engelhaupt, T. Kester, C. Speegle, "Technology development for high-energy x-ray optics," – Proc. SPIE, 6266, pp. 62661I (2006)
6. M. Gubarev, C. Alexander, B. Ramsey, "Alignment, Assembly and Testing of High-Energy X-Ray Optics" –Proc. SPIE v. 5900, pp 232-238, 2005

TONY HULL

University of New Mexico and L-3 Integrated Optical Systems

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Research/Development Interests: Stellar Polarimetry & Photometry, Astrometry, Contact and Over-Contact Binary Star Systems, Exoplanet Imaging, Archaeology: Survey, Rock Art, Archaeoastronomy, Systems Architecture, Large Telescopes, Spaceborne Instrumentation, Electro-Optical Systems, Opto-Mechanics, Dimensional Stability of Materials, Optical Finishing, Program Management

Professional Background

L-3 Integrated Optical Systems

May10-Present University of New Mexico: Adjunct Professor, Department of Physics and Astronomy

Feb09-Present L-3 Integrated Optical Systems (IOS) Manager of Business Development: Astronomy

Aug04-Jan09 L-3 IOS Tinsley: James Webb Space Telescope (JWST) Program Manager & Director of Large Optics

Jet Propulsion Laboratory: Principal Engineer, Interferometry and Advanced Optical Systems Section, Observational Systems Division, Jet Propulsion Laboratory

Optical Corporation of America/Perkin-Elmer

1980–1999 different appointment starting from Project Engineer to Vice President, Chief Scientist, Corning OCA (formerly Optical Corporation of America)

Education

- All But Dissertation, Ph.D. in Astronomy and Astrophysics, NASA Traineeship (3-year), University of Pennsylvania
- B.S. in Mechanical Engineering (Academic Honors), University of Pennsylvania 1967
- UCLA Certificate Program in Archaeology 1996-1999

Professional Organizations:

- American Astronomical Society (Judge Chambliss Student Awards)
- SPIE (Member of Optomechanical Working Group and Session Committee)
- Society for American Archaeology

Selected Publications and Talks (more than 50, last year only cited)

Hull, T: January 2010: Space Optics Topic Expert: Schott invited expert for 2-hour presentation at SPIE LASE, San Francisco.
Hull, A et al: January 2010: Tinsley Progress on Stress Mirror Polishing (SMP) for the Thirty Meter Telescope (TMT) Primary Mirror Segments; Washington DC AAS Meeting, Paper 441.27
Ambruster, C., Hull, T., and Jewell, E.: January 2010: Criteria for the Attribution of Intent to Archaeoastronomical Alignments: Examples from Chaco Canyon, NM; Washington DC AAS Meeting, Paper 331.03
Canzian, B., Gardopee, G., Clarkson, A. and Hull, T: January 2010: Large High Performance Optics for Spaceborne Missions: L-3 Brashear Experience and Capability: Criteria for the Attribution of Intent to Archaeoastronomical Alignments: Examples from Chaco Canyon, NM; Washington DC AAS Meeting, Paper 481.01
Hull, A., October 2009: Two Large Spaceborne Telescopes, Two Distinct Missions: Colloquium to Department of Physics and Astronomy, University of New Mexico
Hull, A. and McKay, October 2009: Optical fabrication of the Primary Mirror Segments of James Webb Space Telescope (JWST), Invited Talk to monthly meeting of the NMOptics
Hull, A. and McKay, June 2009: Optical fabrication of the Primary Mirror Segments of James Webb Space Telescope (JWST), Invited Talk to monthly meeting of the Optical Society of Southern California
Hull, Tony, 2009, Tinsley and Brashear Optics Capability and Capacity for Lightweight Research Telescopes; Pasadena AAS 214
Hull, A. et al, 2009, JWST Mirror Building Paradigms at Tinsley (Part 7); Long Beach, AAS Meeting 426.18, BAAS 41, No.1
Ambruster, C., Hull, A., Koch, R., Mitchell, R., & Smith, R.: The Pierce-Blitzstein Photometer: The PBPHOT; Long Beach, AAS 320.03, BAAS 41, No.1

Gene E. Ice

ORNL Corporate Fellow/ Group Leader: X-ray Scattering and Microscopy Group, Materials Science and Technology Division, Oak Ridge National Laboratory

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Education/Training:

Institution	Degree	Year	Field of Study
U. of Oregon	PhD	77	Physics
Harvey Mudd College	BS	72	Physics

Research and Professional Experience:

Period	Organization	Position
2003-present	ORNL	Corporate Fellow/ Group Leader
1995-2003	ORNL	Group Leader
1979-1995	ORNL	Research Staff
1985-1990	ORNL beamline X14	Beamline Manager
1977-1979	U. of Oregon	Research Associate
1975-1977	Stanford Research Institute	Research Assistant

Honors, Awards: ORNL Corporate Fellow, ASM Fellow, APS Fellow, 2 R&D100 Awards, DOE Sustained Outstanding Achievement Award, 2 U.S. Patents.

Professional Activities: Western Hemisphere Editor J. of Synchrotron Radiation.

Selected Publications:

1. R.I. Barabash, H.B. Bei, Y.F. Gao, G.E. Ice, E.P. George,"3D X-ray microprobe investigation of local dislocation densities and elastic strain gradients in a NiAl-Mo composite and exposed Mo micropillars as a function of prestrain", J. of Mat. Res. **25** 199-206 (2010).
2. Ice, G. E. and J. W. L. Pang, "Tutorial on X-ray MicroLaue Diffraction", *Mater. Charact.* 60 1191-1201 (2009).
3. G.E. Ice, " Chapter 20: 3D Micron-Resolution Laue Diffraction", pp 335-352, *Neutrons and Synchrotron Radiation in Engineering Materials Science*, edited by W. Reimers, A.R. Pyzalla, A. Schreyer, H. Clemens Wiley-VCH, Verlag GmbH & Ci, JGaA, Weinheim ISBN: 978-3-527-31533-8 (2008).
4. **W.J. Liu, G. E. Ice, J.Z. Tischler, A. Khounsary, C. Liu, L. Assoufid and A.T. Macrander, "Short focal length Kirkpatrick-Baez mirrors for a hard x-ray nanoprobe," Rev. Sci. Inst.** 76 **113701 (2005).**
5. **Ice, G. E., C. R. Hubbard, B. C. Larson, J. W. L. Pang, J. D. Budai, S. Spooner and S. C. Vogel, "Kirkpatrick-Baez microfocusing optics for thermal neutrons,"** ***Nuc Inst Met.*** **A** 539 **312-320 (2004).**
6. **Budai, J. D., W. G. Yang, N. Tamura, J. S. Chung, J. Z. Tischler, B. C. Larson, G. E. Ice, C. Park, D. P. Norton,** "**X-ray microdiffraction study of growth modes and crystallographic tilts in oxide films on metal substrates,"** *Nature Materials* 2 **487-492 (2003).**
7. Larson, B. C., W. Yang, G. E. Ice, J. D. Budai, and J. Z. Tischler, "Three-Dimensional X-Ray Structural Microscopy with Submicrometre Resolution," *Nature* **415**, 887 (2002).

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EDUCATION: Ph.D.- Physics **(Optics), University of Pierre et Marie CURIE, 1994**

PROFESSIONAL EXPERIENCE

Since July 2003 Beamline Scientist on the **Metrology and Tests Beamline** of the Synchrotron SOLEIL (Experimental Division)
Beamline Group leader in charge of the construction and development of the SOLEIL Metrology Beamline.
Main research activities, Research Experience and expertise

- ***Ex-* and *In-situ* metrology** - ***X*-ray Focusing optics** - **X-ray wavefront sensors development**	- **Microfocusing and automatic alignment in X-rays** **Optical simulations and algorithm developments**

Last R&D action

- **Development of an active x-ray optics coupled to a Hartmann wavefront analyzer (in collaboration with 2 French SMEs funding from French R&D agencty)**
- **Development of a Digital Wavefront analyzer (a phD Thesis is starting for this project)**
- **Development of a Metrology station for high accurate surface metrology**
- **Zone Plate Fabrication in collaboration with a Microelectronic laboratory**

Chargé de Recherche CNRS:**, Orsay, 1999-2003 Advisor: Dr. Pierre DHEZ**
X-ray optics development. At wavelength (X-ray and EUV) metrology development including wavefront sensor, alignment tools etc ..
Research Assistant: **University of Orsay, 97-99 - Advisor: Dr. Pierre DHEZ**
Post Doc: **Center for X-Ray Optics, Lawrence Berkeley National Lab, Berkeley, CA 96-97- Advisor: Dr. James Underwood**

Summary of (key) publications:

Book

"Modern Developments in X-Ray and Neutron Optics"
Alexei Erko, Mourad Idir, Thomas Krist and Alan G. Michette - Éditeur Springer Berlin / Heidelberg

X-ray active mirror coupled with a Hartmann wavefront sensor
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, In Press, Corrected Proof, Available online 10 November 2009
Mourad Idir, Pascal Mercere, Mohammed H. Modi, Guillaume Dovillaire, Xavier Levecq, Samuel Bucourt, Lionel Escolano, Paul Sauvageot

X-ray digital wavefront sensor development
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, In Press, Corrected Proof, Available online 10 November 2009
Mourad Idir, Sébastien Fricker, Mohammed H. Modi, Jonathan Potier

"A Shack–Hartmann measuring head for the two-dimensional characterization of X-ray mirrors"
Johan Floriot, Xavier Levecq, Samuel Bucourt, Muriel Thomasset, François Polack, Mourad Idir, Pascal Mercère, Thierry Moreno, Sylvain Brochet Journal of Synchrotron Radiation Volume 15 Issue 2 Page 134-139, March 2008

, *"Automatic alignment of a Kirkpatrick-Baez active optic by use of a soft X-ray Hartmann wave-front sensor"*
P. Mercère, M. Idir, Th. Moreno, G. Cauchon, G. Dovillaire, X. Levecq, L. Couvet, S. Bucourt, Ph. Zeitoun, Optics Letters, 31 (2), 199-201 (January 2006).

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Education/Training:

University of California, Berkeley	May 1993	A.B.	Physics
Massachusetts Institute of Technology	June 2000	Ph.D	Physics
Texas A&M University	May 2010	Certificate	National Security Studies

Research and Professional Experience

Lawrence Livermore National Laboratory	Livermore, CA
Group Leader	Jun 2008 – present
Group Leader, acting	Apr 2007– Jun 2008
Physicist, Indefinite Career Appointment	Nov 2006 – present
Physicist, Limited Term Appointment	Jan 2004 – Nov 2006
Space Sciences Laboratory, UC Berkeley	Berkeley, CA
Principal Development Engineer	Sep 2001 – Jan 2004
Therma-Wave, Inc.	Fremont, CA
Senior Staff Scientist	Aug 2000 – Sep 2001
Massachusetts Institute of Technology	Cambridge, MA
Research Assistant	Sep 1994 – May 2000
Space Sciences Laboratory, UC Berkeley	Berkeley, CA
Research Associate	Jun 1993 – Aug 1994

Honors, Awards:

Fellow, Scowcroft Institute of International Affairs, Texas A&M University, 2009–2010

Selected Publications (from more than 40 conference proceedings and 20 refereed articles):

1. A Barty, R Soufli, T McCarville, SL Baker, **MJ Pivovaroff**, P Stefan, R Bionta. "Predicting the coherent X-ray wavefront focal properties at the Linac Coherent Light Source (LCLS) X-ray free electron laser," *Optics Express* 17:15508-15519 (2009).
2. R Soufli, SL Baker, JC Robinson, EM Gullikson, TJ McCarville, **MJ Pivovaroff**, P Stefan, SP Hau-Riege, R Bionta. " Morphology, microstructure, stress and damage properties of thin film coatings for the LCLS x-ray mirrors," *Proceedings of the SPIE*. 7361:73610U1-9 (2009).
3. JE Koglin, H An, KL Blaedel, NF Brejnholt, FE Christensen, WW Craig, TA Decker, CJ Hailey, LC Hale, FA Harrison, CP Jensen, KK Madsen, K Mori, **MJ Pivovaroff**, G Tajiri, WW Zhang. "NuSTAR hard x-ray optics design and performance," *Proceedings of the SPIE*. 7437:74370C (2009).
4. R Soufli, **MJ Pivovaroff**, SL Baker, JC Robinson, EM Gullikson, TJ Mccarville, PM Stefan, AL Aquila, J Ayers, MA McKernan, RM Bionta. "Development, characterization and experimental performance of x-ray optics for the LCLS free-electron laser". *Proceedings of the SPIE*. 7077:707716.1-11 (2008).
5. TJ McCarville, PM Stefan, B Woods, RM Bionta, R Soufli, **MJ Pivovaroff**. "Opto-mechanical design considerations for the Linac Coherent Light Source x-ray mirror system," *Proceedings of the SPIE*. 7077:70770E.1-11 (2008).
6. **MJ Pivovaroff**, RM Bionta, TJ Mccarville, R Soufli, PM Stefan. "Soft x-ray mirrors for the Linac Coherent Light Source." *Proceedings of the SPIE*. 6705:67050O.1-12 (2007).
7. **MJ Pivovaroff**, T Funk, WC Barber, BD Ramsey, BH Hasegawa. "Progress of focusing x-ray and gamma-ray optics for small animal imaging". *Proceedings of the SPIE*. 5923:59230B.1-14 (2005).

Yuri Shvyd'ko

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Education:

04/1998-07/2002 Hamburg University, Germany, Habilitation in Physics (2002)
04/1979-06/1984 Kurchatov Institute, Moscow, PhD in Physics (1984)
09/1972-03/1978 Moscow Engineering Physics Institute, Diploma in Physics (1978).

Positions and Research Experience:

2007 - present Senior Physicist, Argonne National Laboratory
2004 - 2007 Physicist, Argonne National Laboratory
1995 - 2004 Scientific employee - university lecturer, Hamburg University, Germany
1993 - 1995 A. von Humboldt Research Fellow, Hamburg University, Germany
1978 - 1993 Junior - senior scientific employee, Kurchatov Institute, Moscow, Russia

Honors, Awards:

1993-1995 Humboldt Research Fellowship, Germany
1987 Moscow Young Investigator Award, Russia.

Selected Publications:

Book: Yu. V. Shvyd'ko "X-Ray Optics: High Energy-Resolution Applications", (404 p., 181 illus.) Springer-Verlag, 2004, Berlin Heidelberg.

1. Yu. Shvyd'ko, S. Stoupin, A. Cunsolo, A.H. Said, and X. Huang, "High-Reflectivity High-Resolution X-Ray Crystal Optics with Diamonds," Nature Physics **6**, 196-199 (2010).
2. S. Stoupin and Yu. Shvyd'ko, "Thermal expansion of diamond at low temperatures," Phys. Rev. Lett. **104**, 085901 (2010).
3. S.Wakimoto, H. Kimura, K. Ishii, K. Ikeuchi, T. Adachi, M. Fujita, K. Kakurai, Y. Koike, J. Mizuki, Y. Noda, K. Yamada, A. Said, and Yu. Shvyd'ko, "Charge excitations in the stripe-ordered $La_{5/3}Sr_{1/3}NiO_4$ and $La_2(Ba,Sr)_xCuO_4$ superconducting compounds," Phys. Rev. Lett **102**, 157001 (2009).
4. K.-J. Kim, Yu. Shvyd'ko, and S. Reiche, "A Proposal for an X-Ray Free-Electron Laser Oscillator with an Energy-Recovery Linac," Phys. Rev. Lett. **100**, 244802 (2008).
5. Yu. V. Shvyd'ko, M. Lerche , U. K¨ utgens, H. D. R¨ uter, A. Alatas, and J. Zhao, "X-Ray Bragg Diffraction in Asymmetric Backscattering Geometry," Phys. Rev. Lett. **97**, 235502 (2006).
6. Yu. V. Shvyd'ko, M. Lerche, H.-C. Wille, E. Gerdau, M. Lucht, H. D. R¨ uter, E. E. Alp, and R. Khachatryan, "X-ray Interferometry with Micro-electronvolt Resolution.", Phys. Rev. Lett. **90** (2003) 013904.
7. H.-C. Wille, Yu.V. Shvyd'ko, E. Gerdau, M. Lerche, M. Lucht, H.D. R¨ uter, and J. Zegenhagen., "Anomalous Isotopic Effect on the Lattice Parameter of Silicon", Phys. Rev. Lett. **89** (2002) 285901.
8. Yu.V. Shvyd'ko, M. Lerche, J. J¨aschke, M. Lucht, E. Gerdau, M. Gerken, H.D. R¨ uter, H.-C. Wille, P. Becker, E.E. Alp,W. Sturhahn, J. Sutter, and T.S. Toellner, "-ray wavelength standard for atomic scales", Phys. Rev. Lett. **85** (2000) 495.
9. Shvyd'ko Yu.V. "Nuclear Resonant Forward Scattering of X Rays: Time and Space Picture.", Phys. Rev. B **59** (1999) 9132.

Member: Peter Z. Takacs
Education: Ph.D., Physics, The Johns Hopkins University, Baltimore, MD, (1975)
Summary of (key) publications:

Church, E. L., and P. Z. Takacs. "Chapter 8 - Surface Scattering." Handbook of Optics. Ed. Bass, Michael. 3rd ed. Vol. I. Geometrical and Physical Optics, Polarized Light, Components and Instruments: McGraw-Hill, 2009. 1248 p.

Takacs, P. Z. "Chapter 46 - X-Ray Optics Metrology." Handbook of Optics. Ed. Bass, Michael. 3rd ed. Vol. V. Atmospheric Optics, Modulators, Fiber Optics, X-Ray and Neutron Optics: McGraw-Hill, 2009. 1280 p.

Takacs, P.Z., et al., "Long trace profile measurements on cylindrical aspheres", in Advances in Fabrication and Metrology for Optics and Large Optics, Proc. SPIE **966**, eds. J.B. Arnold and R.A. Parks, pp. 354-364 (1988)

Church, E.L. and Takacs, P.Z., "Specifying the Surface Finish of X-ray Mirrors", in OSA Proceedings on Soft X-ray Projection Lithography, eds. A.M. Hawryluk and R.H. Stulen, pp. 105-107 (1993)

Church, E.L. and Takacs, P.Z., “Specification of glancing- and normal-incidence x-ray mirrors”, Opt. Eng. **34(2),** p. 353-360 (1995).

Takacs, P.Z., Furenlid, K., and Furenlid, L., "Damage Observations on Synchrotron Beam Line Mirrors", in Long-Term Degradation of Optical Systems, Proc. SPIE **3427**, pp. 401-410 (1998)

Summary of work

Peter Z. Takacs directs the activities of the Optical Metrology Laboratory in the Instrumentation Division of Brookhaven National Laboratory. He is actively involved in the development of techniques and instrumentation used in the testing of the figure and finish of precision optical surfaces, such as those used for reflecting x-rays at grazing incidence. His work has led to significant improvement in the quality of optical components manufactured for use at synchrotron light sources throughout the world. He holds a patent on the Long Trace Profiler instrument, which was awarded an R&D 100 Award by R&D Magazine and a Photonics Circle of Excellence Award in 1993 as one of the year's most significant technological products. He is the recipient of a number of awards, including the Brookhaven National Laboratory Research and Development Award in 1992 and a Special Award for Excellence in Technology Transfer awarded by the Federal Laboratory Consortium in both 1989 and in 1997.

Dr. Takacs did his undergraduate work at Rutgers University and completed his PhD in Physics at The Johns Hopkins University in 1974. He was a National Research Council postdoctoral research associate at the Naval Research Laboratory until 1976 and then worked on the Voyager spacecraft Ultraviolet Spectrometer experiment while at Kitt Peak Observatory. He came to Brookhaven National Laboratory in 1979 in the Biology Department and since 1981 he has been a member of the Instrumentation Division, with the exception of a one year period spent at TRW Defense and Space Systems in Redondo Beach, CA, in 1982-83. He is a member of the Optical Society of America, a Fellow of the SPIE - The International Society for Optical Engineering, a member of the American Geophysical Union and the American Society for Precision Engineering.

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Education/Training:

Institution	Degree	Year	Field of Study
St. Petersburg Nuclear Physics Institute, St. Petersburg, Russia	PhD	1995	Physics and Mathematics (Experimental Physics)
St. Petersburg State University, St. Petersburg, Russia	Master of Science	1979	Physics (Nuclear Reactions)

Research and Professional Experience:

Period	Organization	Position
05/2004-present	Advance Light Source, Lawrence Berkeley National Laboratory	Staff Scientist
04/1997-04/2004	Department of Physics, University of California, Berkeley	Assistant Researcher, Visiting Researcher

Honors, Awards:

- 2007 R&D Magazines 100 Best Technologies Award for the "Laser Detected MRI" investigation.
- Leningrad Komsomol Prize in Science (1986)

- International Science Foundation grant on Experimental Search for T-violation Effects in Molecules (1994–1995)
- International Science Foundation Personal Research Grant (1993)
- St. Petersburg State University Scholarship (1973 – 1979)

Professional Activities:

Recent Invited talks:

1. *Binary Pseudo-Random Gratings and Arrays for Calibration of Modulation Transfer Function of Surface Profilometers,* International Workshop on X-ray Mirror Design, Fabrication, and Metrology (Osaka University, Suita, Osaka, Japan, September 22 – 24, 2009)

2. *Calibration of Modulation Transfer Function of Surface Profilometers with 1D and 2D Binary Pseudo-random Array Standards,* Optics and Photonics Congress: Frontiers in Optics 2008, Optical Fabrication and Testing Topical Meeting (Rochester, New York, USA, October 20, 2008).

3. *Bendable X-ray Optics at the ALS: Design, Tuning, Performance and Applications*, 2nd Workshop on X-ray and XUV Active Optics ACTOP 2008 (Trieste, Italy, October 10, 2008).

Service as an editor or reviewer for scholarly journals or other publications

Reviewer for an article submitted to "Journal of Optics A: Pure and Applied Optics," optics Express, Optical Engineering, Measurement Science and Technology

Service to scholarly or professional societies (e.g., officer, committee member, or other provision of professional services)

- Member of ANSI Accredited Standards Committee (ASC) OP - Optics and Electro-Optical Standards;

- Member of OSA FiO/LS Optical Design and Instrumentation Committee of Frontiers in Optics 2009;

- Co-Chair of the Organizing Committee for the 3rd International Workshop on X-ray Mirror Design, Fabrication, and Metrology (Osaka University, Suita, Osaka, Japan, September 22 – 24, 2009)

- Chair of Organizing Committee for Development of a new generation Optical Slope Measuring System

- Member of American Physical Society

Selected Publications:

1. V. V. Yashchuk, S. Barber, E. E. Domning, J. L. Kirschman, G. Y. Morrison, B. V. Smith, F. Siewert, T. Zeschke, R. Geckeler, A. Just, *Sub-microradian Surface Slope Metrology with the ALS Developmental Long Trace Profiler,* Nucl. Instr. and Meth. **A 616**, 212-223 (2010).
2. R. Geckeler, Andreas Just, M. Krause, V. V. Yashchuk, *Autocollimators for Deflectometry: Current Status and Future Progress,* Nucl. Instr. and Meth. **A 616**, 140-146 (2010)**.**
3. S. K. Barber, Erik D. Anderson, R. Cambie, W. R. McKinney, P. Z. Takacs, J. C. Stover, D. L. Voronov, V. V. Yashchuk, *Binary Pseudo-Random Gratings and Arrays for Calibration of Modulation Transfer Function of Surface Profilometers,* Nucl. Instr. and Meth. **A 616**, 172-182 (2010)**.**
4. S. K. Barber, P. Soldate, E. D. Anderson, R. Cambie, W. R. McKinney, P. Z. Takacs, Dmytro L. Voronov, V. V. Yashchuk, *Development of Pseudo-random Binary Gratings and Arrays for Calibration of Surface Profile Metrology Tools*, J. Vac. Sci. and Technol. **B 27**(6), 3213-9 (2009).
5. V. V. Yashchuk, *Optimal Measurement Strategies for Effective Suppression of Drift Errors*, Rev. Sci. Instrum. **80**, 115101-1-10 (2009).
6. K. Tsigutkin, D. Dounas-Frazer, A. Family, J. E. Stalnaker, V. V. Yashchuk, D. Budker, *Observation of a Large Atomic Parity Violation Effect in Ytterbium,* Phys. Rev. Lett. **103**, 071601-1-4 (2009).
7. W. R. McKinney, J. L. Kirschman, A. A. MacDowell, T. Warwick, V. V. Yashchuk, *Optimal tuning and calibration of bendable mirrors with slope measuring profilers,* Opt. Eng. **48**(8), 083601-1-8 (2009).
8. M. Kunz, N. Tamura, K. Chen, A. A. MacDowel, R. S. Celestre, M. M. Church, S. Fakra, E. E. Domning, J. M. Glossinger, J. Kirschman, G. Y. Morrison, D. W. Plate, B. V. Smith, T. Warwick, V. V. Yashchuk, H. A. Padmore, and E. Ustundag, *A dedicated superbend x-ray microdiffraction beamline for materials-, geo- and environmental sciences at the Advanced Light Source*, Rev. Sci. Instrum. **80**(8), 035108/1-10 (2009).
9. D. F. Jackson Kimball, K. Nguyen, K. Ravi, A. Sharma, V. S. Prabhudesai, S. A. Rangwala, V. V. Yashchuk, M. V. Balabas, and D. Budker*, Electric-field-induced change of the alkali-metal vapor density in paraffin-coated cells,* Physical Review A **79**(3), 032901-1-14 (2009).
10. T. Karaulanov, M. T. Graf, D. English, S. M. Rochester, Y. Rosen, K. Tsigutkin, and D. Budker*,* E. B. Alexandrov, M. V. Balabas, D. F. Jackson Kimball, F. A. Narducci, S. Pustelny, V. V. Yashchuk, *Controlling atomic vapor density in paraffin-coated cells using light-induced atomic desorption,* Physical Review A **79**(1), 012902-1-9 (2009).
11. A. Cingöz, N.A. Leefer, S.J. Ferrell, A. Lapierre, A.-T Nguyen, V.V. Yashchuk, D. Budker, S.K. Lamoreaux, and J.R. Torgerson, *A laboratory search for variation of the fine-structure constant using atomic dysprosium,* Eur. Phys. J. Special Topics **163**, 71–88 (2008).
12. V. V. Yashchuk, W. R. McKinney, and P. Z. Takacs, *Binary Pseudorandom Grating Standard for Calibration of Surface Profilometers,* Optical Engineering **47**(7), 073602-1-5 (2008).
13. V. V. Yashchuk, E. M. Gullikson, M. R. Howells, S. C. Irick, A. A. MacDowell, W. R. McKinney, F. Salmassi, T. Warwick, J. P. Metz, and T. W. Tonnessen, *Surface Roughness of Stainless Steel Mirrors for Focusing Soft X-rays,* Applied Optics 45(20) 4833-4842 (2006).
14. M. Auzinsh, D. Budker, D. F. Kimball, S. M. Rochester, J. E. Stalnaker, A. O. Sushkov, V. V. Yashchuk, *Can a quantum nondemolition measurement improve the sensitivity of an atomic magnetometer?* Physical Review Letters **93**(17), 173002/1-4 (2004).
15. V. V. Yashchuk, Granwehr J, Kimball D.F, Rochester S.M, Trabesinger A.H, Urban JT, Budker D, Pines A. *Hyperpolarized xenon nuclear spins detected by optical atomic magnetometry.* Physical Review Letters **93**(16), 160801/1-4 (2004).

Lawrence Livermore National Laboratory

June 18, 2010

Steve Dierker
Associate Laboratory Director for Light Sources,
NSLS-II Project Director
Brookhaven National Laboratory
817 Railroad Avenue / P.O. Box 5000
Upton, NY 11973 USA

Dear Dr. Dierker:

We are writing to strongly endorse the new beamline proposal entitled "OFT: NSLSII beamline for at-wavelength-metrology, in-situ surface figuring, crystal optics, radiometry, detectors and instrumentation development." This team, comprised of experts from the breadth of the DOE complex, industry and other US government agencies, has formulated an exciting concept for a beamline that would become a focal point for ground-breaking research and development for X-ray instrumentation.

Besides enabling new classes of science investigations at synchrotron facilities and X-ray free electron lasers, this beamline will aid in the innovation of new hardware and techniques for other research areas. For example, NNSA is investing in the next generation of diagnostics for the National Ignition Facility and LLNL is considering a new LDRD-funded effort for X-ray adaptive optics. Both of these programs would benefit from the construction of this national resource.

Finally, we note that if this beamline proposal is selected, the multi-institutional team will pave the way for productive collaboration between multiple national laboratories and industry. This type of interaction will become increasingly important as DOE and the nation address more complex and challenging scientific and technical problems.

Christian Mailhiot
Division Leader, Condensed Matter and Materials
LLNL DOE/BES Point of Contact

William H. Goldstein
Associate Director
Physical and Life Sciences

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