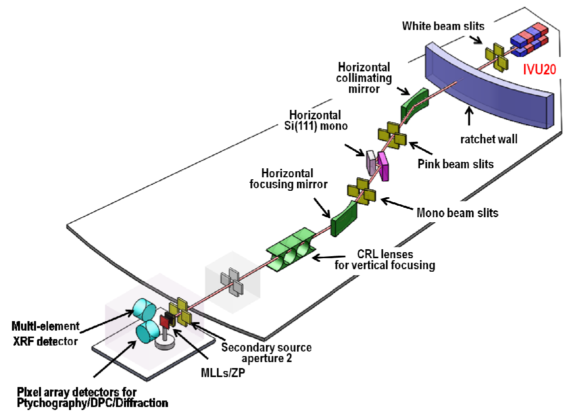
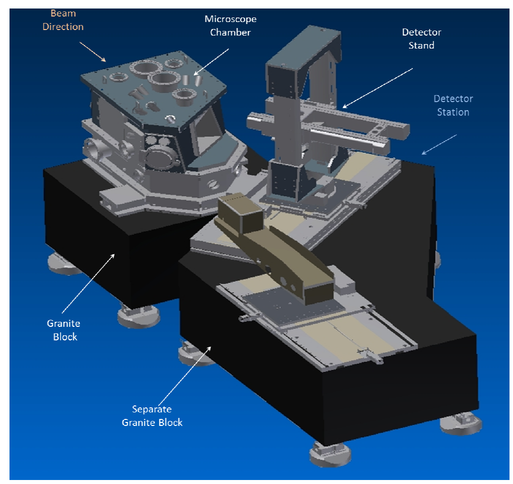
X-ray Nanoprobe (HXN)

Scientific Scope

Functionalities of many material systems are dictated by structural, physical and chemical properties of their constituents at the nanometer scale. Understanding the underlying principles and control mechanisms at such a small length scale, while vital for studies in many areas of science and technology, remains a challenging task due to the lack of noninvasive characterization tools with sufficient sensitivity and spatial resolution. Hard X-rays, because of their weak interaction with matter, have a significant penetration depth and allow studies of buried interfaces, internal sample structure and chemical composition. In combination with their insensitivity to electric and magnetic fields and high sensitivity to structural, elemental and chemical state changes, hard X-rays are ideal tools for *in-situ* characterization of material properties in ambient environments or gases. The hard X-ray nanoprobe (HXN) beamline extends these unique capabilities into the nano world, providing an analytical tool with high spatial resolution. The scientific mission of the HXN beamline is to enable hard X-ray imaging of structure, elements, strain and chemical states with unprecedented spatial resolutions, ultimately down to 1 nm. The temperature control capability at the sample location (~100 K to ~600 K) also enables phase transition studies in various materials systems.



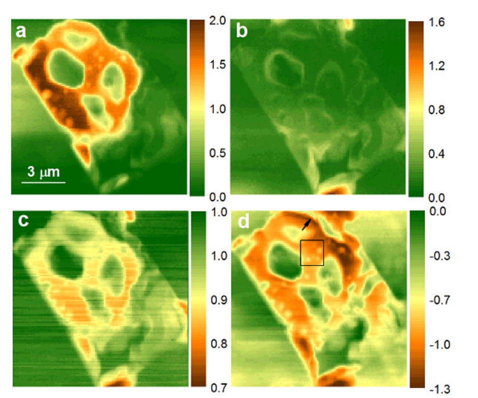
Schematic layout of the beamline



3D drawing of the endstation

Beamline Description

The beamline is designed to take full advantage of the bright, coherent X-ray beam delivered from the undulator source of NSLS-II. The experimental endstation is housed in a separated satellite building, about 110 m away from the source. This design ensures a sufficient demagnification ratio for nanofocusing and vibration isolation from the main ring building. The beamline adopts the concept of secondary source realized by secondary source apertures, mitigating the potential source stability issue caused by beamline optics and enabling the manipulation of the coherence length at the endstation.



Ni Ka fluorescence (a), Pt La fluorescence (b), X-ray transmission (c) and reconstructed phase (d) images (units in radian) of a solid-oxide-fuel cell sample obtained by MLL microscope. Sci. Repts. **3**, 1307 (2013)

The nanoprobe endstation is a scanning microscope consisting of a multilayer Laue lens module for high resolution (10 nm) and a Fresnel zone plate module for moderate resolution (30 nm) to accommodate a great variety of experiments in the energy range of 6-25 keV. Different types of detectors, including multi-element silicon-drift detectors and 2D pixel-array detectors, are placed around the sample, collecting concurrently the maximum amount of scattering signals. Absorption-, phase-, fluorescence- and diffraction- (in Bragg condition for crystalline samples) contrast images will be acquired simultaneously during the raster scans. The microscope can work in high vacuum up to 10^-6 torr, in protective He gas or in air.

Current status:	preliminary design
Construction:	starts January 2012
Commissioning:	begins June 2014
User Operation:	begins June 2015

Techniques

- Absorption-, phase- and fluorescence-contrast imaging (3D in mature phase)
- Nanodiffraction for strain mapping
- Nanospectroscopy for chemical-state mapping (mature phase)
- Ptychography (mature phase)

Beamline Performance

Source	U20 Undulator
Energy range (keV)	6-25 keV
Wavelength range (Å)	0.519 – 2.597
Energy resolution	$\Delta E/E \sim 1.3 \times 10^{-4}$
Beam size at sample (nm^2 FWHM)	10 x 10 (MLL) 30 x 30 (FZP)
Flux at sample @10keV ph/s	$> 5 \times 10^8$

Equipment in Endstation

Nanoprobe

MLL module for 10 nm resolution
FZP module for 30 nm resolution
Rotation stages for tomography
Heating and cooling stages

Detectors

Multi-element SSD detector
Timepix pixel-array 512 x 512 detector
Prosilica high-resolution camera
PI Quad-Ro 4k x 4k CCD
Dexela flat-panel detector
FMB scintillation detector

Signing of agreement between NSLS-II Project Director Steve Dierker and the Beamline Advisory Team. Front, left to right: Tonio Buonassis (MIT), Don Bilderback (Cornell University), Cev Noyan (Columbia University), Steve Dierker (BNL), Qun Shen (BNL), and Yong Chu (BNL). Back, left to right: Pete Siddons (BNL), Ray Conley (BNL), Andrei Fluerasu (BNL), Martin Holt (Argonne National Laboratory), Tony Lanzirotti (University of Chicago), Nick Simos (BNL), Stefan Vogt (Argonne National Laboratory), Kenneth Evans-Lutterodt (BNL), Hanfei Yan (BNL), and Andy Broadbent (BNL).

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Publications

1. H. Yan, Y. S. Chu, J. Maser, E. Nazaretski, J. Kim, H. C. Kang, J. J. Lombardo, and W. K. S. Chiu, "Quantitative X-ray phase imaging at the nanoscale by multilayer Laue lenses," Scientific Reports **3**, 1307 (2013).
2. H. Yan, and Y. S. Chu, "Optimization of multilayer Laue lenses for a scanning X-ray microscope," Journal of Synchrotron Radiation **20**, 89-97 (2013).
3. E. Nazaretski, J. Kim, H. Yan, K. Lauer, D. Eom, D. Shu, J. Maser, Z. Pesic, U. Wagner, C. Rau, and Y. S. Chu, "Performance and characterization of the prototype nm-scale spatial resolution scanning multilayer Laue lenses microscope," Review of Scientific Instruments **84**, 033701-033707 (2013).
4. J. Kim, K. Lauer, H. Yan, Y. S. Chu, and E. Nazaretski, "Compact prototype apparatus for reducing the circle of confusion down to 40 nm for X-ray nanotomography," Review of Scientific Instruments **84**, 035006-035004 (2013).
5. H. F. Yan, V. Rose, D. M. Shu, E. Lima, H. C. Kang, R. Conley, C. A. Liu, N. Jahedi, A. T. Macrander, G. B. Stephenson, M. Holt, Y. S. Chu, M. Lu, and J. Maser, "Two dimensional hard X-ray nanofocusing with crossed multilayer Laue lenses," Optics Express **19**, 15069-15076 (2011).
6. H. Yan, H. C. Kang, R. Conley, C. Liu, A. T. Macrander, G. B. Stephenson, and J. Maser, "Multilayer Laue Lens: A Path Toward One Nanometer X-ray Focusing," X-ray Optics and Instrumentation **2010**, 401854 (2010).