A new ultra-high sensitivity intermediate energy x-ray magnetic circular dichroism facility

This proposal is for building a new beamline for soft x-ray polarization studies. While upgrading beamline 4-ID-C (detailed in another proposal) would produce substantial enhancements for the soft x-ray spectroscopy community, even greater benefits could be realized by building an entirely new beamline for this purpose. These experiments are typically flux limited, therefore significant gains could be made by using two or more insertion devices, which is not possible in the current canted 4-ID design. The increased incident intensity and subsequent sensitivity gain would enable experiments on quantum confined magnetic systems such as 1-D atomic chains and x-ray detected magnetic resonance studies.

Scientific Justification

The advent circularly polarizing insertion devices and associated soft x-ray beamlines with greatly improved flux and polarization control in the 1990s ushered in a new era of experiments which were previously unattainable. As a result, techniques such as polarized XAS, XMCD, X-PEEM have become standard tools in the study of magnetism, electronic ordering, and chiral systems, leading to a deeper understanding of the relation between electronic structure at the atomic level and macroscopic properties, as well as major technological advances. During this time the field has progressed to a stage where very subtle effects have become the crucial components in understanding the behavior. These effects are at the current sensitivity limits of polarized x-ray beamlines even at 3rd generation synchrotrons. For example, the magnetization dynamics of spin-polarized carrier populations in semiconductors is one of the most important questions for the use of these materials in spin-based devices. Element-resolved studies of such phenomena are therefore critical, yet the effects are just barely observable with current sensitivity limits, making time-resolved studies impossible. Other questions facing similar sensitivity limitations are the interplay between electronic structure and magnetism at complex oxide interfaces and in multiferroics. Therefore, the ability of polarized x-ray techniques to contribute similar insights into the most compelling questions of the *next* 10–15 years will be limited without substantial increases in sensitivity over the current capabilities.

This proposal is closely related to two others for upgrading the sector 4 beamlines (4-ID-C and 4-ID-D). While the 1–2 order of magnitude flux increase proposed for 4-ID-C will greatly improve the existing science being done there, the ultimate gains in sensitivity needed for a truly revolutionary capability cannot be achieved without a new source. This would not be compatible within the current limitation of one half of a standard straight section. Therefore, we propose to develop a new intermediate energy x-ray facility with fast circular polarization switching for ultra-high sensitivity in x-ray magnetic circular dichroism.

Added Value of the Mid-term Upgrade

The performance goal of this project will be the detection of magnetic moments that are 3 orders of magnitude below the current sensitivity limit of beamlines in a

comparable energy range. The new facility would meet this goal through the use of specialized undulators, high-efficiency optics, and state-of-the-art instrumentation.

This proposed facility would consist of a single soft x-ray VLS-PGM beamline similar to the upgraded 4-ID-C and IEX beamlines. The source would consist of one or more helical undulators on an extended 8m straight section. The beamline would be outfitted with a 1 T octupole station for XMCD and scattering and a high field (10T) XMCD station. Combined with 4-ID-C, the proposed facility would double the beamtime and instrumentation available at APS for intermediate energy x-ray magnetism studies, an area which runs at a 3-4x oversubscription rate. The two beamlines would be tasked differently, with 4-ID-C handling XPS, PEEM, and the less flux-limited XMCD experiments, while the new facility would take XMCD and soft x-ray reflectivity experiments requiring high sensitivity.

- *Undulators*

One of the key features of this proposed facility is the ability to fully control the polarization, and to switch between polarizations at rates of 20 Hz or higher. This will enable the use of lock-in detection techniques that will improve the signal to noise level. Lock-in detection using phase retarders has been implemented at beamline 4-ID-D at a switching rate of 40 Hz, resulting in signal to noise improvements of an order of magnitude. In the intermediate energy regime, however, the wave-plate approach will not work, therefore the desired polarization states must be generated and switched at the source. There are two approaches to fast switching that appear promising: a fast electromagnetic device and alternating between two devices of fixed polarization. The electromagnetic approach, though, may have limitations in the ultimate switching rate arising from the power supply design eddy currents in the pole pieces. The existing CPU in sector 4 is limited to ~1 Hz, but improvements can be expected for a device designed for faster switching from the beginning. The alternating devices approach uses two EPU-type undulators tuned for opposite polarization and switches their x-ray beams with an orbit bump. This approach is currently in use at SPRING-8 at up to 10 Hz, with improvements foreseen with additional experimentation.

- *Optics*

The optical design of this beamline will be of the varied line spacing plane grating monochromator type. This design is identical, with the exception of the choice of gratings, to the IEX beamline and the proposed upgrades to 4-ID-C. Thus, considerable design and engineering work can be duplicated. Variable-focus Kirkpatrick-Baez mirrors will provide a 100x100 micron spot at the locations of 2-3 experiment stations.

- *Instrumentation*

Two endstations are planned for this beamline. An intermediate-field octupole magnet chamber with integrated scattering detector for XMCD, XAS, and resonant x-ray magnetic scattering will occupy the first position. This chamber will achieve a field of 0.8 T in any direction, and be outfitted with a liquid He cryostat. The second end-station will be a high-field superconducting magnet for horizontal fields of up to 10 T, and sub-K temperatures. The third end-station position will be left open for use by a roll-on chamber or outside user station.

- *Possible canted undulator configurations*

The concept of this new facility calls for a single beamline in a new sector. However, it may be desirable to combine the new beamline and 4-ID-C in a canted arrangement, as the 4-ID-D upgrade proposal may require additional straight section length for the hard x-ray EPU and floor space for expanded hutches. There are two possible approaches to accommodating the two undulators for these beamlines within a single sector. Which one of these is used will depend on the scheme chosen for the fast polarization switching undulator. If a longer electromagnetic device is determined to be the best approach, we envision using the existing CPU with the new device in a canted geometry. Each device will be fitted with sufficient correctors and steering magnets to allow them to operate independently, thus doubling the available beamtime. However, if the alternating EPU device scheme is used, it is less likely that both it and the CPU can be operated in the same sector. Also, because this scheme effectively generates half the flux of a fixed device of the same length, obtaining sufficient flux even within an extended straight section may prove impossible. In this case, we would favor an arrangement in which two beamlines are fed by matched canted EPUs, and one of them may be used in the fast polarization switching mode.

Expected user communities

We expect this facility to draw users from a wide range of communities, including many who are not traditional synchrotron users. The physics of spin in semiconductors and spin-polarized transport has attracted heavy interest from both the semiconductor physics and magnetism communities. Similarly, the ability to study complex oxides with unprecedented sensitivity will attract users working in magnetic devices, multiferroics, and superconductors. While some users can be expected to overlap with the 4-ID-C user base, we expect the uniqueness of the new capabilities to attract a new set of user who have not previously been involved with synchrotron experiments.

Enabling technologies and infrastructure

- Circularly polarizing undulator with >10Hz switching rate.
- Canted design to accommodate existing CPU and 4-ID-C beamline.
- Varied line spacing plane grating monochromator.
- Kirkpatrick-Baez variable refocusing optics.
- 10T, sub-K cryostat endstation.
- 1T, 10K octupole electromagnet scattering endstation.
- Multi-element Si drift detectors.

Partnerships and user interest

Prof. William E. Bailey, Applied Physics Dept., Columbia University
Dr. Dario Arena, NSLS, Brookhaven National Laboratory
Dr. Matthias Bode, Center for Nanoscale Materials, Argonne National Laboratory
Prof. Jacques Chakalian, Dept. of Physics, University of Arkansas
Prof. Bruce Wessels, Materials Science Dept., Northwestern University
Prof. Vitali Methlusko, Electrical Engineering, University of Illinois-Chicago
Scott Chambers, Pacific Northwest National Laboratory

Prof. Darrell Schlom, Dept. of Materials Science, Pennsylvania State University
Dr. John Mitchell, Materials Science Division, Argonne National Laboratory
Dr. Ken Gray, Materials Science Division, Argonne National Laboratory
Prof. Dr. Bernhard Keimer, Max Planck Institute – Stuttgart
Prof. Jim Eckstein, University of Illinois at Urbana-Champaign
Dr. Anand Bhattacharya, Center for Nanoscale Materials, Argonne National Laboratory
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Dr. Annick Froideval, Paul Scherrer Institute
Dr. Xiao-Min Lin, Center for Nanoscale Materials, Argonne National Laboratory

Industry and technology transfer
None is foreseen at this time

Budgetary profile

Front End	$1M
Undulator	$2M
Radiation Safety components	$200k
Beamline Optics (slits, monochromator, mirrors)	$2.2M
Beamline Vacuum systems	$600k
Hutches and work enclosures	$600k
1 Tesla Octupole endstation with support table	$400k
10 Tesla sub-Kelvin end-station with support table	$750k
Detectors	$400k
Total:	**$8.15M**