Beamline 7ID Mid-term Upgrade plan

"*Dream no small dreams for they have no power to move the hearts of men"* Johann Wolfgang von Goethe

In a recent report, the DoE BES Advisory Committee issued some Grand Challenges for science in the 21th century that are now routinely explored at the APS and beamline 7ID. The proposed upgrade described below will address nearly all the Grand Challenges: "How do we control materials and processes at the level of electrons? How do remarkable properties of matter emerge from complex correlations of atomic and electronic constituents and how can we control these properties? Can we master energy and information on the nanoscale? How do we characterize and control matter away—especially very far away—from equilibrium?" [1] The key tools for our investigation of these questions are the combination of Ultrafast laser techniques with state of the art X-ray scattering and spectroscopy methods. The laser enables one to bring matter to excited states and the x-rays probe the decay to the ground state with a 100 ps resolution. Ongoing and future studies by 7ID users include coherent control of chemical reactions, molecular alignment of simple atoms and molecules in gases [2], coherent generation of phonons in condensed matter[3], nanoscale heat and strain propagation [3,4], and studies of laser-induced non-equilibrium phase transitions. The upgrade proposed would deliver pink beam to several of these experiments which would provide a factor 200 enhancement for these studies.

The 7ID beamline pioneered the first experimental demonstrations of time-resolved diffraction from fs-laser-excited semiconductors at the APS with picosecond resolution [3]. This beamline is dedicated to laser-pump/x-ray probe experiments using a 1 or 5 kHz repetition rate, 50 fs long Ti:Sapphire laser which can deliver about 2.5 W of 800nm light on a sample. Since the early demonstration [3], time-resolved diffraction of condensed matter systems has grown to be 7ID's most used technique, with the largest, and growing, user base. Currently, nearly all of the diffraction work at 7ID has coalesced to the six-circle Huber diffractometer in 7ID-C. Recent developments on 7ID have shown that one can control the excited states decay of Kr atoms with fs-laser pulses using the strong field and polarization of the laser [2] or study the photodisociation of Br_2 in dilute hydrated solutions [5]. These achievements were done by probing the excited states of low-density gases or solutions with time-dependent x-ray emission spectroscopy. The use of these techniques has grown on 7ID and we expect to attract in the future more chemistry users. In the past two years we have commissioned a dedicated streak camera in 7ID-C with a time-resolution of 1.5 picoseconds. This camera now enables us to probe time-resolved phenomena in the range of 1-100 ps, and its user program has just started. It is the only dedicated user instrument available for studies with a few ps resolution at the APS. A plan for the upgrade and development of streak cameras on 7ID is discussed in a separate proposal [6]. Our current user community is shown below, and works typically in close collaboration with the sector staff for the success of their experiment.

7ID Pump/probe user community:
Linda Young, Jin Wang (ANL)
Rob Crowell (BNL)
David Reis, Roy Clarke, Roberto Merlin (Michigan)
Paul Evans (Wisconsin)
Martin Nielsen (Niels Bohr Institute)
Ken Finkelstein (CHESS)
SooYong Lee (KRISS, South Korea)
Kelly Gaffney (SLAC)

Crab cavity future users:
Lin Chen (NorthWestern)
David Tiede (ANL)

Following a presentation by Alexander Zholents at the "workshop on Time-Domain Science using X-ray Techniques" in Lake Geneva in 2004, our user community and staff have been very excited by the future of the APS short-pulse crab cavity source. Dr Zholents showed how one might deliver short x-ray pulses at the APS using a pair of crab cavities that induces a correlation between the vertical divergence and the beam arrival time [7]. Following this workshop, the APS has studied the feasibility of this concept and shown that a warm RF cavity option would work to deliver short pulse of x-rays with a FWHM of 2 ps at 1 kHz, but could only run in hybrid-bunch mode. The cost of this option is comparable to the implementation of a cold superconducting RF crab cavity so it has been decided recently to develop the latter instead. The superconducting option will allow the APS user community to have access to a tunable high-repetition rate (6.5 MHz) source of short ps-long x-rays (1 ps FWHM), with 10^{11} ph/s. This approach would complement the LCLS, as it would provide a significant flux of tunable high-energy x-rays and it would bridge the time resolution gap between the XFEL (100 fs) and the synchrotrons (100 ps). Since it operates in all the modes of operations of the APS, this new approach should foster the growth of the national Ultrafast X-ray community and attract international experts. It would provide also some valuable experience in developing techniques and science for higher repetition rate sources such as the APS and CHESS ERLs. It looks like it might be possible to use the crab-cavity scheme in an ERL to reduce the x-ray pulse duration well below a picosecond [8].

We anticipate that our growing user community can use two sectors of the APS, one specializing in time-resolved diffraction, and one in time-resolved spectroscopy. Their beamline optics could be similar in delivering slitted monochromatic or pink beams to samples. The pink beam would enable energy-dispersive transmission spectroscopy for example and time-resolved scattering with bandwidth similar to the beam once delivered at the SLAC Sub-Picosecond Photon Source. Note that the slitted beam would require standard monochromators so that the beam can be micro or nanofocused. Having a nanoprobe with ps resolution would be a unique capability at synchrotrons. The asymmetric crystal compression would also be implemented for time-resolved emission spectroscopy, but the focal spot would be limited to about 0.3 mm [7,8]. A pulse-compressing monochromator that can scan edges in the range of 6 to 15 keV will be developed. One might expect a flux of 10^{12} ph/s with a compression scheme with 10% efficiency. The APS Accelerator Division is studying this mid-term upgrade of the accelerator but it looks like this plan will be implemented within 5 years. The plan is not without challenges and would be the largest beamline/accelerator construction project since the construction of the APS.

The new IXS beamline was recently built for about 7 M$, excluding the cost of the front end development and new undulators. The project team built two separate dedicated instruments in two hutches, with separate optics, several monochromators and detectors. A two-sector scheme would involve three straight sections, providing two straight sections with undulators and two bend magnet beamlines with ps-long beams. The cavities would be located at the upstream end of the first and third straight section. The second straight section could have two undulators either in-line or canted. A one-sector layout enables one ID and one BM with crabbed beams, and affects two adjacent straight sections. A bend-magnet beamline would provide even shorter pulses than an ID so it may be worthwhile to develop. One would estimate a budget of 10 M$ to develop an ID and BM beamline from a green field sector. Some significant cost reductions are possible by retrofitting 7ID and 7BM for this project, and using the existing RF building on the infield. Upgrading an operating beamline would likely impact the user program, and might constrain the optics design. One would likely use the 7ID-B for housing additional optics. The scope of the beamlines developed will be discussed in an upcoming workshop scheduled for May 9, 2008 with a proposal to funding agencies by year ends.

One of the key strength in the past years on 7ID has been microfocusing capabilities. We have focused about 25% of the beam in a ten micron spot size and probed laser-excited materials such as dilute gases and solutions [2,5]. Since the beamline preserves a reasonable fraction of the coherent flux, we have been able to focus the beam to 100 nm and probe time-resolved diffraction from ferroelectric films pumped by large electric fields [4]. Due to access to a white-beam capable hutch (7ID-B), we have also contributed to the development of ultrafast time-resolved phase-contrast imaging [9]. For the largest and growing part of our laser-pump/x-ray probe research program, it would be a real benefit to install beamline mirrors that can collect the horizontal fan of the source and deliver a 100 micron focal spot on the sample. This focused beam could be refocused with existing microfocusing optics. It would also be useful to procure a dedicated zone-plate or kineform refractive lens set up for increasing the focused intensity and reduce the spot size delivered by the microprobe in 7ID-C.

The beamline upgrade will consist in installing a mirror system that can collect all the horizontal fan from the source (factor 3 gain in intensity, reduction of set up time, harmonic rejection), and deliver either focused monochromatic or pink beam (factor 200 gain in intensity). A series of heat load and hybrid mode choppers will reduce the heat load on samples and the beamline equipment downstream of the mirrors. This new system will enable much time-resolved diffraction and diffuse scattering data collection (Reis, Nielsen), and enable fast energy-dispersive transmission EXAFS (Young). This new mirror system would be compatible with the ps-long crab cavity beam if installed on 7ID in about five years. We may choose to implement a double mirror system that deflects horizontally only to reduce the potential impact of modifying the vertical angle/time correlation in the crabbed beam, and allow to deliver a large fraction of the vertical fan either for pulse compression or to multiplex experiments. A dedicated Megapixel Pilatus detector would enable gated detection in 24 and hybrid-bunch mode [6]. Part of this upgrade would also redesign the microprobe station for a dedicated set up with state of the art optics. A proposal to upgrade the 7ID laser system is also described in Ref. [10].

The beamline is also requesting a second undulator in the 7ID straight section for optimizing white-beam phase-contrast imaging experiment in 7ID-B. This undulator would be a shorter period undulator, most likely a U27 (27 mm period) with a tuning range from 7 to 16 keV in 1st harmonics. Using a mirror as a low-pass filter would allow one to isolate the fundamental of U27 to deliver a pink beam with a few percent bandpass. Making the laser beam available in 7ID-B, would allow studies of laser-induced shock propagation with phase-contrast imaging with 100 ps resolution. Having a second undulator would benefit all programs on the beamline. We would keep also our current Undulator A (33mm) inline with this new device so some gain in flux is expected from using both devices at the same time.

Estimated budget:
The capital equipment request includes two state of the art x-ray mirror systems for the 7ID-C Monochromatic KB system (700 k$) and the 7ID-A vertically deflecting double-bounce pink mirror system (775 k$), two new x-ray beamline shutters for personal safety protection (180k$), one x-ray heat load chopper (110k$), one Julich 24-bunch mode chopper (330 k$), modification to some existing hutches and existing component upgrades (360 k$), and finally an upgraded nanoprobe (100k$). The estimated completion is 2 years from the allocation of funds. All cost estimates are in March 2008 US dollars.

Item	Cost (k$)
In-line Short period U27 and U33	~400
7ID Capital equipment	2555
total	2955

Industry and technology transfer : none

References:

[1] Overview of the BESAC Grand Challenge report, taken from recent presentation by John Hemminger http://www.science.doe.gov/bes/besac/Hemminger-02-2008.pdf

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[5] "Transient x-ray absorption spectroscopy of hydrated halogen atom". Christopher G. Elles, Ilya A. Shkrob, Robert A. Crowell, Dohn A. Arms and Eric C. Landahl , J. Chem. Phys **128** 061102 (2008).

[6] See proposal by B. Adams, entitled "Ultrafast Detector upgrades". This proposal describes the procurement and development of ultrafast detectors for 7ID.

[7] A Zholents et al., Nucl. Instrum. and Meth. A 425 p385 (1999).

[8] S. Sashtri, Private communication (2008).

[9] Y. Wang, X. Liu, K.-S. Im, W-K. Lee, J. Wang, K. Fezzaa, D.L. S. Hung, J. R. Winkelman, "Ultrafast X-ray study of dense-liquid-jet flow dynamics using structure-tracking velocimetry", Nature Physics, 2008 (in print)

[10] See also the proposal by Eric Landahl entitled "Femtosync", including some proposed laser upgrades for 7ID.