4.2 EXTREME-CONDITIONS BEAMLINES

FACILITY FOR MATERIALS STUDY IN HIGH-MAGNETIC FIELDS

High magnetic fields can influence the interactions of electron spin and charge with the lattice, giving a unique handle on important material properties such as superconductivity and quantum phase transitions. The National Academies study (Committee on Opportunities in High Magnetic Field Science 2005) concluded that "development of new high-field capabilities at x-ray and neutron scattering centers in the United States could have enormous scientific impact" (p. 5). We propose to develop a new dedicated high-field beamline offering both a cryogen-free ~20 T superconducting and a pulsed 60 T instrument (fig. 4.2.1). A set of split-pair and solenoid geometries are envisioned to fully utilize photon-atom interaction cross sections as required to probe various systems. Furthermore, we will explore with the National High Magnetic Field Laboratory (NHMFL) in Tallahassee and its sponsor, the NSF, the possible establishment of a high-field hybrid DC magnet reaching well beyond 30 T. We have been discussing a split-gap design for this high-field magnet with NHMFL (which has also helped us with our preliminary work on superconducting insertion devices). We note that such a dedicated beamline will provide unique opportunities in the western hemisphere. To take full advantage of these opportunities the beamline will have the flexiblility to accomodate the widest range of techniques. We envision the beamline will include a large energy range, comprehensive polarization manipulation, and adjustable focusing.

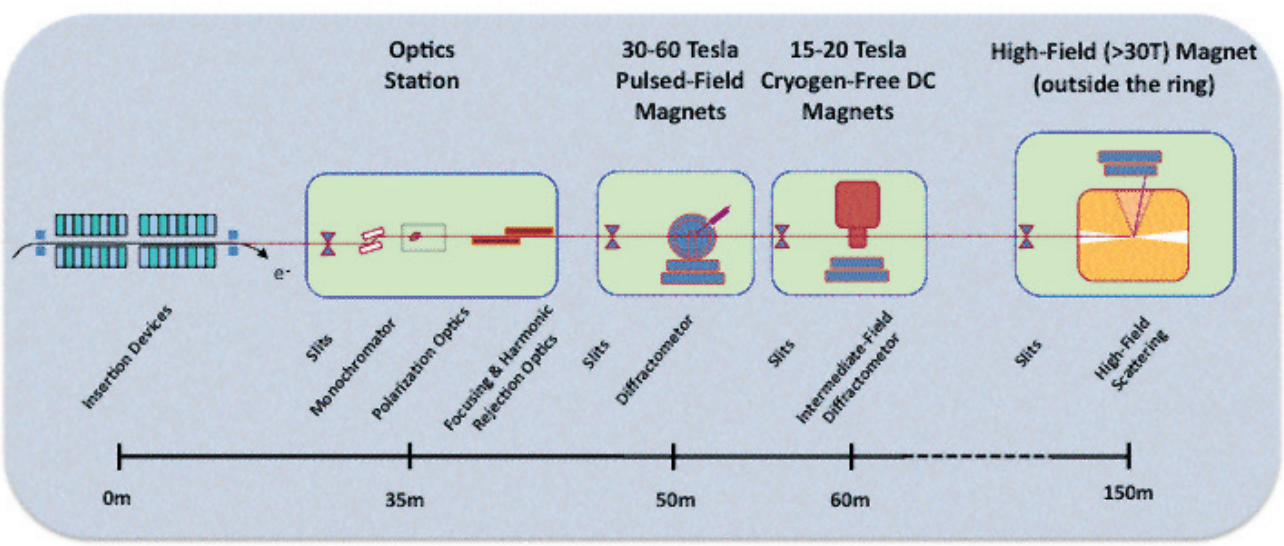

Fig. 4.2.1. Schematic layout of the high magnetic field beamline.

DYNAMIC SHOCK COMPRESSION BEAMLINE

Following a test experiment at the HP-CAT (fig. 4.2.2), a proposal has been made for a dedicated dynamic shock compression beamline. The DOE's NNSA is very interested and has indicated willingness to pay for construction and share in operation costs. We believe that the case for further capabilities in this area is strong, so that we are including it in our planning. If NNSA funding is unavailable, we plan to develop a more modest facility in an existing end station, utilizing high-power lasers as the trigger.

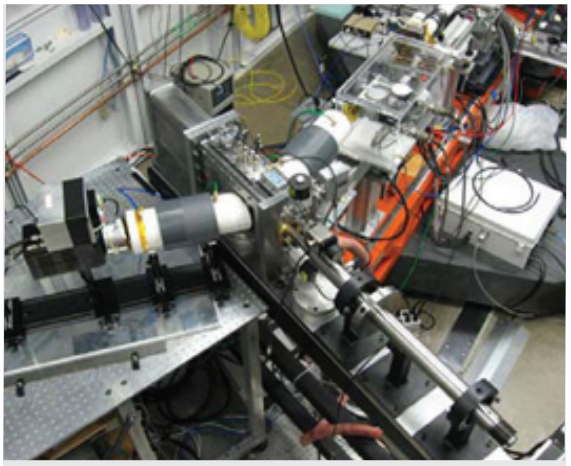

Fig. 4.2.2. *Setup for a shock-wave compression experiment at APS in 2007. The experiment was successful in observing shock compression approaching 5% in LiF, Cu, and Al (courtesy Y. Gupta, unpublished).*

IMPROVEMENTS TO DEDICATED HIGH-PRESSURE BEAMLINES

Sectors 13 (GSE-CARS) and 16 (HP-CAT) are dedicated facilities that are the most productive high-pressure (HP) beamlines on the APS floor today. Both ID beamlines have requested canted undulators, with optimized insertion devices and new focusing optics to improve their ability to access higher extreme regimes, add new techniques, and increase capacity. A factor of 10-30 increase in brilliance is anticipated for dedicated HP lines during the APS renewal. These improvements are prerequisite for developing other novel HP synchrotron techniques, including submicron HP diffraction, submicron HP imaging, Mbar single-crystal diffraction, Mbar HP spectroscopy, high-resolution HP x-ray diffraction, and time-resolved HP synchrotron instrumentation. These techniques will each open an entirely new branch of HP science that does not yet exist or is currently in its infancy. There are many high-pressure techniques that remain flux limited, not only spectroscopic techniques such as HERIX, MERIX, and x-ray Raman, but also diffraction from non-crystalline low-Z materials. Improvements at HP-CAT and GSECARS will greatly expand capability in these areas also.

The renewal improvements allow further reducing the x-ray beam for HP experiments into the sub-micron range. It took three decades to reduce the x-ray beam size from 50 μm to the current 5 μm in HP research. Yet, the impact of this one order-of-magnitude reduction is tremendously significant. While beam sizes of a few tens of nanometers have been reached in specialized beamlines, a beam size of 5 μm is still typical in all leading HP synchrotron beamlines in the world. The enabling of sub-micron beams, optimized and dedicated for HP research, will allow us to probe small sample sizes at ultrahigh pressures approaching the terapascal regime; to investigate grain-to-grain interactions of composite materials by three-dimensional submicron probes (fig. 4.2.3); to map out the grain boundary, phase boundary, chemical ordering, local stress/strain and structure evolution within the individual grain; and to study nanoscale single crystals. The combined orders-of-magnitude improvements from improved (1) x-ray brilliance, (2) spatial, angular, and temporal resolutions, and (3) detector speed and resolution will provide the superior tools for the HP community to lead the next level development of HP energy science in the foreseeable future.

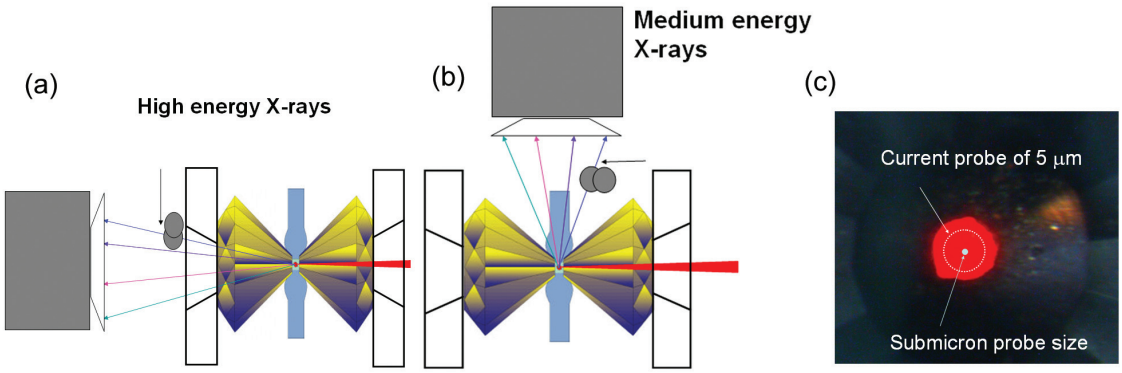

Fig. 4.2.3. *Illustrations of 3D diffraction at high pressures with sub-micron spatial resolution, (a) in the forward geometry with high energy x-rays, (b) in perpendicular geometry with medium energy x-rays; (c) shows an image of the HP sample chamber (red) relative to the size of the current probing beam size (5 μm) and future submicron beams.*

COORDINATED HP SCIENCE BEYOND THE HP BEAMLINES

HPSynC is currently a jointly funded entity that supports four staff members with a mandate to make the pressure variable available across many APS beamlines and to support users of these new capabilities. This approach recognizes that the growth of synchrotron science integrated around the entire APS ring progresses far faster than could be accommodated by a dedicated HP beamline. HPSynC provides a novel mechanism to couple HP science with cutting-edge synchrotron techniques and, thus, forms a valuable complement to "traditional" dedicated HP instruments. As one example, the expertise in 3D tomography on imaging beamlines at the APS is now being developed as a method of measuring equations of state in amorphous materials. This activity builds on the pioneering work of Liu et al. (2008), as shown in fig. 4.2.4) and with renewal improvements the precision of volumes measured in this way can be increased to 0.1% rivalling that achieved by diffraction in crystalline materials. It seems likely that the APS will be at the forefront of an entirely new field of HP imaging.

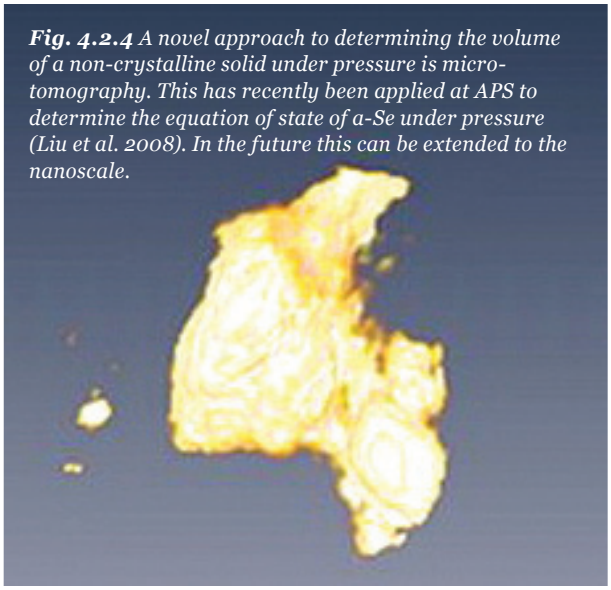

Fig. 4.2.4 *A novel approach to determining the volume of a non-crystalline solid under pressure is micro-tomography. This has recently been applied at APS to determine the equation of state of a-Se under pressure (Liu et al. 2008). In the future this can be extended to the nanoscale.*

In a revitalised APS, an HPSynC with expanded scope would continue to coordinate and extend the suite of capabilities, instruments, and user support available for experiments under extreme conditions. Ongoing innovative technique development will optimize data quality, extend capacity to higher pressures and temperatures, and embed support for combined multiple extreme environments across diverse beamlines.