Inelastic X-ray Scattering at BL12XU

As part of the Taiwan X-ray facility at SPring-8, BL12XU is designed primarily for inelastic X-ray scattering (IXS) experiments on electronic excitations in correlated electron systems with energy resolution from 10 to 1000 meV. The scientific program covers three classes of experiments:

- High-resolution inelastic X-ray scattering: The focus is on the study of single-particle as well as collective electronic excitations in a variety of materials;
- High-resolution resonant X-ray Raman scattering: The emphasis is to explore the large resonant enhancement of the inelastic scattering cross sections to study high-Z materials where strong absorption still posses a major problem;
- Ultra-high-resolution inelastic X-ray scattering: The focus is on the study of lattice dynamics in biomaterials and low-energy electronic excitations in strongly correlated systems.

The construction of BL12XU is carried out in several phases. In Phase I the construction included mainly the main line and the 3-m arm IXS spectrometer (see Fig.1), and has now been completed. A standard SPring-8 in-vacuum undulator was installed into the storage ring in January 2000. The hardware construction of the beamline including the hutch, utilities, and the interlock and control systems were completed by November of 2001, and the beamline was officially approved for operation on December 17.

BL12XU has since been under commissioning. The performance of all installed optical components have been examined and improved where necessary. The IXS spectrometer was installed to the beamline by April 2002. By the time of writing this report, we have carried out some initial measurements using the IXS spectrometer, which indicates that the entire beamline is now ready for non-resonant IXS experiments at a total energy resolution of 250 meV with 10-keV photons. In the present report,

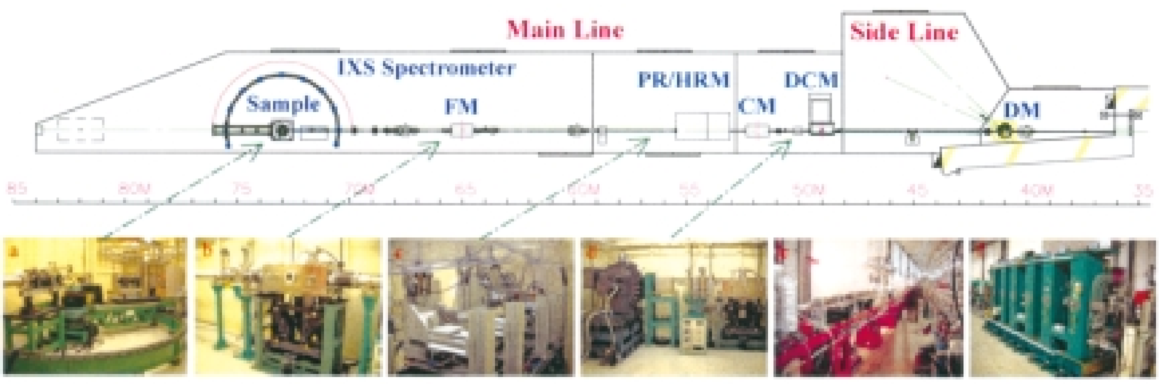

Fig. 1: Beamline layout of BL12XU. Attached photos show (a) the IXS spectrometer, (b) the focussing mirror (FM), (c) the phase retarder and high-resolution monochromator system (PR/HRM), (d) the double-crystal monochromator (DCM) and the collimating mirror (CM), (e) the front end components behind the radiation shielding wall, and (f) the SPring-8 standard in-vacuum undulator for BL12XU.

some of these commissioning works will be presented.

Fig.1 shows the layout of the beamline. The beamline is divided functionally into two parts: the Main Line and the Side Line. The Side Line consists of a single-bounce diamond monochromator (DM) located at 41 m from the source point and a side hutch, providing a monochromatic beam of about 1-eV width over an energy range of 8-32 keV for crystallography and high Q-resolution scattering experiments. This part of the beamline will be built later.

The Main Line is primarily designed for inelastic X-ray scattering experiments, although it retains some capability for elastic scattering experiments with the installation of an 8-circle HUBER diffractometer just downstream of the PR/HRM system (Fig.1). The optical system consists of five major elements, and starts with a high heat-load double-crystal monochromator (DCM), followed by a collimating mirror (CM), a high-resolution monochromator (HRM), a phase retarding plate (PR) to generate circularly polarized light, and a focussing mirror (FM). The DCM is the most important optical component of the beamline, as its performance determines directly the performance of the entire beamline in terms of the flux, the energy resolution as well as the stability of the delivered beam.

Because the natural divergence of the SPring-8 standard undulator beam is smaller than the angular acceptance of the Si(111) reflection within 5-30 keV, no pre-collimation before the DCM is necessary. The DCM is therefore designed to be cryogenically cooled in order to accept the full power of the central cone radiation of the undulator. Under the optimal operation the stability of the DCM was examined, and a rocking width of 0.26 arc second was recorded as the DCM crystals on the Si(333) reflection at 54 keV.

For IXS experiments, because of the low scattering cross section, every photon counts. It is therefore important that the optical design of the beamline maximizes the delivered flux at the sample within the desired energy width. The collimating mirror is designed to collimate the beam further to increase the throughput of the HRM, which in general operates with high-order reflections of Si crystals that have small angular acceptance. With the level of DCM stability mentioned above, beam collimation after the CM was substantially improved and was determined to be less than 0.68 arc second (3.3 μrad).

For the planned IXS experiments, the required relative energy bandwidth ($\triangle E/E$) of the HRM is in the range of 10^{-5} to 10^{-7}. This is accomplished by a design that allows for easy exchange of the channel-cut crystal pairs from either a 2-bounce to an in-line or nested 4-bounce crystal monochromator. Fig. 2 shows three of the possible configurations of the

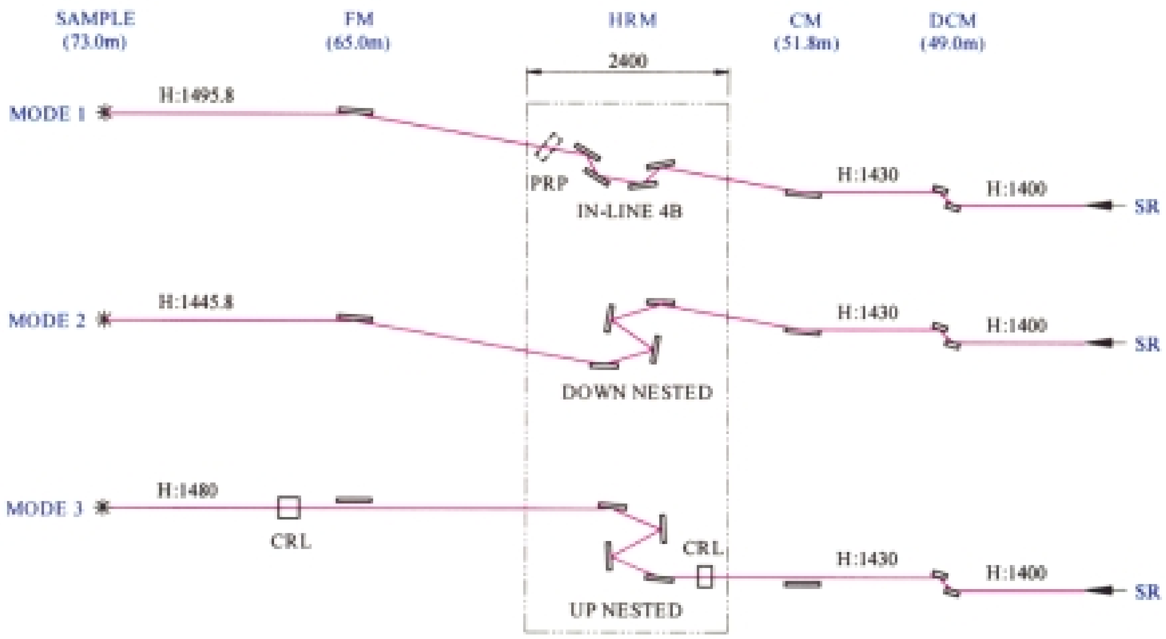

Fig. 2: Three possible configurations of the HRM and beamline optics for BL12XU.

HRM with the rest of the beamline optics. In Phase I the implementation of the HRM is an in-line combination of 2 silicon channel-cut crystals (C.C.) working at the (333) reflection. At around 10 keV, using the Si(555) reflection at near backscattering, the energy resolution of the HRM was determined to be 105 and 52 meV, respectively, after the 1st and the 2nd C.C. After the HRM, the beam is delivered to a focussing mirror, and then focused to the sample position of the IXS spectrometer with a size of 120 (H)$\times$75(V) μm^2. Total flux after the DCM (without the HRM) measured at the sample position was 5×10^{12} phs/sec at 10 keV scaled to 100 mA ring current using a calibrated Si PIN diode.

The intensity and energy stability of the beam from the DCM is another important aspect for a high-resolution inelastic X-ray scattering beamline. We have implemented a dynamic tunning system to maintain the parallelism of the two crystals. With this system, the intensity stability of the DCM has been improved to better than 0.5 %. Work is still under way to improve the system further, including the determination and elimination of any source of energy instability in the system. Further details of the work will be reported elsewhere.

The IXS spectrometer, custom designed and built to accommodate a wide range of experimental requirements, was installed to the experimental hutch in April 2002 (Fig.1a). This instrument is basically a triple-axis spectrometer with a 3-m horizontal arm (Fig. 3). It consists of a heavy-duty Eulerian goniometer tower designed to accommodate a range of sample environments with a load capacity for a cryomagnet. In addition, a cryostat provides a sample environment down to 4 K. The 3-m horizontal arm supports the post-sample slits, the analyser stage, the detector stage and the flight paths. Spherically bent crystal analysers are used to analyse the inelastically scattered photons. The analyser stage can be translated continuously along the arm to accommodate three radii of the analyser for different resolution and angular acceptance requirements of the experiment.

Using a continuously bent Si (555) analyser (bending radius at 2 m) at near backscattering, we obtained the first energy loss spectrum on the plasmon feature of an Al foil (Fig. 4), which compares well with published data. This marks the completion of the beamline construction in Phase I, and shows that the entire beamline is now ready for non-resonant IXS experiments with 10-keV photons at a total energy resolution of 250 meV.

The inelastic X-ray scattering project at SPring-8 has made significant progress in this year. A series of scientific experiments on materials of current interest are now under way, which will provide further tests on and impetus to improve the performance of the entire beamline. Further work underway on instrumentation includes the development of the resonant X-ray Raman scattering capability of the beamline, and a multiple analyser system, both of which are expected to increase significantly the counting efficiency and allow experiments that were not feasible to be performed on the beamline. A high-temperature (up to 1400 ℃) furnace is also under

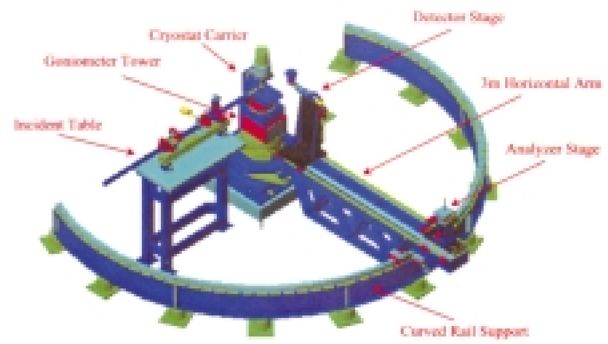

Fig. 3: Overview of the Phase I inelastic x-ray scattering spectrometer, custom designed in collaboration with the Advanced Design Consulting, Inc. NY, USA.

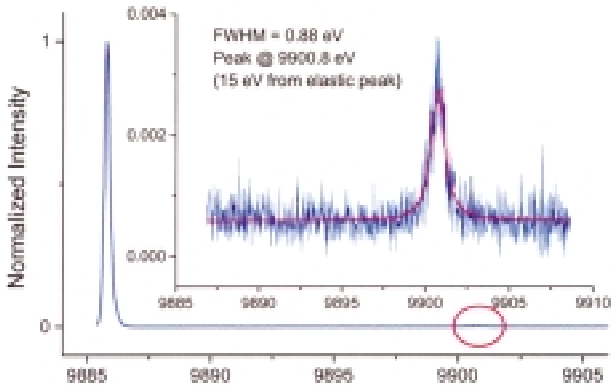

Fig. 4: First IXS spectrum showing the plasmon loss feature from a 150-μm thick Al foil. Momentum transfer was 0.437 Å^{-1}. Total energy resolution was about 250 meV. Count rate on the peak of the plasmon feature was roughly 10c/sec.

development, which should facilitate experiments looking into the melting of a number of interesting systems. The development of the beamline for 10-meV resolution experiments is also planned, where both the HRM and the analyser crystal will be temperature controlled to within ±0.01 K, and the DCM stability be improved to 1 meV. The collimating mirror and the focussing mirrors will also be replaced with compound refractive lenses (CRL) for their better performance in the corresponding energy range (around 20 keV).

With the completion of the Phase I of the entire beamline, the focus of the inelastic X-ray scattering project is now being shifted from instrumentation development to scientific research. We look forward to the great opportunity offered by BL12XU in making significant contribution to the worldwide research efforts on strongly correlated electronic systems.

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Publications:

- Y. Q. Cai, T. E. Dann, C. C. Chen, and C. C. Kao, "SRRC/SPring-8 Undulator Beamline BL12XU Conceptual Design Report", SRRC Internal Report, SRRC/RBM/IM00-01 (2000).
- D. J. Wang, S. Y. Perng, C. K. Kuan, Y. Q. Cai, and P. Chow, "High Performance X-ray Energy Analyzers", SRRC Activity Report 2001/2002 (2002).
- B. Y. Shew, R. S. Huang, D. J. Wang, S. Y. Perng, C. K. Kuan, Y. Q. Cai, P. Chow, M. Schwoerer-Boehning, W. Caliebe, C. C. Kao, and C. T. Chen, Proceedings of SPIE Conference on Nanofabrication of X-ray Optics, Seattle, July 7-11 (2002).