BL09XU
Nuclear Resonant Scattering

1. Introduction

BL09XU, which is known as the Nuclear Resonant Scattering beamline [1], is an X-ray beamline with a 32-mm-period standard linear undulator dedicated to investigating a broad range of science questions. Its operation started in 1997, and it has been mainly used for nuclear resonant scattering (NRS) and hard X-ray photoelectron spectroscopy (HAXPES) since 2014.

2. Beamline Reorganization

From FY2021, BL09XU will also take on the HAXPES activities previously carried out using BL47XU and so will be upgraded as the first dedicated HAXPES beamline in SPring-8. The main aim of this upgrade is to enhance the competitiveness of the HAXPES functionality by integrating dispersed HAXPES activities in SPring-8 into a few beamlines and upgrading the functions of those beamlines. After the end of all beamtimes in FY2020, the NRS instruments were moved to BL35XU, and most of the components in the optics hutch were upgraded for HAXPES experiments. In addition, a Wolter focusing mirror that offers high stability and reproducibility was installed in experimental hutch 1 [2].

3. NRS

NRS is resonant scattering using the transition between the ground state and an excited state in nuclei. The resonance energy width is typically in the μeV–neV range, which is much narrower than eV scales of electron energy levels. Techniques currently conducted in the beamline using NRS include (1) synchrotron Mössbauer spectroscopy (MS), (2) nuclear inelastic scattering (NIS), (3) quasi-elastic scattering (QES) and time domain interferometry (TDI), and (4) nuclear excitation for fundamental physics.

Two low-vibration closed-cycle cryostats were installed in FY2019 considering the supply problem of liquid He in Japan, one for the sample and the other for the analyzer in the energy domain MS [3]. In FY2020, the system was evaluated using Ir-193 having a resonance energy of 73.0 keV and a linewidth of 0.6 mm/s. Non-enriched Ir metal foils of 250 μm and 50 μm thicknesses were used for the sample and analyzer, respectively. The analyzer foil was connected to the Mössbauer transducer to scan the velocity as shown in Fig. 1. The scattered photons and electrons are detected by the 8ch-avalanche photodiode (APD) installed in the vacuum chamber. Mössbauer spectra were measured at several sample temperatures between 7 K and 50 K with a fixed analyzer temperature of 14 K. The observed linewidth of 0.7 ± 0.2 mm/s agrees

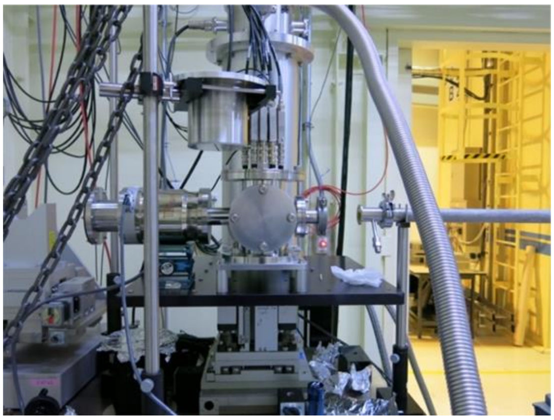


Fig. 1. Analyzer spectrometer for energy domain MS.

with the expected value, and it is confirmed that this liquid-He-free system can be used for nuclei with a linewidth of more than ~0.6 mm/s.

All the NRS instruments were moved from BL09XU to BL35XU after the beamtime ended in February 2021. All the signal and motor cables were also taken out to be replaced. Five optical tables with a typical weight of 3 t, which were used for the high-resolution monochromators and NRS spectrometers, were transported by a truck as shown in Fig. 2.

Fig. 2. Optical tables for NRS experiments were moved from BL09XU to BL35XU.

4. HAXPES

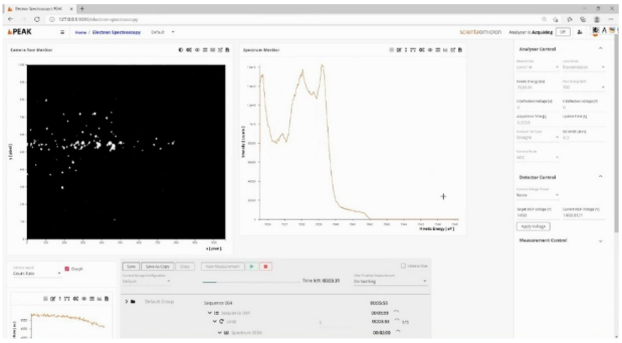
The HAXPES station at BL09XU was opened for public use in FY2014. Its advantages over BL47XU are its high flux and energy tunability [3]. The high-flux microfocus beam with a size of about 5 (vertical) μm × 13 (horizontal) μm is achieved using the long K-B focusing mirror of about 1 m length. The photoelectron detection efficiency at BL09XU is 30 times higher than that at BL47XU. The high-flux beam allows spectra with a high-energy-resolution ΔE of about 100 meV to be acquired and a diamond phase retarder to be used. Hence, the magnetic circular dichroism of HAXPES spectra can be measured by changing the beam polarization, which means that, for example, spintronic materials can be investigated.

An energy-tunable system was developed to realize resonant HAXPES (r-HAXPES) measurements in collaboration with the Partner User (PU) members in FY2017 [4]. The selective utilization of Si 311 and Si 331 channel-cut monochromators (CCM) enables us to measure r-HAXPES spectra with ΔE<300 meV in the incident photon energy range of 4.91–12 keV.

Recently, we have introduced a new photoelectron analyzer control software program to meet the growing need for automatic measurements and HAXPES measurements combined with external field control.

5. New measurement software to enable external control of photoelectron analyzer

The r-HAXPES measurements are conducted with a Scienta Omicron (SO) R4000L1-12kV photoelectron analyzer in addition to the adjustment of the following optical elements for each incident-energy change: the undulator gap, the beamline double-crystal monochromator, the high-resolution channel-cut monochromator, and the KB focusing mirror. We have realized the automatic r-HAXPES measurements by combining with a LabVIEW program to control the optical element adjustments and a SESwrapper LabVIEW library controlling the photoelectron analyzer for the HAXPES measurements. However, this library is strongly dependent on the measurement environment, including the software version and the charge-coupled-device (CCD) camera model used for the photoelectron readout. Recently, HAXPES measurements with sample manipulation and/or under external field conditions such as temperature, electric field, and magnetic field have been increasingly demanded. It was also then difficult to link the photoelectron analyzer with external devices in that library. Therefore, we introduced the new analyzer control software "PEAK" developed by SO to solve these problems. PEAK is not limited to a web-based GUI, but also has a native Python-based external control API, and is designed for the external control of the analyzer.



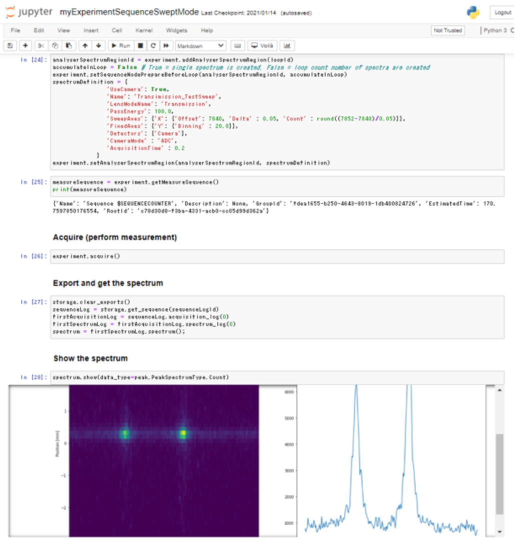


Fig. 3. The left is the Web-based GUI operation software. The appearance has changed significantly from the previous “SES” software developed by SO. The right shows the operation screen using the Python based API, which allows the analyzer to be controlled by external programs such as Jupyter Notebook.

After upgrading the beamline in FY2021, the control of the equipment system will be switched to the BL774 system that is being developed by RIKEN. The system is based on Python, which makes it a very good match for PEAK. Recently, the increasing need for users to perform experiments by remote access from outside the SPring-8 campus has required the development of automatic measurement technology, including sample alignment and sample transfer between ultrahigh-vacuum chambers. With the introduction of this software, we will be able to respond to user needs.

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References:

[1] Yoda, Y. et al. (2001). *Nucl. Instrum. Methods A*, **467–468**, 715.

[2] For more information about the new BL09XU beamline features, please refer to the following URL: http://www.spring8.or.jp/wkg/BL09XU/instrument/lang-en/INS-0000000302/instrument_summary_view

[3] Yoda, Y. et al. (2020). *SPring-8 Annual Report*, 2019, 30.

[4] Ikenaga, E. et al. (2018). *Synchrotron Radiation News* **31**, 10.