UVSOR Synchrotron Facility

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Outline of the UVSOR Synchrotron Facility

Since the first light in 1983, the UVSOR Synchrotron Facility has been successfully operated as one of the major synchrotron light sources in Japan. After the major upgrade of accelerators in 2003, UVSOR Synchrotron was renamed to UVSOR-II Synchrotron and became one of the world's brightest low energy synchrotron light sources. In 2012, it was upgraded again and has been renamed to be UVSOR-III Synchrotron. The brightness of the electron beam was increased further. Today, six undulators are installed in total, and the storage ring, that is *ca.* 53 meters in circumference, is regularly operated in the top-up mode, irrespective of multi bunches or single bunch.

The UVSOR accelerator complex consists of a 15 MeV injector LINAC, a 0.75 GeV booster synchrotron, and a 0.75 GeV storage ring. The magnet lattice of the storage ring consists of four extended double-bend cells with distributed dispersion function. The single bunch top-up operation (176 ns, 5.6 MHz) for time-resolved measurements or low current measurements is also conducted for two weeks per year.

Six undulators and eight bending magnets provide synchrotron radiation (SR). The bending magnet, its radius of 2.2 m, produces SR with the critical energy of 425 eV. There are eight bending magnet beamlines (Table. 1). Three of the six undulators are in-vacuum soft X-ray (SX) linear-polarized undulators (BL3U, BL4U, and BL6U) and the other three are vacuum/extreme ultraviolet (VUV/XUV or EUV) circular-polarized undulators (BL1U, BL5U, and BL7U). Two beamlines, BL1U and BL6U, are so-called "in-house beamlines," which are dedicated to strategic projects conducted by internal IMS groups in tight collaboration with domestic and foreign scientists. Other twelve beamlines are so-called "public beamlines," which are open to scientists from universities, governmental research institutes, public and private enterprises, and also to overseas scientists. After each development, the in-house beamline will be opened for use as a public beamline.

From the viewpoint of photon energies, we have one SX station equipped with a double-crystal monochromator, seven SX stations with a grazing incidence monochromator, three VUV stations with a normal incidence monochromator, two IR/THz stations equipped with Fourier transform interferometers and one beamline for light source development without any monochromators.

Table 1. List of beamlines at UVSOR-III Synchrotron.

Beamline	Optics	Energy Range	Targets	Techniques
BL1B	Martin-Puplett FT-FIR	0.5-30 meV	Solid	Reflection/Adsorption
BL6B	Michelson FT-IR	4 meV-2.5 eV	Solid	Reflection/Adsorption
BL7B	3-m normal incidence	1.2-25 eV	Solid	Reflection/Adsorption
BL3B	2.5-m off-plane Eagle	1.7-31 eV	Solid	Reflection/Absorption
BL5B	Plane grating	6-600 eV	Solid	Calibration/Absorption
BL2B	18-m spherical grating (Dragon)	23-205 eV	Solid	Photoionization Photodissociation
BL4B	Varied-line-spacing plane grating (Monk-Gillieson)	25 eV-1 keV	Gas, Liq. Solid	Photoionization, XAFS Photodissociation, XMCD
BL2A	Double crystal	585 eV-4 keV	Solid	Reflection/XAFS
BL1U	Tandem undulators/ Free electron laser	1.6-13.9 eV	Gas Solid	Laser Compton Scattering Orbital Momentum Light
BL7U	10-m normal incidence (modified Wadsworth)	6-40 eV	Solid	Photoemission
BL5U	Varied-line-spacing plane grating (Monk-Gillieson)	20-200 eV	Solid	ARPES Spin-resolved ARPES
BL6U	Variable-inc.-angle-varied-line-spacing plane grating	40-700 eV	Solid	ARPES XAFS / XPD
BL4U	Varied-line-spacing plane grating (Monk-Gillieson)	50-700 eV	Gas, Liq. Solid	XAFS Microscopy (STXM)
BL3U	Varied-line-spacing plane grating (Monk-Gillieson)	60-800 eV	Gas, Liq. Solid	XAFS / Photoemission Photon-emission

Inter-University and International Collaboration Programs

A variety of molecular science and related subjects have been carried out at UVSOR Synchrotron Facility by IMS and external/overseas researchers. The cumulative total number of visiting researchers (person-days) per year tops > 5000, who come from > 60 different institutes. International collaborations are also pursued actively, and the number of visiting foreign researchers reaches ~70. UVSOR-III Synchrotron invites new/continuing research proposals twice a year. The proposals both for academic and public research (charge-free) and for private enterprises (charged) are acceptable. The fruits of the research activities using UVSOR-III Synchrotron are published as the UVSOR ACTIVITY REPORT annually.

Recent Developments

One of the unique UVSOR research activity is the discovery of the ability of synchrotron radiation to perform coherent control using the tandem undulator BL1U. Synchrotron radiation is usually considered as being of poor temporal coherence, therefore it is hardly thought that there is a hidden capability of coherent control. However, Katoh *et al.*, have demonstrated the capability of synchrotron radiation on the coherent control using the double undulator system which is capable of producing light pulses with tailored waveform.[1,2)]

Wave-particle duality is one of the most fundamental concepts in quantum mechanics. The concept has previously been beautifully demonstrated by the double-slit experiment, in which particles such as electrons, atoms, molecules and neutrons passing through the double-slit exhibit interference patterns in the intensity distribution on a detection screen. To produce the temporal double-slit, a tandem-undulator system is used in which each relativistic electron in the bunch emits a pair of light wave packets that has a mutual coherence between them. A pair of light wave packets sequentially interacts with a helium atom, producing a pair of photoelectron wave packets that propagate in free space and overlap each other, leading to the appearance of the interference pattern. In order to visualize the buildup of the interference pattern, the interference in the energy domain was observed (Figure 1).

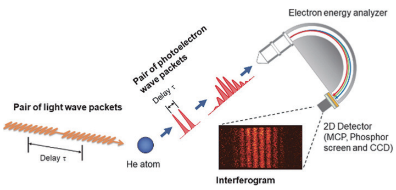

Figure 1. Time-domain double-slit experiment using a tandem-undulator system at BL1U.

Reserch Highlights

Heavy-fermion (HF) systems in rare-earth intermetallic compounds originating from the hybridization between localized *f* electrons and conduction (*c*) electrons are central topics in strongly correlated electron systems. Depending on the *c*–*f* hybridization strength at low temperatures, the ground state changes from a magnetic order to a heavy Fermi liquid. The competition between these two states makes a quantum critical point, resulting in the emergence of exotic quantum phenomena such as non-Fermi liquid and HF superconductivity. The dimensionality of the system characterizes the fundamental physical property. The combination of the HF state and low dimensionality modifies the ground state because the order parameter of these systems is much more sensitive to dimensionality. However, the monoatomic-layer Kondo-lattice showing a two-dimensional (2D) HF state has never been reported. In this study, we report the HF electronic structure of the monoatomic-layer Kondo lattice $YbCu_2$ by angle-resolved photoelectron spectroscopy (ARPES) at UVSOR-III BL5U and BL7U.[3)]

Figure 2(a) shows the ARPES intensity plot around the $\bar{\Gamma}$ point at 7 K. The flat band is close to EF and highly dispersive hole bands are observed near the $\bar{\Gamma}$ point. According to the DFT calculation, the flat band and hole bands originate from the Yb^{2+} $4f_{7/2}$ and the mixing of the Yb 5*d* and Cu *sp* and *d* orbitals. The Yb^{2+} 4*f* flat band is modulated at the cross points to the conduction bands just below E_F, providing evidence of the *c*–*f* hybridization.

The temperature dependence of the quasiparticle peak just below E_F, the so-called Kondo-resonance (KR) peak, is reflected in renormalization due to the development of *c*–*f* hybridization. Figure 2(b) shows the angle-integrated (AI) photoelectron spectra as a function of temperature. The KR peak energy is shifted to the E_F with decreasing temperature, indicating the evolution of the renormalization. Figure 2(c) shows the temperature dependence of the KR peak positions. The peak position shifts with decreasing temperature and is saturated at 30 K. Such saturated temperature represents a coherence temperature (T_{coh}), at which the *c*–*f* hybridization state is fully established, resulting in a HF state.

To investigate the momentum-dependent *c*–*f* hybridization, we took the temperature-dependent peak position of the KR peak at three wavenumbers (k_x = 0.5, 0.0, −0.1 $Å^{-1}$) (not shown). The change of the peak position at k_x = 0.5 $Å^{-1}$ almost follows the AI one. In contrast to the saturated feature in the AI spectrum at T = 30 K, the KR peak positions at k_x = 0.0 and −0.1 $Å^{-1}$ are shifted to the higher-binding energy side below T_{coh}, suggesting the hybridization gap enlargement.

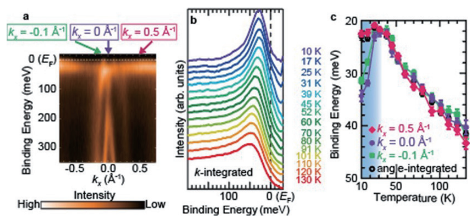

Figure 2. (a) The ARPES intensity plot around $\bar{\Gamma}$ point taken with horizontally polarized 37 eV photons at 7 K. (b) Angle-integrated photoelectron spectra as a function of temperature taken with horizontally polarized 35 eV photons. (c) Momentum dependence of the energy position of the quasiparticle peak plotted on a linear temperature scale.

References

1) Y. Hikosaka *et al.*, *Nat. Commun.* **10**, 4988 (2019); **12**, 3782 (2021).
2) T. Kaneyasu *et al.*, *Sci. Rep.* **12**, 9682 (2022).
3) T. Nakamura *et al.*, *Nat. Commun.* **14**, 7850 (2023).